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The sound environment at preschools and how it may affect children's hearing

Possible correlations between preschool children's DPOAE and the equivalent sound pressure level and room acoustic properties of a playroom in preschools

Master's thesis in Master Programme Sound and Vibration

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Gothenburg, Sweden 2017

Master's thesis BOMX02-17-103

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Cover: Children playing in a preschool generating sound. Illustration Klara Jansson 2017.

Typeset in LaTeX
Gothenburg, Sweden 2017

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Abstract

Children are being exposed to high sound pressure levels during their stay at the preschool. This might have an effect on the children's physical and psychological health. Several studies have been made regarding preschool's sound environment's effect on the personnel but few have been done including the children. There also is very little research about early sound exposure's impact on the hearing later in life.

This thesis investigates the equivalent A-weighted sound pressure level $L_{A,eq}$ exposure for preschool children during playtime indoors as well as the $L_{A,eq}$ in - and room acoustic properties of - a playroom in preschool. The implementation of the study has been a collaboration between me - a master student in technical acoustics - and a one-year master student in audiology. Six sections within four preschools in the Gothenburg region have been investigated regarding children sound exposure, the sound environment in the playroom and possible effects on their auditory function.

To assess the effect of the sound exposure on auditory function, the response of the outer hair cells in the inner ear is measured with DPOAE - Distortion Product Otoacoustic Emissions. DPOAE amplitudes may be reduced after exposure to high sound levels. DPOAE has been measured for seven frequencies between 1 kHz and 10 kHz for children between four and six years old, in the morning and afternoon one day early and one day late in the week. During days of measurements five of the children in the section under investigation wore dosimeters in order to measure their exposure level. There was a fixed microphone hanging from the ceiling in the playroom measuring the sound pressure level during the day and, most of the days, one in the personnel wore a dosimeter as well. Furthermore the acoustic properties of the playrooms has been investigated.

The results show that the children are being exposed to high $L_{A,eq}$ levels and that the levels vary substantial among individuals. The average $L_{A,eq}$ during playtime indoors for children in each section ranges from 75.7 dB to 84.0 dB and for the ceiling microphone from 66.9 dB to 76.8 dB with five sections below 70 dB. The reverberation times of the playrooms lie around 0.3 s-0.4 s with exception of one preschool that has somewhat longer reverberation time, especially for lower frequencies. No correlation between reverberation time and sound pressure level in the playrooms could be seen. Preliminary results of the DPOAE measurements show that there might be a reduction of the DPOAE amplitude for the right ear at 3000 Hz.

Keywords: preschool, children, hearing, equivalent sound pressure level, room acoustics, exposure level.

Acknowledgements

I send sincerely thanks to my supervisor Wolfgang Kropp at Applied Acoustics at Chalmers, thank you for all your time and help with the thesis, finding and testing equipment, programming in MATLAB and extracting data from the measurements. Thank you Sebastian Waltilla for a good collaboration between two areas. Thank you to my other supervisor Kerstin Persson Waye at Occupational and Environmental Medicine and to Sofie Fredriksson for all help and support regarding the hearing part in my work on the thesis.

Thanks to all wonderful children who participated in the study. Thank you for letting us measure your ears and wearing vests all day long at the preschool. Thanks to the preschool teachers who welcomed us to do our measurements and let us be a part of their "business" at the preschools.

Thanks to my mother for her support during the whole time I have been working on this thesis and thanks for sewing two more vests so that we could measure five kids instead of only three per day. Thank you my sisters for supporting me during the thesis work as well. I really appreciate your help, kind words and encouragement during both times of faith and doubt.

And last but absolutely not the least. Thank you the Department of Acoustics at Chalmers, both personnel and fellow students. The atmosphere here is friendly and accepting and it feels almost as my second home. Thank you for all my years here, I have learned a lot and gotten many friends.

Maja Jansson, Gothenburg, December 2017

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Introduction

High sound pressure levels in the preschool is an issue for both children and personnel. Not many studies have been made with the children in focus.

The children are our future. We adults have to take responsibility for them and their environment since they are too small doing it themselves, and they are not covered by any regulations with regards to the acoustic environment.

This study consists of two parts, an acoustical and an audiological. The acoustical perspective gives an overview of sound pressure levels for children exposure, in four different preschools in the Gothenburg region, and investigates whether the room properties influence the, by the children perceived, sound pressure level. The audiological one tries to find a relation between the children's sound exposure and results of a hearing measurement called DPOAE - Distortion Product Otoacoustic Emissions.

The field study for gathering the data for this investigation has been a collaboration between Chalmers University of Technology and the University of Gothenburg in the way that I have collaborated with a one-year master student in audiology, who has performed the hearing measurement and provided the results shown in Section 4.3. This thesis is focused on the acoustics but also treats the hearing part including facts about the human ear and hearing, and the use of DPOAE.

1.1 Background

For a person not used to constantly high sound pressure levels during a working day, spending one day at a preschool could be really exhausting. This is the reality for preschool personnel, but maybe more important - to all children attending the preschool. Studies have been made that show that children are exposed to higher sound pressure levels than the personnel at preschools [1] [2]. In several of the preschools we visited, the personnel was wearing hearing protection during the working day, and one asked for advice regarding which hearing protection to use. The higher exposure for children might be due to the fact that themselves are the dominating sound sources and that they often play and tend to spend their times close to each other [3].

Few studies have been made regarding the exposure level of children at preschools, while more studies are to be found about sound exposure of the personnel. The average A-weighted exposure sound pressure level $L_{A,eq}$ for preschool personnel from different Swedish studies have values of 71 dB [4], 80 dB [5], 76 dB [6] and 77.4 dB [1]. The last mentioned study is from 2004 and investigated sound levels at 103 preschool sections quite close to the Gothenburg region. They also measured exposure levels of five-year-old children and found that when measured at the same time, the personnel had an average $L_{A,eq}$ of 76.9 dB and the children that of 81.1 dB, averaged over ten different measurements. This indicates that children are being exposed to higher levels than the personnel. A research from 2011 [2] made by Occupational and Environmental Health in Gothenburg further confirms higher children exposure with $L_{A,eq}$ values of 77 dB for the personnel and 85 dB for the children.

The amount of children play a role in the sound environment in a preschool. This has been shown in several studies [4] [5] [6] [7]. In a study from Umeå in 2001, Söderberg, Landström and Kjellberg showed a significant relationship between the amount of children in a playroom and the sound pressure level. The analysis indicates that the sound pressure level increased from 64 dBA to 85 dBA when the number of children was increased from 7 to 14 being active in the playroom [6]. This is an increase of approximately 20 dB when the amount of possible sound sources was doubled. This means that the sound levels increased more than the physics law states - the theoretical 3 dB per doubling the source strength - when doubling the number of children. Another study by Landström et al [5], also shows that the amount of children present at the preschool clearly affects the noise level. When taking into account measurements from all different activities, they saw that the sound pressure level increases with 6 dB per doubling amount of children. One conclusion they made was that the sound level can be lowered due to organisational actions with the aim of avoiding too big groups of children. This puts requirements on both personnel and facilities - more personnel and more rooms to divide the children in between. In a study from 2012 [4] Sjödin et al also discuss the sound level increase in connection to the increase of number of children. They saw a relationship between noise level and number of children, and they think that the level increase not only was due to the physics with more sources but also to a behavioral effect: in bigger groups with assumed higher noise level the individual sources will contribute with higher levels as well. In the study by Bistrup et al [3], the personnel was asked to suggest improvements regarding changing the current sound levels. They came with answers such as fewer children in the groups, bigger facilities with more rooms, more personnel, better sound insulation and more absorbing material.

In [4] they conclude that noise exposure at preschools has an essential impact in the development of both short term and long term stress. Noise can also have an impact on the children's pre-reading skills. In a study published 2000 [8] Maxwell and Evans investigated ninety four- and five-year-old children regarding their pre-reading skills with respect of noise exposure. The teachers rated their abilities before and after sound absorbers were installed in the classroom, resulting in both lower equivalent sound pressure level and lower peak levels. After the acoustical treatment the noise exposure was lowered, and the children had better results in recognition of letters, numbers and simple words. They had higher scores on the language scale and showed less helplessness when introduced to solve an unsolvable problem, and solved a solvable problem faster.

There seems to be a lack of knowledge regarding how high sound pressure exposure in a person's younger years affects the risk for hearing impairment later in life. In this study, we try to see a short term difference of the response of the outer hair cells, which could be an indicator of a long term damage on the hearing.

1.1.1 Current existing and non existing regulations regarding noise

In Swedish regulations, school students are seen as employees and are covered by the Work Environment Act (Arbetsmiljölagen) which states the values 85 dB $L_{pAeq,8h}$ for the equivalent level (exposure level called $L_{EX,8h}$) and a maximum level of 115 dB L_{pAFmax} [9]. At and above levels of 85 dB there are requirements that actions shall be taken in order to reduce the exposure. There must for example be a sign telling "Risk for impairment of hearing, wear hearing protection" and limited access should be given to the areas of the high sound level in the working place [9]. If the risks that follow noise exposure can not be prevented by other means, the employees must have access to hearing protection if the $L_{EX,8h}$ is at or above 80 dB, and must be worn by those exposed to 85 dB $L_{EX,8h}$ or higher.

However, children in preschools and youth recreational centers are not included in this law [10] and hence, there are no regulations for which sound pressure levels a child in the preschool is allowed to be exposed of.

1.1.2 Regulations regarding reverberation time

For an existing preschool there are no specific regulations regarding the reverberation time or other room acoustic parameters. However, when a preschool is new built there are Swedish regulations [11] that states that the reverberation time for group rooms, playrooms and food courts (among other rooms) should be 0.4 s for sound class A and 0.5 s for sound class B and C (with sound class A being the highest class).

1.2 Our investigation

We have been at four different preschools in Gothenburg during October 2017, measuring sound pressure levels, room acoustic parameters and otoacoustic emissions of children aged four to six years. In total 42 children have been participating in the study and the duration of our visit at each preschool was one week.

The sound environment in the playrooms is evaluated with regard to the equivalent sound pressure level when the children were present and room acoustic parameters when the children were absent. A description of the visual appearance of the rooms is also performed. To determine the exposure level for the children and to some extent the personnel, they wore dosimeters during the days when hearing measurements took place.

The room acoustic parameters evaluated are the reverberation time T_{60}, strength G and the so called C_{room}. C_{room} is further explained in Section 4.2.2.3.

1.2.1 Aims

The thesis has the following aims.

- What equivalent sound levels are four- to six-year-old children exposed to during playtime indoors in the preschool?
- How does the children exposure level vary between different preschools?
- Does the room acoustic properties of a playroom influence the equivalent sound pressure level in the room?
- Is it possible to see a correlation between the room acoustic properties of a playroom and the measured equivalent level in the room and the exposure level of the children for different preschools?
- What frequencies are most prominent during playtime at the preschool?
- Is children's hearing affected by sound exposure in the preschool after a day's exposure or a week's exposure, defined as an impairment of the function of the outer hair cells in the cochlea measured by distortion product otoacoustic emissions (DPOAE)?

1.2.2 Limitations

The sound pressure level indoors was only measured in one room per section. Even though the measurement run the whole day, only the results from the periods when the children were active in the room is presented. We have only been investigating sections with older children, three to six years old, and the children measured for DPOAE have been four years or older. This is because younger children might find it more difficult to concentrate and sit still during the measurements. We visited four different preschools, all in different districts of Gothenburg. We decided to be one week at each school and four weeks was a reasonable time period being out in the field doing measurements. We could only measure the exposure level for five children a day since we only had five vests. For future study, more preschools could be visited and more children measured. There could also have been stationary microphones in all rooms instead of just the playrooms. The children and personnel in the study were all informed and involved in the study and knew what we were measuring and why. This might have influenced the outcome of the measurements.

1.2.3 Collaboration

The investigation of the preschools and the hearing of the children have been carried out as an collaboration between me and a one-year master student in audiology, Sebastian Waltilla. I have been responsible for the parts regarding the acoustics, such as equipment, measurements and processing of the data. Sebastian has been responsible for the ear and hearing part such as performing tympanometry, measuring DPOAE and processing that data. We have both spent the days at the preschools when doing the measurements, having close contact to both personnel and children but trying not to interfere with the daily activities or influence the sound environment with our presence. In general the personnel was very positive to us when being at their preschool doing the measurements. Most of them seem to have an issue with the current sound situation at their workplace.

1.2.4 Worth to mention

The rooms investigated are called playrooms in the thesis. However, these rooms were not only used for playing. For some of the preschools, the children had their meals in the rooms and some groups spent almost their entire day in them. The periods we have chosen to evaluate have been during the children's playtime, for which reason I choose to call the rooms playrooms.

1.3 Thesis outline

This is a guide to the reader through my thesis structure.

The **theory** chapter first treats the acoustics, both sound pressure level and room acoustic parameters. After that there is a part about the basics of the ear, how the outer hair cells work and what happens to the hearing if they are damaged. It describes how measurements are executed and which equipment that is used for the hearing part.

The **method** chapter contains information about how the preschools were chosen and how we got in contact with the personnel, children and guardians of the children. Everything about the measurements is explained. It is told which equipment was used, which settings were made and how the data was processed.

This is followed by a chapter presenting the **results**. The results are commented, interpreted and discussed as they appear.

In the **discussion** chapter, the results is further discussed together with my own thoughts about the subject.

As a **conclusion**, the results and what knowledge that has been gained throughout this study is summed up.

Additional detailed information is found in the **appendices**.

2

Theory

In this section some relevant theory about sound, room acoustics, the human hearing function and ear measurements is presented in order for the reader to understand the different parts of the study and the results.

2.1 Acoustics

The reader is presumed to have basic knowledge in acoustics. This section focuses on the equivalent sound pressure level and room acoustic parameters.

2.1.1 Equivalent sound pressure level

The equivalent sound pressure level is an energetic average of the sound pressure level over a certain time. It is often A-weighted in order to better represent how humans perceive sound. The A-weighting takes into account how sensitive the human ear is to certain frequencies. The A-weighted equivalent sound pressure level can be calculated according to Equation (2.1)

$$L_{A,eq,T} = 10\log_{10}\left(\frac{1}{T}\int_0^T \frac{\tilde{p}^2}{p_{ref}^2}dt\right) = 10\log_{10}\left(\frac{1}{T}\int_0^T 10^{L_p/10}dt\right) \tag{2.1}$$

where T is the time of the measurement in hours, $\tilde{p}$ is the rms sound pressure, p_{ref} is the reference pressure value of $20{\cdot}10^{-6}$ Pa 20 µPa and L_p is the A-weighted sound pressure level in dB [12].

To calculate one average equivalent sound pressure level out of several $L_{A,eq}$ values with different corresponding measurement times Equation (2.2) can be used [12]

$$L_{A,eq,avg} = 10\log_{10}\left(\frac{1}{T}\sum_i t_i 10^{L_{A,eq,i}/10}\right) \tag{2.2}$$

where T is the total measurement time and t_i is the individual measurement time corresponding to the individual $L_{A,eq,i}$.

2.1.1.1 Dosimeters

A dosimeter is a portable recording device. It consists of a microphone connected with a cable to a "black box".

The dosimeter is programmed in advance using a computer with a certain software connected to the dosimeter. All settings are chosen in advance and cannot be changed during the measurements. Depending on the settings one can obtain different data from the measurement with a dosimeter. Interesting data can be the equivalent sound pressure level L_{eq}, the maximum level L_{max} and the peak level L_{peak}. One can choose whether the different levels should be weighted or not, this must also be done in advance. There is unfortunately no way to listen to the recordings made by a dosimeter used in this study.

2.1.2 Room acoustics

How sound is filtered, amplified or damped in a room depends on the acoustic properties of the room. The properties will vary for different geometries of a room, for different furniture or other obstacles, what kind of material is used - fabric, porous material, concrete, mirrors, wood, metal etc. All these parameters will form the sound and determine how long the sound energy will stay in the room. For a room with little or no absorption, the sound will be reflected many times, and in such rooms it could for instance be hard to understand and distinguish speech. A room like this would be called reverberant.

The characteristics of the properties of a room are given by its impulse response [13]. It describes how a system (here room) responds to an impulse. Using convolution, the impulse response can be used to auralize sound in a room. The room acoustic parameters described below can be obtained from the impulse response.

2.1.2.1 Reverberation time

The definition of reverberation time is the time it takes for the sound pressure level to drop by 60 dB, or in other words, how long time it takes for the energy density to drop until it is one millionth, 10^{-6}, of its original value [14]. Reverberation time is a widely used room acoustic parameter and according to Kuttruff the most important quantity [15].

2.1.2.2 Strength

The strength parameter is often referred to as G, and could be called the room gain. According to Beranek, G is the ratio between the sound energy measured at a given location in a room and the sound energy at a distance of 10 m in free field conditions (an anechoic chamber for example), with the sound energy coming from the same omnidirectional source [16]. It is inversely dependent of the room absorption, so the more absorption a rooms has, the lower G will be. For total absorption, it will be as in free field, which will result in no room gain and hence $G = 0$ ($G = 10\log(1) = 0$, if measured at 10 m distance from the source). Strength can be calculated as

$$G = 10\log_{10}\left(\frac{\int_0^\infty [g(t)]^2 dt}{\int_0^\infty [g_A(t)]^2 dt}\right) \tag{2.3}$$

where g and g_A are the impulse responses at the chosen position in the room and at 10 m distance from the source in free field conditions, respectively, using the same sound source [15].

In Architectural Acoustics [13], Long expresses strength in terms of level instead of energy. He explains it as the difference between the sound pressure level at a given point in the room of interest and that of a free field condition at a distance of 10 m, for an omnidirectional source. In the same book, Long calculates G based on the Sabine reverberant field equation as

$$G = L_p - L_0 = 10\log_{10}\left(\frac{100}{r^2} + \frac{31200T_{60}}{V}\right) \tag{2.4}$$

where L_p is the sound pressure level at a given point in the room of interest, r is the distance from the source to the given location, T_{60} is the reverberation time of the room, V is the volume of the room and L_0 is the sound pressure level at a distance of 10 m in free field conditions. This equation assumes that the sound field consists of two fields, the direct and the reverberant [13].

The first part inside of the brackets in Equation (2.4) corresponds to the direct field and the second part corresponds to the reverberant field, with the reverberant field consisting of all sound waves that have been reflected at least one time. If the sound field is dominated by the direct sound, i.e. the direct field part in the equation is dominant, the direct sound will be more prominent and the properties of the room will not make any significant difference to the total sound pressure level on the measured spot. If instead the reverberant part is dominant, it means that the room has big influence on the sound pressure level measured. The room enhances the sound, hence the expression "room gain".

2.1.2.3 Clarity

Clarity is a measure that compares early and late energy. There are two common types of clarity, C_{80} and C_{50}, where $_{80}$ and $_{50}$ stand for 80 ms and 50 ms, respectively. The sound energy that arrives within the first 80 ms after the direct sound, is compared with the energy that arrives after 80 ms, see definition in Equation (2.5) [15]. Clarity is presented in dB. C_{80} is often used when looking into the room acoustics of a concert hall for music while C_{50} might be of better use for the context of speech. This is because when it comes to speech, in order to be able to hear the letters and pronunciations clearly it is better with early reflections, so the letters not being mixed up altogether, while for music, a bit later reflections could even be beneficial for the music experience. To clarify, for example in a concert hall, clarity would be different for different audience seatings.

$$C_{80} = 10\log_{10}\left(\frac{\int_0^{80ms}[g(t)]^2dt}{\int_{80ms}^{\infty}[g(t)]^2dt}\right) \tag{2.5}$$

where g is the impulse response of the room.

C_{50} is calculated in a similar way but with 50 ms instead of 80 ms. However, clarity may not be the best room acoustic parameter to evaluate the sound environment in a room in a preschool, since there is not one source and one listening audience.

Instead of the traditional C_{80} the parameter C_{room} is presented in Section 4.2.2.3 which compares the energy from the direct sound to the later energy reaching the receiver after the first pulse. This is done in order to see the difference between the contribution to the sound pressure level by the room and by the direct sound.

2.1.2.4 Backward integration

The traditional method to measure the reverberation time is to send out random noise from a loudspeaker in a room, switching it off and from that moment measure the decrement of the sound pressure level. From such measurement one can see how long time it takes for the level to drop by 60 dB, and hence, achieving the reverberation time. It can be difficult to accomplish a drop of as much as 60 dB and in that case the duration for a 20 dB or 30 dB drop can be extrapolated into the reverberation time. However, the decay curve using the traditional method would contain many fluctuations due to the random noise excitation and would be different for every time the measurement was repeated. If this procedure was repeated very many times and the results averaged into one decay curve the final result would be stable with no fluctuations. This would nonetheless be very time consuming. Instead one could use backward integration.

The backward integration is a more neat way to gain the reverberation time and as well with better accuracy than the traditional method [15]. Repeated measurements of this kind would engender the same results over and over again because it is based on the impulse response. One way to obtain the impulse response is to compare the signal measured at the microphone to the signal fed to the loudspeaker. In that way the fluctuations of the noise do not matter. The decay curve would hence not inhold fluctuations though the excitation would be random noise. The backward integration was first introduced by Schroeder in 1965. In [17], he states that just one measurement would give the same results as if averaging over infinitely many decay curves using the traditional method.

The ensemble average of the squared noise decay, the average of all possible decay curves, can be obtained by Equation (2.6) [15] using the impulse response g as input data.

$$\langle h^2(t)\rangle = \int_t^\infty [g(x)]^2 dx = \int_0^\infty [g(x)]^2 dx - \int_0^t [g(x)]^2 dx \tag{2.6}$$

Since the reverberation time and behaviour of the room are frequency dependent, the impulse response is bandpass filtered before the backward integration is performed. The results in each frequency band then corresponds to an individual decay curve.

2.2 Audiology

One part of this investigation is about how the sound exposure of the children could affect the function of the outer hair cells. To get an understanding of the audiology part, here follows a section including the basics of the ear's function, the function of the hair cells and what otoacoustic emissions are.

2.2.1 Basic ear function

This section explains briefly about the function of the ear, how the sound is transported from vibrations in air to vibrations in the cochlea where it is transformed into electrical signals and further transmitted to the brain. Especially important in this context of DPOAE is the function of the inner and outer hair cells. Most of the content in this section is from *Hörseln* [18] by Konrad S. Konradsson who is a researcher at Karolinska Institutet.

The ear consists of three parts, the outer ear, the middle ear and the inner ear. The outer ear includes the pinna (the external ear that we can see) and the ear canal which leads to the tympanic membrane (the eardrum). According to Janina Fels [19] the anatomical outer ear also includes the head and the torso. The properties of the whole outer ear affects the acoustics through reflection, shadowing, diffraction, interference and resonance. The middle ear is the cavity behind the eardrum which contains the three little bones (the ossicles), the hammer, the anvil and the stirrup, which connect the tympanic membrane to the oval window and send forward vibrations to the inner ear. The middle ear is connected to the throat via the Eustachian tube, which can be used to equalize the air pressure in the middle ear (common when flying in an airplane). The inner ear is complex and includes the cochlea, which is a shell formed part that contains the basilar membrane as well as the inner and outer hair cells.

The ear canal is approximately 2 cm to 3 cm long with a varying diameter around 0.6 cm - 0.8 cm [19] and is s-formed, for adults. These dimensions amplify the frequencies that resonate in the ear canal, which is 2000 Hz to 5000 Hz [18], often most prominent around 3000 Hz for adults. However, children have both shorter and more narrow ear canals which result in higher resonant frequencies and this leads to that the enhanced sounds for children more likely lie around 6000 Hz [19]. This means that children probably are more exposed to sounds with higher frequencies[1].

The eardrum is air tight (if not perforated) and protects the middle ear from bacteria and likewise but its main function is to register the vibrations from the sound through the ear canal and send forward the information to the middle and inner ear. It vibrates in line with the incoming sound's frequency and amplitude. At low frequencies the whole eardrum can move in and out, but at higher frequencies, and more complex sound, the movement of the membrane will also be complex, with different parts moving in and out at the same time - different resonance patterns.

The middle ear is filled with air while the inner ear is filled with liquid. The transfer of the vibrations from air to liquid means a big impedance change and therefore, the vibrations need to be amplified. This amplification happens both in the ear canal and via the three little bones. Altogether, according to Konradsson, the sound is reinforced about 800 times on its way from the pinna to the liquid in the inner ear [18].

The cochlea contains three different canals and the basilar membrane which run through the whole shell formation. Both the inner and outer hair cells are located in the middle canal, on the basilar membrane. The hair cells are stimulated by the vibrations along the basilar membrane. The important function of the hair cells is to convert mechanical sound vibrations into electrical signals.

2.2.1.1 Inner and outer hair cells

The hair cells' function is to convert mechanical energy in the form of vibrations into electrochemical energy in the form of electrical signals. These electrical signals are then sent to the brain and we can comprehend a hearing sensation. Both inner and outer hair cells are placed on the basilar membrane but on different locations. There are approximately 12 000 outer hair cells and 3500 inner hair cells, however, this varies between individuals [20].

The inner and outer hair cells have different functions for the hearing. The outer hair cells enhance and clarify the vibrations while the inner hair cells convert the mechanical vibrations into electrical signals, sending the information from the outer hair cells on to the brain [18].

So, the outer hair cells enhance the vibrations on their way to the inner hair cells, but they also create other vibrations, that are sent backwards and turned into sound in the ear canal. This sound is weak, but still loud enough to be able to get measured! This weak sound is the one we will measure in our DPOAE measurements. More about this and how these sounds are provoked in Section 2.2.1.2.

Damages on the hair cells
Damage of the hair cells can be caused by long term noise exposure or short high level sound impacts. Being exposed to loud sounds, the hair cells can get exhausted

[1]When looking at exposure levels, A-weighting most often is used. The A-weighting is based on adults' perception of tones at different frequencies and is perhaps not the ideal weighting for children. Unfortunately there is no such thing as "children-weighting", yet.

but if they have a chance to rest they can recover again. The occasional hearing impairment can reverse and is then called a temporary threshold shift. If the hair cells die, the damage is irreversible, the cells cannot regenerate and the hearing capability will be reduced for life [21].

Damages on the outer hair cells means that the vibrations get damped (and not amplified) and we may no longer be able to hear very weak sound. Also the ability for frequency analysis in the inner ear gets reduced, which means that the speech is not being perceived as pronounced as before. However, we can still be able to hear even if the outer hair cells are completely absent. The maximum hearing impairment for non functioning outer hair cells is 60 dB [18] [22].

This is however not the case with the inner hair cells. If the inner hair cells are absent we will not be able to hear a thing - the sound vibrations cannot be turned into electrical signals which make us hear, and there is no back up system that can do the inner hair cells' work. No inner hair cells means total deafness. [18]

2.2.1.2 Otoacoustic emissions and DPOAE

Otoacoustic emissions are sounds that originate from the outer hair cells in the inner ear. It is a very weak but still measurable sound. The emission can arise spontaneously without any stimuli and is then called SOAE. These are pure tones at certain frequencies which are present among 60 % to 70 % of people with normal hearing [23].

As previous mentioned, the outer hair cells enhance the information onto the inner hair cells and are sometimes therefore called the cochlear amplifier [23]. The reinforcement of the vibrations is mainly for low to medium sound levels. With higher levels as input, the capability of amplification gets saturated [23].

When the cochlea is performing this amplification there is also a production of a byproduct - the otoacoustic emissions (OAE). It is an imperfection of this amplifying mechanism that makes the basilar membrane move in a different way, sending vibrations backwards to the oval window. This makes the ossicles move and at last also the tympanic membrane, creating the sound of the otoacoustic emissions in the ear canal [22]. The cochlea acts non linear, which means that it can respond with additional frequencies that it has not been excited with.

The function of the cochlea is frequency dependent and one way to see the function of the cochlear amplifier at different frequencies is to use DPOAE - distortion product otoacoustic emissions. The hair cells are then excited by playing two pure sinusoidal tones simultaneously with frequencies close to one another, F_1 and F_2. These two tones cause a distortion and the outer hair cells produce otoacoustic emissions of various frequencies, the most prominent at the frequency $f = 2F_1 - F_2$, which is called the characteristic frequency. In average, the optimum relationship between F_1 and F_2 for having the most prosperous DPOAE is that of $F_2/F_1 = 1.22$ [24]. The two tones are having the corresponding levels L_1 and L_2 which could have the same level, but according to Abdala [24], in order to get the biggest DPOAE amplitudes as a result, there should be a level difference of 10 dB to 15 dB with $L_1 > L_2$.

The amplitude of the DPOAE results indicates how well the cochlear amplifier is working. If there is no presence of the DPOAE in the ear canal, it indicates that the cochlear amplifier is dys- or nonfunctional around the excited frequencies. To clarify, the results of the DPOAE show the cochleas performance at neither frequency F_1 nor F_2 but at the characteristic frequency $f = 2F_1 - F_2$, which is a lower frequency than both F_1 and F_2.

DPOAE is probably most known for being used for newborn babies, it is not requiring any subjective feedback from the investigated individual (more than sitting still and being quiet) which is why it is good to use also for young children. One usually tests DPOAE at several frequencies since the results are frequency dependent. More about how the measurement procedure is performed in Section 3.4.

2.2.2 Preparing for DPOAE measurements

Before making a DPOAE measurement the ear canal and the tympanic membrane have to be visually examined as well as the middle ear has to be of normal function. The visual examination is done with the help of an otoscope and the function of the middle ear can be evaluated with a tympanometry.

2.2.2.1 Otoscope

An otoscope is a little hand held device that one uses to look into the ear. Using an otoscope makes it possible to see if the tympanic membrane is perforated and free from damages and/or if there are a lot of earwax or other obstacles in the ear canal that might interfere with eventual following measurements. An otoscope consists of a handle with a lamp and a magnifying glass on the top.

2.2.2.2 Tympanometry

A tympanometry is done in order to assure the function of the middle ear. The compliance of the eardrum is measured while varying the outer air pressure in front of the eardrum. At the highest compliance (when the eardrum is the most movable), the air pressure behind is identical with the air pressure in front of the eardrum. For a correct functioning middle ear this air pressure should be close to or equal to the surrounding outer air pressure under normal conditions. To measure the compliance a tone is sent to the eardrum and the reflections are registered, while varying the air pressure in order to get the compliance for various air pressures. [25] [26]

The result of a tympanometry is called a tympanogram, showing the pressure on the x-axis and the compliance on the y-axis. The unit of compliance is $\mho$, outwritten as "mho"[2]. The tympanogram presents how movable the tympanic membrane and ossicles are at different air pressures in the ear canal.

Why the eardrum is of abnormal stiffness can have various reasons. Explanation of a stiff eardrum can be otitis media (ear inflammation) or a fixation of the ossicles, while a very mobile eardrum could be explained by discontinuity in the ossicle chain or scarification on the tympanic membrane [25] [26].

If the tympanogram shows a normal functioning middle ear, the DPOAE measurement can be performed.

[2]Mho is actually a wordgame. Compliance is the inverse of stiffness, and "mho" is "ohm" backwards, Ω, the unit of resistance [27].

3
Methods

This chapter first describes the selection of the preschools and how the information was delivered to the participants of the study. After that the measurements of the sound pressure levels with fixed microphone position and dosimeters are described. Further, the room acoustic impulse response measurements followed by the measurements of the tympanometry and DPOAE are explained. At last a list of equipment is displayed.

3.1 Selection of preschools

All four selected preschools are municipal preschool within the Gothenburg region. The preschools have been chosen to be located in different districts of Gothenburg having sections divided age-wise. Since we are looking at children of four years or older we have chosen sections for older children and therefore excluded those of mixed ages with children down to one year. In the investigated sections the children could be as young as three years. The preschools were located in the districts Västra Göteborg, Centrum, Norra Hisingen and Örgryte-Härlanda. In order to anonymize the results, the preschools are not called by their names but instead as preschool 1-4 (not numbered according to the previous mentioned order). In preschool 2 and 3, measurements were performed at two different sections, A and B. They are, for example, called preschool 2 section A.

3.1.1 Getting in contact with the preschools

First we got in contact with the manager of the preschools of interest to ask for cooperation and participation in our study. After approval from the manager we talked to the personnel and informed them about the study. We told them why we are doing the study, how it would be performed and what was expected of them.

3.1.2 Contact with the children and information to the guardians

A few weeks in advance, we visited the preschools, said hi and hello to the children, told them what was going to happen in the week of the measurements and showed them some equipment that we were going to use, such as the otoscope and a vest with a dosimeter attached. Information and consent forms to read and sign were distributed to the guardians. For those children who had two guardians, both needed to give their approval in order for the child to be able to participate in the study. In one preschool, the first one, we did not visit the preschool beforehand and talked to the children but only handed out the information and consent forms. Fewer guardians gave their approval for the study from this preschool than the other ones and hence fewer children could participate in the study. This could be a coincidence but in general we saw a benefit of showing ourselves in advance and being clear about what was going to happen. Both for the children, personnel and guardians.

3.1.3 Ethics

The study has been approved by the Central Ethical Review Board in Gothenburg. The children were orally informed about how the study would be done by us visiting the preschools a few weeks in advance. The guardians got information about the study paper wise, with a form they could sign and return to the preschool if they wanted their child to participate. All guardians of the children who wanted to be a part of the study have given their written consent for participation. All were informed that they any time they wanted could withdraw their participation without any reason. They were told that being a part of the study was completely voluntarily and that all data presented would be anonymous.

3.2 Measuring sound pressure levels

All sound pressure levels were measured as A-weighted levels. This in order to correspond to the human perception of sound levels at different frequencies and being able to compare results to previous studies made in the field. The sound pressure level in the playroom was measured with a microphone, a computer with a sound card and the software Audacity®. The microphone was hung from the ceiling, as low as possible without interfering with the movements in the room and not being too visible in order to decrease the risk of changing the behaviour of the children and personnel.

The equivalent level $L_{A,eq}$ for the playrooms was evaluated for periods when children were present and active. The exposure levels of the children were measured using dosimeters worn together with a special sewed vest with the microphone attached on the shoulder, to be as close to their real ears as possible. Some days, some of the personnel also wore a dosimeter in order to see the difference between exposure level for the children and the personnel.

3.2.1 Using dosimeters

As explained in Section 2.1.1.1, the dosimeters consist of a black box and a microphone connected with a cable in between. To simplify the wearing of the dosimeters for the children, special sewed vests were used with a pocket on the stomach for the box and a strip on the shoulder to attach the microphone at. The cable went on the inside of the vest not to interfere with their activities. The personnel had the black box in their pocket, with the cable on the inside of their shirt and the microphone attached on their shoulder. The personal (including both children and personnel) dosimeter microphones all had a windshield.

Dosimeter settings
Measurements were made Monday, Tuesday, Thursday and Friday every week and the dosimeters were programmed for two days at a time. At the resetting every second day of measurement, the dosimeters were calibrated, the batteries were exchanged and the data was extracted and saved using Blaze® Software Version 5.06 [28]. The dosimeters were programmed to measure between 07:30 and 15:30, the sampling time was set to 30 s and the time weighting to Fast (125 ms). The variables chosen to be measured were $L_{A,eq}$, $L_{A,max}$ and $L_{C,peak}$. The dosimeters used were Larson Davis dosimeters, model 705+. Their measurement range was 40 dB to 143 dB for frequencies 10 Hz to 20 000 Hz [29].

When the data was extracted from the dosimeters, the periods of interest were selected from the whole measurement time. The times of interest included playtime indoors and excluded breakfast time, lunch with following resting session, afternoon snack and all sort of outdoor activity (the vests were only worn indoors anyhow). This selection of data was performed in order to obtain the exposure level during the children's playtime.

There were five vests to our disposal, so five children could wear a dosimeter each day. One dosimeter was hung from the ceiling, at the same position as the measurement microphone and at those preschools where measurements were performed at two sections, an additional ceiling dosimeter was placed in the second section, so that both section's playrooms got measured. The children wearing the dosimeters each day belonged to the same section and were preferably the same children as were being measured for the DPOAE. Since it was voluntarily for the children to participate it happened that there were other children wearing the vests, and sometimes fewer children dosimeters than five in total were in use (as can be seen in Section 4.1.1.1).

3.2.2 Frequency analysis

The recordings from the ceiling microphone were analysed in order to get the frequency content for the children's playtime, to see which frequencies that are most prominent. The .wav-files from the measurements were analysed and processed in MATLAB into plots that showed the equivalent A-weighted sound pressure level for every 1/3-octave band for frequencies 100 Hz to 8000 Hz.

3.3 Measuring room acoustic parameters

The room acoustic measurements took place in the playrooms when no children were present. An omnidirectional loudspeaker sent out white noise and the sound was measured at six different source-receiver positions. Two different loudspeaker positions with three different microphone positions each. The microphone as well as the loudspeaker was placed no less than 1 m from any wall, approximately at a height of 1.2 m. The loudspeaker and the microphone had a minimum distance of 2 m and to the greatest extent they were placed at least 0.5 m from any reflective surface. The sampling rate was 44 100 Hz and the measurement time 30 s per position. The used arrangement was based on the standards SS-EN ISO 3382-2 [30] and -3 [31] which is about measuring room acoustic parameters in ordinary rooms and open plan offices, respectively.

The results of the measurements were later processed in MATLAB into an impulse response for the room from which the room acoustic parameters were calculated. The results of the measurements were later processed in MATLAB into an impulse response by calculating a frequency response function and using the inverse Fourier transform. The impulse response was then used to calculate the different room acoustic parameters. All equipment was provided from Applied Acoustics at Chalmers.

3.4 DPOAE measurement and settings

The equipment used to perform the DPOAE was an Interacoustics Titan 440. It is constructed to be used both for measuring otoacoustic emissions and tympanometry. The device was provided by Occupational and Environmental Medicine. The Titan apparatus was connected to a computer with the software Titan Suit 3.4.0 from which the device was controlled and the DPOAE data extracted. A probe is connected to the Titan device via a cable. For the measurement, the probe was placed in the ear canal to measure the DPOAE. The probe had to be air tight, which was done by using a rubber plug with a size that fits the particular ear canal. This plug also blocks some of the background noise. In order to perform the measurement, one had to make sure that the probe was not being blocked against the ear canal walls. The probe has both a loudspeaker and a microphone inbuilt. Since the interesting frequency to measure is $f = 2F_1 - F_2$ there is no problem with sending out and recording sound at the same time.

DPOAE settings
Maximum test time per frequency was set to 30 seconds, before moving onward to the next frequency in line. A particular frequency could be remeasured if there was too much noise around, too high background level or for example if the child talked or moved.

Criteria for passing was set to a minimum of 6 dB Signal-To-Noise ratio (SNR) and a minimal DP-amplitude of -10 dB. The frequencies sent into the ear towards the tympanic membrane from the loudspeaker in the probe were the distorted tones of 1 kHz, 2 kHz, 3 kHz, 4 kHz, 6 kHz, 8 kHz and 10 kHz.

The frequency ratio used was $F_2/F_1 = 1.22$ with corresponding frequency levels of $L_1 = 65$ dB and $L_2 = 55$ dB.

3.5 Tympanometry measurement and settings

Tympanometry was done just before the DPOAE to see the status of the middle ear and if one should proceed with DPOAE measurements or not. The tympanometry was performed with the same equipment as for measuring the DPOAE, the Interacoustics Titan 440. The procedure is the same as for the DPOAE (a probe in the ear canal with a rubber plug making it air tight), but for the tympanometry, the device's ability to change air pressure is used. The cable between the device and the probe is not only for electrical signals, it is also for air. The loudspeaker in the probe sends out a tone, most often at 226 Hz , while the air pressure changes in front of the eardrum. The microphone measures how much sound is reflected back by the eardrum and in that way one gets to know the compliance at different pressures.

The played tone for the tympanometry in this study was chosen to 226 Hz at 85 dB and the air pressure swept from 200 daPa to −400 daPa with 0 daPa corresponding to the surrounding air pressure. (1 Pa is 10 daPa). In tympanograms, the unit of the compliance on the y-axis is often displayed as ml or cc (cubic centimetres), where 1 ml corresponds to 1 m℧ at sea level for 226 Hz [27].

The limits for passing the tympanometry were set to having a compliance peak of magnitude 0.3 ml to 1.6 ml within the range of −100 daPa to 50 daPa.

If the tympanogram showed any kind of middle ear problems, the DPOAE was not measured and the guardians of that child were informed. The measurements of the tympanometry and the DPOAE were performed in a quiet room, for three of the preschools that was a resting/meeting room and for one it was the office of the personnel.

3.6 Equipment list

- Omnidirectional microphone, d:screet™ 4060 Miniature, Hi-Sens
- Sound card, M-Audio MobilePre
- Computer
- Cables
- Omnidirectional loudspeaker, Brüel & Kjær Type 4295, Serial No. 2879487
- Amplifier, Brüel & Kjær, Type 2735, Serial No. 2735-100389

- Otoscope
- Interacoustics Titan 440 for DPOAE and tympanometry, Serial No. 3145885
- Rubberplugs of different sizes
- Dosimeters, Larson Davis, type 705+
- Calibrator, Brüel & Kjær Type 4230, Serial No. 1314124
- Vests, home sewed
- Software: Audacity® to record sound, MATLAB® to process the data, ©Interacoustics® Titan Suite 3.4.0 to obtain the results from the Titan Interacoustics measurements and Blaze® Version 5.06 to manage the dosimeters

4

Results and Discussion

First, an example of a typical day for a child wearing a dosimeter is presented. Secondly, the equivalent sound pressure levels are presented for children, personnel and ceiling microphones for each preschool section, together with the frequency analysis of a playroom. There is also a list of the average children playtime equivalent level, $L_{A,eq,avg}$, for each section. Thirdly, the results of the room acoustic measurements are presented, with different parameters and descriptions of the playrooms. At last, results from the DPOAE measurements are revealed, provided from audiologist Sebastian Waltilla. The results are commented and discussed as they appear and concluded in Chapter 7.

4.1 Sound pressure level measurements

The data is presented as $L_{A,eq}$ values from approximately one hour measurements in the morning and the afternoon. A frequency spectrum for one hour playtime in a playroom is presented in 1/3-octave bands.

4.1.1 Dosimeter results

A typical day at the preschool consists partly of, in chronological order, breakfast, playtime indoors, outdoor play, lunch, rest, playtime indoors and/or outdoors, afternoon snack. The plot in Figure 4.1 shows a typical day at preschool for a child wearing a dosimeter. The level displayed is the equivalent A-weighted level for 30 s. In comparison to other child dosimeter results, this particular example is having one of the lowest playtime exposure levels during the study.

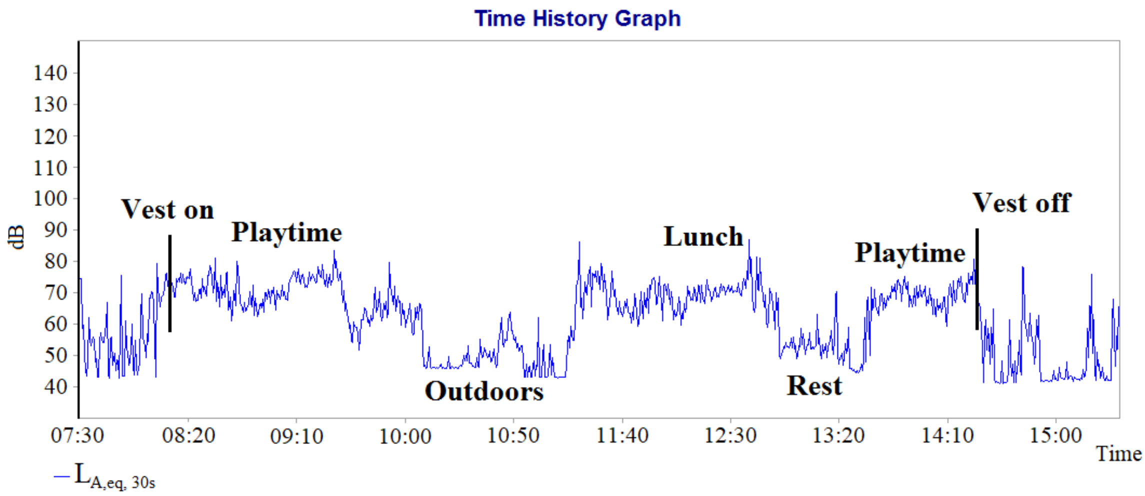

Figure 4.1: $L_{A,eq}$ for every 30 s of a typical day for a child at preschool. The dosimeter was worn between 08:10 and 14:24, and taken off during outdoor stay. The graph is from the Blaze software.

4.1.1.1 Playtime exposure levels

The following plots show the $L_{A,eq}$ for playtime indoors, excluding meals and resting period. Data for children is shown as black circles, for personnel as blue crosses and for the stationary microphone hanging from the ceiling as red diamonds. The measurement times are between 40 min and 1.5 h with most periods being just over one hour. The placement of the levels along the x-axis refers to the time centre of the particular measurement period. The stationary microphone is located at a fixed position in the playroom while both children and personnel could spend their indoor time in other rooms in the preschool as well, since they were wearing their dosimeters on their own shoulder. This means that high exposure levels do not have to mean high sound pressure levels in the playroom. The personal dosimeter data show the children's and personnel exposure levels during active time indoors.

(Nota bene: the microphone recording the sound pressure level in the playroom hanging from the ceiling is called different things in the comments below. It can be ceiling microphone, stationary microphone, fixed microphone, but they all mean the same thing: the microphone hanging from the ceiling.)

In advance it can be told that, in general, the stationary microphone levels are lower than the personal exposure levels, this is expected since the microphone was hanging from the ceiling approximately 2 m from the floor and children tend to play, and generate sound, close to each other, and hence being exposed of higher sound pressure levels.

The plots in Figure 4.2 show $L_{A,eq}$ results for preschool 1.

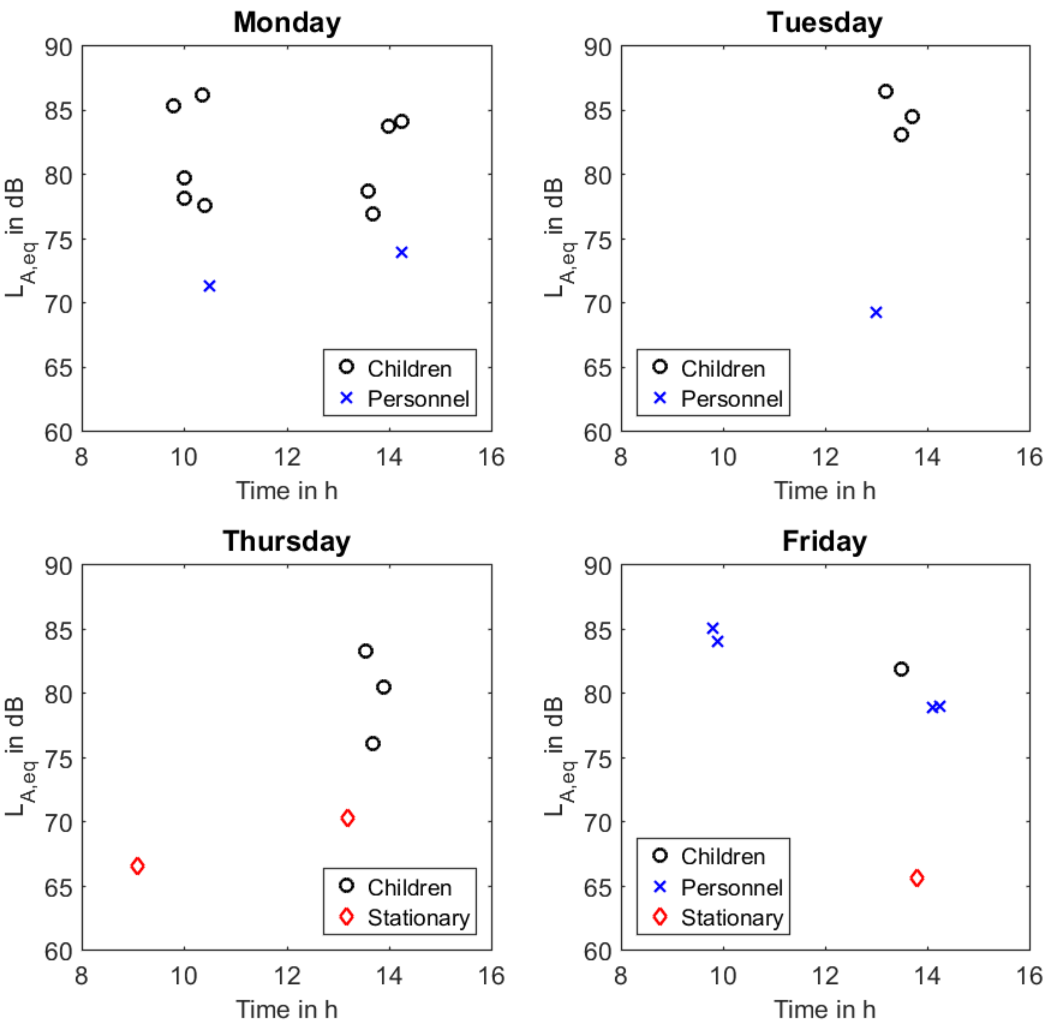

Figure 4.2: Preschool 1. $L_{A,eq}$ exposure values for children during playtime indoors, exposure for personnel working indoors and stationary values for ceiling microphone in the playroom. The number of children present was 17, 25, 26 and 25, for Monday, Tuesday, Thursday and Friday respectively (28 children if no one absent).

In preschool 1 the measurements were performed in only one section, therefore there are results from four days. A tendency can be seen that the personnel has in general lower exposure values than the children. The high levels for the personnel on Friday morning together with no children data are explained by the facts that the children were outside playing while the personnel spent time indoors having "planning time" in the morning before lunch. (The reason to why the planning time generates so high sound levels is another interesting matter but will not be dealt with here.) There is no visible correlation between level and number of children, however, it is difficult to compare when there is a lot of data from the first day but not so much from the rest of the days, regarding the children[1]. From the days when data is available from

[1] On Monday there was no stationary data due to technical issues. On Tuesday and Thursday half of the group was visiting the forest in the morning, on Tuesday there was no representing data and on Thursday the children wearing the vests were unfortunately the ones who went to the forest and hence hung the vests in the hallway.

the ceiling dosimeter, the results show that the stationary values have significant lower levels than the personal exposure levels.

Figure 4.3 and Figure 4.4 shows the equivalent sound pressure levels for preschool 2, section A and B, respectively.

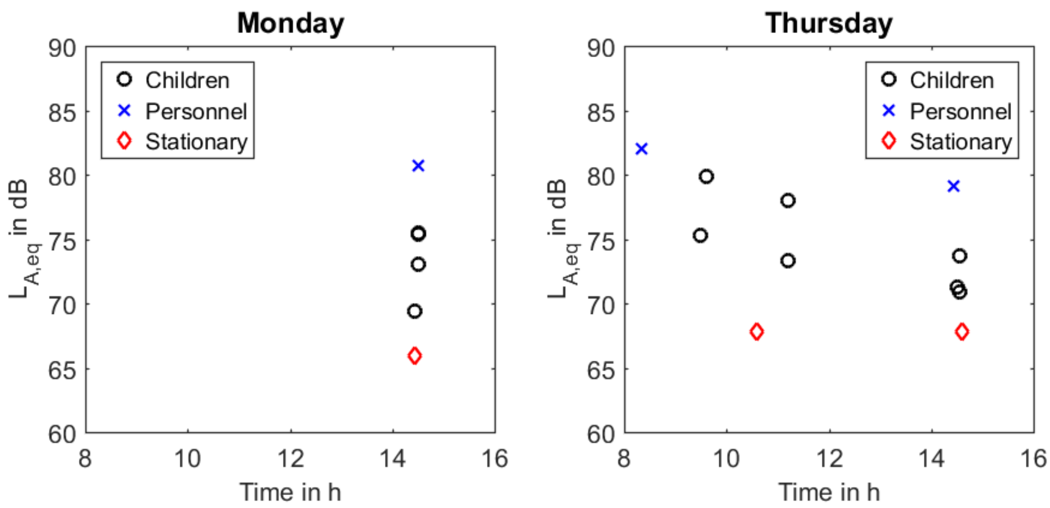

Figure 4.3: Preschool 2, section A. $L_{A,eq}$ exposure values for children during playtime indoors, exposure for personnel working indoors and stationary values for ceiling microphone in the playroom. The number of children present each day was 12 and 14, for Monday and Thursday respectively (16 children if no one absent).

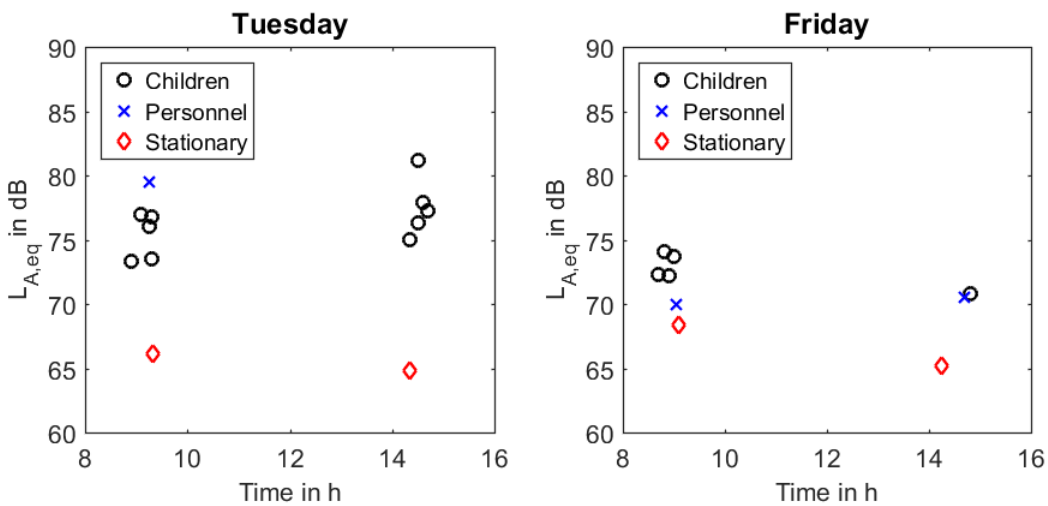

Figure 4.4: Preschool 2, section B. $L_{A,eq}$ exposure values for children during playtime indoors, exposure for personnel working indoors and stationary values for ceiling microphone in the playroom. The number of children present was 23 and 18, for Tuesday and Friday respectively (23 children if no one absent).

In preschool 2 it seems like the personnel are having higher exposure levels during children playtime than the children except for Friday. This is not in line with earlier studies but can have various reasons, for example there was only one in the personnel wearing a dosimeter each day and since the recorded exposure level to some extent is affected by the own speech, there will be differences whether one speaks a lot or not and how loud one talks. These characteristics vary a lot among all people, including preschool personnel. Therefore, the data should be taken with some caution since it is only telling the exposure level for one particular person. However, having personnel talking loud could affect the general sound environment having the children talking loud as well.

As in preschool 1 the stationary levels are consistently lower than the personal exposure levels[2]. For preschool 2 section B, in general higher equivalent sound pressure levels for the children can be seen on Tuesday compared to Friday which could be related to the number of children present that day, 23 compared to 18. The same tendency with the number of children can be seen in preschool 3.

The $L_{A,eq}$ values for preschool 3 is presented in Figure 4.5 and Figure 4.6, section A and section B, respectively.

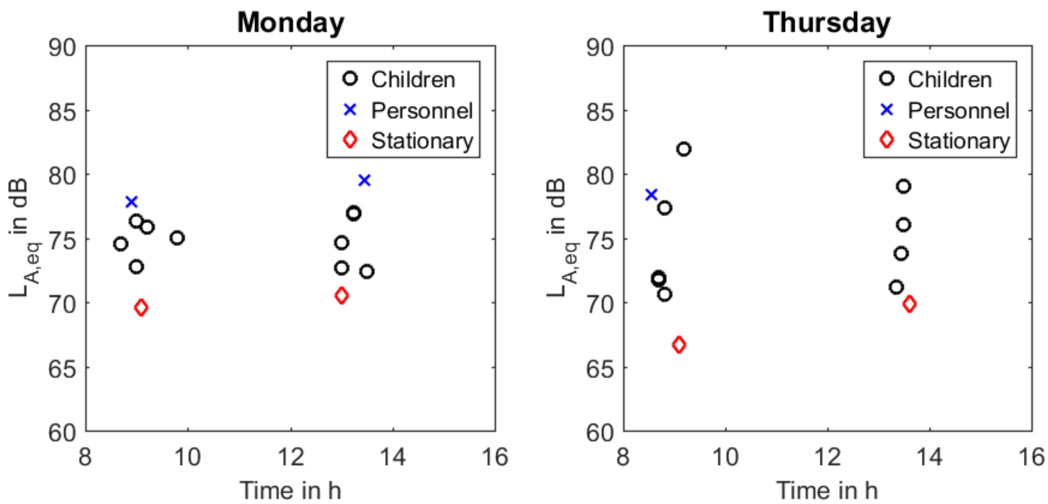

Figure 4.5: Preschool 3, section A. $L_{A,eq}$ exposure values for children during playtime indoors, exposure for personnel working indoors and stationary values for ceiling microphone in the playroom. The number of children present was 19 and 22, for Monday and Thursday respectively (23 children if no one absent).

[2]The lack of data for Monday morning is due to that the children were outdoors all morning.

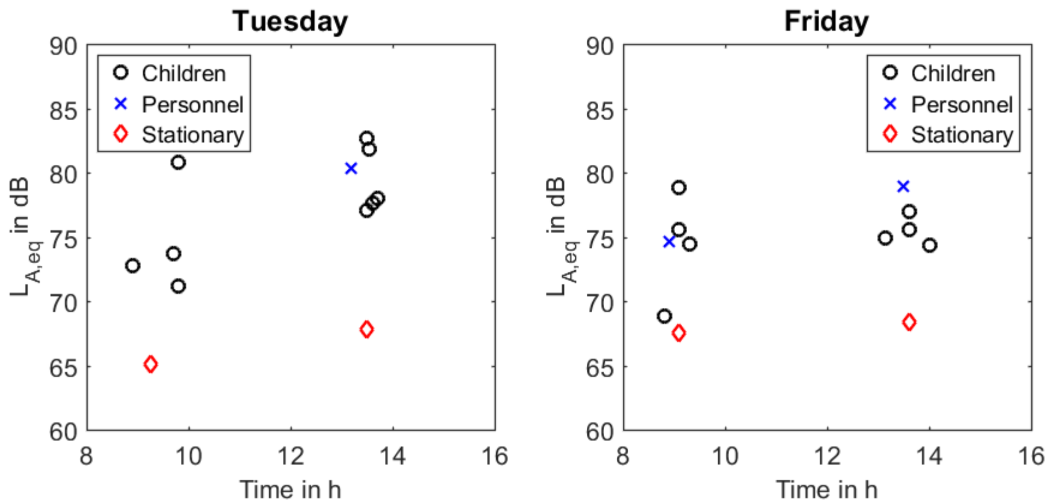

Figure 4.6: Preschool 3, section B. $L_{A,eq}$ exposure values for children during playtime indoors, exposure for personnel working indoors and stationary values for ceiling microphone in the playroom. The number of children present was 20 and 17, for Tuesday and Friday respectively (23 children if no one absent).

The results show that the personnel has higher than or about the same exposure level as the majority of the children and the stationary levels are consistently lower than the personal levels. In both sections a tendency can be noticed that shows higher levels the days when there are more children present (Thursday for section A and Tuesday afternoon for section B, but it could be just a coincidence). Noteworthy, it looks like the results for the days with more children have a more pronounced distribution - it differs more in level between different children at the same measurement period in the same section. This could be because the teachers are more likely to divide the group into several smaller groups when a lot of children are at the preschool. These groups could be doing different activities at the same time with big difference in sound generation: compare building with blocks to painting for example, or having intense role games compared to sitting down listening to someone reading a book in a quiet room.

Figure 4.7 shows the frequency content of the $L_{A,eq}$ measurement in preschool 3 section A Thursday morning in 1/3-octave bands. Low frequencies having low equivalent levels and the level increases with frequency up to 1250 Hz where the maximum value 61 dB is found. For higher frequencies the level decreases slightly.

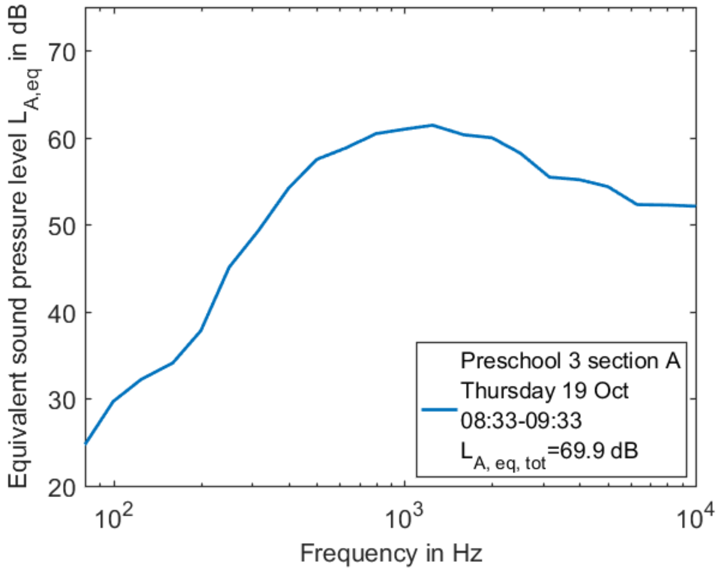

Figure 4.7: Preschool 3 section A. The plot shows the frequency components of the A-weighted equivalent value for the ceiling microphone that can be seen in Figure 4.5, the morning value on Thursday.

The frequency content of the sound in the playroom during playtime was analysed for five sections (with the exception of preschool 3 section B where the sound pressure level only was measured with a dosimeter in the playroom). The results were very similar to Figure 4.7 (for which reason they are not presented in this section but in the appendix). They all had their maximum value at 1000 Hz or 1250 Hz. The maximum value was around 60 dB for all sections except for preschool 4 which had its maximum at approximately 70 dB at 1250 Hz. The shape of the curves for the different sections all look the same with low values for lower frequencies, going steady upwards and peaking around 1000 Hz and then dropping successively for higher frequencies. To see the frequency analysis for the playrooms see Appendix A.2.

Figure 4.8 shows the equivalent sound pressure levels for preschool 4. This is the school that differs the most of the investigated schools, both building wise and result wise. It is an old school from the 1970's and was for example the only one in the investigation without acoustic ceiling tiles. The indoor height was also lower than for the rest of the schools.

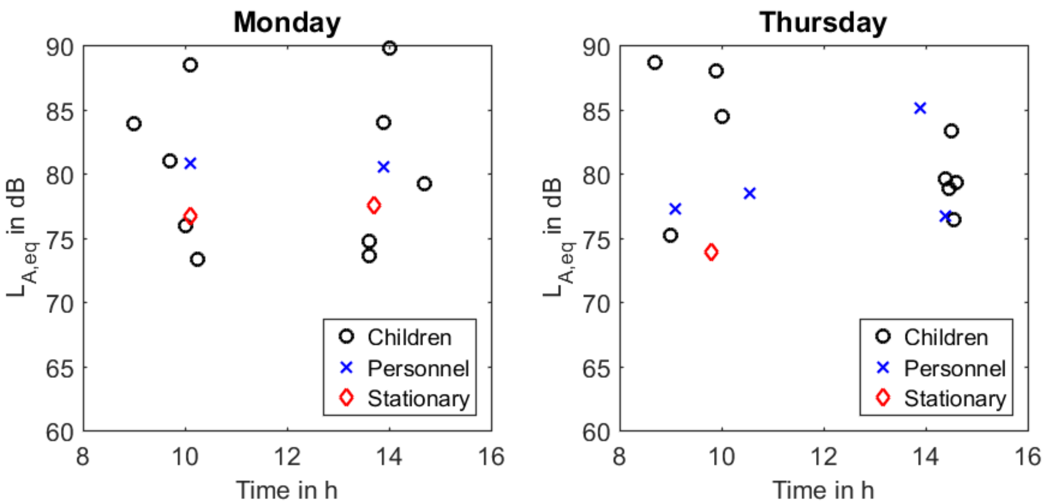

Figure 4.8: Preschool 4. $L_{A,eq}$ exposure values for children during playtime indoors, exposure for personnel working indoors and stationary values for ceiling microphone in the playroom. The number of children present was 17 and 19, for Monday and Thursday respectively (19 children if no one absent).

In preschool 4 there are no signs of particularly high values for the personnel in comparison to the children but the children have in general high exposure levels, compared to the other sections. The distribution of the children's $L_{A,eq}$ in preschool 4 are more stretched out than in the other preschools. On Monday, some children even had lower exposure levels than the stationary microphone. This can be due to that the playroom, where the fixed microphone was placed, was a so called "movement room". The children spent a limited amount of time in this room, it was not an "allround" room like the ones that were measured in the other preschools where a variety of activities was taking place during the day. The children with lower levels maybe did not even spend any time at all in the movement room during the measurement period. The non-existing ceiling microphone level for Thursday afternoon is because there was no activity in the movement room: the children must have spent their time elsewhere indoors.

To summarise, in the other schools the measured room played a big role in the section, it was the biggest room where most of the children and personnel spent most of their time during they were indoors. Further, the stationary levels in preschool 4 can be a bit misleading due to the activities meant for the movement room[3]. Nonetheless, the children in preschool 4 are being exposed to high sound pressure levels.

Summation

For all preschools, except preschool 4, the stationary microphone level was lower than

[3]When, in accordance with the personnel, choosing which room to measure, we did not know it was a movement room. In retrospect, preschool 4 had many rooms where the children could be so if I was to redo the measurement I do not know which of the rooms being the most presentable, being comparable to the other playrooms in the study regarding amount of time children spent in it and what activities that were being performed. Maybe "Allrum 2" in Figure 4.13 but there were mostly tables and chairs.

the personal exposure levels. This is not surprising since the personal dosimeters are much closer to the sound sources than the ceiling microphone. A suggested reason for the higher stationary level in preschool 4 has been mentioned before.

The varying sound pressure level results from the fixed microphone (both between and within sections) can be explained by the number of children present in the playroom, what activities that are taking place and what type of children being present; loud or quiet.

There are quite big differences in exposure levels between individual children, not only between the different sections but also within the same preschool and section. This is because all children are individuals. They think different, have different personalities and behaviour and this could somehow be mirrored in the plots. The personnel as well are different human beings. Some talks a lot, some do not. Some works close to the children, some do not. With that said, what we see in these plots is no truth, it is just an example of what can be seen in a preschool, regarding different exposure levels[4].

The average equivalent sound pressure level for children during playtime indoors for each preschool section is shown in Table 4.1 together with the average equivalent sound pressure level in the playrooms during playtime indoors measured with the microphone hanging from the ceiling.

Table 4.1: The averaged $L_{A,eq,avg}$ children exposure level and ceiling microphone level during playtime indoors for each preschool section.

Preschool section	$L_{A,eq,avg}$ children (dB)	$L_{A,eq,avg}$ ceiling mic.(dB)
1	82.0	67.6
2a	76.4	67.7
2b	75.7	66.9
3a	76.6	69.9
3b	77.8	67.6
4	84.0	76.8

There can be seen a difference in the results between the stationary microphones and the ones worn by children (and personnel, even if not displayed in the table), with the stationary positions having lower levels. This is however not surprising since the stationary microphones were hanging from the ceilings (approximately 80 cm down) and hence had a longer distance to the sound events than the microphones attached

[4]Worth to mention is that when talking to the personnel in preschool 3, they told us about the difference of the indoor sound level between summer and winter. Their personal experience was that it was a lot higher levels indoors during winter time than the rest of the year, since the children tend to spend less time outdoors due to the cold and wet weather (it also takes more time and effort to dress and undress all children, why they maybe go out more seldom) and had to live out their energy indoors instead. All measurements for this study were made in October 2017. In October in Sweden it is autumn and this particular autumn was a mixture of grey, rainy, cold days and very nice, sunny, crispy days. So perhaps there was a good mixture of the weather generating representing data.

to the shoulders (on the persons who most probable also were causing the sounds). The results from the ceiling microphones can give a picture of the general sound pressure level in the room and can make it possible to compare the general sound pressure levels in the playrooms at different preschools.

The low amount of children data in general for preschool 1 is simply due to that the children were not so keen to wear the vests there. Some days there is no data for children in the morning because they were not inside playing but instead spent time outdoors in the yard. Since preschool 1 have so few data for children exposure the averaged result may be misleading. Nevertheless, it is the average of the children actually wearing the dosimeters.

To the greatest extent we wanted the children that were measured for DPOAE to also wear the dosimeters, in order to be able to compare sound pressure levels to DPOAE amplitudes, but this could not be achieved all the time. Sometimes the children did not want to wear the vests and then someone else got the opportunity to wear the dosimeter. In preschool 2-4 this could be done to some extent but in preschool 1 the vests changed wearer often during the days.

4.2 Room acoustics

In this section, a brief description of the room acoustic properties of the playrooms is given, followed by the results of the room acoustic measurements, including reverberation time T_{60}, strength G, and C_{room}.

4.2.1 Room acoustic description

The description of the playrooms contains the area and the volume, a little bit about the furniture and what has been done acoustically. There are also blueprints of the sections with the playroom marked with red boundaries. A more detailed version can be read in Appendix A.1, which also includes a bit more information about the rest of the preschools' properties.

Preschool 1
The playroom is L-shaped and has an area of $50\,m^2$ and a volume of $151\,m^3$. The walls are made out of concrete and there are many windows toward the yard and to an adjacent room. The ceiling consists of acoustic tiles of 2 cm fiberglass placed 60 cm below the structural ceiling. There was no absorption in between, only air and some installations. In the playroom are some carpets but most floor area is plain plastic floor. The furniture is made out of wood, some bookshelves and a small table with chairs. The main absorptive furniture is a corner sofa with approximately 20 cm thick cushions. The curtains at the windows are made of thin fabric. On one of the walls, three fabric sheets of $0.8x2\,m^2$ each were placed with a small air gap from the wall and with some lining behind the textile.

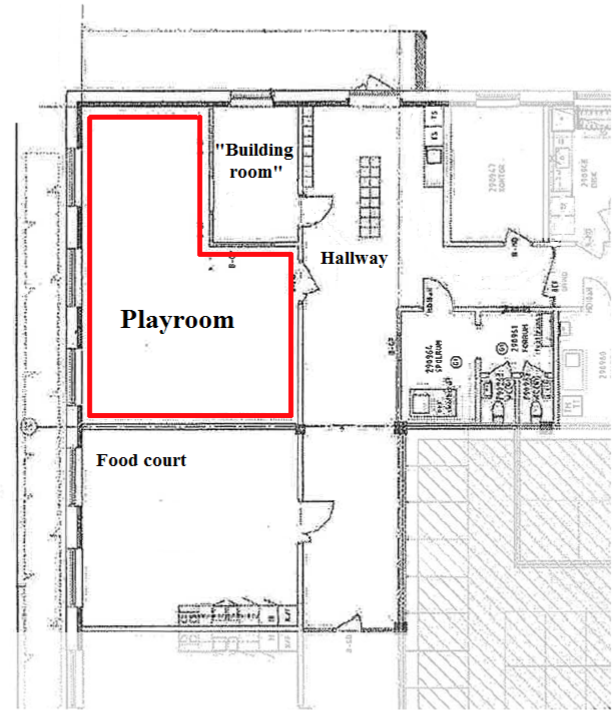

Figure 4.9: The blueprint of a part of preschool 1. The red marked room is the playroom being evaluated room acoustically and being measured with a fixed microphone hanging from the ceiling.

Preschool 2 section A

The room is rectangular, the area is 32 m^2 and the volume 86 m^3. This room is quite cramped with furniture and there is not much empty floor area. The ceiling is made of acoustic tiles with a thickness of 1.5 cm and has approximately 1 m empty space up to the structural ceiling. The outer wall has windows toward the yard and in one of the corners there are two low heights mirrors. There are several carpets in the room.

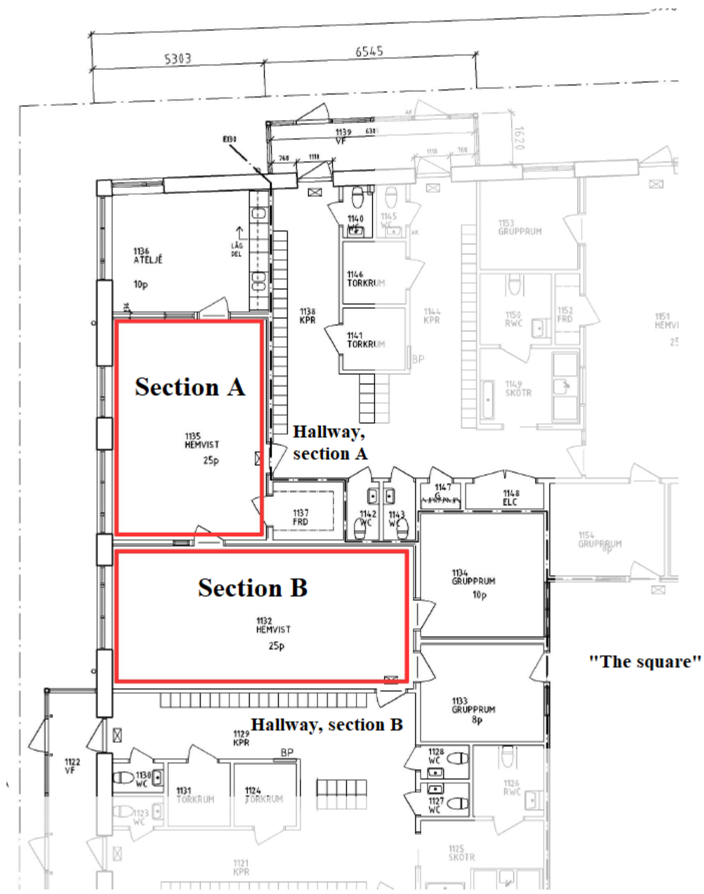

Figure 4.10: The blueprint over section A and B in preschool 2. The red marked areas are the rooms being evaluated room acoustically and being measured with a fixed microphone hanging from the ceiling.

Preschool 2 section B

This room is also rectangular but a bit bigger than section A. The playroom has an area of 41 m^2 and a volume of 111 m^3. The room has quite much free floor area. The ceiling is identical to that in section A with acoustic tiles with a thickness of 1.5 cm and approximately 1 m empty space up to the structural ceiling. On two of the walls, there are small perforated holes with absorptive material behind. The outer wall has windows against the yard, but otherwise there are no big glass surfaces. The room has some carpets. None of sections A and B in preschool 2 have any sofa in their playrooms.

Preschool 3 section A and B

The two playrooms in preschool 3 are similar, therefore they are described together. They are almost of the same size with areas of 48 m^2 and 48.5 m^2 and volumes of 127 m^3 and 131 m^3 for section A and B respectively. Both rooms have a lot of furniture, tables, chairs, bookshelves and carpets. Section A has an armchair and section B a sofa. In both rooms there are quite many windows - both facing the yard and smaller adjacent rooms to the playroom. Both rooms have a kitchen area and the children have their meals in their respective playroom. Section A has an absorbing painting in the playroom, approximately 1.2x1.2 m^2, hanging 1.2 m above the floor. Section A also has an acoustic screen which they can place between two tables where they usually sit and eat/paint/jigsaw-puzzle etc. The ceiling is made of 3 cm thick acoustic tiles with 70 cm air gap up to the structural ceiling.

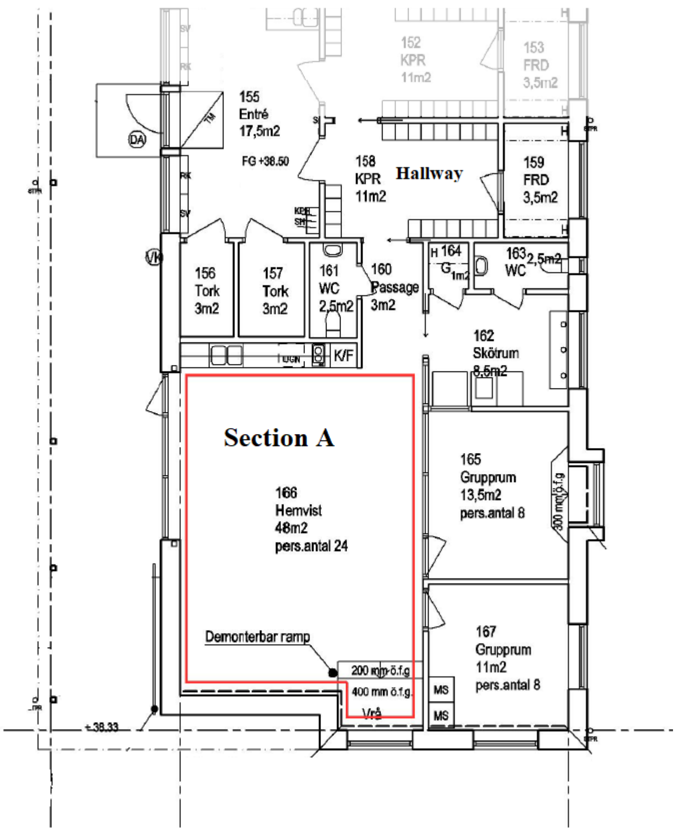

Figure 4.11: The blueprint over section A in preschool 3. The red marked area is the room being evaluated room acoustically and being measured with a fixed microphone hanging from the ceiling.

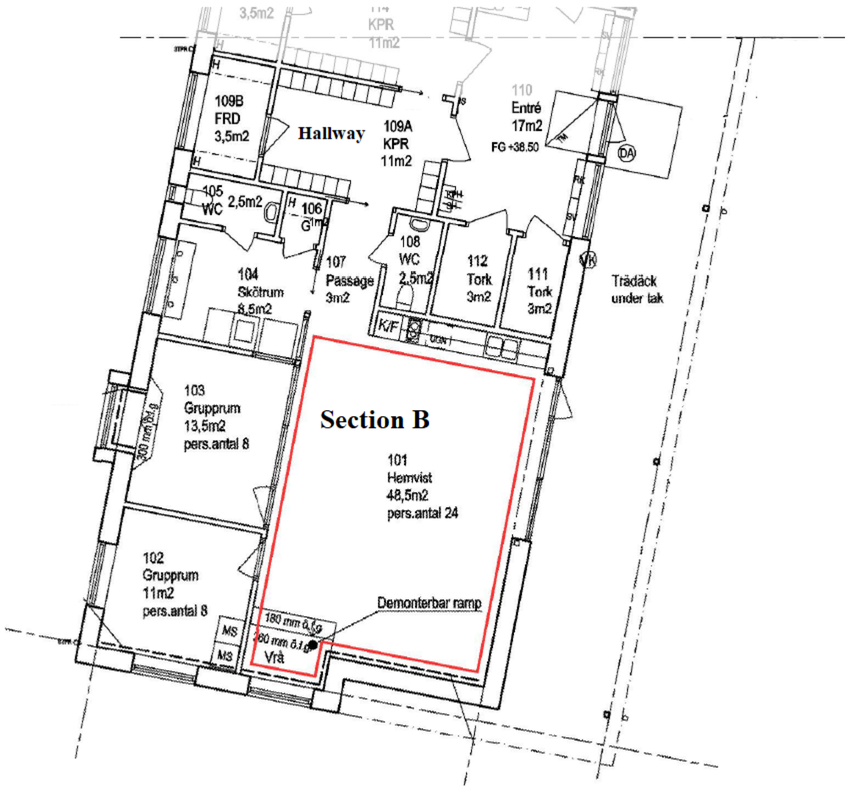

Figure 4.12: The blueprint over section B in preschool 3. The red marked area is the room being evaluated room acoustically and being measured with a fixed microphone hanging from the ceiling.

Preschool 4

The playroom in preschool 4 is not a common room as for many of the other sections but is called a "movement room". The area is 26 m^2, the volume 65 m^3 and it has a quite low headroom. The ceiling is not made of acoustical tiles but of some kind of painted wooden fibreboard and there could not be seen any room acoustic enhancements in the room. There is moderate amount of furniture, mostly made of wood and one sofa. In one of the corners there is a mattress (placed in the "förråd", see Figure 4.13). One of the long sides of the room consists of a wall which is a sliding wall that can be folded. This wall faces a similar room belonging to another section at the preschool and is not air tight when closed. The fact that it is not air tight means that some of the sound generated in the room could escape through the air gaps (making the room less reverberant), but it also means that if there is activity in the adjacent room that sound could easily transmit through the sliding wall into the playroom.

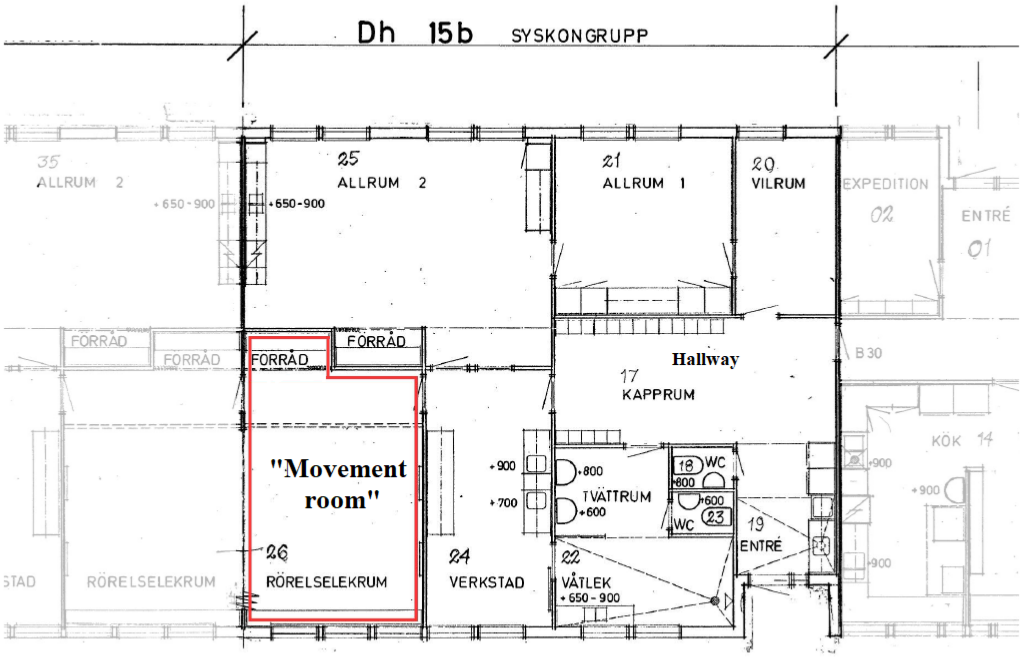

Figure 4.13: The blueprint over the chosen section in preschool 4. The red marked area is the room being evaluated room acoustically and being measured with a fixed microphone hanging from the ceiling.

4.2.2 Room acoustic parameters

Here follows an evaluation of the parameters reverberation time, strength and a sort of clarity for the playrooms. There have also been done calculations of the reverberation radius in order to see the partition of the direct and reverberant field.

4.2.2.1 Reverberation time

The reverberation time was calculated in 1/3-octave bands from the impulse response using backward integration averaged over the six different source-receiver positions in each room (see the positions in Appendix A.4).

Figure 4.14 shows the reverberation times for each room. To clarify, in the following text the playrooms are called only preschool X or preschool Y section Z, but it is the reverberation time in the playrooms that is discussed. The volume of each playroom can also be seen in the plots.

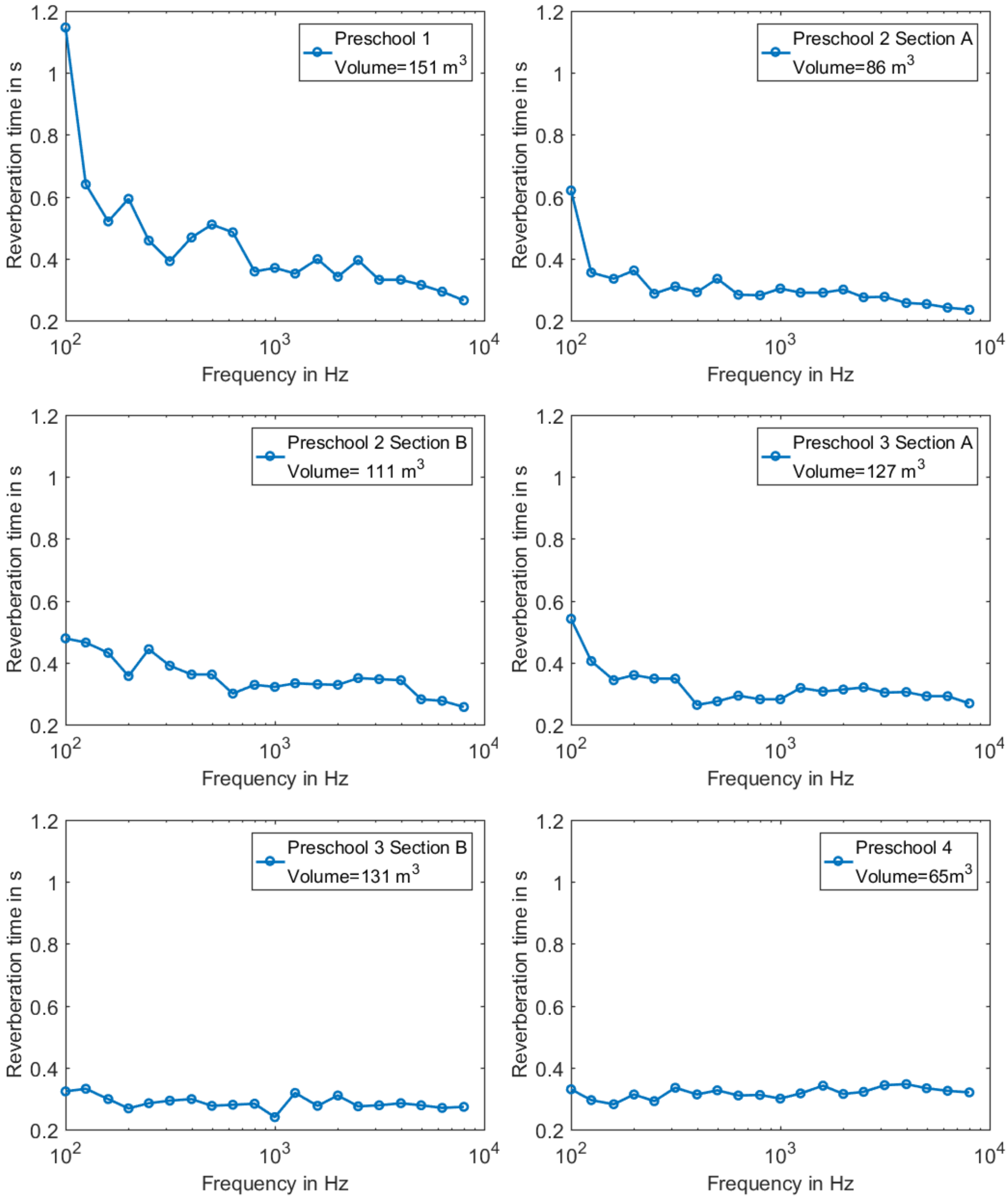

Figure 4.14: The reverberation times for all preschool playrooms in 1/3-octave bands.

The reverberation times are in general low for the preschools studied, lying around 0.3 s for most of the sections with exception for preschool 1. This playroom has the biggest volume, and with Sabine's formula $T \approx 0.161V/A_S$ (where A_S is the equivalent absorption area), these results seems reasonable. Preschool 1 has not much visible absorption, one corner sofa that may be the main absorptive object in the room. There is some thin fabric hanging in front of a wall that could absorb some higher frequencies. There is quite much empty floor area, and hence not so much furniture in the room (for more room acoustic description of the rooms see Section 4.2.1 and Appendix A.1). Even though the reverberation time for preschool 1 in general is higher than the other preschools, the value at 100 Hz, 1.15 s, seems untrustworthy and cannot be taken for the true value. When obtaining the impulse response, the results for the low frequencies should be taken with care, due to how the data is processed.

For preschool 2 section A, the same tendency can be seen with a much higher value for the 1/3-octave band with center frequency at 100 Hz. In preschool 2, section A has lower reverberation time than section B, which is not surprising since the volume is smaller and there was a lot of furniture and things in section A. Thus, the value at 100 Hz for section A should be taken with some caution. However, the values for the lower frequencies in general are not as interesting or important as higher frequencies, since most of the energy lies around 1000 Hz, approximately between 300 Hz and 5000 Hz. See an example of the frequency analysis in Figure 4.7 with maximum $L_{A,eq}$ around 1000 Hz. For 100 Hz, there are low values for the $L_{A,eq}$ for all sections. (To see more frequency analyses of the playrooms, see Appendix A.2).

The sections in preschool 3 have approximately the same volumes but section B has slightly lower reverberation time. This could be because they have more furniture, things and also a sofa that section A do not have. Taking a look at Table 4.1 one can see that section B has 2 dB lower $L_{A,eq}$ for the ceiling microphone in the playrooms during playtime (they have the same number of children in their groups).

Regarding furniture and reverberation time. When having an acoustic ceiling, reflective furniture in the room could lower the reverberation time since the sound waves can be reflected towards the ceiling, get damped there, and hence lower the reverberation time.

The results of the reverberation time in preschool 4 are somewhat surprising since the room felt undamped. The room has little visual absorption, no acoustic ceiling tiles, but is rather small, only 65 m^3. However, the low reverberation time, especially for the low frequencies, might be explained by the fact that one of the walls is a sliding wall that is flexible and also not air tight. This can lead to that sound energy is taken from the room. Considering that this room is called the "movement room", and that Table 4.1 shows that it has significantly higher $L_{A,eq}$ than the other measured playrooms, it is good that the reverberation time is comparatively short. With longer reverberation time, the sound will linger longer in the room and hence raise the sound level.

4.2.2.2 Strength

To see how much the rooms enhance sound, calculations have been made according to Equation (2.4) which was presented in the theory chapter. Remember that strength is the difference between the sound pressure level measured at a certain position in a certain room and the sound pressure level measured at a distance of 10 m in free field conditions, with the same source. The results of the strength calculations can be seen in Table 4.2.

Table 4.2: A table showing the different playroom's volume, average reverberation time, room strength, reverberation radius, strength maximum deviation and maximum and minimum distances between source and receiver. G is calculated for each position and 1/3-octave band and then averaged to one single value for each room.

Room	V (m^3)	T_{60} (s)	G (dB)	r_h (m)	G_{dev} (dB)	r_{min} (m)	r_{max} (m)	Ceil. mic (dB)
1	151	0.45	**19.5**	1.11	0.6	3.25	6.41	67.6
2a	86	0.31	**20.8**	0.97	0.4	2.41	3.31	67.7
2b	111	0.35	**20.2**	1.02	0.3	2.88	5.79	66.9
3a	127	0.32	**19.4**	1.14	0.4	2.48	4.53	69.9
3b	131	0.29	**18.8**	1.22	0.4	3.01	4.80	67.6
4	65	0.32	**22.2**	0.81	0.2	2.54	4.22	76.8

V is the volume of the playroom, T_{60} is the reverberation time averaged over positions and frequency, G is the strength factor, r_h is the reverberation radius and G_{dev} is the maximum deviation to the mean value for the different source-receiver positions. The distances r_{min} and r_{max} are the minimum and maximum source-receiver distances for each playroom. These are displayed to show that G is rather stable regardless of distance differences. In fact no correlations can be seen between deviation to the mean value of G and distance between source and receiver for different positions. In addition, the $L_{A,eq,avg}$ values for the playrooms from Table 4.1 are displayed, to be able to connect these new results to the measured sound levels in the rooms.

From Equation (2.4) ($G = 10\log_{10}(100/r^2 + 31200T_{60}/V)$) one can see that the strength factor will be larger with longer reverberation time and smaller with bigger volume. For small rooms, which the playrooms are (compared to concert halls for example), the second term in the brackets will most probable be dominant and hence the distance between the source and receiver will have less impact on the results. This confirms what just has been seen regarding the distance differences having little or no influence on G. This is good since it is more convenient with one approximate value for the strength in average in the room instead of different values for particular source and receiver positions. (The latter is more useful when evaluating a concert hall when the source is on the stage and different audience positions are having different values of strength.)

The reverberation radius r_h is the distance from a source where the direct and the reverberant sound are equally strong. From Table 4.2 we see that the reverberation radius is around 1 m for all rooms. In theory, having a reverberation radius of 1 m and being in the reverberant field, i.e. being more than 1 m from the source, the strength factor would be $\sim$ 20 dB regardless of the distance[5]. In the table we can see that G is around 20 dB for all rooms. The results seem to be reasonable.

The reverberation radius is calculated according to Equation (4.1) which is based on formula $L_p = L_w + 10\log(1/4\pi r^2 + 4/A_S)$ in Acoustics and Audio Technology [12] and Sabine's formula $T \approx 0.161V/A_S$, it can also be found in [15]. The first part in the brackets in the first equation representing the direct field and the second part

[5]If $r_h = 1$ m, then $L_{direct} = 10\log_{10}(100/1) = 20$ dB, and thus also the reverberant part. Since the reverberant field is suppose to be the same in the whole room, G would be 20 dB or just above regardless of the distance. At r_h it would be 23 dB since 20 dB+20 dB=23 dB.

the reverberant field. Having these two parts equally big and using Sabine's formula results in a reverberation radius of

$$r_h = \sqrt{\frac{V}{100\pi T_{60}}} \tag{4.1}$$

r_h is calculated with the reverberation time in 1/3-octave bands for all different positions and at last averaged to one single value for each room.

The smaller the value of r_h the bigger will the reverberant field of the room be. It can be seen in Table 4.2 that preschool 4 has the shortest reverberation radius and also the biggest strength factor. This is also the preschool that has the highest sound levels in the playroom and the highest exposure levels for the children. It is the smallest playroom in the study, one can think that one takes a room with a bigger volume and just compresses it. Then the reverberant field will be more concentrated, the reverberation radius shorter and the over all sound level in the room higher.

4.2.2.3 Clarity

As described in Section 2.1.2.3, clarity is of better use when evaluating the room acoustics of a concert hall for music or speech than that of a room full of moving sound sources and no intended listeners. A high clarity would mean many early reflections, which can be beneficial for music experience and speech intelligibility. However, the question is what would be favorable for a preschool? Early reflections? Late reflections? Or maybe no reflections at all? It would be interesting to compare how much the direct sound contributes compared to the sound from the room. Therefore, for this thesis, a new parameter has been constructed, C_{room}, which compares the amount of reflected sound energy to that of direct sound. C_{room} is calculated from an impulse response, where the direct sound is the first sound reaching the receiver. The two different parts are called the direct part and the room part. Without the room, like in a free field, there would be only direct sound, but for a reverberation chamber for instance, the room part, the reflected sound, would make a big contribution to the total sound pressure level at the receiver position. Since the direct sound is decreasing with increasing distance, the results are dependent on distance.

How much bigger the room part is than the direct part can be calculated from the impulse response h according to Equation (4.2). The unit of C_{room} is dB.

$$C_{room} = 10\log_{10}\left(\frac{\left(\sum[h_{roomresponse}(t)]^2\right)}{\left(\sum[h_{directsound}(t)]^2\right)}\right) \tag{4.2}$$

Since the results differ quite a lot between different measurement positions in the rooms, they have not been averaged into one value per playroom, instead all the

C_{room} values are presented below in Table 4.3-4.8. For an overview of the source-receiver positions, see Appendix A.4.

Table 4.3: C_{room} for different positions and distances in the playroom in preschool 1.

Preschool 1						
Position	1	2	3	4	5	6
Distance (m)	3.32	3.25	6.41	6.23	4.71	3.35
C_{room} (dB)	11.8	9.4	12.7	13.1	9.6	7.8

Table 4.4: C_{room} for different positions and distances in the playroom in preschool 2 section A.

Preschool 2 section A						
Position	1	2	3	4	5	6
Distance (m)	3.28	3.01	3.31	2.41	3.12	2.91
C_{room} (dB)	10.6	8.5	9.0	8.1	8.8	7.8

Table 4.5: C_{room} for different positions and distances in the playroom in preschool 2 section B.

Preschool 2 section B						
Position	1	2	3	4	5	6
Distance (m)	3.14	4.47	5.79	2.88	3.79	5.08
C_{room} (dB)	9.4	11.5	12.4	8.9	11.4	11.7

Table 4.6: C_{room} for different positions and distances in the playroom in preschool 3 section A.

Preschool 3 section A						
Position	1	2	3	4	5	6
Distance (m)	4.20	3.04	2.85	4.53	4.36	2.48
C_{room} (dB)	10.2	7.5	8.0	9.1	11.1	7.5

Table 4.7: C_{room} for different positions and distances in the playroom in preschool 3 section B.

Preschool 3 section B						
Position	1	2	3	4	5	6
Distance (m)	4.80	3.96	3.01	3.58	3.63	3.23
C_{room} (dB)	10.6	9.3	7.5	9.3	8.6	9.6

Table 4.8: C_{room} for different positions and distances in the playroom in preschool 4.

Preschool 4						
Position	1	2	3	4	5	6
Distance (m)	2.54	2.71	4.22	2.54	2.97	2.93
C_{room} (dB)	10.4	9.7	12.5	9.9	12.8	11.1

When looking into the tables above, a slight tendency can be seen for a higher C_{room} for longer distances between source and receiver, i.e. the direct sound gets less prominent farther away from the source. It is not a surprise that a shorter distance would have a bigger contribution of the direct sound. These differences due to distance are the reasons why the values are not averaged over position as they were for the strength parameter. From the results of C_{room} one can in all cases conclude that the room enhances the sound pressure level in all rooms compared to only the direct sound. This is however also not surprising since all positions are outside of the reverberation radius (where direct field and reverberant field are equally strong).

This parameter also has similarities with the strength parameter, but strength compares the total sound in a certain position to the direct one in a distance of 10 m in free field conditions.

In order to show that C_{room} is representing in some way the contribution of the direct sound and the reflected sound on the equivalent levels, the impulse response function is convolved with a broad band noise signal.

The impulse response $h(t)$ can be seen as an addition of the direct part $h_d(t)$ and the room part $h_r(t)$ see Equation (4.3) and Figure 4.15.

$$h(t) = h_d(t) + h_r(t) \tag{4.3}$$

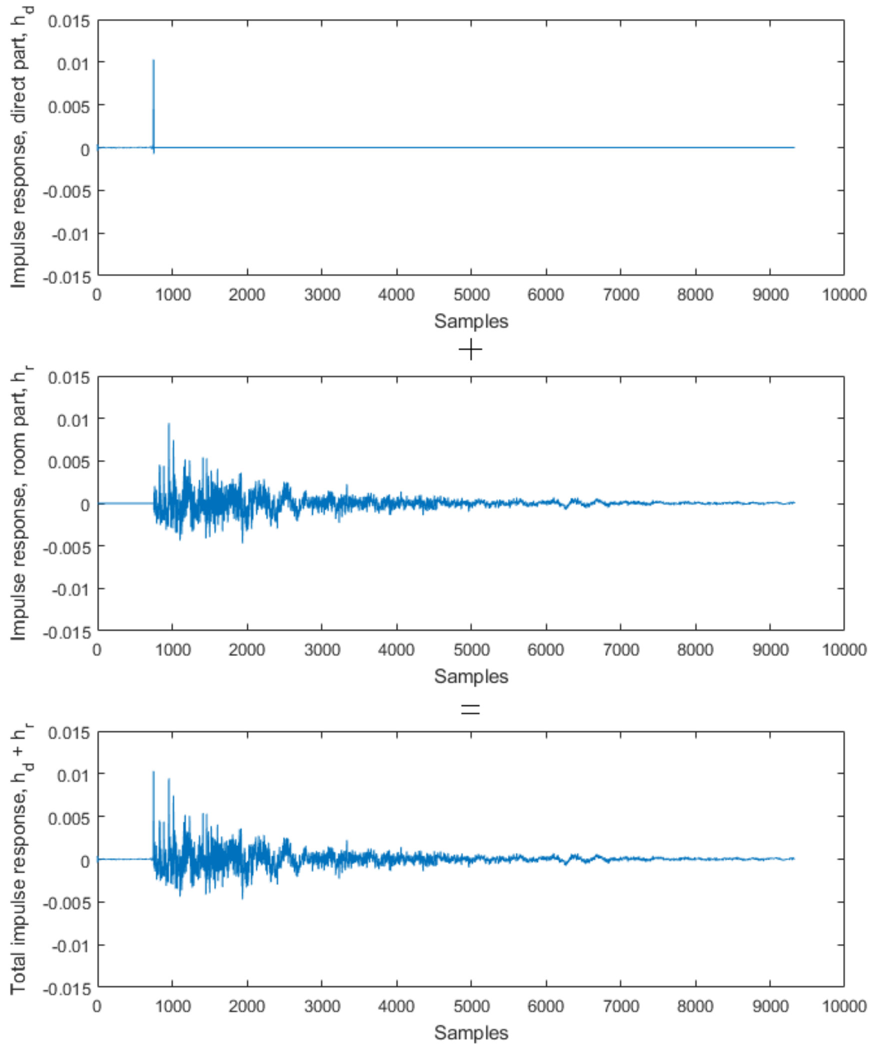

Figure 4.15: The total impulse response consisting of the direct part and the room part. This particular example is preschool 2 section B, source-receiver position 3.

Suppose that the loudspeaker is excited with random noise. To see how the room would response to this sound the given impulse response is convolved with such random noise $q(t)$ and squared according to Equation (4.4).

$$\begin{aligned} h(t) &= h_d(t) + h_r(t) \\ (q(t)^* h(t))^2 &= (q(t)^* h_d(t) + q(t)^* h_r(t))^2 \\ &= (q(t)^* h_d(t))^2 + (q(t)^* h_r(t))^2 + 2q(t)^* h_d q(t)^* h_r \end{aligned} \tag{4.4}$$

To be able to compare the energy of the room part with the direct part, an average over time is performed and the equivalent energy p_{eff}^2 is obtained according to Equation (4.5).

$$\underbrace{\frac{1}{T}\int_0^T (q(t)^* h(t))^2 dt}_{p^2_{eff}} = \underbrace{\frac{1}{T}\int_0^T (q(t)^* h_d(t))^2 dt}_{p^2_{eff,direct}} + \underbrace{\frac{1}{T}\int_0^T (q(t)^* h_r(t))^2 dt}_{p^2_{eff,room}} + \underbrace{2\frac{1}{T}\int_0^T q(t)^* h_d q(t)^* h_r dt}_{\to 0} \tag{4.5}$$

where the last term is so small and imaginary that it can be neglected. C_{room} can then be calculated according to Equation (4.6).

$$C_{room} = \frac{p^2_{eff,room}}{p^2_{eff,direct}} \tag{4.6}$$

When comparing the room part and the direct part it can be seen that the results from the two different methods to calculate C_{room} are very similar. The results for preschool 2 section B can be seen in Table 4.9. The calculations have been made for all sections and the similarity between the two methods is equal for all sections and positions.

Table 4.9: C_{room} for different positions and distances in the playroom in preschool 2 section B, calculated with both methods.

Preschool 2 section B						
Position	1	2	3	4	5	6
Distance (m)	3.14	4.47	5.79	2.88	3.79	5.08
C_{room} from eq. (4.2) (dB)	9.4139	11.5474	12.4067	8.9252	11.3861	11.7057
C_{room} from eq. (4.6) (dB)	9.3921	11.5429	12.4095	8.9289	11.3540	11.7081

Since the impulse response is convolved in MATLAB with random noise, the resulting output will vary between calculations, but looking at Table 4.9, C_{room} for the two methods are very similar.

The direct sound from an omnidirectional source is distance dependent having a decrement of 6 dB per distance doubling. The room part and the direct part are theoretically equally big at the reverberation radius (Equation (4.1)) and hence at that distance from the source C_{room} =0 dB. To see if the reduction of the direct sound can explain the differences in C_{room} due to different distances to the source, the calculated values from the impulse responses were compared to theoretical results (Figure 4.16 shows the difference between the room part and the direct part in dB). The farther away from the source, outside of the reverberation radius, the bigger is the difference with the room part being the dominant part. To make this theoretical approach it is assumed that the reverberant field is having the same sound pressure level regardless of distance from the source. The change of the magnitude of the direct sound in dB can be calculated as $20\log_{10}(r_1/r_2)$ with r_1 being the original distance to where the total sound pressure level was measured and r_2 being the new distance. Hence, if $r_2 < r_1$ the direct contribution will increase and vice versa. The comparison between theoretical and measured C_{room} can be seen in Figure 4.16 with the reverberation radius as r_h =1.2 m.

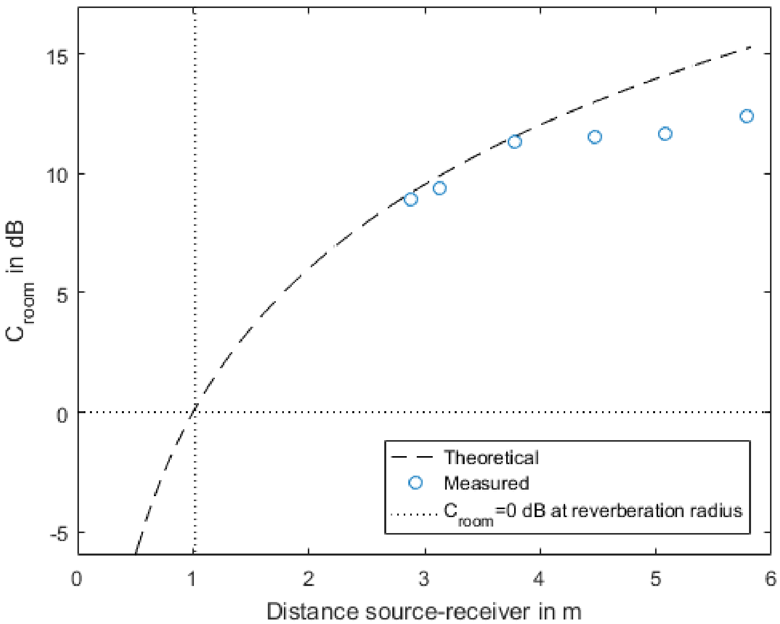

Figure 4.16: The calculated C_{room} for preschool 2 section B together with the theoretical difference between the room part and the direct part.

For the three shorter distances the measured and calculated C_{room} fits well with the theoretical values but for longer distances the room part falls off a bit from the theoretical curve. The assumption made about the reverberant field being equally strong everywhere in the room is probably not true, at least not for lower frequencies. This can be one explanation for the divergent values for longer distances.

Statistical room acoustics in principle does not exist in the real world. But nonetheless, trying to find another explanation to the lower C_{room} values, an indicator to that the results are reasonable even though they are divergent from the theory is found in an article about energy relations in concert auditoriums.

Barron and Lee [32] found, after measurements in concert halls, that the level of the reflected sound (i.e. the reverberant field) is distance dependent, with decreasing reflected level as the distance from the source is increased, this in contrary to classic statistical room acoustic theory. This could explain why the C_{room} values for the longer distances in Figure 4.16 is lower than the theoretical.

Further, if the room has more absorption, the reverberant field will be smaller and the reverberation radius longer. Therefore, the direct sound will dominate in a bigger volume of the room, but the over all sound level in the room will be lower.

Furthermore regarding C_{room}, inside the reverberation radius, the direct sound will dominate and hence the room will not make so big difference to the sound level at that position. There is no way to know how close to each other the children play, but one can think that they often do play close to each other. If so, the room will not influence the exposure level particularly much, but the configuration and furnishing of the room can still affect the children's behaviour and sound generation.

4.3 DPOAE

An example of the test results from a DPOAE measurement is presented in Figure 4.17. It shows the amplitude of the otoacoustic emissions for different frequencies. The picture is a screenshot from the Interacoustics Titan software.

Figure 4.17: An example of the result from a DPOAE measurement.

The green check signs in the "DP-Gram" indicate that the response at each frequency is matching the predetermined requirements for an OK response (minimum of 6 dB Signal-To-Noise ratio (SNR) and a minimal DP-amplitude of -10 dB). The grey area below the check signs shows the background noise level. The "Response" box shows excitation frequencies f_1 at 65 dB and f_2 at 55 dB. The red staple is the characteristic frequency $2f_1 - f_2$ which is the response measured.

A normal result of the tympanometry is shown in Figure 4.18 where the peak of the compliance is within the set limits for an approved tympanometry.

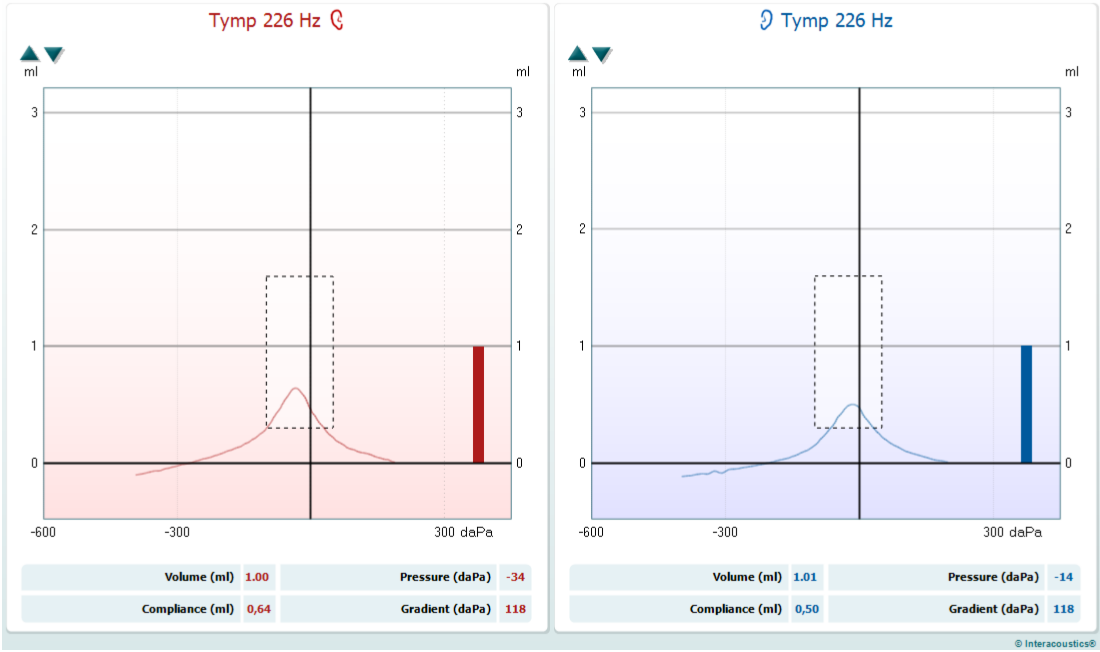

Figure 4.18: An example of a normal tympanometry.

Throughout the four weeks at the preschools 42 children were participating in the hearing measurements of which 37 passed the tympanometry and was measured for the DPOAE.

There are unfortunately not as many results from this part of the study to show as was thought from the beginning. A frequency that shows a possible reduction of the DPOAE amplitude between the measurements is that of 3000 Hz for the right ear. The measured DPOAE amplitudes can be seen in Table 4.10.

Table 4.10: DPOAE amplitudes in dB for 3000 Hz for the right ear. Missing amplitudes are due to non passed tympanometry, failed measurement or the fact that the child had went home without us knowing it.

Child No.	**Day 1**		**Day 4**	
	Morning	**Afternoon**	**Morning**	**Afternoon**
1	8.1	10.2	10.3	12.3
2	3.1	1.9	-1.6	3.3
3	10.4	10.5	10.1	10.0
4	10.3	10.7	8.6	9.7
5	6.3	4.3	-1.1	-1.6
6	2.5	-3.4	-2.0	-4.0
7	15.6	11.6	4.3	14.1
8	14.4	13.3	15.0	14.5
9	12.8	10.6	10.2	9.4
10	8.3	6.4	-	-
11	13.1	11.4	-	-
12	5.3	7.3	1.9	2.0
13	1.5	4.0	-9.5	-9.8
14	4.4	4.4	4.3	4.2
15	14.9	10.3	8.7	11.0
16	16.0	13.2	16.1	15.8
17	12.6	16.3	15.3	16.2
18	7.1	2.8	2.5	4.5
19	14.8	15.9	16.0	14.6
20	0.2	0.9	7.6	-3.4
21	15.1	-	-	-
22	2.6	-0.1	-0.3	-6.6
23	7.7	12.1	10.0	6.1
24	-	-	-	-
25	15.1	15.2	15.8	14.9
26	8.8	8.9	9.8	8.4
27	16.1	15.7	17.1	14.5
28	11.8	7.5	9.0	6.3
29	2.1	1.9	-	-
30	-	-	-	-
31	-0.1	4.9	0.8	2.2
32	9.8	9.5	8.6	9.8
33	-	-	-	-
34	-	-	-	-
35	5.5	3.7	3.9	6.2
36	11.5	11.0	11.8	4.8
37	7.1	9.7	9.0	6.1
38	-	-	-	-
39	13.6	13.5	13.4	12.1
40	13.0	12.5	14.1	12.4
41	13.6	-	11.9	3.3
42	4.5	3.9	-4.2	-4.2
Average	9.18	8.36	7.50	6.64
Median	9.80	9.70	9.00	6.30

If eliminating all children that do not have results for all four measurements the average and median value are according to Table 4.11.

Table 4.11: The average and median values of the DPOAE amplitudes for 3000 Hz for the right ear for children measured at all four occasions.

	Day 1		**Day 4**	
	Morning	**Afternoon**	**Morning**	**Afternoon**
Average	8.98	8.53	7.36	6.74
Median	9.30	9.95	8.85	7.35

The results show that both the average and the median value of the DPOAE amplitudes of the measured children decrease when comparing morning day 1 with afternoon day 4. This applies for 3000 Hz for the right ear. These results are preliminary and may change throughout further analysis. However, when comparing the results from morning day 1 with afternoon day 4, the change of the DPOAE amplitude shows a significant reduction. The significant reduction was tested using paired T-test. This means that each child's value in the morning was compared to its value in the afternoon, hence showing inter-individual variations. A significant reduction could also be seen when comparing morning day 1 with morning day 4 for the same ear and frequency.

The results from the tympanometry and DPOAE measurements are obtained from audiologist Sebastian Waltilla. It was supposed to be a more extensive analysis regarding the hearing part, but due to that he has not been able to deliver more comprehensive results in time, these are the results displayed in this thesis. However, for the interested reader, the results from his master thesis are expected to be published in the spring of 2018. Even though there are no further results to present here, readers who have gone through the theory and the methods chapters have at least learned a bit about the ear and hearing measurement techniques and hopefully gained some knowledge that they did not had before.

4.4 Voices from the personnel

As a closure of the Results and Discussion chapter some thoughts from the personnel are displayed. Some of the personnel working at the preschools in the study answered a questionnaire regarding the sound environment. All personnel that filled in the questionnaire thought that noise in the preschool affects the children's behaviour. Some answers to the question of how the children are affected by noise are: "They get more active, some yell more loudly than others, some get tired, some get unconcentrated." "They try to overcome each other soundwise, they get less concentrated." "Noise feeds noise. If one starts it will spread". "The children get more tired, having a difficult time focusing on what they are doing." "The more noise the louder and active the children become. It gets harder for them to unwind." "They get anxious, raise their voices and some get tired."

5

Further discussion and personal thoughts

Due to incomplete results from the DPOAE measurements and analyses, I cannot fully answer one of my aims regarding how the children's hearing is affected by their sound exposure. Further conclusions might be drawn later, after the collaborating audiologist has made more thorough analyses of the data. However, preliminary results indicate that there are no clearly visible reductions of the DPOAE amplitudes after preschool sound exposure for most frequencies but a significant reduction could be seen for right ear at 3000 Hz, between morning day 1 and morning day 4 as well as between morning day 1 and afternoon day 4.

One of the main aims with this study was to see if the sound exposure of the children affected the DPOAE amplitudes. The results that have been displayed regarding the amplitudes do not include any of the data from the acoustic measurements. It would be really interesting to compare the individual exposure levels to the individual dosimeter results.

It would also be interesting to see how the change of DPOAE amplitudes over the measurements vary for the different preschool sections, if there are any differences between the different schools. If that is the case, these results could be compared to the sound pressure levels in the playrooms to see any possible connections.

It seems that it is difficult to connect the results of the room acoustic parameters to the sound levels in the investigated rooms. I think that this is an area for future research. Many room acoustic parameters are most useful in performance situations, where there is a limited area from where the sound origins (like the stage) and most of the people in the room being quiet listening. It would be good with parameters that can handle several moving and varying sources. It also needs to be investigated what actually is good room acoustic properties for a preschool. In my opinion, I would say that much absorption and low reverberation times are preferable. But maybe even more important is to have furnishing and toys that do not generate much sound. It is always good to try to influence the sources and make them less sound generating. Even though absorbers are good, it is even better if there is not so much sound to actually absorb.

Simple solutions in preschool can for instance be to work with chair and table legs. The impact between the legs and the floor can generate high sounds. By putting tennis balls on the legs, the sound from these would be lowered (tennis balls on chair legs could be seen in one of the preschools in the study). Another good thing is acoustically damped table surfaces, which also make the impact between the table and some obstacle, for example plates and cutlery, less sound generating. Carpets on the floor can also help, especially if building with blocks. Making a tower that is later destroyed and overturned can generate much sound, but if the blocks fall on a carpet, it will result in less sound.

In some cases we see that the personnel has higher $L_{A,eq}$ than the children. This is not in line with earlier studies that show that children are more exposed to high sound levels than adults. This was believed in advance to be the case since the children are playing on the same low height, close to each other and that children in general generate a quite high sound pressure level, both by talking loud and screaming but also playing with blocks and like wise. This higher personnel level can partly be explained by a high sound pressure level in general and that the personnel have to raise their voice in order to get heard through the noise. However, this may not be the most successful technique, often maybe it is better to lower ones voice in order to get heard, because then the listeners have to be quieter in order to hear the message. However, to get attention through the noise, one has to talk with loud voice in order to get heard in the first place.

In addition, as discussed in the result section, all children and personnel are individuals with different backgrounds and behaviour. Different individuals will simply generate different much sounds. It might be that way that the personnel that wore the dosimeters with high exposure levels in our study had particularly loud voices.

In general during our study, the personnel seemed worried about the high sound levels in the preschools. Some of them already had problem with the hearing which they thought was due to their presence at the preschool. Some of them actually wore hearing protection during their work, this was more common in the sections for younger children though.

Even though sound and high sound pressure levels might be bad for children and we want them to have silence and peace, the children also sometimes need to be able to be messy and loud. The children's needs need to be met, and it is us adults that have the responsibility for that.

One way to let the children live out their energy is to spend time outdoors, for example in the forest. There they can be free and do whatever they want, they can be loud and scream and running around. As described earlier in the thesis, the personnel at one of the preschools did experience a difference in indoor sound level when comparing wintertime to the rest of the year. Their impression was that the sound level was higher during winter when the children spent less time outdoors and had to live out their energy indoors instead. I think that this is very interesting.

The influence of the configuration of the preschool and the individual sections is believed to have a quite big effect on the sound pressure level. Having several rooms so that the whole group can be divided into smaller groups during the day seems to be good for the sound environment. Children tend to trigger each other when sounding a lot or running around. The background level caused by the rest of the group in a room will effect the strength of the speech that is needed in order to get heard. The sound generation of that talking or playing child will in turn add a contribution to the total sound pressure level and maybe further force others around to raise their voices even more in order to get heard. This phenomenon can be seen in many places, not just in preschools, such as cafes, restaurants, pubs etc. It can be referred to as the "cocktail party effect"[1].

However, even though the room acoustic properties are of importance, a perfect room regarding the acoustics would maybe not solve the sound problems in preschools. As was seen in earlier studies, the amount of children in the group seems to be of importance. With bigger children groups and fewer teachers the teachers have smaller possibility to guide and control the activities, which can lead to higher sound pressure levels. A combination of really good room acoustic properties and smaller groups of children with more teachers around could, in my opinion, make a tremendous difference of the sound environment.

Having fewer rooms (often with one big main room, where most of the action takes place) means that all the children and adults in the same room can be heard by the others present in the room, everyone making some kind of sound on their own. If the section on the contrary is divided into several, smaller rooms, it is possible to divide the whole group into smaller groups which then can be acoustically isolated. Of course, the persons in each room will be able to hear one another but the number of sources will be fewer, and probably the general sound pressure will be lower which in turn leads to that the persons in the room do not have to raise their voices in order to get heard.

Since recent studies have shown that children are more exposed to different frequencies than adults, partly due to the fact that children are having different geometries of their bodies, it would be interesting to have a "children-weighting". How could that be performed? When constructing the A-weighting a lot of people were to listen to different frequencies at different sound levels and rank them to be percept as equally high. This could perhaps be difficult for a child to achieve.

The sensitivity to noise can be very individual, so even if the limit for a risk of a hearing damage is set to 85 dB $L_{pAeq,8h}$ by the Swedish Work Environment Authority [9], some persons, due to individual sensitivities, risk to suffer from hearing damaged if exposed to long term noise around 75 dB to 80 dB.

[1] In the book Architectural Acoustics, Long talks about the cocktail party effect which also can be applicable in a preschool. It is a theory about, depending on the room size and the room absorption, how close two people have to stand together and how low they can talk to each other to still be in the direct field in order to be able to hear one another clearly without having the reverberant field interfering. While more and more people enter the room, the minimal distance between the two persons in each pair (one assumes that all talk in pairs), decreases. With more and more people in the room, one could also expect that people will talk louder, and at the same time moving closer to each other. The louder talking will increase the background noise which drives the people to talk even louder. The kernel of this that more room absorption will let more persons conversing at a pleasant level without having a sore throat or ringing ears after such an event. I think that one can compare this cocktail to a preschool with more and more children entering the playroom which will increase the total level in the room. Another aspect is that with more children it will probably be more movements and the children will behave more active if there are many children present instead of just a few when the playing scene often, one can assume, is more calm.

In general but especially in environments with high sound levels it is of importance to get some restorative periods between the louder sessions. Both in regard to the general health - lower the stress level - but also to the fact that the hair cells need recreation in between loud sound events in order to stay high functional. The children have at least one more quieter period a day, the resting session after lunch, which seems to be a procedure that most preschools have. In the resting session for example the children get to listen to one of the teachers reading a book. Some children might even fall asleep. These quieter and more peaceful periods are really good in my point of view, not only for children but for all people. I think it could make life better for many of us to increase the amount of quieter periods in preschool and establish them on every workplace.

It seems that noise problems are increasing in the society. Why is this? Are we just more aware of the problem or has the noise actually increased? I would say that it could be a combination of both. We gain more and more knowledge of what the noise can do to our health and this awareness makes us maybe more aware of the actual sounds around us. In addition, everything in the world is developing. The traffic is increasing, there are more airplanes flying in the air, the loudspeakers get more powerful, we listen to music with headphones or ear plugs, the classes get bigger with more children - everything adds up to us, the people, being more exposed of noise. And at the same time, the tempo in life in general for a common person is higher than it has ever been. We are almost always online and available nowadays, there are not many moments when we are in complete stillness, both in body and mind, and have it quiet around us. Maybe we should make a bigger effort finding these moments, and find a way to include the children around us to these more peaceful and quiet events.

6

Future research

This topic evokes many thoughts and ideas. Here follow some suggestions for future research

- Children weighting. Since studies indicate that children perceive sound different than adults it would be interesting to develop a new frequency weighting for children instead of using the A-weighting that is based on adult hearing.
- Investigate what room acoustic parameters that actually are suitable for describing rooms in a preschool.
- Since the impact of sound exposure is far more extensive than affecting the function of the ear it would be interesting to further study how the preschool stay regarding sound exposure have an effect on children, both psychologically and physiologically, short term and long term.
- Study how young children are exposed to sounds outside of preschool hours.
- Study exposure differences with regard to amount of children in the groups they spend their preschool stay in. For example, being all in one big group or divide it into several smaller within the same section.
- Further investigations regarding the influence of number of children present in the room and the sound pressure level there, as well as exposure level for the children. Since the sound generation varies a lot between children due to individual personalities, measurements could be performed during many days. One could for example let a certain number of children play a standardized game and vary the amount of children as well as the participants for the different measurement days.
- Measuring the sound pressure level in all rooms of a preschool and at the same time count the children present in each room trying to see the influence of the amount of children on the sound level.
- Measure exposure level and stress - the cortisol level - on regular days compared to days with quieter sessions, for example having the children massaging each other while listening to classical music and lowering the lights. Investigate how this affects the exposure level for the rest of the day, and for example changes in the cortisol level. Doing this not just for one day each but a bit longer, at least one week of each.

7
Conclusion

Children are being exposed to high sound pressure levels during their playtime in the preschool. The average $L_{A,eq}$ for children attending the preschools in the study, lies between 76 dB and 84 dB, averaged for each section. The individual exposure levels vary a lot among individuals with values between 69 dB and 90 dB. Altogether, the averaging is made out of 101 separate measurement periods throughout the four weeks stay at the different preschools.

The comparison between children and personnel exposure shows that the personnel are exposed to both higher and lower level than the children during their playtime with values ranging between 69 dB and 85 dB, this not saying too much since only one among the personnel wore a dosimeter each day. The sound pressure levels measured in the playrooms with a microphone hanging from the ceiling consistently show lower levels than the exposure levels, for all playrooms except of preschool 4. This preschool has the measured playroom intended for movement and was not available for the children during the whole days. The average $L_{A,eq}$ for the playrooms in preschool 1-3 are between 67 dB and 70 dB while preschool 4 has an average level of 77 dB.

The reverberation times for the playrooms are in general low, around 0.3 s - 0.4 s, except for preschool 1 where the reverberation time is somewhat longer, especially for lower frequencies. This preschool has the playroom with the biggest volume and not so much furniture or other absorption. The general low reverberation time includes that of preschool 4, whose playroom has the highest playtime sound level and is the smallest room in the study. The reverberation times of the playrooms all are below the Swedish regulations set values regarding reverberation time in playroom for a new built preschool.

Further, the room acoustic evaluation shows that all playrooms have quite short reverberation radius, that is the distance from the source where the direct field and the reverberant field are equally strong. For all six investigated sections, the reverberation radius, r_h, is around 1 m. The strength parameter G was calculated for the six sections and varies between 18.8 dB and 22.2 dB with the lowest value corresponding to the longest r_h (1.22 m) and the highest value to the shortest r_h (0.81 m). The highest G and the lowest r_h belong to preschool 4 and the so called "movement room" mentioned above. This is also the preschool that has the highest children exposure levels. G was measured for six different source-receiver positions in each room and shows little variation between different distances from the source (all well beyond r_h in the reverberant field).

The clarity parameters C_{50} and C_{80} were decided not being that interesting parameters for a preschool (comparing early and late energy) and instead C_{room} was calculated. C_{room} tells how much bigger the reverberant part of the sound (i.e. the room contribution) is than the direct part (the direct sound). The results from the C_{room} calculations show that the direct sound decreases as expected with distance from the source, but also that the reverberant field decreases slightly with distance, in contrary to classical statistical room acoustics.

No clear relation between the room acoustic parameters and the equivalent sound pressure level in the playrooms can be seen. This may indicate that the number of children, their behaviour and what they do in the playroom are important parameters regarding sound level in the room. However, adding absorption in the room will lower the overall sound pressure level.

The frequency analysis performed in the playrooms during playtime shows similar results for all sections. Little energy is found for lower frequencies, increasing steady with frequency having, the maximum around 1000 Hz. For frequencies above 1000 Hz the energy decreases again, though not as steep as for lower frequencies.

The preliminary results of the DPOAE measurements show a significant reduction of the DPOAE amplitude when comparing the response measured morning early in week and afternoon late in week, for the right ear at 3000 Hz. These results are provided by the collaborating audiologist. Further statistical analyses including different data from the investigation are supposed to be performed throughout the work with his thesis which is to be published in the spring of 2018. Due to different time perspectives the outcome from the hearing measurements presented in this thesis is all that has been provided to me till this date.

As a conclusion, children are exposed to high sound levels and the exposure varies much between individuals. The room acoustic properties are important for the sound environment but not crucial for the sound pressure level in the playroom. The reverberation times do not directly relate to the sound pressure levels measured in the playrooms.

In general, the sound pressure level at a preschool is due to much more than just the number of children and the properties of the facilities. It depends on the amount of personnel, the behaviour and pedagogical work of the personnel, the type of children in the group (loud or quiet for example), amount of spent time playing outdoors and most certainly a lot of other things. But making the indoor environment better acoustically surely helps on the way achieving a good sound environment in a preschool for the children.

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A

Appendix 1

A.1 Detailed room acoustic descriptions

A.1.1 Preschool 1

The building is a former school for higher education but was rebuilt into a preschool a few years ago. The preschool is divided into two sections - one for older children (the one we did measurements within) and one for younger children. Further is the children in each section divided into two groups[1].

The investigated section consists of a hallroom, a large playroom, a small "building room", a relatively big food court and a sort of corridor. In this corridor there are tables for eating and drawing/puzzling as well as other small playing areas and devices. One room worth to mention is the "building room" which consists of a 2x2 m^2 small room with mostly acoustical hard surfaces. One wall with a door and a mirror, two walls completely made of glass facing the playroom and one wall with windows facing the yard. The only absorbing material seen in the building room (with exception of the acoustic ceiling) was a plastic mat of approximately 1.5 m^2 in one of the corners about 1 cm thick which was probably placed there for the children to play and build with blocks on, and one very thin fabric placed above the low hanging mirror. This fabric I think did not make any difference regarding absorbing sound since it was very thin. No measurements were performed in this room but I think the sound pressure level inside here can reach high levels due to block building and not much absorption.

The food court, where most of the children eat their meals, is a big room but with no visible absorbing material. One good thing sound wise is that all chairs have tennis balls on their feet. This reduces the noise generated by the interaction between the floor and the chair legs. There is also a table outside of the food court in the corridor where some of the children are sitting during meals, which means that the full group does not eat in the same area, which also presumably is good regarding sound level during meals. All tables and chairs are made of wood. When asking the

[1] According to the website, these smaller groups are used throughout most time of the day. However, this was not really seen when we were there, more than that they went to the forest one day each with the smaller groups - this was really good since it meant that fewer children were left at the preschool while the other half of the section was in the forest spending much energy and coming back hopefully calmer.

personnel if the sound level was higher during meals we got the answer that it was no difference - "the children sound a lot all the time". In general it seems like the sound insulation between the different rooms was good.

Properties of the playroom
The playroom has an area of 50 m^2 and a volume of 151 m^3 and is L-shaped with the "building room" in one of the corners. Without children in the room the room was perceived as not particularly damped but rather reverberant. The walls are made of concrete and there are big windows facing the courtyard. The walls belonging to the small building room facing the playroom are mostly made of glass. The floor consists of a plastic mat and in the room there are only two carpets, both with a circular shape and approximately 2 m in diameter. One of them used for the daily "gatherings" and the other one with a table and chairs upon, children sized. The curtains at the windows are made of thin textile which I do not think contribute much to the absorption of the room. On one concrete wall, three fabric sheets 0.8x2 m^2 are hanging with a small air gap from the wall and with some lining behind the textile. I believe they are placed there for absorption but they are quite light weighted and not so thick so if they damp some acoustic energy I think it is rather high frequencies, considering the thickness of the installation[2]. The main absorptive object in the room is a corner sofa with approximately 20 cm thick cushions. There are several lower bookshelf with some books and obstacles which can contribute to scattering and some absorption. The ceiling consists of 2 cm thick ceiling tiles made of fiberglass placed 60 cm below the structural ceiling. There was no absorption in between, only air and some installations. The tables, chairs and almost all other furniture were made of wood.

In addition, it seems like the personnel is aware of the sound issue, they kept reminding the children to keep the volume down during our visit. Whether that was biased by our presence or not is impossible to say. The children spend time outdoors every day and visit the forest once a week.

A.1.2 Preschool 2

This preschool is quite new and was finished in the autumn of 2012. It consists of eight different sections, divided according to age. There are three sections for older children of which measurements were performed on two of them. In the middle of the eight sections there is a so called "square" where the children can spend time during the day (which can be glimpsed in Figure 4.10). The children in some of the sections have their meals in the square while other eat in their own section rooms[3].

[2] A thickness of 1 cm would attenuate frequencies above 8500 Hz considering the rule of thumb of "one-fourth-of-a-wavelength". That is, an absorber attenuates frequencies that could fit at least one fourth of a wavelength in the thickness of the absorber.

[3] When I read about this square, according to the preschool's website "The preschool is built for encounters with a fantastic square placed in the middle of the building as the central place where everyone can meet och different relations can develop." Before visiting the school I suspected that this square could be horrible sound wise (based on the description that everyone could meet there) but it actually seemed to work quite well.

The ceiling height in the square is really high, at least 8 m, and my impression of the environment was that is was calm and of quite low sound level, even when children was around and during meals. They have divided this big square-like room into several smaller rooms "in the room" - one place to read stories, one stage, one cosy area, some low tables where they have their meals, a variety of forms, colours and functions. This square increases the amount of places where the children can spend their days during their stay at the preschool, which seems to be good. They can be outdoors, indoors, in their different rooms in their "home section" and in the square. It seems like the teachers are good at having the children from the different sections apart from each other - not all groups seems to be in the square at the same time, when some groups are outside playing, other groups are indoors etc. This is especially good for particularly this preschool since it seems to be poor sound insulation between the rooms indoors, for example between different sections. One can clearly hear what the people are doing in the adjacent rooms. I think that the building has a light weight structure, which can explain the insufficient sound insulation.

The two sections under investigation are quite small, especially section A. It basically consists of one playroom, which is quite packed with furniture and toys and one smaller room which I think is used for painting and such. The general feeling in the playroom is that it is cosy but a little bit cramped. Section B ha a bigger playroom than section A and two smaller rooms which seems to be one painting room and one room for building.

Properties of the playrooms

Section B
Section B's playroom has an area of 41 m^2 and a volume of 111 m^3. The room is a quite long rectangular room. The walls are made of gypsum, the short side facing the yard has quite big windows and the four doors in the room are all made of wood with a big part of glass. Here, two of the walls have small perforated holes with absorptive material behind.The floor consists of a plastic mat and there is one big circular carpet with a diameter of 3 m in the middle of the room for gatherings and to play on, and one smaller rectangular carpet.Regarding the furniture they have several lower bookshelves and two low tables with chairs around, all made of wood. The table surfaces are plastic but I don't think they are made of any acoustical damping material. The table and chair legs do not have any damping towards the floor as could be seen in preschool 1 and the sound was quite prominent when moving around the chairs. The feeling in the room was, even though there were a lot of stuff, quite spacious but at the same time familiar. There were things hanging from the ceiling which made the atmosphere quite cosy.

Section A
The playroom in section A is smaller than the one in section B and they have seven less children in their group. The area is 32 m^2 and the volume 86 m^3. The room is filled with stuff and furniture, which maybe make it hard to have "wild" games and running around. There is simply not room for that. They have a big circular carpet in the middle of the room, and two smaller rectangular ones elsewhere. They

also have two lower tables with chairs similar to section B. In one corner they have placed two low hanging mirrors on the wall and two low screens facing the rest of the room. If children are playing there on their low height level I think that the sound pressure level can get high because of the reflections. They have quite a lot of lower bookshelves and they also have a lot of stuff hanging from the ceiling (maybe not changing the sound environment but making the atmosphere more enjoyable and caring).

In both rooms, the ceiling height is 2.7 m with 1.5 cm thick fiberglass tiles with approximately 1 m air gap up to the structural ceiling. When we talked to the personnel they were complaining about the acoustics, they told us that one can hear sounds easily from other rooms. They said that it sounds as the doors are wide open when they are actually closed. Also they told us that there is a lot of sound coming from above, though there is no second floor. They thought it was from the ventilation system, that the sound propagates between rooms via the ventilation system and it makes it sound as someone is walking in the ceiling.

The children spend time outdoors everyday. This in general seems to have a really positive impact on the sound pressure level indoors afterwards - the children can loose some energy being outside playing and running and jumping.

A.1.3 Preschool 3

The preschool is relatively new built. The facilities are modern but I am surprised over the size they have built the sections in - it felt small compared to the number of children in the groups. The school has two sections for younger children and two sections for older. The older sections are called section A and section B, both having 23 children in their groups. The personnel area is separated from the school area, being placed at the upper floor of the building. Here is for instance an office, a resting room and a coffee room which was spacious and inviting.

The sections are similarly planned, with one bigger room, where they in principle do everything: playing, learning, having their gatherings, having their meals etc. They even have a complete kitchen on one side of the room (see Figure 4.11 and Figure 4.12). There are also two smaller rooms, which according to the personnel had a restriction of maximum 5 children being in the room at the same time. It was one "doll room" and one "painting room" (looking at the blueprint it says maximum 8 persons). In the morning in section A for example, when having breakfast, all children and the personnel sit in the main room room along two tables. They have an acoustic screen which they can place between the two tables.

Properties of the playrooms
The properties of the two different playrooms are very similar why I describe them together and instead point out the differences. Section A and B are of almost the same size with an area of $48\,m^2$ and $48.5\,m^2$, respectively, and a volume of $127\,m^3$ and $131\,m^3$, respectively. They have, just as the previous preschools described, one big circular carpet for gatherings, approximately 3 m in diameter and they

have both quite many lower bookshelves. Section B has two round tables and one rectangular all with chairs around and all of children size. Section B is slightly more "welcoming" in the atmosphere, with a little more "familiar stuff", also here things are hanging from the ceiling, and they have a sofa which made the room more cosy and contributed to the absorption. Both section were really welcoming in the atmosphere. Section A do not have a sofa but they do have a bigger armchair and an absorptive fabric painting in the playroom, approximately 1.2x1.2 m^2, 1.2 m above the floor, hanging close to a table where they can paint and play and puzzle and likewise. Section A has two rectangular tables which are of normal height and one round table of children size. The chairs around the table do not have any visible acoustic damping on their legs (as could be seen in preschool 1 and which seems to be a simple solution for lowering the sound when moving around the chairs) but they didn't sound so much when moving around them. The table surfaces are acoustically damped and at section A they have an acoustic screen, as mentioned, which they can place between the two rectangular tables. The personnel had a positive experience of this screen and said that the sound environment was better when the screen was in use. I think it absorb and block sound between the two tables, but also the fact that it breaks the line of sight between the tables can have an influence, so that the children not are able to disturb or interact with each other. At section B I could see neither absorptive paintings nor screens, but they on the other hand have their sofa.

The ceiling is made of 3 cm thick acoustic tiles with 70 cm air gap up to the structural ceiling.

As a summary, there are really many children spending time in a small area, but my impression was that the teachers were really good and calm and it seemed like the children had respect for their teachers and that made the situation work out well. In general the playroom environment was very friendly and cosy and almost family like.

The sections we measured have direct access to the courtyard from each playroom. They seem to be outdoors everyday, but it also seemed like the children could choose to stay indoors if they wanted to.

A.1.4 Preschool 4

The preschool is built in the 1970's and can be compared to a barrack. The overall indoor environment was not excellent: it was quite cold, the ventilation could be heard in all rooms and the facilities in general were quite worn down. Even though the focus is on the sound environment, the atmosphere in the school or working place can make a difference for ones behaviour. Which in turn can affect ones sound generation. The preschool has three sections, one for younger children and two for older children and siblings. Only one section was included in the measurements (the preschool had a so called "study day" on Friday in the week of measurements which meant that we only could do measurements Monday and Thursday, and could hence only study one section). The investigated section consists of several rooms, one bigger "common room" with tables and chairs and a kitchen, one smaller room for calmer playing, one "workshop room" for painting and likewise and one "movement room". The sound pressure measurements were done in the movement room[4].

Properties of the movement room
The area is $26\,m^2$ and the volume $65\,m^3$ with a quite low headroom. The ceiling is not made of acoustical tiles but of some painted fibreboard and there could not be seen any room acoustic enhancements in the room. Even though there are quite a lot of furniture, the room felt bare (maybe because there are not much things on the walls). It was quite chilly temperature wise, the lightning was cold and the ventilation sounded quite a lot. Furniture was placed almost in the middle of the room, a small table with chairs around, a bookshelf. In one corner there is a small sofa and in one corner a mattress which I believe is the main acoustical absorbing objects in the room. One of the walls is a sliding wall which can be folded. This is not air tight when closed, which means that sound can escape through the air gap, but also that one could clearly hear sound from the adjacent room if there were people there. In general, the sound insulation between rooms in preschool 4 is not good, there are for example air gaps between doors and the floor.

[4]When, in accordance with the personnel, choosing which room to measure, we did not know it was a movement room

A.2 Frequency analysis

A frequency analysis of approximately one hour measurement in the playroom of each section is presented below[5]. The equivalent A-weighted sound pressure level is presented in 1/3-octave bands.

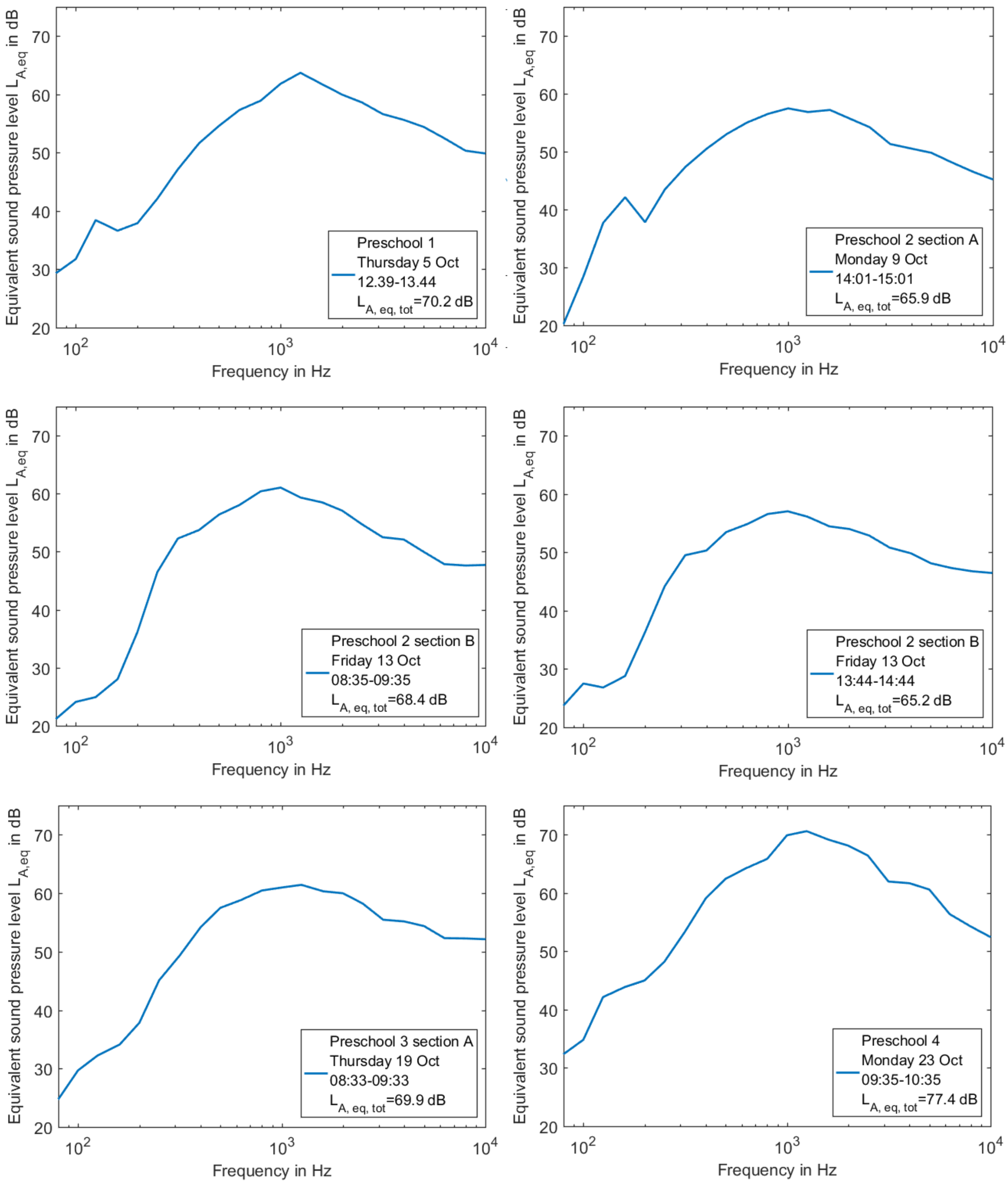

Figure A.1: The frequency components of the equivalent values for the ceiling microphone that can be seen for respectively section in the $L_{A,eq}$plots Section 4.1.1.1.

[5]In preschool 3 the ceiling microphone was only used in section A, section B still had an dosimeter in the ceiling, measuring the equivalent level.

A.3 Impulse responses

The impulse responses for six different source-receiver positions per playroom are presented below.

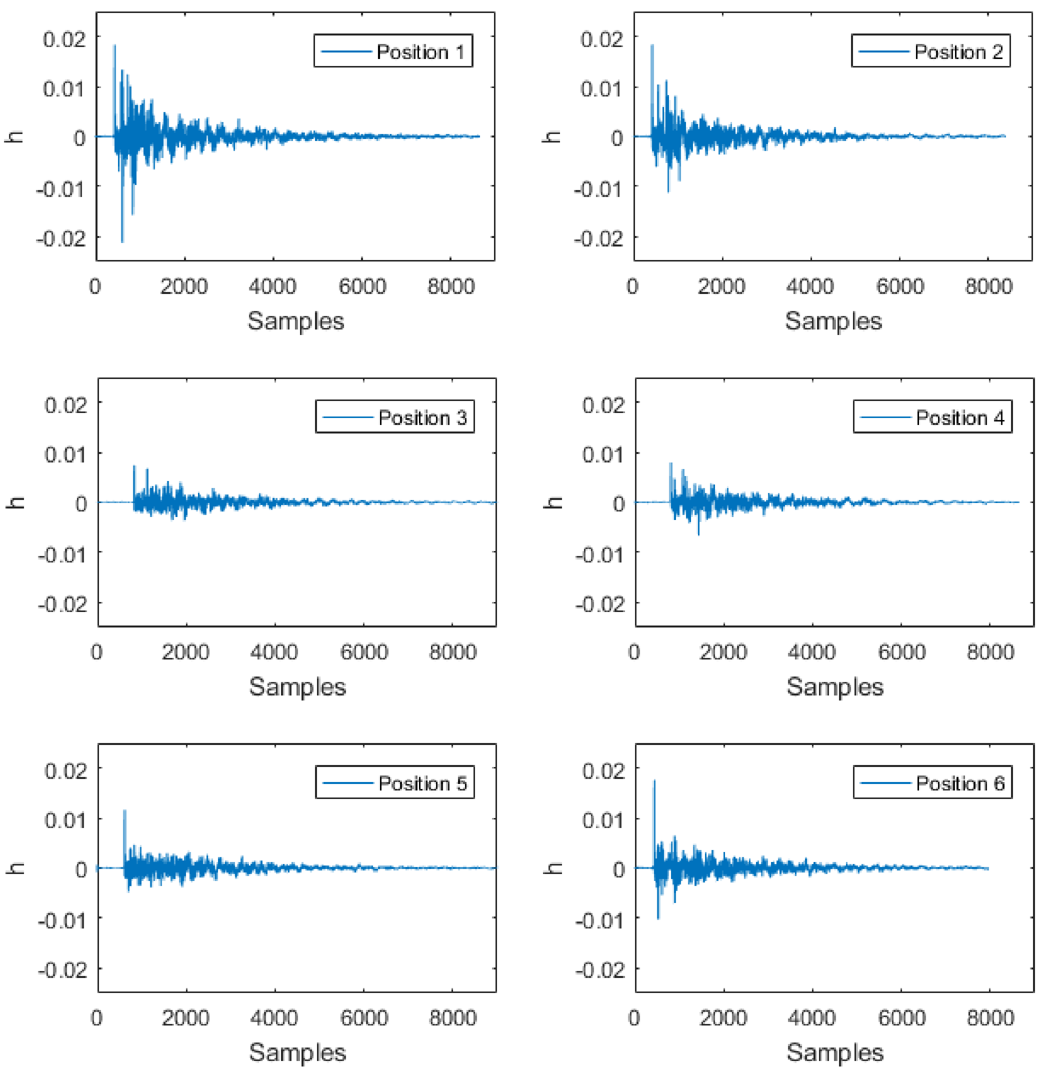

Figure A.2: The impulse response for six different source-receiver position, preschool 1.

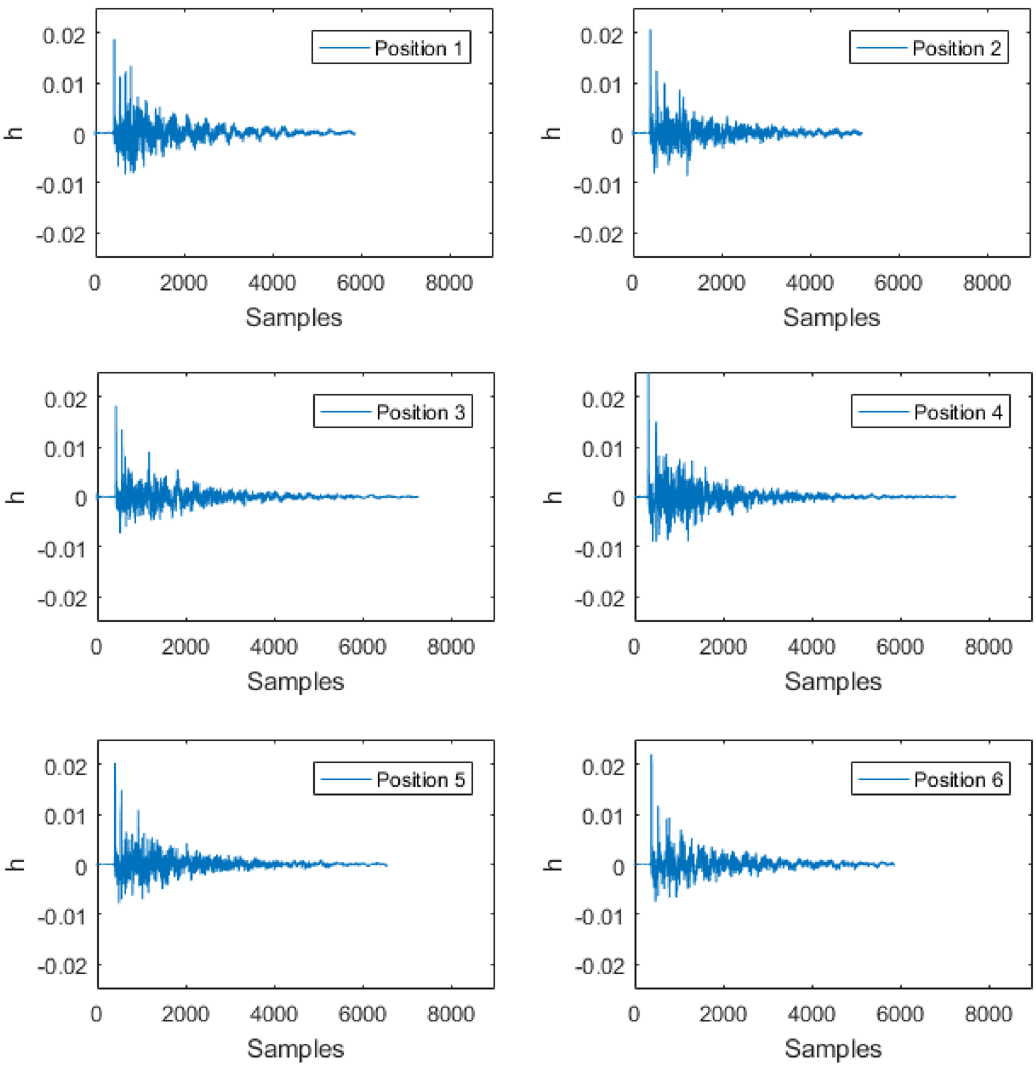

Figure A.3: The impulse response for six different source-receiver position, preschool 2 section A.

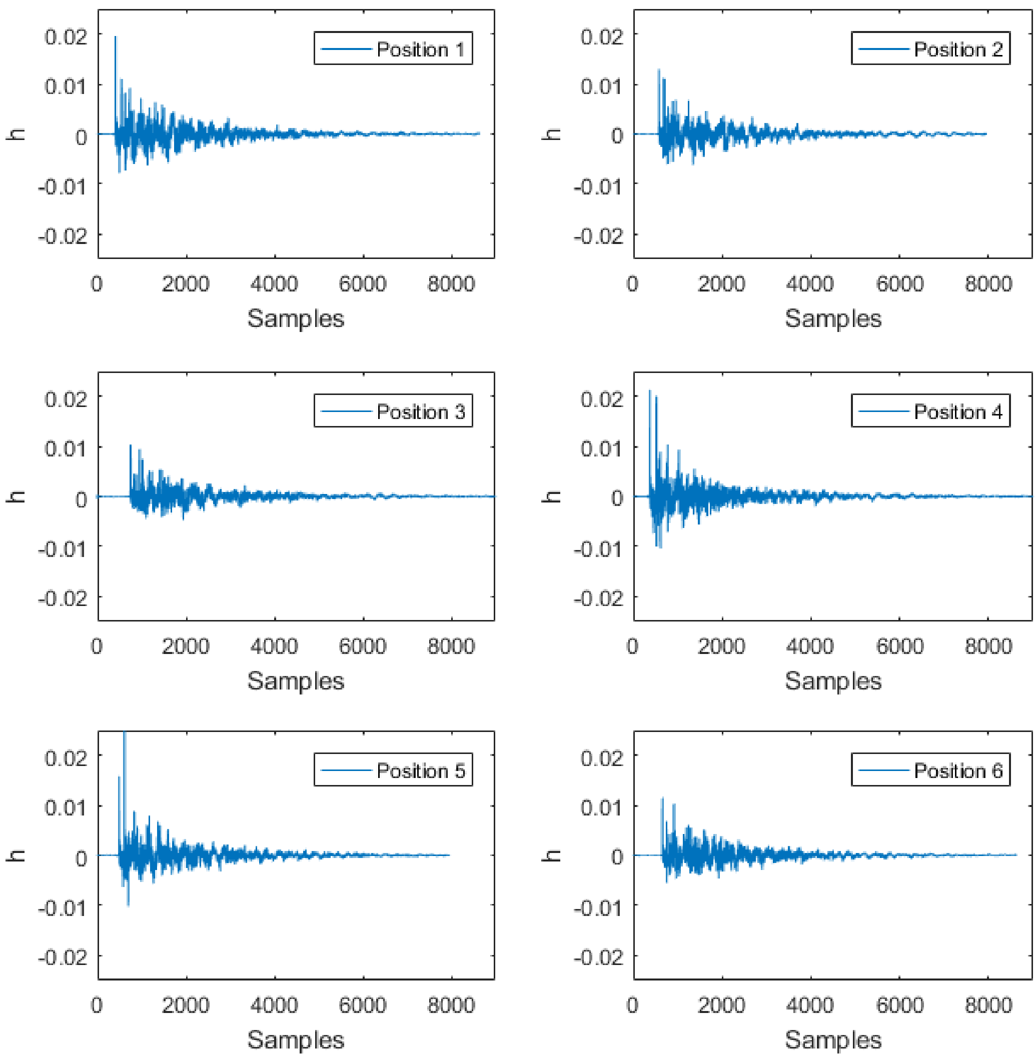

Figure A.4: The impulse response for six different source-receiver position, preschool 2 section B.

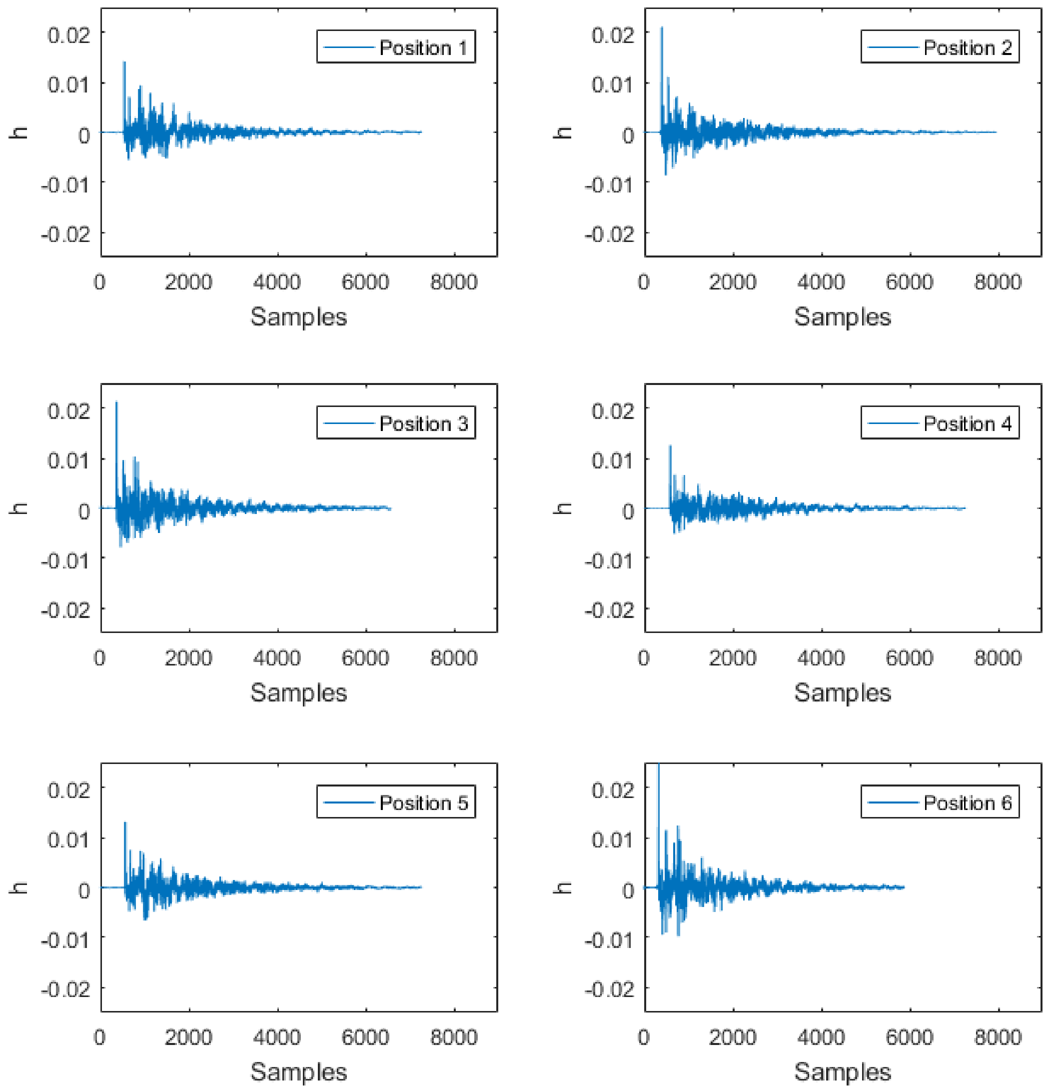

Figure A.5: The impulse response for six different source-receiver position, preschool 3 section A.

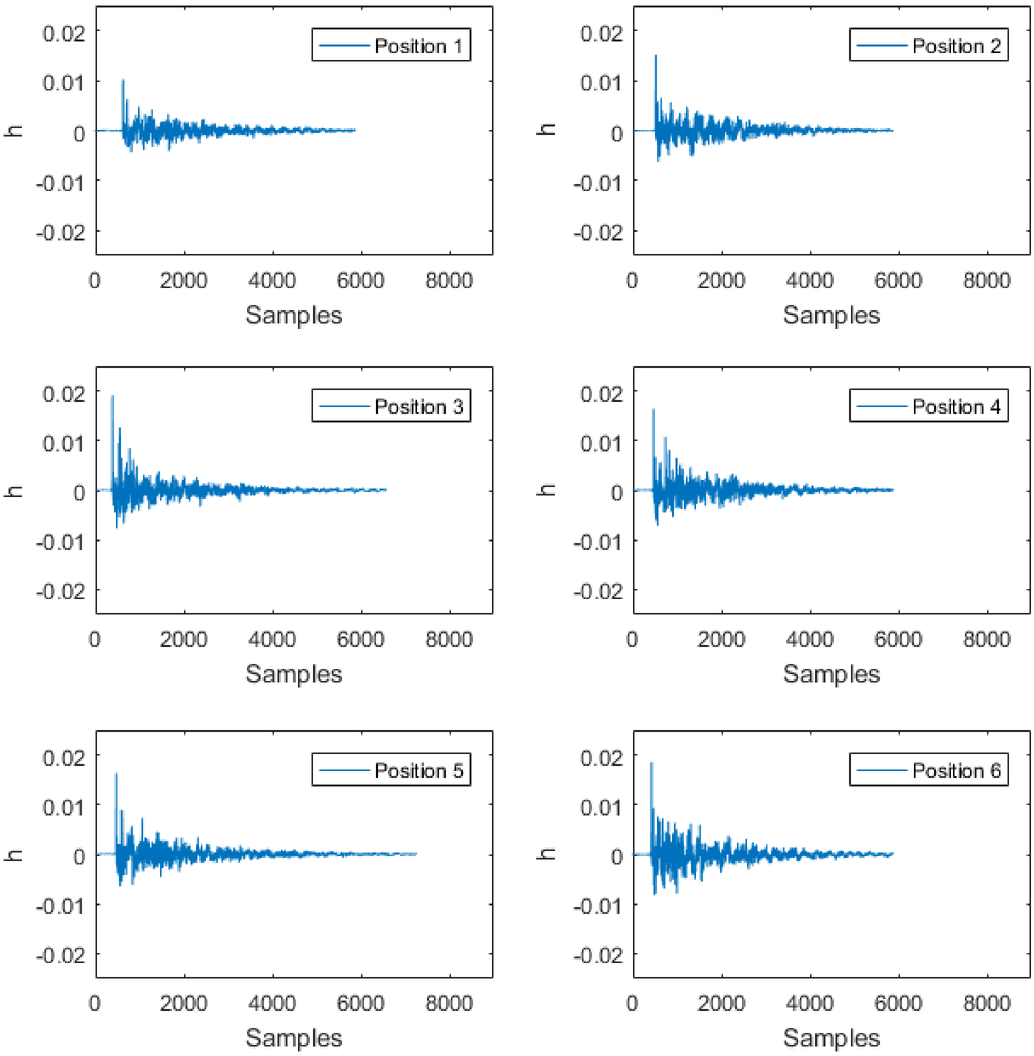

Figure A.6: The impulse response for six different source-receiver position, preschool 3 section B.

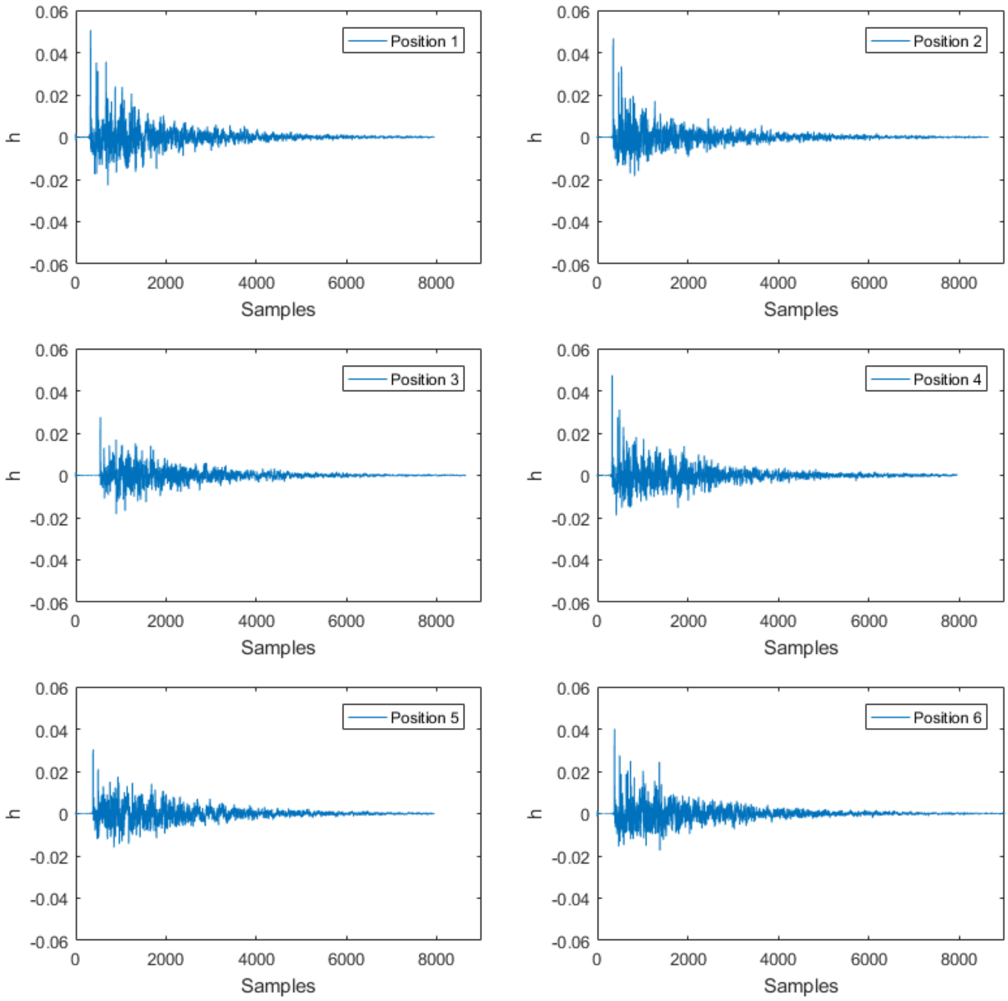

Figure A.7: The impulse response for six different source-receiver position, preschool 4.

A.4 Source-receiver positions for the impulse response

Microphone position 1, 2 and 3 was used for source position 1 and 4, 5 and 6 was used for source position 2. Note that the positions in the drawings are approximate.

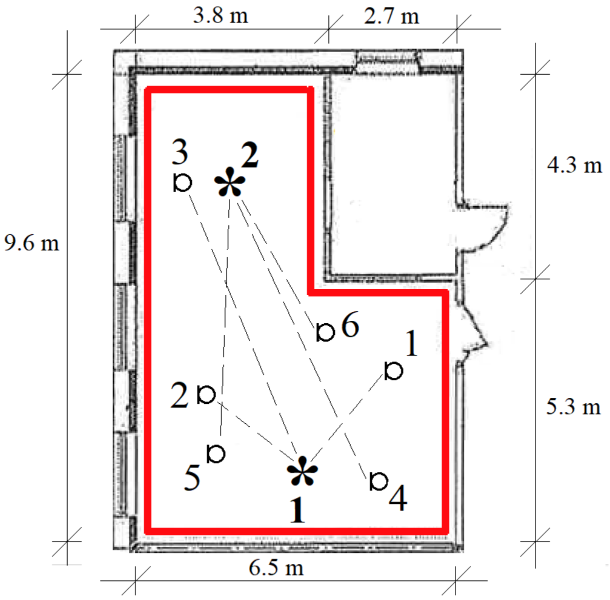

Figure A.8: The six different source-receiver positions, preschool 1.

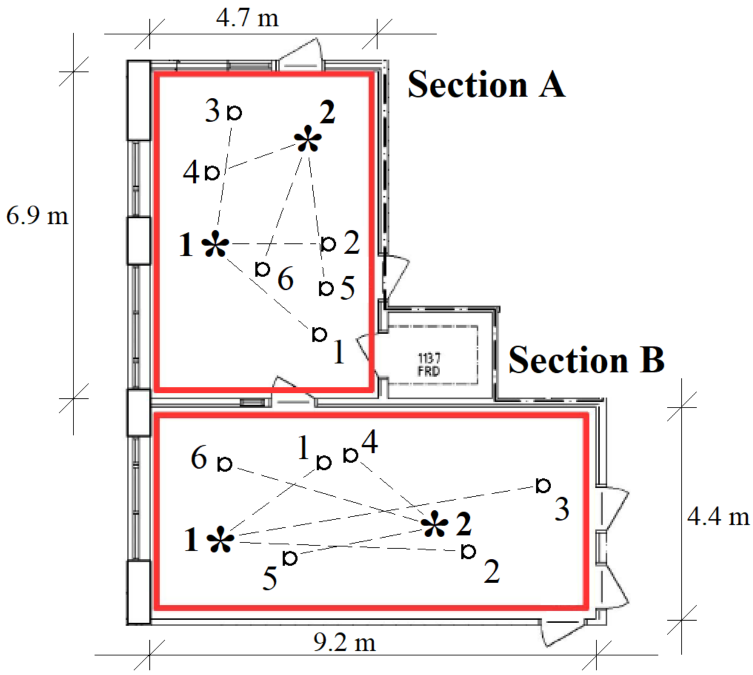

Figure A.9: The six different source-receiver positions, preschool 2. Section A was cramped with furniture why the source and receiver could only be placed at limited locations not being too close to reflective surfaces.

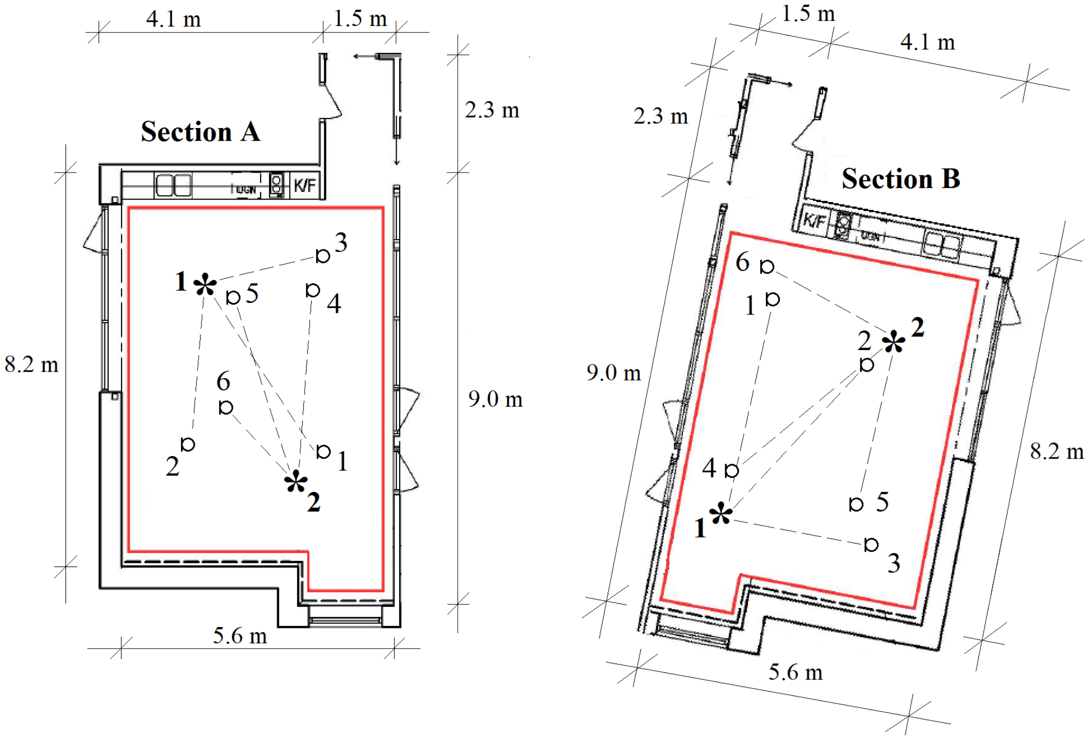

Figure A.10: The six different source-receiver positions, preschool 3. Section B had quite much furniture and surfaces that limited the choice of positions.

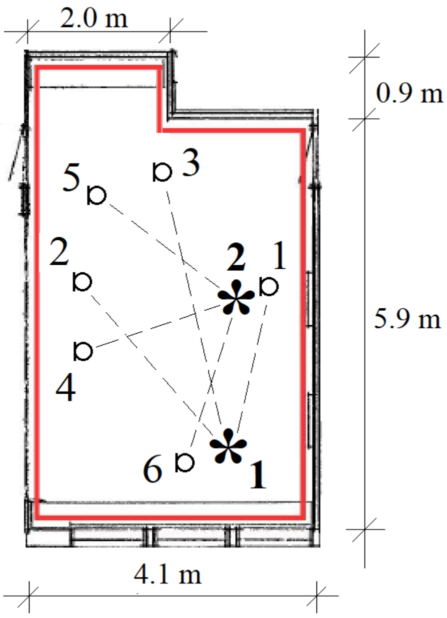

Figure A.11: The six different source-receiver positions, preschool 4. There was furniture in the middle of the room why no source or receiver were placed there during the measurements.

A.5 Information to the guardians

GÖTEBORGS UNIVERSITET
Sahlgrenska akademin
Avdelningen för samhällsmedicin och folkhälsa/Arbets- och miljömedicin
CHALMERS
UNIVERSITY OF TECHNOLOGY

Undersökning av ljudnivåer i förskolan och tillfällig påverkan på hörsel

Information till vårdnadshavare

Nya studier visar att barn och personal exponeras för ljudnivåer vid de gränsvärden som satts upp av Arbetsmiljöverket. Dessa gränsvärden är satta för att förebygga risk för att personalen drabbas av hörselskada efter mångårig exponering. Det finns forskning som pekar mot att barn eventuellt kan vara extra känsliga för höga ljudnivåer, men ingen forskning finns om huruvida barnens hörsel påverkas av ljudmiljön i förskolan. Detta projekt är en del i två examensarbeten vid Chalmers tekniska högskola repsektive Göteborgs universitet där fyra förskolor i Göteborg är inblandade, vilket kan ge information om huruvida ljudmiljön kan ge upphov till effekter på barnens hörsel. Det blir i sådant fall en viktig faktor i arbetet för att förbättra miljön i förskolan.

Hur går studien till?
Studien görs i samråd med förskolepersonalen för att så långt som möjligt inte störa den normala verksamheten.

Vi kommer med hjälp av ljudnivåmätare med mikrofoner på ditt barns axel mäta vilka ljudnivåer barnet utsätts för under tiden inomhus på förskolan. Som referens mäter vi också med en fast ljudnivåmätare i förskolans lokaler. I analysen kommer vi inte använda avsnitt med innehållsinformation eller tydliga meningar som kan identifiera vissa individer.

Vi kommer också vid totalt 4 olika tillfällen mäta ditt barns hörsel för att identifiera eventuella effekter på hörseln över tid. Detta gör vi genom att jämföra mätningar som görs på morgonen när barnet kommer till förskolan mot mätningar på eftermiddagen samt jämförelse med en dag i början av veckan mot en dag i slutet av veckan. Mätningen av hörsel görs rutinmässigt inom klinisk hörselmätning och tar bara några minuter varje gång och medför inga hälsorisker. Mätningen utförs av legitimerad audionom och är jämförbar med den nyföddhetsscreening av hörsel som genomförs på alla barn i Sverige. Om ditt barn ändå uppvisar tecken på en hörselpåverkan som Du som vårdnadshavare inte kände till kommer vi att ge information och kontakt till läkare vid behov.

Deltagande i studien innebär förutom ovan nämnt även att Du tillsammans med ditt barn fyller i ett frågeformulär om ditt barns hälsa och välbefinnande.

Ditt barn kan delta om barnet är 4 år eller äldre, är heltid på förskolan varje dag (ca kl. 8-15) och inte har någon känd hörselskada.
Vi kommer att besöka er förskola vecka 41 det vill säga 9-13 oktober 2017.

Hantering av data och sekretess
Alla enkätsvar samt data från hörselmätning och ljudmätning som samlas in behandlas så att inga obehöriga kan ta del av dem. Data sparas kodat och avidentifierat på datamedium som förvaras i låsta utrymmen där endast behöriga forskare har åtkomst. Endast behöriga forskare har tillgång till den kodnyckel som kan identifiera data. Denna kodnyckel förvaras i låst utrymme separat från data. Insamlat material sparas enligt Universitetets rutin i 10 år. Redovisning av resultaten från projektet kommer att ske i vetenskapliga tidskrifter, vid konferenser samt via Göteborgs Universitet och Arbets- och miljömedicins hemsida (www.amm.se). All redovisning sker på gruppnivå där dina svar är helt anonyma.

Ansvarig för dina personuppgifter är Göteborgs Universitet. Alla personuppgifter hanteras enligt personuppgiftslagen (1998:204). Personuppgiftsombud på Göteborgs universitet är: Kristina Ullgren, telefon: 031-786 1092, e-post: kristina.ullgren@gu.se.

Hur får jag information om studiens resultat?
Information om resultat från projektet kan fås av projektansvarig och på samma sätt kan deltagare begära att få ta del av sina individuella data.

Ersättning
Ingen ersättning ges för deltagande i projektet.

Frivillighet
Deltagande i projektet är frivilligt. Om ni som vårdnadshavare samtycker till att ert barn deltar, men barnet vid mätning inte vill delta kommer mätningen genast att avbrytas. Ni kan när som helst avbryta er medverkan, utan att behöva ange någon särskild förklaring. Ni kan också be om att få insamlad data samt personuppgifter raderade alternativt anonymiserat för behöriga forskare. Om du i efterhand vill avbryta ditt deltagande – vänligen kontakta projektansvarig.

Ansvariga
Forskningshuvudman är Göteborgs universitet. Huvudansvarig för projektet är Maja Jansson och Sebastian Waltilla som gör detta som en del i sitt examensarbete vid Chalmers tekniska högskola respektive Göteborgs Universitet med hjälp av professor Kerstin Persson Waye vid Arbets- och miljömedicin, avdelningen för Samhällsmedicin och folkhälsa vid Göteborgs universitet. Projektet är helt fristående från kommun och förskoleverksamhet.

Om ni har några frågor kontakta oss gärna via e-post eller telefon!

Vänliga hälsningar

Maja Jansson
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Projektutförare
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majaja@student.chalmers.se

Sebastian Waltilla
Magisterstudent inom audiologi
Projektutförare leg. Audionom
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sebastian.waltilla@vgregion.se

Kerstin Persson Waye
Professor
031 - 786 36 04
Kerstin.persson-waye@amm.gu.se

Samtyckesblankett

Vi är tacksamma om ni lämnar denna blankett till förskolepersonalen så snart som möjligt och allra senast onsdag den 27 september 2017

Ditt barn kan delta om barnet är 4 år eller äldre, är heltid på förskolan varje dag (ca kl. 8-15) och inte har någon känd hörselskada.

Du samtycker till att delta i projektet ”Undersökning av ljudnivåer i förskolan och tillfällig påverkan på barns hörsel”. I projektet ingår besvarande av ett frågeformulär, ljudnivåmätning och hörselmätning för ditt barn samt akustikmätning i förskolans lokal. Du samtycker också till att insamlad data sparas avidentifierat i låsta utrymmen i 10 år där endast behöriga forskare har åtkomst. All data behandlas enligt personuppgiftslagen.

Ni har när som helst möjlighet att tacka nej till deltagande utan att ange orsak även om ni tidigare har lämnat ert samtycke. Kontakta oss då gärna via mail (Maja eller Sebastian).

❒ Jag samtycker till att mitt barn deltar.

❒ Jag vill veta mer innan jag bestämmer mig och vill därför bli kontaktad (ange kontaktuppgift nedan).

Ort: .... Datum:...

Underskrift vårdnadshavare 1: ....

Namnförtydligande vårdnadshavare 1: ....

Underskrift vårdnadshavare 2: ....

Namnförtydligande vårdnadshavare 2: ....

Er kontaktinformation:

Telefonnummer 1: ....

Telefonnummer 2: ....

E-postadress: ....

A.6 Personnel questionnaire

Namn och avdelning du arbetar på:

Frågeformulär om

hörsel, hälsa, arbete och ljudmiljö

GÖTEBORGS UNIVERSITET

Sahlgrenska akademin

Avdelningen för samhällsmedicin och folkhälsa/Arbets- och miljömedicin

CHALMERS

UNIVERSITY OF TECHNOLOGY

Så här fyller du i frågeformuläret:

Vi vet att det ibland kan vara svårt att hitta ett svarsalternativ som fullt ut speglar den egna upplevelsen. Välj därför det alternativ som stämmer *bäst* in på just dig.

Sekretess:

Din identitet kommer aldrig att kunna utläsas vid redovisningen av resultaten från denna studie.

Om du har några frågor är du välkommen att kontakta oss på nedanstående telefonnummer eller e-postadress!

Maja Jansson
Masterstudent inom akustik,
projektutförare
0709 – 99 46 61
majaja@student.chalmers.se

Sebastian Waltilla
Leg. Audionom, magisterstudent,
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sebastian.waltilla@vgregion.se

Kerstin Persson Waye
Professor, projektansvarig
031 - 786 36 04
kerstin.persson-waye@amm.gu.se

Frågor om ljudmiljön på din arbetsplats

Besvara frågorna i vänster kolumn utifrån din nuvarande arbetsplats.

1. Störs du av ljud/buller...

På din nuvarande arbetsplats?

- A1 ☐ Inte alls
- A2 ☐ Något
- A3 ☐ Ganska mycket
- A4 ☐ Mycket
- A5 ☐ Oerhört

2. Är ljudnivån ibland så hög att du har svårt att höra vad andra säger...

På din nuvarande arbetsplats?

- A1 ☐ Aldrig/nästan aldrig
- A2 ☐ Omkring 25 % av tiden
- A3 ☐ Omkring 50 % av tiden
- A4 ☐ Omkring 75 % av tiden
- A5 ☐ Alltid/nästan alltid

3. Hur ofta exponeras du för så höga ljudnivåer att du måste höja rösten för att kunna prata med andra människor...

På din nuvarande arbetsplats?

- A1 ☐ Aldrig/nästan aldrig
- A2 ☐ Omkring 25 % av tiden
- A3 ☐ Omkring 50 % av tiden
- A4 ☐ Omkring 75 % av tiden
- A5 ☐ Alltid/nästan alltid

4. Har någon av följande åtgärder eller ombyggnationer genomförts för att förbättra ljudmiljön...

*Du kan välja **flera** alternativ.*

På din nuvarande arbetsplats?

- A1 ☐ Ljuddämpande absorbenter/paneler/plattor på väggar och/eller tak
- B1 ☐ Golvbeläggning
- C1 ☐ Stolar och/eller bord har anpassats
- D1 ☐ Annan åtgärd för att förbättra ljudmiljön
- E1 ☐ Nej, inga åtgärder
- F1 ☐ Vet inte

5. Beträffande buller i allmänhet, anser du dig vara:

Inte alls känslig	Inte särskilt känslig	Ganska känslig	Mycket känslig
1 ☐	2 ☐	3 ☐	4 ☐

Frågor som rör förskolan

Besvara kommande frågor utifrån din nuvarande arbetsplats på förskola respektive din arbetsplats för fem år sedan om denna var på förskola. Besvara de senare även om du arbetade på samma förskola som idag.

6. När började du arbeta på nuvarande förskola? Månad och år: ______________________

T.ex. augusti, 1997

7. Hur många barn finns/fanns i barngruppen på din avdelning...

A **På din nuvarande arbetsplats?** Antal barn: ____________

B **På din arbetsplats för fem år sedan?** Antal barn: ____________

8. Hur många i personalgruppen är/var ni på din avdelning, räknat i antal heltider...

Två personer som arbetar 75 % av heltid anges som 1,5 antal heltider eller två personer på 50 % anges som 1 heltid.

A **På din nuvarande arbetsplats?** Antal heltider: ____________

B **På din arbetsplats för fem år sedan?** Antal heltider: ____________

9. Vilken ålder har/hade barnen på din avdelning...

På din <u>nuvarande</u> arbetsplats?

- A1 ☐ 1 – 5 åringar/blandade åldrar
- A2 ☐ 1 – 3 åringar (småbarnsgrupp)
- A3 ☐ 3 – 5 åringar
- A4 ☐ Annan ålder: ____________

10. Vilken pedagogisk inriktning har/hade din förskola...

På din <u>nuvarande</u> arbetsplats?

- A1 ☐ Ingen speciell inriktning
- A2 ☐ Ur & skur
- A3 ☐ Montessori
- A4 ☐ Waldorf
- A5 ☐ Annan: ____________

11. Tycker du att buller från verksamheten påverkar barnens beteende?

Inte alls	Något	Ganska mycket	Mycket
1 ☐	2 ☐	3 ☐	4 ☐

Om ja, beskriv kortfattat hur barnen påverkas: ____________________

____

Några sista bakgrundsfrågor om dig

12. Vilket år är du född? Årtal: ________

Egna kommentarer: ____________________

____

____

____

TACK!