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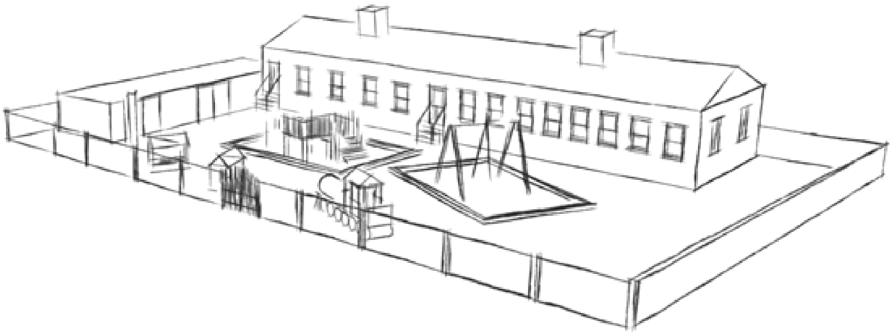

EVALUATION OF OUTDOOR ENVIRONMENT IN PRESCHOOLS USING THE SOUNDSCAPE APPROACH

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MASTER'S DISSERTATION

EVALUATION OF OUTDOOR ENVIRONMENT IN PRESCHOOLS USING THE SOUNDSCAPE APPROACH

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Abstract

Exposure to high levels of noise may affect a person's health and behavior. A lot of education in Swedish preschool occurs outdoor, which makes having good sound environment important for the children and the teachers. Today, Swedish preschools use equivalent sound level L_{eq24h} and max sound level L_{max} for outdoor sound environment benchmark values. These standardized sound level indicators have shown some limitations in certain sound conditions such as tonal components, multisource environments, or low frequency noise.

During the last couple of years, the soundscape research has seen growth. With information from new research and ISO standards, the soundscape method could prove to be a good complementary to the current standardized approach.

This master thesis, among other things, examines how soundscape study can improve the outdoor sound environment in preschools and assesses correlation between measurements and the subjective experience of the participants.

Outdoor measurements are conducted in preschools, where educators answer a soundscape questionnaire. The results of the measurements and questionnaires are compiled and analyzed using statistical methods. Psychoacoustic metrics loudness, roughness, sharpness, and fluctuation strength are calculated.

In general, no clear correlation is found between questionnaire answers and the parameters. The highest correlation is found between max loudness N_{max} and the perception of natural sound.

Soundscapes can give more tools to distinguish what type of sound environment more easily is perceived as good or bad, which can be used by not only acousticians but also other professions.

With more statistical data better prediction models could be created to predict what type of levels of sharpness, or other indicators, would be necessary to affect how well the sound environment would be perceived. Soundscape method is still however new, especially in terms of standardization and is still being improved upon.

Keywords: *Soundscape, statistical analysis, psychoacoustics, outdoor sound environment, sound environment in preschools.*

Sammanfattning

Höga ljudnivåer kan inverka på en människas hälsa och beteende. En god ljudmiljö är viktig för barnen och pedagogerna. I svenska förskolor sker en stor del av undervisningen utomhus, vilket sätter stora krav på att ljudmiljön utomhus är bra. I Sverige använder man sig av ekvivalent ljudnivå L_{eq24h} och maxljudnivå L_{max} som riktvärde för buller på skolgårdar. Ljudnivå har visat sig ha några begränsningar sett till vissa ljudförhållanden, så som vid ljudmiljöer med flera ljudkällor, lågfrekvent ljud samt vid hörbara tonkomponenter.

Under de senaste åren har soundscape forskningen sett stor utveckling. Med nya upptäckter från forskning kan soundscape visa sig vara ett gott komplement till dagens standardmetoder.

Detta examensarbete undersöker bland annat hur man kan använda soundscape för att förbättra förskolornas ljudmiljö utomhus, samt korrelationssamband mellan mätdata och deltagarnas subjektiva upplevelse av ljudmiljön.

Mätningar görs utomhus på förskolor och pedagoger besvarar standardiserade soundscape enkäter. Resultaten från mätningarna och enkäterna sammanställs för vidare korrelation- och regressionsanalys. Psykoakustiska parametrarna loudness, roughness, sharpness och fluctuations strength beräknas från mätdata.

Resultatet visar ingen tydlig korrelation mellan enkätsvar och dem beräknade parametrarna. Högst korrelation hittades mellan max loudness N_{max} och förekomsten av naturljud.

Soundscape kan användas för att lättare urskilja mellan bra och dålig ljudmiljö, vilket kan vara till stor nytta för akustiker samt andra yrken. Större mängd statistiska data kan ge bättre prediktionsmodeller. Dessa modeller skulle kunna användas för att förutse vilka nivåer av till exempel sharpness, eller andra indikatorer som behövs för att skapa en god ljudmiljö. Det bör dock anmärkas att soundscape metoden är fortfarande relativt ny och därmed fortfarande under bearbetning. Det finns fortfarande flera aspekter som inte har standardiserats som till exempel vissa parametrar, men med fortsatt användning bör utvecklingen ske snabbt.

Acknowledgments

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Notations and symbols

L_{eq}	[dB]	Equivalent sound pressure level
L_A	[dB]	A – weighted sound pressure level
L_B	[dB]	B – weighted sound pressure level
L_C	[dB]	C – weighted sound pressure level
L_{max}	[dB]	Maximum sound pressure level
$L_{\%}$	[dB]	Percent exceeded sound pressure level
N_{eq}	[sones]	Equivalent loudness
N_{max}	[sones]	Maximum loudness
$N_{\%}$	[sones]	Percent exceeded loudness
$S_{\%}$	[acum]	Percent exceeded sharpness
R	[asper]	Roughness
F	[vacil]	Fluctuation Strength

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1.Introduction

1.1 Background

Today, around 2 million people in Sweden are exposed to high levels of noise. Exposure to high levels of noise may affect a person's health and behavior. Some of the negative effects of noise pollution include concentration difficulties, tiredness and lowers productive capacity, more so in children than in adults (Folkhälsomyndigheten, 2019).

A lot of education in Swedish preschool occurs outdoor, which makes having good sound environment important for the children and the teachers. Today, the aim in Sweden is that the noise level should not exceed 50 dBA L_{eq24h} or 70 dBA L_{max} in school- and preschool yards (Boverket, 2015).

There are several common ways to reduce sound level such as reducing the speed limit of vehicles or the use of noise barriers. These solutions might not always be possible or enough for various reasons, such as aesthetical reasons or due to limited space. The denser the cities get the more difficult it might become to build preschools with good sound environment. Therefore, it might be reasonable to look for other less conventional solutions such as soundscape.

Soundscape is an approach which relies on perception of the sound environment from human experience. The more standardized indicators have shown some limitations in certain sound conditions such as tonal components, multisource environments, or low frequency noise. This is something the soundscape research has in aim to avoid and focus more on evaluating how people perceive their sound environment. The aim is to find indicators that fit the desired circumstances culturally, socially, personally et cetera (Brooks et al, 2014).

During the last couple of years, the soundscape research has seen growth (Aletta F & Kang J, 2018). In 2018 and 2019 two new parts of the new ISO standard 12913 on soundscape research were published. With more information from the research, the new standard soundscape method could prove to be a good complementary to current standardized approach.

1.2 Problem formulation

The purpose of the study is to present more analytical tools provided in soundscape studies as well as introduce other relevant parameters for measurements and analysis of an outdoor sound environment in preschools. The result from this study will provide a complementary method to the more standardized approach.

How can the soundscape approach and different psychoacoustic parameters be used in outdoor measurements for preschools?

1.3 Aim and objectives

The purpose of this Master thesis is to investigate the current guidelines for outdoor measurement for preschools, introduce new methods used in previous soundscape studies and the newly published ISO 12913-2:2018 and 12913-2:2019. Questions to be answered are what other parameters could be used together with the standard parameters, how a soundscape study could be used together with standard measurement and if there is any correlation between the subjective perception and the measured data.

This thesis will aim to:

- Examine how a soundscape study can improve the outdoor sound environment in preschools.
- Look to find correlation between measurements and the subjective experience of the participants.
- Discuss current limitations and suggest improvements for future projects and studies.

1.4 Limitations

There are many parameters within psychoacoustics that could be studied for potential use in outdoor measurements but due to time limitations it will not be possible to cover all of them in this research. Some of the parameters discussed in this study have recently been standardized or are yet to be standardized and because of this there are certain limitations in calculations of these parameters. The calculations done in this study have been done with MATLAB and the codes used in this study have been either used in other studies or have been provided by people who have valid experience within the psychoacoustic field. However, there are other programs that could have been used for further validations of the calculations. Due to limited funds these programs were not possible to acquire for this study. Binaural recordings were suggested in the ISO 12913, but were also neglected due to limited funds.

The measurements were done in four preschools and there were 25 participants answering the questionnaire. Ideally more measurements and participants would provide a better result. The measurements were supposed to be done in at least five preschools. Due to the time constraint and the COVID-19 pandemic outbreak during the writing of this thesis, acquiring the last measurements provided to be very difficult.

The measurements were done while the children were indoors, even though they should be considered as part of the sound environment.

1.5 Disposition of the study

The content of this thesis will be divided into following sections:

1. Introduction
2. Theory
3. Guidelines on Soundscape
4. Swedish guidelines for Preschools
5. Methodology
6. Results
7. Discussion
8. Conclusion

Section *2. Theory* will provide the reader with some basic knowledge needed to understand the content provided in the later chapter such as basic acoustic terms, explain different parameters and briefly explain statistical analysis theory used in this study.

Section *3. Guidelines on Soundscape* will introduce methods and requirements in soundscape studies, while Section *4. Swedish guidelines for Preschool* will introduce parameter benchmark values in Swedish preschools.

Section *5. Methodology* will explain the method chosen in this study and lastly section *6. Results* will give the results from measurements and the analysis performed in this thesis. Lastly section *7. Discussion* and *8. Conclusion* will discuss and summarize the results from the previous section.

1.6 Literature review

EU acknowledged that urban sound environment can no longer rely on simply noise control (EU, 2002). Traffic noise being thought as harmful for children especially during sensitive stages of development was further discussed in recent study were the researcher suggested that exposure to residential traffic noise might further increase the risk to develop hyperactivity in children or inattention symptoms at age of 7 years (Sørensen, 2017). With these developments a shift towards soundscaping becomes even more interesting.

A study from 2016 (Aletta et al) tried to answer some of the more important questions regarding soundscapes such as definitions and discussed emerging soundscape science on currently relevant practices and studies. Some of the more important topic discussed in the conclusion was the fact there is no clear definition on how to analyse soundscape data but some of the research focused on finding correlation between physical and perceptual data. The same paper also mentioned the importance of continuing development of predictive models for the perception of acoustic environment.

Going back a couple of years researchers (Kang J & Yang M, 2012) worked on trying to standardize definitions, analysis procedures and methodologies. The study focused on studying the psychoacoustic parameters loudness, sharpness, roughness, fluctuation strength and tonality. The study found some correlation between these psychoacoustic parameters and sounds such as wind, water and birdsong, as well as urban and natural sounds.

In a study by Genuit K & Fiebig A (2016) the authors discuss the importance of using psychoacoustic parameters in soundscape studies. It is mentioned that an A-weighted sound pressure level is useful in assessment of physical damage on human hearing but does not help in evaluation of a perceived soundscape in terms of for instance pleasantness or eventfulness. Previously mentioned metrics such as loudness, sharpness, roughness and fluctuation strength are discussed further and analysis is done using statistical analysis. The analysis showed that loudness has a higher correspondence to the sensation of volume than a sound level indicator. The researchers conclude that a simple use of psychoacoustic metrics is not enough to assess the soundscape and suggests comparing it to the perception of people living in the soundscape of interest (Genuit & Fiebig, 2016).

In a study from 2010 (Axelson et al) the authors looked at developing a predictive model by looking at 115 soundscape attributes and combined them into three basic components of soundscape perception called Pleasantness, Eventfulness and Familiarity. This model has seen continued development calling it The Swedish Soundscape-Quality Protocol. The researchers hoped that it would help so called non experts to measure soundscape quality more easily and eventually reach future guideline values of the World Health Organization (Axelsson et al, 2012). The SSQP model was further tested, with new development suggesting accessing perceived sound quality using pleasantness and eventfulness. The authors conclude that this model gave the most relevant information (Axelsson et al, 2015).

In a study aiming to characterize and reveal how soundscape of the Valley Gardens in the city of Brighton, a method consisting of soundwalk, statistical analysis and collecting audio samples was used (Aletta et al, 2015). While conducting a soundwalk, the participants moved between several study points while answering a questionnaire.

A more recent study continued the development of predictive models for soundscape and researched the descriptor called vibrancy. The vibrancy model showed that parameters such as roughness, presence of people, fluctuation strength, loudness and presence of music can explain up to 76 % of the variance, which means there is high correlation between these parameters and vibrancy (Aletta F & Kang J, 2018). This study looked to further analyze the term vibrancy from the earlier study (Cain et al, 2013) where the researchers showed that even though sound levels were similar, the term calmness and vibrancy were differently perceived. This showed that simply using an objective measure may not be enough to access a sound environment.

A different study (Axelsson et al, 2018) aimed to further examine the previously mentioned Swedish Soundscape-Quality Protocol on the influence of socio-cultural context, including language. Adjectives in several languages were studied such as English, French, Swedish and Korean, concluding that a cross-national comparison with a standardized data collection procedure is needed to be sure that the results obtained in different linguistic versions are comparable (Axelsson et al, 2018). The Swedish-English wording that correlated were *pleasant– trivsam, unpleasant – störande, eventful – händelserik, uneventful – händelselös, exciting – spännande, monotonous – enformig, calm – lugn* and *noisy – bullrig*.

The first official ISO standard on Soundscape, ISO 12913-1, was published in 2014 to help enable a broad international consensus on the definition of soundscape. ISO 12913-1:2014 explains a couple of definitions relevant to soundscape and some of the conceptual framework. In 2018 and 2019, two new parts of the ISO 12913 are released on data gathering and data analysis for soundscape research.

Several programs have been used for calculating sound quality metrics. In a research by López et al (2012) on acoustic quality of university facilities, Brüel & Kjaer Sound Quality type 7698 was used for calculations of metrics such as loudness, sharpness, roughness and fluctuation strength. Similar program cited as Brüel & Kjaer Sound Quality software was used in the previously mentioned research by Cain et al from 2013. In a soundscape project for a German park called Nauner Platz Artemis by HEAD acoustics was used for the analysis of the psychoacoustic measurements (EEA, 2012). Other programs used for calculations include MATLAB with codes developed by Genesis used in a study about soundscape in restaurants (Frid, 2013).

2.Theory

2.1 Basic acoustics

To grasp the content of this thesis more easily, some basic acoustic terms will be introduced in this section.

2.1.1 What is sound and how is it measured?

Sound is pressure waves generated by vibrating objects. These sound waves propagate through a medium, such as air (Boverket, 2015). The strength of the sound is described using pressure, which is measured in Pascal. The speed of which the sound vibrates is measured in *hertz*, the unit of frequency (Boverket, 2015). Frequency can be described as the number of times a sound wave cycle repeats during a given time period. It can be calculated using the simple formula:

$$F = \frac{1}{T}[Hz]$$

Where T is the wave period, the amount of time for the wave cycle to complete, as seen in Figure 1.

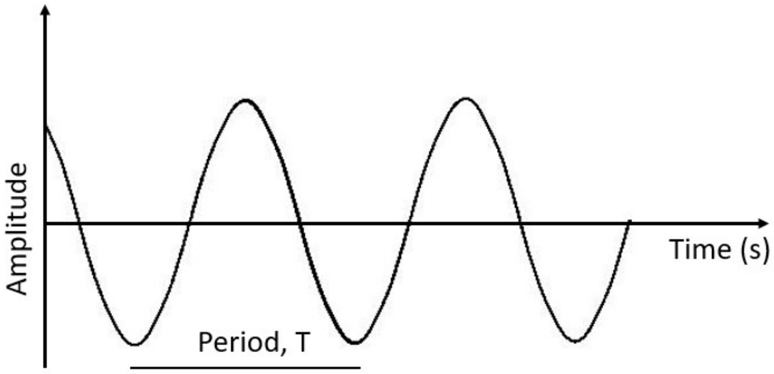


Figure 1 Basic wave.

Figure 2 shows that sound with high frequency will sound darker, while a sound with low frequency will sound lighter. Some examples of low frequency sounds can be sound from a lawn mower, chain saw or even a car, while a high frequency sound could be a phone ringing or a birdsong.

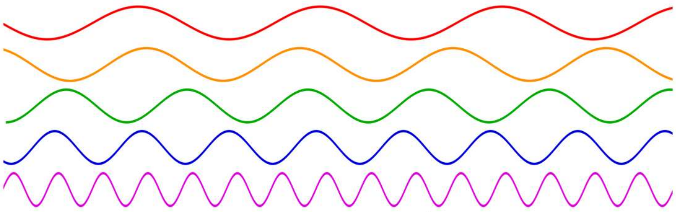


Figure 2 Frequency increasing from top to bottom. Red being low frequency and purple high frequency.

The sound pressure threshold for a human ear spans between 10 µPa to 60 Pa. This is quite a large span and therefore not the most practical metric for a linear scale (Nilsson et al, 2008). In 1920 a new logarithmic scale was introduced using sound pressure level L_p with the metric decibel (dB), which is the one being used today (Nilsson et al, 2008). The comparison of Pa versus decibel can be seen in Figure 3. Another common way to express sound pressure level is L_{eq} equivalent sound pressure level and L_{max} max sound pressure level. Equivalent sound pressure level represents an average value during a certain time period, while max sound pressure level is the highest value during a certain time period (Boverket, 2015).

Sound can be divided into smaller segments called octaves. Octaves are useful in an analysis of sound as it allows for identification of sound across individual frequencies (Nilsson et al, 2008).

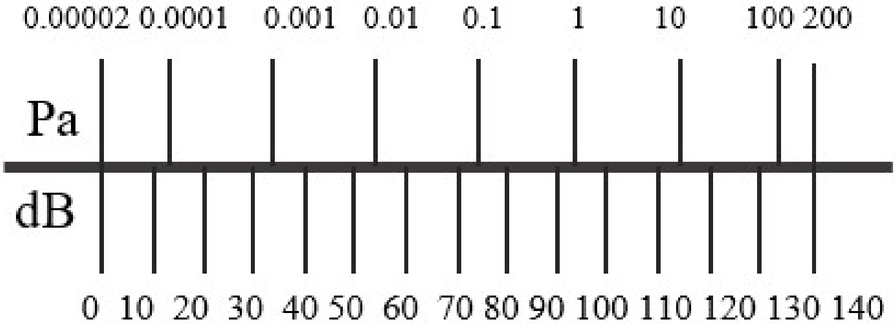


Figure 3 Illustration of Pascal scale compared to decibel scale

2.1.2 Human hearing area

A healthy person can hear sound ranging from approximately 20 Hz to 20 kHz. The hearing area, when plotted, is usually shown with frequency on a logarithmic scale together with the sound pressure level on a linear scale, as seen in Figure 4 (Fastl & Zwicker, 2007). The figure shows that depending on the frequency, the sensitivity is different. The greatest sensitivity is around 2 kHz where the human ear can hear from between 0 to 120 dB. Normal speech sounds usually vary between 100 Hz to 7 kHz.

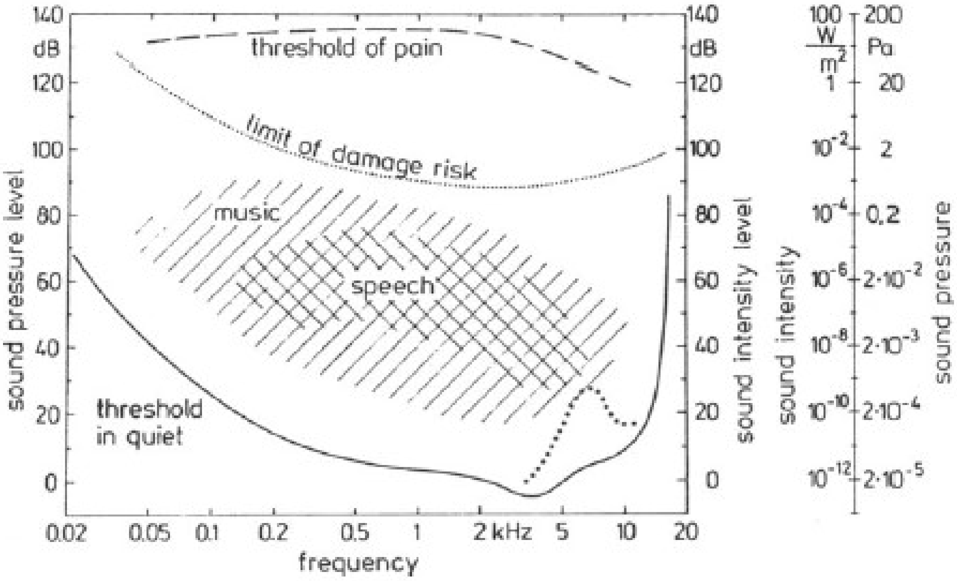


Figure 4 Human hearing area (Fastl & Zwicker, 2007).

The dotted line in Figure 4 shows the limit of damage risk. The limit for damage risk is lower at frequencies where the hearing is more sensitive. In the more sensitive range between 1 and 5 kHz the limit of damage can be as low as 90 dB. It should be noted that this limit differs as some people have more sensitive hearing than others. The limit is set for an exposure which lasts for 8 hours, 5 days a week. If a person were to be exposed to higher sound level, then the time for exposure would decrease. If a person were to be exposed to 100 dB in the sensitive frequencies, then the limit would be set at around 50 minutes and at 110 dB for 5 minutes. The result of overexposure begins with temporary shifts in the threshold. With more overexposure it can become permanent and may result in hearing loss. If it were to be explained using Figure 4, it would mean that the threshold for quiet shifts towards higher sound levels permanently (Fastl & Zwicker, 2007).

Decibel values are sometimes used together with weighting curves. There are several weightings such as A-D and Z, as seen in Figure 5. The purpose of these weighting curves is to give a better indication on how the sound is perceived (Nilsson et al, 2008). The most used weighting when measuring noise is the A-weighting *dBA,* and possibly the C-weighting *dBC.* The A-weighting is used for weaker sounds, decreasing in the lower frequencies and increasing in the medium frequencies (Boverket, 2015). For sound in lower frequencies such as fan noise the C-weighting is more commonly used, as it gives a better indication of the low frequency noise (Boverket, 2015).

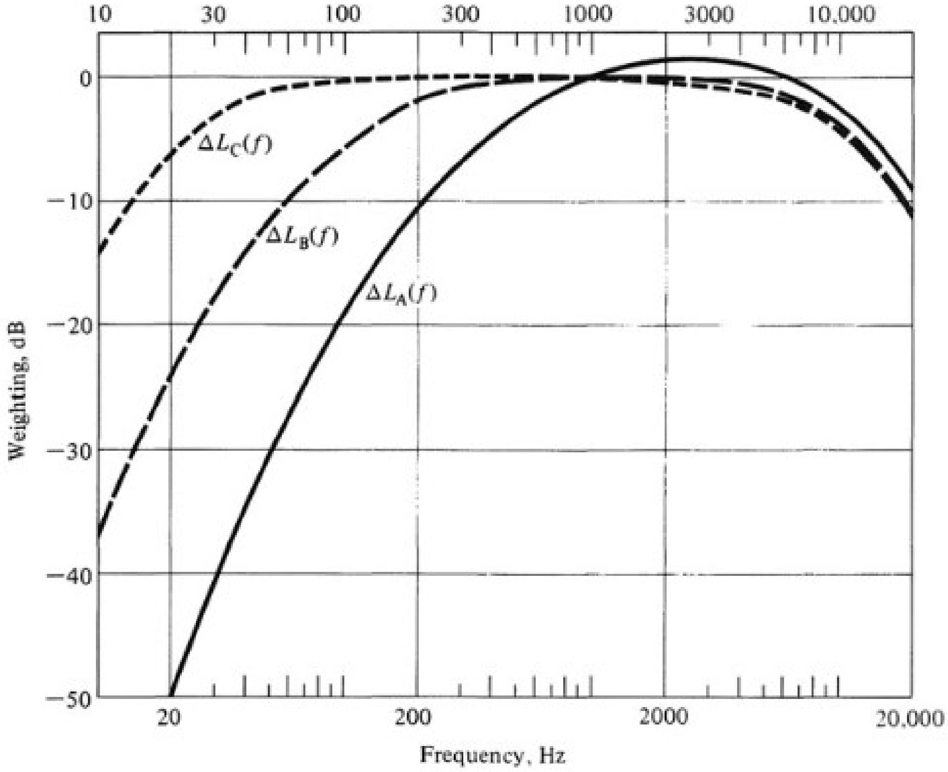


Figure 5 Illustration of the weighting curve for A-, B- and C- weighting (Pierce, 1981).

2.2 Psychoacoustics

Psychoacoustic is the study of sound perception, for instance how humans perceive sounds and what type of psychological response a certain type of sound can cause (Ballou, 2008).

2.2.1 The effect of sound and noise

The difference between sound and noise is that noise is an unwanted sound (Nilsson et al, 2008). Not only is noise an unwanted sound due to annoyance, but it has a negative effect on health. The negative effect on health include for instance hearing impairment, heart disease, sleep disturbance and lowered concentration levels (Folkhälsomyndigheten, 2019).

The annoyance level from noise depend on several aspects such as which frequencies dominate. The equivalent sound level is used for measurement of annoyance, while max sound level is important for evaluating sleep disturbance (Boverket, 2015). Low frequency noise is harder to reduce than high frequency noise (Nilsson et al, 2008). Low frequency noise is better at travelling through walls, while high frequency tends to be reflected. Sound with low frequency have longer wavelengths, which is why it can bend around objects more easily (Nilsson et al, 2008).

There are several ways to reduce outdoor noise such as lowering the speed limit, increasing the distance away from the noise or applying different materials to the surrounding such as different type of asphalt (Boverket, 2015). Another common tool to treat outdoor noise is using noise barriers.

Noise barriers are however mostly effective for higher frequency noise (Nilsson et al, 2008), which is illustrated in Figure 6.

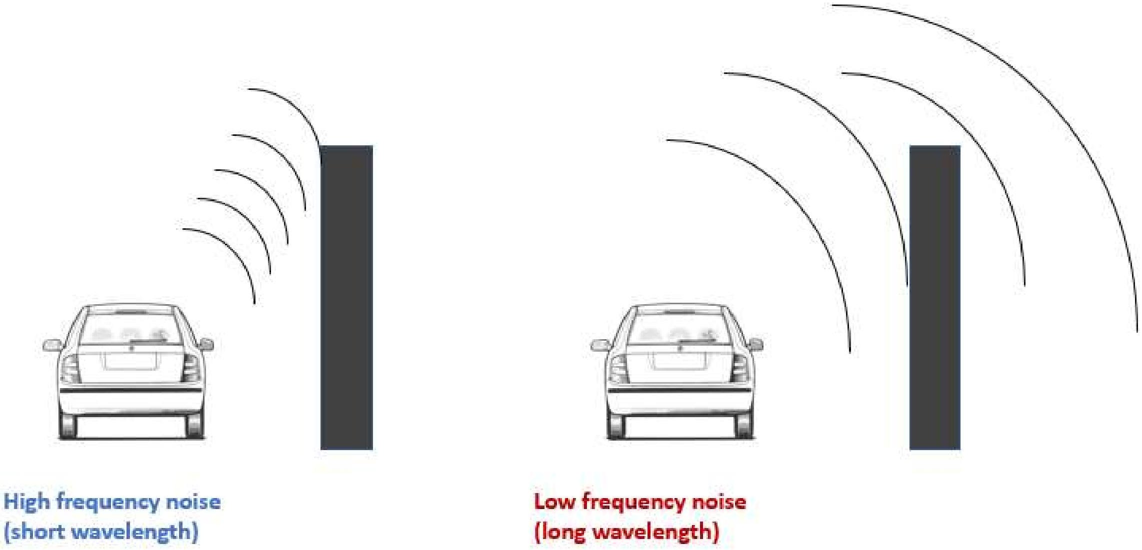


Figure 6 Low frequency noise travels more easily through noise barriers.

2.2.2 Psychoacoustic parameters

Sound quality is a term used to describe a listener’s opinion on how acceptable a sound is (SIRC, 2020). Within the definition of sound quality there is a large amount of metrics. The metric individually does not give a good indication of the sound quality. This is due to sound quality usually uses the principle of how well the sound of a product matches a user’s expectation (SIRC, 2020).

Within the sound quality, metrics such as *Loudness*, *Sharpness*, *Roughness*, *Tonality*, *Fluctuation Strength* can be found. These parameters have been applied in calculation of unbiased annoyance metric and sensory pleasantness (SIRC, 2020).

Loudness

Loudness is measured in sones or phons and can be described as a perceptual measurement or an intensity sensation. Loudness measures the energy content effect on the ear. It is dependent of the frequency content of the sound, for instance a low frequency sound of 20 Hz at 40 dB could be perceived quieter than a sound of 1 kHz at 40 dB. When loudness is measured in phons it directly responds to sound level (dB) at 1 kHz frequency, so for instance a sound of 40 dB at 1 kHz corresponds to 40 phons. This can be seen in Figure 7. It means that sound level at 1 kHz can be used to define the loudness. This does however mostly apply to simple cases. With more complex sounds the calculations should include critical band width, a measure of the frequency resolution of the ear (Fastl & Zwicker, 2017).

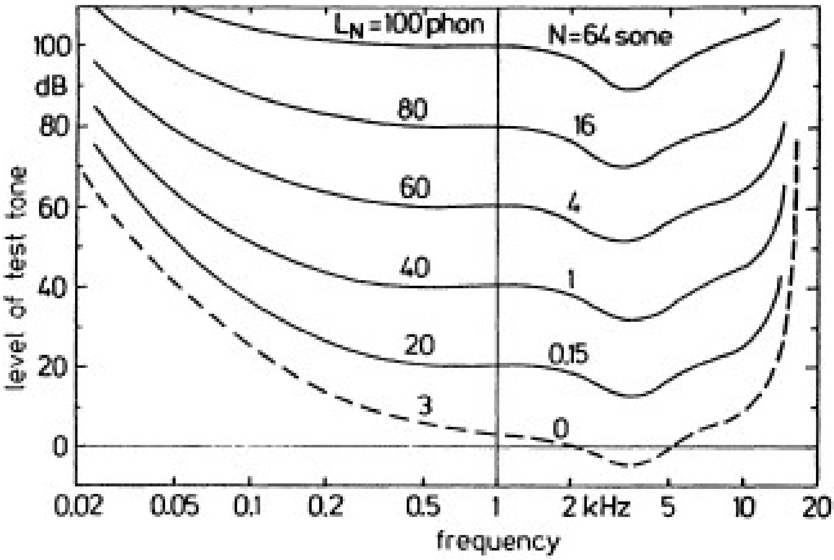


Figure 7 Equal-loudness contours showing phons versus sones (Fastl & Zwicker, 2007).

The equation for loudness can be calculated the following way:

$$N = \int_{0}^{24Bark} N' dz$$

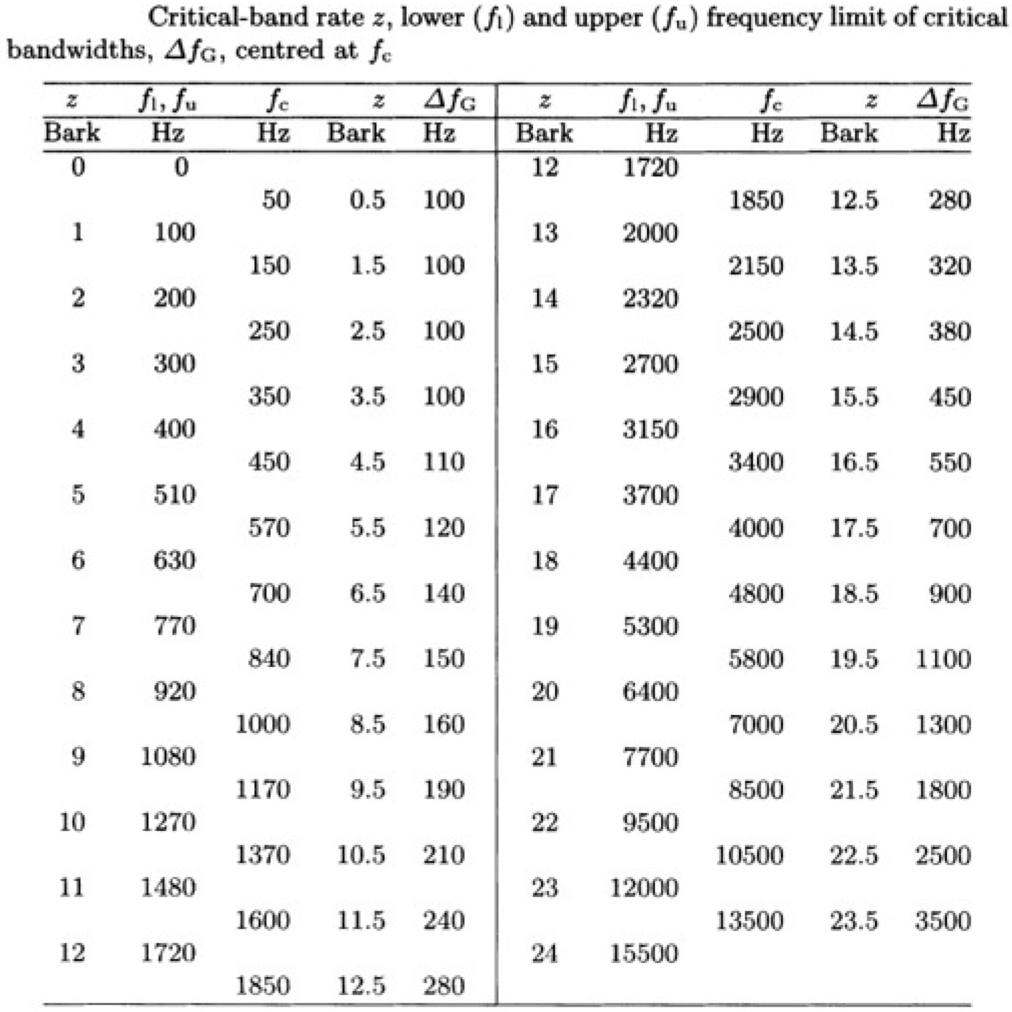
The z value is the critical band rated measured in Bark, see Figure 8. N is the final value for loudness, N' is the specific loudness calculated using a power law (Fastl & Zwicker, 2017).

The Bark scale was suggested by Eberhard Zwicker. The Bark scale is named after Heinrich Barkhausen, a German physicist, who suggest the first subjective measurement of Loudness. The scale can be described as a psychoacoustic scale or measure, which is divided into an audible range of 24 bands (Fastl & Zwicker, 2017).

The conversion between frequency in Hz to Bark can be done using the following equation (Fastl & Zwicker, 2017):

$$Bark = 13arctan(0.00076f) + \arctan\left(\left(\frac{f}{75000}\right)^2\right)$$

In the lower frequencies of 500 Hz and below, the scale is more linear, while above it becomes more logarithmic.



Critical-band rate z, lower (f_l) and upper (f_u) frequency limit of critical bandwidths, Δf_G, centred at f_c

z	f_l, f_u	f_c	z	Δf_G	z	f_l, f_u	f_c	z	Δf_G
Bark	Hz	Hz	Bark	Hz	Bark	Hz	Hz	Bark	Hz
0	0				12	1720			
		50	0.5	100			1850	12.5	280
1	100				13	2000			
		150	1.5	100			2150	13.5	320
2	200				14	2320			
		250	2.5	100			2500	14.5	380
3	300				15	2700			
		350	3.5	100			2900	15.5	450
4	400				16	3150			
		450	4.5	110			3400	16.5	550
5	510				17	3700			
		570	5.5	120			4000	17.5	700
6	630				18	4400			
		700	6.5	140			4800	18.5	900
7	770				19	5300			
		840	7.5	150			5800	19.5	1100
8	920				20	6400			
		1000	8.5	160			7000	20.5	1300
9	1080				21	7700			
		1170	9.5	190			8500	21.5	1800
10	1270				22	9500			
		1370	10.5	210			10500	22.5	2500
11	1480				23	12000			
		1600	11.5	240			13500	23.5	3500
12	1720				24	15500			
		1850	12.5	280					

Figure 8 Bark versus Hz (Fastl & Zwicker, 2007).

As seen in Figure 7 the scale goes up to 13500 Hz centered frequency. Loudness can be expressed in several different ways (Aletta F & Kang J, 2018) such as Loudness Variability over time (N_{10}-N_{90}) which is the difference between Loudness peak value (N_{10}) and Loudness background values (N_{90}).

There are other methods for Loudness calculation, beside the method developed by Zwicker. While the Zwicker method has been standardized in ISO 532-1:2017, there is also a method developed by Moore-Glasberg described in ISO 532-2:2017. The main difference between the two methods is that the Zwicker and Fastl's model calculates loudness as a function of time, while the Glasberg and Moore model does calculations of loudness as a function of time for time-varying sounds (Genesis S.A, 2009a).

The more commonly used unit in sound quality evaluation for loudness is sones. To easier comprehend how the sone unit compares to the dBA unit, Figure 9 will illustrate how sounds compare between dBA and sones (Fastl H, 2006).

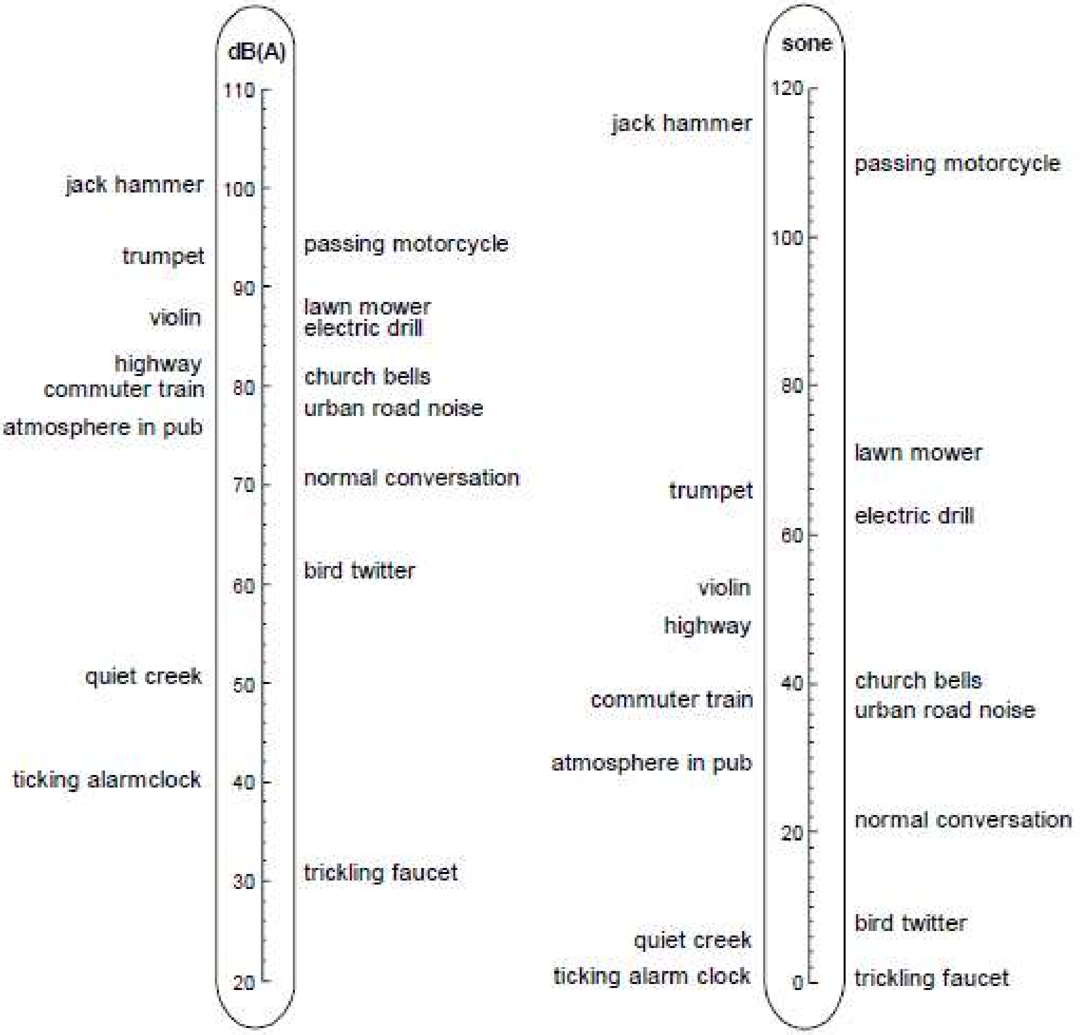


Figure 9 Illustration of sounds in dBA scale versus sones (Fastl et al. 2006).

The biggest difference between the sounds seen in Figure 9 is that in the dBA scale the sound for trumpet is considered louder than the sound of a lawn mower, while it is the opposite on the sone scale. The same happens for the sound of the violin, which has approximately the same value as the electric drill on the dBA scale but not on the sone scale. Fastl (2006) writes that this might be due to different spectral distributions, which are not accounted for on a single channel analysis with a sound level meter. This is different on a multi-channel analysis as it accounts for minute spectral differences, which is closer to the human hearing system (Fastl H, 2006).

Sharpness

Sharpness is measured in acum. The biggest effect on a sound's sharpness comes from a sounds spectral content. A greater proportion of high frequency gives a sharper sound (Fastl & Zwicker, 2017). There are several methods used to calculate sharpness. Using the method described by Fastl & Zwicker (2017) it can be calculated with the following equation:

$$S = 0.11 \frac{\int_0^{24Bark} N'g(z)zdz}{\int_0^{24Bark} N'dz}$$

The parameters are the same as in the loudness equation, with some small differences. The upper integral uses the factor $g(z)$ which is critical rate dependent (Fastl & Zwicker, 2017).

Sharpness is an important metric in the sound quality engineering and is sometimes described as the measure of tone color (Fastl H, 2006). A higher amount of sharpness can give a sense of powerfulness to the sound. A clean note guitar sound at 65 dB would give approximately 0.85 acum and at 90 dB 0.96 acum (Cook J, 2016). A study by (Yang M & Kang J, 2012) noted that small rivers, most subcategories of birdsongs, fountains and machine sounds could register relatively high values of sharpness up to over 3 acum. A church bell could register a value of approximately 1.6 acum.

Roughness

Roughness is measured in aspers and is described as a perception effect of fast modulation of a sound between frequency of 15-300 Hz (Aletta F & Kang J, 2018). One asper can be compared to roughness produced by a 1 kHz tone of 60 dB which then is 100% amplitude modulated at 70 Hz (Fastl & Zwicker, 2017). Assuming this the following equation can be used:

$$R = 0.3 \frac{f_{mod}}{kHz} \int_0^{24Bark} \frac{\Delta L_E(z)}{dB/Bark}$$

ΔL_E representing masking depth and f_{mod} modulation frequency. The roughness metric has not yet been standardized with several methods proposed for calculation (SIRC, 2020). There are several difficulties when it comes to developing a proper algorithm for roughness calculation like for instance properly quantifying the masking depth ΔL_E or get the algorithm to return low values of roughness for random sounds like for instance pink noise (SIRC, 2020). There are several different methods suggested by different researcher for instance a method which requires calculating a generalized modulation depth called $m_i{}^*$ or a method using specific loudness made every 2 ms to acquire a time variable of a masking pattern from which ΔL_E can be calculated (SIRC, 2020). Yang & Kang (2012) noted that small rivers, machine sounds, and fountains could register values of above 3 aspers. A church bell could register a value of approximately 1.5 asper.

Fluctuation Strength

Fluctuation strength is comparable to roughness and is measured in vacil. It is described as a slowed-up amplitude modulation in the frequency of up to 20 Hz (Aletta F & Kang J, 2018). One vacil can be compared to fluctuation strength produced by a 1 kHz tone of amplitude modulated at 4 Hz (Fastl & Zwicker, 2017). Fluctuation strength can be calculated with equation:

$$F = \frac{0.008 \int_0^{24Bark} \left(\frac{\Delta L}{dB} Bark\right) dz}{\left(\frac{f_{mod}}{4} Hz\right) + \left(\frac{4Hz}{f_{mod}}\right)}$$

Fluctuation strength has an important role in assessment of human speech. Fluctuation of fluent speech has a maximum of around modulation frequency of 4 Hz and roughly compares to the number of syllables pronounced/second (Fastl H, 2006). Human speech creates speech sounds with dominant fluctuations to which the human hearing is most sensitive. This plays an important role in development of warning signals, with these signals having high Fluctuation strength values. (Fastl H, 2006). Yang & Kang (2012) noted that music, human voice, footstep, birdsongs could average approximately values of 0.04 to 0.11 vacil.

Tonality

Tonality describes the amount of pure tones in the noise spectrum. The calculation compares the overall signal to the relative strength of the tones. By varying the frequency resolution to the frequency of human hearing it can search the spectrum for likely tones to compare with tone loudness to the sound loudness (NI, 2016).

There have been several methods for quantification of tonalities such as Prominence Ratio, Tone-to-Noise Ratio or Psychoacoustic Tonality all described in ECMA-74 standard (Becker et al, 2019). The Psychoacoustic Tonality was first standardized in the 15th edition of ECMA -74 which was published 2019 (Becker et al, 2019). The difference between Psychoacoustic Tonality and the previous methods is that the Psychoacoustic Tonality is based on human hearing model and can better predict human perception, while the other only do that to some extent (Becker et al, 2019).

2.3 Statistical data analysis

To make sense of collected data, sometimes a statistical analysis is necessary. There are several statistical methods that can be used for data analysis. This section will briefly explain regression analysis.

2.3.1 Regression analysis

Regression analysis is a statistical method that is used to estimate the relation between dependent variables Y and independent variable X (Rawlings et al, 1998). The independent variable Y is assumed to be continuous and follows a random distribution, while the X is non-random. In regression analysis the observations are assumed to be normally distributed.

A simple linear regression equation can look the following way, as well as seen in Figure 10:

$$Y_i = \beta_0 + \beta_1 X_i + \varepsilon_i$$

The β_0 is the intercept value, the β_1 slope of the line, ε_i is the value for random error and the i indicates the amount of observations (Rawlings et al, 1998). When there is more than one independent variable, it is called multiple linear regression. Another way of looking at regression is to view it as a way of finding parameters of the equations that best fit the observed data.

2.3.2 Correlation coefficient and the statistical significance

The coefficient of determination R^2 is a measure of contribution of the independent variable, or simply the square of the correlation coefficient between Y_i and X_i. Correlation measures the linear relationship between two variables. The correlation ranges from -1 to 1.

The R^2 ranges from 0 to 1 (Rawlings et al, 1998) and indicates the strength of the linear association between x and y. If the R^2 has a value of for instance 0.80 of the total variation, then it would mean that 80% of the total variation in y can be explained by the relationship between y and x. The other 20% would remain unexplained.

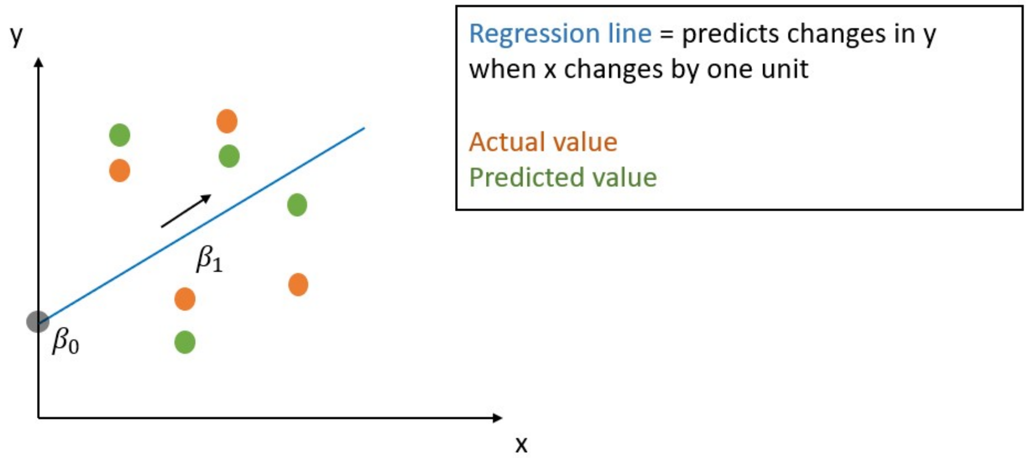


Figure 10 Graphical illustration of a regression model. When actual value and predicted value is close together, the R^2 value is high.

The correlation of determination can sometimes be easier to interpret than the coefficient of correlation. An example will illustrate how the R^2 can be used to easier see correlation strength between two different values:

If one were to compare two coefficients of correlation of for instance 0.7 and 0.5 it would be more difficult to determine how big of a difference the correlation really is. If instead the correlation of determination is used on the above values, the result would look the following way:

$$R^2 = 0.7^2 = 0.5 \qquad 50\%\ variation\ is\ explained$$

$$R^2 = 0.5^2 = 0.25 \qquad 25\%\ variation\ is\ explained$$

This example shows that 0.7 can explain two times more variation than 0.5.

In some cases, when analyzing two variables, such as for instance the rainfall data in two different cities it can become difficult to choose which of the variables should be considered X or Y. Both variables can be considered “same value” in which case a correlation coefficient is considered more suitable than a correlation of determination (Matematikcentrum, 2014).

The probability value, also simply called p-value, helps determining the significance of the results in relation to a so-called null hypothesis (Agresti, 2017). A null hypothesis declares that there is no relationship between the two tested variables and are instead due to chance and therefore not significant enough to investigate. The p-value is usually expressed between 0 to 1. A small p value shows a strong evidence that the null hypothesis should be rejected. If the p value is smaller than $p < 0.05$ the correlation can be assumed to be significant (Agresti, 2017).

Confidence intervals can often be used when evaluating samples for statistical analysis. A confidence interval shows the probability that a sample will fall between two set of values for certain percentage of time (Matematikcentrum, 2014). The most common interval probability is 99% or 95% confidence interval (Matematikcentrum, 2014). The equation for the confidence interval can be calculated with:

$$\overline{x} \pm z \cdot \frac{\sigma}{\sqrt{n}}$$

Where $\overline{x}$ is the mean sample, σ is the margin of error, n the sample size and z is a value for given confidence level, which for instance for 95% would be 1.96 (Matematikcentrum, 2014).

3. Guidelines on Soundscape

3.1 Soundscape

The definition of “soundscape”, as described in the handbook of Acoustic Ecology (Truax, 1999), is a sound environment which focuses on how it is perceived by an individual or society. The idea was first introduced as an alternative to the current evaluation of noise and how it affects life quality (Brooks et al, 2014). Until recently there were no definitive way on how to perform a soundscape approach. There was however a consensus that it should rely on several investigation techniques such as interviews, measurements and questionnaires (Brooks et al, 2014). However, with the new ISO 12913 a broader international consensus now exists to provide the framework and methodology for soundscape. ISO 12913 is divided in 3 parts; ISO *12913-1:2014* on definition and conceptual framework, *12913-2:2018* on data collection and reporting requirements and *12913-3:2019* on data analysis.

The main idea of soundscape lies within using available resources and provide an alternative to current evaluation of noise because the current noise parameters have shown limitations in several circumstances such as with tonal components, low frequency noise or with multisource environment Brooks et al (2014).

3.2 Data gathering and reporting

The idea behind the soundscape is to provide a holistic approach to the acoustic environment, by analysing all perceived sound in the given environment (ISO 12913-2:2018). Soundscape firstly relies upon human perception and secondly turns to physical measurements. The ISO 12913-2:2018 provides information on the minimum reporting requirements to be considered soundscape study. The minimum requirements provided by the standards are

a) Selection and classification of participants
b) Characterization of studied acoustic environment
c) Data collection with regard to human perception of the acoustic environment

In case of field studies, which is the most common approach, the participants usually are visitors or residents of the studied area. These types of participants are in the studies called local experts, which is a description used for people who are familiar with the investigated area (ISO 12913-2:2018). The standard requires the motivation of choosing the participants as well as age and gender distribution, if they are experts relevant to the study or simply visitors or residents in the investigated area and other relevant information such as hearing ability.

The characterization of studied acoustic environment is usually done by binaural or ambisonics recordings. The binaural measurements are performed to closely resemble the way human beings perceive the acoustic environment, by using an artificial head (ISO 12913-2:2018). An example of binaural headset is seen in Figure 11.

Figure 11 binaural headphones and artificial head.

The measurement should have a sample frequency to be at least 44.1 kHz with a depth of 24 bit (ISO 12913-2:2018). The measurement protocol should also provide information measurement points, date, time and duration of the measurement, weather conditions, description of sound sources during the measurement and a visual description of the environment.

The binaural measurement should be used in further computer-based analysis. Using binaural technology enables the researcher to re-experience the acoustic environment more properly acoustically, due to the ability to better understand complex sound situations such as more properly distinguish the location of the sound source (Genuit, 2018). A single channel microphone measurement will not be able to grasp the physical environment the way a human normally would (Genuit, 2018).

Data collection should be done in a way where people's subjective perception is considered, as well as including the acoustic environment and a combination of several investigative methods (ISO 12913-2:2018). The combination of several investigative methods refers to *triangulation*, see Figure 12. It is a method that helps validating data through cross verification of three components; people, context, and acoustic environment (ISO 12913-3:2019).

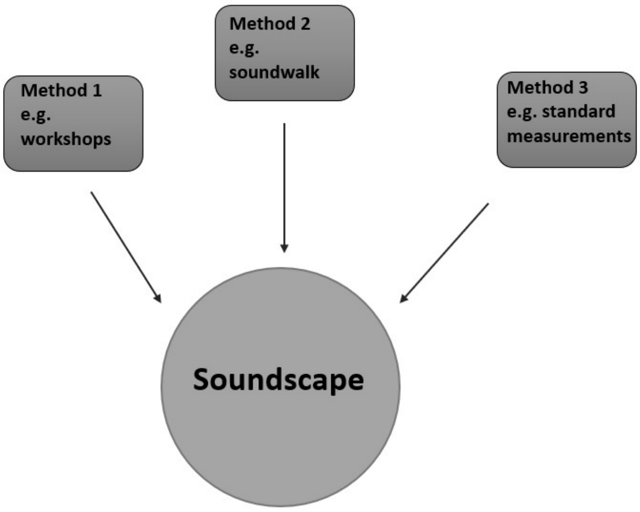


Figure 12 Example of triangulation method.

To investigate the environment from several viewpoints the ISO 12913-2:2018 requires the researcher to perform a soundwalk and/or questionnaire and/or a guided interview in addition to binaural measurements. Soundwalk is a method that helps provide human sensations of the environment and is performed by a group of participants listening to the sounds while walking in the investigated environment (ISO 12913-2:2018). The standard provides guidelines to the interviews and questionnaire on type of questions that should be asked. The research should provide the chosen design of questionnaire. It should also show what language was used, how the questions used looked in the original language and the translated version (ISO 12913-2:2018).

A popular real-life example on how the triangulation method was interpreted when applied to Soundscape is the Nauner Platz in Berlin. The project was awarded European Soundscape Award in 2012 by the European Environment Agency (EEA), an agency of the European Union tasked to support sustainable development of Europe's environment (EEA, 2012). The process began by having the researchers involve the locals living in the area of the Nauner Platz playground (Brooks et al, 2014). The locals were involved in several different steps starting with public hearings and workshops, where they could discuss the intentions and expectations regarding the renovation of Nauner Platz (Brooks et al, 2014). The researchers also used soundwalks, interviewed locals and lastly performed measurements of several psychoacoustic parameters (Brooks et al, 2014). All this would then provide the researchers with different set of data to better understand how to improve the environment.

The improvements for the playground were for instance using a more esthetically pleasing gabion wall as a noise barrier and inserting sound installations in several playground objects to generate more pleasant sound such as bird sounds. The idea behind these changes were to shift focus from the traffic noise holistically, making the traffic less visible and having people focus on the more pleasant sound from the installations (EEA, 2012).

3.3 The analysis of gathered soundscape data

The more common acoustic measurements, such as sound pressure levels are usually complemented with psychoacoustic measurements such as loudness, sharpness, roughness and fluctuation strength or tonality (ISO 12913-2:2018). The psychoacoustic metrics have shown correlation with the perception and assessment of noise sources such as traffic noise. However, these parameters are not meant to explain the level of appropriateness or pleasantness in its entirety (ISO 12913-2:2018). The parameters can be seen in Table 1.

Table 1 Suggested standards for calculation of each parameter in ISO 12913-3:2019. Note that the standard references literature for Roughness and Fluctuation Strength.

Parameter	Reference
Sound pressure level	ISO 19996-1
Loudness	ISO 532-1
Sharpness	DIN 45692
Psychoacoustic tonality	ECMA 74
Roughness	(Fastl & Zwicker, 2017)
Fluctuation Strength	(Fastl & Zwicker, 2017)

These measurements are calculated from the binaural recordings in accordance to the ISO 12913-2:2018 by taking the signals from left and right ear channel and separately processed to determine the previously mentioned psychoacoustic metrics (ISO 12913-3:2019). The highest value of both signals is used as a single value representing the overall hearing experience. A mean value of ratios determined for the right and left side can also be calculated if more extensive evaluation is required.

There are three different data analysis methods provided in ISO 12913-3:2019. Method A is used for analysis of the questionnaire designed according to ISO 12913-2:2018. Method B is linked to a five-point unipolar continuous category scale usually used in soundwalks and Method C provides an analysis guideline for interview questions.

All three methods should be analysed through correlation. Method A suggests linking data from the questionnaire to the acoustic data to identify possible relationships. ISO 12913-3:2019 suggests using statistical analysis like for instance correlation analysis or linear regression. The established correlation should then be reported as a numerical measure of a statistical relationship between the two variables. The standard suggests to additionally report the determined statistical significance of correlation and the probability value (ISO 12913-3:2019). Method B suggests using Pearsons correlation coefficient for the statistical analysis. Method C does not specify what type of correlation method to use.

3.3.1 Two-dimensional model

In section *1.6 Literature review* the two-dimensional model is briefly mentioned and referred to for instance as SSQP model. The two-dimensional model provided in ISO 12913-3:2019, and seen in Figure 13, is based on some of the previous studies mentioned in the same section. The standard provides a general model that can be used for analysis but notes that the model is still under examination and requires further validation across languages and sites (ISO 12913-3:2019).

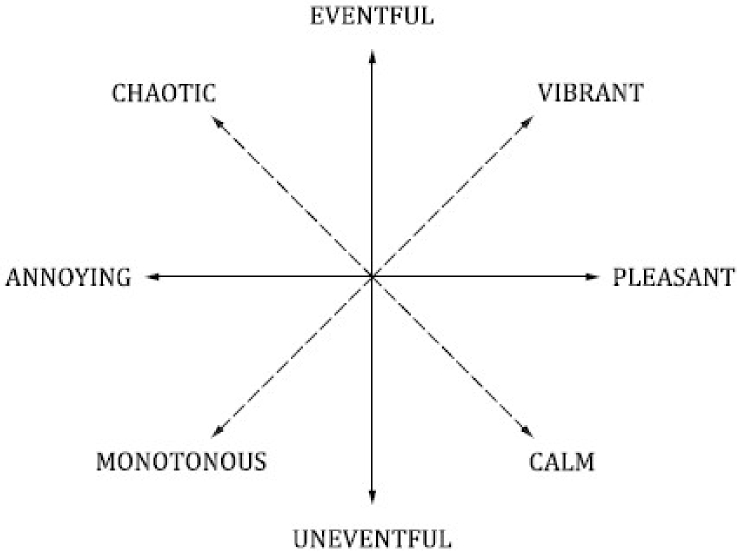


Figure 13 the two-dimensional model provided in ISO 12913-3:2019.

The purpose of the model is to determine how the environment is perceived based on affective quality response. The main dimension is related to how pleasant or unpleasant the environment is, and the second dimension is related to activity and is described as eventful or uneventful (ISO 12913-3:2019). It is further explained that an eventful environment would be considered busy with human activity and an uneventful would be the opposite with no human activity (ISO 12913-3:2019).

The two main dimensions are accompanied by two more dimensions rotated 45° from the main dimensions and represent chaotic versus calm environment as well as monotonous versus vibrant environment. The positioning means that for instance a vibrant soundscape is considered both eventful and pleasant et cetera (ISO 12913-3:2019).

The questionnaire results, where the participant answers how he or she perceives the soundscape based on these adjectives can be plotted on the two-dimension model according to equation provided in (ISO 12913-3:2019):

Pleasantness coordinate P:

$$P = (p - a) + cos45°\cdot(ca - ch) + cos45°\cdot(v - m)$$

Eventfulness coordinate E:

$$E = (e - u) + cos45°\cdot(ch - ca) + cos45°\cdot(v - m)$$

Table 2 provides the abbreviations of the parameters used in the coordinate equations.

Table 2 Parameters used in coordinate equations provided in ISO 12913-3:2019.

a	annoying
ca	calm
ch	chaotic
e	eventful
m	monotonous
p	pleasant
u	uneventful
v	vibrant

3.4 Noise treatment with Soundscape

There have been several instances where soundscape has been used as a method of noise treatment. One instance is the previously mentioned Nauner Platz, where researchers used noise barriers made of gabion stones as well as inserting loudspeakers in the playground which would play pleasant sounds such as birdsongs. This method of noise treatment can be described as visual masking and sound masking (EEA,2012). The main purpose of masking is to shift focus from noise sources (Cerwén et al, 2017).

In a research article titled *Soundscape actions: A tool for noise treatment based on three workshops in landscape architecture* the researchers (Cerwén et al, 2017) noted that in recent years landscape architects have benefited from the use of the soundscape approach. It is mentioned that little attention has been paid to the practical use of soundscape in planning and design phase. The workshops, in the same article were for three different locations in Sweden. The method discussed was based on three categories.

1. Localization of functions
2. Reduction of unwanted sounds
3. Introduction of wanted sounds

The first category analyzes the location of interest and looking at what type of sounds fit to this location. Second category analyzes what type of ways unwanted sounds can be reduced, for instance with noise screens. The third category introduces wanted sounds to the location such as for example water sound (Cerwén et al, 2017).

One of the locations discussed in the article was Malmö, where a noise treatment was done by adding an arbour with loudspeakers. The purpose the arbour was to screen some of the noise from the nearest traffic road together with the loudspeakers, which masked some of the traffic by playing forest sounds through the loudspeakers (Cerwén, 2016). This experiment showed that even though the sound level increased by 1.5-20 dBA from the use of the loudspeaker, it still resulted in a better experience compared to when no sound was played (Cerwén, 2016).

Soundscape approach as a way of treating noise was also used in several parks in Italy where loudspeakers were placed at several locations within these parks to help mask unwanted sound (Brusci et al, 2010).

4. Swedish guidelines for Preschools

4.1 Outdoor benchmark values for schools and preschools

The guidance on outdoor noise when actions need to be taken to reduce noise levels, or roads and railways generate excessive noise levels have been drawn up by The Environmental Protection Agency, in Sweden known as Naturvårdsverket (2019a). These are given based on supervisory guidance of the Environmental Supervision Ordinance.

The benchmark values for preschools are under the same category as the ones for schools and have different values for new and old schoolyards. New schoolyards should not have values higher than 50 dBA Leq_{24h} and 70 dBA L_{max} in parts of the schoolyard intended for playing, resting or educational activities (Naturvårdsverket, 2019b). In the other parts it should be no more than 55 dBA Leq_{24h} and 70 dBA L_{max}. The definition of a new schoolyard is a school, preschool, or after-school centre which began operating after the benchmark values were set in 2017 (Naturvårdsverket, 2019b). The benchmark values are provided in Table 3.

Table 3 Benchmark values for traffic noise in new schoolyards.

New schoolyard area	**L_{eq24h}**	**L_{max}**
Intended for playing, resting or educational activities	50	70
Other parts	55	70[I]
[I] Should not be exceeded more than 5 times/h during 24h time, during school period.		

Older schoolyards should not have values higher than 55 dBA Leq_{24h} and 70 dBA L_{max} in parts of the schoolyard intended for playing, resting or educational activities (Naturvårdsverket, 2019b). The benchmark values for older schoolyards are provided in Table 4.

Table 4 Benchmark values for traffic noise in old schoolyards.

Old schoolyard area	**L_{eq24h}**	**L_{max}**
Intended for playing, resting or educational activities	50	70[I]
[I] Should not be exceeded more than 5 times/h during 24h time, during school period.		

The equivalent sound level values in Table 3 and 4 are free field values. Free field values mean that no reflected sound waves from nearest facades should be included (Naturvårdsverket, 2019b).

These sound levels are usually measured, but since wind and weather conditions affect the result of the measurements it is often preferred to do calculations based on traffic conditions, distance to buildings and type of surface (Boverket, 2015). Calculation models can sometimes be difficult to use, due to lack of information or more complex noise situations. In more complex situations a combination of measurements and calculations might be preferred (Boverket, 2015).

5. Methodology

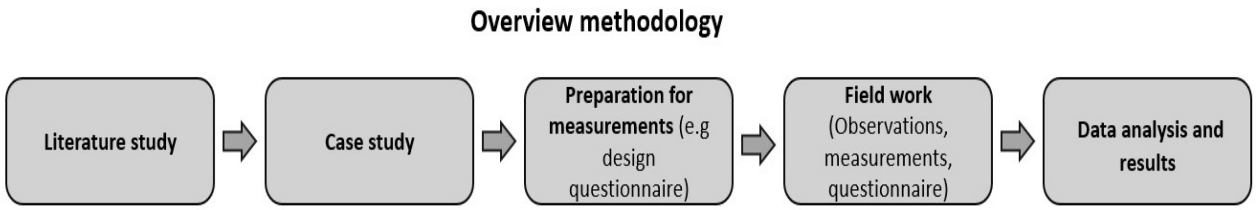


Figure 14 Illustration of the framework.

The research will use quantitative methods such as measurements and qualitative methods such as questionnaires. The overview of the methodology is provided in Figure 14.

5.1 Literature study

A literature study is conducted to research what type of work has previously been done on the subject. The literature study helps the writer in finding relevant information and getting a better understanding of what type of difficulties previous researchers came across when studying the subject of interest. It also provides validity by using previous findings and methods.

The literature study helps deciding on the content in the theory section. This is important because it provides the reader with tools to understand the content, purpose and the reasoning behind chosen methodology. Part of the literature study is presented in a form av literature review, which is found in section *1.6 Literature review*.

5.2 Case study

A case study is conducted for preschools in Malmö, Sweden. The purpose is to get a better understanding on the number of preschools, where they are located, the environment and then compare it to a local noise map. Due to the time limitations five preschools are chosen at the beginning of the study, for the measurements. The preschool measurements are then decreased to four as the last measurement was difficult to book because of the unusual circumstances with the COVID-19 pandemic. The four preschools are chosen in consultation with supervisors. Preschools are picked based on different characteristics. These characteristics are based on where in the city the preschools are located, environmental settings, some differences in possible noise sources, as well as noise maps. The noise maps are from measurements done in 2017 and are provided by Malmö stad (Malmö, 2019).

5.2.1 Preschool 1 - Juvelens förskola

The preschool is located in a newly built block in a central part of the city. The distance to the nearest more trafficked road is approximately 90 m and close to a crossing. The playground is on the inside of the block. There is a park nearby and a Secondary school. Preschool 1 has 16 teachers and 87 children. The noise map in Figure 15 indicated noise levels between 55-60 dB.

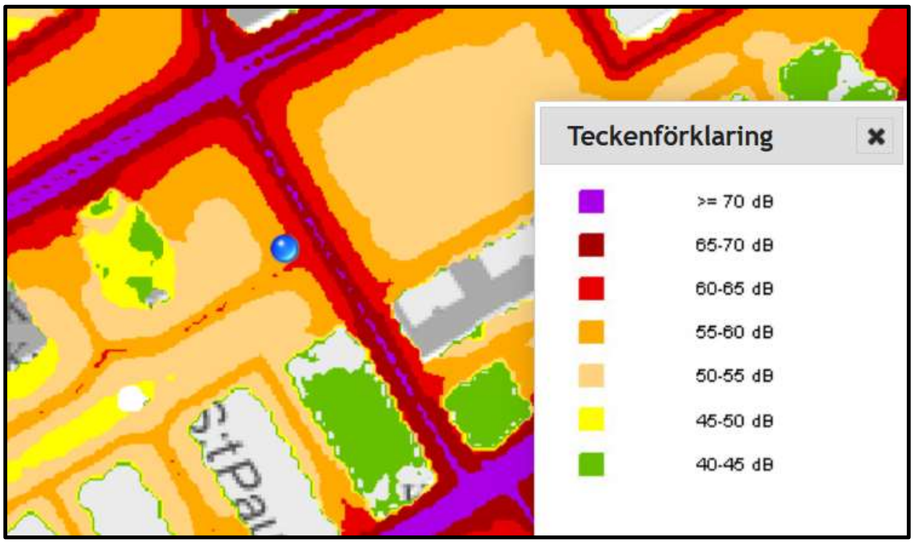


Figure 15 Noise map for Juvelen (Malmö, 2019).

5.2.2 Preschool 2 - Pilängens förskola

Located in the outer part of Malmö, with a lot of vegetation nearby, allotment areas and less trafficked roads. Preschool 2 has a total of approximately 16 teachers and 85 children, including all the departments as well as the outdoor department. The noise map in Figure 16 indicated noise levels between 45-50 dB.

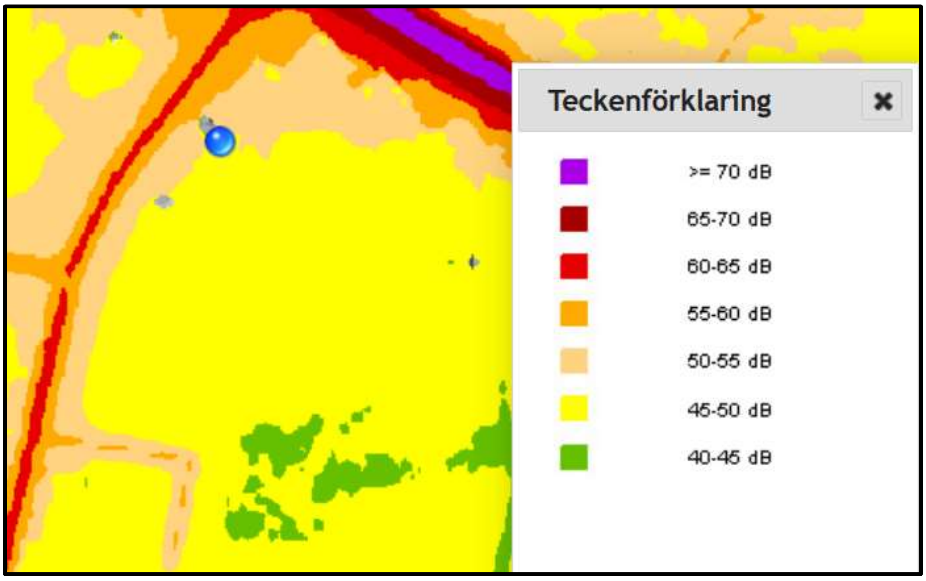


Figure 16 Noise map for Pilängen (Malmö, 2019).

5.2.3 Preschool 3 - Förskolan Äpplet

The preschool is in a denser part of the city close to a central bus station. It is also close to several popular meeting points, with different type of activities such as a school or a folkpark. Preschool 3 has 12 teachers and 70 children. The noise map in Figure 17 indicated noise levels between 45-55 dB.

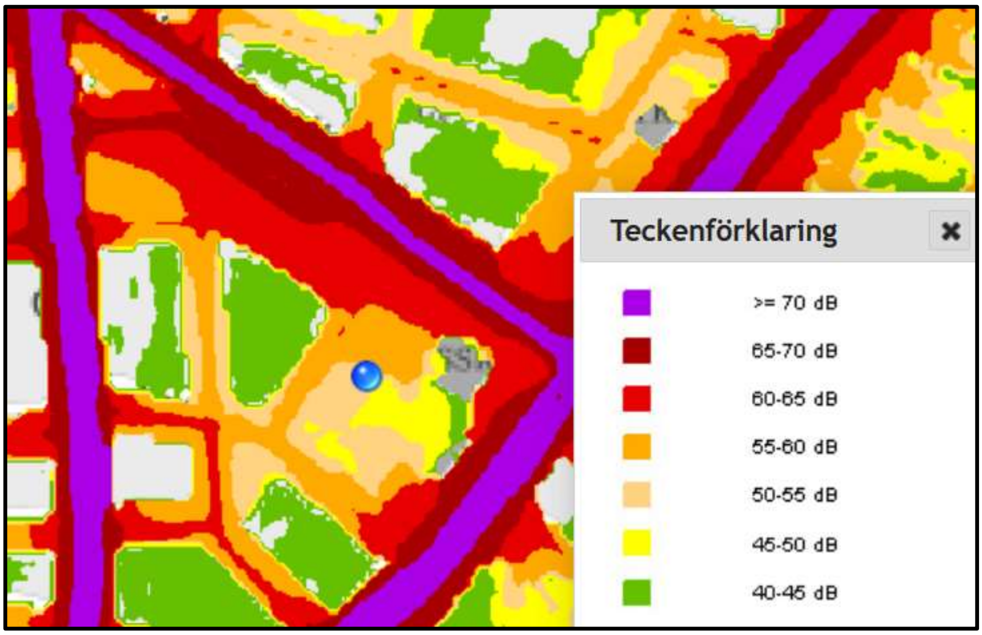


Figure 17 Noise map for Äpplet (Malmö, 2019).

5.2.4 Preschool 4 - Berga förskola

Preschool 4 consists of an outdoor department. In the outdoor department children spend most of the time outdoors. Preschool 4 is located in an outer part of Malmö. The preschools have a total of 90 children and 16 teachers. The noise map in Figure 18 indicated noise levels between 40-45 dB.

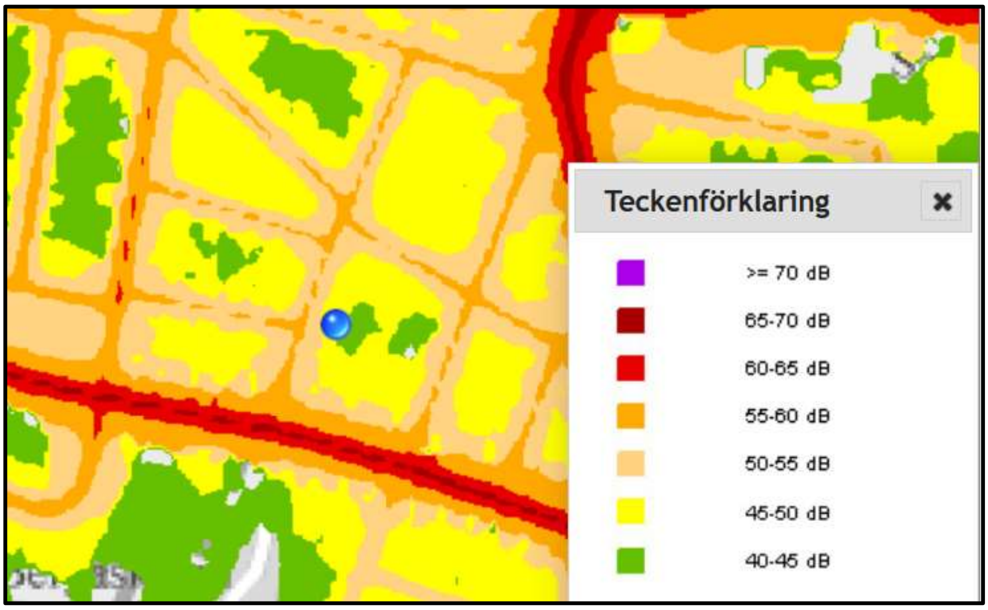


Figure 18 Noise map for Berga (Malmö, 2019).

5.3 On site observations

On site observations are carried out. Previous studies on soundscape method suggests that a holistic overview is important to understand the sound environment. The observations focused on getting a better understanding from a visual point of view. Pictures are taken together with minor notes, which are presented in Appendix 1.

5.4 Questionnaire

The questionnaire is presented in Appendix 2. The questionnaire used for this survey is in Swedish, but both Swedish and English questionnaires are shown in Appendix 2.

The questionnaire is based on the design provided in ISO 12913-2:2018. There are some changes done to the questionnaire. The questionnaire is translated to Swedish and already tested Swedish wordings for the adjectives are taken from a study (Axelsson, 2018) on linguistic differences. The chosen adjectives are presented in Table 5. Picking words that were previously used with success should result in a better outcome, as previous studies have concluded.

Table 5 Adjectives used in questionnaire.

English	**Swedish**
Eventful	Händelserik
Pleasant	Trivsam
Monotonous	Enformig
Uneventful	Händelselös
Calm	Lugn
Exciting	Spännande
Noisy	Bullrig
Unpleasant	Störande

There are 5 questions in the questionnaire. The first question is in a categorical scale and participants are asked to answer how they rate the sound environment from very bad to very good. Question 2-4 are in a scale from 0 (not at all) to 10 (dominates completely). In these questions' participants are to draw lines and show to which extend they agree or disagree. The participants are personnel working in the preschools, as they are to be considered as local experts. The ISO 12913-2:2018 requires that there should be a question, on age, gender, and hearing ability. This is asked in question 5.

5.5 Measurements and recordings

The measurements and recordings are performed in each preschool yard. The equipment used for the measurements are three Norsonic 140 and three tripods on which the measurement equipment are placed on, which can be seen in Figure 19. The recordings are done with the Norsonic instruments and not with a binaural headset. ISO 12913-2:2018 states that binaural headset should be used, but due to no access to this kind of equipment, a Norsonic 140 is used for the recording.

Figure 19 Norsonic 140 on a tripod.

Two of the instruments are placed close to the corners of the yard and one closer to the location of where the children usually play. The measurement duration is approximately 30 minutes, during which the personnel answers the questionnaire.

The measurement and questionnaire process are explained before the start of measurement to minimize confusion during the measurement.

The measurement is done while the children are indoors, while the personnel shifts in going outdoors and answering the questionnaire.

The recordings have a sample frequency of 48 kHz and a depth of 24 bit and the weather conditions are monitored as the wind and rain affects the measurement results.

5.6 Data analysis

The data analysis is done according to ISO 12913-3:2019, Method A. This method consists of compiling questionnaire answers and measurement recordings for each preschool. The two soundscape dimensions are determined based on the responses from the questionnaires. The two-dimensional model presented in the ISO 12913-3:2019 is still under examination and therefore a modified two-dimensional model is used, with adjectives already previously tested in Swedish studies. The modified two-dimensional model is presented in Figure 20.

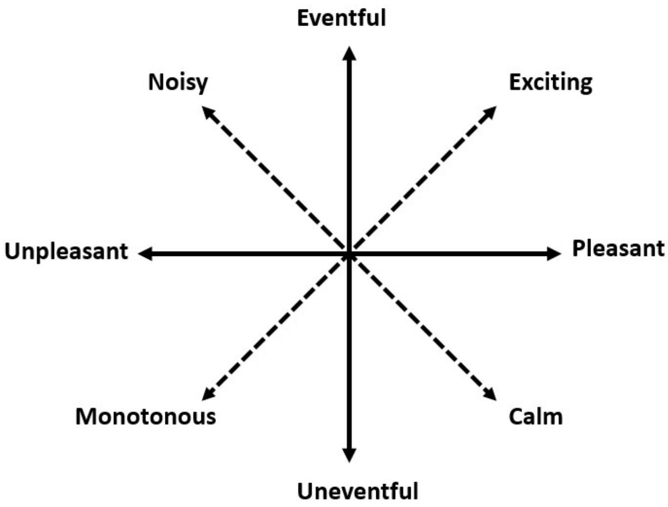


Figure 20 Modified two-dimensional model used in this study.

Modified equation for the coordinates:

Pleasantness coordinate P:

$$P = (p - \mathrm{un}) + cos45° \cdot (ca - n) + cos45° \cdot (\mathrm{ex} - m)$$

Eventfulness coordinate E:

$$E = (e - u) + cos45° \cdot (n - ca) + cos45° \cdot (\mathrm{ex} - m)$$

Table 6 provides the abbreviations of the modified parameters used in the coordinate equations.

Table 6 Modified parameters used in coordinate equations.

un	unpleasant
ca	calm
n	noisy
e	eventful
m	monotonous
p	pleasant
u	uneventful
ex	exciting

The measurements are used for calculation of parameters shown in Table 7:

Table 7 Calculated metrics in this thesis.

Parameter [units]	
Sound pressure level [dBA]	$L_{eq30min}$, L_{max}, $L_{5\%}$, $L_{95\%}$
Loudness [sones]	$N_{eq30min}$, N_{max}, $N_{5\%}$, $N_{95\%}$
Sharpness [acum]	$S_{5\%}$, $S_{95\%}$
Roughness [asper]	R
Fluctuation Strength [vacil]	F

The sound pressure levels are calculated using NorXfer 6.1, while the psychoacoustic parameters are calculated in MATLAB. Due to the complexity of the psychoacoustic metric equations, already written MATLAB codes are used. The tested parameters sharpness, roughness and fluctuation strength are calculated using the toolbox called *matlab_real_time_sound* provided by Dr Stefan Bleeck a professor of Hearing Science and Technology at University of Southampton (Bleeck S, 2020). Loudness is calculated by a thirdparty toolbox within *matlab_real_time_sound* originally created by Genesis S.A, called Loudness Toolbox 1.2. The Loudness Toolbox is provided with a validation document of implemented loudness algorithms (Genesis S.A, 2009b).

Psychoacoustic Tonality is not calculated, as the standardization of the metric was just recently introduced in 2019, and therefore no codes or available software was found that could be used in this thesis. There are several other parameters within the loudness, sharpness, roughness, and fluctuation strength suggested in the ISO 12913-3:2019, such as the roughness exceeded in 10% of the time interval R_{10}. Those are not calculated.

Method A suggests the use of a statistical method to measure relationship between two variables, as well as reporting the statistical significance of the correlation and the probability value. In this study a regression analysis is used for this purpose. The data from measurements as well as questionnaire is used in a simple linear regression model, where the parameters are considered as non-random X values, while the questionnaire answers are the random Y values. The regression analysis is done in MATLAB using the `fitlm` function for the coefficient of determination R^2 and the p-value and `[R,P] = corr(...)` function for the coefficient of correlation R.

6. Results

6.1 Questionnaire results and the two-dimensional model.

Preschool 1 and 2 sample size are six each, Preschool 3 have a sample size of five and Preschool 4 a sample size of eight. The total participant sample size denoted as *n* is 25. Answers from question 5 are summarized in Figure 21.

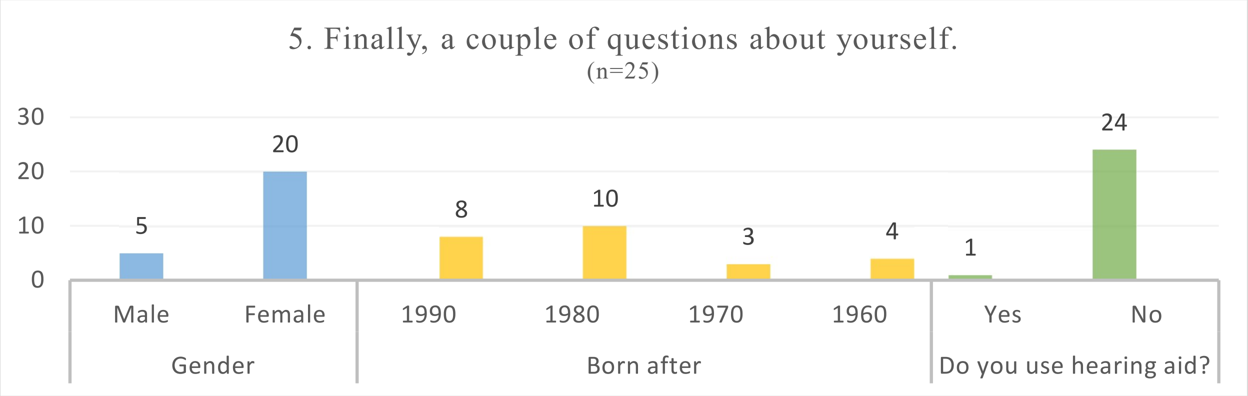


Figure 21 Participant answers on question 5.

Figure 21 shows that majority of the participants are females and that most of the participants are born after 1980 and 1990. Only one of the participants uses hearing aid at home or work.

The participants are asked to describe the surrounding sound environment and about their sensitivity to sound, on a categorical scale. These two questions are presented in Figure 22 and 23.

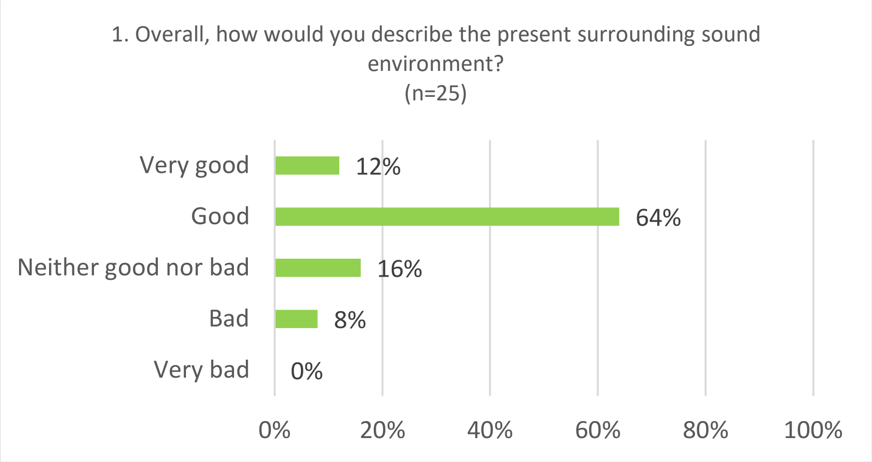


Figure 22 Participant answers on question 1, in percent.

Figure 22 shows that majority of the participants consider their sound environment either *good* or *very good*. Only 8% consider their sound environment bad.

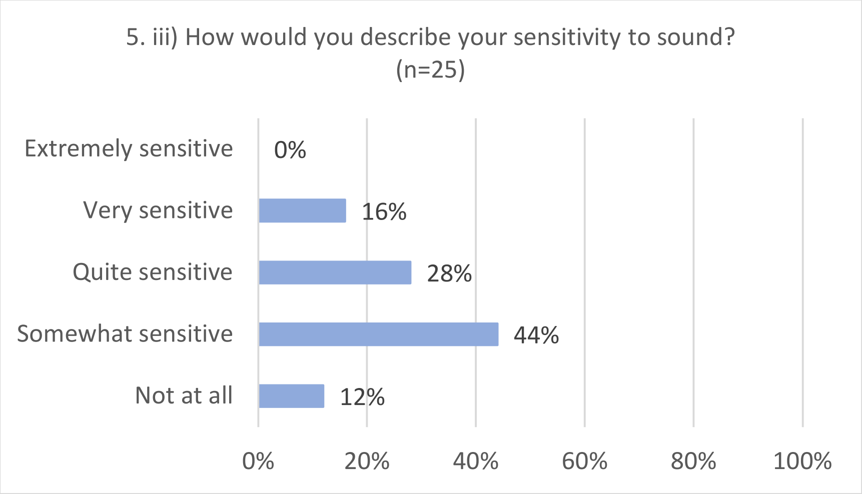


Figure 23 Participant answers on question 2, in percent.

Figure 23 shows that the answers are quite spread, with *somewhat sensitive* having the highest value of 44% and *quite sensitive* having the second highest value of 28%.

The mean values for the other questions are shown in Figure 24. For questionnaire design see Appendix 2.

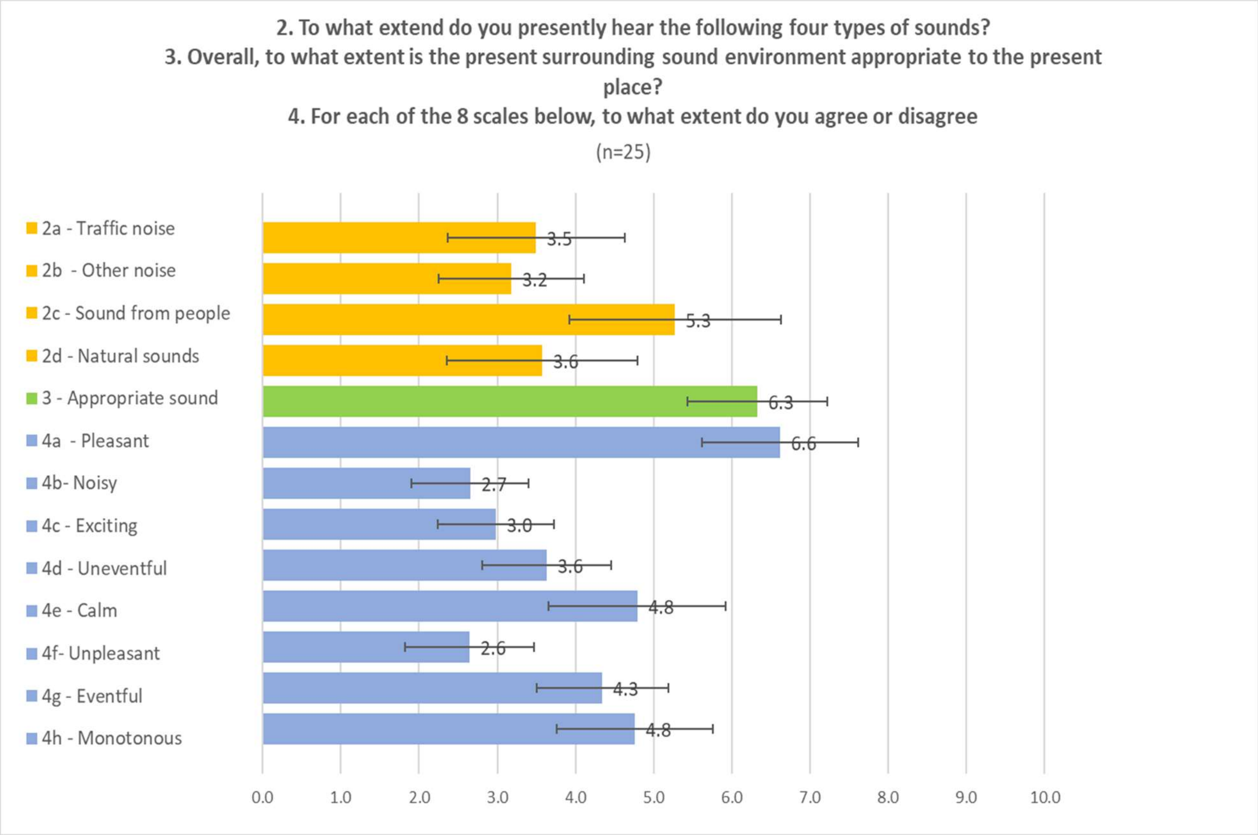


Figure 24 Participants answer on question 2-4. Error bar shows the 95% confidence interval.

Figure 24 shows that *sound from people* dominates the sound environment. The lowest, albeit by a small margin, is the value for *other noise*. The participants consider the sound environment appropriate with a value of 6.3. The value for *pleasant* got the highest score with 6.6, while *unpleasant* got the lowest score. The value for *monotonous* and *calm* is the same, with a score of 4.8. Error bars for the 95% confidence interval are added to give a better indication on the data spread. Error bars represent the variability of data. Longer error bars suggest that the data is more spread. The purpose of the confidence interval is to show how accurate the estimate is likely to be. The bar is narrow when sample values have low variation. Figure 24 shows that the error bars are rather wide, indicating that the answers are of higher variation.

There were some comments made by the participants:

- A few participants note that the sound environment at the moment of the measurement, was either better than usual or worse than usual.
- Two participants note that they felt it was unnecessarily to go outdoors to answer the questionnaire, as they spend enough time outdoor to know how the outdoor sound environment is.
- A few participants comment on the preference of being outdoor instead of indoors, as the screaming from children is more manageable outdoors.
- 7 participants are asked if there is a specific sound outside that they find annoying. On this question 4 said no. One participant answers ambulance siren, but also notes it is not necessarily annoying but eventful. One mentioned seagulls and last participant answers that the screaming from the nearby retirement home could get a bit annoying sometimes.
- Lastly, 3-4 participants note that they enjoyed being asked how they feel about the sound environment. The participants indicated they felt important being included in the process.

The results from the 4th questionnaire question are used to calculate the P and E coordinate using the two equations presented in section *5.6 Data analysis.* The two-dimensional model is compiled from the questionnaire answers and presented in Figure 25.

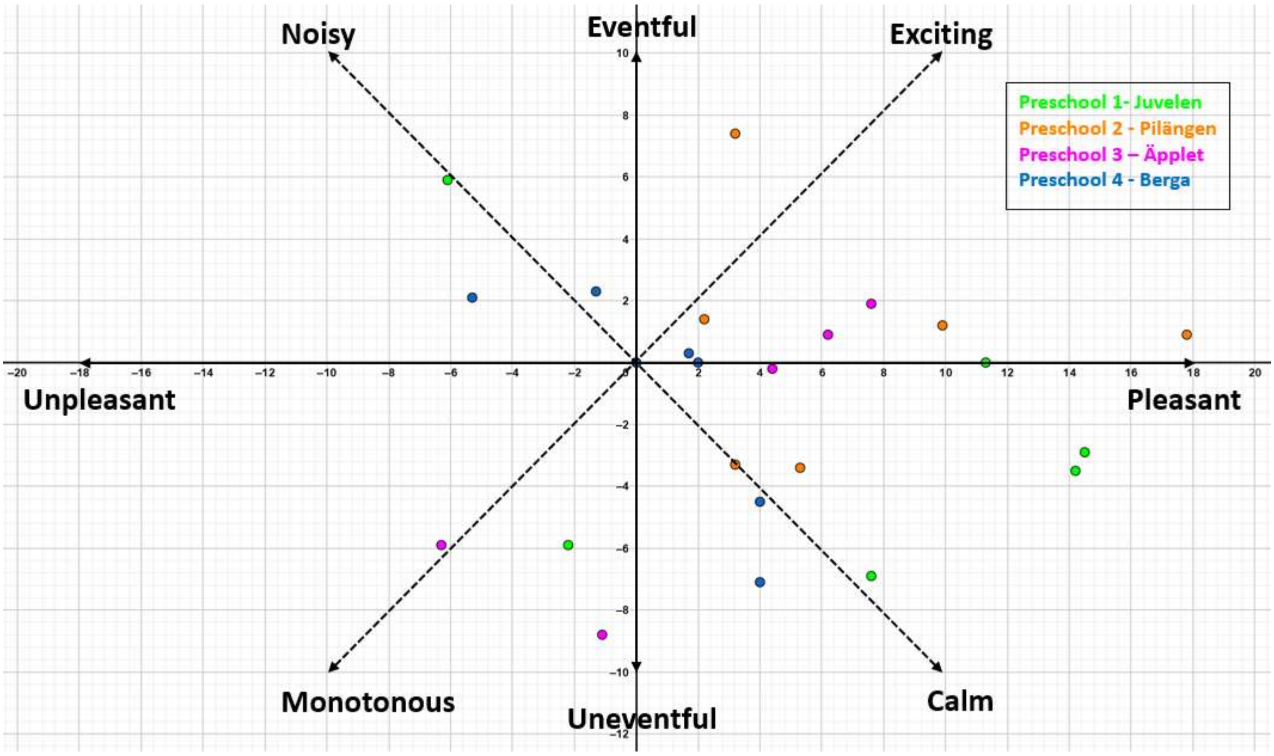


Figure 25 Two-dimensional model for the 4 preschools.

Figure 25 show that majority of the values are found to be loading on the *Pleasant* component. Six of the coordinates are found loading on the *Unpleasant* side of the component. The blue values, representing Preschool 4, have the biggest spread across the model, while the other lean towards the right side of the model. The green values, representing Preschool 1, are on the *Pleasant-Calm* side of the model. The purple coordinates, representing Preschool 3, are on the *Exciting-Pleasant* side. The orange coordinates for Preschool 2 are between *Exciting-Pleasant* and *Pleasant-Calm*. The ISO 12913 does not make any mention to what a desired outcome for the coordinate positions in the model would be.

6.2 Measurement results

The results of the three measurement positions are all presented together with an average, while the approximate positions of the instruments are shown in Appendix 1. The results between all three measurement instruments are mostly similar, with the only difference being the measurement done in Preschool 1. One of the measurement equipment registered much higher values, most notably the L_{max} being 87.8 dBA compared to the other two values being 66.9 and 69.2 dBA.

The sound level values registered in the preschools are shown in Table 8. Those values can be compared to the benchmark values presented in section *4.1 Outdoor benchmark values for schools and preschools* in Table 3 and 4. The benchmark values for L_{eq} are set at 50 dBA, which would mean that the measured values could be considered high. However, the measurements are 30 minutes, while the benchmark values are for 24h period. The measured values are therefore not comparable as the average over a 24h period would be different. The values for L_{max} are exceeded in Preschool 1 and 3 while Preschool 2 and 4 are below the benchmark value of 70 dBA.

Table 8 Compiled results of the sound level measurements.

Preschool	**Sound level**	**L_{max} [dBA]**	**$L_{eq30min}$ [dBA]**	**$L_{5\%}$ [dBA]**	**$L_{95\%}$ [dBA]**
1	**Instrument name**				
	N0	87.8	59.4	60.2	41.9
	NB	69.2	46.1	50.3	40.1
	N5	66.9	45.2	48.9	40.3
	Average	**74.63**	**50.23**	**53.13**	**40.77**
2	**Instrument name**				
	N0	65.2	50.4	53.4	47.3
	NB	70	51	53.7	47.5
	N5	68.5	49.9	53	46.4
	Average	**67.90**	**50.43**	**53.37**	**47.07**
3	**Instrument name**				
	N0	77.7	57.6	60	51.7
	NB	78.1	60	64.5	52.3
	N5	77.8	58.6	64	51.2
	Average	**77.87**	**58.73**	**62.83**	**51.73**
4	**Instrument name**				
	N0	68.2	51.9	58.1	43.5
	NB	70.7	52.8	58.5	43.4
	N5	65.4	47.1	51.4	42.5
	Average	**68.10**	**50.60**	**56.00**	**43.13**

The table shows that the highest average value for L_{max} is 77.9 dBA and lowest average is 67.9 dBA. Highest average $L_{eq30min}$ is 50.2 dBA and lowest average is 58.7 dBA.

The sound quality metric values are shown in Table 9. Highest sharpness is registered in Preschool 1 and lowest in Preschool 2 and 4. Highest roughness is at Preschool 3 and lowest at Preschool 1. Highest fluctuation strength is at Preschool 3, while the lowest is at Preschool 2, which was 0.

Table 9 Compiled results of the sound quality metrics.

Preschool	Sound quality	$S_{5\%}$ [acum]	R [asper]	F [vacil]	N_{max}[sones]	$N_{5\%}$ [sones]	$N_{95\%}$ [sones]	$N_{eq30min}$[sones]
1	**Instrument name**							
	N0	0.87	0.04	0.10	68.46	10.44	2.83	2.69
	NB	1.44	0.03	0.00	15.56	4.90	2.32	2.12
	N5	1.56	0.02	0.00	21.82	5.04	2.01	1.62
	Average	**1.29**	**0.029**	**0.033**	**35.28**	**6.79**	**2.39**	**2.15**
2	**Instrument name**							
	N0	1.29	0.04	0.00	21.18	6.51	3.96	3.93
	NB	0.78	0.04	0.00	18.08	6.08	3.51	3.48
	N5	1.36	0.05	0.00	20.75	6.14	3.56	3.53
	Average	**1.15**	**0.042**	**0.000**	**20.00**	**6.24**	**3.67**	**3.65**
3	**Instrument name**							
	N0	1.30	0.04	0.02	27.35	10.73	6.45	5.79
	NB	1.47	0.05	0.12	25.85	12.10	6.09	5.38
	N5	1.52	0.05	0.24	22.71	11.89	6.08	6.04
	Average	**1.43**	**0.05**	**0.127**	**25.30**	**11.57**	**6.21**	**5.73**
4	**Instrument name**							
	N0	1.65	0.03	0.00	19.78	9.91	3.32	3.45
	NB	1.78	0.03	0.01	19.77	9.99	3.18	3.15
	N5	1.60	0.04	0.00	19.86	5.67	2.60	2.35
	Average	**1.68**	**0.032**	**0.004**	**19.80**	**8.53**	**3.03**	**2.99**

- The highest average value for N_{max} is at 35 sones and lowest average is at 20 sones. Highest average $N_{eq30min}$ was at 5.73 sones and lowest average is at 2.15 sones.
- The highest average $S_{95\%}$ is 1.14 acum and lowest 0.96 acum.
- The highest average roughness is 0.05 asper and lowest 0.03 asper.
- The highest average fluctuation strength is 0.13 vacil and lowest was 0 vacil.

The sound quality metrics have no benchmark values to compare against. It is therefore more difficult to distinguish what is considered high or low. Some comparison is made in *section 2.2.2 Psychoacoustic parameters,* referring to the study done by Yang & Kang (2012). Based on the comparison made by the researchers, the results seem within reasonable value range. The only exception possibly being roughness, which might have lower values than expected. This is however based on a very small sample given by the research.

Sound sources registered in each measurement are presented in Table 10.

Table 10 Sound registered during measurement.

Preschool	Sound registered
1	traffic, children
2	construction, children, birdsongs, 1 plane passing, traffic
3	children, music from music player, traffic, ambulance sirens, people talking, pavement work
4	cars, birdsong, sound of wind and leafs

The biggest variation of sound sources is found in Preschool 3 and the lowest variation is in Preschool 1. Preschool 4 registered sound of individual cars, which is why it is called cars instead of traffic.

Frequency response graphs are included for a better overview. There are only minor differences between the three measurements and therefore only one instrument data is included for each preschool. One more frequency response graph is included for Preschool 1, due to registering much higher values compared to the other two measurement instrument. The higher values are registered between the 7th minute and 12th minute of the measurement when the educators and children were passing by the microphone on their way back to the preschool, as shown in Figure 26. The figure also shows that the 70 dBA has been exceeded more than 5 times.

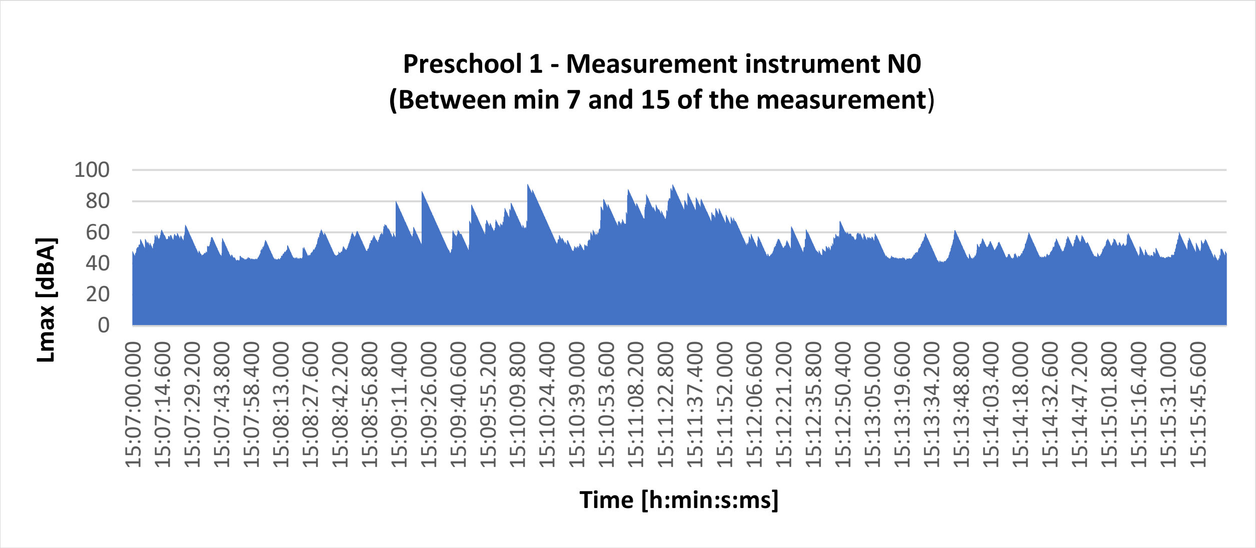


Figure 26 Closer look on the sound level variation between 7th and 12th minute of the measurement in Preschool 1.

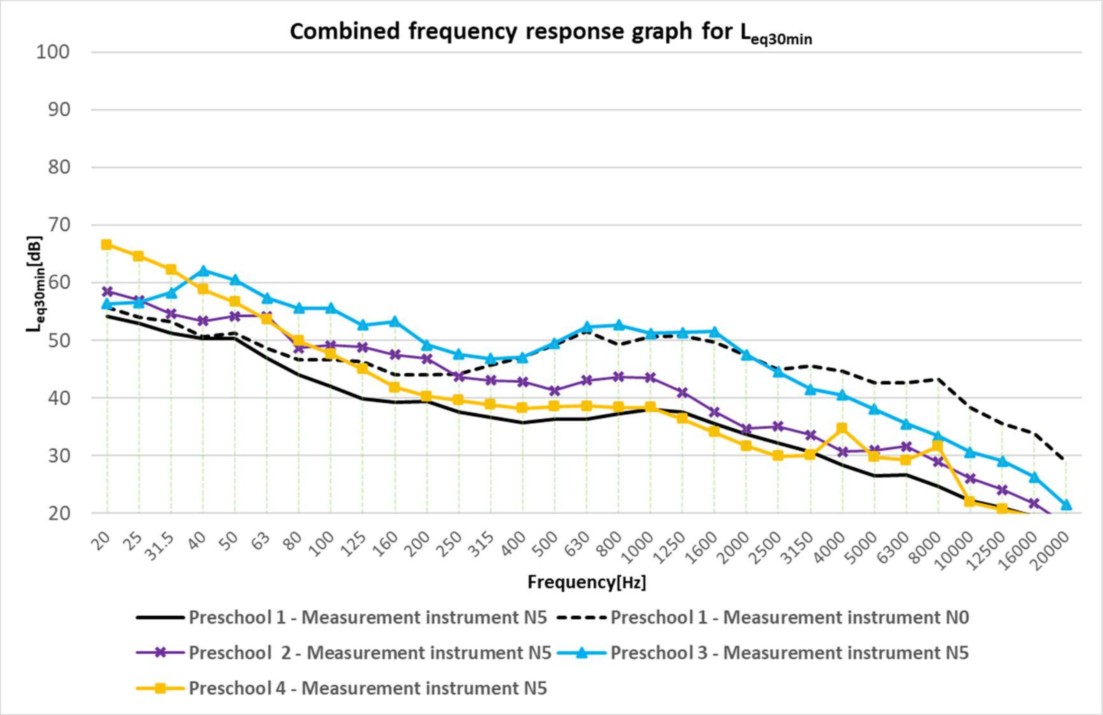


Figure 27 Frequency response graph of the $L_{eq30min}$. Data from measurement instruments called N5. N0 for Preschool 1 is included due to registering higher values.

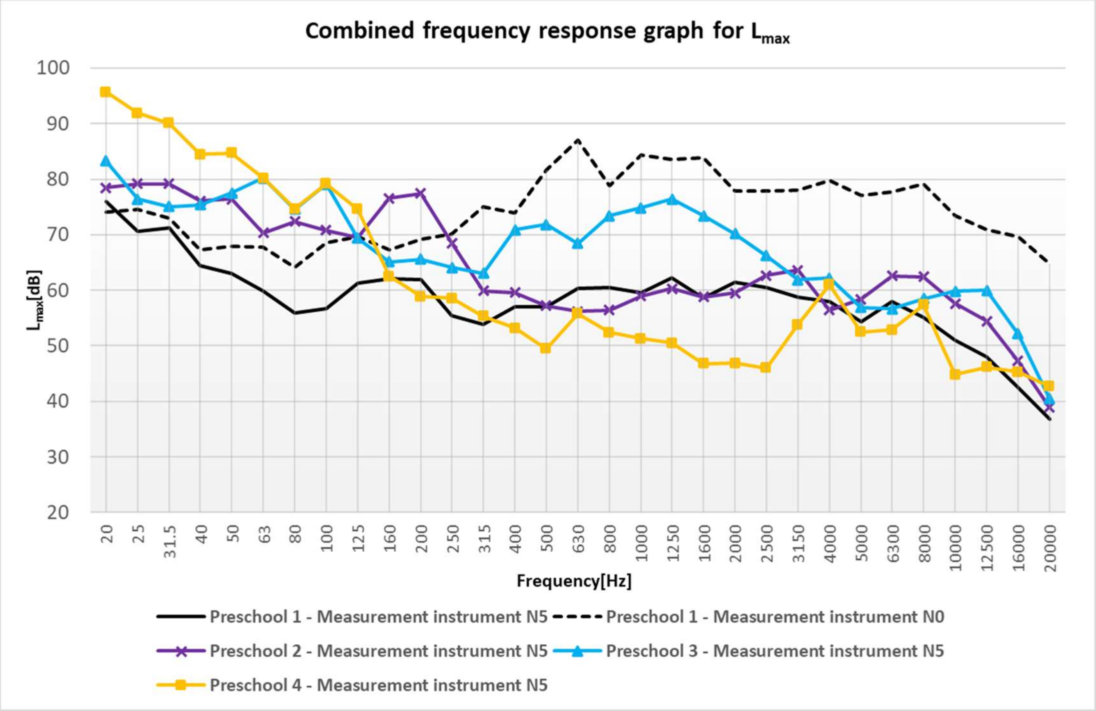


Figure 28 Frequency response graph of the L_{max}. Data from measurement instruments called N5. N0 for Preschool 1 is included due to registering higher values.

Figure 27 and 28 show higher values in the lower frequencies. The lower frequencies should dominate due to being able to travel through objects more easily, as mentioned in section *2.2.1 The effect of sound and noise.* As seen in Figure 27 and 28, the result from the measurement instrument N0 and N5 is significantly different. Figure 27 shows that Preschool 3 registered the highest values in the sensitive frequencies, while Preschool 1 have the lowest values in the sensitive frequencies.

The psychoacoustic metrics, as described in section *2.2.2 Psychoacoustic parameters*, are calculated using the Bark scale. The Bark scale goes from 0 to 13.5 kHz centered frequency. The measurement using the Norsonic 140 instruments are measured from 6.3 Hz to 20 kHz. The values registered beyond 13.5 kHz are therefore not registered in the psychoacoustic metrics calculations.

6.3 Statistical analysis of the questionnaire response and measurement results

This section evaluates the statistical relationship between two variables. The analysis is done between 3 pairs of variables. The first correlation analysis is done for the parameters as the X values and the questionnaire answers as the Y values. Table 11 and 12 presents the correlation results between the measured parameters and questionnaire answers.

Table 11 Coefficient of determination for questionnaire versus parameter. P-values *<0.05.

R^2	L_{max}	$L_{eq30min}$	$L_{95\%}$	N_{max}	$N_{eq30min}$	$N_{95\%}$	$S_{95\%}$	R	F
Q2a	0.04	<0.00	0.04	0.09	0.02	0.01	0.09	0.06	0.01
Q2b	<0.00	<0.00	0.01	<0.00	<0.00	<0.00	<0.00	0.01	<0.00
Q2c	0.05	0.01	0.01	0.04	0.01	0.01	0.03	0.01	0.03
Q2d	0.10	0.01	0.11	***0.35**	0.10	***0.07**	0.36	0.12	<0.00
Q3	<0.00	0.11	0.06	0.12	0.11	0.10	0.10	0.03	0.05
Q4a	<0.00	0.01	<0.00	0.02	<0.00	<0.00	0.02	0.02	<0.00
Q4b	0.04	<0.00	<0.00	0.07	<0.00	<0.00	0.07	<0.00	0.01
Q4c	0.01	<0.00	<0.00	0.04	<0.00	<0.00	0.04	<0.00	0.91
Q4d	<0.00	0.07	***0.16**	0.12	0.15	0.13	0.14	***0.17**	0.02
Q4e	0.01	0.04	0.02	<0.00	0.03	0.03	<0.00	0.01	0.03
Q4f	0.01	0.10	0.05	0.04	0.08	0.08	0.06	0.46	0.06
Q4g	***0.16**	0.05	<0.00	0.12	<0.00	0.01	0.10	0.01	0.10
Q4h	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00

Table 12 Correlation coefficient for questionnaire versus parameter. P-values *<0.05. Light green color for 0.5<R<0.7.

R	L_{max}	$L_{eq30min}$	$L_{95\%}$	N_{max}	$N_{eq30min}$	$N_{95\%}$	$S_{95\%}$	R	F
Q2a	0.21	<0.00	-0.21	0.30	-0.15	-0.12	0.31	-0.25	0.10
Q2b	0.03	0.02	0.08	0.02	0.05	0.05	0.02	0.10	0.03
Q2c	-0.21	-0.11	-0.08	-0.20	-0.07	-0.09	-0.19	-0.09	-0.16
Q2d	-0.32	0.11	0.34	***-0.59**	0.31	***0.26**	-0.60	0.35	-0.07
Q3	-0.01	-0.33	-0.25	-0.25	-0.33	-0.32	0.37	-0.18	-0.22
Q4a	0.02	-0.10	0.06	0.13	-0.02	-0.03	0.13	0.13	-0.06
Q4b	-0.20	-0.03	0.06	-0.27	0.05	0.03	-0.26	0.07	-0.11
Q4c	-0.11	0.04	0.05	-0.21	0.07	0.05	-0.21	0.03	-0.02
Q4d	0.05	-0.26	***-0.40**	0.34	-0.38	-0.36	0.37	***-0.41**	-0.14
Q4e	-0.11	-0.19	-0.13	0.05	-0.17	-0.17	0.07	-0.10	-0.17
Q4f	0.09	0.31	0.22	-0.21	0.29	0.29	-0.24	0.15	0.24
Q4g	***-0.40**	-0.23	0.03	-0.34	-0.04	-0.09	-0.32	0.09	-0.32
Q4h	-0.06	-0.04	0.01	-0.05	-0.01	-0.01	-0.05	0.02	-0.05

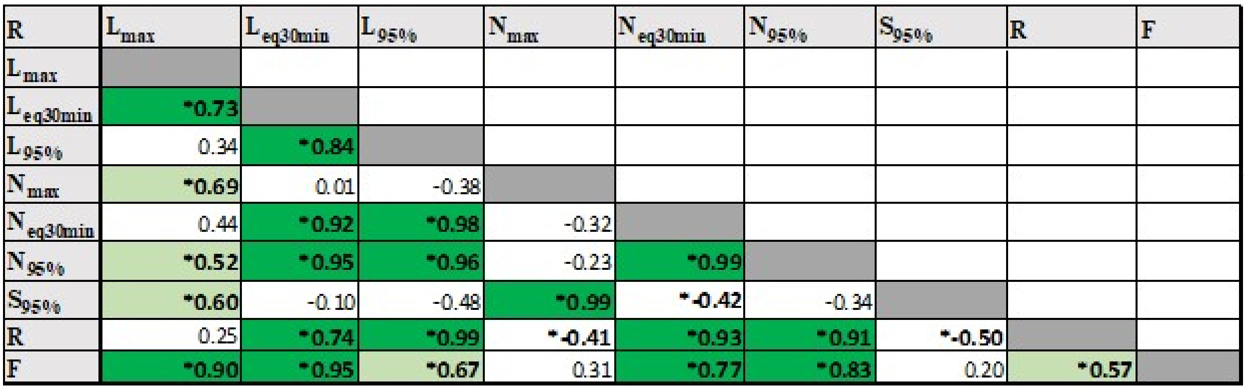
Table 11 shows that no clear correlation is found between the questionnaire answers and the parameters. The highest R^2 is between question 2d and loudness N_{max}. Question 2d asked *to what extend do you presently hear natural sounds*. The value is however too low to determine a correlation between these two variables. The table for the correlation coefficient R gives the R value of -0.59 showing that the correlation is negative. A study (Kang J & Yang M, 2012) in section *1.6 Literature Review,* also mention that some correlation was found between the psychoacoustic metrics and natural sounds such as wind, water and birdsong.

Other, albeit small R^2 values, is between question 4g and Sound level L_{max}, question 4d and Sound level $L_{95\%}$ and question 4d and roughness R.

Question 4 asks *for each of the 8 scales below, to what extent do you agree or disagree that the present surrounding sound environment is…*, g is for adjective *eventful* and d is for adjective *uneventful*. All three pairs have a correlation coefficient of approximately 0.40 and all three are showing a negative correlation.

The correlation of determination R^2 is not used for the comparison between the same set of variable analysis, as the variables are of "same value". In these types of cases the correlation coefficient is deemed more suitable, as briefly explained in *2.3.2 Correlation coefficient and the statistical significance.*

Table 13 Correlation coefficient for parameter versus parameter. P-values *<0.05. Light green color for 0.5<R<0.7 and darker green color for 0.7<R.



R	L_{max}	$L_{eq30min}$	$L_{95\%}$	N_{max}	$N_{eq30min}$	$N_{95\%}$	$S_{95\%}$	R	F
L_{max}									
$L_{eq30min}$	*0.73								
$L_{95\%}$	0.34	*0.84							
N_{max}	*0.69	0.01	-0.38						
$N_{eq30min}$	0.44	*0.92	*0.98	-0.32					
$N_{95\%}$	*0.52	*0.95	*0.96	-0.23	*0.99				
$S_{95\%}$	*0.60	-0.10	-0.48	*0.99	*-0.42	-0.34			
R	0.25	*0.74	*0.99	*-0.41	*0.93	*0.91	*-0.50		
F	*0.90	*0.95	*0.67	0.31	*0.77	*0.83	0.20	*0.57	

Table 13 shows that correlation is found between several parameters. This result does not show anything of interest, more than proves that the correlation analysis works as intended. The results show that different parameters within each metric, such as the equivalent level and the percentile value correlate. There was a correlation between roughness and loudness. This is due to the psychoacoustic parameters all are based on the Bark scale. For the equations see section *2.2.2 Psychoacoustic parameters*.

Table 14 Correlation coefficient for questionnaire versus questionnaire. P-values *<0.05. Light green color for 0.5<R<0.7 and darker green color for 0.7<R.

R	Q2a	Q2b	Q2c	Q2d	Q3	Q4a	Q4b	Q4c	Q4d	Q4e	Q4f	Q4g	Q4h
Q2a													
Q2b	0.03												
Q2c	-0.24	0.13											
Q2d	-0.31	-0.19	***0.45**										
Q3	-0.09	-0.06	0.13	0.12									
Q4a	***-0.35**	0.16	0.24	0.24	***0.78**								
Q4b	0.13	-0.04	0.20	0.18	-0.24	-0.28							
Q4c	-0.16	0.23	-0.06	0.04	-0.25	0.04	-0.26						
Q4d	-0.11	0.11	0.18	***-0.37**	0.01	-0.05	-0.16	-0.09					
Q4e	-0.19	0.00	0.16	0.10	***0.57**	***0.51**	-0.25	-0.03	-0.03				
Q4f	0.39	0.31	0.18	0.14	***-0.49**	***-0.37**	***0.64**	0.05	-0.09	***-0.40**			
Q4g	0.24	0.04	-0.17	0.28	-0.04	0.10	***0.43**	0.27	-0.33	-0.05	0.33		
Q4h	0.03	-0.13	0.20	0.31	0.26	0.29	0.16	-0.33	0.05	0.19	0.17	0.19	

Table 14 shows the R values for questionnaire versus questionnaire relationship. There is only one stronger correlation found in this category. Question 4a and question 3 have a R value of 0.78. Question 3 asks *overall, to what extent is the present surrounding sound environment appropriate to the present place* and question 4a is for the adjective *pleasant.* Other slightly lower values are between question 3 and 4e asking about the adjective *calm.* The adjective *pleasant* and *calm* also have a smaller correlation, as well as *noisy* and *unpleasant.* The correlation coefficient is positive for all these values.

A regression model is created for the most significant correlation, N_{max} and Question 2d. The Y value is represented by question 2d and the X value is represented by N_{max}. The equation for this simple linear regression model is:

$$Y_{heari \quad natural\,sounds} = 10.4 - 0.28 \cdot N_{max}$$

The graphical representation of this model is shown in Figure 29. The model indicates that lower loudness level will result in increased dominance of natural sounds in the sound environment. Lower levels of N_{max} would possibly mean that the environment would be perceived as more pleasant, due to having more natural sounds. Higher values of sones are expected to have lower natural sound scores.

Figure 29 can be read to predict what levels of N_{max} in sones would be needed to generate higher score in natural sounds.

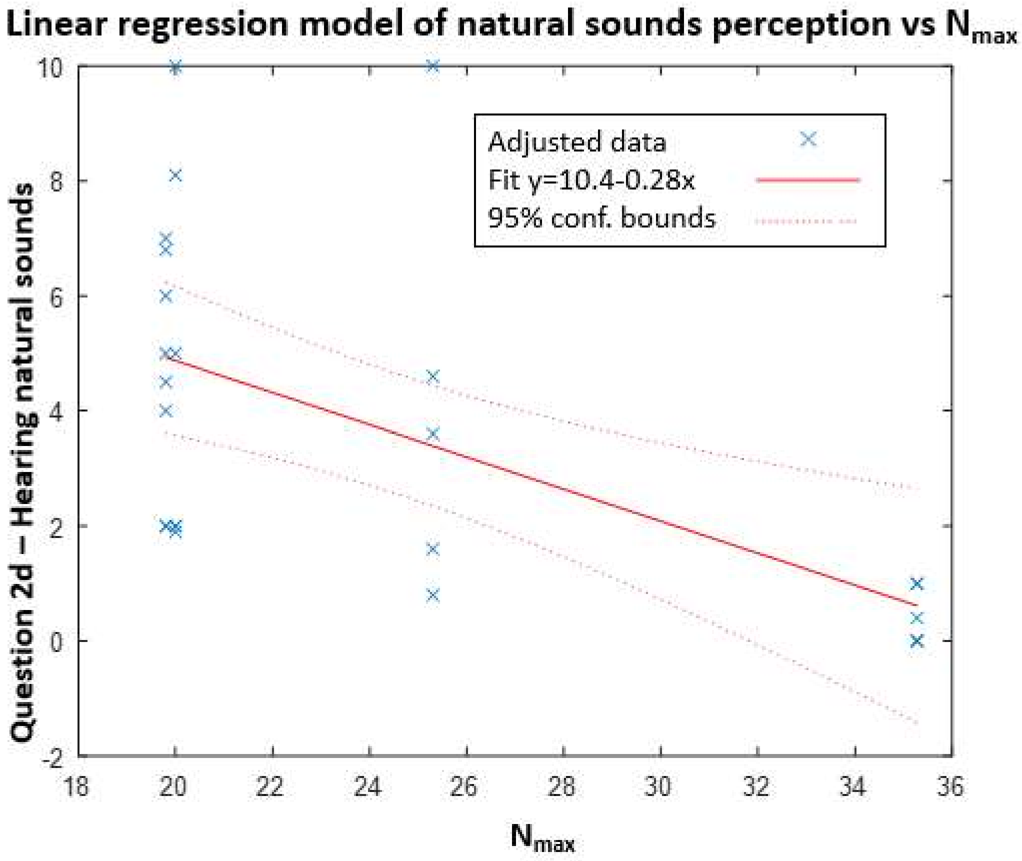


Figure 29 Regression model of max loudness versus existing natural sounds.

Three examples of predicted natural sound values are presented in Table 15. The values are read from Figure 29 by following the red line.

Table 15 Illustration of some predicted values approximated from Figure 29.

N_{max} [sones]	**Predicted natural sound value**
20	5
26	3.5
32	1.8

Lower sones result in higher natural sound value, as shown in Table 15.

7. Discussion

7.1 Interpreting the result

The results from the questionnaire, presented in Figure 22 section *6.1 Questionnaire results and the two-dimensional model*, show that most of the participants consider the sound environment as good. A total of 76 % consider the sound environment *good* or *very good*. As shown in Figure 24 in the same section, the most dominant sound is from people. There are only two questions that score above 5 on a scale from 0 to 10. The first question is on *sound from people* and the other on the pleasantness on the sound environment. It would be interesting to see if the results would average a bit higher if the scales were different, especially since the ISO 12913-2 suggests a scale of 1-5.

The-two-dimensional, presented in Figure 25 in section *6.1 Questionnaire results and the two-dimensional model,* shows that most of the values are found on the *Pleasant* component, while only 6 of the coordinates are found on the *Unpleasant* component. The coordinate position suggest that variability of sound might affect the perception of the environment. Preschool 2 and 3 have the biggest sound variability, which resulted in having more values leaning towards the *Exciting* component. Another important comment regarding the two-dimensional model is that, as mentioned in section 6.1, there is no stated preference in the ISO 12913 in terms of coordinate position in the model. It would however be reasonable to assume that the preference would be to avoid the *Noisy*, *Unpleasant* and *Monotonous* component. The preferable outcome would possibly be *Exciting* or in some cases *Calm,* depending on the subjective preference of the participants.

In section *6.2 Measurement results,* Table 8 shows that the sound levels are quite high. The measurements are however done for shorter time periods. With longer measurements, it would most likely average down especially if the measurements were done for 24 hours. One of the higher values is registered at Preschool 1, where the L_{max} is close to 90 dBA. The higher values are in the more sensitive frequencies of 600-1600 Hz, which going by Figure 4 in section *2.1.2 Human hearing area,* could be considered at the limit of damage risk. This might not necessary be a fair result compared to the rest, as during the other measurements no children were passing by the microphones. It might, in a way be more realistic to include children in measurements as it is a more realistic environment both the children and educators experience daily.

Table 9, in section *6.2 Measurement results,* shows that some of the measurements registered very low values of roughness and fluctuation strength. The fluctuation strength is 0 in Preschool 2 measurements. Preschool 1 and Preschool 4 have registered lower values of fluctuation strength in some locations of the measurement. It is difficult to assess why this is the case, as no real correlation is found during the statistical analysis. One assumption that can be made is that fluctuation strength registered human speech. The strongest argument for this theory is that the instrument called N0 is the only instrument that picked up fluctuation strength at Preschool 1. This is also the same instrument that the children passed by, while the other instruments were further away. Another argument for this theory is that Preschool 3 had consistent values of fluctuation strength, which is where children were heard the most. Lastly, section *2.2.2 Psychoacoustic parameters* mentions that fluctuation strength has an important role in assessment of human speech.

The frequency response graphs Figure 27 and 28, in section *6.2 Measurement results*, show that the sound levels are higher in the lower frequencies and goes lower with the higher frequencies. This is because sound can travel more easily through objects. The graph for Preschool 4 shows a more significant difference between low frequency sound levels and the higher frequency, compared to the other graphs. This could have been caused by the wind, which was present during some instances in the measurement. Some comments have been made on this in Appendix 1. Preschool 3 shows the most constant sound levels between the frequencies, which was most likely due to having a big variation in different sound sources.

Table 11, in section *6.3 Statistical analysis of the questionnaire response and measurement results,* shows the results for the coefficient of determination for questionnaire versus parameter. Not much correlation is found between the metrics and questionnaire answers. More data might have given a better result, especially if more measurements were possible. The biggest correlation is between *natural sound* and the N_{max} value. The correlation is negative and therefore can be interpreted as natural sound is less prevalent when the N_{max} is higher.

The other values have too low correlation to give a proper interpretation. It is possible that, with more data, the lesser values such as eventfulness and L_{max} or between uneventfulness and roughness would correlate.

Another way of comparing the correlation is by looking at the psychoacoustic indicators versus the sound level indicators. The columns in Table 11 show that the R^2 of the psychoacoustic parameters, especially loudness versus sound level, are generally showing higher correlation to the questionnaire answers. In a study, mentioned in section *1.6 Literature review,* a similar conclusion was made by the researchers. Genuit K & Fiebig A (2016) concluded that loudness showed higher correspondence to volume sensation than the sound level indicator. The observation in this study is solely based on the R^2 values. It should be noted that this assumption disregards the p- values and therefore not necessarily valid. This finding shows that it could be useful to at least include loudness when evaluating if the sound environment. The inclusion of loudness together with sound level indicators could add more validity when reviewing the perception of the sound environment.

Table 13, in section *6.3 Statistical analysis of the questionnaire response and measurement results,* showing a lot of correlation is not very surprising. The psychoacoustic metrics consist of same input values because all of them use the Bark scale. Sound level and loudness also have similarity, such as at 1000 Hz the sound level value correspond to the phon value, which one of the two units used in loudness.

Table 14 shows the highest correlation for the questionnaire answers, which is between pleasantness and the appropriateness to the present place, as well as the adjective *calm*. This corresponds well to the fact that most participants answered that they found the sound environment either *good* or *very good.*

The Figure 29 of the regression model, in section *6.3 Statistical analysis of the questionnaire response and measurement results,* shows that lower N_{max} will result in hearing more natural sounds.

7.2 Limitations in the result and method used

The two biggest limitations in the result is the lack of enough data and not using binaural recording for the measurement. The study was supposed to have at least 5 measurements, but ideally even more would be needed to have proper amount of data. Before the situation with COVID-19 the plan was to begin with 5 measurements and gradually add more. The remaining time that was available would have allowed to do possibly 2-3 more measurements.

The measurements were recorded with single channel microphones, but as the standard suggested binaural recording would give a better result. The biggest advantage with binaural recording is being able to grasp location of the sound source more easily. Single channel recording cannot grasp the physical environment the same way a binaural recording can, which more closely resembles humans hearing. In section *2.2.2 Psychoacoustic parameters* a brief explanation is made on how the perception of sound is different between a single- versus a multi-channel analysis. Some sounds may be perceived as louder or quieter when accounting for minute spectral differences. This can also explain why the loudness values seem slightly lower than expected compared to Figure 9, in section *2.2.2 Psychoacoustic parameters*. The Figure shows that a normal conversation can be around 20 sones, while the result shows an equivalent loudness of between 2-6 sones. This seems low compared to the sound levels, where the equivalent sound level is between 50-60 dBA. The calculation results would most likely be different with binaural recording, but not necessarily given much higher values.

There are not many benchmark values to go by when it comes to psychoacoustic metrics. With no benchmark values to compare the results to, the best interpretation can be made from the statistical analysis. Access to commercial software such as one developed by Artemis or Brüel & Kjaer, which has been used in more studies could give more validity to the results obtained in this study.

The ISO 12913-2 offers certain suggestions on questionnaire templates, questions for interview or soundwalk questions in English. The questionnaire was translated to Swedish and the adjective chosen were taken from previously tested Swedish wordings. There was no translation available for the rest of the questions, which means that there might have been some linguistic differences in wording. Linguistic differences can have a certain effect on the result, as previously mentioned in section *1.6 Literature review.* One method to validate the chosen wordings could have been to perform a small exercise with some participants and ask them to translate the Swedish sentences to English and see how closely it would resemble the original wording from the ISO 12913-2.

This thesis looked to study the sound environment the children and the educators are exposed to from the outside, and therefore the children were asked to stay indoors for the measurements. A more realistic scenario would probably be to include the children in the measurements as they are also part of the sound environment. There were however shorter periods when the children were present in some capacity, but this was unintentional. There are however no guidelines for soundscapes suggesting that they should be present.

The educators were asked to answer the questionnaire during the measurement. This was done during different times when the measurement was recorded. Some of the questionnaires were answered after the measurement, as more data was needed. The purpose of having the participants answer the questionnaire was to get a close correlation to the measurement recording. Answering the questionnaire can take between 5-10 minutes to answer, which is shorter than the measurement recording.

A second approach could have been to ask the participants to sit and listen to the sound environment during the whole measurement and then answer the questionnaire. This was not done because the educators were already occupied with the children and being away for 30 minutes would be very difficult.

Alternatively, an assumption could have been made that the sound environment is approximately the same during most of the day that children play outdoor. The participants would not have to go outdoors to answer the questionnaire and instead answer it when they have more spare time. This assumption could possibly make it easier to get more questionnaire answers, as the participants answer when they have more time.

7.3 Future work

Future work should look to improve the mentioned limitations in the previous section. The most important part would therefore be to do more measurements. The recording of the measurement should be done binaurally or using both single channel and binaural recordings for comparison.

Another aspect that could have been studied is how the amount of personnel versus number of children affects the sound environment. More children could affect the perception of the sound environment. The size of the schoolyard versus the number of children and educators could also be included in this analysis.

Question 5 in the questionnaire gives statistical answers regarding age, sound sensitivity and gender. It might be worth studying the correlation between the answers from question 5 and compare it to the other parameters. However, this is not something that is standardized in accordance with ISO 12913.

Different software could be used to see if the results would differ and more parameters could be studied, such as Psychoacoustic Tonality, or metrics not previously used in soundscape studies.

This study used method A in ISO 12913-3:2019 for data analysis, which consists of using questionnaires. In future studies guided interviews and/or soundwalk could be used instead of questionnaires. Another suggestion could be to try using a similar soundscape method for locations where preschools are in the process of being built.

Sound masking has been briefly mentioned in this thesis. Sound masking has been used as a way of noise treatment in some projects. A suggestion could be to use loudspeakers in preschools and play different type of sounds that would be considered pleasant. The perception of the sound environment could then be compared by performing a soundscape study before and after.

8. Conclusions

The purpose of this Master thesis is to examine how a soundscape study can improve the outdoor sound environment in preschools. The early sections introduce the guidelines in Sweden for outdoor measurement in preschools.

Soundscape method together with several common psychoacoustic parameters is presented to further examine how this method can be used to complement todays standard. This method consists of qualitative and quantitative methods in the form of questionnaires, measurements, parameter calculation and statistical analysis.

This chapter will summarize the result section and give final thoughts on the soundscape method as a complement to today's standard measurement methods.

8.1 Summary on the results

The results show that 76% of the participants considers their sound environment *good* or *very good.* The two-dimensional component loaded most of the coordinates on the *Pleasant,* with only 6 out of 25 coordinates are loaded on the *Unpleasant* side of the component.

The sound level measurements are done for only 30 minutes, which resulted in some L_{eq} values being slightly higher than the benchmark values in section *4.1 Outdoor benchmark values for schools and preschools*. The duration for the L_{max} values is easier to compare to, as the benchmark state that the values should not be exceeded more than 5 times during a 1-hour period. If 70 dBA is exceeded 5 times during a 30-minute period, then it becomes a valid comparison. Figure 26 in section *6.2 Measurement results* showed that this was the case for Preschool 1.

The psychoacoustic metrics are more difficult to assess, due to not having any benchmarks values to compare against. The results show mostly low values for roughness and fluctuation strength. For Preschool 2 the fluctuation strength is 0, while for Preschool 1 and 4 the values are lower in some positions of the measurements. Conclusion is made that the fluctuation strength variates depending on how much human speech is heard in the measurement. More human speech results in higher values of fluctuation strength.

Low correlation is found between questionnaire responses and parameters. The biggest correlation is between *natural sound* and the N_{max} value. Regression model is created for this correlation, which can be used to assess what level of max loudness is needed to obtain a preferred value for the *natural sound.*

8.2 Soundscape study as a complement to today’s standard methods?

This study showed that there might be a stronger correlation between psychoacoustic parameters and perception of the sound environment, than that between sound level parameters and the sound environment. It could therefore be useful to complementing the sound pressure indicators with, at least the loudness parameter to get a better evaluation on how the sound environment could be perceived. This conclusion is based more so on the previous findings in research done by Genuit & Fiebig (2016), but also based on the conclusion in section 6.3. The researchers Genuit & Fiebig (2016) as well as Kang & Yang (2012) have found correlations for the parameters of loudness and natural sound. This suggest that it might be relevant to continue studying these two parameters in further soundscape studies or studies that look to evaluate the subjective experience of the sound environment.

Having more tools to distinguish what type of sound environment is perceived as good or bad is important. This is something the sound level indicator alone might not be able to do. Acousticians, architects, or others might be able to find better tools to help them categorize good and bad sounds with more knowledge on this subject. This can be useful both in the planning phase of new projects and in finished projects.

Better prediction models could be created with more statistical data. If better correlation is found between indicators of interest, then these could be used to predict what type of improvements would give desired outcomes. For instance, creating a model that could predict what type of levels of sharpness, or other indicator, would be necessary to affect how well the sound environment will be perceived.

This thesis already mentioned several projects where soundscape has seen used as a way of treating noise in a holistic way. Therefore, there is certainly use for soundscape in today’s standard methods, especially with more information and continued improvements in the field.

Soundscape method is still however new, especially in terms of standardization and is still being improved upon. There are several aspects that are yet to be standardized such as some parameters, but the development will improve fast with continued use of the soundscape methodology.

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Appendix

Appendix 1: Protocols

Measurement protocol

Preschool: Juvelen

Equipment

- 3 Norsonic 140
- 3 tripods
- Questionnaires

Weather condition

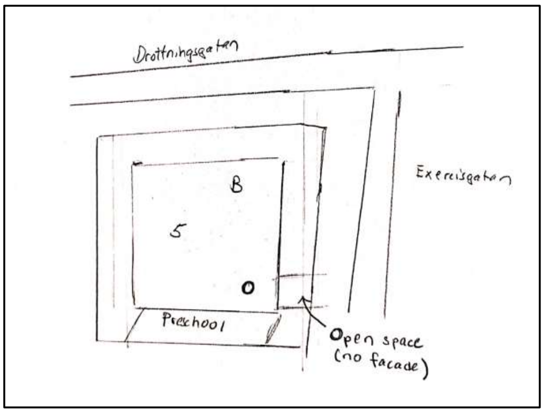
Temperature 6 °. Humid weather, windspeed 3-4 m/s, wind direction was west. Clear sky

Position of measurement equipment

- Height: approx. 1,6 m

Position:

Norsonic instruments called 5, O and B in sketch.



Measurement start-finish

- Date: 2020-02-13
- Time: 14-14.30

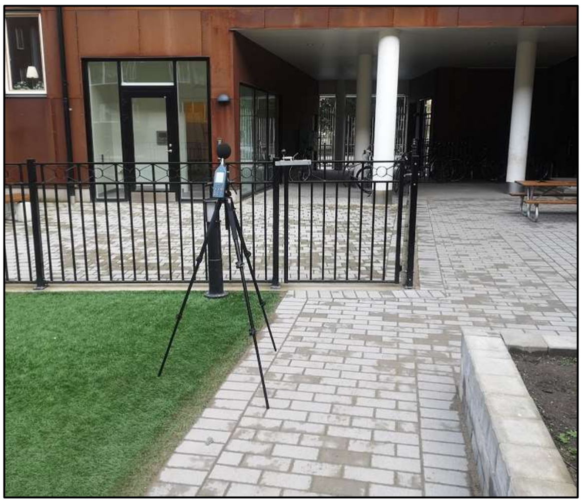
Comments

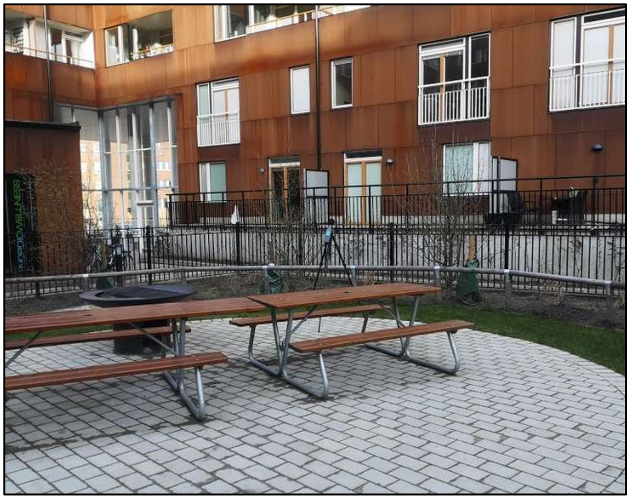
Measurement recorded with 3 Norsonic instrument during the whole duration of the measurement. The questionnaires answered by preschool educators.

Sound source; traffic sound, especially close to Norsonic *O* (se position picture), children from time to time. At 14.10 a group of children went by the Norsonic *O*.

Questionnaires answered at the beginning of the measurement. Preschool surrounded by facades, a lot of hard surfaces, potentially causing some reflections.

Pictures





Measurement protocol

Preschool: Pilängen

Equipment:

- 3 Norsonic 140
- 3 tripods
- Questionnaires

Weather condition

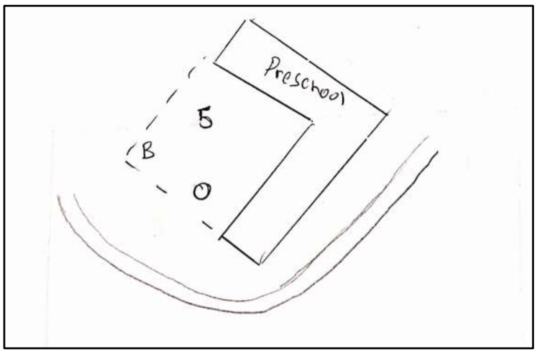
Temperature 8°. Humid weather, windspeed 6 m/s, wind direction was west. Clear sky.

Position of measurement equipment:

- Height: approx. 1,6 m

Position:

Norsonic instruments called 5, O and B in sketch.



Measurement start-finish

- Date: 2020-02-21
- Time: 13.45-14.15

Comments:

Measurement recorded with 3 Norsonic instrument during the whole duration of the measurement. The questionnaires answered by preschool educators.

Sound sources: nearby construction, children, birdsongs, 1 plane passing by and couple of cars passed by during the measurement.

One of the participants commented that it was unusually loud today, more than usual. The questionnaire answered were spread out during the measurement.

Pictures

Measurement protocol

Preschool: Äpplet

Equipment:

- 3 Norsonic 140
- 3 tripods
- Questionnaires

Weather condition

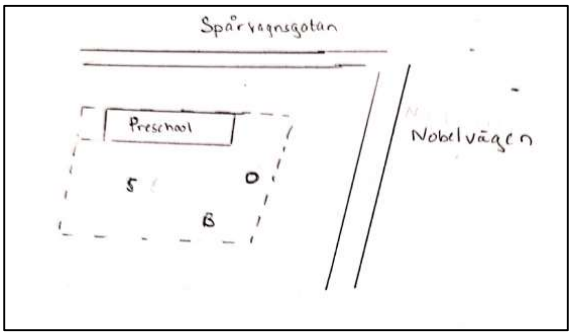
Temperature 3-4 °. Weather was humid, but clear sky. Windspeed approx. 6-7 m/s, wind direction west.

Position of measurement equipment

- Height: approx. 1,6 m

Position:

Norsonic instruments called 5, O and B in sketch.



Measurement start-finish

- Date: 2020-02-14
- Time: 9.35-10.05

Comments

Measurement recorded with 3 Norsonic instrument during the whole duration of the measurement. The questionnaires answered by preschool educators.

Sound sources; children, music from music player, traffic, ambulance sirens, people talking, pavement work.

The questionnaires were answered in the beginning and in the middle of the recording. The participant commented that they feel like it would not be necessary to go outdoors to comment on the sound environment, which could mean that they already had made up their mind on the sound environment before answering.

Pictures

Measurement protocol

Preschool: Berga

Equipment

- 3 Norsonic 140
- 3 tripods
- Questionnaires

Weather condition

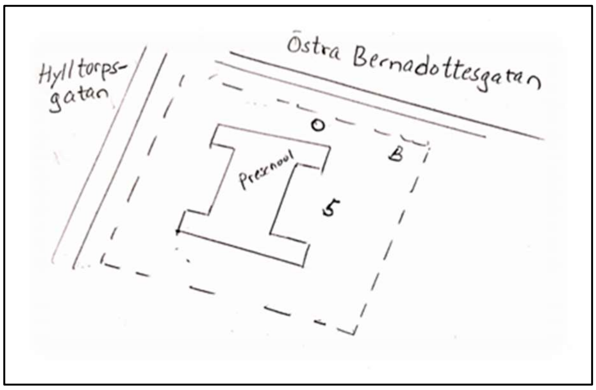
Temperature 5°, windspeed 7-8 m/s and direction west. Humid climate, with a little bit of rain during the measurement (beginning) after 10-15 min the rain stopped, and it was a bit sunny.

Position of measurement equipment

- Height: approx. 1,6 m

Position:

Norsonic instruments called 5, O and B in sketch.



Measurement start-finish

- Date: 2020-02-18
- Time:9.10-9.40

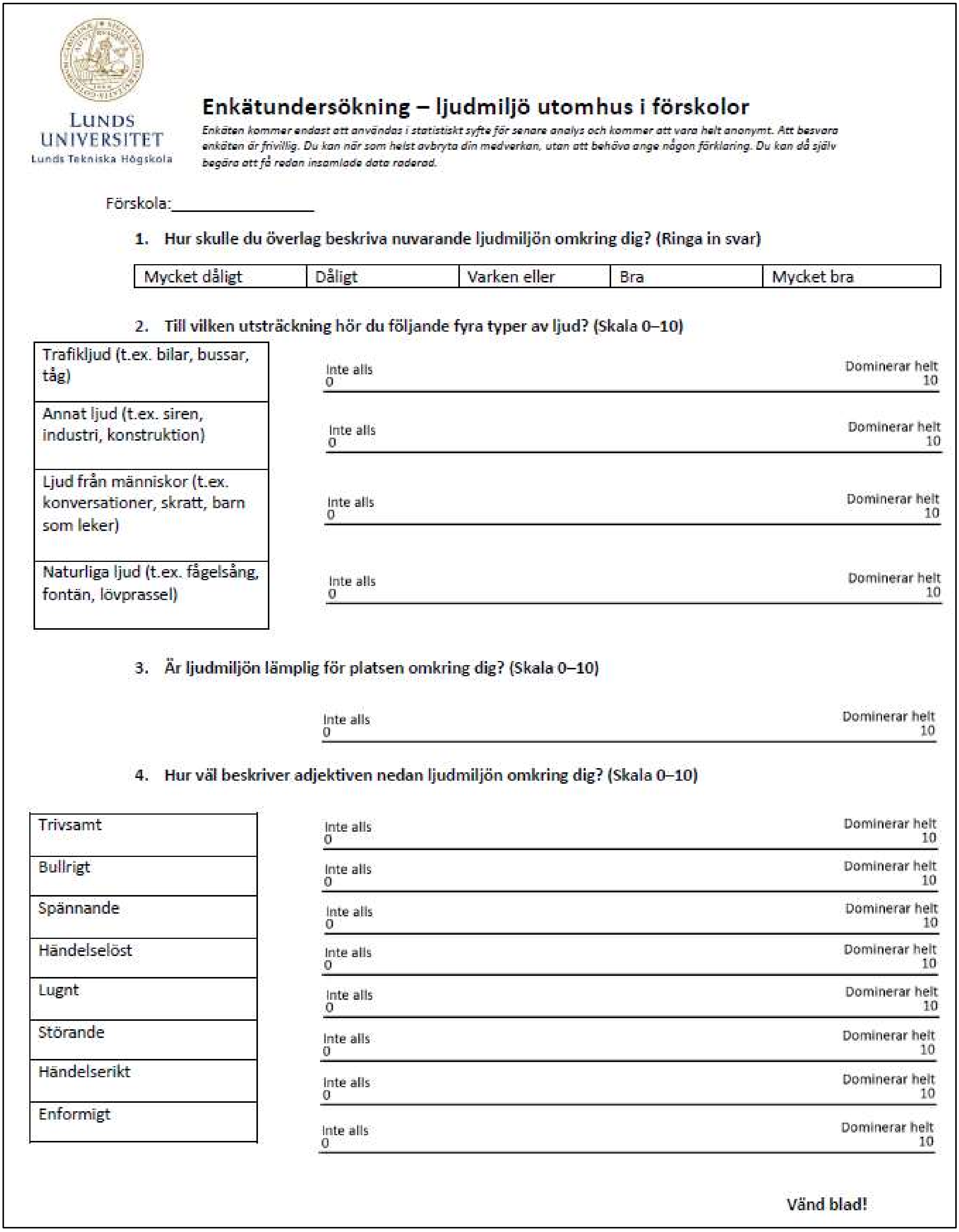
Comments

Measurement recorded with 3 Norsonic instrument during the whole duration of the measurement. The questionnaires answered by preschool educators. Sound sources were cars, birdsong, sound of wind and leafs. There were parts during the measurements where it got a bit windy, mostly in the beginning. This seemed to have some effect on the measurement (approx. 3-4 dB increase at strongest wind). The questionnaires were answered at the end towards 9.30 when it was the least windy and got quite sunny.

Pictures

Appendix 2: Questionnaires

Swedish Questionnaire



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Lunds Tekniska Högskola

Enkätundersökning – ljudmiljö utomhus i förskolor

Enkäten kommer endast att användas i statistiskt syfte för senare analys och kommer att vara helt anonymt. Att besvara enkäten är frivillig. Du kan när som helst avbryta din medverkan, utan att behöva ange någon förklaring. Du kan då själv begära att få redan insamlade data raderad.

Förskola:________________

1. Hur skulle du överlag beskriva nuvarande ljudmiljön omkring dig? (Ringa in svar)

Mycket dåligt	Dåligt	Varken eller	Bra	Mycket bra

2. Till vilken utsträckning hör du följande fyra typer av ljud? (Skala 0–10)

Trafikljud (t.ex. bilar, bussar, tåg)	Inte alls 0	Dominerar helt 10
Annat ljud (t.ex. siren, industri, konstruktion)	Inte alls 0	Dominerar helt 10
Ljud från människor (t.ex. konversationer, skratt, barn som leker)	Inte alls 0	Dominerar helt 10
Naturliga ljud (t.ex. fågelsång, fontän, lövprassel)	Inte alls 0	Dominerar helt 10

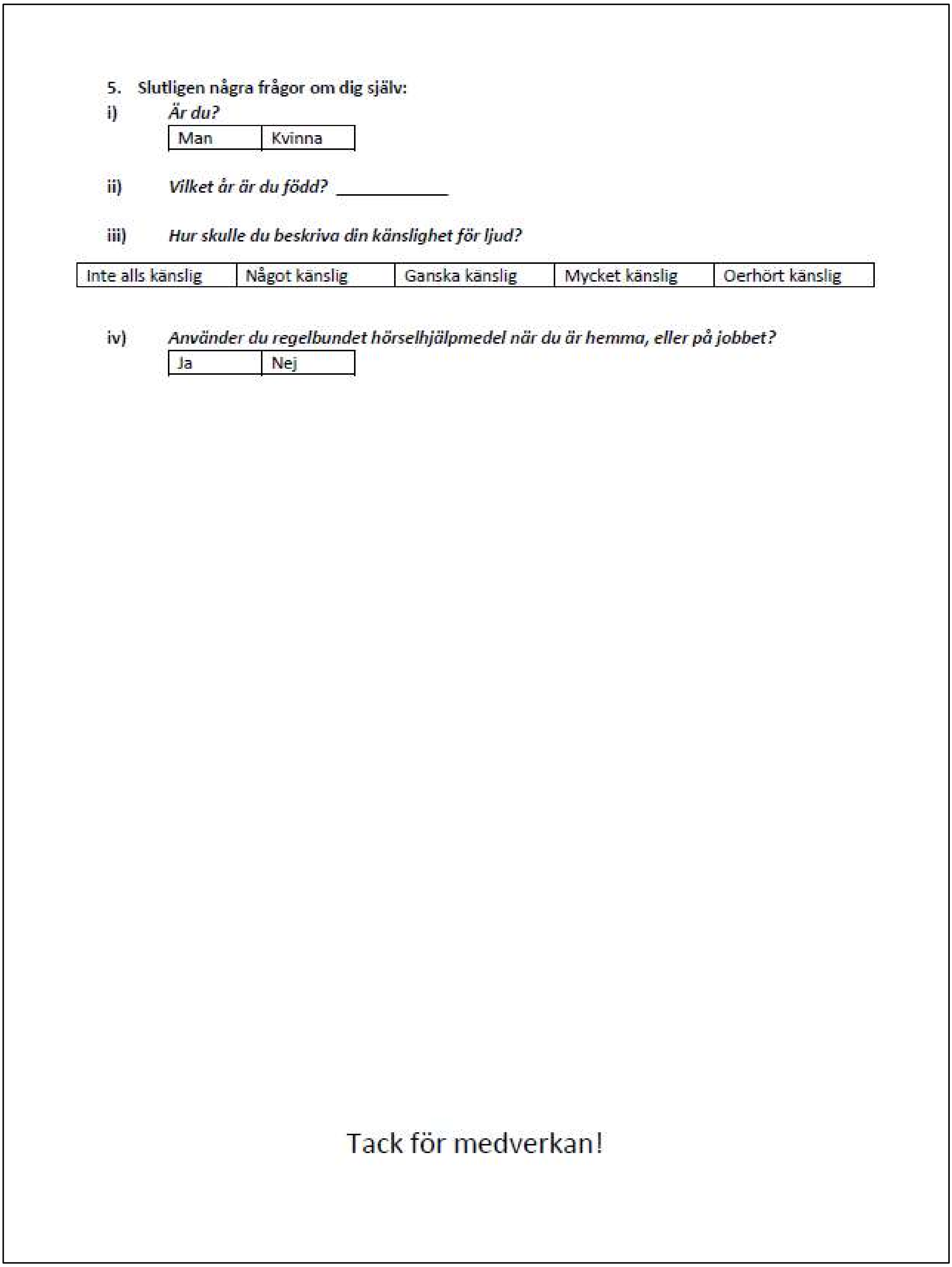
3. Är ljudmiljön lämplig för platsen omkring dig? (Skala 0–10)

Inte alls 0 ____________________ Dominerar helt 10

4. Hur väl beskriver adjektiven nedan ljudmiljön omkring dig? (Skala 0–10)

Trivsamt	Inte alls 0	Dominerar helt 10
Bullrigt	Inte alls 0	Dominerar helt 10
Spännande	Inte alls 0	Dominerar helt 10
Händelselöst	Inte alls 0	Dominerar helt 10
Lugnt	Inte alls 0	Dominerar helt 10
Störande	Inte alls 0	Dominerar helt 10
Händelserikt	Inte alls 0	Dominerar helt 10
Enformigt	Inte alls 0	Dominerar helt 10

Vänd blad!



5. **Slutligen några frågor om dig själv:**

i) ***Är du?***

Man	Kvinna

ii) ***Vilket år är du född?*** ____________

iii) ***Hur skulle du beskriva din känslighet för ljud?***

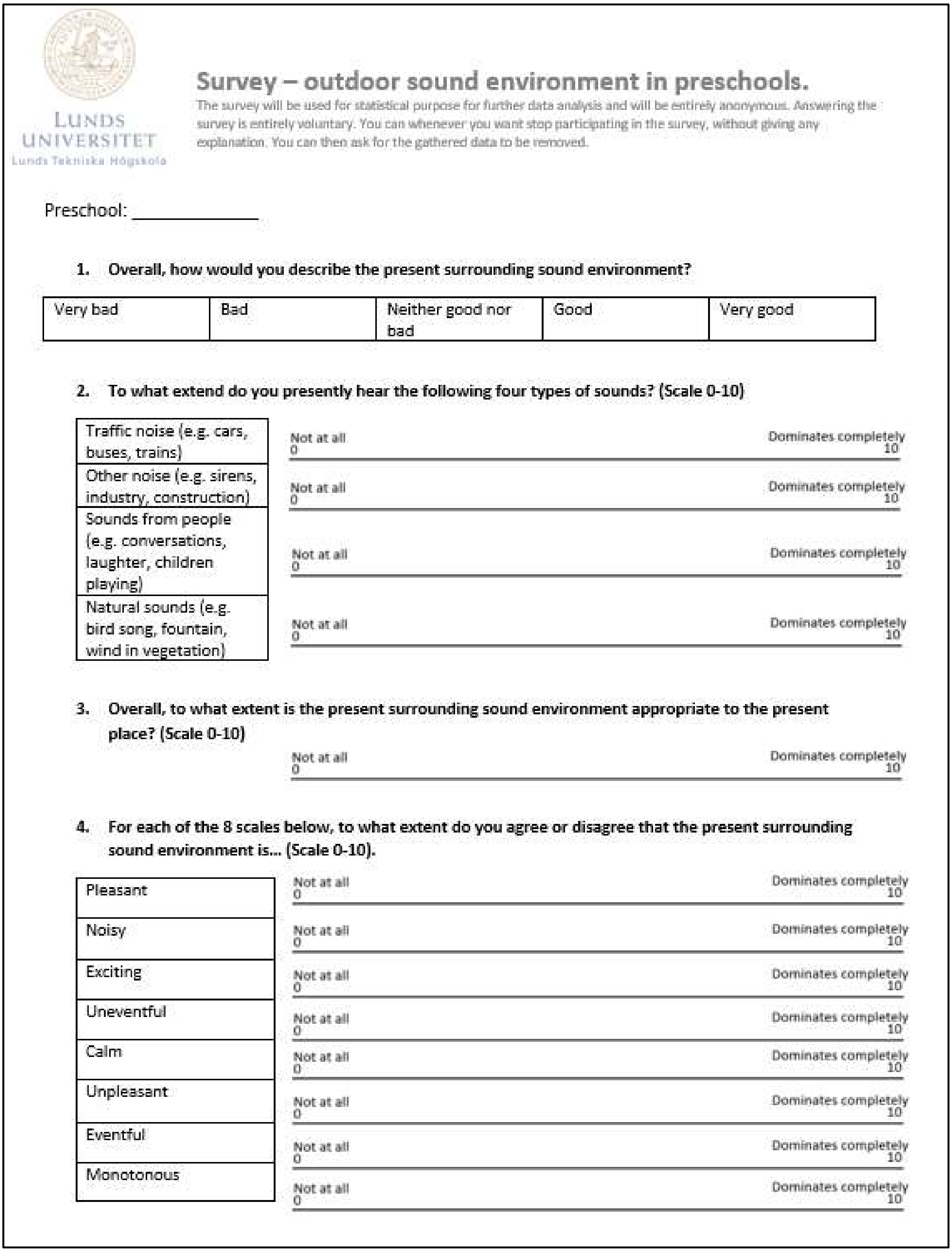
Inte alls känslig	Något känslig	Ganska känslig	Mycket känslig	Oerhört känslig

iv) ***Använder du regelbundet hörselhjälpmedel när du är hemma, eller på jobbet?***

Ja	Nej

Tack för medverkan!

Swedish Questionnaire translated to English



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Survey – outdoor sound environment in preschools.

The survey will be used for statistical purpose for further data analysis and will be entirely anonymous. Answering the survey is entirely voluntary. You can whenever you want stop participating in the survey, without giving any explanation. You can then ask for the gathered data to be removed.

Preschool: ____________

1. **Overall, how would you describe the present surrounding sound environment?**

Very bad	Bad	Neither good nor bad	Good	Very good

2. **To what extend do you presently hear the following four types of sounds? (Scale 0-10)**

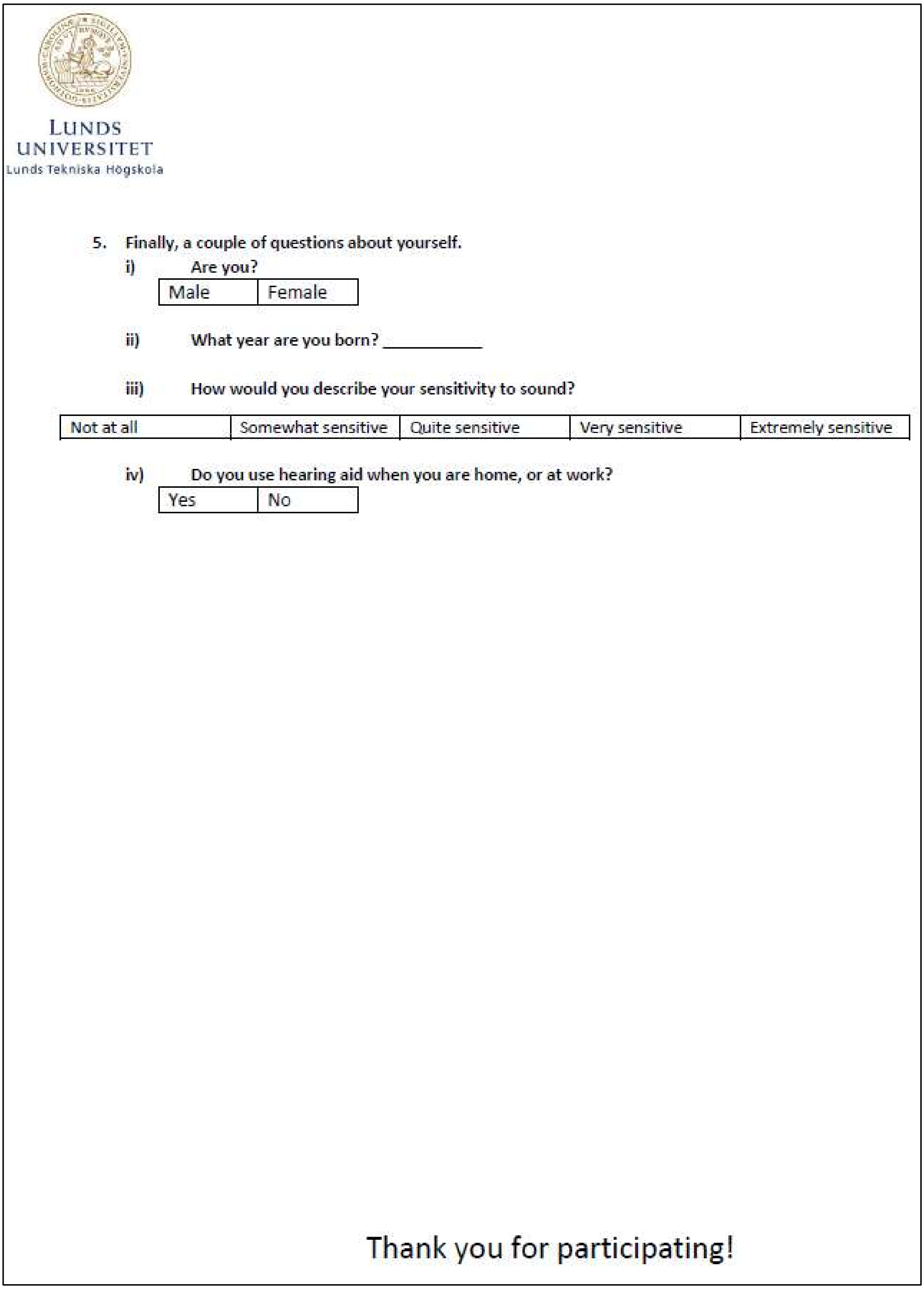
Traffic noise (e.g. cars, buses, trains)	Not at all 0	Dominates completely 10
Other noise (e.g. sirens, industry, construction)	Not at all 0	Dominates completely 10
Sounds from people (e.g. conversations, laughter, children playing)	Not at all 0	Dominates completely 10
Natural sounds (e.g. bird song, fountain, wind in vegetation)	Not at all 0	Dominates completely 10

3. **Overall, to what extent is the present surrounding sound environment appropriate to the present place? (Scale 0-10)**

Not at all 0 — Dominates completely 10

4. **For each of the 8 scales below, to what extent do you agree or disagree that the present surrounding sound environment is… (Scale 0-10).**

Pleasant	Not at all 0	Dominates completely 10
Noisy	Not at all 0	Dominates completely 10
Exciting	Not at all 0	Dominates completely 10
Uneventful	Not at all 0	Dominates completely 10
Calm	Not at all 0	Dominates completely 10
Unpleasant	Not at all 0	Dominates completely 10
Eventful	Not at all 0	Dominates completely 10
Monotonous	Not at all 0	Dominates completely 10



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5. Finally, a couple of questions about yourself.

i) Are you?

Male	Female

ii) What year are you born? ___________

iii) How would you describe your sensitivity to sound?

Not at all	Somewhat sensitive	Quite sensitive	Very sensitive	Extremely sensitive

iv) Do you use hearing aid when you are home, or at work?

Yes	No

Thank you for participating!