Evaluation of masking sounds in an existing open-plan office

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

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Abstract

The use of sound masking systems has a history back into the 1960s when the first open-plan office was established. Even though the technique of electronic masking systems is quite old and encouraged by many design guidelines, it is not used very frequently. This master's thesis was supported by Akustikon/Norconsult in Stockholm. The goal was to evaluate masking sounds in an existing open-plan office. Five masking sound conditions were evaluated by a listening experiment with twenty participants. The experiment included a serial recall task, complemented by a questionnaire and was performed in an open-plan office with ten workstations at Norconsult in Stockholm. The acoustic quality of the room was determined by STI measurements and calculations of single number quantities, i.e. distraction distance (r_D) and privacy distance (r_p). The five masking sound conditions tested in this study were silence, irrelevant speech, pink noise, water waves and chatter, where the last three sounds were played together with irrelevant speech. The results showed that masking sounds do increase the work performance and privacy in an open-plan office. It also showed that some sounds may be more preferable as masking sounds than the filtered pink noise usually used in offices today. Objective measurement for the different sound conditions showed an increased acoustic quality in the office in the form of distraction distance.

Keywords: sound masking, masking sounds, performance, speech transmission index, distraction distance, serial recall task, open-plan office

Contents

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Johannes Carlsson
Uppsala, December 2014

1. Introduction

1.1. Background

The first open-plan office was designed and built in Germany in the middle of 1960s. The purpose was to establish physical accessibility and encourage communication between employees. This would achieve a more efficient organization [1]. The ideas of easy access and communication between employees are some of the benefits with the design. But after the design was introduced, employees started to criticize the office type and several studies have been done showing some of the disadvantages.

While the open-plan office costs less to build and creates easier access to colleagues, the price to pay is impaired concentration and reduced acoustical satisfaction. Studies have shown that employees working in open-plan offices show more fatigue and have a harder time to concentrating compared to people working in cell-offices [1, 2]. This affects the work ability and has negative effects on the work performance. Most disturbances in an open-plan office are reported to be the sound environment [3]. Co-workers talking, keyboard typing and phone calls are all main issues in an office environment. The most critical sound source has been evaluated as irrelevant speech from co-workers and lack of privacy [1, 4].

Even though there are studies showing the drawbacks of the open-plan office concept, the concept is growing. With an increase of building and changing cell offices into open-plan spaces, the office design is an important issue to deal with.

To improve the environment in an open-plan office, big efforts should be put into the acoustical design of the rooms. Different acoustical solutions can be used. Depending on room, absorption in the ceiling, walls and furniture and high partition screens between workstations are some examples that can be used to improve the room. A study from 2012 [5] at Norconsult/Akustikon show that sufficient privacy cannot be attained without masking. The use of sound masking systems are also recommended in a study by Haapakangas et al. [3] to reach a desired privacy. Sound masking does not reduce the speech level but it does reduce the intelligibility of speech in the office. Haapakangas et al. [4] refer to several experiments showing that the level of speech does not impact the disruptive effect of speech but the speech intelligibility does.

The use of sound masking systems has a history back into the 1960s when the open-plan office design came around. Even though the technique of electronic masking system is quite old and encouraged in many design guidelines, it is not very common in

Scandinavia and Europe.

A study by Ceder and Hellström [6] gave the result that irrelevant speech masked by white noise had positive effects on the memory capacity and improved the learning ability compared to speech without noise. They also refer to several studies showing that the use of sound masking systems increases work performance, as a consequence of the reduced intelligibility, and decrease disturbances of speech and phone calls.

White noise was the most common sound to use in sound masking systems. Nowadays the use of filtered pink noise has been more popular, although white noise still appears. Pink noise has a more pleasant character and has a similar frequency spectrum to speech, which makes it to an efficient sound masker. The optimum spectrum for sound masking is said to be pink noise filtered to -5 dB/octave between 125 - 8000 Hz [3, 7, 8].

Aside from the two kinds of noise, white and pink, different sounds have been tested as masking sounds before. Haapakangas et. al. [3] did a study with five different sounds in a laboratory with 54 subjects. They concluded that spring water was the best sound for sound masking, with its spectrum and character. Schlittmeier and Hellbrük [9] tested different types of music as speech maskers in laboratory environment. There findings were that only pink noise reduced the impact of office noise but most of the participants would prefer legato music as the masking sound.

1.2. Purpose

As there has been no satisfactory masking sound up to now, the purpose of this thesis is to find masking sounds that reach higher acceptability by the users. The Akustikon team at Norconsult wants to evaluate a theory of how to produce the sound in every specific open-plan office environment. Sounds will be designed and played through a sound masking system installed in the office. Listening experiments, where both subjective and objective aspects are studied, will evaluate the different sound conditions. The experiment will hopefully help to understand how a masking sound system may be used in order to improve the privacy and the working performance in an open-plan office. Also how masking sounds could be designed to get further implementation in offices in Europe.

1.3. Aim of the study

The aim of the study is to find a sound that both increases the acceptance by employees and increases the work performance compared to pink noise. The main part of this study is to evaluate what kind of sounds can be used as masking sounds by comparing the working performance.

1.3.1. Research questions

After this study the following questions will be answered.

Q1. Does speech without masking give the lowest task performance, i.e. lowest mean score, comparing the five sound conditions? It is stated as the most disturbing sound in an open-plan office by earlier studies.
Q2. Do masking sounds differ in task performance and acoustic satisfaction from each other?
Q3. Do any of the designed sounds give better results in performance tasks than pink noise?

2. Theory

2.1. Measurement quantities

Designing an open-plan office requires some kind of evaluation tool to measure the sound environment quality of the office. One parameter used for this is the speech transmission index (STI). This method is an objective measure of the speech intelligibility and uses weighting contributions of different frequency bands in the frequency range of speech signals. STI includes reverberation and distortion in the time domain such as echoes and interfering noise and gives values between 0.00 and 1.00. Beside STI, which is mostly used in Europe, two other methods are used sometimes. Those methods are the Articulation Index (AI) and the Speech Intelligibly Index (SII), where the later is a newer version of AI. These two methods are more used in America and do not include the reverberation of the room as STI does.

In offices the term privacy index has earlier been used in several studies and literature. Privacy index is based on Articulation index and is determined by 1-AI. For STI no official privacy term is used. A lower STI increases the privacy in terms of intelligibility and the reversed STI (1-STI) could therefore be explained as speech privacy[10].

STI values by itself usually refer to the nearest work station. To be able to tell more about the overall acoustic condition of the office, other quantities should be used in addition to the STI.

Virjonen et. al. [11] suggested to combine STI measurements and sound pressure level (SPL) measurements along with distances to calculate single number quantities. Their suggestions are now used in the ISO standard 3382-3:2012 [12], where the measurement procedure for open-plan offices is described. A deeper description of the quantities; distraction distance r_D, the privacy distance, r_P, spatial decay of A-weighted speech per distance doubling DL_2 and the sound pressure level of speech at a distance of 4 meter $L_{p,s,A,4m}$ and how they are determined is explained in section 2.1.2.

2.1.1. Speech transmission index

The speech transmission index (STI) is a standardized quantity to objectively measure the intelligibility of the sound. The intelligibility is modeled by determining the modulation transfer function for the relevant frequencies of natural speech signals. STI can be calculated from an impulse response or measured directly from a modulated test signal of band-limit noise. The test signal is used to determine the transmission quality of speech and simulate the speech characteristics of a talker. The signal is played from a loudspeaker at 1.2 m height and measured at the receiver position also 1.2 m above the floor. The STI is then determined by calculating a sum of reductions in each modulation index by the effective signal-to-noise ratio.

The STI is measured in seven octave bands, 125 Hz to 8000 Hz, with fourteen modulation frequencies for each band, from 0.63 Hz up to 12.5 Hz. The calculated signal-to-noise ratio (SNR) is limited to the range of -15 to 15 dB for each band. [13]

STIPA

The speech transmission index have three different simplifications of the method, one of them is STIPA. The STIPA method uses two modulation frequencies instead of 14 for each frequency band. It is a useful tool that shortens the measurement time compared to the full STI method. Even though it is useful, the method has some limitations. The method should not be used if the public address system, for which the STIPA method is developed, introduces a frequency shift, frequency multiplication, strong non-linear distortion components, or if the system includes vocoders or if the background noise is impulsive.[13] As this is not the case in this thesis, STIPA is the measurement method used here.

2.1.2. Single number quantities

To calculate the single number quantities mentioned earlier, a couple of different measurements have to be done in the office [11, 12]. The sound pressure levels and STI have to be measured in octave bands between 125 - 8000 Hz. Along with that, the distance should also be measured at each measurement position in office. The distance is measured from the sound source to the receiver position in meters. The three single number quantities and the A-weighted background noise level are then determined from those measurements. The A-weighted background noise is simply measured in each position without any speech or masking sound present. The distraction distance r_D is read from a STI vs. distance plot and gives the distance [m] from the speaker where the STI falls below 0.50. In order to do this an interpolated line between the measured points has to be used. The privacy distance r_P is determined in the same way, except that the $STI \leq 0.20$ is used. Because of the low STI value, it is not always possible to determine the privacy distance.

The DL_2 is read from a SPL vs. distance graph using a logarithmic x-axis and an interpolated line between the measurement points. The distance between 4 and 8 meters is used as a reference and the quantity is determined by the sound pressure level difference between these points [12]. The specific distances are used due to the far field,

Class	DL_2 [dB]	$L_{p,S,4m}$ [dB]	r_D [m]
A	> 11	< 48	< 5
B	9 to 11	48 to 51	5 to 8
C	7 to 9	51 to 54	8 to 11
D	< 7	> 54	> 11

Table 2.1.: Acoustic environmental classes of an open-plan office. [11]

which starts at a distance of about 4 m [11].

The last single number quantity, $L_{p,A,S,4m}$, is determined from the same graph as the DL_2. Its SPL value is basically read from the graph where the line crosses the distance of 4 m. The DL_2 and $L_{p,A,S,4m}$ do not take masking sounds and reverberation times of the room into account, but tell more about the absorption of the room. Because the latter two quantities, DL_2 and $L_{p,A,S,4m}$ are based on the sound pressure level and not the STI, they are irrelevant when masking sounds are used.

Guidelines for target values

In ISO 3382-3:2012 [12] some examples of target values are given. An office with good acoustic conditions is given the target values $DL_2 \geq 7$ dB, $L_{p,A,S,4m} \leq 48$ dB and $r_D \leq 5$ m. These values are similar to what Virjonen et al. [11] proposed as a class A office in their study. They gave target values for four different classes. The classes can be used to determine the quality of an open-plan office and are rated from Class A to Class D by the single number quantities, see Table 2.1.

To reach the different classes different designs have to be done. To be able to reach the highest class, Class A, the masking sound has to be included together with sufficient absorption and screen heights in the office.

2.2. Masking sound

The open-plan office was introduced in the 1960s in Germany. Shortly after the introduction it spread across Europe and the United States[1]. Even at the inception of open-plan office use, the necessity of masking sound was discussed [7, 14].

Artificial masking sounds are used to mask or cover other sounds, such as irrelevant speech. An alternative to artificial masking sounds is natural produced noise. The most common noise for this is the ventilation noise or road traffic noise from outside the office. But usually this is not enough since the ventilation is built to be very quiet today and masking sounds are recommended if the background noise is below 40 dBA. Several studies show that an adequate acoustic design prevents privacy problems and reduced working performance. An adequate acoustic design includes the use of sound masking systems in open-plan offices [4, 7, 15, 16].

Artificial sound masking usually consists of white or pink noise, where the latter is preferred. White noise was the most common sound in the masking systems when the technique became an alternative in offices. Today filtered pink noise is the most common sound in sound masking systems. It is also said to be the optimum masking sound [7] and showed to be the most effective sound masker in several studies [8, 9, 17]. The recommended sound spectrum is similar to the human speech spectrum. It has a - 5 dB/octave slope in the frequency range 125-8000 Hz [3, 7, 8]. Studies have also concluded that a preferable A-weighted sound pressure level for the masking sound is around 45 dBA and should not exceed 48 dBA [16].

White and pink noise are two of the most referenced sounds in earlier studies. Some studies have compared these sounds with other kind of sounds. Schlittmeier and Hellbrök [9] tested two kind of music (legato and staccato music) as an alternative to continuous pink noise. They found that continuous pink noise was the best sound for masking office noise but legato music was the most preferred sound by the participants.

Haapakangas et. al. [3] have also experimented on how other kinds of sounds perform compared to pink noise. They tested five different sounds, instrumental music, vocal music, ventilation noise and recorded spring water sound along with pink noise. In there laboratory experiment with 54 participants, they found that spring water sound was the most preferable sound both in the performance result and in the subjective questionnaire. Their study also showed that vocal and instrumental music should be avoided and common sounds as filtered pink noise and ventilation sound work as masking sounds in open-plan offices.

A type of sound that has been mentioned in reports but not tested in open-plan office environments are babble or chatter [3, 9]. Different number of voices have been tested by Jones and Macken [18] who showed that babble from more than six people reduced the disruptive effect on short-term memory significantly compared to only one or two voices.

2.3. Masking sound system

Artificial masking sounds are produced by a sound masking system. It consists of loudspeakers, amplifier, equalizer and some kind of signal generator. Systems can be found both for local and overall masking, where the latter is most common. It uses a network of loudspeakers to give an overall background sound level in the office. The loudspeakers are usually built as a network and are located above a suspending ceiling. This has some advantages, i.e. the loudspeakers are not visible and it gives a more diffuse sound field in the room. The loudspeakers can also be placed in an open ceiling, below a raised floor or facing downward above a suspending ceiling. To obtain a diffuse sound field in the room, the loudspeakers are usually facing upward.

Static masking systems have from the beginning been the most common system. This means that the system uses the same sound pressure level and frequency spectrum all the time. But more advanced systems are available from many manufacturers today. An example of this kind of system is the automatic level and spectrum adjusting system. These systems automatically adjust the sound pressure level depending on the level in the office. Another system uses time control adjustments. The user adjusts the level of the system for different times of the day and can match the times in the office. When the work is slower with less people talking, the level of the system can be reduced, e.g. in the mornings and late afternoons. [19] The system from SoftdB used in this thesis had the feature of automatic level and spectrum adjustments, even though the features were not used in the listening experiment.

2.4. Evaluation of masking sounds

To get an idea on how background sounds affect employees, different tests can be used. One of the most common tests to evaluate how irrelevant sounds affect employees in offices is the Serial recall task. It has been used in several studies [3, 9, 20] and is described to be a classical task when irrelevant background sounds are tested. The Serial recall task investigate how sounds impact on the cognitive performance [9] and the short term memory capacity, which has an important role in office work [15].

A serial recall task lets the participants memorize the order of digits or words on a computer screen. After seven to nine different digits have been shown, one by one, the participant has to recall the digits in the exact position as they were shown.

The description of the test can be seen in the next chapter Method, 3.4.5.

2.5. Economic effects of decreased productivity

Since most studies show a reduced work performance in open-plan offices with intelligibility speech it is possible that the decreased performance give some economic effects. A mathematical model, Figure 2.1, developed by Hongisto [21] shows the relationship between STI and work performance. The model was developed based on literature reviews of earlier studies. It is also referenced in the ISO standard 3382-3:2012 [12] and used in other studies. The model shows that the performance starts to decrease when STI exceeds 0.20 and reaches its maximum when STI exceeds 0.60. Hongisto tells about a reduced performance of about 7 % depending on tasks. Studies using cognitively demanding tasks have shown an error rate between 4 % and 45 % for speech compared to silence depending on the type of task [12, 21].

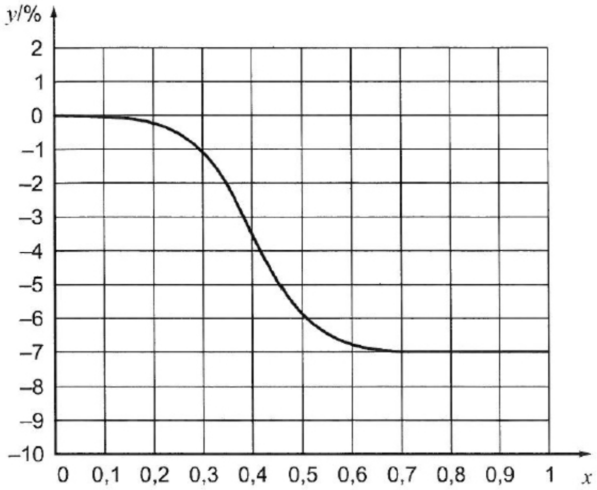

Figure 2.1.: Hongisto's model over the relationship between decreased performance in percentage (y-axis) and STI (x-axis) [12, 21].

Another study by Jahncke et. al. [15] showed that irrelevant background speech may affect the productivity around 2-10 % compared to silence. In Jahncke's doctoral thesis from 2010 [22], she gives a calculation example on the economic effects by reduced productivity. She uses a decreased productivity by 2 % and a normal open-plan office with 110 employees and a 45 hour work week. Her calculations include 52 % social security contribution and ends up to cost as much as 1 000 000 SEK per year due to decreased productivity. This is with a decreased productivity of only 2 %.

3. Method

The first section 3.1 explains how the sounds were designed. The following section 3.2 explains the office room used for the present study. In section 3.3 the measurement procedure is described for the objective measurements in the room, including the equipment list. The last section, 3.4 describes the procedure and the tools used for the listening experiment, including the analysis portion.

3.1. Sound design

The sounds used for the thesis were designed from ideas by the acoustic department at Norconsult AB and the author of this thesis. Some of the thoughts came from earlier reports and papers stated in Chapter 2. Four different sound ideas were designed to be used as masking sounds:

- Filtered pink noise
- Water waves
- Chatter / Babble
- Forest wind

The filtered pink noise was used since it is the most common masking sound on the market today. It is also used in several studies and is here used as a reference sound. The masking sound system installed and used for this thesis also uses a filtered pink noise as the preset sound. The filtered pink noise was digitally created in the software Audacity and equalized to have a 5 dB drop per octave above 150 Hz as described in the Theory.

Water waves was designed in the software Cubase Elements 7 and was a mix of several recordings[1]. *Ocean waves crushing* gave the sound of waves and a dynamic in the track, while the track *North sea* gave a more constant and static background sound. The sound was equalized and compressed to get a good mix. The sound water waves was

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[1] Oceanwavescrushing.wav By Luftrum: www.freesound.org/people/Luftrum/sounds/48412/?page=1# and Northsea Denmark.wav By inchadney: www.freesound.org/people/inchadney/sounds/194478/

compressed quite hard to get a lower dynamic in the sound. A few samples with different mixes were exported as wav-files. The final edition used in the listening experiment was chosen by the author and colleagues, who subjectively evaluated the sounds.

The sound called chatter could also be called speech babble or multi-speech. It is based on recordings of people talking in an office and duplicated several times to get a metabolic effect, [23]. The idea was to get a diffuse sound of chatter without any clear voices. Similar to the sound that can be expected in an office when several people are talking. Several mixes were designed by different sources. The first samples were based on recordings from a crowded area and a restaurant[2]. Since the recordings did not come from an office but a restaurant, the sound did not fit into the expected environment, i.e. the office, very well. The mix also gave an expression of a bigger room, more like a waiting hall at a train station or similar. New recordings were conducted in the actual office where the listening experiment later took place. The recordings were made by nine people talking simultaneously. To make it easier to talk for a longer time, each person was reading texts from magazines. The recordings were multiplied with an offset several times to get an even more diffuse sound without any distinguished words and voices. The sound was equalized and compressed with plug-ins in Cubase to get a better character.

The fourth idea designed was the forest wind. It was chosen as a design idea due to its natural sound and many people might feel a relaxed experience in forests. The sound forest wind was based on recordings downloaded from freesound.com[3] and pink noise. Each sound got an equalizer curve and also a compressor. The final sound-mix was equalized and compressed by Cubase plug-ins.

Due to limitations in time for the listening experiment, the number of sounds had to be limited to three masking sounds. After discussions with colleagues and subjective evaluations, the forest wind sound was decided to be excluded from the final presentation. The choice to exclude this sound was based on its similar characteristics to pink noise and the specific character of the other two sounds, *water waves* and *chatter*. The filtered pink noise was included to be a reference, since this is a common sound for sound masking today. The measured frequency spectrum for the sounds can be seen in Figure 4.3.

3.2. The office layout

The room used for this thesis measured 10 by 5 meters and had a ceiling height of 5 meters. Sixteen absorbing panels were hung from the ceiling at different locations and

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[2] Crowd-chatter-and-talking.mp3 By evsecrets: https://www.freesound.org/people/evsecrets/sounds/135729/ and Club-chatter-london.mp3 By mlteenie: https://www.freesound.org/people/mlteenie/sounds/152874/

[3] Autumn-Forest-Wind By Akacie: https://www.freesound.org/people/Akacie/sounds/73723/ and Forest-Day-Wind-Roadhumm-02.wav By Apostolinkyyti: https://www.freesound.org/people/Apostolinkyyti/sounds/128941/

Frequency [Hz]	125	250	500	1000	2000	4000
Reverberation time [s]	0.87	0.65	0.45	0.38	0.40	0.38

Table 3.1.: Reverberation times in the bands 125 to 4000 Hz.

Figure 3.1.: Layout of the office used for the measurements and listening experiment.

heights in the room. The room had ten workstations, which were separated by 1.4 meter high screens. The screens were both isolating and sound absorbing. Bookshelves were used between some of the workstations. The room had three big windows, approximately 2.9 m x 1.7 m, facing a courtyard, a street and further away also the water. The room also consisted of a smaller window and three door openings, see Figure 3.1.

The walls and ceiling were made of concrete. Most of the ceiling was covered by an absorbing material called ”Träullit”, which is cement-bonded wood wool. The room had a wooden floor on top of concrete and some cabinets along one of the walls.

The reverberation time in the room was measured and averaged for five positions in the room. The reverberation times are shown in octave bands in Table 3.1 .

3.3. Measurement

STI measurements were performed according to the ISO-standard 3382-3 [12] and [13] for the different sound environments. Measurements have also been performed at different times of the work. The acoustical environment in the office has been improved during the time the study was running. STI measurements were performed before and after partition screens and absorbing panels were installed. The first measurements were performed with a NTI AL1 Acoustilyzer and a Tivoli Audio loudspeaker.

The STI was also measured for the different sound conditions used in the listening experiment. It was measured both in the workstations selected for the listening experiment and at the workstations along a line in the room, according to ISO 3382-3:2012. STI at the two workstations used for the listening experiment, was measured using the same sound pressure level for the test signal as was used for the speech signal in the experiment, i.e. 52 dBA at 1 meter from the source. It was measured with a modulated pink noise signal played from the NTI signal generator, where the signal was stored.

The rest of the measurements used the test signal played at 60 dBA at 1 meter from the source. Three measurements were averaged for each of the four measurement positions on the line. The measurement procedure was repeated five times, one for each sound condition. In the sound conditions where masking sounds were used, they were played at a sound pressure level of 45 dBA calibrated in the two workstations used for the listening experiment. Due to the placement of absorbing panels hanging from the ceiling, the sound pressure level varied ±1 dB over the room and gave higher levels in some of the workstations.

The reverberation times were measured with an omnidirectional loudspeaker and the measurement software Samurai installed on a Panasonic computer. The Soundbook sound card, which was installed to the computer, was also used to measure the spectrum of the different sound conditions.

3.3.1. Equipment

The equipment used for the measurements and listening experiment can be seen in the list below. The STI measurements were performed with two different types of equipment. This due to availability of equipment at the points when the measurements were performed. In the final measurement a Genelec 2910A was used instead of the Tivoli Audio to reproduce the test signal. The reason for that was that the Genelec speaker was used in the listening experiment. This loudspeaker model has also been used in other studies [24] for STI and SII measurements.

- NTI Minirator MR-PRO (signal generator)
- Tivoli Audio loudspeaker
- Genelec 2910A loudspeaker
- M-audio Fast Track Pro (sound card)
- SMS STR (Sound masking loudspeaker)
- Norsonic Power Amplifier 260

- Panasonic CF-19, SINUS Messtechnik GmbH Soundbook with Samurai software
- Microphone: BSWA Tech MPA 261, Serial No: 501109
- Microphone: BSWA Tech MPA 261, Serial No: 501103
- Nor 270 Norsonic Omnidirectional loudspeaker
- NTI AL1 Acoustilyzer
- NTI MiniSPL IEC 61672
- NTI XL2 audio and acoustic analyser
- NTI microphone M4260 Serial No: 3091

3.4. Listening experiment

The listening experiment included five sound conditions. One condition was silence where speech and masking sounds were absent and one consisted of only highly intelligible speech without masking. The three conditions with masking sounds were presented together with speech. The speech was reproduced by a loudspeaker placed between the two workstations on the opposite side of the participants, see Figure 3.1. It was placed between two workstations to produce the same sound pressure level in the positions used by the participants. The loudspeaker was used to reproduce a talking colleague in an office. Both silence and speech were included as reference conditions.

Since the order of the presented sounds may affect the results, the order of the sounds were shifted between the participants to get a random order. This means that each session had a unique order of the sounds, which was ordered by a Latin square [4]. This minimizes errors such as fatigue and learning. Each sound was named with an alphabetic symbol, like A, B, C etc. The order of the sounds was then varied for each listening session and mirrored after half of the sessions. The order of the sounds could look like A, B, E, C and D for one session and B, C, A, D and E for the next.

Each sound condition was presented in about five to seven minutes depending on how long the participant needed to complete the task. The next condition started when both participants had completed the serial recall task with associated questions.

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[4] Square array where each sound occurs only ones in each row and ones in each column.

3.4.1. Subjects

Twenty-two office employees with age 24 to 55 years old (M=34.4 years) participated in the listening experiment. They responded to an email invitation sent to all the employees at Norconsults office in Stockholm. Two of the participants were excluded from the analysis since they for various reasons did not follow the instructions. An analysis including the two participants was consistent with the reported results. Three of the remaining twenty participants (12 males and 8 females) reported a slight hearing impairment, which did not affect the results and were therefore neglected. Eleven listening sessions were performed, where each session included two participants.

3.4.2. The environment

The office room used for the listening experiment is described in Section 3.2. Four of the workstations were occupied and used for the listening experiment. Two workstations in the room were empty and not used at all and the rest of the places were sometimes used by employees during the experiment times. Since the experiment took place in a real office building, i.e. not in a laboratory environment, the room could not be occupied for the experiment only. The non participant employees in the office had to work with their real projects. They were told to be as quiet as possible and to not use the phone during the listening session.

3.4.3. Audio material

The masking sounds used for the experiment are described in Section 3.1. Together with most of the sound conditions, also an audio track containing spoken sentences were present. These sentences were used to represent disturbing speech in the office. The audio material used for the speech was binaural recordings recorded in an anechoic environment by the University of Gävle. The sentences were read by a male actor in Swedish. They have earlier been used in studies at the University of Gävle, and are originally coming from the Hagerman test [15]. Each sentence contained four words (names, verbs etc.) and lasted about 3 seconds. The used audio track with the sentences was approximately 5 minutes and was cut to have about one second pause between each sentence. It was sampled at 48 kHz and stored on a NTI Minerator MP-pro. The material was reproduced by a Genelec 1029A loudspeaker placed between two workstations. The speech was played with an A-weighted sound pressure level of 51 dB at one meter, resulting in a sound pressure level of 42 dBA at the used workstations. The spectrum of the speech can be seen in Figure 4.3.

3.4.4. Questionnaire

A questionnaire was used during the listening experiment with questions according to the present sound environments. In the beginning of the experiment before the first sound condition was started, background information of the participant was asked. This included age, gender, hearing loss, alertness and work load. For each sound condition, 16 questions were asked after the serial recall task was completed. These questions were taken from the study by Haapakangas et al. [3] and Haka et al. [25]. It was based on how the participants perceived the sound environment and their subjective performance in the task. The questions together with the results are shown in Table 4.4, Chapter 4. For each of the 16 questions the participants had to rate on a 5-point Likert scale [4] how much they agreed or disagreed on the given statement. To answer the statements the participants used the computer keyboard and buttons 1 to 5.

3.4.5. Performance test

A serial recall task was chosen as the performance test. This test gives an idea how well the participants perform for the different sound conditions. The test consisted of nine trials for each sound condition. Each trial had a sequence of eight digits between 1 and 9, presented on a computer screen in random order. The digits were presented on the screen with the 72-point fontsize . Each digit only appeared once in a sequence and was displayed for 500 ms with an inter-stimuli interval of 300 ms before the next digit was displayed. After a sequence of eight digits the participants were required to recall the digits in the exact same order as they were shown. The digits were recalled by using the numbers on a computer keyboard.

3.4.6. Procedure

The experiments were conducted twice per day during two weeks. The first time was in the morning at 10.15-10.45 and the next was after lunch at 13.15-13.45 o'clock. It took place in a room that can be considered as a medium sized open-plan office [1], described in Section 3.2. The room is one of the rooms at Norconsult's office in Stockholm. The masking sounds were played from two loudspeakers faced upward the ceiling and hanged above the workstations used for the test. They were connected to a Norsonic power amplifier fed through a M-audio sound card from a MacBook Pro. The sounds were played from ITunes where the order of the sounds were set manually. A Genelec 1029A was placed at 1.2 meters above the floor between the two workstations on the opposite side of the partition screen and used to play the speech sound.

A short introduction about the experiment and the setup was given to the participants at the beginning of each listening session. Before the first round of the serial recall task was performed, the participants started to fill in their background information, described in Section 3.4.4. The first sound condition was then played and the experiment continued with the rest of the sound conditions. At the end of the session the participants answered some questions about the other disturbances that might affected them during the experiment, e.g. how much the light or temperature affected them during the test.

The evaluation was performed using a software called *Kogtest*, developed by researchers at the University of Gävle. It has earlier been used in other studies, e.g. by Sörqvist [20]. The setup of the software was changed to fit the present research of this study. It included questionnaires and the Serial recall task. Two workstations were prepared with a computer, screen and keyboard at each position. Each session lasted for approximately 30 minutes. During this time the participants were informed of the structure of the experiment and presented to the five sound conditions. The serial recall task was repeated nine times for each condition, i.e. 45 times in total for the five sound conditions.

3.4.7. Statistical methods

The analysis of the listening experiment was made in SPSS statistics version 22 with a within-person design, i.e all subjects participated in all sound conditions. Both the serial recall test and the questionnaire were analyzed by repeated measures analysis of variance (ANOVA), which is used to determine if there are any statistically significant differences between the sound conditions. A paired-comparison t-test was used to compare the sound conditions among each other.

4. Results

The results are divided into two sections: The first section contains the results from the objective measurements of the room and the sound conditions, i.e. STI measurements and single number quantities. In the section that follows, the analyzed results from the serial recall task and the questionnaire.

4.1. Objective measurements

As described in Chapter 3, the speech transmission index was measured a couple of times during the study because of the improved acoustics in the office. Table 4.1 shows the acoustic quality of the room from the first and the final measurements. The first measurements were measured without any screens and absorbing panels in the room, as in Figure 4.1. The final measurements were taken when absorbing panels and partition screens had been installed in the room, see Figure 4.2. The table shows the measured STI and SPL in the nearest workstation with the measurement signal played at 60 dBA at one meter from the source. The single number quantities r_D, DL_2 and $L_{p,A,S,4m}$ are calculated from the measured results in the room.

Similar measurements were also conducted for the different sound conditions present. These measurements can be seen in Table 4.2 where the sound pressure levels and STI measurements are presented for the nearest workstation to the source. The total A-weighted sound pressure level and background noise level in the room are shown. The single number quantities are calculated for the different sound conditions. Due to the fact that the highest STI values were measured around 0.45 in the nearest workstation when masking sounds were present, the distraction distance, r_D, was calculated to around 2 meters. Along with that the privacy distance, r_P, was also calculated.

The spectrum for the used masking sounds and sound conditions are presented in Figure 4.3. The A-weighted sound pressure level and spectrum of each sound were measured in the used work stations for the listening experiment, at ear-height, i.e. 1.2 m above the floor. The Figure shows the spectrum for the background noise, the used speech and the three masking sounds, pink noise, water waves and chatter. The three masking sounds have similar spectrum, while speech has lower levels in the frequency band 125 Hz - 2000 Hz. The background noise has the lowest levels at all frequencies. The STI values were also measured for each sound conditions at these positions, see Table 4.3.

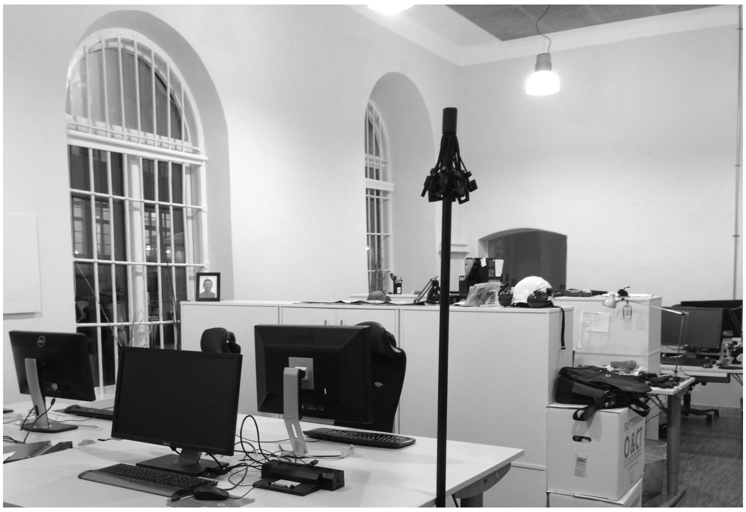

Figure 4.1.: The office before any absorbing panels and screens were installed.

Figure 4.2.: The office after the absorbing panels and screens were installed.

Measurement	Background [dBA]	SPL [dBA]	STI	r_D [m]	DL_2 [dB]	$L_{p,A,S,4m}$ [dB]
Without acoustic imp.	30	59	0.66	20	4	55
With acoustic imp.*	30	52	0.62	12	4	49

Table 4.1.: Measured STI and SPL values in the nearest workstation without and with acoustic improvements. The single number quantities are based on the measured STI and SPL values. * Includes: absorbers hanging from the ceiling, screens and bookshelves.

Sound condition	Background [dBA]	SPL [dBA]	STI	r_D [m]	r_p [m]	DL_2 [dB]	$L_{p,A,S,4m}$ [dB]
Speech	30	52	0.62	12	-	4	49
Pink noise	44	53	0.45	2	11	1.5	51
Water waves	44	53	0.43	2	8.5	2	51
Chatter	44	53	0.41	2	9	2	51

Table 4.2.: Measured STI and SPL values in the nearest workstation with the measurement signal at 60 dBA 1 meter in front of the source. The single number quantities are based on the measured STI and SPL values. Values with ”-” could not be calculated.

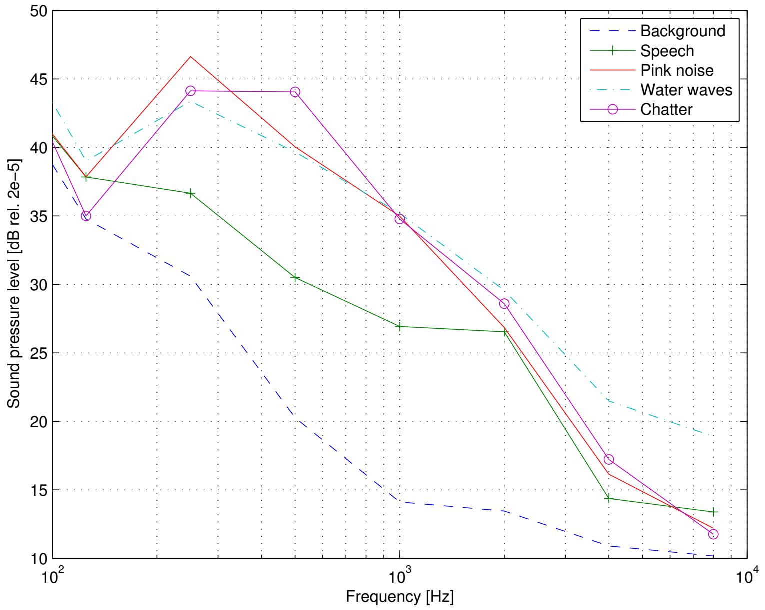

Figure 4.3.: Recorded spectrum from the different sound environments.

Sound condition	Distance [m] pos1/pos2	Background [dBA]	Total SPL [dBA]	STI
Silence	2.4/2.5	30	30	-
Speech	2.4/2.5	30	42	0.48
Pink noise	2.4/2.5	45	47	0.20
Water waves	2.4/2.5	45	47	0.19
Chatter	2.4/2.5	45	47	0.23

Table 4.3.: Measured sound pressure levels and STI values for the five sound conditions in the listening experiment condition. The values represent the two workstations used for the listening experiment and the measurement signal was played at 51 dBA 1 meter in front of the source.

4.2. Listening experiment

The sound pressure level of the measurement signal (speech test signal) was for the listening experiment adjusted to 51 dBA at one meter from the source. Table 4.3 shows the measured background levels, the total sound pressure levels, the STI values and the distance to the source. The sound pressure levels were measured to ± 0.5 dBA at the two positions used for the listening experiment. The given values in the table are the average of the two positions and averaged from three measurements in each position.

The analyzed results from twenty participants in the listening experiment are divided into two subsections, i.e. the serial recall task and the subjective measures.

4.2.1. Serial recall task

The serial recall task was scored according to the strict serial recall criterion, i.e. only digits recalled at the correct serial-position were scored as correct. The resulting scores were calculated as percentage and revealed the following results for the five sound conditions, Silence (M = 68.3, SD = 12.3), Chatter (M = 68.3, SD = 13.7), Water waves (M = 64.5, SD = 13.7), Filtered pink noise (M = 60.8, SD = 11.3) and Speech (M = 57.6, SD = 15.9). These results are also shown in Figure 4.4 as mean with 95 % confidence interval for the five sound conditions.

The analysis of the serial recall task revealed a statistically significant main effect of the sound conditions for mean correct recalled digits in percentage, $F(4, 76) = 4.71, p = .002$, partial $\eta^2 = .20$.

Paired comparison performed with t-tests gave a significant increase of correct recalled digits when speech was compared to silence (t(19) = 3.18, p = .005, two-tailed), and compared to the masked speech conditions, chatter (t(19) = 3.21, p = .005, two-tailed) and water waves (t(19) = 2.3, p = .033, two-tailed). But it did not show any

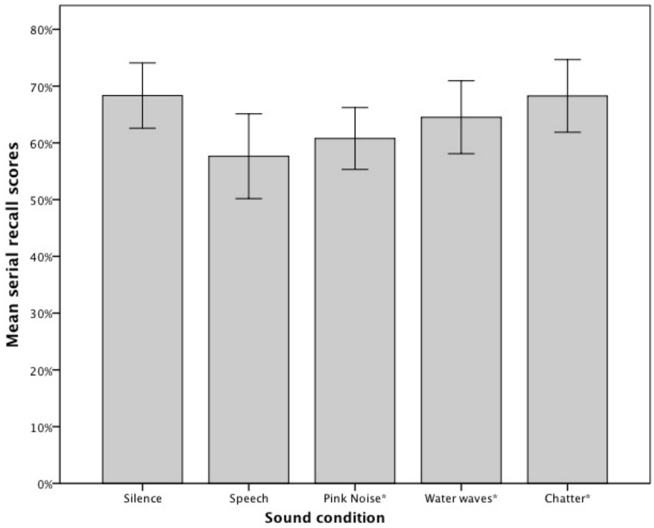

Figure 4.4.: Mean serial recall scores in percentage and 95 % CI for the five sound conditions. The conditions with the asterisk (*) were presented together with speech.

significant difference compared to filtered pink noise (t(19) = 0.80, p = .434, two-tailed). Between the masked speech conditions, chatter showed a significant increase in performance compared to filtered pink noise (t(19) = 3.1, p = .006, two-tailed) but otherwise there were no significant differences.

4.2.2. Subjective measures

The subjective measures are the analyzed results from the questions and statements answered during the listening experiment for each sound condition. The results are summarized in Table 4.4 and divided into three parts. The first part includes the first eleven questions and is summarized as acoustic satisfaction. This is the most interesting part and is summarized in a diagram in Figure 4.5 for the different sound conditions. The different sound conditions had Cronbach's Alpha[1] between 0.87 to 0.91 for the acoustic satisfaction, Table 4.5. The acoustic satisfaction showed a statistically significant main effect for the different sound conditions, $F(4,76) = 17.16, p < .001$, partial $\eta^2 = 0.47$. Four of the questions were reverse-scored in the sum variable. Question twelve was supposed to be included into the summation variable, but the question was not included into the questionnaire from the beginning and was therefore excluded from acoustic satisfaction.

Paired t-test was used to determine any differences in acoustic satisfaction between

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[1] Cronbach's Alpha is used to determine the reliability of the sum variable and the internal consistency.

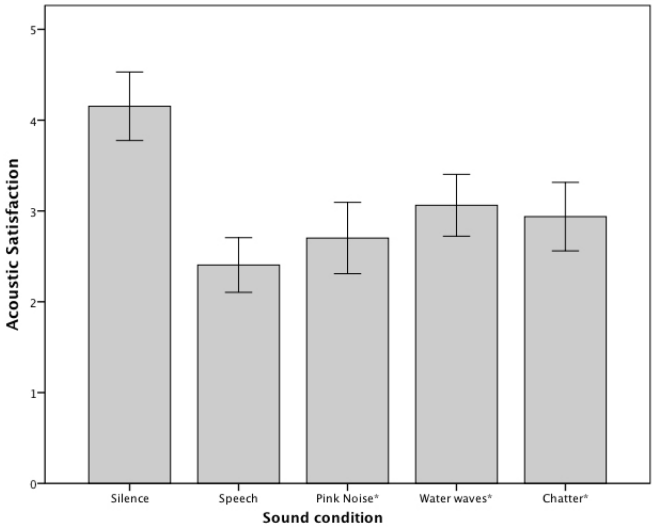

Figure 4.5.: Means with 95 % CI for Acoustic satisfaction, scaled 1-5, showed for the five sound conditions. The conditions with the asterisk (*) were presented together with speech.

the different sound conditions. acoustic satisfaction for silence showed a statistically significant mean increase in the score compared to speech, $t(19) = 8.82, p < .001$, two-tailed. It also showed the same significant increase in satisfaction compared to all masked speech conditions, $p < .001$, two-tailed. Speech is perceived as the least satisfying sound condition and show a significant decrease compared to both chatter ($t(19) = 2.19, p = .041$, two-tailed) and water waves (t$(19) = 3.06, p = .009$, two-tailed). But it did not show any significant difference compared to pink noise ($p = .159$).

Subjective workload in Table 4.4 was calculated as a mean single value from questions 14 to 16 for each sound condition. The repeated measure analysis of variance for the subjective workload showed a statistically significant difference between the sound conditions ($F(4,76) = 16.23, p < .001$, partial $\eta^2 = .46$. There was a significant difference between silence and all other sound conditions. Subjective workload was higher in the speech condition compared with both the water waves condition, $t(19) = 3.11, p = .006$, two-tailed) and the chatter condition, $t(19) = 4.56, p < .0005$, two-tailed. But it did not show any significant difference compared to the pink noise condition, $t(19) = 0.98, p = .340$, two-tailed).

Variable / Question	Silence	Speech	Pink*	Water*	Chatter*
Acoustic satisfaction (question 1 - 11)	*4.2(0.8)*	*2.4(0.6)*	*2.7(0.8)*	*3.1(0.7)*	*2.9(0.8)*
1. SE was pleasant	4.2(1.3)	2.1(0.8)	2.2(1.0)	2.7(1.2)	2.3(1.1)
2. SE was disturbing [r]	1.7(1.1)	4.2(1.1)	3.5(1.4)	3.3(1.1)	3.3(1.2)
3. SE was acceptable	4.5(0.9)	2.5(0.9)	2.7(1.2)	2.9(0.9)	2.6(1.0)
4. SE was loud [r]	1.1(0.4)	2.3(0.7)	2.5(1.0)	2.5(1.0)	3.1(1.1)
5. Overall I was satisfied with SE	4.1(1.4)	2.1(1.1)	2.0(1.1)	2.6(1.2)	2.2(1.0)
6. Habituation to SE was easy	4.2(1.4)	2.2(1.0)	2.3(1.2)	3.0(1.2)	2.8(1.1)
7. Surprising changes occurred in SE [r]	2.2(1.1)	2.3(1.4)	2.1(1.2)	2.0(1.3)	1.9(1.1)
8. SE caught my attention often [r]	1.9(1.0)	3.5(1.3)	2.7(1.3)	2.5(1.1)	2.2(1.1)
9. I could work uninterrupted during the exp.	3.5(1.4)	1.8(1.0)	2.5(1.3)	3.0(1.1)	2.8(1.4)
10. I could work effectively during the test	3.9(1.0)	1.9(1.1)	2.5(1.2)	2.9(1.0)	3.2(1.1)
11. SE would not annoy me	4.2(1.0)	2.2(1.1)	2.0(1.1)	2.7(1.2)	2.3(1.0)
12. I can accept SE consid. my normal work[1]	4.6(1.2)	2.2(1.1)	1.8(1.0)	2.1(1.3)	2.6(0.9)
13. How much did the following disturb your performance?					
a. Speech	1.6(1.3)	4.0(1.1)	3.4(1.4)	2.7(1.3)	2.6(1.3)
b. Masking sound	1.1(0.2)	1.3(0.8)	2.7(1.2)	2.9(1.1)	2.6(1.2)
c. Keyboard typing	2.1(1.1)	1.7(1.0)	1.8(1.1)	1.6(1.1)	1.5(0.8)
d. Sound level	1.4(0.6)	2.6(0.8)	2.5(0.8)	2.9(0.9)	2.7(0.9)
Subjective workload (question 14-16)	*2.4(0.7)*	*4.1(0.8)*	*3.9(0.9)*	*3.4(0.7)*	*3.2(0.9)*
14. SE impeded my ability to concentrate	1.9(1.2)	4.2(1.1)	3.9(1.1)	3.2(1.1)	3.0(1.1)
15. SE impaired my performance	1.7(1.0)	4.2(1.0)	3.8(1.2)	3.4(0.9)	3.0(1.0)
16. The task felt difficult	3.6(1.0)	4.1(0.7)	4.1(0.9)	3.7(1.0)	3.5(1.1)

[1] The question was answered by fourteen participants.

Table 4.4.: Questions and results from the listening experiment. The scale are between 1 - 5 (completely disagree - completely agree). SE = sound environment, r = reverse-scored in the sum variable Acoustic satisfaction. exp.: experiment, consid.: consider. The conditions with the asterisk (*) were presented together with speech.

Variable	Silence	Speech	Pink*	Water*	Chatter*
Cronbach's Alpha	0.91	0.88	0.91	0.87	0.91

Table 4.5.: Cronbach's Alpha for acoustic satisfaction when Question 1 to 11 was summarized for each of the five sound conditions.

5. Discussion

The five sound conditions evaluated in this thesis show some interesting findings. The sound conditions were evaluated by three methods; acoustic quality in form of STI and SPL measurements, a performance measure in form of a Serial recall task and a subjective measure from a questionnaire.

5.1. Objective measurements

The measurements performed in the office with and without acoustic improvements and masking sounds show both similarities and differences. The measurements without any acoustic improvements in the room, such as absorbing panels and partition screens between workstations do not differ in all aspects compared to the final measurements when the improvements were installed. The comparison between the office with and without acoustical improvements was not a main question in the present thesis and the improvements were not a part of this investigation. The office used for the thesis was fairly new for the company and was not completely finished when this thesis started. Because of the improvements that were made in the room, it could be an interesting aspect to show and discuss in this work.

From the results in Table 4.1 some differences may be obtained. The A-weighted sound pressure level in the nearest workstation from the source was reduced by 7 dB when absorption and partition screens were installed. This is quite a bit and is mostly due to the installed screens between the workstations, which block and also absorb some of the sound. The absorbing panels hanging from the ceiling also help to reduce the sound and reduce some of the ceiling reflections. The single number quantity $L_{p,A,S,4m}$ which depend on the SPL and the distance was also decreased in consequence of the reduced levels, from 55 to 48 dB. On the other hand, the DL_2, which also depend on the level vs. distance did not change and was 4 dB even after the improvements in the room. This might be due to the distance of four and eight meter used for the calculation of the quantity. Even if the level itself is reduced, the relative level reduction might not be changed. This is probably due to the size of the room where the last measurement point furthest away was at 8 meters. This point could be affected by reflections from the back wall, and due to this do not change so much from the first measurement. Looking at the distraction distance, r_D, which depends on the STI value, one can see a clear difference and improvement in the room. The distraction distance is reduced from 20 to 12 meters, which is a good reduction. Although the quality of the room is still categorized as a Class D office when the quantities are compared to the values in Table 2.1 recommended from Virjonen et. al. [11]. It still shows an improvement and the importance of screens and absorbing materials for the room and its acoustic quality.

The same type of measurements were also conducted in the room with the different sound conditions, which is the main study of this thesis. The results from these measurements, Table 4.2, shows a big difference in privacy and the distraction distance. When masking sounds were used in the office, the STI values decreased to below 0.50 in the nearest workstation. The distraction distance, was then calculated to around 2 meters. The next quantity, privacy distance $r_p \leq 0.20$, can then be applied. The distraction distance of 12 m without masking decreased to 2 m with masking in the room and a privacy distance between 11 and 8.5 m were reached when masking sounds were used. It is also interesting to see that the total SPL in the room only increases by 1 dB when masking sounds are used compared to only the test signal without masking. The other two quantities, DL_2 and $L_{p,A,S,4m}$ are not relevant for masking sounds, which can be seen in the table 4.2. These quantities do not take masking sounds into account and are based on the total SPL in the room.

5.2. Listening experiment

The main goal with this study was to evaluate different masking sounds and compare them to silence and speech. The results from the listening experiment show evident results on the improvements when masking sounds were used. The objective performance, i.e. serial recall task, showed a significant increase in performance for water waves and chatter compared to speech. The serial recall task require a high amount of concentration to perform well and the study showed an expected picture on how irrelevant speech affect the concentration and performance in this task. The results agreed well to the hypothesis asked in Q1, in the Introduction. Speech by itself was also rated as the lowest sound condition in the variable acoustic satisfaction.

Pink noise showed lower scores in both the acoustic satisfaction and the serial recall task than the two other masking sounds. This is a little bit unexpected since it is the most common sound in commercial sound masking systems. Looking at the objective measurements it is also shown to have the highest privacy distance, 11 m, Table 4.2. On the other hand it does not show any difference in the STI measurements performed for the sound conditions at the workstations, where the listening experiment took place, Table 4.3. Another reason for the difference in objective performance and acoustic satisfaction may be that both water waves and chatter have temporal variations in the sounds, while pink noise is a constant masking sound. The study by Haapakangas et. al. [3] showed similar results. In their study the sound *spring water* did very well in the serial recall task and better than both ventilation noise and pink noise. They discussed that it may be due to the temporal variations in the sound and that the sound's modulation coincide with the modulation of speech. When the masking sound itself contains small temporal variations, the variations caused by the irrelevant speech may not affect the concentration as much as with a constant masking sound.

In acoustic satisfaction, both water waves and chatter showed a significant difference to irrelevant speech but pink noise did not. As an answer to research question Q2 the water waves showed the best results for acoustic satisfaction even though chatter was close and did not show any significant differences. For the serial recall task, speech masked with chatter showed the best results, except for silence, although water waves was not far behind. This also answer question Q3 where both the masking sounds chatter and water waves gave higher scores in the performance task than pink noise.

Question twelve in the questionnaire "I can accept the sound environment considering the work I do" was answered by thirteen participants. The question was excluded from the analysis of the acoustic satisfaction since it was added too late and almost half of the participants had already done the listening experiment. However, it is a relevant question and a majority of the participants who did answer the question, answered that they totally agreed to that statement in the sound environment silence, i.e. they can accept the sound environment considering the work they do. This is not a surprise, since it has been experienced to be the optimal condition in several studies and the condition people want to reach. The other sound conditions did not show as clear results. Speech masked with chatter was rated as the second best (M=2.6, SD=0.9) and pink noise as a masker was the least accepted sound (M=1.9, SD=1.0). The four sound conditions except silence, were all rated low on the acceptance scale. They did not show any significant difference between each other. With a larger group of participants the results may be more clear.

The three masking sound conditions received the mean score between 2.6 and 3.0 for question 13b, how much the masking disturbed the performance, Table 4.4. In question 13a, how much speech disturbed the performance, irrelevant speech showed the highest mean score (M=4.1, SD=1.1). The masked conditions water waves and chatter scored (M=2.7, SD=1.2) and (M=2.6, SD=1.3) respectively, while pink noise got (M=3.5, SD=1.4). This shows that the disturbance by speech may be reduced when speech is masked by water waves ($p = .001$) and chatter ($p = .01$). It may be reduced when it is masked by pink noise as well, but it did not show any significant difference here.

The sum variable subjective workload, including question 14 to 16 show a similar pattern where speech is rated to affect the workload most, which is in line with earlier studies and researches, e.g.[3, 7]. By the masked speech conditions, water waves and chatter do best and speech masked by pink noise disturb the workload a little bit more. This may be due to the temporal variations in the masking sounds as discussed earlier where pink noise has a constant sound. This is also in line with Norconsult's theory, where they wanted to test natural sounds of the environment. The frequency spectrum of pink noise shows a higher level of low frequency sound than water waves, but it is similar to chatter. This frequency difference should not affect the workload and neither should STI. The measured STI of the sounds in the listening experiment conditions, Table 4.3, show a low STI for all three masked conditions.

5.3. Limitations

There are several limitations in this work. The listening experiment was performed in an existing open-plan office where people worked. This has both advantages and disadvantages. The positive aspects are that the participants were real employees that were used to working in open-plan offices and the environment gives a ”real” office feeling. Some of the drawbacks may be that employees had to work in the room when the listening experiment took place. They were asked to be as silent as possible and not to disturb the participants. Nevertheless some sounds occurred during the tests which may disturb the participants. Sounds such as keyboard typing and smaller conversations are hard to avoid in an office building where people work. Another limitation was the time schedule used for the listening experiment. Due to employees participation in the listening experiment, it could not be held for too long, since they had other work to do. The experiment was held as short as possible which did not leave any room for habituation periods, recommended by Haapakangas et al. [3]. As soon as each sound condition was started, the participants started with the serial recall task and continued with the following tasks.

The use of absorbing panels hanging from the ceiling created small changes in sound pressure level over the room. Especially the different characters of the sounds were noticed to give some changes in sound pressure levels in different places in the room. Some spaces with bigger distances between the panels received higher levels while some workstations covered by a panel received slightly reduced sound pressure levels.

6. Conclusion

The aim of this study was to evaluate different masking sounds and find alternatives to pink noise, which is currently used in offices that use masking. The results show that masking sounds do increase the work performance and privacy in an open-plan office. It also shows that some sounds may be more preferable as masking sounds than the filtered pink noise usually used in offices today. Objective measurements for the different sound conditions showed an increase for the acoustic quality factor distraction distance, r_D. When masking sounds were present, the distraction distance decreased from 12 m without masking to about 2 m.

The type of sound and character may influence the performance and acoustic satisfaction beside the used STI values. The results from the listening experiment showed that the sound condition where speech was masked by water waves was rated as the most pleasant and gave the highest acoustic satisfaction. From the serial recall task, used as the performance measure, the masked condition containing chatter gave the highest score and least changes compared to silence. Silence was rated with the highest acoustic satisfaction and gave the best performance in the serial recall task. As expected the sound condition with irrelevant speech and no masking sound was rated as the least preferable. It also gave the lowest score in the serial recall task, which is used as a standard task when irrelevant sounds are tested.

The listening experiment took place in an open-plan office building with employees from the companies Astando, Norconsult and Technogarden. This implies that the participants are used to working in the present environment even though the use of masking sounds was something new. The drawback with this was a tight time schedule and that the listening experiment had to take place within a limited amount of time.

7. Future work

This thesis showed some interesting results with sounds more preferable than the usually used pink noise. Though the listening experiment was somewhat limited, it would be interesting to see how the different sound conditions would perform if the employees were exposed for a longer period of time. With the present study where each sound was presented for about five minutes, it would be interesting to see the effects if they are used for a day or a week. It would also be interesting to see the results from other performance tests.

Another interesting aspect could be to test a stereo or multichannel system as the masking system. This could give the sounds an even more natural sound. In this thesis the masking sounds were played in a mono system, i.e. same channel and sound to all loudspeakers installed in the ceiling.

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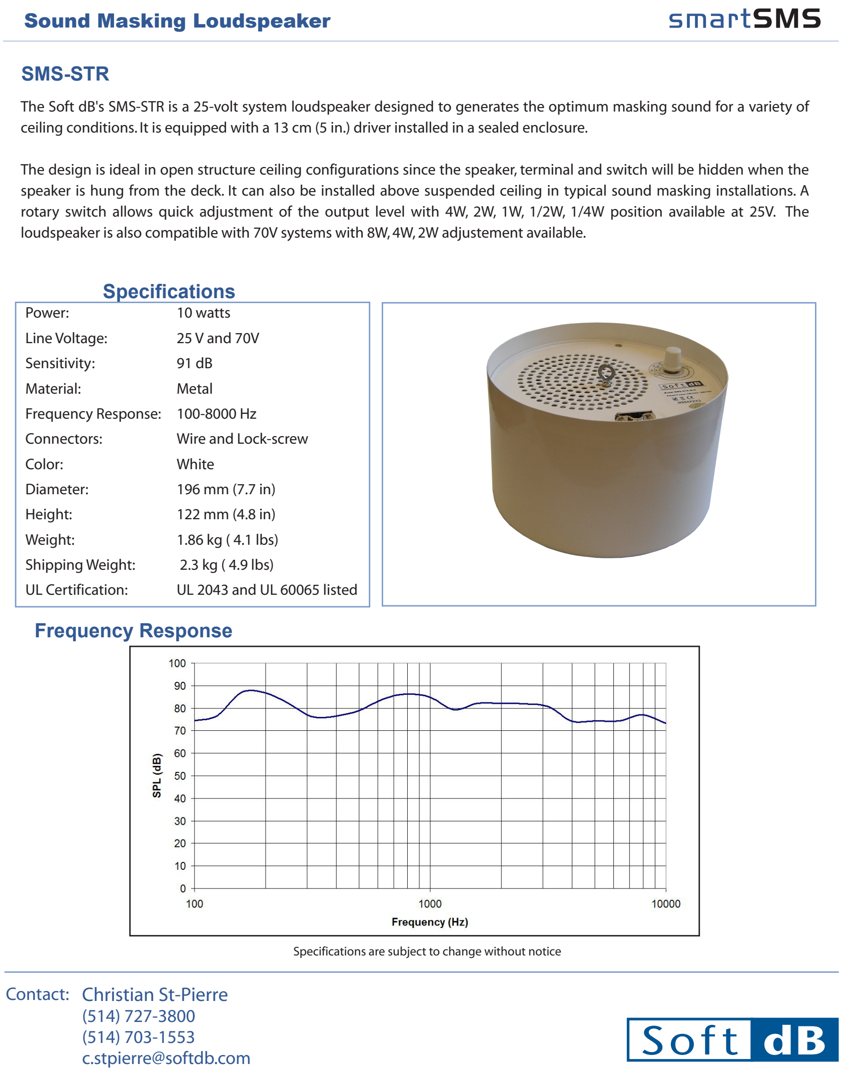
A. Sound masking loudspeaker



Sound Masking Loudspeaker

smartSMS

SMS-STR

The Soft dB's SMS-STR is a 25-volt system loudspeaker designed to generates the optimum masking sound for a variety of ceiling conditions. It is equipped with a 13 cm (5 in.) driver installed in a sealed enclosure.

The design is ideal in open structure ceiling configurations since the speaker, terminal and switch will be hidden when the speaker is hung from the deck. It can also be installed above suspended ceiling in typical sound masking installations. A rotary switch allows quick adjustment of the output level with 4W, 2W, 1W, 1/2W, 1/4W position available at 25V. The loudspeaker is also compatible with 70V systems with 8W, 4W, 2W adjustement available.

Specifications

Power:	10 watts
Line Voltage:	25 V and 70V
Sensitivity:	91 dB
Material:	Metal
Frequency Response:	100-8000 Hz
Connectors:	Wire and Lock-screw
Color:	White
Diameter:	196 mm (7.7 in)
Height:	122 mm (4.8 in)
Weight:	1.86 kg (4.1 lbs)
Shipping Weight:	2.3 kg (4.9 lbs)
UL Certification:	UL 2043 and UL 60065 listed

Frequency Response

Specifications are subject to change without notice

Contact: Christian St-Pierre
(514) 727-3800
(514) 703-1553
c.stpierre@softdb.com

Soft dB

Figure A.1.: The specification sheet for the SMS-STR loudspeaker used to play the masking sounds.