Sound intolerance:
Characteristics, psychosocial work factors and reactions to exposure

Johan Paulin
To Hanna and Hedvig.

Words can’t describe...
Table of Contents

Abstract .......................................................................................................................... 3
List of Abbreviations .................................................................................................... 5
List of Papers ................................................................................................................ 6
Enkel sammanfattning på svenska .............................................................................. 7

Introduction ................................................................................................................ 9
Terms and definitions .................................................................................................. 9
Theories of altered sound perception and sound intolerance .................................... 11
Methods for assessment of sound intolerance and hyperacusis .............................. 13
Prevalence of sound intolerance ............................................................................... 14
Symptoms, comorbidity and risk factors ................................................................... 14
Sound intolerance in the workplace .......................................................................... 15
Laboratory studies ....................................................................................................... 16
Aims of the thesis ........................................................................................................ 16

The empirical studies ................................................................................................ 18
Methods ....................................................................................................................... 18
Participants ................................................................................................................ 18
Questionnaires and Assessments ............................................................................. 20
Data analysis ................................................................................................................. 22
Ethical considerations ............................................................................................... 23

Study I - Characteristics of Hyperacusis in the General Population ...................... 25
Aims and method ......................................................................................................... 25
Results and discussion ............................................................................................... 25

Study II - Associations between hyperacusis and psychosocial work factors in the general population ................................................................. 29
Aims and methods ....................................................................................................... 29
Results and Discussion .............................................................................................. 30

Study III – Reactions to white noise exposure in sound intolerance: Perception, symptoms, cognition and autonomic responses .......... 33
Aims and methods ....................................................................................................... 33
Results and Discussion .............................................................................................. 34

General discussion .................................................................................................... 39
Summary of findings: A prevalent and multifaceted problem .................................. 39
Study I ......................................................................................................................... 39
Study II ....................................................................................................................... 39
Study III ..................................................................................................................... 40
Coping with sound intolerance .................................................................................. 40
Reactions to exposure ............................................................................................... 41
Some notes on underlying mechanisms .................................................................... 42
Further reflections ...................................................................................................... 43
Additional limitations of the thesis .......................................................................... 44
Classification ........................................................................................................... 44
Validity ..................................................................................................................... 45
Future directions ..................................................................................................... 45
Treatment ................................................................................................................ 46
Geographical differences ....................................................................................... 46

Acknowledgement .................................................................................................. 48
References .............................................................................................................. 50
Abstract

Sound intolerance refers to an adverse reaction to sounds at sound pressure levels most people do not find bothersome. It is sometimes associated with hearing loss and tinnitus, but neither conditions are a prerequisite for being intolerant to sounds. The processes underlying the heightened reactions to sound, or how sound intolerance is related to other afflictions is not fully known, and research in this area can still be described as being in an early stage. This thesis aims to broaden the knowledge about sound intolerance and the sub-category of hyperacusis by using cross-sectional epidemiological and quasi-experimental methods of inquiry.

The thesis consists of three studies, each approaching the subject from a different perspective with the aim to better understand various characteristics of sound intolerance in general, its relation to psychosocial factors in the work environment, and its effects during noise exposure. Studies I & II are cross-sectional studies using two different data sets with similar design. Study I was based on data from a stratified sample in the Västerbotten Environmental Health Study. It examined the characteristics, background descriptions and comorbidities of self-reported and physician diagnosed individuals with hyperacusis, and compared them to a healthy referent group. Analyses revealed that a majority of both hyperacusis groups actively tried to avoid sound sources, and experienced that they for the most part could affect the environment to make it less noisy. There were significantly increased risks for other diagnosed illnesses in the hyperacusis groups compared to the healthy referent group, with large odds ratios (ORs) for the psychiatric illnesses anxiety, depression, post-traumatic stress disorder and exhaustion syndrome. Other common illnesses were tinnitus, hearing impairment and musculoskeletal disorders. Study II used data from the Österbotten Environmental Health Study and focused on the psychosocial work environment for people with hyperacusis. Working participants with hyperacusis who were employed/on leave of absence/paternal leave/long-term sick listed were compared to a working sample without hyperacusis on measures of effort-reward imbalance, work over commitment, emotional and social support and worry at work. The hyperacusis group scored significantly higher on worry, social support, and reward, whereas the groups did not differ significantly with respect to emotional support, over commitment or effort. In the final study, a quasi-experimental design was employed to investigate how individuals with sound intolerance react to noise exposure over time, in terms of perceived sound intensity, unpleasantness, rated distractibility, symptoms, heart rate variability and cognitive performance. Participants were divided into three groups of equal size based on their self-rated sound intolerance, which resulted in low, medium, and high sound intolerance groups. Results revealed large variations across
individuals in several outcome variables. Compared to the other two groups, the high sound intolerance group perceived the noise as more unpleasant, stronger, and more distracting. They further rated the symptoms as higher in intensity, showed deviations in heart rate variability, and performed poorer on a cognitive task selected to measure inhibition.

In conclusion, the results suggest that persons with sound intolerance have relatively poor general health and hearing as well as high odds of comorbidity with various symptoms, including psychiatric diagnoses and functional somatic syndromes. In a working population, the sound intolerant show high odds for worrying about things at work, perceiving low social support at work and not feeling rewarded at work. Finally, the results suggest that persons with high sound intolerance have increased distractibility, sound unpleasantness, symptoms over time as well as lowered heart rate variability and cognitive performance when exposed to sounds.
# List of Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>ADHD</td>
<td>Attention deficit hyperactivity disorder</td>
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<tr>
<td>ANF</td>
<td>Auditory nerve fiber</td>
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<td>ANOVA</td>
<td>Analysis of variance</td>
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<tr>
<td>CI</td>
<td>Confidence interval</td>
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<td>dB</td>
<td>Decibel</td>
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<tr>
<td>EI</td>
<td>Environmental intolerance</td>
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<td>EMFs</td>
<td>Electromagnetic fields</td>
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<td>GAD</td>
<td>Generalized anxiety disorder</td>
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<td>HRV</td>
<td>Heart rate variability</td>
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<td>IBS</td>
<td>Irritable bowel syndrome</td>
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<td>LDL</td>
<td>Loudness discomfort level</td>
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<td>NSS</td>
<td>Noise Sensitivity Scale</td>
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<tr>
<td>OR</td>
<td>Odds ratio</td>
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<td>PTSD</td>
<td>Post-traumatic stress disorder</td>
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<td>SD</td>
<td>Standard deviation</td>
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<td>SPL</td>
<td>Sound pressure level</td>
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<tr>
<td>SDNN</td>
<td>Standard deviation of the normal-to-normal interbeat intervals</td>
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<td>VEHS</td>
<td>Västerbotten Environmental Health Study</td>
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<td>ÖEHS</td>
<td>Österbotten Environmental Health Study</td>
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List of Papers


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föreslår resultaten att personer med hög ljudintolerans upplever hög distraktion, obehag, och symptom över tid samt sänkt hjärtslagsvariabilitet och presterar relativt dåligt på kognitiva uppgifter vid exponering för ljud.
Introduction

Terms and definitions

Unwanted sounds, i.e. noise, affects us all. At sufficiently high levels, everyone (except the deaf) will find noises irritating or disturbing. Indeed, the textbook definition of noise is “any sound that is undesired or interferes with one's hearing of something” (Merriam-Webster). Usually, this applies to sounds at a high decibel (dB) level, or from unexpected sound sources, for example the waiter dropping a load of plates in the restaurant or the wailings of a baby. Some individuals, however, experience negative reactions from sounds at levels that most find acceptable, and from sources much more benign such as the murmured voices at a café, or the crinkle of newspaper or the low hum of a computer fan. This is what people suffering from sound intolerance experience on a regular basis. The consequences can range from mild inconvenience to being so debilitating that they must avoid places or situations in which they cannot control the noise. Everyday sounds can thus be perceived as louder, more uncomfortable, painful or disturbing at sound levels with which the majority of people have no problems. The general nature of the sound sources evoking adverse reactions are highlighted in a quote from a patient with severe sound intolerance:

Many sounds that I would not have characterized as remotely loud prior (...) felt physically painful or uncomfortable (...) for as long as the sound lasted. These sounds included high-frequency or resonant adult voices, a crying baby, the voices or laughter of young children, a party, the percussive sound of a glass being placed on the counter, a dog barking, a bird whistling, silverware dropped in the sink, the clatter of dishes being placed in the dishwasher, a garbage disposal or vacuum cleaner, a piano, a sax, trumpet, flute, violin, or drums, my own singing, some flushing toilets, a leaf blower, a dentist's drill, shopping malls, grocery stores, movie theaters, most restaurants, announcements over a loudspeaker, a car horn, squealing brakes, and the sounds of road noise when driving (Littwin, 2018, pp. 242).

Whereas not all cases of sound intolerance are as debilitating as described above, the impact of sound intolerance on a person’s life can be substantial even in milder forms. In the literature, terms such as (1) hyperacusis, (2) noise sensitivity, (3) hypersensitivity, (4) noise intolerance and (5) misophonia have been used somewhat interchangeably with the same term used to describe different symptoms, and vice versa, different terms have described similar symptoms (Phillips & Carr, 1998). The variety of terms and labels is a challenge for anyone who tries to make a foray into the research field. I will therefore
summarize how these terms have been used in previous research, and what differentiates them.

Hyperacusis is arguably the most prevalent term in research and clinical settings. Although it does not have a general definition, a common description is “everyday sounds being perceived as intense and overwhelming” (Baguley & Hoare, 2018). Adverse reactions to sound was first referred to as hyperacusis by Dr. Henry B. Perlman, an otolaryngologist, in 1938. Research did not really gain traction and wider interest until the late 90’s (Fagelson & Baguley, 2018a). Today, the interest of the phenomenon has widened to include researchers from audiology, psychology and to some extent environmental health. Recently, efforts have been made to differentiate expressions of hyperacusis (Fagelson & Baguley, 2018b; Tyler et al., 2014) by outlining four sub-categories: Fear, Pain, Annoyance and Loudness hyperacusis. Fear hyperacusis is manifested as an expression of fear or reluctance to being exposed to sounds or noisy environments. This can result in avoidance behavior and, by extension, social isolation. Pain hyperacusis implies that the sufferer experiences pain when exposed to certain sounds. Annoyance hyperacusis implies a negative emotional reaction to noise, either specific sounds or a group of sounds, often manifested as irritation, anxiety or tension. Lastly, loudness hyperacusis is when the sufferer experiences that sound as louder than commonly perceived. As alluded to in the quote above, these definitions can be somewhat arbitrary in that they tend to overlap. It is, for example, difficult to state with any degree of precision the conceptual boundaries between e.g. annoyance, fear or pain. Likewise, annoying, fearful and painful sounds would arguably often also be perceived as loud. As evident by the descriptions above, hyperacusis can be seen as a subcategory of sound intolerance, describing severe cases. Hyperacusis has the ICD-10 listed diagnosis code H93.2 (Socialstyrelsen, 2010).

Heinonen-Guzejev (2009) describes noise sensitivity as an umbrella term meant to capture physiological, psychological and attitudinal aspects, or even a personality trait (Stansfeld, 1992; Zimmer & Ellermeier, 1999). The pervasive and heightened reactivity to sounds of noise sensitivity is, similar to sound intolerance, not correlated with noise level (Stansfeld, 1992). In other words, given enough loudness, everyone will be annoyed by a sound, but being noise sensitive might predispose you to be more easily annoyed. Noise sensitivity is not to be confused with hypersensitivity, which is usually used in the context of an unwanted reaction of the immune system. Nevertheless, many studies have used the term to describe symptomology fitting with the term hyperacusis (Anari, Axelsson, & Eliasson, 1999; Bläsing, Goebel, Flötzinger, Berthold, & Kröner-Herwig, 2010; Fackrell, Fearnley, Hoare, & Sereda, 2015; Nelting, Rienhoff, Hesse, & Lamparter, 2002; Salloum et al., 2016). As Tyler et al. (2014) point out, the term sensitivity has in a psychoacoustic context historically been referred to
hearing threshold. Since adverse reactions to sound does not necessitate more acute hearing or lower auditory thresholds, Tyler et al. (2014) argue against equating hypersensitivity with hyperacusis. Noise intolerance (4), has been used to denote severe cases, with similar symptomology as the hyperacusis label (Nordin, Neely, Olsson, & Sandström, 2014; Vernon, 1987). The two terms have also been used interchangeably. Lastly, misophonia (5) has been used to describe cases in which specific sounds (i.e. chewing, breathing, pen clicking) elicit intense responses in individuals, such as irritability, disgust or anger (Cavanna & Seri, 2015; Pawel J Jastreboff & Jastreboff, 2014). This is in contrast to hyperacusis, which tends to be triggered by sounds in general, and which shows a broader palette of reactions than just anger, including fear and pain (Tyler et al., 2014).

In this thesis, I have chosen to use the term sound intolerance as an umbrella term referring to adverse reactions to sound that are generally tolerated – from slight unpleasantness to debilitating forms. Sound intolerance is to be seen as an all-compromising term denoting many of the sub-categories of sound problems listed above, including all types of hyperacusis. The label closest to sound intolerance is noise intolerance. However, I have opted to use the word sound rather than noise, as noise in itself carries the connotation of something unwanted. By that rationale, all noise is inherently unwanted and disturbing, whereas sound is a more neutral term which can hold both positive and negative meaning. When I further describe the research on sound intolerance in its many forms below, I will nevertheless use the authors’ original terms.

**Theories of altered sound perception and sound intolerance**

Historically, hyperacusis was first observed in patients with hearing loss and later tinnitus. Around the 1930’s - when audiometers started to improve in precision, and hearing thresholds were more accurately measured - scientists observed that some people with hearing loss reported a stimulus 10 dB above their hearing threshold as louder than the same (relative loudness) stimulus for individuals without hearing loss. In other words, a sound with the same relative loudness level was perceived to be louder by the person with the hearing loss than by the healthy hearing individual. This phenomenon was dubbed loudness recruitment, and is, in addition to hearing loss, associated with an adverse reaction to sound at frequencies specific to the hearing impairment (Blåsing & Kroener-Herwig, 2012).

Recruitment, while also a type of sound intolerance, differs from hyperacusis in prevalence and origin, as well as the way symptoms manifest. Hyperacusis patients may or may not have hearing loss accompanying their intolerance, and while recruitment is often occurring in the same frequency range as the hearing loss - with fast climbing initial spikes to reach near normal levels at higher dB -
hyperacusis patients often report normal loudness levels at lower intensities with more perceived rates of discomfort and loudness at higher intensities (Fagelson & Baguley, 2018b; Noreña & Chery-Croze, 2007). A person with recruitment is typically hard of hearing up until a certain loudness level and suddenly it is too loud. That is why people with hearing impairment might sometimes say “What? What? What? Don’t yell at me!” To them the first three calls for attention went unheard, due to the hearing loss, and the fourth was way too loud when the loudness of the sound finally reached a level that the person could hear. For someone with hyperacusis even that first low-level call may have been perceived as uncomfortably loud. Whereas it may seem counterintuitive, hyperacusis sufferers do not have a more acute or superior hearing compared to the majority (Sheldrake, Diehl, & Schaette, 2015).

As for many issues regarding sound intolerance, the direct causes and mechanisms involved in the condition is not clearly established. A current theory is that of increased neuronal gain in the central auditory system (Auerbach, Rodrigues, & Salvi, 2014; Diehl & Schaette, 2015). This theory basically stipulates that due to damage to the auditory nerve fibers (ANF), the neural activity sent from the cochlea to the central auditory system is decreased, which increases the central auditory activity. The effect is something similar to turning up the volume (gain) on a stereo receiver, causing the incoming signal to be processed as much louder. For individuals with hyperacusis, this would mean that the incoming sound, even at low levels, is perceived by the brain as louder. Another theory speculates that more peripheral mechanisms are at play, with different types of damage to the ANF causing different types of hyperacusis. The type II ANF, which have been shown to act as both detectors of damaged tissue (Liu, Glowatzki, & Fuchs, 2015) and conveyors of pain signals (Flores et al., 2015) to the brain, are believed to be acting as pain fibers in the ear. Thus, damage to type II fibers might be a cause of pain hyperacusis.

There exists several other theories regarding mechanisms behind sound intolerance. These include neural sensitization to stimuli in which there is the progressive amplification of a response over time from continuous or repeated, intermittent exposures to a stimulus. Alternatively, the normally occurring habituation process is not taking place but rather sensations are increasing in perceived strength, despite the stimulus being the same, or even, decreasing (Bell, Baldwin, Fernandez, & Schwartz, 1999; Nijs et al., 2012). In neurogenic inflammation various types of stressors cause release of inflammatory neuropeptides (e.g. substance P), resulting in inflammatory symptoms (P. H. Black, 2002). Another possible theory is that due to previous history, sounds or certain environments have become associated with negative experiences, and by repeated conditioning these associations have been strengthened, resulting in even low levels of stimuli being sufficient to evoke the conditioned reaction. An
example is a case in which one associates the workplace and the noises therein with the cause of burnout. This will over time evoke a conditioned response of negative symptoms even when one is away from the workplace. These type of phenomena are well-documented in other types of environmental intolerances, such as in chemical intolerance (van den Bergh et al., 2001). These underlying mechanisms may explain some aspects of sound intolerance. It is also possible that different mechanisms elicit the same symptomology, but for different reasons. This may explain the wide variety of medical histories found among people with sound intolerance, as well as on a wider plane, the comorbidity between various environmental intolerances (EI; Palmquist, Claeson, Neely, Stenberg, & Nordin, 2014).

**Methods for assessment of sound intolerance and hyperacusis**

The concept of sound intolerance is usually operationally defined on a more general level, taking into account single-item questions of sound intolerance or high scores on questionnaire instruments. When going through the steps of assessing whether, and to what degree, someone experiences sound intolerance or, more specifically, hyperacusis it should be noted that no official or definitive protocol for such assessments exists (Fackrell & Hoare, 2018). Depending on whether the first contact is taken with an audiologist, otolaryngologist, or general practitioner, or whether the individual is part of a research program, the procedures may vary. Commonly, the assessment involves several different modes of inquiry and tests that are not necessarily combined to form a comprehensive diagnosis. The first step is often to assess possible hearing impairment using pure tone audiometry. Although not a prerequisite for sound intolerance, hearing impairments often co-occur. The next step is establishing the patient’s loudness discomfort level (LDL; sometimes referred to in the literature as uncomfortable loudness level) by measuring the dynamic range of the auditory system by presenting pure tones at different frequencies, at increasing loudness levels (decibels) until the patient indicates that the tone is uncomfortably loud, either using a numerical scale, a list of descriptors or both. This may be difficult for the patient and should be done with care as to not inflict unnecessary pain or discomfort (Aazh et al., 2018). With this, together with the patients’ anamnesis, the physician or audiologist can give a diagnosis of hyperacusis. It should be noted that there are no established or standardized protocols for measuring LDLs (Tidhall & Fagelson, 2018), nor are there agreed upon cutoffs for LDLs (Aazh et al., 2018; Anari et al., 1999; Bläsing & Kroener-Herwig, 2012; Sheldrake et al., 2015).

Beyond measuring the dynamic range of hearing, the patient is also typically asked to describe her medical history, when the hyperacusis first manifested, if she attributes any specific event to the manifestation, if the problems have
increased over time, and about symptoms and how the hyperacusis affects the patient’s social and personal life. Usually the patient is asked to fill out a questionnaire to further build a basis for diagnosis. There are a number of scientifically validated questionnaires. Those most commonly used are the Hyperacusis Questionnaire (Khalfa et al., 2002), the Noise Sensitivity Questionnaire (Schütte, Marks, Wenning, & Griefahn, 2007), the Multiple Activates Scale for Hyperacusis (Dauman & Bouscau-Faure, 2005) and the Noise Sensitivity Scale (Weinstein, 1978), but as for LDL limits, the cutoffs for the Hyperacusis Questionnaire, for example, are not universally agreed upon (Aazh et al., 2018). The cutoff score for the original study (Khalfa et al., 2002) was 28, whereby Meeus, Spaepen, Ridder, and Heyning (2010) and Fackrell, Fearnley, Hoare, and Sereda (2015) by comparing single-item questions and other questionnaires to the Hyperacusis Questionnaire, recommend a lower (unspecified) criterion to avoid misdiagnosing patients.

**Prevalence of sound intolerance**

There is a limited number of prevalence studies of sound intolerance and hyperacusis. Karvala, Sainio, Palmquist, Nyback, and Nordin (2018) identified four recent studies pertaining to noise; Andersson, Lindvall, Hursti, Carlbring, and Andersson (2002), asking the question “Do you consider yourself sensitive to everyday sounds?” estimated the prevalence to 8.6%, while in a Dutch cross-sectional study (Baliatsas, van Kamp, Swart, Hooiveld, & Yzermans, 2016) 12.5% answered “absolutely agree” to the statement “I am sensitive to noise”. The highest estimation, 22%, was found in a meta-analysis (Miedema & Vos, 1999) of pooled datasets measuring annoyance caused by environmental noise from North America, Europe and Australia. A Polish study (Fabijanska, Rogowski, Bartnik, & Skarzyński, 1999) settled for a prevalence of 15.2%, although it is unclear as to how they defined hyperacusis. Among children and adolescents the prevalence has in a recent meta-analysis been reported to be 3.2-17.1 % (Rosing, Schmidt, Wedderkopp, & Baguley, 2016), and in an older Finnish population the prevalence was 17.2% (Hannula, Bloigu, Majamaa, Sorri, & Mäki-Torkko, 2011).

**Symptoms, comorbidity and risk factors**

The most common complaints in sound intolerance are tinnitus, headaches or migraines, difficulties concentrating, dizziness, feelings of irritation and worry/fear (G. Andersson et al., 2002; Baguley, 2018; Tyler et al., 2014). People suffering from hyperacusis commonly report comorbidities with mental health problems; with one study finding that 56% suffered from at least one psychiatric disorder and that 47% had an anxiety disorder (Jüris, Andersson, Larsen, & Ekselius, 2013). Similarly, exhaustion syndrome (Hasson, Theorell, Bergquist, & Canlon, 2013; Wallén, Hasson, Theorell, & Canlon, 2012), anxiety, burnout and
depression have been found to be significant risk factors for hyperacusis. In a longitudinal study of environmental intolerances, including sound intolerance, Palmquist (2017) found significantly increased odds of developing sound intolerance within three years for those who initially suffered from burnout (odds ratio, OR 1.58), anxiety (OR 1.12), depression (OR 1.12) or stress (OR 1.07). The reverse cause-effect orders were, however, not found. In a study using the same dataset, Palmquist, Claeson, Neely, Stenberg, and Nordin (2014) also found a large overlap with idiopathic environmental intolerances attributed to chemicals, certain buildings and electromagnetic fields (EMFs), with 35.1% of those having self-reported hyperacusis also reporting one or more of the other intolerances.

The everyday experiences and conditions patients with hyperacusis go through describe patterns of behavior that include avoidance of sounds or situations that the person attribute to the hyperacusis symptoms, as well as generally worse quality of life compared to those without hyperacusis (Shepherd, Welch, Dirks, & Mathews, 2010; Welch, Dirks, Shepherd, & McBride, 2018). This type of behavior runs the risk of escalating if the symptoms become worse, or if the threshold for tolerable noise is lowered (Bläsing & Kroener-Herwig, 2012; Tyler et al., 2014). Clearly, hyperacusis is a debilitating illness with many negative consequences for the individual.

**Sound intolerance in the workplace**

Given the relatively high prevalence of sound intolerance, it is of interest to assess the potential effect the condition/state has on the psychosocial health at work, as well as vice versa. The link between adverse health effects in a work environment and loud sounds has been documented previously. Fried, Melamed, and Ben-David (2002) found a greater risk of absenteeism the noisier the workplace. Another study found higher heart rate and increased levels of norepinephrine and cortisol as well as decreased reaction times during a high noise condition (Tafalla & Evans, 1997). Several studies have also found that the stressor is not necessarily dependent on the loudness of the stimulus, but rather how predictable it is and degree of perceived control (Beaman, 2005; Ljungberg, Neely, & Lundström, 2005). It is therefore probable that similar effects are found when studying the psychosocial work environment among people with sound intolerance. Intrusive sounds, even at moderate levels, can be assumed to negatively affect psychological wellbeing as well as social interactions and work performance. Work-related stress caused by a negative psychosocial work environment probably plays a part in increasing the risk of acquiring sound intolerance, and the opposite as well; having sound intolerance may cause you to perceive the psychosocial work environment as more negative. The problem with hyperacusis is that it operates at sound levels well below the standards that normal workplace noise are protected against. Considering that people with sound intolerancerisk
becoming hyper vigilant for sounds beyond their control, or being in unpredictable environments, it is likely that the psychosocial work environment will also have an effect on the employee’s sound intolerance.

**Laboratory studies**

There are few studies investigating how people with sound intolerance respond to sounds during exposure in a controlled environment. Most of the research has been fieldwork, focusing on healthy workers’ exposure to noise, be it heavy industry or office environments, documenting their everyday perceptions, and sometimes quantifying the experiences using questionnaires and LDL’s. In studying healthy adults a clear dose-response relationship has been shown between noise levels and annoyance (Park & Lee, 2017), with test subjects reporting noises as more annoying and noticeable the louder they are. This relationship is, for one reason or another, not functioning in people with sound intolerance, making the existing noise limits at work or public spaces not adequate since they have been developed for people with normal hearing.

In a study using pre-recorded road traffic noise as exposure stimuli, Goran Belojevic, Öhrström, & Rylander (1992) found that participants with high scores on Weinstein’s Noise Sensitivity Scale also reported significantly higher annoyance, as well as lower performance on short term memory (word recollection) and mental arithmetic tasks. Using similar stimuli, Sandrock, Schütte, & Griefahn (2009) found that people with hyperacusis (as measured by the NoiSeQ questionnaire) were significantly more distracted, annoyed and reported higher level of strain during mentally taxing tasks, than healthy participants. Similar results have been found using low frequency noise at low levels (40 dB); affecting both response time on a verbal grammatical reasoning task, proof-reading, as well as participants reporting more annoyance and impaired working capacity (Persson Waye, Bengtsson, Kjellberg, & Benton, 2001; Persson Waye et al., 2002).

**Aims of the thesis**

The general aim of this thesis is to better understand various characteristics of sound intolerances as well as its relation to psychosocial factors in the work environment, and its effects during noise exposure. In Studies I and II participants who gave an affirmative answer to a single-item question (“Do you have a hard time tolerating everyday sounds that you believe most other people can tolerate?”) constituted a self-reported hyperacusis group, and those who answered affirmatively to the question “Have you been diagnosed by a physician for (...) sensitivity to sounds (noise)” constituted a physician-diagnosed
hyperacusis group. Study III used a three-way median split on results from the NSS to create low, medium and high sound intolerance groups.

The research questions were:

1. What characterizes sound intolerance with respect to demographics, health, lifestyle and comorbidity in the general population and the working population?
   a. Do cases with sound intolerance differ from the rest of the population?
   b. Is there an association between sound intolerance and negative psychosocial factors at work in a working population?

2. Do psychological and physiological reactions to noise differ in subsamples with high, medium and low sound intolerance?
   a. Do the groups rate unpleasantness, distractibility, symptoms and loudness differently over time when exposed to noise?
   b. Do the groups differ in performance on cognitive tests?
   c. Do the groups differ in autonomic nervous system reactivity?
The empirical studies

Study 1 described persons with hyperacusis on demographics, life-style, aspects of their intolerance, and comorbidity with other diagnostic illnesses, using a Swedish general population sample. The focus was on assessing how this condition affects persons with hyperacusis, and to what extent they are more likely to have other types of illnesses or diagnosis compared to a reference group of persons without hyperacusis.

Study 2 investigated hyperacusis in its relation to psychosocial work factors. Given the relatively high prevalence found in previous studies it is of importance to establish how common hyperacusis is in the working population, and how it relates to measures of psychosocial wellness such as worry at work, effort-reward imbalance, social support and work over commitment.

Study 3 explored how sound exposure affects individuals with sound intolerance problems with regards to perception of the exposure, symptoms and physical responses and cognitive performance through a controlled laboratory study using artificial noise.

Methods

Participants
In the first two studies, data were used from the population-based Västerbotten and Österbotten Environmental Health Studies, whereas the participants of the third study were recruited through convenience sampling. The Västerbotten Environmental Health Study (VEHS) and the Österbotten Environmental Health Study (ÖEHS) are investigations with a shared interest in how environmental health factors affect populations in Sweden and Finland. The Västerbotten (Sweden) and Österbotten (Finland) regions are separated by Kvarken in the Gulf of Bothnia; the strait distance between the counties is about 80 km, they have similar population densities, and are both Swedish speaking.

The VEHS randomly selected 8530 adults (18-79 years) from the county of Västerbotten, Sweden, after stratification for sex and six age strata. The sample was based on the lowest expected prevalence for a specific environmental intolerance by sex, in this case EI attributed to EMFs for men (1.1%) (Hillert, Berglind, Arnetz, & Bellander, 2002). With a precision of 0.55% the sample size was calculated to 1382 men. The sex distribution of Västerbotten was 50.3% men in 2010 (Statistics Sweden, 2010), and the number of women needed was rounded up to the same number as men. The sample size was estimated to 4607
with an expected response rate of 60%. However, since the study was part of a longitudinal project, with expected accessibility of 90% and a response rate of 60% at the second data collection, the total sample size was estimated to 8530 people, rounded up to 8600. Eighty persons were not found by the post office, so the final sample size was 8520.

The procedure for the Finnish sample was conducted in a way similar to that of the Swedish sample, with a final sample of 4606 adults from the county of Österbotten, Finland. After two reminders three weeks apart to non-respondents, the final response rate for the samples were 40.0% (n = 3406) for the VEHS and 33.3% (n = 1535) for the ÖEHS. Number of respondents in the two studies based on the population registry after stratification for sex and six age strata are shown in Table 1. In the Swedish sample, 313 (9.2%) met the criteria for self-reported hyperacusis by answering “Yes” to the question “Do you have a hard time tolerating everyday sounds that you believe most other people can tolerate?”. Sixty-six (1.9%) of that group also answered affirmatively to the question “Have you been diagnosed with sound intolerance by a physician?” and were placed in the group Physician diagnosed hyperacusis. For the Finnish sample of working individuals, 47 (5.5%) fell in the self-reported hyperacusis group, after excluding those unemployed, retired, or studying.

Lastly, in the third study 64 participants were recruited by digital and printed ads, seeking people who compared to most others considered themselves being either very bothered or barely bothered at all by noise. The idea was to recruit participants with a broad spectrum of responses to noise. Eighteen (28.1%) out of 64 answered affirmatively to the question “Do you have a hard time tolerating everyday sounds that you believe most other people can tolerate?”, When dividing the participants into low, medium and high groups based on their score on the 21-item version of the NSS (Weinstein, 1978), the overlaps with their answer to the “everyday sounds” question were quite similar, with 88.9% of those reporting having a hard time tolerating everyday sounds, falling into the High sound intolerance group, and 5.6% of the Low sound intolerance and Medium sound intolerance groups respectively.
Table 1. Numbers of respondents (and percentage of those invited) across age and sex strata for the two samples. *Adapted from* Karvala, Sainio, Palmquist, Nyback, and Nordin (2018).

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Swedish</th>
<th>Finnish</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Women</td>
<td>Men</td>
</tr>
<tr>
<td>18-29</td>
<td>307 (32.1)</td>
<td>179 (17.3)</td>
</tr>
<tr>
<td>30-39</td>
<td>266 (40.3)</td>
<td>177 (24.7)</td>
</tr>
<tr>
<td>40-49</td>
<td>288 (40.5)</td>
<td>230 (31.0)</td>
</tr>
<tr>
<td>50-59</td>
<td>367 (50.9)</td>
<td>295 (39.5)</td>
</tr>
<tr>
<td>60-69</td>
<td>405 (58.4)</td>
<td>356 (50.7)</td>
</tr>
<tr>
<td>70-79</td>
<td>265 (53.8)</td>
<td>271 (63.9)</td>
</tr>
<tr>
<td>Total sample</td>
<td>1898 (45.2)</td>
<td>1508 (34.9)</td>
</tr>
</tbody>
</table>

**Questionnaires and Assessments**

*Study I*

Sound intolerance. The 11-item version of the NSS (S. Nordin, Palmquist, & Claeson, 2013) was used in Studies I & II. The NSS measures affective reactions to, and behavioral disruptions by, environmental sounds. The scale consists of 11 statements such as “I am more aware of noise than I used to be” and “Even music I normally like will bother me if I’m trying to concentrate” which are to be answered using a Likert scale. Some item responses are reversed so that a high total score represents high levels of reactivity. Swedish translations of the questionnaire were used in this thesis, which show good reliability and validity in both the 11- and 21-item versions (S. Nordin, Palmquist, & Claeson, 2013; Weinstein, 1978).

Physician diagnosed illnesses. Participants were asked to choose from a list of illnesses for which they had received a diagnosis from a physician, any which applied to them. The illnesses used for this purpose were back/joint muscle disorder, post-traumatic stress disorder (PTSD), generalized anxiety syndrome.
(GAD), tinnitus, hearing impairment, chronic fatigue syndrome, migraine, attention deficit hyperactivity disorder (ADHD), fibromyalgia, irritable bowel syndrome (IBS), panic disorder, depression, and exhaustion syndrome.

**Study II**

Psychosocial work environment. In addition to the NSS-11, the participants completed five questionnaire instruments that tap into six different facets of psychosocial health. These were the 10-item version of the Effort-Reward Imbalance instrument that measures effort and rewards at work (Siegrist, Wege, Pühlhofer, & Wahrendorf, 2009). Three questions measured effort (e.g., “I have constant time pressure due to a heavy work load”) and seven measured reward (e.g., “I receive the respect I deserve from my colleagues”). Overcommitment to work was measured with Siegrist et al.’s (2004) Work Overcommitment Scale (e.g., “I start thinking of work immediately when I wake up”). Worry at Work (Peter et al., 1998) is a 10-item scale dealing with how much structural aspects of the work environment causes worry (e.g., “To have an accident at work”, “relocation of job”, and “job reorganization”). The atmosphere and mood at work was measured using the seven social support items of the Demand-Control-Support instrument ((Johnson & Hall, 1988; Karasek & Theorell, 1992; e.g., “There’s a calm and pleasant atmosphere at my work”). Lastly, emotional support at work was measured using the 3-item version of Availability of attachment instrument (Henderson, Duncan-Jones, Byrne, & Scott, 1980). The three items measure support, closeness to someone else, and appreciation by others (M. Nordin, 2006).

**Study III**

The participants filled in the full-form 21 item version of the Weinstein NSS (Weinstein, 1978) at home, after they had completed the exposure protocol.

Stimulus perception. The participants performed perceptual ratings of unpleasantness and intensity of the noise exposure, the effect the exposure had on their concentration ability and symptom intensity. These were conducted using a Borg CR-100 scale (E. Borg & Borg, 2002). The scale is a verbally anchored ratio scale (G. Borg & Borg, 2001; G. A. V Borg, 1998) using descriptive adjectives that correspond to specific numbers on the scale: Nothing at all = 0; minimal = 2; extremely weak = 3; very weak = 6; weak = 13; moderate = 25; fairly strong = 37; strong = 50; very strong = 70; extremely strong = 90; almost maximal = 100. The scale is not labeled beyond 100, but extends to roughly 120.

Symptoms. During the noise exposure the participants responded to a list of nine symptoms using the Borg CR-100 scale. The symptoms were chosen from a previous study (L. Andersson, Claeson, Ledin, Wisting, & Nordin, 2013) and were eye irritation, nervousness, heaviness in the chest or breathing difficulties,
concentration difficulties, dizziness, tiredness, headache, nausea, and (emotional) irritation. The total mean of the nine symptoms were used as a composite score in the statistical analysis.

Heart rate and heart rate variability. Electrocardiograms were recorded during the exposure session using a Biopac MP150 system with a wireless BioNomadix® amplifier (BIOPAC Systems, Inc) to assess heart rate and heart rate variability (HRV). HRV in a form of standard deviation of the normal-to-normal interbeat intervals (SDNN) are extracted in the present study in five minute segments using Kubios HRV software (Kubios, 2019). Both heart rate and SDNN reflects changes in autonomic nervous system activity – the latter is a global index of HRV that has been associated with stress or strain (Kim, Cheon, Bai, Lee, & Koo, 2018).

Cognitive tests. Stroop (Stroop, 1935) and 3-back (Kirchner, 1958) were used as measures of cognitive load, and input was recorded using voice and a keypad, respectively. The Stroop task measures the interference from contradictory stimuli on a task and consists of words written in different colored font, with the words being the names of colors. None of the font colors match the words. The task is to name the font color of each word as fast as possible, while ignoring the meaning of the actual word. If, for example, the word green is written in a yellow font, the objective is to say “Yellow”. 3-back presents the participant with an automated series of numbers that change every 0.5 seconds. The task is to press a green key on a keypad if the number is identical to the one three numbers back, if not the red key is to be pressed. The 3-back task is meant to measure how well subjects can update the objects held in memory as new objects are input. Both cognitive tasks are often used in psychological research (Jaeggi, Buschkuehl, Perrig, & Meier, 2010; MacLeod, 1991).

Data analysis
All statistical analyses were performed using the Statistical Package for the Social Sciences (IBM SPSS Statistics for Windows, Versions 21.0 and 25.0; Armonk, NY). In Study I and II the hyperacusis groups were compared with the referents on demographics, lifestyle, perceived general health and hearing ability with independent \( t \) tests and \( \chi^2 \) analysis. Logistic regression analyses were conducted to obtain crude and adjusted ORs (in Study I adjusted for age, sex, and education; in Study II for sex) for studying comorbidity in hyperacusis with the various diagnoses in the Swedish general sample, and the various aspects of psychosocial work environment in the Finnish working sample. For Study III, Greenhouse-Geisser corrected two-way mixed model analysis of variance (ANOVA) were performed with the factor Time as a within-subjects factor and Group (low/medium/high sound intolerance) as a between-subjects factor, for each of the seven outcome variables. The factor Time had fourteen levels for intensity,
unpleasantness and distractibility; four levels for symptom intensity; and two levels for Stroop and 3-back. However, main effects of Time were not included in the hypotheses. The $\alpha$-level was set at 0.05. The heart rate variability data collected in Study III were analyzed in five minute segments using Kubios HRV Standard 3.2.0 software (Kubios, 2019) to obtain data on SDNN.

In order to deal with missing data in the VEHS and ÖEHS databases, a method known as multiple imputation was used. The idea is to create multiple copies of the database and replace the missing values with values drawn from the predictive distribution of the already observed data. This is done multiple times (in this case five times) to take the natural variance of data into account, and are then analyzed using the same procedure as the original dataset. This yields parameter sets and standard errors for each copy of the dataset, which are finally pooled together into a new database (Baraldi & Enders, 2010). For a more in depth explanation of the steps taken see Palmquist (2017).

**Ethical considerations**

All three studies were conducted in accordance with the Helsinki Declaration. Study I and III were approved by the Umeå Regional Ethics Board (Dnr 09-171M and Dnr 2016/5131, respectively). Study II was approved by the Ethical Board at Pirkanmaa Hospital District (R12052). The participants in all three studies were informed that none of their individual data would be able to be identified or linked to any of the results published in manuscripts, presentations etc., and that no unauthorized persons would have access to their data. All personal information such as name, address and personal identification number were replaced with an identification number, and a key codes were kept in a safe.

Studies I and II were mail-based questionnaires, with no intention of affecting the participants in any way. However, personal data and health information were collected, which might be seen as an invasion of privacy. In the introduction letter it was specified that by filling in the questionnaires and mailing it back to the researchers, the participants agreed to the conditions stated in the introduction letter. To avoid that the individuals who did not respond felt pressured, we did not inquire as to why they did not participate.

Study III was a laboratory-based quasi-experiment with a test leader present. At arrival all participants received information in writing about the study. They were also informed that they could cancel their participation at any time for any reason, and when having no further questions they were given a consent form to sign. Given the sample, it can be argued that subjecting people who already suffer from sound intolerance to noise for a prolonged time is questionable. We tried to make sure that the participants were as safe as possible, with the possibility to
exit the sound proof booth at any time, as well as having a test leader present for the duration of the exposure. However, given that the objective of the experiment was to investigate if we could elicit different responses between those with varying levels of hyperacusis, a certain degree of unpleasantness was necessary. The participants were informed that the sound stimuli would vary in loudness over time, but not in what way. This was to avoid expectation effects, and were not assumed to cause the participants any particular distress.
Study I - Characteristics of Hyperacusis in the General Population

Aims and method
This study was designed to provide an overview of the characteristics of severe sound intolerance in the general population by assessing the prevalence and characteristics of people with self-reported and physician diagnosed hyperacusis. Data were used from the VEHS, a large-scale population-based questionnaire study. We created two case groups – individuals with self-reported hyperacusis and those with a physician-administered diagnosis – to investigate (1) demographics, lifestyle, perceived general health and hearing ability in hyperacusis in comparison to individuals without hyperacusis, (2) hyperacusis-specific characteristics and behavior, and (3) comorbidity in hyperacusis.

Among the 3406 respondents to the survey, 313 (9.2%) met the criterion for self-reported hyperacusis, and 66 (1.9%) the criterion for physician-diagnosed hyperacusis. Self-reported hyperacusis was defined by responding affirmatively to the question “Do you have a hard time tolerating everyday sounds that you believe most other people can tolerate?” From those 313 individuals a sub-group with physician-diagnosed hyperacusis was formed, that also responded affirmatively to the question “Have you been diagnosed with sound intolerance by a physician?”

Using a cross-sectional design, the two case groups were compared with a reference group (n = 2995) with no reported hyperacusis. Through independent t test and χ² analysis the two case groups were compared with the referents on demographics, lifestyle, and perceived general health and hearing ability. Logistic regression analyses were conducted to obtain crude and adjusted (for age, sex, and education) ORs for comorbidity in hyperacusis with the various diagnoses. The symptoms ADHD and panic disorder were excluded from the analyses for the physician-diagnosed group because of less than five cases reporting the two diagnoses. The α-level was set at .05.

Results and discussion
Compared with the referents, the physician-diagnosed group was significantly older in age. The self-reported group was younger and had higher education. Both case groups consisted of a larger proportion of women, reported poorer health, and more commonly perceived their hearing ability to be below normal.
Frequencies of hyperacusis-specific characteristics and behavior are shown in Figure 1. In both case groups a majority reported actively trying to avoid sound sources, and mostly being able to affect the sound environment, whereas a majority in the physician-diagnosed group, but not the self-reported group, also reported having sought medical attention. Around half of the participants in the case groups reported that the hyperacusis started after high-dose or long-term sound exposure, and less than a third reported that they had received treatment. For all five aspects, the proportions were larger in the physician-diagnosed group than in the self-reported group.

Figure 1: Hyperacusis-specific characteristics and behaviors among participants with physician-diagnosed hyperacusis and self-reported hyperacusis

The physician-diagnosed group was found to more frequently have had problems and for longer duration than the self-reported group. In the physician-diagnosed group, 48.5% reported daily, 34.8% reported once or a few times a week, and 15.2% reported once or a few times a month. Corresponding rates for the self-reported group were 34.2, 42.5, and 22%, respectively. The mean number of years experiencing hyperacusis was 13.54 (standard deviation, SD = 8.52) for the physician-diagnosed group and 11.06 (SD = 9.24) for the self-reported group.

Percentage of the participants in each case group, who also had a certain diagnosis, is depicted in Figures 2 and 3. The ORs for comorbidity in hyperacusis with the various diagnoses when unadjusted (crude) and adjusted showed that the OR for all diagnoses, with the exception of migraine in the physician-diagnosed group, were significantly higher than unity. In both hyperacusis groups the ORs were particularly high for PTSD, chronic fatigue syndrome, and GAD, although with wide confidence intervals. The ORs were generally larger in the physician-diagnosed group than in the self-reported group.
Figure 2: Percentage of participants with physician-diagnosed hyperacusis who reported a certain diagnosis as well as odds ratios, confidence intervals (CIs), and p values for comorbidity with a certain diagnosis when unadjusted (crude) and adjusted for age, sex, and education.
Figure 3: Percentage of participants with self-reported hyperacusis who reported a certain diagnosis as well as odds ratios, confidence intervals (CIs), and p values for comorbidity with a certain diagnosis when unadjusted (crude) and adjusted for age, sex, and education.

Overall, the results from the study suggest that people with hyperacusis are more likely to be women and experience they have worse health and hearing compared to what is normal. The majority try to avoid sound sources, and people with both self-reported and physician-diagnosed hyperacusis experience various illnesses in comorbidity, including psychiatric, otorhinolaryngological and musculoskeletal diagnoses, as well as functional somatic syndromes. Based on the results from this study, nine percent of the general population identify themselves as having hyperacusis, which in Sweden would equate to tens of thousands of people. Unwanted sounds are increasingly difficult to avoid in daily life due to music played in stores, more densely populated cities, and more vehicles around. It places an added strain on people with hyperacusis, and although it is not clear whether there is a causality, it is not surprising that there is a strong link between hyperacusis and increased risk of other illnesses.
Study II - Associations between hyperacusis and psychosocial work factors in the general population

Aims and methods

This study explored a possible association between hyperacusis-specific sound intolerance and psychosocial factors in the work environment. It is established that psychosocial factors contribute to stress at the workplace, and multiple theories on the relationship between work stress and health have been presented. These include the Job Demands–Resources model (Bakker & Demerouti, 2007), the Demand–Control model (Karasek & Theorell, 1992), and the Effort–Reward Imbalance model (Siegrist, 1996). Well-known stressors at the workplace according to the different models include some form of lack of control, high demands, and not enough resources. The lack of control can include not enough decision latitude resulting in a lack of freedom, lack of social or emotional support, or the inability to shape the work environment to personal needs. A common external stressor is noise of various types. It may therefore be expected that persons with hyperacusis also suffer more from work-related stress than non-hyperacusis persons (S. Nordin, Ljunberg, Claeson, & Neely, 2013). The aims were to investigate (i) prevalence and characteristics (among age, sex, access to social support at home, education, smoking, physical exercise and perceived general health) of hyperacusis in a general working population, and (ii) associations between hyperacusis and psychosocial factors in the work environment. The psychosocial work aspects included effort, reward, overcommitment, worry, and social and emotional support. Data were used from the ÖEHS.

After excluding those older than average Finnish retirement age (60 years) and those unemployed, the sample contained 856 participants. Out of these, 47 (5.5%) were identified as having hyperacusis by responding affirmatively to the question “Do you have a hard time tolerating everyday sounds that you believe most other people can tolerate?”. The remaining 809 participants constituted a reference group.

The two groups were compared on demographics, lifestyle, perceived general health and affective and behavioral reactions to sound with independent t-test and chi-square analyses. The participants were categorized as either high (upper quartile; meeting criteria for poor psychosocial work environment) or low (remaining quartiles) on the work-related factors. Logistic regression analyses were conducted to obtain crude and adjusted (for sex, which differed between the
hypercusis group and referents) ORs for the various aspects of poor psychosocial work environment for the hyperacusis group. The α-level was set at .05.

**Results and Discussion**

The hyperacusis group typically had had their intolerance for several years (mean = 7.4, SD = 9.2), and two thirds (66 %) of the group experienced symptoms daily or weekly. Similar to Study I, the hyperacusis group, compared to the referents, consisted to a significantly larger proportion of women, and reported poorer general health.

With respect to the six psychosocial work environment factors. The hyperacusis group had significantly higher scores than the referent group on worry, social support, and reward, whereas the groups did not differ significantly with respect to emotional support, overcommitment or effort (Table 2).
Table 2. Mean ± SD scores on psychosocial work environment factor in the hyperacusis and reference groups, and group comparisons with results from t test and Chi-square analysis

<table>
<thead>
<tr>
<th></th>
<th>Hyperacusis (n=47)</th>
<th>Referents (n=809)</th>
<th>Total (n=856)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Worry at Work, mean ± SD</td>
<td>3.05 ±2.35</td>
<td>2.06 ±1.91</td>
<td>2.12 ±1.95</td>
<td>.003</td>
</tr>
<tr>
<td>Availability of Attachment, mean ± SD</td>
<td>6.34 ±2.16</td>
<td>5.84 ±2.05</td>
<td>5.86 ±2.06</td>
<td>.105</td>
</tr>
<tr>
<td>ERI Reward, mean ± SD</td>
<td>7.94 ±6.76</td>
<td>7.66 ±5.72</td>
<td>7.67 ±5.80</td>
<td>.024</td>
</tr>
<tr>
<td>ERI Effort, mean ± SD</td>
<td>16.48 ±2.71</td>
<td>14.61 ±2.91</td>
<td>14.71 ±2.90</td>
<td>.214</td>
</tr>
<tr>
<td>Work Over Commitment, mean ± SD</td>
<td>15.64 ±3.09</td>
<td>15.90 ±2.98</td>
<td>15.89 ±2.98</td>
<td>.084</td>
</tr>
</tbody>
</table>

Figure 4 shows percentage of employed participants with hyperacusis with poor psychosocial work environmental factors and ORs. Between 17.0 and 42.6% of the hyperacusis group scored in the upper quartile of the six work environment factors. Relative to the reference group there was a significantly increased risk in the hyperacusis group, when adjusted for sex, of scoring high on worry, social support, and reward (ORs = 1.91–2.56), but not on emotional support, overcommitment or effort (ORs = 1.30–1.72). The unadjusted ORs were in general very similar to corresponding adjusted ORs.
Figure 4. Percentage of employed participants with hyperacusis who also had various aspects of poor psychosocial work environment (upper quartile) as well as odds ratios, confidence intervals (CI), and $p$ values when unadjusted (crude) and adjusted for sex.

Worry is a prominent stressor, and as such worrying about work and perceiving lack of social support and reward from coworkers and supervisors are likely to contribute to stress. Adding to that, the inability to properly tolerate everyday sounds may create a vicious cycle of compromised work performance and increased worry. Although we cannot state whether or not the psychosocial work environment contributed to employees developing hyperacusis or vice versa, is not surprising that there is comorbidity given the previous association between hyperacusis and psychological distress such as general anxiety, depression and phobia (Aazh & Allott, 2016; Auerbach et al., 2014; Jüris et al., 2013; Sahley & Nodar, 2001).
Study III – Reactions to white noise exposure in sound intolerance: Perception, symptoms, cognition and autonomic responses

Aims and methods

Being that sound intolerance research is a fairly young area of science; having received academic and medical attention for only 20-30 years, there are few studies reporting how people react to noise during actual exposure. Often people with hyperacusis have been assessed using surveys in combination with establishing the presence of lowered LDLS, or as secondary findings from audiology screenings. Whereas people without sound intolerance usually have LDLS above 95 dB (Goldstein & Shulman, 1996; Pienkowski et al., 2014), people with sound intolerance often have LDLS below 80 dB, with some as low as 30 dB (Anari et al., 1999). This implies that many aspects of life are likely to be affected in people with sound intolerance. In an experiment studying effects of road traffic noise, Belojevic, Ohrstriim, and Rylander (1992) found that participants scoring higher on the NSS also reported significantly more annoyance and performed poorer on short term memory (word recollection) and mental arithmetic tasks. Similar results were found by Sandrock et al. (2009) in which people scoring high on a hyperacusis questionnaire were significantly more distracted, annoyed and reported higher level of strain during mentally taxing tasks when exposed to road traffic noise than did participants with low scores. In an experiment intended to mimic low frequency sound of an indoor office area at a low level (40 dB), Persson Waye et al. (2002) found that the stimuli affected response time on a verbal grammatical reasoning task (proof-reading) as resulted in participants reporting more annoyance and impaired working capacity.

The aim of this study was to compare how people with varying degree of sound intolerance react to noise. We therefore assessed sensory perception and symptom, cognitive performance and stress-related physiological reactions over time during continuous exposure to white noise in persons with different levels of self-reported sound intolerance. This was conducted in a sound isolated chamber in which participants were exposed to white noise while rating sensory perception and symptoms, performed cognitive tasks as well as being assessed on stress-related physiological reactions. A timeline for the exposure session is outlined in Figure 5. By dividing the participants into a high, medium and low sound intolerance group based on total NSS score, we hypothesized that greater sound intolerance would be associated with greater perceived loudness,
unpleasantness and distractibility of the noise exposure, and more symptoms over time. Further, we hypothesized that higher self-reported sound intolerance would be associated with lower heart rate variability (a measure of autonomic nervous system strain) and decreased performance on cognitive tasks.

Figure 5. Overview of tasks over the exposure session.

**Results and Discussion**

Based on the participants’ total score on the NSS-21 (Weinstein, 1978) they were placed into three groups: a low (n=21; Mscore = 54.76; SDscore 10.32), a medium (n=20; Mscore = 75.35; SDscore = 4.25), and a high (n=23; Mscore = 95.17; SDscore = 8.14) sound intolerance group. Cronbach’s α for the present sample (n=64) was .911.

Repeated measures ANOVAs revealed a significant main effect between groups for perceived intensity of the white noise (p = .011, ηp² = .14), as well as significant interaction effects for unpleasantness (p < .001, ηp² = .16), distractibility (p = .009, ηp² = .10), symptoms (p < .001, ηp² = .19), and the Stroop task (p = .018, ηp² = .13). The α-level was set at 0.05. Results from two-way mixed model ANOVAs and post hoc analysis with Bonferroni correction are shown in Table 3. Means values across participants in the three sound intolerance groups on the perceptual outcome variables are presented in Figure 6, heart rate variability in the form of standard deviation of the normal-to-normal interbeat intervals in Figure 7, and the results on the cognitive tasks with mean proportions of correctly answered digits for 3-back and mean number of correct words for Stroop in Figure 8.

All cases in which post-hoc tests using Bonferroni correction were conducted showed significant group differences, except for 3-back. In general, the direction of the differences were in accordance with the hypothesis (Table 3).
Table 3. Results from two-way mixed model ANOVA with the factor Time as within-subjects factor and Group (high [H], medium [M] and low [L]) as between-subjects factor. Post-hoc test using Bonferroni correction comparing low, medium and high sound intolerance groups, and groups across time.

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Effect</th>
<th>df</th>
<th>F</th>
<th>p</th>
<th>ηp²</th>
<th>Post-hoc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perceived intensity</td>
<td>Group</td>
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<td>4.82</td>
<td>.011</td>
<td>.14</td>
<td>H &gt; L; H &gt; M</td>
</tr>
<tr>
<td></td>
<td>Time</td>
<td>3.27</td>
<td>199.37</td>
<td>&lt;.001</td>
<td>.77</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Group × Time</td>
<td>6.54</td>
<td>1.78</td>
<td>.099</td>
<td>.055</td>
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<tr>
<td>Perceived unpleasantness</td>
<td>Group</td>
<td>2</td>
<td>11.67</td>
<td>&lt;.001</td>
<td>.28</td>
<td>H &gt; M &gt; L</td>
</tr>
<tr>
<td></td>
<td>Time</td>
<td>2.86</td>
<td>64.48</td>
<td>&lt;.001</td>
<td>.52</td>
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<td></td>
<td>Group × Time</td>
<td>5.72</td>
<td>5.86</td>
<td>&lt;.001</td>
<td>.16</td>
<td>H &gt; M &gt; L</td>
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<tr>
<td>Distractibility</td>
<td>Group</td>
<td>2</td>
<td>15.84</td>
<td>&lt;.001</td>
<td>.35</td>
<td>H &gt; M &gt; L</td>
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<tr>
<td></td>
<td>Time</td>
<td>2.15</td>
<td>45.86</td>
<td>&lt;.001</td>
<td>.43</td>
<td></td>
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<tr>
<td></td>
<td>Group × Time</td>
<td>4.31</td>
<td>3.42</td>
<td>&lt;.001</td>
<td>.10</td>
<td>H &gt; L; M &gt; L</td>
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<tr>
<td>Symptom intensity</td>
<td>Group</td>
<td>2</td>
<td>7.17</td>
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<td>.19</td>
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Figure 6. Means and confidence intervals of ratings in the low, medium and high sound intolerance groups.
Figure 7. Log-transformed standard deviation of the normal-to-normal interbeat intervals (SDNN) for the low, medium and high sound intolerance groups.

Figure 8. Means and confidence intervals of 3-back and Stroop for the low, medium and high sound intolerance groups.
The results suggest an association between sound intolerance and several outcome variables during noise exposure. There are many ways in which hyperacusis affects an individual, and the experience is not only limited to unpleasantness of sounds, but also to negative impact on cognitive performance (specifically inhibition), symptomology, distractibility and heart rate variability. Given these results it is perhaps not surprising that sound intolerance is correlated with both multiple diagnoses and psychosocial work environment factors, as seen in Studies I and II. The results in Study III include issues that make everyday life more complicated for people with hyperacusis, such as not being in control of the sound exposure, resulting in disruption of concentration ability. Another issue is the low heart rate variability the high sound intolerance group displayed. Assuming that it is an indication of stress, it means that in everyday life people with sound intolerance are under prolonged strain, given how common unwanted sounds are in the environment. Based on the presently used criterion for sound intolerance, the intolerance does not seem to affect sensory acuity since all participants successfully identified the intensity of the noise over time. However, the groups differed in ratings of perceived symptoms, annoyance, discomfort, etc. This is in line with results of Ellermeier, Eigenstetter, and Zimmer who in their 2001 study found no significant differences between low and high noise sensitivity groups regarding intensity discrimination or hearing thresholds, but significant differences in unpleasantness ratings.
General discussion

Summary of findings: A prevalent and multifaceted problem

Study I. I investigated characteristics and behaviors such as demographics, health, lifestyle and comorbidity in individuals with both self-reported and physician diagnosed severe sound intolerance (hyperacusis). According to our estimates, some form of hyperacusis is present in 9.2% of the population. The majority of respondents had experienced problems for several years, and it had an impact on social relations among those afflicted, in both private and professional relationships. The two hyperacusis groups also reported several comorbidities, the most common being tinnitus, hearing impairment and back/joint/muscle disorders. Compared to the non-hyperacusis group, the hyperacusis respondents had higher odds ratios for reporting one or more diagnoses, especially psychiatric conditions such as PTSD, GAD, depression and exhaustion. These findings are in line with previous studies showing high comorbidity between sound intolerance related problems and psychiatric diagnoses (Anari et al., 1999; D. W. Black, 2000; Jüris et al., 2013), hearing related illnesses (Noreña & Chery-Croze, 2007; Sheldrake et al., 2015), and diagnoses of functional somatic syndromes such as fibromyalgia, irritable bowel syndrome and chronic fatigue. The high prevalence for back/joint/muscle disorders in hyperacusis is somewhat novel, but musculoskeletal pain and sound intolerance is often reported in cases of fibromyalgia (Geisser et al., 2008; McDermid, Rollman, & McCain, 1996), and exhaustion syndrome (Åsberg et al., 2003; Jensen & Rundmo, 2015). It might even be so that various psychosomatic illnesses have more in common than they have differences, which could explain the overlap seen in many studies (Buchwald & Garrity, 1994; Jason, Taylor, & Kennedy, 2000; Palmquist, 2017; Wessely, Nimnuan, & Sharpe, 1999).

Study II. Using cross-sectional data, this time from the Österbotten county in Finland, I investigated the prevalence of severe sound intolerance (hyperacusis) in the workplace, and to what extent having the condition was associated with psychosocial environmental risk factors at the workplace. I found that the participants with hyperacusis had significantly higher scores on the NSS and high odds ratios for worrying about things at work, perceiving low social support at work and not feeling rewarded at work. Reports of poor emotional support, being overcommitted and spending much effort at work were not significantly different between the hyperacusis group and referents. Thus, if hyperacusis was present, odds for co-occurring factors related to worry, social support, and not feeling rewarded was higher. In sum, our results from Study II show that the psychosocial health in workers with hyperacusis can be precarious, and that there remains a lot of questions as to how to address this imbalance, given that
knowledge of the need to mitigate noisy work environments, beyond what is required by policy regulations, is not always available.

**Study III.** I investigated how participants with varying degree of sound intolerance reacted over time when exposed to white noise in a laboratory setting. The hypothesis was that the higher the participants rated their sound intolerance (using the NSS), the greater they would perceive intensity, distractibility, and unpleasantness, that they also would experience more symptoms, express lower heart rate variability and lower performance on cognitive tests. The results of the study are summarized under the heading “Reactions to exposure” below.

**Coping with sound intolerance**

A majority of both self-reported (74.9%) and physician-diagnosed (87.7%) respondents reported that they actively try to avoid sound sources, and 67.9% and 75% respectively, stated that they in most cases could affect the noisy environment, such as closing a door. The effectiveness of these strategies are not investigated further in this thesis, but taken together the results imply that strategies affecting external factors are very common. Examples of this can also be found in tinnitus and pain, in which an effective strategy is to involve some type of acceptance, preferably targeting several aspects. This includes reducing avoidance behavior, encouraging activity engagement, and openness to experience unpleasant or painful sensations, as opposed to focusing on distractions or avoidance (Hesser, Westin, Hayes, & Andersson, 2009; Weise, Kleinstäuber, Hesser, Westin, & Andersson, 2013; Westin, Östergren, & Andersson, 2008). Such strategies have also been found to be commonly used by persons with environmental intolerances, including sound intolerances, who have recovered from that condition (Palmquist, 2017). Only 15.6% of the presently studied self-report hyperacusis group stated that they had received treatment for their illness, and the corresponding number for the physician diagnosed group was 29.7%. Unfortunately, we do not have data pertaining to what type of treatment had been received, or how effective it was. It is also somewhat surprising to see that only 65.2% of the physician-diagnosed group reported having sought medical attention for their hyperacusis. I speculate that there is room for a more liberal interpretation of the question among the participants. If taken literally, it is possible to interpret the question as “have you sought medical attention [specifically] for your hyperacusis” (emphasis in brackets), meaning that the person might have sought for another illness, for example, burnout or tinnitus, and that they might have received a secondary diagnosis of hyperacusis from the physician. It is also possible that an offhand speculation such as “that might be hyperacusis” by the physician can have been interpreted by the patient as a diagnosis.
According to the Effort-Reward Imbalance model (Siegrist, 1996), the individuals’ feeling of social reciprocity at work is vital for what Siegrist called the work contract, implying that the level of the worker’s reward is intrinsically linked to the amount of effort she puts in to the task. When the reciprocity is disrupted, in cases of high cost and low gain, Siegrist predicts that negative emotions and stress are experienced. During prolonged exposure this may cause long-term adverse health effects (Siegrist, 2010). If the worker already experiences stress and negative emotions from living with hyperacusis, there is a risk that these negative reactions are exacerbated if the perceived effort he/she puts into the work is not balanced by the perceived rewards. Our results revealed that individuals with hyperacusis were roughly 1.5 times more likely to score high on Worry at work (Peter et al., 1998) compared with referents; indicating that worrying about structural problems at work such as accidents, reorganizations, and relocations is prevalent in the hyperacusis group. There are different ways of interpreting this finding; one alternative is that the participants expressed a genuine worry and uncertainty regarding the stability of their work environment. Another is that their worry was an extension of the strain their hyperacusis exerted on them, or lastly, a combination of both. It is possible that a work environment with low rewards and an inadequate social support system contributes to the workers’ hyperacusis. Another possibility is that those already affected by issues with sound have more difficulties handling the intricacies of the workplace, and therefore are more susceptible to negative aspects of the psychosocial work environment. Suffering from hyperacusis leaves persons in a vulnerable spot, and social support becomes more important for their wellbeing at work than emotional support.

Reactions to exposure
Sound intolerance can evolve as a secondary complaint from a variety of different conditions such as tinnitus, head trauma, Bell’s palsy, etc., but commonly a sudden onset is cited; 41.3% of the self-reported hyperacusis group in Study I attributed their sound intolerance to an intense sound or a long-term exposure to sounds. Similarly, Anari et al., (1999) found that 50.5% of people with sound intolerance claimed a sudden onset, with 20% unsure and 29.5% reporting that it developed slowly.

Results from Study III revealed that compared to participants with low and moderate sound intolerance, those with a high sound intolerance demonstrated a decreased tolerance to noise over time, as well as indications of diminished cognitive performance. They also reported a greater time-dependent increase in distractibility and unpleasantness during exposure compared with the other two groups. The high sound intolerance group also differed from the other two groups by rating symptoms as increasing over time of exposure. Figure 6 may give the
impression that the differences were quite small, but it should be noted that the variable is based on nine different symptoms collapsed into one mean value. There was a significant group by time interaction for heart rate variability – an effect mainly expressed as a difference between the high and moderate sound intolerance groups. Figure 7 suggests a U-shaped variation for the groups with low and moderate sound intolerance, and a flatter line for the high sound intolerance group. Regarding the ratings of intensity, there were significant differences between the three groups during the experiment. However, we did not see any interaction effect between the groups across time. The only significant effect on the cognitive tasks was a Group by Time interaction for the inhibition-related task (Stroop): the increase in performance over time was less pronounced for the high sound intolerance, compared with the low sound intolerance group.

Some notes on underlying mechanisms

The mechanisms underlying sound intolerance are not well understood. Several hypotheses and models have been proposed, including neural gain and sensitization. Comparable arguments are found in nocebo and expectation effect explanations (Rubin, Hillert, Nieto-Hernandez, van Rongen, & Oftedal, 2011; Witthöft & Rubin, 2013). Sensitization implies that the response to repeated invariant stimuli increases progressively over time (Overmier, 2002), or, at least, that the habituation is less pronounced. Nocebo, Latin for “I shall harm”, is the opposite of the placebo effect and refers to an adverse effect, based on negative expectations, when no harmful treatment is present; i.e. nocebo is the introduction of a condition along with the suggestion that it will have negative effect on the recipient (Hahn, 1997; Häuser, Hansen, & Enck, 2012; Kennedy, 1961). It can also induce worsening of an effect due to expectations, even though no stimulus is being introduced (Benedetti, Lanotte, Lopiano, & Colloca, 2007; Van den Bergh, Brown, Petersen, & Witthöft, 2017). Arguments for sensitization are mostly based on the results of Study III, as the term necessitates response increments to actual stimulation. At a glance, it may seem reasonable that the outcomes are due to sensitization – the high, compared with the low and medium sound intolerance groups, expressed a greater response increase in several outcome variables, including perceived unpleasantness and distractibility of the noise, and symptoms. However, the results may also be explained as lack of habituation.

Sound intolerant individuals could hypothetically get progressively worse at inhibiting incoming signals, whereas the inhibitory abilities of less sound intolerant individuals persists. There was, in fact, a significant group by time interaction effect for Stroop, which is generally assumed to probe inhibition (albeit in cognitive terms) – all groups increased their performance over time, which can be seen as a general training effect. This effect was, however,
significantly less pronounced in the high compared to the low sound intolerance group, which could be interpreted as a generally weaker inhibitory ability. This argument can be taken further by including the heart rate variability results. The plots indicate non-linear effects, i.e. the low and medium sound intolerance groups seem to express decreased, then increased heart rate variability, whereas the high sound intolerance group seems to express a flatter line. Several recordings were lost due to recording artifacts or excessive movement, which calls for certain caution. Nevertheless, low heart rate variability has been associated with lack of inhibitory control (Thayer, Hansen, Saus-Rose, & Johnsen, 2009), which at the very least suggest that the role of weakened inhibition in sound intolerance should be further studied in the future.

A third possible interpretation of our results, not necessarily contradicting previous arguments, is that the sound intolerant individuals were experiencing negative affect prior to the actual exposure. Living with sound intolerance is arguably taxing; involving different degrees of preparation or worry of encountering noise. Study I, as well as several other studies (Bläsing & Kroener-Herwig, 2012; Jüris et al., 2013; Jüris, Andersson, Larsen, & Ekselius, 2014; Pienkowski et al., 2014), found that people with sound intolerance tend to have a higher comorbidity of anxiety, depression, exhaustion syndrome and PTSD, which may also affect individuals high on stress or worry. This distress is a hallmark in mechanisms such as sensitization, neurogenic inflammation, nocebo, and classical conditioning (Overmier, 2002; Van den Bergh, Witthöft, Petersen, & Brown, 2017; Webster, Weinman, & Rubin, 2016). The heart rate variability effects may also be seen as an indication of an effect associated with stress or strain (Kim et al., 2018). It would therefore be informative to further study the role of autonomic nervous system regulation in sound intolerance over greater periods of time – hours, or even days prior to exposure – to see potential fluctuations and establish baselines for each participant in advance.

Further reflections

Sound intolerance research is still in a dynamic, early phase where knowledge is constantly added and expanding. Based on the findings in this thesis a couple of things stand out. The prevalence is something that deserves to be studied further. Although not a specific research question, there was a difference between Sweden and Finland in reported cases of severe sound intolerance, despite the many demographical similarities. The corresponding number in Österbotten was 5.5% of the working population, but regarding the entire sample of the ÖEHS, Karvala et al. (2018) found a similar percentage (5.4%; n = 83). Given that the majority of studies has come from the USA, U.K and Scandinavia it would be valuable to know how prevalence and attribution to sources vary across countries and cultures. Another reflection to be made based on the thesis is how common it is
to have one or several illnesses in addition to the sound intolerance. Whereas the exact sizes of odds for comorbidity in hyperacusis with PTSD, GAD and chronic fatigue in Study I should be viewed with caution given the large CIs, it should be noted that 29.4% of the self-reported hyperacusis group had a hearing impairment, and there was about five times greater odds (adjusted) of having exhaustion syndrome or depression together with hyperacusis. Just how difficult it may be to live with hyperacusis can be seen in Study III regarding how the concentration and inhibition abilities of the high sound intolerance group drop while symptoms and sound unpleasantness increase. Our laboratory exposure lasted for 45 minutes, and only the last 20 minutes had exposure at 60 dB, which is comparable to the loudness of a normal conversation. It is not difficult to imagine how strenuous it would be to work eight hours in an environment with similar, or higher, sound levels, and how detrimental it would be for performance and the employees’ long-term health if being sound intolerant. Jobs at places such as preschools, restaurants and hospitals have noisy environments, in which the possibility for the individual employee to shield herself is very limited (Fredriksson, 2018; Sweetow & Tate, 2000). Indeed, there is a three time higher risk of adult-onset sound intolerance in preschool teachers (Fredriksson et al., 2019). Considering the results of this thesis, raising public awareness of sound intolerance and hyperacusis should be of increased priority for medical professionals and researchers.

**Additional limitations of the thesis**

**Classification**

In addition to the limitations discussed in prior sections, no loudness discomfort level-tests were conducted in the first two studies due to them being administered via mail. Whereas this is not a prerequisite for establishing hyperacusis it places more faith in the reports of the participants. Although one should be careful labeling hyperacusis, the participants can definitely be regarded as sound intolerant. The participants in Study III performed a provocation test to gauge discomfort thresholds, although not being a strict LDL test. There is also a very rudimentary classification of employment in Study II, offering no details as to what type of work the participants had (industrial, white collar, etc.), something that might have provided further information. The response rates in Study I (40.0%) and II (33.3%) were relatively low, but increased with age and were higher in women than in men. Low response rates appears to have become an increasing problem over time. For example, the most recent environmental health study that focuses on adults, and are performed every eight years by the Public Health Agency of Sweden observed that response rates have been dropping with each data collection wave (72% in 1999, 59% in 2007, and 42% in 2015). They also noted a similar trend with a larger proportion of women participating
as well as response rates increasing with the age groups (Folkhälsomyndigheten, 2017). Notably, a review by Galea and Tracy (2007) shows that the impact of participation rate on representativeness is quite stable in the range 30—70%. Nevertheless, the response rate in Study I and II is a concern. Due to ethical constraints, analysis of why invited persons chose not to participate was not possible for ethical reasons. In Sweden the researcher is not allowed to ask these persons about reasons for their decline or about information on other variables. Hence, information of this kind, obtained from the population registry, was limited to age and sex (Table 1).

Validity
Whereas the internal validity in laboratory exposure studies in general is good, including Study III, there are in general limitations regarding the external validity. The results were acquired in an artificial environment (e.g. exposure booth) using artificial sound exposure (e.g. white noise), and the question is if the findings can be generalized to daily situations encountered by person with sound intolerance? The choice of testing environment was a trade-off between ecological validity and experimental control. By using a sound booth we could ensure that unwanted sounds were kept to a minimum, and while not an environment the participants would encounter in daily life, the silence of the booth was similar to a normal, empty room. It would have been possible to choose a sound stimuli with more natural properties, but with the risk of accidentally (a) choosing a sample recording with contextual connotations that could affect perceptions (e.g. conversation murmur, silverware clatter, air-conditioning hum, etc.) or (b) choosing a sound with frequencies some participants might find more troublesome than other. The latter could be mitigated by selecting a wide set of sounds, but it would still run the risk of not being inclusive enough.

Another question is to what extent results from non-randomly selected participants (e.g. recruitment by flyers), can be generalized to the study population (e.g. persons with sound intolerance)? There is the obvious risk when recruiting that the most motivated to participate are also those who are the least affected by the stimuli (in this case sound), and thus will skew the results in favor of a very low response. This does not appear to be the case in study III, according to at the range of responses to the white noise.

Future directions
This thesis should be seen as a small step towards greater understanding of a phenomenon that we still know relatively little about. My findings illustrate just how all-encompassing having sound intolerance can be, and how it is associated not only with personal health, but also how one copes with it in a work environment and in social settings. There remains many challenges when it
comes to sound intolerance. In a recent study aimed at prioritizing research questions regarding hyperacusis, Fackrell et al. (2019) with the help of people with lived experience and professionals, identified ten research questions for future research. Chief among them are matters of evaluating treatments, prevalence in both general and specific populations and mechanisms governing the illness. Historically, there have not been many studies addressing the prevalence; the most cited study, by Andersson et al. (2002), is by now 17 years old, with others including Fabijanska et al. (1999), Hannula, Bloigu, Majamaa, Sorri, and Mäki-Torkko (2011). Another question of interest is the everyday experiences of people with sound intolerance as they are exposed to naturally occurring sounds. As speculated regarding Study III, it is possible that people with sound intolerance experience more stress on an everyday basis, and it would be informative to explore this by using multiple modes of input (heart rate monitor, diary, decibel meter, questionnaires) over an extended period of time (days or weeks).

**Treatment**

Although not discussed in this thesis, treatments seem to largely come down to cognitive behavioral therapy, counseling and sound therapy (Fackrell et al., 2017). One of the most used treatments is the Tinnitus retraining therapy championed by Pawel and Margaret Jastreboff (2000; 2014), which combines elements of the above mentioned methods and claim good success rates. What is missing, however, seems to be classical randomized control trials to objectively gauge the effectiveness of the various treatments. Another question is whether hyperacusis should be considered a separate illness since it co-occurs in patients with high stress, burnout or exhaustion, or should they be viewed as fundamentally the same in underlying mechanisms.

**Geographical differences**

Given the results of Study II, it is perhaps necessary to take a deeper look as to how employees with hyperacusis might be better accommodated in the workplace. Having hyperacusis might complicate or even hinder certain types of jobs, since hearing and reacting to sounds is important in many professions, and it would be advantageous for employers to be more aware of how the sound environment affects the employees. As of now, hyperacusis has an identification code in the ICD-10 (Socialstyrelsen, 2010) and, at least in Sweden, the recommended invalidity repayment for work related accidents causing hyperacusis is 1-2% (Svensk Försäkring, 2015). This highlights the importance of further research and the need for the scientific community to cooperate interdisciplinary between psychologists, and otorhinolaryngologists in establishing relevant and functional guidelines for diagnosing, treating and informing patients. It is unlikely that our social and work environments will
become less noisy in the future, making it vital in how to prevent the onset of hyperacusis in the population. What role does self-efficacy and job crafting play in wellbeing at work in people with sound intolerance?

Whereas both Studies I and II had cross-sectional designs with similar methodological approach, they revealed varying prevalence rates. Most studies conducted have been geographically located in North America, Scandinavia and the U.K. It is possible that there are differences in cultural or structural approach as to how diseases are perceived and classified that affect observed prevalence rates of hyperacusis, explaining the variation in prevalence across sample groups. It has been found that environmental intolerances, such as building-related intolerance, chemical intolerance and symptoms attributed to EMFs have been shown to vary between countries (Karvala et al., 2018; Palmquist, 2017). Similarly, negative media reports have been found to affect the likelihood of experiencing EI attributed to EMFs (Witthöft & Rubin, 2013). It would be valuable to expand the approach to include more, non-European countries to assess if there are cultural or structural aspects that influence how prevalent hyperacusis is, how it is viewed and how people attribute the symptoms.
Acknowledgement

How does one write an acknowledgement without acknowledging that there will always be someone forgotten, that deserved praise? Maybe by doing just that, acknowledging, and then accepting. Overall, this journey towards a final thesis has been filled with acceptance. Accepting that I will never be 100% satisfied with what I write, this including the drafts I reluctantly, after much insistence, let my poor supervisors read. Exposing your (sometimes) imagined flaws to others is not easy. But accepting that it is hard, while acknowledging that you’re probably overreacting, is probably the most valuable lesson I’ve learned throughout the years. That, and the fact that I’m simply incapable of completing something unless I have the sharp blade of a deadline looming precariously over my neck. It’s not great, but it works for me. If I have to summarize this period of my career I must say it has been challenging, but fun. Like all great things, you savor the good parts, and accept the bad parts. And in the end, you come out humble, grateful, proud and really, really tired.

While it’s my name on the front page of this thesis, there are scores of people who made it possible, and I wouldn’t be here without them. First of all, I have to thank my eminent supervisors Steven and Linus. You’ve both taken turns being my main supervisor so by now I’ll just consider you a joint entity. They say that you’re only as good as those you surround yourself with and I dearly hope that is true because I couldn’t have been in finer company. You may not realize it but you complement each other perfectly; Steven, you always have a discreet and tactful way of delivering criticism that makes it seem like most changes are my idea! In contrast, you Linus have an uncanny ability to cut to the core of an argument/theory/text and distill the essence of it and then present to issue to me. Not as an answer, but as a question. Having me have to work out the answers myself, guided by you, have been very educational and I’m sure somewhat frustrating for you, as I’ve not always caught on immediately. At the end of the day, you have both been attentive to my needs, keen to adapt and give me space when needed, as well as apply pressure when I’ve stalled. I couldn’t have asked for better friends and supervisors.

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