Perception of disturbing sounds
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ÅSA SKAGERSTRAND

Perception of disturbing sounds
Investigations of people with hearing loss and normal hearing
Abstract


The present thesis concerns the daily sound environment and the human perception of the same. The sound environment affects the possibility to be active in a communication. With background noise, it may be harder to hear desired signals, and when suffering from a hearing loss, negative effects of the background noise increase. Previous research has explored, that persons with hearing loss benefit from hearing aid usage, but there is a risk of non-usage due to low sound quality. The non-usage of hearing aids has furthermore been described as a cause of isolation and social withdrawal for persons with hearing loss.

The general aim of the present thesis is to explore the concept of disturbing sounds in a daily sound environment and to examine the influence of hearing loss and hearing aid usage. Disturbing sounds were investigated in means of perception of loudness and annoyance, where loudness concerned the acoustical properties, mainly sound level, whereas annoyance concerned the psychological phenomenon, defined as an individual adverse reaction to noise. The results of studies I and II showed, that hearing aid users experience disturbing sounds more or less daily, and that those sounds resulted in a decreased usage of hearing aids. The effect of disturbing sounds seemed to rely on several factors, acoustical as well as psychological, and there was not one single factor providing a full explanation of disturbance. In study III and IV, the perception of sounds in normal hearing and hearing impaired persons were thoroughly examined and revealed that hearing thresholds affect the perceived loudness and annoyance. Furthermore, the effect of hearing aids on loudness and annoyance perception was investigated. The results showed that hearing aids restored the loudness and annoyance to levels comparable to people with normal hearing function. The results of the studies stress that additional research should focus on the implementation of knowledge of disturbing sounds in audiological rehabilitation, in order to increase the benefit of hearing aid usage.

Keywords: perception, annoyance, loudness, hearing loss.

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List of studies

Study I

Study II

Study III

Study IV
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## Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
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<tr>
<td>AR</td>
<td>Audiological Rehabilitation</td>
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<tr>
<td>CI</td>
<td>Cochlear Implant</td>
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<td>dB</td>
<td>decibel</td>
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<td>dB HL</td>
<td>decibel Hearing Level</td>
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<td>dB SPL</td>
<td>decibel Sound Pressure Level</td>
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<td>DLM</td>
<td>the Dynamic Loudness Model</td>
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<td>EM</td>
<td>Energetic Masking</td>
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<td>HA</td>
<td>Hearing Aid</td>
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<td>HINT</td>
<td>Hearing in Noise Test</td>
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<td>Hz</td>
<td>Hertz</td>
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<td>ICF</td>
<td>International Classification of Functioning</td>
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<td>IHC</td>
<td>Inner Hair Cells</td>
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<td>IID</td>
<td>Interaural Intensity Differences</td>
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<td>ILD</td>
<td>Interaural Level Differences</td>
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<td>IM</td>
<td>Informational Masking</td>
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<td>IPD</td>
<td>Interaural Phase Differences</td>
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<td>ITD</td>
<td>Interaural Time Differences</td>
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<tr>
<td>kHz</td>
<td>kiloHertz</td>
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<tr>
<td>MLB</td>
<td>Monaural Loudness Balancing test</td>
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<tr>
<td>PTA4</td>
<td>Pure Tone Average for 0.5, 1, 2, and 4 kHz</td>
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<td>TVM</td>
<td>the Time Varying Model</td>
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1. Introduction

The surrounding urban environment is built up of physical properties and acoustic characteristics as well as individual perceptions from vision, smell, and hearing. The urban environment is increasingly affected by sounds of varying sources and quiet places are rarely to be found. Lack of silence affects the human body in many ways, and the possibility to avoid sound is not always given. Sound can be somewhat ambiguous as it provides necessary information, entertainment, and relaxation but can, on the other hand, cause disturbance, in form of annoyance or masking, reducing the possibility to perceive desired signals. It is often assumed that everyone can perceive oral information, such as announcements at train stations, buses, television, and homepages on the internet. All informative sound sources almost omnipresent in our environment also create a never silent soundscape filled with concurrent sounds. This diffuse soundscape aggravates separation between different stimuli and creates confusion, especially for hard of hearing people.

This thesis aims to highlight the perception of sounds, occurring in our surroundings, often perceived as disturbing and that affects persons with hearing loss, in an already difficult listening situation.

2. Background

Hearing loss is one of the more common disabilities in Sweden. Approximately 18% of the Swedish population between 16 – 84 years’ experience subjective hearing loss according to StatisticsSweden (2015). Subjective hearing loss is there defined as “having problems to hear in a conversation between several persons”. Problems to hear a conversation can occur due to several reasons; poor conditions in the sound environment or poor input signals, e.g. unclear speech, psychological conditions, or a hearing problem (Hallam & Corney, 2014). Problematic situations within a conversation can occur due to speech-signals that are deteriorated by a disturbing soundscape, thereby increasing the risk of information loss for the persons involved in the conversation (Rawool & Keihl, 2008, Lemke & Scherpriet, 2015). Not to be able to take part in a conversation can reduce a person’s participation in society and cause exclusion, subjective and/or objective (Lemke & Scherpriet, 2015). The first level of inclusion in auditory communication is a usable hearing function provided by a functioning cochlea, nerve fibres and adequate brain capacity. However, a functioning hearing
organ is not sufficient for a beneficial auditory communication. The surrounding environment can be a facilitator or a hindrance due to e.g. background noise. Describing both internal and external aspects of auditory communication highlights the situation including bio-psycho-social aspects and not just aspects of a person’s damaged hearing organ. The bio-psycho-social aspects of a communication disability are summarized in the International Classification of Functioning (ICF) (WHO, 2001). Within the ICF framework, health conditions are not only described as a patchwork of body parts that fail to provide good health and quality of life when damaged, but also describing psychological and social consequences of this health condition (WHO, 2001).

Research as well as clinical experience from rehabilitation of persons with hearing loss, provides information of the, often negative, consequences due to hearing loss in a person’s daily life (Manchaiah & Stephens, 2013). As mentioned above, the sound environment can cause decreased audibility due to e.g. background sounds. When a person suffers from a hearing loss, the possibilities for auditory communication are further reduced. In order to overcome audibility problems, the use of technical devices, predominantly hearing aids, can be recommended (Bentler et al., 2004, Dawes et al., 2013a). Nevertheless, hearing aids are not generally beneficial in all situations, and may also create problems for the user instead of improving audibility and possibilities of participation. Furthermore, sounds *per se* have both positive and negative effects on human beings. These effects, especially the negative effects, are well studied. Sound masks other sounds and reduces audibility, but furthermore causes physical reactions, e.g. insomnia, stress, cardiac problems, but also a more diffuse feeling of being disturbed (Canlon et al., 2013, Maris et al., 2007, Ndrepepa & Twardella, 2011). Previously no, or very little, attention has been paid to persons with hearing loss or persons using listening devices regarding sound disturbance.

### 2.1 The concept of sound

Sound, the physical phenomenon of a vibratory motion, causes the density of molecules in a medium, to fluctuate and thereby produce a soundwave travelling through the medium (Yost, 2007). Most often, sound propagation in air is described, since the human ear most commonly perceives sound via sound propagation through air. The above mentioned fluctuation of molecule-density in the air consists of areas of compressions and rarefactions due to changes in distance between the molecules.
The change of density in the medium can be measured by different means, e.g. intensity or sound pressure. The larger the difference in density within the medium is, the stronger the level of the sound. The amplitude of a sound, is often reported as the level, a description using a logarithmic decibel (dB) scale. The decibel scale describes the ratio between the sound pressure of two sounds, the sound pressure of the signal in question and a reference sound pressure. As reference sound pressure, the amplitude where a normal hearing person just can detect a sound of 1 kHz, standardized as 20 µPa, most commonly is used and is referred to as dB SPL.

Furthermore, sound is described by means of frequency, which specifies the number of periods, or sound wave cycles, occurring in 1 second, i.e. cycles per second measured in Hertz (Hz). If frequency is the physical property of the sound, pitch is the corresponding psychoacoustical property. Pitch is the perception of the frequency, sounds with high frequencies represent high pitch sounds and low frequencies represent low pitch sounds.

Sound propagates spherically in the surrounding medium if there are no reflective surfaces. Due to this spherical propagation, sound intensity declines according to the inverse square law, i.e. when doubling the distance between the sound source and the listener, sound intensity reduces to $\frac{1}{4}$, provided that there are no reflections. Sound propagation is also affected by obstacles causing alterations of the sound wave. Sound waves can be reflected, refracted, diffracted or absorbed. These wave phenomena result in an ever changing sound environment as the physical properties of sounds together form the surrounding soundscape or sound environment (Yost, 2007).

### 2.2 Hearing and listening

The auditory system provides the human being with the possibility of being able to hear as well as the function, or rather the activity, of listening. The functions of hearing and listening are interchangeable dependent on each other.

#### 2.2.1 Hearing function

The function of hearing relies on two parts, the peripheral and the central auditory system. The peripheral system is responsible for receiving sound signals from the surrounding environment and the initial signal processing within the cochlea. The central system, within the brainstem and the auditory cortex, is responsible for further sound processing.
The peripheral system consists of the external ear, the middle ear and the inner ear (figure 1). The external ear, which includes the pinna and the external auditory canal, captures, amplifies and transmits the sound to the tympanic membrane. Via the tympanic membrane, the sound wave propagates through the ossicles (malleus, incus, and stapes) in the middle ear, to the oval window. The initial air borne sound wave is thereby transformed into a mechanical vibration, amplified by the area ratio between the tympanic membrane and the stapes footplate, and passed on to the liquids, endolymph and perilymph, in the inner ear via the stapes footplate in the oval window. The peripheral system thereby acts as a sound amplifier, improving the strength of the signal with up to 20 dB, improving the perception of weak sounds. The inner ear, the cochlea, functions as a converter from liquid borne soundwaves to electrical signals that trigger the nerve fibres in the 8th cranial nerve (the auditory nerve).

Figure 1: Schematic figure of the human peripheral auditory system

Furthermore, the cochlea supports the initial signal processing of a sound. As a sound wave travels through the cochlea, the basilar membrane is set in motion, from the base toward the apex of the cochlea. The traveling wave of the basilar membrane has an excitation pattern with the highest ampli-
tude at the distance from the oval window, where the frequency of the present sound is processed (Moore, 2004). This representation of frequency in the inner ear is described by the place theory. The place theory is a basic explanation of frequency perception, even though there are other factors influencing frequency perception. The place theory explains how the tonotopical organisation of the basilar membrane influences the perception of frequency of a sound, where high frequency sounds are mainly processed close to the oval window (the base of the cochlea) while low frequencies are mainly processed in the apex of the cochlea (Zwicker & Fastl, 1999). The hair cells within the cochlea together with the afferent nerve fibres are responsible to process a specific frequency. Also loudness perception depends on sound processing within the cochlea’s basilar membrane. Firing rates of nerve fibres alter due to the intensity of a sound; sounds with higher sound level cause a higher firing rate, as more nerve impulses arise.

The central auditory system processes the neural signals from the fibres in the auditory nerve. Information from the inner hair cells (IHC) is transmitted to the auditory nerve, which consists of both afferent and efferent fibres. Afferent fibres transmit signals to the cochlear nucleus complex in the brainstem and the efferent nerve fibres transfer signals from the superior olivary complex to the organ of corti (Palmer & Rees, 2010). Via the cochlear nucleus, the signal is transmitted further on to the auditory cortex in the temporal lobe (figure 2). The nuclei active in the auditory system have different features. The cochlear nuclei are, similar to the cochlea, structured tonotopically, which provides the possibility to differentiate between e.g. tones and noise, before the signals are conveyed further on the central auditory pathway (Palmer & Rees, 2010). The superior olivary complex is important for sound localization as the nuclei decode differences in intensity, time, and phase for signals to the right and left ear respectively. These differences are referred to as interaural level differences (ILD), interaural intensity differences (IID), interaural time differences (ITD), and interaural phase differences (IPD). The inferior colliculus is sensitive to spectral changes (amplitude and frequency modulations), but also to ILDs and ITDs. The sensitivity of spectral changes within the inferior colliculus is essential for phoneme recognition. Hence, there is signal processing throughout all nuclei, but the final signal identification takes place in the auditory cortex, also tonotopically organized. (Saenz & Langers, 2014, Palmer & Rees, 2010). Timbre discrimination, spatial localization, and noise filtering are functions associated with the auditory cortex. All signals are transmitted.
from the peripheral system by mainly contralateral but also ipsilateral pathways within the auditory system to the auditory cortex. This design provides a bilateral stimulation of the brain, thereby providing an optimized basis for sound localization and speech perception.

**Figure 2: Schematic figure of the auditory pathways**

### 2.2.2 Listening

The function of listening depends on several factors, described within the scientific field of psychoacoustics. Psychoacoustics is studying the physical, psychological, and perceptual correlates of sounds. Some of the key aspects for the function of listening, and by that the possibility to be able to interpret sound signals, are described in the following sections.

In order to quantify auditory sensations within the field of psychoacoustics four types of methods are used; detection, discrimination, identification, and rating. The measurement of detection basically consists of discovering
the presence of sound stimuli, used in e.g. pure tone audiometry, while discrimination targets distinguishing and differentiating between different stimuli. Identification requires the skill to both detect and distinguish sounds to be able to recognize (identify) a stimulus. The top level of psychoacoustic measures is rating, where sound stimuli are quantified according to some predisposed component. Most commonly, rating is used for loudness measurements, but also for quality or perceptive ratings. Rating sounds provide information of the perceived experience of a psychological correlate to the physical characteristics of sound. The subject will be asked to judge a stimulus using verbal descriptors, in several steps. Within the literature there are several descriptions of different scales used for rating tests (Cox et al., 1997).

2.2.2.1 Frequency
The interpretation of a sound is, among other factors, based on the perception of frequency. Speech perception depends on the ability to detect and discriminate between frequencies. As previously mentioned, the basilar membrane is tonotopically organized, and so is the brainstem, and the auditory cortex, providing a distinct separation of frequency as each tone of a stimulus causes a region of the basilar membrane to vibrate (Zwicker & Fastl, 1999). Frequency selectivity and frequency resolution, describing the ability of the auditory system to separate the components of a complex sound, are interdependent of each other (Moore, 2004). Frequency analysis has been described as a mechanism of overlapping band-pass-filters, referred to as auditory filters (Moore, 2004). Fletcher described this as a theory of critical bands where he assumed that the ear behaves as a bank of band-pass filters. His experiment showed that a tone was masked by a band-pass filtered noise masker, centred at the frequency of the tone. But, if the bandwidth of the masker increased, the detection threshold of the tone would remain constant. In other words, with increasing bandwidth of the masker, the threshold of the tone increases monotonically with the masker bandwidth. At a certain bandwidth, known as the critical bandwidth, the threshold of the tone becomes constant (Zwicker & Fastl, 1999).

2.2.2.2 Loudness
The possibility to perceive sound and to obtain variations in magnitude is a very important factor in human evolution and modern life. Loud sounds are often connected to alarm for danger, such as thunder or a passing train. The
perception of the physical property of sound amplitude or intensity is loudness. Loudness perception supports the determination of for example distance and localization of a sound source (Lotto & Holt, 2011, Moore, 2004). To perceive sound signals, one has to relate to the concept of loudness of a sound, defined as the subjective impressions of the magnitude of a sound (Moore, 2004). The perception of loudness primarily takes place in the nucleus of the auditory nerve, but also in the auditory cortex of the brain (Dix et al., 1948). Besides being determined by the physical intensity of a sound, loudness is affected by spectral content and temporal variations (Thwaites et al., 2016, Rasetshwane et al., 2015). A broadband signal is usually perceived as louder than a narrowband signal at the same sound pressure level (Oberfeld et al., 2012, Fletcher & Munson, 1933). This effect occurs due to the auditory system analysis by critical bands as a broadband signal activates a greater amount of critical bands than a narrow band signal and thereby causes a perception of increased loudness (Oberfeld et al., 2012, Moore, 2002). A complex sound with a given energy, and with its bandwidth within a single critical band, has loudness independent of the bandwidth. However, if the bandwidth of the complex sound is increased beyond the critical band, the perceived loudness begins to increase (Moore, 2004).

The perception of loudness is furthermore affected by temporal factors. A signal of short duration, at a certain sound pressure level, is often perceived as softer than a signal at the same sound pressure level but with longer duration. As there are frequency-specific processing channels responsible for the neural activity within the IHC in the cochlea, loudness perception is also dependent on frequency (Phillips & Carr, 1998).

To better comprehend and deal with the concept of loudness, several loudness models have been developed. Models for the prediction of loudness are valuable tools as they can reduce the use of time consuming subjective tests. Loudness models are for example used for development of algorithms calculating individual amplification in hearing aids (Rennies et al., 2010). During the years, several loudness models have been applied to model and explain the loudness function within the human auditory organ. In the 1950’s Steven’s power law was used to establish new models. Steven’s power law relates subjective loudness to the intensity of a stimulus, measured in sone, i.e. the sone-scale relates loudness to a reference (in general 1 sone correspond to an input signal of 40 dB SPL at 1 kHz) (Appell et al., 2002). A doubling on the sone-scale corresponds to a doubling in perceived loudness. According to the equation for Steven’s power law the perceived loudness are doubled with a 10 dB increase of the input level. The drawback
of Steven’s power law for loudness prediction is that it does not take into account the absolute threshold where the changes in loudness are more rapid (Appell et al., 2002). Furthermore, Steven’s power law does not incorporate the effect of the spectrum of the sound for loudness predictions. Several models were evolved, based on Steven’s power law, which intended to adjust for those drawbacks (Appell et al., 2002). Zwicker extended the model to predict loudness not only as a function of intensity but also as a function of spectral shape of a sound (Appell et al., 2002, Zwicker & Fastl, 1999) which formed a base for following loudness models. The model by Zwicker was appropriate for stationary sounds and was further extended to predict the loudness for time varying sounds (Zwicker & Fastl, 1999). The model proposed by Zwicker (Appell et al., 2002) accounts for several psychophysical facts: hearing threshold, the change in loudness with level, spectral masking of frequency components, and the effect of spectral loudness summation. Additionally, a model for hearing impaired listeners accounted for alterations in perception as raised hearing threshold, loudness recruitment, and reduced spectral loudness summation (Zwicker & Fastl, 1999). The general structure of the loudness model by Zwicker is based on filtering of the outer and middle ear, auditory filtering, calculation and transformation of excitation patterns. The filtering represents critical bands within the cochlea and the excitation patterns are calculated for several channels. Several loudness models have used that general structure when extending the models to better explain the loudness function of the human auditory function (Zwicker & Fastl, 1999, Appell et al., 2002, Moore & Glasberg, 1997).

Loudness models predict the auditory loudness function for either steady state sounds or for time varying sound sources. The models primarily used simple steady state sounds as sinusoidal tones, tone bursts or noise (e.g white or pink noise). If, at constant overall intensity, the bandwidth of a signal is varied, keeping the signal’s bandwidth within the same critical band/s, the overall loudness remains constant. If the increasing bandwidth of the signal involves an increasing number of critical bands, the loudness increases due to spectral loudness summation. However, this is only valid for steady state sounds. For time-varying sounds, more properties are affecting the perceived loudness, the so called temporal integration of loudness (Rennies et al., 2010). The effects of temporal integration indicate that perceived loudness increases with duration even though the sound-intensity is constant. So, the models using steady state sounds predicted the basic loudness function but were not sufficient as descriptors and predictors for
a real world sound environment, since temporal properties of the input was ignored (Rennies et al., 2010). A need for models predicting loudness for time-varying sounds was raised and new models have been established. To fully depict the loudness function, the models had to take into account both spectral and temporal aspects of loudness. Few models accounts for both of these aspects, most established are the models of Chalupper & Fastl (2002) and Glasberg & Moore (2002). Those two originate from the Zwicker model (Zwicker & Fastl, 1999) but with differences in used temporal constants where the model by Glasberg and Moore (TVM = the Time Varying Model) is seen as more elaborated since it use several time constants compared to the Chalupper and Fastl model (DLM = the Dynamic Loudness Model) that includes only one time constant (Rennies et al., 2010).

Initially, the loudness models were established for normal hearing thresholds and in order to extend those models to incorporate hearing impaired listeners, two major strategies were proposed, the one-component and the two-component approach. The one-component approach assumes that perceived loudness is modelled by one single parameter, a parameter describing the hearing loss (Appell et al., 2002). The two-component approach was presented by Launer (1995) and argued that perceived loudness is predicted by the hearing threshold and the reduced dynamic range independently (Appell et al., 2002).

Measurements of loudness have during the years been developed and incorporate several psychoacoustic procedures, such as loudness matching, magnitude estimation/production, and categorical loudness scaling (Marks & Florentine, 2011, Launer, 1995). For a more detailed description of the development of loudness measurements, see Florentine et al. (2011).

The loudness matching technique requires the listener to compare the loudness of two sounds (reference and target) and to adjust one in order to produce equal loudness. Magnitude estimation is a rating task where the listener is asked to assign perceived loudness on a corresponding position on a scale (Ellermeier et al., 2001). Those scales can be continuous or unbounded, either marked with verbal descriptors or by numbers. The magnitude production on the other hand consists of a task where the listener is requested to adjust the intensity of a sound to achieve a loudness perception proportional to a specific given number. The cross-modality matching is a variation of the magnitude estimation where the listener is asked to adjust the magnitude of a physical property of a sound (e.g. the brightness or the length) to match the loudness of a sound (Rasetshwane et al., 2015, Marks & Florentine, 2011, Launer, 1995). Finally, the categorical loudness scaling
is a task where the listener is presented with stimuli at different levels and frequencies and asked to scale loudness using presumed verbal descriptors like “very soft” to “very loud” (Rasetshwane et al., 2015, Florentine et al., 2011, Cox et al., 1997, Robinson & Gatehouse, 1996). The loudness category scaling is a robust and reliable test for both normal hearing people as well as persons with hearing loss, well suited for e.g. hearing aid fitting (Robinson & Gatehouse, 1996). However, the method is considered as time consuming in a clinical setting and the outcome is dependent on type of stimulus (Robinson & Gatehouse, 1996). The stimuli used in loudness measurements have been tones, speech and noises, but recently, the interest for more ecological valid sounds has emerged (Arlinger et al., 2009).

2.2.2.3 Temporal aspects
Sounds are most often fluctuating over time, and thereby temporal aspects are of importance for hearing (Moore, 2004). Temporal features of sounds, i.e. the sequence of intensity and frequency variations, have been demonstrated to be crucial determinants of perception, important for both localization and identification of a sound (Deneux et al., 2016) as well as loudness perception (Ferguson et al., 2011). To detect the presence of a sound, the sound’s duration has to have sufficient length but also sufficient intensity. The term temporal integration, or temporal summation, describes the effect on perceived loudness by the duration of a sound. It has been shown that a short duration is perceived as having low loudness whereas longer duration increases the perceived loudness (Moore, 1993, Xu & Ye, 2015). A sound exceeding 500 ms in length does not influence perceived loudness with increased duration. For sounds with shorter durations than 200 ms, an increase in sound pressure level is needed for detectability (Moore, 2004). Furthermore, the perception of a sound depends on the listeners’ ability of temporal resolution. The temporal resolution can be described as the ability of the auditory organ to detect changes in duration of an auditory stimulus or to discriminate and to separate sound stimuli in the temporal domain. The temporal resolution can be tested with a gap detection test, where the person has to detect if there is a pause in a continuous sound, for example a white noise. The shorter the gap that can be detected, the better the temporal resolution of the subject (Moore, 1993).
2.2.2.4 Spatial aspects
The previously described abilities of the human auditory organ to discriminate between sounds with different loudness, frequency and temporal aspects, provide the listener with the ability to extract spatial information from acoustical cues of the environment. Furthermore, the interpretation of sounds is facilitated by the possibility of binaural hearing in a sound field. Binaural hearing improves the capacity of the auditory cortex, resulting in e.g. improved hearing thresholds in the sound field, improved localisation and perception of distance. Binaural hearing is also beneficial for speech perception.

Localization is possible due to ITDs and ILDs. ITDs describe the discrepancy between the two ears perceiving the signal from a specific sound source at different timings (Bernstein, 2001, Fullgrabe & Moore, 2014). The nearer ear perceives the sound slightly earlier than the more distant ear. The ITD’s are more prominent for low-frequency sounds, typically below 1 kHz (Bernstein, 2001). For frequencies above 1.5 kHz the IID or ILD are responsible for the possibility of localizing sounds. The IID describes the difference in intensity caused by the head shadow between the ears. The nearer ear will perceive the sound as louder than the more distant ear (Moore, 2004, Taillez et al., 2017). For sounds in the frequency area between 1 and 1.5 kHz localization relies on both the ITD and the IID.

2.3 Sound Environment and Auditory perception
All sounds present in a given situation, form the sound environment, consisting of a complex pattern of direct and indirect sounds. The sounds are affected by reflection, diffraction, refraction, and absorption, causing a constant variation of the sound environment. Schafer (1993) initiated substantial work on the concept of soundscape, described as an extended sound environment. Schafer stated that even though the sound environment is the acoustical description of sound, there is also a need of an extended implementation of other events taking place in the environment perceived by the listener. This has culminated in an ISO standard, accepted 2014, where soundscape is defined as: "an acoustic environment as perceived or experienced and/or understood by a person or people, in context" (ISO, 2014). The soundscape does not describe the sound environment solely as a negative or a positive environment; a soundscape can be classified as either or, depending on the context and the listening persons. The sound environment affects the human in several ways, physically as well as psychologically. Nu-
Numerous studies have investigated the effect of the sound environment, especially effects of noise on, e.g. levels of stress, insomnia, and blood pressure (e.g. Beaman, 2005, Muzet, 2007, Persinger, 2014, Pedersen & Persson Waye, 2007, Lambert et al., 2015). Sounds can be a hindrance, for example due to masking, when the possibility of communication is reduced by background sounds (Evans et al., 2016, Mattys et al., 2012). If the environment has good acoustical conditions, communication is facilitated also for a person who is hard of hearing.

To take part of a sound environment implies both conscious and unconscious listening, i.e. individuals listening are affected by the environmental sound stimuli. Gaver (1993b) describes two ways of conscious listening; musical listening and everyday listening. Musical listening embraces the conscious awareness of acoustical characteristics of a sound, while the everyday listening comprises events, to perceive e.g. which car is approaching, or who is going in the stairs. According to Gaver, there should be a desire of a more complete picture of listening and the affection from sounds, providing a description of perception with an ecological approach (Gaver, 1993b, Gaver, 1993a). The ecological approach of perception is suggested by Gaver to respond to two main themes; 1) what we hear, and 2) how we hear. The first theme has been studied in both the acoustical and psychoacoustical research area. Lately, the second theme of how we hear has developed as the field of cognitive hearing science. To adhere to the idea of Gaver of the ecological approach for perception, the relevance and usage of ecological sound stimuli need to increase. Audiological measurements have been developed for speech or tone stimuli, and those are still the most common used stimuli. But as hearing sciences evolve both technically and by demands from hearing impaired persons, it seems plausible to evolve measurements to broaden the used stimuli to include more complex and more ecologically valid sounds.

The sound environment is a complex structure of different sound sources and factors influencing the sounds, as for example reflective and/or absorbing materials. Together, sounds and environment create an intensive soundscape. When e.g. a communication situation takes place in a good acoustical environment, a dialogue is simplified. This can be due to the absence of disturbing background sounds or optimized room acoustics, improving audibility of the sounds, the listener wants to hear. A sound environment with high levels of background sounds can reduce the audibility and make it impossible to achieve communication.
For many persons, the sound environment is consistent with noise, and is perceived as a negative impact on social life, hindering for example the possibility to communicate with others because of masking sounds. Noise can be divided in three different types (Basner et al., 2014); 1) occupational noise, 2) social noise, and 3) environmental noise. These three types of noise may cause hearing loss but also non-auditory health effects, such as cardiovascular conditions, sleep disturbance, annoyance and impaired cognition (Basner et al., 2014, Hammer et al., 2014).

Perception, the awareness, recognition, and interpretation of sensory stimuli processed in the brain, i.e. the analysis of sensory information (Braisby & Gellatly, 2005), depend on the human capacity of detecting sensations. The sensory organs need therefore to be able to detect various forms of energy, such as light or sound. Thereby, perception is the process of constructing and describing the surrounding world. Perception is based on the cognitive processes activated by the human senses when exposed to visual, auditory, olfactory, and/or tactile stimuli. Perception forms a base for decisions on either action or recognition of stimuli in the surrounding environment.

Auditory perception is defined as the ability to receive and interpret information reaching the peripheral auditory system and is activated by sound stimuli (Leonard et al., 2016). It relies on the complex auditory system, providing us with the possibility to interpret speech even though the signal might be interrupted by noise (Leonard et al., 2016). Auditory perception occurs by information analysis, providing an internal description of the environment. This process has been established within the area of psychology as a bottom-up process. A bottom-up process depends on the perception of sensory stimulation and functioning processes within the nervous system. To ensure a reliable interpretation of a situation or a stimulus, the human is also dependent on top-down processes. A top-down process involves making use of prior knowledge of a phenomenon or stimulus such as for example a word (Braisby & Gellatly, 2005).

Disturbance due to sound is affected by several factors, auditory perception of sound being of crucial importance. Auditory perception is strongly correlated with hearing capacity as well as cognitive capacity, and those two are strongly dependent of each other. Previously, a correlation between hearing and cognition has been shown (Ronnberg et al., 2016, Beck & Clark, 2009), as well as a correlation between hearing and loudness perception (Launer, 1995, Moore et al., 2014). It has also been shown that there
is a strong correlation between loudness perception and annoyance perception (Maris et al., 2007, Laszlo et al., 2012, Miedema, 2007). In this work, the connection between hearing capacity and annoyance perception as well as the possible connection between cognitive capacity and loudness and annoyance are investigated. These connections are described in figure 3. Known connections are shown with solid lines, and the possible connections previously not investigated are shown with dashed lines. Sounds used are based on hearing impaired persons’ perception of disturbing sounds in their personally soundscapes.

![Diagram](image)

*Figure 3: Connections within auditory perception. Known connections are indicated with straight arrows and possible connections previously not investigated indicated with dotted arrows.*

### 2.3.1 Factors influencing auditory perception

Perceiving sounds is not just a mechanical transformation of sounds from the outer ear to the auditory cortex. Perception of sound, as described, also depends on psychological processes present in the human brain. Both physical and psychological processes influences the auditory perception.

#### 2.3.1.1 Hearing loss

Hearing loss affects a person’s health condition in several ways. Overall, with a hearing loss, sounds appear weaker, and become harder to perceive, interpret and understand (Arlinger et al., 1996). The consequences of hearing loss are correlated with type and degree of hearing loss. Primarily, hearing loss is classified as conductive or sensorineural hearing loss, or a com-
Combination of both, with varying causes and consequences. A conductive hearing loss implies that the functional lesion is situated in the outer or the middle ear. This causes a reduced sound transmission of the airborne sound to the cochlea. When the attenuated sound is processed in the cochlea, the interpretation of the sound is undamaged and the experience of the sound is normal, but weaker. More common is a sensorineural hearing loss, which is the cause for approximately 85% of hearing impaired people. Sensorineural hearing loss can be situated in the cochlea, the auditory nerve, the brainstem, or in the auditory cortex in the temporal lobe. Most commonly, the hearing loss is situated in the cochlea where the hair cells are affected by the lesion. A sensorineural hearing loss causes reduced audibility as well as reduced frequency and temporal selectivity, thereby decreasing a person’s ability to interpret incoming sounds. Even if the sound is audible, with or without gain, the sound signal is distorted because of the hair cell degeneration within the cochlea or structures of the central auditory system, reducing the clarity of the sound. Temporal aspects of hearing are also affected by sensorineural hearing loss leading to reduced temporal integratio (Moore, 2008).

A sensorineural hearing loss increases the risk of loudness recruitment (Moore, 2004). Loudness recruitment is defined as an abnormal loudness growth, meaning that at soft sound levels, sounds are perceived as softer than for a normal hearing person, whilst at high sound levels, sounds are perceived as equally loud as for a normal hearing person (Phillips & Carr, 1998). This has been described by Dix et al. (1948, p 517) as “the deafness of the affected ear present at threshold disappears at higher intensities, and this in its simplest terms constitutes the phenomenon of Loudness Recruitment.” For the hearing impaired, the growth of loudness is more rapid than normal, and a risk of unpleasantness arise with perceived sound level (Moore, 2004). Perception of loudness is of great importance for normal hearing persons, as well as for persons with hearing loss as a descriptor of sound quality and, in the latter case, as a descriptor for satisfaction of e.g. hearing aid gain (Rasetshwane et al., 2015).

2.3.1.2 Cognitive aspects
Within audiology, an increased interest for the concept of cognition has arisen over the years and has emerged in a separate discipline, cognitive hearing science (Arlinger et al., 2009). The study of the interactions between auditory and cognitive processing has improved the understanding of how listeners perform in ecologically realistic situations (Neuhoff, 2004).
A person’s cognitive ability has large impact on the possibility to shift and split attention to a stimulus. The capacity to shift and split attention is crucial e.g. in a conversation when having a hearing loss, and when adjusting to hearing aids (Rudner et al., 2009, Getzmann et al., 2017, Davies-Venn & Souza, 2014). The ability to attend to an auditory signal and to suppress unwanted sounds is influenced by both auditory factors and cognitive capacity (Mattys et al., 2012, Oberfeld & Klockner-Nowotny, 2016). Furthermore, cognitive aspects important for sound perception are strongly connected with memory, especially working memory (Arlinger et al., 2009, Carpenter et al., 2013, Arehart et al., 2013). Working memory, a cognitive system with a limited capacity that involves short time storage and processing of information (Daneman & Carpenter, 1980), is affected by noise (Jahncke et al., 2011, Hua et al., 2014a). People with good working memory capacity can expend more effort to extract a target signal in noise than people with poor working memory capacity, resulting in better auditory performance (Rönnberg et al., 2016). Furthermore, people with good working memory capacity are better at ignoring irrelevant signals than people with poor working memory capacity (Sorqvist et al., 2012).

2.3.1.3 Emotional aspects

Suffering from a hearing loss, there is a risk of reducing the capability to communicate, affecting the possibility of activity and participation in various situations. It is plausible to assume, that a hearing loss and it’s negative consequences produce negative emotional effects (Danermark, 1998). Emotions can be seen as an outcome of the interaction between human beings, where interactions enforce emotions, either in a positive or a negative way.

The theory of coping highlights the way a person handles difficult situations. A person suffering from hearing loss can use different kinds of coping strategies to handle the interaction to other persons in various situations (Danermark, 1998). Repair strategies mean to try to take control over the situation and are considered as positive strategies for persons with hearing loss. However, it is more common, that persons with hearing loss use avoiding strategies when confronted with problematic communication situations, thereby enhancing negative emotions that can be hard to deal with. The emotional consequences of coping strategies affect not just the person with a hearing impairment, but also the communication partner. Negative emotions can therefore evolve, when communication is affected by hearing loss. If the communication situation furthermore suffers from poor sound environment and disturbing sounds, possible negative emotions are enhanced.
Decreased possibility of a good communication may evolve negative feelings, but not in all situations or for all persons. This implies that there are other mechanisms or factors affecting the emotional outcome. To study emotional aspects is troublesome due to the lack of possibilities to isolate factors of human feelings. Furthermore, people can be reluctant to share feelings present due to problematic communication (Danermark, 1998).

2.3.1.4 Annoyance
As loudness has been a key interest within hearing science, the concept of annoyance has increased in interest over the years (Berglund et al., 1976, Lekaviciute & Argalasova-Sobotova, 2013, Guski et al., 1999, Stallen, 1999). The term annoyance to sounds has interchangeably used terms like unpleasantness, or disturbance and is defined as a displeasure by sound exposure (Guski, 1997). As loudness, annoyance was seen as a negative reaction due to sound level. Annoyance, or unpleasantness, can be seen as one indicator of the quality of sound, where pleasantness is the equivalent of a positive factor for sound quality (Guski, 1997). Lately, the concept of annoyance has been widened to not only concern the acoustical features of noise, but also the psychological and physiological effects on humans, such as stress, sleep disturbance, and blood pressure (Canlon et al., 2013, Laszlo et al., 2012, Maris et al., 2007). Annoyance has been referred to as a phenomenon of mind and mood (Stallen, 1999), because the reaction to a sound is not just set to acoustical factors but also influenced by context and personal factors as annoyance judgements have been shown to be more subjective than loudness judgements by people with normal hearing (Kuwano et al., 1988). Annoyance is a concept describing the perception and reaction to sound and is defined in concordance with the definition in ISO 15666 as “a person’s individual adverse reaction to noise”. The term reaction to noise denotes an emotional response and relates to dissatisfaction and bother due to sound (Holm Pedersen, 2007). A reaction to noise or sound can be described as an emotional response and is often an initial and immediate reaction. In Hiramatsu et al. (1988), fifty subjects rated the annoyance and loudness for 59 environmental sounds. The results showed a correlation \( r=0.676 \) between loudness and annoyance for comparisons of sounds at the same perceived level. Hiramatsu et al. (1988) raised the question whether measurements of annoyance were possible, and argued that annoyance is defined by loudness. Even if annoyance is an individual reaction to sound, there is a benefit in the possibility to quantify the degree of annoyance. Used measurements for annoyance are, as for loudness measurements,
based on scaling tests. Scaling tests use a response scale with various numbers of points, either even or uneven steps, and most often verbal descriptors are used for each step. An advantage of scaling tests is the ease of use for the participants, even for untrained subjects (Guski, 1997). Nevertheless, there have been debates of the number of steps for reliable results, and also of the verbal descriptors (Williams et al., 2013). So far, there is no consensus of best practice, as the scale usually has to be adapted to the aim of the test.

In the work by Ellermeier et al. (2001), the term of annoyance is studied in form of noise sensitivity as they argued, based on previous studies, that strong correlations between noise sensitivity and noise annoyance had been found. They stated that participants indicating themselves as noise sensitive, judged sounds as louder and as more annoying than less sensitive participants, thereby raising the question of attitude towards a sound as predictor of annoyance. Later research has raised the question if one should focus on the non-acoustic factors associated to sound annoyance when studying the concept of annoyance (Stallen, 1999, Maris et al., 2007). Compared to loudness, annoyance and the perception of annoyance have been described as effects of internal processes, if an individual perceive disturbance and/or control depicted by Maris et al. (2007) in a social psychological model. The model considers the sound itself and its management as determinants of noise annoyance. The perception of these two external processes results in disturbance or control (named as the internal processes) and if a misbalance between those two occurs, it results in annoyance. The model predicts that improvement of acoustics or sound management can reduce annoyance. In a psychosocial context, the model highlights the importance of a person’s ability to manage the sound and sound sources, in order to reduce annoyance and thereby the negative influence in the context.

2.3.1.5 Subjective aspects
Subjective aspects of psychological effects on sound perception are associated with e.g. attitudes and expectations of sounds.

Beside auditory perception, hearing loss furthermore affects all situations in life, not just for the person with hearing loss, but also for family, friends, colleagues, and others in the surrounding. To improve the situation for all involved persons, actions might be needed for the individual as well as in the environment, changes in a person’s attitude and more. A negative attitude from one self as well as from society and significant others can impede a person’s health condition. In a survey of the Swedish National Board of Health and Welfare (SCB, 2011) it was shown that persons with hearing
loss associated themselves as having a bad health condition, almost a third of the persons with hearing loss stated severe problems of ache. This comprises a significantly bigger proportion than within other subgroups of the survey and indicates a substantial impact from hearing loss on quality of life.

Personality factors as well as psychosocial factors have been shown to be influential in audiological rehabilitation (Hallam & Corney, 2014).

2.4 Rehabilitation for persons with hearing loss

2.4.1 Rehabilitation
Rehabilitation is a process with focus on regaining a function that has been reduced due to an injury, illness, or function loss. The main goal for rehabilitation is to improve the possibility of activity and participation in the daily life (WHO, 2001, SOSFS, 2008:20). The rehabilitation process is individual and has to be adapted to a person’s abilities, possibilities and goals.

2.4.2 Communication
Information exchange can take place in several ways, within this work, the focus will be auditory communication. Auditory communication is a much more complex process than mere sending and receiving of information (Lemke & Scherpiet, 2015). Auditory communication is more of a social act, an interaction between people. Communication originates from the human need to express oneself and to relate to others, and comprises a wide range of areas, perception, cognition, psychology, and sociology. Auditory communication depends on the sound environment as well as on the hearing ability. For functional auditory communication, assistance might be needed, either by improved sound environment or by assistive listening devices.

2.4.3 Audiological rehabilitation
A successful audiological rehabilitation (AR) supports a person to achieve improved possibilities to be active and participate in society as it comes to listening and communication (Boothroyd, 2007, Grenness et al., 2014b). AR combines actions within the medical, pedagogical, technological, as well as the psychosocial area, based on a thorough assessment of a person’s needs regarding listening, surveying the person’s life situation. To improve this assessment, it is useful to use a structured tool such as e.g. the ICF (WHO, 2001). A structured tool is useful in mapping the situation for a
person in order to provide a plan for forthcoming rehabilitation. In the clinical situation, information is needed of the person’s body functions and structures as well as the environmental and personal factors and their impact on activities and participation. The primary goal for AR is for most people with hearing loss, to improve audibility and the possibility to take part in a social context, such as communicating with others or receiving auditory messages. This goal is often achieved with assistive listening devices, appropriate for the individual, such as hearing aids (HA), cochlear implants (CI), and/or communication devices. A secondary goal for AR is to reduce the negative influences of hindering factors, such as noise or negative attitudes, as well as to increase the positive influences of facilitating factors. Most often, a person with hearing loss is in need of, and supplied with, technical rehabilitation meaning being provided with a hearing aid(s). However, this is not always sufficient in order to improve the possibility of activity and participation in social contexts. Many persons are in need of a combination of medical as well as psychosocial and pedagogic rehabilitative actions.

For persons with hearing loss, hearing aids are often considered the primary intervention within rehabilitation to ease communication and interaction with other people. Research strongly suggests that hearing aid users benefit of improved speech perception and thereby better communication possibilities (Petry et al., 2010, Lane, 2017, Kochkin, 2011). However, a hearing aid is not beneficial in all situations, in noisy environments limited benefit has been reported (Hoppe et al., 2016, Kochkin, 2000). Even though the settings of the hearing aid are optimized for desired sounds, negative effects such as reduced sound quality or uncomfortably high sound levels do occur, as has been confirmed in numerous studies (e.g. Kochkin, 2007a, Kochkin, 2007b, McCormack & Fortnum, 2013, Gygi & Hall, 2016).

The development of hearing aids, from analogue devices to the present digital era, has changed, and in many ways, improved the situation for persons in need of amplification. Nevertheless, there are still issues that need to be addressed to further improve the benefit from hearing aids. McCormack & Fortnum (2013) showed in a review that there are numerous reasons for a person not to use a hearing aid, even though hearing thresholds indicate that hearing aids could be beneficial. The most common complaints were background noise and lack of improvement in desired situations. Situations with background noise where seen as particularly negative, because of high levels or masking problems. Gygi & Hall (2016) also performed a review of background noise where they identified problems of
background noise due to hearing aid technology as well as non-auditory influences. They also noted the increased awareness and interest among researchers to address the topic of background noise, even though there is limited research on what kind of background noise that is perceived as most aversive or annoying.

When using hearing aids, all sounds in the surrounding soundscape are processed in the hearing instrument, and not just the desired signals. The more advanced hearing aid the more advanced processing of the signals can be conducted, in order to improve the hearing impaired person’s ability to perceive desired sounds. Hearing aid signal processing uses amplification, compression and filtering for improvement of wanted signals as well as reduction of unwanted signals. Noise reduction systems are used for suppression of surrounding noise while a directional microphone is used to improve the signal to noise ratio for frontal sounds. Even though modern hearing aids deal with signals in sophisticated ways, the outcome of using a hearing aid also depends on the hearing impaired person’s ability to make use of the hearing aid processed signals. Listening through a hearing aid is an auditory as well as a cognitive task. As an example, Saeki et al. (2004) studied the effect of acoustical noise on a mental task, such as a digit span test. They found that meaningful noise (in their study a male voice) is more annoying than a meaningless noise. These results were more obvious when the digit task was presented aurally than when the digits were presented visually. Annoyance of a sound increases with increased loudness level of the noise (Maris et al., 2007), thereby affecting the outcome of the hearing aid for the listener. Loudness of a sound is based on the intensity, the duration and the spectral configuration of the stimulus and is used to define and describe how a person precepts and reacts to different sound levels (Lotto & Holt, 2011).

To improve the perception of the surrounding environment, the hearing aid signal processing aims to resemble the function of the auditory organ. This can be accomplished by auditory scene analysis. In auditory scene analysis the sound signal is divided in two steps according to Bregman (1990). The sounds are grouped according to acoustical properties and the grouped sounds are compared and the sound classified as more significant are further processed. The outcome of the process is referred to as an auditory stream. To describe the auditory stream, the spectral and temporal processes need to be separated. Spectral processes are responsible for the grouping of elements while temporal processes are responsible for forming the time sequence interpretable by the auditory brain (Szabo 2016).
2.5 Aims

The general aims of this thesis are to explore and examine the concept of disturbing sounds in a daily sound environment and to examine the influence of hearing loss and hearing aid usage. Furthermore, the thesis aims to examine the perception of loudness and annoyance of ecologically valid sound examples in a controlled setting and relate the outcome to degree of hearing loss, cognitive factors, as well as acoustical factors of the sounds such as level, temporal, and spectral variations on the other hand.

Particularly, the following questions were studied within the framework of the thesis:

• What sounds are perceived as disturbing for people using hearing aids and is the perceived disturbance affected by hearing aid experience?
• What are the effects from disturbing sounds while using hearing aids?
• What acoustic patterns of the sounds are perceived as disturbing by hearing aid users?
• How is perception affected by different types of sound stimuli?
• Is the degree of disturbance affected by hearing thresholds or hearing aid usage?
• Is the sound perception affected by further factors than auditory (e.g. attitude, cognition, memory)?

2.6 Interdisciplinary research

The study of perception of disturbing sounds is important for people affected by the sounds, independently of hearing ability. However, the study of disturbing sounds is also of significant importance for society in general, by increasing the possibility to reduce negative consequences of disturbing sounds. Reduced negative consequences of disturbing sounds facilitates improved quality of life, enhance an active daily living, and thereby increasing the possibility for an individual to better take control over one’s life situation (Seidman & Standring, 2010, Dalton et al., 2003). The use of a biopsychosocial model for this purpose has been shown to be advantageous in order to describe the consequences of a function or a disability (Rönnberg et al., 2013).

Furthermore, it has been shown to be advantageous to use an interdisciplinary approach where scientific fields and methods enriches each other,
where the studied areas can be described in levels, such as the molecular, the biological, the psychological, and the societal level. Every level and research area has their problem areas and research questions. Using interdisciplinary research, new interactions and models can be implemented (Danermark, 2001, Rönnberg et al., 2013). Within disability research, the bio-psycho-social model as well as an interdisciplinary approach, are central concepts suitable for the study of a complex phenomenon such as hearing and hearing perception. In the present thesis, the focus is to describe cause, effect, and consequence due to disturbing sounds for persons with normal hearing threshold levels, persons with hearing loss and for hearing aid users, using multiple research methods and approaches to highlight occurring problems. In clinical settings, it has been a well-known fact that problems occur due to disturbing sounds, but the scientific evidence has been inadequate for persons with hearing loss. Previous research has considerably studied and illustrated problems connected to disturbing sounds in residential and work environments, but there still is a lack of research studying disturbing sounds in the daily environment.
3. Empirical studies

Within the framework of the thesis, a series of experimental studies were performed. These studies resulted in four reports describing perception of disturbing sounds, both for persons with normal hearing as well as for persons with mild to moderate hearing loss. The reports are referred to as studies I, II, III and IV.

3.1 Aims of studies I - IV

3.1.1 Study I
The primary aim of the study (Skagerstrand et al. 2014) was to describe sounds that hearing aid users experienced as annoying in their everyday soundscape. A secondary aim was to investigate if personal or hearing aid related factors such as age, amount of hearing loss, sex, hearing aid experience, or signal processing affected the hearing aid users’ experience of annoyance from specific sounds. Furthermore, the study investigated actions taken by the hearing aid users to avoid annoyance.

3.1.2 Study II
The study aimed to describe acoustic factors, i.e. sound pressure level, spectral and temporal patterns, of a selection of everyday sounds hearing aid users found annoying in study I Skagerstrand et al. (2014). The study forms a basis for studies of perception of annoying sounds.

3.1.3 Study III
The aims of the study (Skagerstrand et al. 2017) were to investigate the annoyance and loudness of eight everyday sounds, that previously had been identified as annoying by hearing impaired persons (Skagerstrand et al. 2014), as a function of sound pressure level in participants with normal hearing. The relations between ratings of loudness and annoyance and results from auditory tests and a test of working memory capacity were investigated.

3.1.4 Study IV
The aim of study IV was to investigate the perception of annoyance and loudness of eight previously studied everyday sound sources (Skagerstrand et al. 2014, Skagerstrand et al. 2017) as a function of sound pressure level for participants with mild to moderate high frequency hearing loss and the
influence from hearing aid usage on both loudness and annoyance perception. Furthermore, the study aimed to investigate the relation between ratings of loudness and annoyance and results from tests of auditory performance and working memory capacity.

### 3.2 Ethical approval and considerations

The guidelines of the World Medical Association (WMA) Declarations of Helsinki, Ethical principles for medical research involving humans were followed. For study I, III and IV approval by the regional ethical committee in Uppsala, Sweden, was obtained. Signed informed consent was obtained from all participants. All participants were informed that participation was voluntary and confidential. Analyses were conducted on group level.

### 3.3 Participants

A compilation of the participants is presented in table 1. All participants gave informed consent prior to their participation in the studies.

#### 3.3.1 Study I

The study population was a clinical sample of 60 persons with bilateral sensorineural hearing loss. The participants used the hearing aids they had perceived during clinical rehabilitation. In total, 21 female and 39 male persons participated. Forty-three of the participants were experienced hearing aid users (>1 year of experience) and 17 were newly fitted with hearing aids (3 months ago) when entering the study. Group 1, which consisted of experienced hearing aid users, had a mean age of 68.8 years and a mean pure tone threshold for the frequencies 0.5, 1, 2 and 4 kHz (PTA4) of 42.4 dB HL. Of the 43 participants in group 1, seventeen were female. Group 2 consisted of 17 persons (four female) with a mean age of 66.8 years and sensorineural bilateral hearing loss with a mean pure tone threshold (PTA4) of 39.7 dB HL. Data on the participant’s hearing thresholds and hearing aids were collected from their records at the clinic. Hearing threshold data were obtained for the audiometric frequencies between 0.125 and 8 kHz for both air and bone conduction, as well as uncomfortable levels (UCL) measured between 0.5 – 4 kHz. Prior to the study a pilot study was performed to verify the questions in the diary the participants were to answer. The pilot group consisted of 10 university students (8 female) with a mean age of 23.3 years ranging from 20 to 36 years. They all had pure tone thresholds better than 20 dB HL at the audiometric frequencies.
3.3.2 Study III
Study III investigated the perception of sound in people with normal hearing. The 21 participants had all present otoacoustic emissions, and hearing thresholds better than 20 dB HL for the audiometric frequencies between 0.125 and 8 kHz. Prior to inclusion, baseline pure tone hearing thresholds were measured according to the Hughson-Westlake procedure in a sound proof booth for both air and bone conduction using an Interacoustic AC40 audiometer calibrated according to IEC 60645-1 (IEC, 2012). Furthermore, otoacoustic emissions (TEOAE) were measured bilaterally at 84 dB SPL with an Otodynamics ILO OAE system version 6, in half-octave bands with centre frequencies 1.0, 1.4, 2.0, 2.8, and 4.0 kHz. The group of participants comprised 15 female and 6 male persons with a mean age of 55.2 years (24 – 71 years).

3.3.3 Study IV
Study IV examined the perception of sounds in persons with hearing loss, and in total 43 persons participated, 27 of whom were hearing aid users, and 16 non-users. Participants were recruited from the audiological clinic at Örebro university hospital, Sweden. Furthermore, participants were recruited amongst persons who had paid interest in study III, but not fulfilled the criteria for normal hearing threshold levels required for participation in that study. The entire group of participants comprised 22 female and 21 male persons with a mean age of 68.7 years and pure tone average threshold levels of 32.2 dB HL. When grouped according to hearing aid used, the hearing aid users had a mean age of 69.4 years and a pure tone average threshold of 39.2 dB HL, and the non-users mean age was 67.6 years with a mean pure tone average threshold of 20.4 dB HL.
Table 1. Study participants

<table>
<thead>
<tr>
<th></th>
<th>Experienced hearing aid users Study I</th>
<th>New hearing aid users Study I</th>
<th>Normal hearing people Study III</th>
<th>Hearing aid users Study IV</th>
<th>Hearing impaired Study IV</th>
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<tbody>
<tr>
<td>Number</td>
<td>43</td>
<td>17</td>
<td>21</td>
<td>27</td>
<td>16</td>
</tr>
<tr>
<td>Sex (females %)</td>
<td>42.5 %</td>
<td>29.4 %</td>
<td>71 %</td>
<td>44.4 %</td>
<td>62.5 %</td>
</tr>
<tr>
<td>Mean age (years)</td>
<td>68.8 (SD 8.6)</td>
<td>66.8 (SD 7.2)</td>
<td>55 (SD 14.6)</td>
<td>69.4 (SD 6.6)</td>
<td>67.6 (SD 5.1)</td>
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<tr>
<td>Age (min-max)</td>
<td>44 – 82</td>
<td>51 - 76</td>
<td>24 – 71</td>
<td>55 - 79</td>
<td>61 – 77</td>
</tr>
<tr>
<td>Hearing threshold (PTA4) dB HL Mean</td>
<td>44.8 (SD12.6)</td>
<td>39.7 (SD11.6)</td>
<td>5.98 (SD 5.4)</td>
<td>39.2 (SD 5.8)</td>
<td>20.4 (SD 9.6)</td>
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<tr>
<td>High frequency hearing threshold (PTA1-6kHz)</td>
<td>64.2 (SD14.4)</td>
<td>58.6 (SD15.9)</td>
<td>58.6 (SD10.1)</td>
<td>39.6 (SD15.8)</td>
<td></td>
</tr>
</tbody>
</table>

3.4 Methods

A variety of methods, both subjective and objective, was used in the studies to investigate the research questions. For study I, III and IV, clinical hearing tests were used, either performed within the study or in terms of data collection from the participants’ clinical records. Study II comprised acoustical measurements and analysis.

3.4.1 Study I

Both experienced and new hearing aid users filled in a diary daily during 14 days to identify sounds hearing aid users found disturbing in their daily environment. The diary consisted of four open-ended questions about sounds and situations where the sounds were perceived as disturbing. The four questions were:

1. Which sound/sound source was annoying?
2. Which characteristic of the sound was annoying?
3. In which situation was the sound annoying, and how were you occupied in that situation?
4. What did you do to reduce the annoyance?
The participants also provided information about possible action caused by disturbing sounds. The participants moreover denoted their daily hearing aid usage. The results from the diaries were analysed with content analysis (Graneheim & Lundman, 2004). Every comment given in the diary was condensed to a meaningful unit with focus on information of the sound and/or sound source mentioned as annoying. These condensed meaningful units were then categorized, counted, and ranked, resulting in a final categorization of the comments. Two persons performed the categorization independently. When differences in categorization of comments between the two readers were found, those comments were re-analysed so consensus collectively was reached.

3.4.2 Study II
An acoustic analysis was performed for five categories of sounds that in study I had been found to be perceived as disturbing and reduced hearing aid usage. The five sound categories were sounds from running water, porcelain and cutlery, rustling papers, household appliances, and the sound from TV (more precise the variation of sound levels between program and commercial breaks). The recordings and measurements of the five sound categories were conducted in a common Swedish home environment, illustrating a realistic situation where the sound may appear. The sounds were digitally recorded using an Edirol UA25 sound card and software SoundForge 8.0, with a sampling frequency of 44.1 kHz and stored as 16 bits wav files. A Sennheiser ME67 microphone (supercardioid characteristic) with a bandwidth of 40 – 20 000 Hz and linear response for sound levels up to 126 dB SPL was used. High ecology of the sound examples was desirable and they were recorded with permanent background sounds, such as ventilation, sounds from refrigerator, and outdoor sounds. The microphone was placed at the position of an imagined listener’s ear. Sound level measurements were performed using a Brüel & Kjær 2260 Observer sound level meter. Analyses were done in MatLab® (MathWorks). Analyses were performed for overall loudness and temporal and spectral variations.

3.4.3 Studies III and IV
For study III and IV identical methods and test setups were used. The main assessments in studies III and IV were ratings of loudness and annoyance (Cox et al., 1997) as described below. Prior to the rating tests, thorough hearing examinations and cognitive testing were performed. The auditory testing comprised pure tone audiometry with air and bone conduction.
Baseline pure tone hearing thresholds were measured with the Hughson-Westlake procedure in a sound proof booth, commonly used for hearing tests, using an Interacoustic AC40 audiometer calibrated according to IEC 60645-1 (IEC, 2012). Air conducted pure tone thresholds were tested at the audiometric frequencies between 0.125 and 8 kHz and bone conduction as well as uncomfortable levels for tones were tested at the audiometric frequencies between 0.25 and 4 kHz. To investigate the integrity of the outer hair cells, transient otoacoustic emissions (TEOAE) were measured bilaterally at 84 dB peSPL with the Otodynamics ILO OAE system version 6. The TEOAE’s were obtained in half-octave bands with centre frequencies 1.0, 1.4, 2.0, 2.8, and 4.0 kHz. Furthermore, the participants’ loudness growth functions were obtained at 2, and 4 kHz using the monaural loudness balancing test (MLB) for pure tones (Gelfand, 2009, Roeser et al., 2007). The MLB test was performed using the audiometer AC40 and TDH39 headphones in the sound proof booth as a monaural comparison of loudness for two different tones, where tones of 2 and 4 kHz were used as test frequencies with the 500 Hz-tone as reference. Speech test audiometry was performed using the Swedish hearing in noise test, HINT (Hällgren et al., 2006). The HINT was done in a sound field with speech and noise from one loudspeaker at 0˚ azimuth using the audiometer AC40. The speech signal was fixed at a level of 60 dB SPL and the noise level adaptively varied in steps of 2 dB.

To control for subjective sound sensitivity, the participants fulfilled the Weinstein sound sensitivity questionnaire (Weinstein, 1978). The Weinstein noise-sensitivity questionnaire consists of 20 statements with degrees of agreement graded from 1-6. According to the results of the study of Belojevic et al. (1992), a participant was considered noise sensitive if the score was above the mean + 1 SD of the tested group. The capacity of working memory was assessed with the Reading Span test (Daneman & Carpenter, 1980). The Reading Span test examines working memory using a dual task test. The participant is requested to process three-word sentences by judging them as semantically correct or not, e.g. “The ball bounced low” or “The chisel laughed quietly” (translated from Swedish). After a certain number of sentences (3 to 5), the participant is prompted to repeat either the first or last word in each sentence, in order of appearance. Before testing, a training session with two sentences was presented. In the current implementation, the number of sentences before word recall was twice 3, 4, and 5. Consequently, the maximum score for correct word recall was 24 (Rönnberg et al., 1989).
The loudness and annoyance of the sounds were assessed using rating tests (Cox et al., 1997). For the testing, category scaling was used, meaning that the participant judged the sound and labelled it according to seven predetermined labels. The tests were performed in an anechoic chamber at the Audiological Research Centre, Örebro, Sweden, and the sounds were presented in a sound field through a loudspeaker in front of the listener. The system was calibrated to provide a sound level at the position of the participant’s head that corresponded to the recorded level of the used sound stimulus. The recorded levels were used as the normal playback level and the levels were randomly varied by ± 20 dB around the recorded level in steps of 5 dB during the rating procedure. The ratings were obtained for 8 sounds and each sound was presented at 9 levels. To prevent uncomfortable and hazardous stimulation levels, the maximum level was set at 100 dB SPL (RMS). This meant that for three sounds (cutlery, electric mixer, and power drill), the maximum level was 15 dB above the recorded level and only eight levels were rated for those sounds.

The participants rated loudness and degree of annoyance on labelled scales with seven steps where 1 indicated inaudible and 7 indicated unpleasant as described in table 2.

<table>
<thead>
<tr>
<th>Loudness</th>
<th>Annoyance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unpleasant</td>
<td>Unpleasant</td>
</tr>
<tr>
<td>Very loud</td>
<td>Extremely annoying</td>
</tr>
<tr>
<td>Loud</td>
<td>Very annoying</td>
</tr>
<tr>
<td>Comfortable</td>
<td>Annoying</td>
</tr>
<tr>
<td>Soft</td>
<td>Slightly annoying</td>
</tr>
<tr>
<td>Very soft</td>
<td>Not annoying</td>
</tr>
<tr>
<td>Inaudible</td>
<td>Inaudible</td>
</tr>
</tbody>
</table>
4. Results

4.1 Study I
The notations of the 60 participants in the diaries ended up providing information of 1018 events during 14 days where the sounds were considered as disturbing. The notations were categorized into 18 categories of sounds based on content analysis (Graneheim & Lundman, 2004), and ranked after the number of persons that mentioned the category. Sounds noted as disturbing were sounds occurring in an ordinary daily sound environment. The by far most mentioned disturbing sound was verbal human sounds, followed by sounds from TV/radio, and sounds from vehicles. The sounds may not have been disturbing for all occasions, but they were regularly perceived as disturbing, and caused negative hearing effects. The main effect of disturbing sounds for a hearing aid user was decreased usage of hearing aids. Few significant differences were found when subgrouping the hearing aid users according to age, degree of hearing loss, sex, hearing aid experience, and signal processing used in the hearing aids.
Table 3. Categories of disturbing sounds

<table>
<thead>
<tr>
<th>Stated annoying sound or sound source</th>
<th>Description</th>
<th>Whole group (n = 60)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Number of notations</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number of persons</td>
</tr>
<tr>
<td>Verbal human sounds</td>
<td>Sounds produced by people, verbal. An example of these sounds is murmuring</td>
<td>157</td>
</tr>
<tr>
<td>TV/Radio</td>
<td>Sounds emitted from the loudspeakers of TV and/or radio</td>
<td>176</td>
</tr>
<tr>
<td>Vehicles</td>
<td>Sounds produced by vehicles with engines; cars, trains, motorcycles, etc.</td>
<td>11</td>
</tr>
<tr>
<td>Machine tools</td>
<td>Sounds produced by e.g. power saw, drilling machine</td>
<td>76</td>
</tr>
<tr>
<td>Household appliances</td>
<td>Sounds produced by ordinary household appliances such as washing machine, vacuum cleaner, or electric mixer</td>
<td>82</td>
</tr>
<tr>
<td>Natural sounds</td>
<td>Sounds typically heard in the open, e.g. wind, walking on gravel, etc.</td>
<td>81</td>
</tr>
<tr>
<td>Domestic sounds, porcelain and cutlery</td>
<td>Sounds from typical situations in the kitchen when preparing dinner, setting the table or when eating.</td>
<td>77</td>
</tr>
<tr>
<td>Music</td>
<td>Both live music and music played on high fidelity systems</td>
<td>26</td>
</tr>
<tr>
<td>Non-verbal human sounds</td>
<td>Sounds produced by people, non-verbal sounds. Examples of these sounds are coughing, laughter, etc.</td>
<td>17</td>
</tr>
<tr>
<td>Telephone</td>
<td>Sounds emitted when speaking on the telephone, and the telephone signal</td>
<td>51</td>
</tr>
<tr>
<td>Rustling sounds</td>
<td>Rustling sounds from plastic bags, paper, and newspapers</td>
<td>42</td>
</tr>
<tr>
<td>Background noise</td>
<td>Sounds where the informants are unable to specify the sources and only mention it as background noise</td>
<td>23</td>
</tr>
<tr>
<td>Domestic sounds, running water</td>
<td>Sound from running water in the household. Examples are running water when doing the dishes, or when cleaning the house or in the bathroom</td>
<td>48</td>
</tr>
<tr>
<td>Impulsive sounds</td>
<td>Sounds with high level and short duration. In this category, for example, hammer-blow and rifle shot are mentioned</td>
<td>26</td>
</tr>
<tr>
<td>Speaker system</td>
<td>PA systems used for example at train stations</td>
<td>5</td>
</tr>
<tr>
<td>Combined sounds</td>
<td>Sounds from many sources which cannot be separated in the analysis</td>
<td>6</td>
</tr>
<tr>
<td>Office machines</td>
<td>Sounds produced by machines used in ordinary office work: Computer, printer, copying machine, etc.</td>
<td>12</td>
</tr>
<tr>
<td>Ventilation</td>
<td>Sounds from ventilation in buildings</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total number of notations</strong></td>
<td></td>
<td><strong>1018</strong></td>
</tr>
</tbody>
</table>

(Skagerstrand et al., 2014)
4.2 Study II

The sounds studied were sounds perceived as annoying resulting in reduced hearing aid usage according to study I. The sounds from water, porcelain and cutlery, household machines, paper, and television were investigated for overall sound level, temporal and spectral patterns. The disturbance and reduced hearing aid usage caused by those five sounds could not be entirely explained by the investigated acoustical factors. The examined sounds differed in amplitude, as well as spectral and temporal patterns. Sounds from paper were low-level sounds with distinct peaks at high frequencies and large temporal variations. Sounds from porcelain and cutlery had similar spectral and temporal variations but higher amplitude compared to the sounds from paper. Sounds from water and household appliances had a low degree of temporal variation, but higher overall amplitude compared to the sounds from papers and porcelain and cutlery. The informants in study I stated that the ratio between the sound of a TV-program and the sound of a commercial break was highly disturbing. This difference in level between program and commercial break was the focus of interest for the sounds from TV in study II. The result showed that there is a difference between types of TV-shows regarding sound levels. During the measurements the volume control of the TV was set at a constant level and no changes were made during the measurements. It was found that for programs with high degree of musical elements, the difference between program and commercial break was low where the sound of the program in general had higher sound pressure level than the commercial break. In programs with a large proportion of speech had a difference between program and commercial break of up to 6.5 dB.

4.3 Study III

For the eight sound types tested in study III, persons with normal hearing thresholds, rated the sounds emitted from paper as having greater loudness, but also being more annoying than the other sound sources when comparing the sounds at identical sound pressure levels. It was also found that the perceived loudness and annoyance were primarily driven by the sound level. Tested cognitive and auditory abilities did not influence the perception of loudness and annoyance among the participants. It seemed as if expectation of a sound influenced the ratings of loudness and annoyance more than the auditory performance and the working memory capacity. The ratings of loudness for the participants were compared to a loudness model for time
varying sounds, the 2014 TV model (Moore, 2014). The outcome of the predicted loudness differed from the perceived loudness, as the ranking order varied. The loudness model predicted that the sounds with highest temporal variations, i.e. sounds from papers, porcelain and cutlery, should, according to the model, be ranked as having the highest loudness. In reality, with normal hearing people, the sounds from porcelain and cutlery were rated as having the same loudness as sounds from water, power drill, and electric mixer.

Table 4. Result of loudness rating and loudness calculation with the 2014 TV model for people with normal hearing function, tested at the same sound pressure level, 68 dB SPL. The first sound type in respective column was rated/calculated as the loudest sound.

<table>
<thead>
<tr>
<th>Loudness rating</th>
<th>Loudness calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Newspaper</td>
<td>Newspaper</td>
</tr>
<tr>
<td>Documents</td>
<td>Cutlery</td>
</tr>
<tr>
<td>Traffic</td>
<td>Documents</td>
</tr>
<tr>
<td>Porcelain</td>
<td>Porcelain</td>
</tr>
<tr>
<td>Water</td>
<td>Electric mixer</td>
</tr>
<tr>
<td>Electric mixer</td>
<td>Traffic</td>
</tr>
<tr>
<td>Cutlery</td>
<td>Water</td>
</tr>
<tr>
<td>Power drill</td>
<td>Power drill</td>
</tr>
</tbody>
</table>

The ratings of annoyance were not directly comparable to the loudness ratings as the used verbal descriptors were not equal. Nevertheless, the rank order for loudness and annoyance revealed similarities between the two. For both loudness and annoyance, sounds from newspaper, documents, traffic and porcelain were ranked as the first four, i.e. having the highest loudness and being most annoying. And the last four were the same for both loudness and annoyance even though the ranking order was not identical between the two factors investigated.
Table 5. Result for loudness and annoyance rating shown as rank order at 68 dB SPL for normal hearing people. The first mentioned sound type was perceived as loudest and most annoying when tested at the same sound pressure level.

<table>
<thead>
<tr>
<th>Loudness rating</th>
<th>Annoyance rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Newspaper</td>
<td>Documents</td>
</tr>
<tr>
<td>Documents</td>
<td>Newspaper</td>
</tr>
<tr>
<td>Traffic</td>
<td>Traffic</td>
</tr>
<tr>
<td>Porcelain</td>
<td>Porcelain</td>
</tr>
<tr>
<td>Water</td>
<td>Electric mixer</td>
</tr>
<tr>
<td>Electric mixer</td>
<td>Water</td>
</tr>
<tr>
<td>Cutlery</td>
<td>Power drill</td>
</tr>
<tr>
<td>Power drill</td>
<td>Cutlery</td>
</tr>
</tbody>
</table>

4.4 Study IV

The perception of loudness and annoyance for persons with hearing loss showed similar results as for the normal hearing persons in study III. The rating curves had similar shapes and rank orders as the results for normal hearing people. The participants in study IV were divided according to their hearing thresholds. For the group with the greater hearing loss, (hearing aid users) the results were presented both aided and unaided. A clear influence of sound level for perception was found as the ratings for both loudness and annoyance increased with increased sound level. Furthermore, the hearing loss affected the perceived loudness and annoyance, greater hearing loss revealed less perceived loudness and annoyance than for persons with milder hearing loss. The loudness increased, in relative terms, more with level for people with more severe hearing loss than with milder hearing loss. The hearing aids restored both the loudness and the annoyance to levels comparable to people with normal hearing thresholds investigated in study III.
Table 6. Result for loudness and annoyance rating shown as rank order at 68 dB SPL for persons with hearing impairment. The first mentioned sound type was perceived as loudest and most annoying when tested at the same sound pressure level.

<table>
<thead>
<tr>
<th></th>
<th>Persons with mild hearing loss, unaided condition</th>
<th>Persons with moderate hearing loss, unaided condition</th>
<th>Persons with moderate hearing loss, aided condition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Loudness rating</strong></td>
<td><strong>Annoyance rating</strong></td>
<td><strong>Loudness rating</strong></td>
<td><strong>Annoyance rating</strong></td>
</tr>
<tr>
<td>Newspaper Documents</td>
<td>Newspaper Documents</td>
<td>Newspaper Documents</td>
<td>Newspaper Documents</td>
</tr>
<tr>
<td>Traffic</td>
<td>Traffic</td>
<td>Traffic</td>
<td>Traffic</td>
</tr>
<tr>
<td>Porcelain</td>
<td>Water Porcelain</td>
<td>Porcelain Water</td>
<td>Porcelain Cutlery</td>
</tr>
<tr>
<td>Power drill Electric mixer</td>
<td>Electric mixer Power drill</td>
<td>Electric mixer Cutlery</td>
<td>Electric mixer Water</td>
</tr>
<tr>
<td>Cutlery</td>
<td>Cutlery</td>
<td>Power drill</td>
<td>Cutlery</td>
</tr>
<tr>
<td>Water</td>
<td>Power drill</td>
<td>Power drill</td>
<td>Power drill</td>
</tr>
</tbody>
</table>
5. Discussion

The question of disturbing sounds is not a new topic. But, the connection between hearing ability and annoyance and the connection to the concept of loudness has previously not been investigated with sounds determined as disturbing by hearing aid users. The findings have implications for audiological rehabilitation and for hearing aid fittings, but above all, for information and counselling of people suffering from hearing loss and their next of kin.

The results from the present studies indicate an always present problem due to the sound environment, listening and disturbance. The research area of sound disturbance is vast, grasping many targets of sounds and their consequences. Most studies of sound disturbance have focused on sounds from transportation systems, such as aircraft, train and traffic (Crichton et al., 2015, Di et al., 2015, Gidlöf-Gunnarsson & Öhrström, 2010, Janssen et al., 2014, Hammer et al., 2014). These studies are of great importance for the daily life as the consequences are of importance for a number of people. Disturbing sounds have been investigated as source for e.g. distress, insomnia, and cardiac failures (Basner et al., 2014, Belojevic & Paunovic, 2016, Stansfeld & Matheson, 2003). Disturbing sounds also have a negative impact on learning as sounds can impede the cognitive resources of school children leading to disturbed concentration and learning (Beaman, 2005).

In the present thesis the focus was to investigate a clinical population, and to evaluate the persons’ opinion of disturbing sounds. In study I, all persons had completed a regular auditory rehabilitation, and there was a wide inclusion range of hearing losses to provide as broad input as possible. In the following studies, a more narrow inclusion criterion according to hearing (normal or mild to moderate hearing loss) was chosen. Persons with mild to moderate hearing loss are one of the larger groups in the clinical population, since it nowadays is more common to reach out for audiological rehabilitation in an earlier stage of hearing impairment, also with a mild hearing loss.

5.1 The presence of disturbing sounds (study I)

Study I showed that people found their sound environment somewhat troublesome and disturbing. Nearly 92 % of the participants reported disturbance more or less daily, indicating disturbing sounds has to be considered as a present and real problem. Primarily since most of the participants
choose to reduce their hearing aid usage due to the disturbing sounds. The sound sources perceived as disturbing, are sounds present in the daily environment. For hearing aid users, the disturbing sounds cause a reduced hearing aid usage thereby reducing the possibilities to take part in communication and to participate in social life. People with mild hearing losses as well as more profound hearing loss benefit from the use of hearing aids (Dillon, 2012), but there is a risk that the sound environment reduces that benefit. Furthermore, the use of binaural hearing is crucial to the experience of improved hearing as well as increased sound quality (Gatehouse & Akeroyd, 2006). With an asymmetrical hearing, according to Gatehouse & Akeroyd (2006), in dynamic listening situations, such as a somewhat noisy environment, speech performance is reduced, but also attention and localization skills.

The intention of the diary survey (study I), was to obtain the participants’ individual opinion of their sound environment. Kaun (2010) discussed advantages of diaries, primarily as the method provides the possibility of capturing subjective states and perception of participants. Since the main question was to investigate, which sounds that were perceived as disturbing, the diary was considered as a reliable method. A structured diary with open questions was used and, both in the pilot study and the main study, showed robust results. A drawback with open questions might be that participants can be somewhat reluctant to write down complete information. The use of diaries for data collection put requirements on the participants, they need to have certain abilities (Jacelon & Imperio, 2005). The participants need to be literate and to have the physical capacity of writing, or have someone to assist. There is a need of keeping the diary for one to two weeks, to be able to achieve reliable data. Within a research diary, the first entries can be tentative and brief, but after a few days the participants are more comfortable with the data collection and provide more information. There is a balance act to not keep the diary for too long since there is a risk of losing interest (Jacelon & Imperio, 2005).

In study I the participants’ hearing threshold levels were collected from the individual journals. Since the participants had been rehabilitated over a period of time, there was a variation in how recent the pure tone audiometry had been measured. For some persons, there was a possibility that the hearing ability had altered compared to what the previous audiogram had shown. However, the participants did not indicate that their hearing subjectively had deteriorated since the collected audiogram was measured.
5.2 Acoustical properties of disturbing sounds (study II)

The investigation of sound sources perceived as disturbing by the hearing aid users in study I revealed few clear conclusions of the acoustic properties that could be determined as the source of disturbance. The studied sounds were examples of sounds that reduced hearing aid usage in study I. The studied sounds were all indoor sounds, present in an ordinary home situation. Those sounds seemed to be more disturbing than other sound sources mentioned in study I, as those sounds reduced the participant’s hearing aid usage. At the same time, those sounds are daily present for most people and thereby more likely to be mentioned by more persons. For example, we are all, more or less, exposed to sounds when preparing food and/or eating. Previous studies that examine acoustical properties of disturbing sounds have primarily focused on high-level sounds since disturbance has been assumed to be primarily driven by sound level (e.g. Warner & Bentler, 2002, Hall et al., 2013). It has been clearly stated that high level sounds per se are disturbing, as they may be a risk of damage and unpleasantness (Berglund et al., 1976, Guski et al., 1999). Low level sounds have been shown less attention even though they can be disturbing especially for persons with hearing loss due to the risk of masking.

The sounds used in this study showed a variation in RMS level, temporal and spectral pattern. It seemed plausible that the spectral pattern of a sound has a high impact of the perception aside the RMS level. But no common frequency areas were found that could highlight the negative effect on hearing aid usage of the investigated sounds. There were a variation of the peaks in the studied frequency area and spectral peaks have formerly been shown to have an impact on sound perception. Jerger & Thelin showed in 1968 that speech recognition was decreased when tested with peaky frequency response compared to speech recognition tested with a smooth frequency response (reviewed in Warner & Bentler, 2002). Byrne et al (1981) found that the preferred listening level was negatively affected by spectral peaks of a sound stimulus (reviewed in Warner & Bentler, 2002).

Overall loudness has previously been shown to be a determinant for a person not to benefit from hearing aid amplification (Warner & Bentler, 2002), a fact that also can be clinically recognised. Since previous studies predominantly have focused on overall loudness or high level sounds, there was a need to examine if there were signs of some acoustical properties in ordinary daily sounds of varying sound levels that could be seen as a determinant of disturbance of sounds.
5.3 Perceptual outcomes (study III and IV)

A person suffering from a mild hearing loss, most often has few problems in silence, but is suffering from problems in noisy environments, due to normal (or near-normal) hearing thresholds up to 1 kHz and moderate hearing loss at higher frequencies (Garcia et al., 2016).

5.3.1 Auditory and cognitive testing

For the tests of hearing ability and working memory capacity used in the present thesis, existing validated tests were used. Using existing methods has the advantage of providing the possibility for comparison between studies. In order to investigate the effect of hearing ability on loudness and annoyance perception in study III and IV, several psycho-acoustical measurements were used. All participants within study IV suffered from mild to moderate high-frequency sensorineural hearing loss. A loss of frequency components in the high-frequency area, above 3 kHz, has been shown to reduce speech intelligibility with approximately 10% (reviewed in Moore, 2016). Furthermore, the outcome of speech intelligibility was improved when persons with high frequency hearing loss were provided with amplification (Hornsby & Ricketts, 2006). When testing for perception of sounds other than speech, the contribution from the high-frequency area was somewhat problematic. The results showed an improved hearing ability when using hearing aids, so it was presumably beneficial for speech intelligibility. The results for loudness rating in study III and IV indicated that the perception of loudness was restored to perception more similar to normal hearing people. At the same time, the annoyance of sound increased and reduced the perceived overall benefit of the hearing aids.

5.3.2 Rating tests

The used rating tests were based on the method by Cox et al. (1997) using a seven-graded scale, with numerical values connected to the verbal descriptors. However, during the analysis there were indications in the result that the participants tended to think that a higher number indicated a worse rating. Indeed, this was in general correct for the loudness rating, but for the annoyance rating the verbal descriptors were not equal to increasing numerical values for the entire range. Furthermore, a scale with seven descriptors can be discussed not to be detailed enough, thereby causing a loss of information. Several scaling methods use an eleven-graded scale which ensures a somewhat higher differentiation for how a person perceives a
sound. One example of eleven-graded scales is the ACALOS method (adaptive categorical loudness scaling) introduced by Brand and Hohmann in 2002 (Oetting et al., 2014). At the same time, an eleven-graded scale may introduce an uncertainty of the judgement in rating. Here we preferred a seven-graded scale in order to reduce the time used for the rating.

5.3.3 Loudness models
Loudness models initially were based on stationary sound and the result was momentary loudness perception. For a more complete prediction of loudness perception one cannot base the models on stationary sounds, consequently loudness models have been developed for time varying sounds. Models based on time varying sounds calculate the global loudness, assuming that the hearing system performs an averaging over time for the tested stimulus. Ponsot et al. (2016) showed that this kind of calculations does not provide a correct and reliable response for loudness perception. Instead, global loudness with present methods may only represent a form of momentary loudness for the high-level parts of the sound. In order to achieve more correct methods for global loudness, the use of molecular psychophysics has been suggested (Ponsot et al., 2016). Molecular psychophysics is based on stimuli with simultaneous background sounds and performing a numerous number of ratings. Even though this could be a more reliable way of testing loudness perception there are drawbacks with the method, since type of sound stimulus has high impact on the outcome, both in temporal, spectral and level aspects (Ponsot et al., 2016).

Loudness models are the foundations for the algorithms of hearing aid settings. If the models provide incorrect predictions of loudness perception, the resulting output signal of a sound in a hearing aid will not be optimal. Some sounds, such as the well-studied stimuli of speech, will most likely provide sufficient gain and smooth spectral resolution. Other sounds risk to be causing disturbance or perceived negatively.

5.4 Ethical considerations
During the data collection, an ethical dilemma appeared as persons volunteered to participate in study III, where persons with normal hearing threshold were sought. Within the phase of measurements for verifying the inclusion criteria some of the persons did not fulfil the inclusion criteria regarding hearing threshold levels within the normal range. They, themselves, thought they had normal hearing, but pure tone audiometry showed a hear-
ing loss, primarily in the high frequency area. Those persons did not experience, to our knowledge, any problems due to hearing, and did not use assistive listening devices. For some of the volunteers it was unexpected that they had a hearing loss. They were all offered further information of hearing and rehabilitation at the audiological clinic. This implies that the criteria of normal hearing used here, and the question of when a person experience hearing loss could be discussed. The medical criteria, used here and elsewhere, defines normal hearing thresholds as showing results better than 20 dB HL. The experience of hearing loss for the individual is very subjective; one person can see themselves as suffering from hearing loss even with hearing thresholds better than the medical criteria. And other persons, do not experience hearing problems even though they have worse hearing thresholds than defined as the normal range. In the national quality register of aural rehabilitation (Hörselbron) it has been shown, that persons with mild hearing losses benefit from the use of hearing aids. The experience of hearing loss is, as said, individual and maybe determined more by the communication demands in daily life than by the actual hearing threshold. In Sweden, there is an ongoing debate of hearing screening, especially among elderly people. The voices pro the suggestion claim that it is necessary to find people suffering from hearing loss in order to increase their activity and participation in society. Previously, it has been shown that the development of poor mental health may be delayed with improved hearing ability since the hearing handicap is reduced (Dawes et al., 2015). Furthermore, it has been shown that moderate or severe hearing loss is associated with an increased risk of dementia (Deal et al., 2017). The responsibility for hearing conservation programs by hearing health care can be discussed in this context. With a higher impact in the public debate (by information of sound environment, sounds, hearing losses and the benefit of rehabilitation), there is a possibility of reducing the number of persons suffering from hearing loss.

All participants in the present studies involved in audiological rehabilitation, had been treated at the same clinic (publicly financed). This could be considered as a risk of bias. The clinic is considered to be a large clinic (approximately 60 employees, of whom 25 are clinical audiologists) and the participants had been treated by several different audiologists. All participants using hearing aids had been rehabilitated using the same routines, which can be considered as a risk for bias, but also as a strength in the study.
5.5 General discussion

5.5.1 Age
The risk of decreased hearing ability increases with age (Hoppe et al., 2016). Furthermore, besides the increased risk for developing a hearing loss, the aging human will deteriorate in cognitive function, and nerve activity, leading to a reduced possibility to select and interpret stimuli. Even normal hearing persons therefore experience increased disturbance at higher age, but the risk of being disturbed by sounds increases even more with a hearing loss (Lisowska et al., 2014). The increased disturbance occurs according to Lisowska et al. (2014) mainly due to degenerative changes in the cochlear nucleus and the auditory nerve with higher age. Since elderly people most often also show signs of decreasing cognitive function, a function crucial to the perception of sounds, listening problems appear. Sounds will be audible, but interpretation will be aggravated.

In everyday listening, it has previously been shown that older persons experience more difficulties compared to younger ones, problems especially occurring in the presence of background noise (Fullgrabe et al., 2015, Gatehouse & Noble, 2004). In study I younger participants gave more information and more notations in the diary than elderly participants. This result does not reveal if the difference is due to age or due to being more disturbed by sounds. There were neither indications that younger subjects participated in a greater amount of activities, nor that they had better hearing thresholds, than the elder ones.

Generally, it seems to be more demanding for an elderly person to be active and to participate in an everyday conversation compared to a young person. It could be debated if sounds are, per se, more disturbing for elderly persons due to the degeneration in the hearing system since an elderly does not perceive sounds in the same way as a younger person. It could also be questioned if disturbance of sounds are depending on how exposed a person is to different sound sources and sound environments, i.e. if a person is used to hear the sound or not.

5.5.2 Hearing aid experience
Hearing aid usage has been stated as beneficial for persons with hearing impairment, for improving speech perception, spatial information as well as sound quality (Gatehouse & Akeroyd, 2006, Aazh & Moore, 2017, Dawes et al., 2015). A bilateral fitting is primarily beneficial for improved spatial information compared to unilateral fitting (Gatehouse & Akeroyd, 2006).
Bilateral fitting have implications for the perception of loudness since a non-fitted ear can show signs of lower uncomfortable loudness levels compared to a fitted ear (Hamilton & Munro, 2010). Non-usage of hearing aid/s deteriorate the possibility to be a part of aural communication, especially with present background sounds, since speech perception is affected by hearing impairment but also the possibility to switch attention between sound streams (Gatehouse & Akeroyd, 2006).

Study I investigated the differences in perception of disturbing sounds in correlation to hearing aid experience. The results showed no statistically significant differences in expressed annoyance with regard to hearing aid experience. Grade of adaptation to hearing aid amplification has been considered as an indicator of an improved hearing situation and also improved speech perception. These statements have recently been debated and there are contra-indications on adaptation to hearing aid amplification being the main factor influencing speech perception for hearing aid users (Dawes et al., 2013b). For example, Petry et al. (2010) compared hearing aid users’ results on speech reception tests and found no significant differences between users who had been using hearing aids for 14 and 90 days respectively. Furthermore, Petry et al. (2010) found no significant indications that the age of the hearing aid user had an effect on speech perception.

To improve listening abilities, adaptation to hearing aids is important, to get used to wear hearing aids, and realising the effect of hearing aids, both positive and negative. One can hypothesize that the algorithms used in modern hearing aids not entirely can compensate for the reduced hearing ability and thereby not provide full compensation even after full adaptation. On the other hand one has to discuss the ability of auditory acclimatization. The term auditory acclimatization was established by (Arlinger et al., 1996) and has been well investigated for linear signal processing with focus on improvement of speech perception. However, the scientific evidence of auditory acclimatization for linear signal processing is not clear. Some studies show significant signs of improved speech perception due to acclimatization whilst other show no significant evidence. There are less studies on acclimatization for nonlinear hearing aid signal processing. (Dawes et al., 2015) showed low improvement in speech perception due to auditory acclimatization. In their study, the effect of acclimatization for experienced hearing aid users and non-experienced hearing users as well as unilateral and bilateral hearing aid usage was compared. The authors state, that the effect of auditory acclimatization is absent and should be disregarded as a factor to be taken into account within audiological rehabilitation (Dawes et al., 2015).
Nevertheless, during initial hearing aid fitting, the impact of improved speech perception definitively has to be taken into account.

5.5.3 Energetic and informational masking
Noise is often regarded as disturbing due to its effect of masking wanted sounds. The effect of masking has been well studied, both temporal and spectral masking, but more often in a context of explaining reduced speech perception than explaining sound perception. In relation to sound perception, masking sounds can be divided into energetic masking and informational masking. Energetic masking (EM) is defined as “the masking results from competition between target and masker at the periphery of the auditory system” (Moore, 2016, p 708). EM occurs, when a signal is partially degraded by background sounds within the same spectro-temporal regions. Informational masking (IM) occurs with the introduction of additive acoustic stimuli (Durlach et al., 2003) and corresponds to the consequences in the central auditory system due to background sounds (Mattys et al., 2010). According to Mattys et al. (2010), informational masking can be divided into three categories:

1. Competing attention of the masker, i.e. the cost of the effort involved in ignoring the masker by stream segregation or selective attention (speech in background of babble.
2. Interference from a known language, the detrimental effect of a masker when the masker itself is intelligible and meaningful (lexical-semantic interference).
3. Cognitive load, i.e. the depletion of processing resources when listeners are required to divide their attention between the main task and the masker.

Speech understanding in noisy environments can be compromised through EM and IM. EM reduces intelligibility of target speech through spectro-temporal overlap with the masker at the auditory periphery level. IM refers to the higher-level interference, such as competing attention, linguistic interference, and increased cognitive load. Both the EM and the IM can furthermore be interfered by surrounding disturbing sounds, thereby reducing the sound perception. The interference are both acoustically and psychologically demanding, which may result in a deteriorated communicative situation.
5.5.4 Psychological effects of disturbing sounds

Beside physiological effects, disturbing sounds also have psychological effects on the human being. The most common discussed psychological effect is stress, which has been shown to largely affect the human. Lately, the interest of sounds’ effects on cognitive skills and learning performance have been raised (e.g. Lercher et al., 2002, Hua et al., 2014b, Sandrock et al., 2009, Alimohammadi et al., 2013, Belojevic et al., 1992). The effect of noise on psychological performance can have both an acute and a chronic effect, where the acute effect can be e.g. stress and distraction, leading to a chronic effect in form of reduced learning and productivity (Hammer et al., 2014).

To completely avoid the acute effects is neither possible nor desirable, an instant reaction to sounds (“fight-or-flight-response”) can even be crucial for survival. Reducing occasions with disturbing sounds that cause an acute effect is of great importance in order to avoid a chronic effect as much as possible. Reducing psychological effects generally important for all people, but may be especially crucial for persons suffering from hearing loss. In a clinical setting, speech perception in noise is regularly tested within the context of evaluating audiological rehabilitation and especially hearing aid fitting. These tests indicate the possibility of the auditory system to interpret sound signals. However, the individual is affected by several personal factors that impede the rehabilitative outcome. Individuals have varying acceptance towards noise. The Acceptable Noise Level (ANL)-test produced by Nabelek (2006) is a behavioural assessment tool of background noise acceptance with the intend to describe the individual difference of acceptable background noise while listening to a conversation. The results of this assessment has shown that acceptance of background noise is a personal factor and not affected by e.g. age, sex, or hearing sensitivity (Nabelek, 2006, Nichols & Gordon-Hickey, 2012). The acceptance of noise can be referred to as a question of an individual’s locus of control. Locus of control refers to how a person views outcomes in life, i.e. if a person views events as a result of his or hers own actions. If a person experiences events as the result of own actions, the person is stated as having an internal locus of control. Having an internal locus of control has been found to decrease stress reactions and to increase health-promoting behaviours (Nichols & Gordon-Hickey, 2012). Furthermore, the acceptance of background noise is affected by self-control, i.e. an individual’s ability to control thoughts, emotions, impulses and performance, and is affected by the situation. Nichols & Gordon-Hickey (2012) showed, that persons with more self-control are willing to accept more background noise, compared to persons with
lower levels of self-control, but no impact of locus of control was found. The psychological effect on degree of disturbance has furthermore been shown to have a positive effect of and is determined by the sense of control a person has over a sound (Maris et al., 2007). A clear example of the psychological reaction to sounds based on control is music. A person listening to self-selected music, has control of the sound and can tolerate even rather high sound levels, whereas a person listening to the same music involuntarily can regard it as disturbance, no matter what the level of the sound is (Hammer et al., 2014). In study I, it is clear that a number of the mentioned disturbing sound sources can be regarded as situations with a lack of control for the participating hearing aid user. The situations where one can argue that the person lack control of the sound sources were recognisable in all analysed categories, maybe most obvious for household appliances, porcelain and cutlery, music, and verbal sounds (Skagerstrand et al., 2014).

The perception of sounds is furthermore affected by the psychological emotion of the listener. Emotions, either positive or negative, enhance the reaction to stimuli, whether it is sound or any other stimulus. Furthermore, the same sound will be experienced differently from time to time, depending on the mood. Expectations of a sound source have high impact on the perception of a sound. I.e. if a person has a negative experience of a sound, the negative emotions rise and affect the result of a perception test (Smith & Lane, 2016).

All the above mentioned psychological reactions to noise and sounds have influence on the sense of annoyance caused by a sound. Reduced annoyance is important for improvement of peoples’ viability (Andringa et al. 2011). The main annoying sources were, according to Andringa et al (2011), road traffic and aircraft noise and the effects on their life were irritation and lower quality sleep. The results were interpreted as to influence the participants’ emotions, well-being, satisfaction, and viability. The perception of disturbing sounds is thereby not just an implication of acoustical but also psychological factors.

5.5.5 Implications for audiological rehabilitation
The main focus of audiological rehabilitation is to improve hearing, and has over the years evolved to be a story of the caretaker and the caregiver in a mutual relationship, described as the model of patient centred audiological rehabilitation (PCAR) (Grenness et al., 2014a). Within PCAR, one goal is to improve the person’s activity and participation within the rehabilitative process to improve hearing in the daily environment. Within audiological
rehabilitation, the technical support, mainly support with hearing aids, is crucial to make sounds audible, thereby improving hearing sensitivity. To date, in the human, there is no possibility to heal an impaired hearing system, and one important rehabilitative intervention is fitting hearing aids. A hearing aid is a compensatory intervention and it’s fitting is based on compromises. Broadened knowledge about an individual’s surrounding sound environment as well as the effects on the individual, improve person centred rehabilitation. The technical interventions have to be supplemented with psychological, sociological, and pedagogic interventions to achieve the goal of audiological rehabilitation for the individual person.

Beside improved audibility, there is clear evidence that hearing aid usage has a positive impact on quality of life for persons suffering from a hearing impairment (Aazh & Moore, 2017, McCormack & Fortnum, 2013, Kochkin, 2011). With successful audiological rehabilitation, including technical interventions, a person can socialize with other and thereby gain a better quality of life.

Despite this proven effect of improved quality of life with hearing aid usage, several studies show evidence that persons suffering from hearing impairment do not use their fitted hearing aids (Aazh & Moore, 2017, Kochkin, 2007b, McCormack & Fortnum, 2013). The reasons for not using hearing aids are multiple. McCormack & Fortnum (2013) have in a review listed the most common reasons with low benefit from the hearing aids stated as the most common reason for rejecting hearing aid amplification. Low benefit was connected with low improvement of speech perception, especially in background noise, and poor sound quality. Furthermore, there were physical statements such as problems handling the hearing aid, low comfort, and problems in maintenance. The same problems were present for both new and experienced hearing aid users and the conclusion is drawn that the professionals have a crucial task to evaluate the possibility for the hearing impaired person to achieve benefit from the hearing aid. Otherwise, there is a risk of non-usage and thereby decreased quality of life for the hearing impaired person (McCormack & Fortnum, 2013). Non-usage of hearing aids have several negative consequences for the person, the next of kin, as well as for the society. The person can suffer, as previously mentioned, from lower quality of life, reduced participation in communication, and isolation. For the society it is primarily an economic issue, if a person is provided a hearing aid and become a non-user, with misused resources of equipment as well as professionals (Aazh & Moore, 2017).
Hearing aid fitting, as earlier mentioned, improves primarily audibility of sounds. The audiological rehabilitation has the challenge to facilitate hearing in order to ease the challenge to hear WHAT is said than just that something IS being said. To facilitate hearing, it is of great importance that the fitted hearing aid is being used, but with disturbing sounds in the environment there is a great risk of reduced hearing aid usage. So, with the aim to improve the hearing impaired person’s possibility to be active and to participate in daily communicative situations, an important challenge for the audiologists has to be how to reduce the disturbance of hearing aids, both by proper hearing aid settings and by knowledge of the sound environment based on the needs of the person.

5.6 Future directions
The present thesis has given a description of disturbing sounds with focus on the perception of those sounds by persons with hearing loss as well as persons using hearing aids. Disturbing sounds have been shown to have an impact on persons’ well-being and their experience of sounds. The current results have given more clues regarding the knowledge about disturbing sounds, but further work has to be accomplished. Future research should focus on the question of acclimatization, if one can acclimatize to sounds and thereby learn to suppress disturbing sounds. Another aspect connected to this question, of course is, if the sounds classified as most annoying in this study, would be similarly perceived, if the sounds just were part of an acoustic background, instead of being the only sound presented. Future research should also follow up how technical interventions within audiological rehabilitation can be improved, based on the knowledge of perception of disturbing sounds. The results also indicate a need for further multi-disciplinary collaborations, especially regarding audiology and psychology, in order to create a better understanding of factors connecting underlying mechanisms of sound-annoyance.
6. Conclusion

The present thesis describes examples of sounds perceived as disturbing by hearing aid users and how persons with normal hearing as well as persons with a hearing loss perceive these sounds. Irrespectively of hearing threshold, hearing aid usage or signal processing, there are sounds that, more or less daily, are perceived as disturbing by hearing aid users. However, these sounds are most often sounds that are common components of an everyday sound environment.

The perception of disturbing sounds is more complex than to be explained by acoustical factors only. Nevertheless, it is not clearly stated which different aspects influence perception of disturbing sounds. Sounds that are perceived as disturbing have a negative effect on people with hearing loss, and reduce the motivation to use prescribed hearing aids, regardless of degree of experience with hearing aid amplification. Unexpectedly, some sounds, such as sounds from paper, were classified as loud and highly annoying when presented as isolated sound sources. Hearing impairment affects sound perception regarding both loudness and annoyance, but the effect was reversed towards a perception similar to normal hearing persons when using hearing aids. Working memory capacity does not seem to influence perception of loudness or annoyance when the disturbing sounds are presented as isolated sources.
7. Sammanfattning på svenska

Titel: Perception av störande ljud


Det övergripande syftet i denna avhandling var att belysa störande ljud i en daglig ljudmiljö och hur hörselnedsättning och användande av hörapparat kan påverkas negativt av störande ljud. För att beskriva området genomfördes fyra delstudier med följande syften:
1. Att beskriva vilka ljud som hörapparatanvändare uppfattar som störande i sin dagliga miljö och vilka åtgärder personerna vidtog för att minska störningen.

2. Att beskriva akustiska faktorer för några av de ljudexempel som framkom i studie I. De ljud som studerades var sådana ljud som ofta minskade hörapparatanvändandet.

3. Att studera hur normalhörende personer reagerar för störande ljud avseende upplevd styrka och störningsgrad. Syftet var också att se om auditiva eller kognitiva faktorer påverkade uppfattningen om ljud.

4. Att studera hur personer med mild och måttlig hörselnedsättning reagerar för störande ljud avseende upplevd styrka och störningsgrad, samt inverkan av auditiva och kognitiva faktorer. Syftet var dessutom att studera om och hur hörapparatanvändande påverkade den upplevda styrkan och störningsgraden.


Sammantaget visar resultaten från de olika studierna att störande ljud är närvarande i människans dagliga miljö och att de påverkar hörapparatanvändandet negativt. Ljud som uppfattas som störande är ofta ljud som finns i vår närhet och det är ljud som i ett sammanhang är önskat men som i ett annat sammanhang kan uppfattas som störande. Det ljud som flest personer angav som störande var mänskligt tal och ljud från TV/radio samt fordon. Beroende på ljud var åtgärden för att minska störning något varierande, vanligaste åtgärden var att stänga av eller ta av hörapparaten. Det resulterade i sin tur med att personen då inte uppfattade önskade ljud i situationen. Resultaten i studierna kan inte klargöra en enskild orsak till att personer upplever ljud som störande. Inga gemensamma akustiska mönster kunde

8. Acknowledgement

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And now, the next chapter can finally begin…
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*Investigations of people with hearing loss and normal hearing*

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