Hearing-related symptoms among women

Occurrence and risk in relation to occupational noise and stressful working conditions

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Abstract

A considerable amount of research has been devoted to the risk of noise-induced hearing loss among industry workers – the majority of whom are men. Much less research has been done in female-dominated human service occupations, including obstetrical care and preschools. These work environments can be characterised by noise from intense speech communication and screaming and by stressful working conditions. To address the lack of studies in female-dominated workplaces we have assessed the occurrence and risk of hearing-related symptoms among obstetrical personnel (n 115), the diagnostic validity of self-reported symptoms (n 55), and the relative risk of hearing-related symptoms among female preschool teachers (n 4718) compared to women in the general population (n 4122).

The main finding of this thesis was that women working in obstetrical care and preschools have an increased risk of hearing-related symptoms. We found that equivalent sound levels measured in the obstetrical ward exceeded 80 dBA in 45% and 85 dBA in 5% of the work shifts measured. Maximum levels >115 dBA were measured during ongoing labours. We found an increased risk of tinnitus and sound-induced auditory fatigue in association with occupational noise exposure among obstetrical personnel. Sound-induced auditory fatigue was also associated with noise annoyance. Work-related stress slightly missed significance in a multivariable model. We found an acceptable diagnostic validity for the questionnaire item assessing sound-induced auditory fatigue. It identified >85% of women with fairly mild hearing disorder diagnosed by pure-tone audiometry and by otoacoustic emissions and simultaneously correctly dismissed 70%. The items assessing hearing loss and tinnitus had a sensitivity around 70% in relation to pure-tone audiometry, but wide confidence intervals. Items had low validity in relation to very mild diagnosed hearing disorder. We also found that preschool teachers had higher prevalence of hearing-related symptoms and reported symptom onset earlier in life compared to women in the general population. The relative risk was more than twofold for sound-induced auditory fatigue, hyperacusis and difficulty perceiving speech and less pronounced for hearing loss and tinnitus. The risk of hyperacusis was pronounced among preschool teachers who reported exposure to loud noise. Stressful working conditions had a similar effect on sound-induced auditory fatigue, but the prevalence of sound-induced auditory fatigue was much higher among those reporting noise exposure. We found that working in equivalent sound levels in the range of 75–85 dBA (assigned by a Job-Exposure Matrix) increased the hazard of adult-onset hyperacusis among women in general, and particularly among women working in preschools who had a threefold hazard ratio compared to women working in exposure to equivalent sound levels below 75 dBA.

Prospective longitudinal studies are needed to ascertain causality. Nevertheless, the pronounced risk of hearing-related symptoms in the occupations studied should be taken seriously and consequences need further study. In addition, our studies showed that hearing protection is rarely used by obstetrical personnel and by preschool teachers. Hence, suitable and acceptable hearing preventive methods and noise-mitigating measures need further development in communication-intense sound environments.

Keywords: Hearing-related symptoms, occupational noise, stressful working conditions

Sammanfattning på svenska

Många studier har undersökt risken för hörselnedsättning bland arbetare som exponeras för buller inom traditionellt mansdominerade yrken och det finns ett starkt vetenskapligt stöd för ett orsakssamband. Mycket färre studier har genomförts bland kvinnor och i kvinnodominerade arbetsmiljöer, såsom inom förlossningsvården och förskolan. Ljudmiljön präglas i dessa yrken av skrik och hörselkrävande kommunikationsintensivt buller. I yrken som dessa, där personalen främst arbetar med människor (så kallade kontaktyrken), är de emotionella kraven höga och stress-relaterad sjukdom är vanligt. Forskning tyder på att stress kan påverka hörselsystemet, men orsakssambandet är inte klarlagt.

Syftet med denna avhandling var att adressera bristen på forskning inom kvinnodominerade kontaktyrken genom att studera förekomst och risk för hörselrelaterade symtom i relation till bullerexponering i arbetet samt i relation till arbetsrelaterad stress. Två yrkesgrupper har studerats: förskollärare och personal inom förlossningsvården. Sammanfattningsvis visade resultaten på en ökad risk för hörselrelaterade symtom i dessa yrkesgrupper.

Resultaten från ljudnivåmätningar inom förlossningen visade att den genomsnittliga ljudnivån överskred 80 dBA vid 45% av arbetsskiften och 85 dBA vid 5% av skiften. Maximal ljudnivå över 115 dBA uppmättes bland annat under pågående förlossningar. En orsak antas vara skrik från födande mammor. Analyser visade på ett samband mellan en beräknad bullerexponeringsdos och hörselsymtomen tinnitus och ljudtrötthet bland förlossningspersonalen. Ljudtrötthet hade även ett samband med rapportering av att vara störd av buller på arbetet, men vi kunde inte säkerställa ett samband med arbetsrelaterad stress.

Vidare fann vi att den enkätfråga som mäter ljudtrötthet kunde identifiera mer än 85% av personer med en lätt hörselskada diagnostiserad med hörseltestet tonaudiometri (som mäter förmågan att uppfatta svaga toner) eller genom mätning av otoakustiska emissioner (som mäter funktionen i innerörats sinnesceller för hörseln). Enkätfrågor som mäter självrapporterad hörselnedsättning och tinnitus kunde identifiera omkring 70% av individer med diagnostiserad hörselskada. Beräkningarna var dock osäkra. Det var generellt svårare att, med hjälp av enkätfrågor, identifiera personer med mycket lätt diagnostiserad hörselskada.

Vid en analys av enkätsvar från 4718 kvinnor med förskollärarexamen och 4122 slumpmässigt utvalda kvinnor från den generella befolkningen som inte har arbetat i förskola fann vi att en större andel förskollärare rapporterade hörselrelaterade symtom jämfört med kvinnor i den generella befolkningen. Förskollärarna rapporterade även att symtomen uppkom tidigare under yrkeslivet. Skillnaden i symtomförekomst mellan de två grupperna (relativ risk) var störst för symtomen ljudtrötthet, ljudöverkänslighet (hyperakusis) och svårighet att uppfatta tal. En något mindre uttalad relativ risk sågs för hörselnedsättning och tinnitus. Förekomsten av symtom var generellt hög bland de som rapporterade bullerexponering i arbetet. Den relativa risken för ljudöverkänslighet var särskilt hög bland de som rapporterade buller. Bland de som rapporterade stressande arbetsförhållanden var den relativa risken särskilt hög för ljudtrötthet.

Slutligen fann vi att risken för att drabbas av ljudöverkänslighet var högre för kvinnor som arbetade i måttligt höga bullerninvåer, med en genomsnittlig ljudnivå på 75-85 dBA, jämfört med en referensgrupp som arbetade i ljudnivåer under 75 dBA. Risken var signifikant ökad för kvinnor i allmänhet, men särskilt hög bland kvinnor som arbetade i förskolan. Förskolegruppen hade tredubbelt så hög risk jämfört med referensgruppen.

Nu krävs ytterligare studier där vi följer personer över tid för att bekräfta de förmodade orsakssambanden. Intervjustudier behövs också för att öka förståelsen för hur en kommunikationsintensiv ljudmiljö upplevs och hur de symtom som rapporteras påverkar individen och arbetsförmågan. Vi anser dock att de höga ljudnivåerna inom förlossningsvården och den uttalade risken för hörselrelaterade symtom bland förskollärare ger tydlig indikation på att det behövs förebyggande åtgärder. I förskolan vore en sådan strategi inte bara hälsofrämjande för personalen, utan också för förskolebarnen som vistas stor del av sin vakna tid i förskolans miljö. Trots att personalen i båda dessa yrkesgrupper rapporterar att de utsätts för buller och höga ljud i arbetet, så är det få som uppger att de använder hörselskydd. Detta kan bero på att ljudmiljön är kommunikationsintensiv, och att bullret innehåller viktig information som är nödvändig att uppmärksamma. Det behövs därför mer kunskap om lämpliga och godtagbara förebyggande åtgärder som är anpassade för dessa ljudmiljöer.

List of papers

This thesis is based on the following papers, referred to in the text by their Roman numerals.

I. Fredriksson S., Hammar O., Torén K., Tenenbaum A., Persson Waye K. (2015). The effect of occupational noise exposure on tinnitus and sound-induced auditory fatigue among obstetrics personnel: a cross-sectional study. BMJ open 5(3): e005793.

II. Fredriksson S., Hammar O., Magnusson L., Kähäri K., Persson Waye K. (2016). Validating self-reporting of hearing-related symptoms against pure-tone audiometry, otoacoustic emission, and speech audiometry. International journal of audiology 55(8): 454-462.

III. Fredriksson S., Kim J-L., Torén K., Magnusson L., Kähäri K., Söderberg M., Persson Waye K.. Increased risk of self-reported hearing-related symptoms among women who have worked in preschool: a cohort study. *Submitted for publication.*

IV. Fredriksson S., Hussein-Alkhateeb L., Torén K., Sjöström M., Selander J., Gustavsson P., Kähäri K., Magnusson L., Persson Waye K. Occupational noise exposure and adult-onset hyperacusis in a cohort of Swedish women. *Manuscript.*

Content

Abbreviations

ABC	Alternative Birth Care
ABR	Auditory Brainstem Response
AFS	Regulation set by the Swedish Work Environment Authority
AIC	Akaike's Information Criterion
AV	The Swedish Work Environment Authority (Arbetsmiljöverket)
CI	Confidence Interval
COPSOQ	The Copenhagen Psychosocial Questionnaire
Cpeak	C-weighted, instantaneous sound pressure
dB HL	Decibel Hearing Level
dB SL	Decibel Sensation Level
dBA	A-weighted Decibel Level
DPOAE	Distortion Product Otoacoustic Emission
ERI	Effort-Reward Imbalance
EU-OSHA	European Agency for Safety and Health at Work
f	Frequency
HINT	Hearing in Noise Test
HPA	Hypothalamic-Pituitary-Adrenal
HR	Hazard Ratio
Hz	Herz
ICBEN	International Committee for the Biological Effects of Noise
IHC	Inner Hair Cell
IQR	Interquartile Range
IR	Incidence Ratio
IRR	Incidence Rate Ratio
ISO	International Standards Organisation
ISO/TS	International Standards Organisation Technical Specification
JEM	Job-Exposure Matrix
kHz	Kiloherz
L	Level
*L*Aeq	Equivalent A-weighted Level

*L*AFmax	A-weighted Fast Maximum Level
LEX,8h	Daily Exposure Level averaged over 8 hours
LLS	Long-lasting stress
n	Number of subjects
NA	Not Applicable/Not Avilable
NIHL	Noise-induced hearing loss
NIOSH	The National Institute for Occupational Safety and Health in the US
NPV	Negative Predictive Value
OAE	Otoacoustic Emission
OHC	Outer Hair Cell
OR	Odds Ratio
p	p-value (probability value)
PB	Phonemically Balanced
PPV	Positive Predictive Value
PTA	Pure-tone Average
RR	Risk Ratio
SD	Standard Deviation
SEK	Swedish krona
SNR	Signal-to-Noise Ratio
SPL	Sound Pressure Level
TMD	Temporomandibular Disorder
ULL	Uncomfortable Loudness Level

Introduction

Background and rationale

Occupational noise exposure is the leading cause of work-related disorders in Europe and the fourth most common in Sweden. Among men, the largest number of claims of work-related disorders due to noise are found in the manufacturing industry, while education is the most common sector among women (The Swedish Work Environment Authority, report 2016:3). More men than women report occupational noise exposure. The difference can be explained by occupational gender segregation. Because men and women tend to work in different occupations and sectors (Anker 1997), and are thus exposed to different occupational hazards, they may suffer different risks at work (Eng et al. 2011).

A considerable amount of research has been devoted to the deleterious effect of occupational noise exposure on hearing within male-dominated occupations in the industry sector, which is not surprising given the extent and degree of noise exposure (Concha-Barrientos et al. 2004, Nelson et al. 2005, Kurmis et al. 2007, Lie et al. 2016). Much less attention has been paid to female-dominated occupations. In 2013, the European Agency for Safety and Health at Work presented a review, in which they emphasised the lack of risk assessment specifically within the healthcare and education sectors (EU-OSHA 2013).

Risk assessment of noise exposure within the obstetrical care is virtually non-existent. A workplace inspection at an obstetrical ward in Skövde, Sweden, has indicated that equivalent sound levels may exceed the lower action value for daily exposure 80 dBA and the limit for maximum sound levels ($_{LFmax}$)115 dBA, predominantly due to mothers screaming during labour (Tenenbaum et al. 2010). Research on the general occurrence of hearing-related symptoms among obstetrical personnel, however, are completely lacking.

In contrast, high sound levels in preschools have been reported for more than 30 years and the equivalent sound levels are generally found to be around 80 dBA (Gärding 1980, Truchon-Gagnon et al. 1988, Picard 2004, Grebennikov 2006, Rubak et al. 2006, McLaren 2008, Persson Waye et al. 2010, Sjödin et al. 2012, Gerhardsson et al. 2013). Many studies have noted that the sound levels in preschools vary greatly throughout a working day and frequently, but intermittently, reach or exceed the exposure limits (McLaren 2008, Persson Waye et al. 2010, Sjödin et al. 2012). Two large population studies concluded that, compared to other occupations, preschool teachers do not have an increased risk of measured pure-tone hearing loss (Rubak et al. 2006, Engdahl et al. 2010). However, a smaller cross-sectional study, which included 101 preschool teachers, found that hearing thresholds were slightly worse than the population reference data (Sjödin et al. 2012). Most notably, a high prevalence of self-reported hearing-related symptoms, including tinnitus and hyperacusis (sound sensitivity), were reported by the preschool personnel, around 30 to 40 %, respectively (Sjödin et al. 2012). However, there is a lack of relevant population prevalence data among women to compare with in order to assess the relative risk of symptoms.

Interestingly, a rather new paradigm regarding the auditory effects of noise has emerged from experimental research during the last decade (Kujawa et al. 2015). It suggests that noise-induced hearing disorders may develop without a hearing loss being detected when using standard clinical tests measuring pure-tone hearing thresholds (Liberman et al. 2016), but could present as difficulty perceiving speech, tinnitus or hyperacusis (Bharadwaj et al. 2014, Hickox et al. 2014).

Exposure to stressful working conditions has also been hypothesised as an important factor for hearing-related outcomes. Firstly, associations between hearing-related symptoms and long-term stress and burnout have been found in a larger cross-sectional study within the general Swedish population (Hasson et al. 2011). Although causal effects have not been clearly shown, long-term exposure to stress have been suggested to negatively affect the auditory system (Canlon et al. 2011). Secondly, noise and stressful working conditions are stressors with similar pathways, including activation of the hypothalamic-pituitary-adrenal (HPA) axis and subsequent release of stress hormones such as glucocorticoids (Ising et al. 2000, Lupien et al. 2009, Canlon et al. 2013). Thus, interactions between exposure to noise and stress may be hypothesised, similar to what has been shown for myocardial infarction and coronary heart disease (Selander et al. 2013, Eriksson et al. 2018). It is also worth bearing in mind that hearing impairment in itself has been shown to entail worse health outcomes under stressful working conditions (Danermark et al. 2004).

Many human service occupations, such as those within health care and education, are stressful. One important cause of stress within human service occupations relates to emotional demands, such as having to hide emotions in interpersonal interactions (Dollard et al. 2003), or what preschool teachers have described as difficulties meeting children's needs (Kelly et al. 1995). A cross-sectional survey has found that the prevalence of personal burnout, which includes emotional exhaustion, was 40% among Swedish midwives (Hildingsson et al. 2013). A large Danish study has found significantly increased risk of being diagnosed with stress-related disorders among female preschool teachers (Wieclaw et al. 2006).

In summary, exposure to occupational noise and stressful working conditions are important work environment factors in obstetrical care and in preschools. There is, however, a knowledge gap concerning the occurrence and risk of hearing-related symptoms among personnel in these occupations relative to women in the general population. The main purpose of this thesis is to address this gap.

Occupational noise

Definitions

Within acoustics, noise refers to sound, which in physical terms are mere waves of vibrating molecules propagating from a source through air, fluids or solids. The amplitude of a sound is usually measured in decibel sound pressure level (dB SPL) and frequency is measured in hertz (Hz).

Acoustically, the term *noise* may simply refer to sounds with random fluctuations over time and energy in a wide spectrum of frequencies (e.g. "white noise" or "pink noise"). However, not all such sounds are conceptualised by the listener as noise (e.g. certain speech sounds, like the voiceless labiodental fricative [f], are noise-like). Therefore, when studying the adverse health effects of noise a common definition of noise is "unwanted sounds". However, this psychoacoustic definition is not suitable when assessing the risk of auditory damage because any type of sound that is loud and has a long exposure duration can be hazardous. Thus, a sound can be wanted and yet be physiologically damaging (Kryter 1984).

This may be illustrated by a quotation from Burns (1973), page 189:

> *"Noise may not be devoid of use, since it may give essential information to the operator of a machine, for example, and although his hearing may be at risk as a result, the sound could not be classified as unwanted, since the safety of the machine, and even of the operator and of others, may depend upon the continual flow of information produced by the noise."*

We use the term *communication-intense noise* to refer to noise arising from human activity, interaction and speech communication; predominantly vocal sounds at high sound levels or intense multi-talker speech communication, sounds which may be necessary to attend to because they carry meaning and information for the listener. Examples relevant to the occupational setting in preschools and obstetrical care are: loud screaming voices from children playing or crying; screaming from mothers giving birth; multiple-talker speech conversations; speakers who raise their voice due to multiple simultaneous conversations; alarm signals from medical equipment or telephone signals. Although noise is most often thought of in terms of loud sounds from machines, tools, fans or the like, which are generally unwanted sounds. In a large Canadian study, women were found to report "people or music" as the source of noise exposure to a greater extent (31%) compared to men (13%), who more often reported noise from machinery or transportation (Feder et al. 2017).

We hypothesise that communication-intense noise, like other sources of noise, have the potential to be loud enough and of a long enough duration to cause hearing damage. In addition to sound level and duration, other aspects may be important for the risk of hearing-related symptoms, such as variability of the sound levels, and intermittency and suddenness of particularly high sounds levels. Another important aspect, which may affect the risk of hearing-related symptoms, is the perceived difficulties of using hearing protection in communication-intense sound environments, which is most likely related to the need of attending to the acoustic information and the high demands of perceiving speech communication. Studied have also shown that preschool teachers feel reluctant to use hearing protection due to it being uncomfortable in relation to parents (Koch et al. 2016).

Numerous studies have reported high sound levels in preschools, on average around or just below equivalent sound levels 80 dBA (Gärding 1980, Truchon-Gagnon et al. 1988, Picard 2004, Voss 2005, Grebennikov 2006, McLaren 2008, Persson Waye et al. 2010, Sjödin et al. 2012, Gerhardsson et al. 2013, Neitzel et al. 2014). As seen in figure 1, the sound level vary a lot throughout the day in a preschool, and although equivalent levels only occasionally exceed the 8-hour exposure limit 85 dBA, the equivalent sound level may frequently exceed 85 dBA in one-minute loggings – up to 100 times per hour throughout the day (Sjödin et al. 2012). The number of events with high sound levels is, however, not considered in the current noise regulation, as discussed further in the next section. The example shown in figure 1 was measured in 2014 using a dosimeter worn by a preschool teacher, and shows great similarities with previous published data from preschool (Persson Waye et al. 2010, Sjödin et al. 2012). Furthermore, we hypothesise that other communication-intense sound environments may be similar to the preschool sound environment. However, with regard to the sound environment in obstetrical care, corroborating data is limited. Only one report from a work inspection has been found (Tenenbaum et al. 2010). The inspection showed that equivalent sound levels exceeded 80 dBA in 7% and maximum ($_{LFmax}$) 115 dBA in 25% of the measured work shifts in an obstetrical ward in Skövde, Sweden.

Although this thesis focuses on women in general, it is important to emphasise that individuals with hearing loss may have particular difficulties in this type of sound environment. An interview study among preschool personnel with hearing impairment highlights how the high and strenuous sound levels negatively affects the basic conditions of speech communication (Danermark et al. 2003). Many of the interviewees expressed an acute need for rest and recovery after work, which they perceived as being due to the efforts of working in a communication-intense sound environment (Danermark et al. 2003). The increased effort required for individuals with hearing loss when listening and perceiving speech in challenging acoustic environments may cause fatigue and stress (Hétu et al. 1988). Recognising and distinguishing between sounds has been found to be significantly associated with stress-related sick leave (Kramer et al. 2006). The increased listening effort may be explained by the effortful cognitive and linguistic processing load required for perceiving speech in noise (Zekveld et al. 2011, McGarrigle et al. 2014). Interestingly, the pronounced need for silence after work has also been reported among preschool personnel in general, regardless of their hearing ability (Persson Waye et al. 2010, Sjödin et al. 2012).

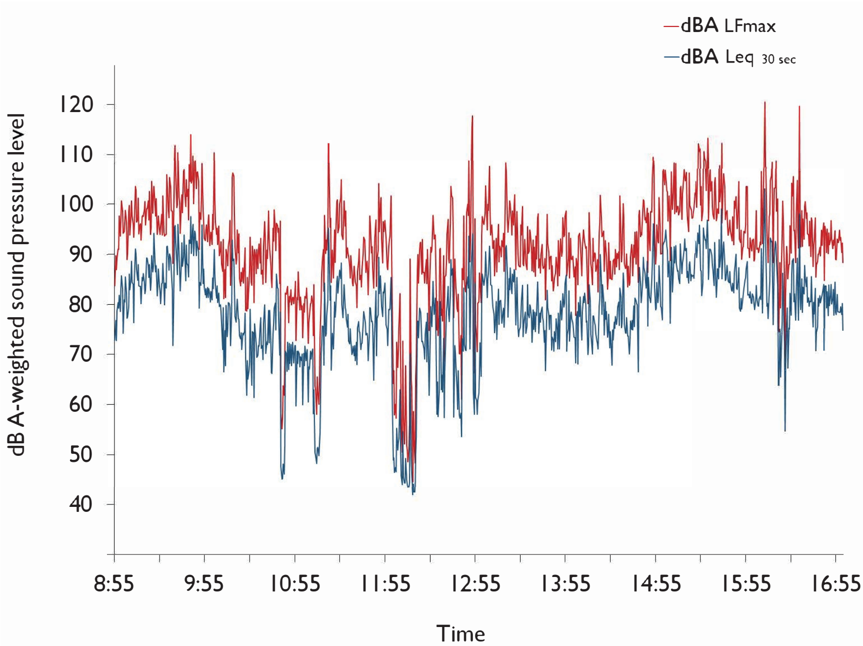


Figure 1. Sound level measurement using a dosimeter on a preschool teacher (unpublished data from 2014).

Noise exposure assessment

The term noise exposure can be used to refer to the total acoustic stimulus received by the ear or by the whole body (Burns 1973). The current regulations pertaining to risk of auditory effects from occupational noise exposure focus mainly on the physical properties of sound, mainly sound level, and duration of exposure. The Swedish regulation set by the Swedish Work Environment Authority (AFS 2005:16) lays down exposure limit values – which may not be exceeded – and exposure action values – where noise-mitigating measures to prevent risk are to be implemented (table 1). The Swedish regulation is based on based on the EU directive (2003/10/EC).

The risk of hearing damage from noise exposure is often discussed in relation to the equal-energy hypothesis (or equal-energy principle), which states that equal amount of sound energy will produce equal amounts of hearing loss, regardless of the distribution over time (NIOSH 1998). Therefore, the 8-hour A-weighted equivalent sound level (i.e. the sound level equivalent to the total sound energy measured over a stated period of time) is traditionally measured to assess the risk of exposure throughout a day or a week. However, impulse noise is assessed based on the instantaneous maximum sound pressure level, the C-weighted peak level, as the risk of damage to the organ of Corti is thought to be determined by the maximum sound pressure level (Arlinger 2013). The current regulations of impulse noise, by using the C-weighed peak, does not consider the total energy, the frequency content, the duration of the exposure or the number of events of high sound levels. Studies suggest that highly varying noise may pose a greater risk of damage to the auditory system compared to continuous noise (Zhao et al. 2010). To what extent this applies to communication-intense noise needs further study.

Importantly, exposure below the limits is not completely "safe". Depending on the definition of hearing loss, different estimates of excess risk have been reported. ISO 1999:1971 reported a 10% excess risk for a 40-year lifetime exposure to equivalent levels of 85 dBA, while a 15% excess risk in exposure to 85 dBA and 3% in exposure to 80 dBA was reported by NIOSH 1972, as cited by Prince et al. (1997). At present, there is some disagreement about what constitutes a "safe" level of exposure. "Effective-quiet", assumed to entail negligible risk of hearing damage, have been suggested to correspond to 76-78 dBA (Melnick 1991), as cited by (Arlinger 2013). In a review, Eggermont reported findings mainly from experimental studies, suggesting central auditory plastic changes occurring as a consequence of noise exposure at or below 80 dB SPL (Eggermont 2017). Arlinger concluded in a review, that exposure already at 8-hour equivalent levels of 75–80 dBA may presents a risk of hearing damage, at least among susceptible individuals (Arlinger 2013).

The regulations pertaining to hearing damage from occupational noise (AFS 2005:16) require that measures are to be taken to eliminate the source of the noise or that noise is reduced to the lowest possible level. Measures can include technical ones, such as installing sound absorbents, or organisational changes, such as limiting the exposure duration by adjusting working hours. If the risk of noise exposure cannot be prevented by other measures, and the lower action values are reached or exceeded, hearing protection shall be made available to employees. If the upper exposure values are reached or exceeded, employees must use hearing protection and the employer must see to it that they do and that it effectively eliminates or minimises the risk of hearing damage.

Table 1. Exposure values pertaining to risk of hearing damage from occupational noise exposure regulated by the Swedish Work Environment Authority (AFS 2005:16).

	Action values		**Limit values***
	Lower	Upper	
Daily exposure level dBA LEX, 8h	80	85	85
Maximum exposure level, dBA LFmax	-	115	115
Instantaneously peak exposure level, dB Cpeak	135	135	135

* The attenuation provided by use of hearing protecting devices is to be accounted for when applying the limit values.

SOUND LEVEL MEASUREMENTS

Risk assessment of noise exposure in the workplace is usually done by measuring sound levels, preferably using portable sound levels dosimeters which estimates the individual exposure dose. Measurement duration should be long enough to capture time variation in sound levels and the equivalent level should thus reflect the overall acoustic energy in the exposure. However, it may be difficult to capture representative equivalent levels if the sound environment is highly varying and intermittent. Thus, the focus on the equivalent levels has been criticised. This is partly due to the fact that irregular noise with different frequency and temporal characteristics may have the same total acoustic energy, but still differ in the potential for causing hearing loss (Henderson et al. 2001). Assessing noise exposure using sound level measurements has other limitations. One is that it is not feasible to perform individually on a large scale. In addition, it may also be difficult to estimate a representative exposure dose in environments where noise sources are not static or immobile (e.g. a child running around and suddenly screaming).

Furthermore, in communication-intense sound environments it is important to consider the effect of the speakers own voice on the measured sound levels. It has been shown that the effect is greater at lower exposure levels than at higher. For example, a study estimated that the speech contribution (e.g. the addition of the own voice to the overall measured sound level) is less than 2 dB at equivalent noise levels of 75 dBA with a percentage of speaking time from 10 to 20%

(Ryherd et al. 2012). Even with a high percentage of speaking time, the contribution in these background noise levels is only about 5–6 dB. At equivalent noise levels above 80 dBA, the contribution of the speaker's own voice is usually considered negligible. Although the ideal placement of the microphone, in order to capture the exposure to the ear of the worker, is an upright position on the shoulder, some studies have adopted a neck placement of the microphone in order to minimise effects of the wearers own voice (Sjödin et al. 2012). However, this approach could also underestimate the exposure by the ear.

SELF-REPORTED NOISE EXPOSURE

Noise exposure can also be assessed using self-reporting, which answers some of the above-mentioned limitations, but has its own, such as not being internationally standardised. However, studies have validated self-reported items against sound level measurements and found that subjects are generally capable of differentiating between different noise levels using self-report (Neitzel et al. 2009). Good agreement has also been found between self-report compared to exposure assessed by using a Job-Exposure Matrix (Schlaefer et al. 2009). Often, questionnaire items are constructed to capture the noise exposure by assessing interference with speech communication, for example asking whether noise is so loud that the speaker has to raise their own voice or noise being so loud that it is difficult to hear a regular conversation. The former has been noted to correspond to exposure levels around 85–90 dBA (Nelson et al. 2005).

JOB-EXPOSURE MATRIX FOR OCCUPATIONAL NOISE

An approach which, in some ways, lies between sound level measurement and self-reporting is the use of a Job-Exposure Matrix (JEM). The Swedish JEM for occupational noise constructed by Sjöström et al. (2013), assigns exposure to job families (containing several similar occupations) determined based on a large number of sound level measurements from different occupations and consensus judgements made by occupational hygienists for occupations where noise measurements were not available. Each job family is assigned to one of three equivalent noise level intervals: <75 dBA, 75–85 dBA and >85 dBA. These intervals are unfortunately rather wide, and the JEM is currently under development in order to differentiate job families into more narrow noise level intervals. For example, the current Swedish JEM assigns preschool teachers working in preschool to the 75–85 dBA interval. In the updated version, this occupation will be assigned to the 80–85 dBA interval (Sjöström, personal communication, April 2018). The JEM also include an assessment of the likelihood of impulse noise (peak levels) for different job families, but these are deemed less valid as it has showed a systematic difference in classification by different assessors (Sjöström et al. 2013).

By using the JEM, individual exposure assessment is less subjective compared to self-reported exposure and can also be done retrospectively by using occupational history records or self-reported job titles. Two important limitations of using a JEM are misclassification of exposure due to incorrect assignment of job families (e.g. based on inadequate or limited information of job titles) and miss-classification due to difference in exposure for occupations or work activities categorised within the same job family.

Noise annoyance

Noise exposure can also be regarded as a stressor. The effect can be measured by assessing noise annoyance. Annoyance is a commonly described non-auditory effect of noise exposure. Thus, it is commonly viewed as a secondary reaction to noise, rather than an exposure rating. It has been suggested to act as a mediator in the cause-effect relationship between noise and health outcomes such as cardiovascular effects (Babisch 2002), or may have a modifying effect (Babisch et al. 2003). Noise annoyance is a multi-faceted psychological concept, which includes behavioural effects, such as disturbance and interference with activities, and evaluative aspects such as nuisance and unpleasantness (Guski et al. 1999). Assessment of annoyance from environmental noise is standardised in the ISO/TS 15666:2003 and the recommendation from the International Committee for the Biological Effects of Noise (ICBEN) (Fields et al. 2001). There is however no standardised questionnaire assessing noise annoyance in an occupational setting.

The correlation between noise annoyance and environmental noise exposure is moderate and statistically significant and the odds of being highly annoyed increases with increasing exposure level (Guski et al. 2017). However, annoyance reactions are only partly related to noise level. Other physical characteristics of the noise, such as frequency content and temporal variability, plays an important role in annoyance reactions (Kjellberg 1990). Interestingly, the information content, unpredictability and necessity of the noise and noise source are also important factors in determining annoyance reactions (Kjellberg 1990). These factors are likely important in relation to communication-intense noise. It is conceivable that sudden unpredictable and unnecessary screaming from children in preschools, which interferes with an ongoing conversation, may be perceived as annoying. Similarly, midwives may perceive irrelevant speech in a crowded nurses' office as annoying when performing medical assessments and doing documentation. One study among preschool personnel have found that children's voices and activities are the most annoying sounds (Sjödin et al. 2012). Another study found that almost 90% of the personnel reported that screams were rather, very or extremely annoying (Persson Waye et al. 2010). One of these studies found that annoyance increased with increasing noise level and with the number of sound events exceeding 1-minute equivalent sound level 85 dBA, however the correlation was not statistically significant (Sjödin et al. 2012).

Stressful working conditions

Definitions

The term *stress* is ambiguous. It can be used to describe either stressful working conditions or a physiological response to stressors in the environment that trigger a stress-response.

Stressful working conditions (sometimes referred to as psychosocial working conditions) may be viewed as conditions which "cost" more than what is "gained" (e.g. working under time pressure, but not feeling appreciated) as described by the Effort-Reward Imbalance (ERI) model (Siegrist et al. 2004). It can also be viewed as conditions characterised by high demands and low control (e.g. having to work hard, but not being able to control when or what should be done) defined by the Job-Demand-Control model (Karasek et al. 1998).

When we perceive events as stressful, the body can respond by releasing hormones that can protect us and help us to handle stressful situations (e.g. increasing the heart rate in order to "fight back"), but when the exposure is prolonged without sufficient recovery, these reactions may be damaging and we may experience being "stressed out" (McEwen 2006). The hypothalamic-pituary-adrenocortical (HPA) axis plays an important role in the physiological stress response (Koolhaas et al. 2011). Lack of rest from an effortful workload, and need for recovery after work, have been identified as risk factors for stress-related disease and sickness absence (de Croon et al. 2003), as well as health-outcomes such as musculoskeletal disorders (Lundberg 2003). Long-term exposure to stress and has also been suggested to negatively affect the auditory system via the HPA-axis (Canlon et al. 2011, Canlon et al. 2013).

Personnel in human service occupations may be at increased risk of stress-responses, such as burnout (Maslach et al. 1986). In human service work, emotional demands have been suggested as particularly stressful (Dollard et al. 2003). Due to the interactions and interpersonal relationships in human service occupations, emotional demands may be an even more important factor than quantitative demands (Vegchel et al. 2004). A European report on work-related stress found that personnel within the health care, social services, and education sectors are the most at risk for work-related stress (Houtman 2005). Preschool teachers have described stressful conditions as including difficulties meeting children's needs (Kelly et al. 1995), and female preschool teachers have been found to have significantly increased risk of being diagnosed with stress-related disorders (Wieclaw et al. 2006). Moreover, the prevalence of personal burnout, including emotional exhaustion, was found to be 40 % in a cross-sectional survey among Swedish midwives (Hildingsson et al. 2013).

Assessment of exposure to stressful working conditions

Stressful working conditions are generally assessed by self-report questionnaires, which measure either the explicit demands and working conditions, or the outcome of exposure to stress, such as burnout. One model in common use, is the effort-reward imbalance model (ERI) proposed by Siegrist et al. (1996). The model is based on the assumption that an experienced lack of reciprocity or balance between requested efforts (e.g. having a lot of responsibility at work) and given rewards (e.g. being appreciated in an adequate way) can cause sustained strain reactions in the autonomic nervous system (i.e. a stress-response) (Siegrist 1996). Another model commonly used is the demand-control model (Karasek 1979), which has been criticised to lack validity for female workers (Van der Doef et al. 1999) as it does not capture emotional demands. The Copenhagen Psychosocial Questionnaire (COPSOQ) has been developed to measure a variety of aspects relating to stressful working conditions, including emotional demands (Kristensen et al. 2005).

Hearing

Definitions

In this thesis, the term *hearing disorders* is used to indicate pathological abnormalities or disturbances (i.e. disease) in the auditory system, sometimes in reference to a specific pathophysiological mechanism or condition and sometimes as a general term of disorders affecting the auditory system. In contrast, the term *hearing-related symptoms* is used to describe the subjective evidence and signs of a physical disturbance observed by the individual, such as that obtained from self-report questionnaires. The term *hearing impairment* is occasionally used when citing other researchers. Impairment often refer to functional disorders, in contrast to disability (i.e. resulting perceived difficulties) or handicap (i.e. non-auditory consequences on the individual's life) (Stephens et al. 1991). We have adopted the term hearing disorders in place of impairment, as the latter is often used to denote only hearing loss.

Anatomy and physiology

Hearing is a sensory process in which sound waves collected by the pinna of the outer ear are led mechanically via the eardrum through the bones in the middle ear into the fluid-filled inner ear and the cochlea, in which the organ of Corti rests on the basilar membrane. The motion in the inner ear fluid causes displacement of the basilar membrane. This in turn causes bundles of stereocilia on top of the sensory cells (inner hair cells IHC, outer hair cells OHC), located in the organ of Corti, to initiate a mechanoelectrical transduction, which converts mechanical energy into neural impulses (Robles et al. 2001). From the afferent synapses connecting to the sensory cells (mainly IHC), cycles of excitation and inhibition are produced, and nerve impulses travel from the cochlea via the auditory nerve and further through the afferent auditory neural pathway towards the auditory cortex, where the central processing of auditory information take place. The afferent pathway, which is largely contralateral to the stimulated ear, is shown in blue in figure 2. The sensory cells in the cochlea also receive efferent innervation (mainly OHC), which project towards the cochlea primarily from the superior olivary complex in the brain stem (Ryugo et al. 2010). The efferent pathway is not shown in the figure.

The IHCs are mainly responsible for a rather passive transduction of sound into neural activity. However, there are also active processes within the cochlea (i.e. the "cochlear amplifier"), which by electromotility of the OHC, causes sharper frequency tuning and increased sensitivity of the IHCs. The by-product of this process is called otoacoustic emissions (OAE), which can be registered as sounds in the ear canal (Kemp 2002, Manley et al. 2007). Due to the efferent innervation of OHCs, a contralateral suppression of OAEs have been assumed capable of measuring the integrity of the efferent system (Collet et al. 1990).

The healthy human ear can perceive sound in the frequency range of 2 to 20,000 Hz, but about 20 Hz is usually required to perceive tonality (Gelfand 2004). Hearing sensitivity is not equal for all frequencies within this range. For example, a tone of 1000 Hz require 7.5 dB SPL to reach the average hearing threshold, defined as 0 dB HL, whereas a tone of lower and higher frequency will require a higher SPL to be detected (ISO 226:2003). This is mirrored in the A-weighting filter, which, as discussed earlier, is often used to measure sound levels in the workplace. However, even before sound is transmitted into the cochlea, the so-called stapedius reflex can be initiated by very loud sounds, causing a contraction in the stapedius muscle, which changes the impedance of the middle ear and dampens the sound. The reflex threshold range from 85–100 dB SPL for pure tones of 250–4000 Hz and is about 20 dB lower for broad band noise (Gelfand 2004). However, the reflex has a latency (about 150 milliseconds at 80 dB SL to 40 milliseconds at 100 dB SL for a 1000 Hz tone) and the contraction starts to decline after a few seconds (Gelfand 2004). Thus, limiting its protective effect for sudden loud noise and prolonged exposure.

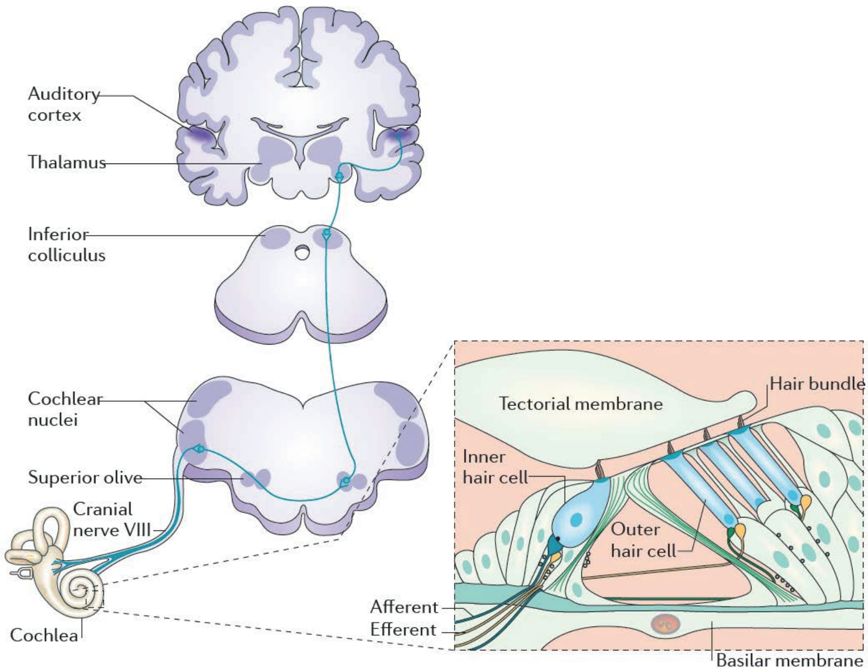


Figure 2. The human auditory pathway, adapted with permission from Springer Nature (Elgoyhen et al. 2015).

Hearing disorders and hearing-related symptoms

HEARING LOSS

The most researched hearing disorder relating to occupational noise exposure is noise-induced hearing loss (NIHL), which is characterised by a loss of hearing sensitivity, which, measured by the psychoacoustic test pure-tone audiometry, predominantly affects hearing thresholds in the higher frequencies (3 000–6 000 Hz) with the largest effect at 4 000 Hz (Concha-Barrientos et al. 2004). It is widely accepted that there is a dose-response relationship between the degree of NIHL and the amount of noise exposure. The prevalence of a permanent threshold shift differs depending on occupation (Engdahl et al. 2010, Masterson et al. 2013), but also increases depending on age, and factors such as concurrent exposure to solvents and genetic susceptibility and is more common among men than among women in the general population (Arlinger 2013, Lie et al. 2016). The global burden of NIHL has been estimated at over 4 million disability-adjusted life years and 16% of adult-onset hearing loss have been estimated to be attributable to occupational noise exposure (Nelson et al. 2005). The consequences for the individual, as with hearing loss in general, can be extensive and cause disability and handicap (Barrenas et al. 2000) as well as feelings of resignation and stigmatization (Hallberg et al. 1996). A self-report item asking "Do you feel you have a hearing loss?", has been shown to have a sensitivity and specificity at 71% in relation to pure-tone hearing loss in a population of 3556 adults age 43–92 years (Nondahl et al. 1998). In contrast, the same study showed that screening for hearing loss using a questionnaire (Hearing Handicap Inventory) in the same group had a sensitivity of only 34%, but a specificity of 95%. A more recent study showed that sensitivity of both the single item question on hearing loss and the hearing handicap inventory was better (93% and 80% respectively) for moderate hearing loss (PTA 0.5, 1, 2 and 4 kHz >40 dB HL) than mild loss (Sindhusake et al. 2001).

The underlying mechanisms of NIHL have traditionally focused mainly on the sensory cells within the cochlea. Mechanical and structural damage, such as broken stereocilia (Liberman 1987), and molecular processes, such as glutamate excitotoxicity (Pujol et al. 1999), have been described. A number of studies have also suggested that increased reactive oxygen species and toxic free radicals may trigger the death of hair cells (Henderson et al. 2006). Recent experimental studies have, in contrast to the traditional view of hair cell death being the initial and primary source of NIHL, suggested lingering post-exposure neural damage caused by loss of ribbon synapses (the synapses between hair cells and cochlear nerve terminals) with progressive loss of spiral ganglion neurons (Kujawa et al. 2015). This pathology has been shown to affect mainly high-threshold auditory nerve fibres (Furman et al. 2013), which may explain why noise-exposed subjects experience difficulty perceiving speech, even when hearing thresholds are within the normal range (Liberman et al. 2016). This clinical picture has lead researchers to use the term "hidden hearing loss" (Plack et al. 2014, Liberman et al. 2016).

In summary, recent studies suggest that the focus on NIHL and the measurement of pure-tone hearing thresholds as the gold standard indication of hazardous noise exposure may be too narrow. It could potentially mean that subjects and occupational groups at risk of noise-induced hearing disorders are overlooked.

DIFFICULTY PERCEIVING SPEECH

Difficulty perceiving speech is, from clinical experience, probably the most common complaint and reported disability among subjects with hearing loss. Thus, it may be viewed as a symptom or consequence of hearing loss, rather than a disorder in itself and many studies reporting prevalence of self-reported hearing loss in fact asks about difficulty perceiving speech. For example, a large population based study in Sweden reported a prevalence of "hearing loss" at 11% among women and 15% among men aged 16–64 years, when in fact asked "How difficult is it for you to (without hearing aid) hear what is said in a conversation between several people?" (prevalence referring to responses "quite difficult" and "very difficult") (Hasson et al. 2010).

However, as discussed earlier, it has been suggested that specific noise-induced disorders can cause difficulty perceiving speech despite normal hearing thresholds (i..e. "hidden hearing loss"). For example, a study showed that noise exposed pilots had elevated speech in noise thresholds compared to unexposed controls with similar pure-tone thresholds (Hope et al. 2013). Moreover, an earlier study, which included preschool teachers and shipyard workers, showed that test results relating to cortical sound processing of speech stimuli and attention control over distracting sounds were similar in the two exposed groups, and worse compared to an unexposed control group, even though hearing thresholds were similar (Kujala et al. 2004). Another study have shown similar results for speech perception tests, where a group of teachers and preschool teachers had results similar to a group of noise exposed industry workers (Lindblad et al. 2014). These studies indicate that difficulty perceiving speech could be viewed as a sign or symptom of a specific type of hearing disorder.

Moreover, functional deficits relating to disorder of the active processes in the cochlea, such as decreased frequency selectivity, intensity discrimination and temporal resolution, may cause difficulties particular to processing of speech which are only partly explained by reduced audibility (i.e. hearing loss) (Moore 1996). Thus, speech is a stimulus that requires advanced signal processing and requires not only audibility, but also comprehension of what is said. The complexity of central auditory processing and speech perception is not fully understood, but it has been shown that "top-down" skills such as knowledge about the language and cognitive ability also plays a role in speech perception (Akeroyd 2008). Thus, measuring hearing function with speech stimuli will not only reflect the function in the peripheral auditory system.

TINNITUS

Tinnitus is a symptom that has been studied almost as much as NIHL. Subjective tinnitus can be defined as a phantom auditory perception of sound (Jastreboff 1990) or a sound sensation in the absence of an external stimulus (Eggermont 1990). Tinnitus cannot be measured objectively and thus, clinicians and researchers have to rely on self-report. Although, in a few subjects with tinnitus, spontaneous otoacoustic emissions at frequencies corresponding to the perceived tinnitus have been found (Penner 1992). Prevalence of tinnitus in the general adult population has been reported around 10–15% and increases with increasing age and a slightly higher prevalence is often found among men compared to women (Axelsson et al. 1989, Johansson et al. 2003, Hasson et al. 2010, Krog et al. 2010, Shargorodsky et al. 2010). However, a recent review indicate that reported prevalence vary even more in different studies (5–43%), but slightly less within studies using similar symptom definitions (12–30%) (McCormack et al. 2016). The most common definition found in the review was "Tinnitus lasting for more than 5 min at a time" (McCormack et al. 2016). A study from the US has indicated an increase in tinnitus prevalence, closer to 20%, in more recent birth cohorts (Nondahl et al. 2012). The results led the authors to discuss if increased noise exposure may be the explanation, or whether increased public awareness and higher health-related expectations could be the reason for the increase. This development is in contrast to what has been noted regarding pure-tone hearing loss, for which prevalence has decreased particularly among older men, which have led researchers to suggest that decreases in occupational exposure, and consequently decrease in NIHL, may be an explanation (Hoffman et al. 2010, Hoff et al. 2018).

Different triggering and sustaining mechanisms of tinnitus have been suggested. One model assume that tinnitus is maintained by abnormal spontaneous neural activity (i.e. increased firing rates and neural synchrony) caused by an initial cochlear damage and loss of sensory input (Roberts et al. 2010). Another model suggests that tinnitus is a result of "central gain", also here as a result of peripheral auditory damage (Jastreboff 1990, Jastreboff et al. 1993). Although these model suggest that hearing loss is required for tinnitus to develop, tinnitus is also reported among subjects with pure-tone thresholds within the normal hearing range. However, these subjects may still show other signs of auditory disorder, such as inner-ear dysfunction (Weisz et al. 2006, Lindblad et al. 2011).

Generally, the association between tinnitus and noise exposure is well accepted, and many experimental models use noise as an eliciting agent. Prevalence of noise-induced permanent tinnitus has been assumed to be around 20–40% among noise exposed workers (Axelsson et al. 2000), and is generally found to be higher among subjects reporting noise exposure (Shargorodsky et al. 2010). A large study from Norway, which analysed data on bothersome tinnitus from the late 90s among subjects aged 20–101 years, showed that men who held known noise exposed occupations (e.g. miners and military officers) had a high prevalence ratio of tinnitus, while laboratory assistant was the occupation among women which showed the highest prevalence ratio (Engdahl et al. 2012).

Although prevalence of tinnitus is high, a lower percentage develop severe or debilitating tinnitus. For example, in a study in the general Swedish population, only 5–8% of those reporting that tinnitus occurred "sometimes" or more often, also reported severe tinnitus (Hasson et al. 2010). Thus, distinguishing between the occurrence and severity of tinnitus is important. Tinnitus severity has been suggested to be related to depression and anxiety and may come with great consequences for the individual, including sick-leave (Holgers et al. 2000), and sleep difficulties (Tyler et al. 1983).

HYPERACUSIS

Hyperacusis, which causes sounds at even low to moderate levels to be perceived as very loud or even painful, has been studied to a lesser degree than tinnitus, and the studies are often performed among subjects with tinnitus. Perhaps this is why similar mechanisms have been suggested for the two symptoms (Pienkowski et al. 2014, Tyler et al. 2014, Jastreboff et al. 2015). Other forms of loudness disorder includes misophonia and phonophobia, which, unlike hyperacusis, are characterised by strong emotional reactions and fear response to specific sounds (Jastreboff et al. 2015).

The understanding of mechanisms relating to hyperacusis is limited. One hypothesised mechanism describes hyperacusis as a perceptual outcome of neural hyperactivity or an increased gain in the central auditory pathways resulting from neural plasticity and adaptation to a loss of peripheral input (Knipper et al. 2013, Pienkowski et al. 2014). There has also been suggested that dysfuntion in the efferent auditory pathway, which modulates auditory gain, could result in hyperacusis (Jastreboff et al. 1993). Although research is limited, noise exposure has been suggested as a likely cause of hyperacusis (Axelsson et al. 1987, Anari et al. 1999, Aazh et al. 2014, Tyler et al. 2014). A study has also showed that a large proportion of a selected group of hyperacusis patients in an Ear, nose an throat clinic, had anxiety disorders, such as social phobia (Jüris et al. 2013). As noted in a review, it is possible that the experience of hyperacusis may lead to anxiety and depression (Tyler et al. 2014). However, causality is yet to be determined.

The prevalence of hyperacusis in the general population has been reported at 8–9% among subjects aged 16–79 years measured using the question "Do you consider yourself to be sensitive to everyday sounds?" and the response "yes", while the prevalence was much higher for responding "sometimes" (37–42%) (Andersson et al. 2002). Another study including subjects 18–79 years reported a prevalence of 12% among women and 6% among men with affirmative responses to the question "Do you have a hard time tolerating everyday sounds that you believe most other people can tolerate?" (Paulin et al. 2016). There are also longer questionnaires used to assess attentional, social, and emotional consequences of hyperacusis (Khalfa et al. 2002). As indicated in a review, both the definition of hyperacusis and the assessment differs greatly among studies (Pienkowski et al. 2014).

An attempt to classify clinical hyperacusis has been made in an early study by Goldstein & Shulman (1996). The researchers suggested the use of uncomfortable loudness levels (ULL) to assess hyperacusis, which is a test that determines the lowest sound level judged to be uncomfortably load by the listener. ULLs of 70 dB HL or lower has been proposed as a diagnostic criterion for hyperacusis (Anari et al. 1999), compared to about 100 dB HL among subjects without hyperacusis (Sherlock et al. 2005). However, a study among hyperacusis patients has showed that 90% sensitivity of ULL at about 100 dB HL results in low specificity, and the study concluded that it might be difficult to derive a diagnostic criteria based only on this test (Sheldrake et al. 2015).

SOUND-INDUCED AUDITORY FATIGUE

A less studied outcome is a symptom we have termed "sound-induced auditory fatigue". Previous research among preschool personnel reported a prevalence of the symptom, which was then referred to as "hearing fatigue", at 54% assessed using the question "Are you during or after work experiencing sound fatigue (Swe. "ljudtrötthet")"? (Persson Waye et al. 2010). In another study among 101 preschool personnel the prevalence of a similar symptom referred to as "sound fatigue" was 30% assessed by the question "In what degree do you experience sound fatigue?" and responses "every day except weekends", "a few times each week" or "every day" (Sjödin et al. 2012). Interestingly, in the former study, hearing fatigue was found to relate to hyperacusis and tinnitus in a factor analysis (Persson Waye et al. 2010). Both studies have found significant correlations with noise annoyance.

It is our experience that, when preschool teachers are asked about how they perceive hearing fatigue, they respond that they have a feeling of fatigue in the ear and report a pronounced need for silence after work. We have developed the terminology from "hearing fatigue" to "sound-induced auditory fatigue" mainly because the former does not reflect that the questionnaire item used to assess the symptom explicitly asks about a reaction to sounds. Moreover, the term also marks a relationship with hearing, which we assumed important based on our previous studies as well as the studies included in this thesis. This aspect is not captured in the term "sound fatigue" used by Sjödin et al (2012). Moreover, as we have used a slightly different questionnaire item than Sjödin et al., we found it necessary to separate the two outcomes.

We hypothesise, however, that the symptom is not merely an auditory consequence of the sound energy or noise exposure, such as that seen in temporary threshold shifts, but rather that it can also be a consequence of the demanding listening situation in a communication-intense sound environment. As such, it may possibly also relate to, or be a consequence of, effortful listening (Zekveld et al. 2011, McGarrigle et al. 2014). However, more research is still needed to fully understand mechanisms and causes as well as to explore the possibility of physiological dysfunctions relating to this symptom. Furthermore, we need to develop our understanding of the consequences for the affected individual. For example, anecdotal evidence from preschool teachers explain how they express an urgent need for silence after a day at work, which may conflict with other family members and with social life.

Summary of introduction

Noise can be defined as disturbing or loud sounds. The latter, combined with exposure duration, is usually used as determinants for the risk of hearing disorder. Most research on noise exposure and effects on hearing has been performed among industrial workers, most of whom are men. In contrast, female-dominated human service occupations, such as preschool teachers and obstetrical personnel, have been studied to much lesser extent. Noise in these occupations can be described as communication-intense, as high sound levels relate largely to multi-talker speech communication.

A workplace inspection at an obstetrical ward in Sweden has indicated that very high maximum sound levels may occur, predominantly due to mothers screaming during labour. However, there is a lack of research on the potential effects on hearing among obstetrical personnel. Equivalent sound levels in preschools has been reported around 80 dBA in numerous studies, but higher sound levels occur frequently. Preschool personnel have generally been found to have pure-tone hearing thresholds within the normal range, but hearing-related symptoms such as tinnitus and hyperacusis are commonly reported by the personnel. There is a lack of studies comparing symptom occurrence in this group to symptom occurrence in the general population.

Recent, mainly experimental, research suggest that noise exposure may cause hearing disorder that is not detected using standard clinical hearing tests such as pure-tone audiometry. The disorder may, however, explain the experience of hearing-related symptoms such as tinnitus, hyperacusis and difficulty perceiving speech. Furthermore, stress has been shown to be associated to hearing-related symptoms. Stressful working conditions are common in human service occupations, with emotional demands playing a prominent role.

Thus, communication-intense occupational noise and stressful working conditions are important work-related exposures in obstetrical care and in preschools and they could be hypothesised as risk factors of hearing-related symptoms among exposed personnel. The purpose of this thesis is to study that hypothesis and to address the lack of research within female-dominated occupations.

Aim

The overall aim of the thesis is to study the occurrence and risk of hearing-related symptoms in relation to occupational noise exposure and stressful working conditions among women working in communication-intense, human service occupations.

The specific aims for each of the four papers were:

Paper I	To evaluate sound levels at a labour ward and to analyse the effect of occupational noise exposure, noise annoyance and stressful working conditions on hearing-related symptoms among obstetrical personnel, as well as possible interaction effects between noise exposure, noise annoyance and stressful working conditions.
Paper II	To assess the diagnostic validity of questionnaire items corresponding to hearing-related symptoms in detecting clinically diagnosed mild and fairly mild hearing disorders among women working in communication-intense noise.
Paper III	To assess whether having worked in preschools increases the relative risk of hearing-related symptoms among women, and whether age, occupational noise exposure or stressful working conditions affect the level of risk.
Paper IV	To assess the hazard of adult-onset hyperacusis in relation to occupational noise exposure among women in general and among women working in preschools in particular.

Methods

Overview

This thesis is based on four papers: Paper I and II on a study performed in 2011 within a general obstetrical ward, and Paper III and IV on a larger questionnaire survey performed in 2013 and 2014. This section begins with an overview of the four papers (table 2). Then, a discussion of the main methodological issues follows. Details on the methods can be found in Papers I–IV.

Table 2. Overview of papers.

Paper	I	II	III	IV
Study design	Cross-sectional study	Validation study	Cohort study (baseline and retrospective)	Cohort study (retrospective)
Study population	Personnel at a general obstetrical ward (n 115), all women, ages 22 – 65	Women with (n 26) and without (n 29) specific hearing-related symptoms (from Paper I), ages 22 – 63	Preschool teachers (n 4,718) and population controls (n 4,122), all women, ages 24 – 65	Preschool teachers (n 4,566) and population controls (n 3,762), ages 24 – 65
Data collection method	Questionnaire survey and noise level measurements	Questionnaire survey (Paper I) and standard clinical hearing tests	Questionnaire survey	Questionnaire survey and JEM
Main outcome measure, risk estimate and statistical method	Prevalence, odds ratio, and logistic regression	Sensitivity, specificity and predictive values	Prevalence, incidence rate, risk ratio, incidence rate ratio and binomial regression	Incidence rate, hazard ratio and survival analysis

Study design

All four papers are based on observational studies, which are appropriate when it would be unethical to expose a person to a potential cause of disease (e.g. noise) (Rothman et al. 2008). Each design will be discussed briefly in relation to the limitations most relevant for this thesis.

For the purpose of Paper I, a cross-sectional study was performed in which a representative sample of the study population (i.e. obstetrical personnel) were selected without regard to exposure or disease status. One limitation in this design was in the difficulty determining the time order of events. Another limitation of a cross-sectional design, particularly when preformed within an occupational setting, is potential bias from the so-called healthy-worker effect. This effect may bias the result if the outcome causes subjects to leave the occupation, causing a larger proportion of healthy exposed subjects to remain, which may underestimate the risk of exposure. Moreover, if data on exposure and outcome are collected at the same time using the same method (e.g. questionnaire survey), bias may arise from the so-called common-method variance such that the association between measured variables may be overestimated.

For the purpose of Paper II, a validation study was performed, which in design resembled the clinical epidemiological approach of studies of diagnostic and screening tests (Rothman et al. 2008). An important limitation in this design is that the validity depends on how typical, or representative, the subjects in the study population with symptoms are in relation to the population in which the test is intended to be used.

For the purpose of Papers III and IV, we initiated a larger cohort study in which we intended to measure prevalence (baseline, cross-sectional) and retrospectively reported incidence of hearing-related symptoms. A cohort study can either include prospective longitudinal follow-up, which may require many years of observation, or may include retrospective report of exposure or outcome. Retrospective report increases feasibility as subject do not have to be followed during a long period, but the approach shares the limitations of the cross-sectional design, in that data on exposure and outcome were collected at the same time. In addition, retrospective reports may suffer from recall bias, such that subjects with a disease or symptom recalls circumstances surrounding the onset (e.g. occupational exposure) differently than subjects who do not have the disease or symptom. In addition, recall may be difficult if extending too far back in time.

Study population

Papers I and II

STUDY CONTEXT

The research for Papers I and II was performed within a general obstetrical ward at the Sahlgrenska University Hospital in Gothenburg, Sweden. This obstetrical ward is the third largest in Sweden. At the time of the study in 2011, 160 personnel were employed at the ward, all were women. The general obstetrical ward has a labour ward, a post-partum ward and an outpatient care ward. Almost half of the personnel rotated between the three wards, while 40% worked only in the labour ward, and a smaller percentage (14%) worked only in the post-partum ward. About a third worked only night shifts, while the rest worked day and evening shifts. A majority worked 75–100% of full-time. Ten personnel worked each shift (seven midwives and three assistant nurses or other, such as nursing assistants).

PARTICIPANTS IN SOUND LEVEL MEASUREMENTS (PAPER I)

All ten personnel working in the labour ward during each shift measured were included. No exclusion criterion was imposed. Due to the high number of shifts measured, we assumed that the data were representative for all personnel in the labour ward. The analysis also showed that the average levels recorded did not differ significantly between different groups.

PARTICIPANTS IN QUESTIONNAIRE SURVEY (PAPER I)

All 160 personnel employed in the general obstetrical ward were invited to participate in the survey. No exclusion criterion was imposed, but personnel on leave of absence were less likely to participate as the information was sent via the work e-mail and distributed at the workplace. Health-care personnel from other wards (e.g. medical doctors called in for assessments) were not part of the source population and were thus not included in the study population.

The response rate was 72% (n 115) after two reminders. About half responded to a web survey (n 63) and the rest to a paper survey (n 52). Selected characteristics of the respondents are shown in table 3, and the number and proportion of participants in different age groups are shown in a subsequent section on page 34, figure 6.

PARTICIPANTS IN CLINICAL HEARING TESTS (PAPER II)

The study population for the clinical hearing tests was a sub-sample of the survey participants (figure 3). Participants were selected based on them having reported at least one of the following symptoms: hearing loss, poor hearing, tinnitus and hyperacusis, or not reporting either of these symptoms. Subjects reporting only difficulty perceiving did not meet the inclusion criteria, which limits the external validity (i.e. generalisability) of the results.

The selection of a sub-sample was necessary because of limitations on the number of participants it was feasible to measure within the project time. The sampling of subjects based on having reported certain symptoms was done so as to have a reasonable number of subjects with hearing test results indicating a hearing disorder. A fully randomised selection would likely have resulted in too few subjects diagnosed with a hearing disorder, which would reduce the power of the analysis. In the analysis, the sampling procedure was controlled for by using weighted calculations.

Table 3. Selected characteristics of participants in Paper I.

		Range	Mean (SD)	% (95% CI)
Age		22–65	45 (11)	
Years worked in obstetrical care		0.5–40	12 (11)	
Years worked at this ward		0.5–39	9 (9)	
Professional groups:	**Midwife**			68 (58–76)
	Assistant nurse			25 (18–34)
	Other			7 (4–14)

CI: confidence interval, SD: Standard deviation

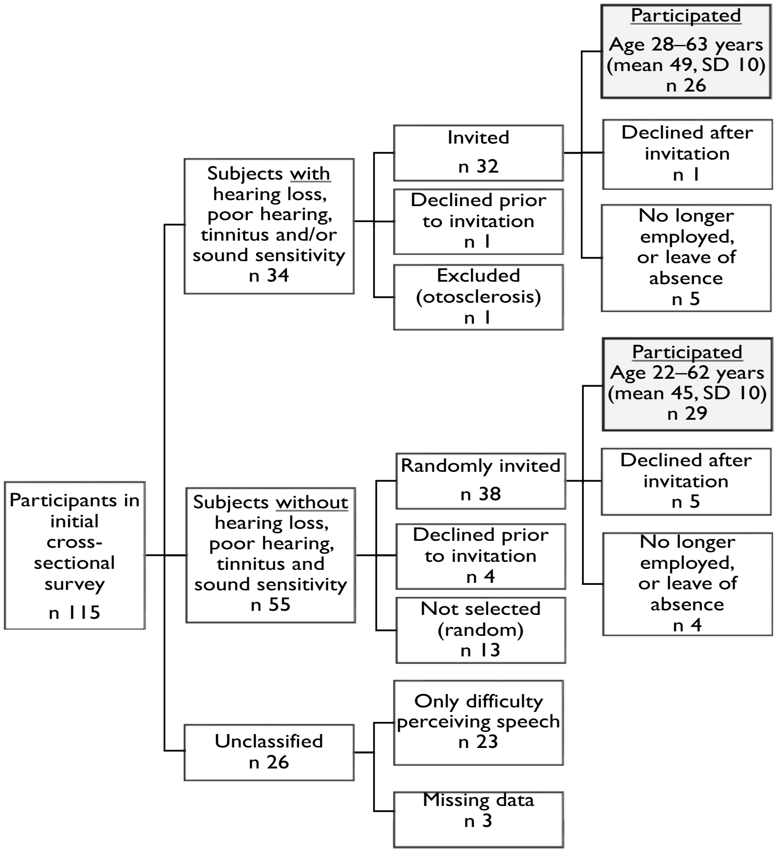


Figure 3. Flow chart illustrating the selection of study participants for Paper II

Papers III and IV

STUDY CONTEXT

Papers III and IV report on data from a newly initiated cohort study, which included women sampled from two source populations: preschool teachers and the general population. Because the majority of preschool teachers in Sweden are women (about 96% according to official statistics), we chose to include only women in the population cohort and analysed only female preschool teachers due to the small sample of male preschool teachers.

THE PRESCHOOL TEACHER AND POPULATION CONTROL COHORTS

The preschool cohort was selected based on records of preschool teachers' degrees issued between 1980 and 2012 from universities in Västra Götaland County of Sweden (University of Gothenburg, University of Borås, University of Skövde and University West). In total, 11850 subjects were found in the records. Postal addresses for 11276 were available in the Swedish Tax Agency Register, and 44 surveys were returned by the postal office because the subject had moved or died. Thus, 11232 subjects with preschool teachers' degree received the questionnaire. The response rate was 51% (n 5687) in the preschool cohort. Only n 168 men responded, and they were excluded from the analysis. The final study sample in the preschool cohort was n 4718, and a subsample of currently working women n 3277.

The population control cohort was randomly selected from the Swedish Tax Agency Register. Women born between 1943 and 1989 (24–70 years old at the time of the study) were included. We sampled from Västra Götaland County in order to have a control cohort representative of the preschool cohort, which was assumed to reside mainly in the same region. This was later confirmed by assessing the postal addresses for the responding group of preschool teachers. We aimed for equal number of respondents in each cohort. Thus, we initially selected 15000 random women as the response rate was assumed to be lower among controls. A number of the women (n 266) were already included in the preschool cohort, and were therefore excluded from the control cohort. Out of the 14734 questionnaires sent out, 210 were returned because the subjects had moved or died. Thus, 14524 controls received the questionnaire. The response rate was 38% (n 5480) in the population control cohort. The final study sample in the control cohort was n 4122, and a subsample of currently working women n 2844.

The data collection and selected characteristics of study populations for Papers III and IV are detailed in figures 4, 5 and 6, and tables 4 and 5.

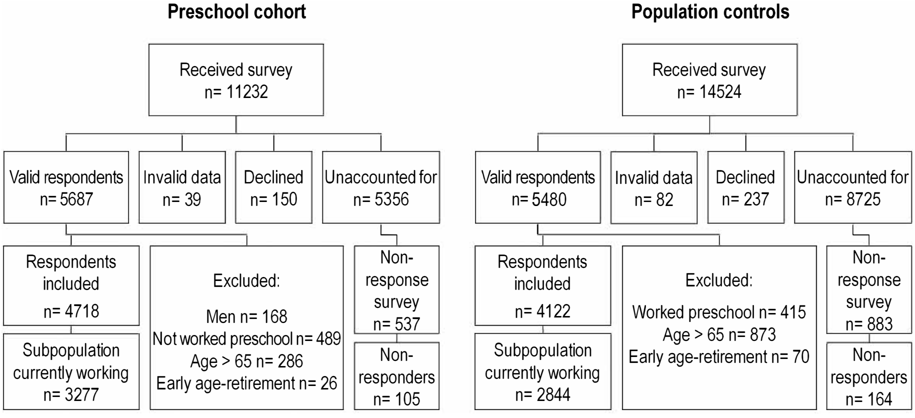


Figure 4. Flow chart illustrating the selection of study participants for Paper III.

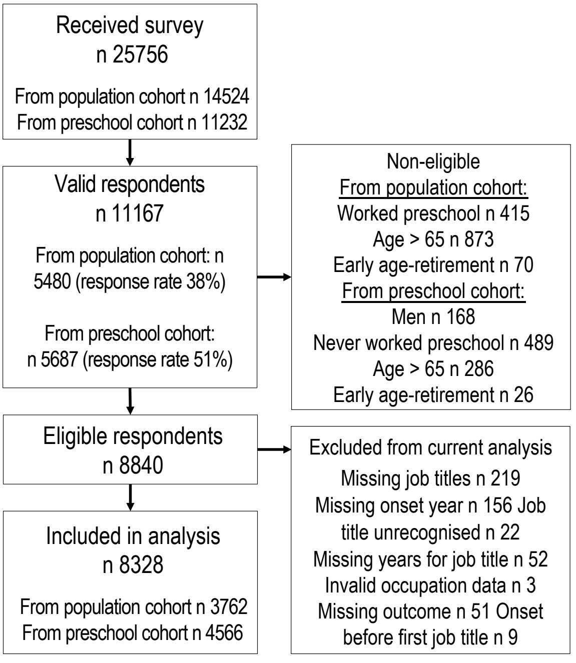
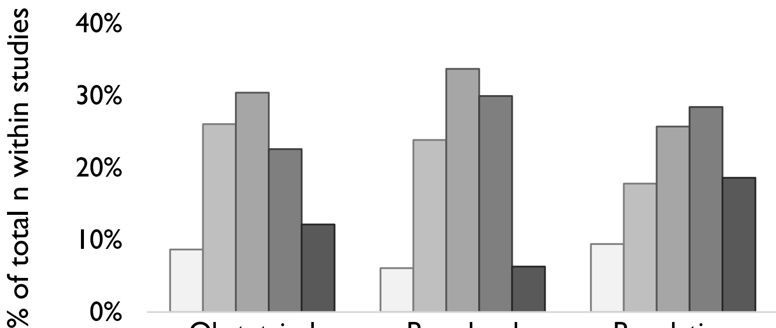


Figure 5. Flow chart illustrating the selection of study participants for Paper IV.



N within studies	Obstetrical personnel (Paper I)	Preschool cohort (Paper III)	Population controls (Paper III)
20–29	10	289	389
30–39	30	1126	734
40–49	35	1591	1060
50–59	26	1413	1172
60–65	14	299	767
Total	115	4718	4122

Figure 6. Number and proportion of subjects per age category in Paper I and Paper III.

Table 4. Selected characteristics of participants in Paper III.

	Preschool cohort		**Population controls**	
	Range, median (IQR)	**% (95% CI)**	**Range, median (IQR)**	**% (95% CI)**
Age*	24–65, 45 (38–53)	-	24–65, 48 (39–57)	-
Currently working		90 (90–91)		80 (79–82)
University education, ≥3 yrs.		100 (NA)		54 (52–55)
Family monthly income, ≥ 30 000 SEK		82 (81–83)		72 (70–73)

CI: confidence interval, IQR: Inter-quartile range, NA: Not applicable, SEK: Swedish krona
* Mean age preschool cohort 45 years (SD 10), population controls 47 years (SD 12).

Table 5. Selected characteristics of participants in Paper IV.

	Range	Median (IQR)	%
Initially population control cohort			45
Initially preschool cohort			55
Follow-up period (calendar year)	1961–2014		
Age*	24–65	47 (38–55)	
University education, ≥3 yrs.			80
Family monthly income, ≥ 30 000 SEK			79

CI: confidence interval, SD: Standard deviation, SEK: Swedish krona
* Mean age 46 years (SD 11).

Data collection method

Sound level measurements (Paper I)

For the purpose of Paper I, we collected sound level measurements at the labour ward in May and June 2011. Practical restrictions prohibited measurements in all three wards. Because the highest sound levels, with the greatest risk for hearing damage, were expected to occur in the delivery rooms due to mothers screaming during childbirth, the labour ward was chosen over the post-partum and outpatient ward. This limits the generalisability to labour wards.

We measured 62 full work-shifts, using ten dosimeters per shift – one for each person working that shift. Day and evening shifts were measured during separate periods due to overlapping hours. Table 6 gives an overview of the number of sound level measurements performed and evaluated. During some shifts, fewer than ten dosimeters were used. Two likely reasons are that batteries had not been charged and that some measurements were excluded later due to technical errors. Another reason may be loss of commitment by the personnel, as fewer dosimeter were being used at the end of the measurement period, or lack of time to engage in the measurements.

Personal dosimeters Larson Davis 705+ were used. They were calibrated using the software Blaze V.5.06 before measurements began and programmed to measure A-weighted equivalent and maximum (fast) levels with a sampling interval of 30 seconds. A work environment engineer at the Occupational Health Care unit retrieved the data every fifth day, reviewed all the measurements and excluded data with obvious technical errors.

The personnel were instructed on the handling of dosimeters (e.g. performing daily battery change, placement of the microphone on the shoulder, and taking care not to bump or hit the microphone and cause impact noise). The microphone should have ideally been in upright position a few centimetres above the shoulder. However, from experience we knew that placing a microphone in this position could be difficult in the field. Personnel were also instructed to document their work activities during the measured shifts, in a written time-log.

Table 6. Overview of sound level measurements at the labour ward (Paper I).

Period	**Work shifts**		**Median number of dosimeters used per shift (range)**	**Dosimeter measurements assessed per shift, n**
	Shift type (n)	**Shift hours (length)**		
19th to 31st of May	Evening (13)	13:45–21:00 (7 h 15 m)	10 (9–10)	127
	Night (13)	21:00–07:00 (10 h)	10 (9–10)	127
4th to 22nd of June	Day (19)	07:00–15:30 (8 h 30 m)	8 (3–10)	139*
	Night (17)	21:00–07:00 (10 h)	8 (5–10)	136*

* Three measurements were excluded before the assessment due to invalid data. This was in addition to the initial exclusion of erroneous data done by the work environment engineer: day shift n 1, nightshift n 2.

Questionnaire surveys (Papers I–IV)

SURVEY PROCEDURE PAPERS I–II

For the purpose of Papers I and II, a web and paper questionnaire survey was conducted in November 2011. Three reminders were sent.

Initially, a link to a web questionnaire was e-mailed to the study population. The e-mail addresses were collected with the help of a coordinator nurse and the head of the ward. Two reminders were sent out to non-responders via e-mail. One individual did not receive the e-mails because we were given the wrong e-mail address. Then non-responders received a third reminder at their workplace, which included a paper questionnaire. One individual started the web survey, but did not finish it.

The questionnaire items and response alternatives were identical in the web and paper surveys. The web survey method was tested with the intent of giving respondents easy access to the survey, and thus potentially increasing the response rate. Data from the web survey and the paper survey were pooled in the analysis presented in Paper I, as there were no statistical differences found after comparing the explanatory and outcome variables from the surveys ($p>0.05$), using independent sample t-test for continuous variables and Pearson Chi-Square for binary variables.

SURVEY PROCEDURE PAPERS III–IV

For the purpose of Papers III and IV, a postal questionnaire survey was conducted between October 2013 and July 2014. Two reminders were sent.

The questionnaire had been evaluated in face-to-face interviews using the think-aloud method with verbal probe questions (Willis 2005), prior to data collection. The method allows for understanding how respondents react to items and response alternatives, and their recall strategies. Five (one male) of the interviewees worked in preschool, but were not included in the preschool cohort (25–56 years old, mean 38 years). Five (one male) additional interviewees, representing controls, had experience in other occupations (21–58 years old, mean 35 years). The participants in think-aloud interviews received a movie ticket for taking part. After minor corrections and clarifications based on the results from the interviews, the questionnaire was deemed suitable for data collection.

QUESTIONNAIRE ITEMS ASSESSING HEARING-RELATED SYMPTOMS

The hearing-related symptoms hearing loss, tinnitus, hyperacusis, difficulty perceiving speech and sound-induced auditory fatigue were assessed in Papers I, II and III. Paper IV assess only hyperacusis. Paper I also assess a symptom termed poor hearing and also reporting any of the above mentioned symptoms (i.e. one or more symptom).

Hearing loss was defined by a "yes" response to the question: "Do you have a hearing loss?" Difficulty perceiving speech was defined by "yes" responses to the questions: "Do you at work have difficulty perceiving speech in an environment where several people are speaking at the same time?" and "Do you in leisure time have difficulty perceiving speech in an environment where several people are speaking at the same time?". Tinnitus, hyperacusis and sound-induced auditory fatigue were defined by responses "sometime each week" or more often to the questions: "Do you have tinnitus (a ringing, whistling or other sound without an external source), lasting for more than five minutes each time?", "Are you sound-sensitive (feel discomfort or pain by everyday sounds)?" and "Do you during or after work experience sound-fatigue?". In the survey used for Papers I and II, the items assessing tinnitus, hyperacusis and sound-induced auditory fatigue were included in a matrix with other symptoms (e.g. headache), and the explanation of tinnitus was not included in the questionnaire. In the survey in Paper III, only sound-induced auditory fatigue was included in the matrix. The other symptoms were asked separately. Poor hearing included in Paper I was defined by responses ""bad" or "very bad" to the question: "How do you think your hearing is?". Paper III also included assessment of symptom onset by retrospectively report for hearing loss, tinnitus, hyperacusis and difficulty perceiving speech. Year or age was asked for and reported in free text to the question "When did you first notice [symptom]?". Paper IV assessed only onset of hyperacusis.

The questionnaire items were developed based on our previous studies and other published studies (Nondahl et al. 1998, Sindhusake et al. 2001, Persson Waye et al. 2010, Persson Waye et al. 2010). The items assessing symptom onset was developed based on questionnaires used to assess asthma (Torén et al. 2006). In order to measure symptom prevalence, the response scales generally focused on how frequent symptoms were experienced. However, the items assessing hearing loss and difficulty perceiving speech had the response alternatives yes/no/don't know and yes/no, respectively, similar to our previous studies.

QUESTIONNAIRE ITEMS ASSESSING OCCUPATIONAL NOISE EXPOSURE

Two questionnaire items assessing self-reported current occupational noise were used in the surveys reported in Papers I and III. Noise exposure was generally defined by a report of "about 25% of time at work" or more to the questions: "How often is the sound level at your workplace so loud that you have to raise your own voice to be able to talk to other people?" and "Is the sound level at your workplace sometimes so loud that you have difficulty hearing what other people are saying?". In Paper III, we also assessed affirmative responses to the question "Have you ever changed jobs or workplace due to noise at work?".

In Paper I, we used several questionnaire items including the two exposure items detailed above, to construct an occupational noise exposure index for assessing accumulating dose. Paper III assessed current exposure by responses "25% of the work time" or more often to either one or both of the two items detailed above. In Paper IV, we instead used a JEM to assess noise exposure.

CALCULATED OCCUPATIONAL NOISE INDEX

The occupational noise exposure index, which was used in Paper I, included 6 items. The included items were as follows: two items assessing current exposure to loud noise (detailed above), one item assessing use of hearing protection at work, one item reflecting cumulative exposure (number of years worked in obstetrical care) and one categorical variable reflecting the proportion of working time spent in the labour ward versus the post-partum ward. Finally, we included one item number of years worked with the Alternative Birth Care (ABC) method. These items were selected based on a priori assumptions of face validity (i.e. including items relating to the degree of occupational noise exposure). A post hoc principle component analysis was conducted on the six items with Varimax rotation and extraction of components with eigenvalues >1. As shown in table 7, the index could be described by three factors.

It is possible that the noise index underestimate the total exposure history by not including previous occupations with noise exposure. Fifteen subjects had started working in obstetrical after the age of 40, which indicate possible previous exposure for some subjects. Furthermore, anecdotal evidence indicated that subjects who worked during the 1990s, when the so-called ABC-method was in common practice, may have been exposed to higher sound levels in the delivery rooms because of non-use of analgesics. Including this variable may have introduced bias, as we had no means of assessing the impact of such practices on the level of exposure and may have overestimated the exposure among those who reported to have worked with the ABC-method. However, only a few subjects were given additions to the index by this variable (n 18, reporting 1–10 years, mean years 4, SD 3). Thus, it should have only minor effects on the overall exposure assessment. Furthermore, we included a variable relating to the extent of time working in the labour ward only, partly or not at all. This was based on the high maximum sound levels measured in the delivery rooms, which was assumed not to occur in the post-partum ward. The latter was confirmed by reports from the personnel. Thus, subjects working only or partly in the labour ward (40% and 46%, respectively) received slightly higher noise index compared to those who worked only in post-partum care (14%). Use of hearing protection was also included to correct for potential attenuation of the exposure. Overall, the number of years worked within the obstetric care made the largest impact on the exposure assessment. (the range of years worked was 0.5–40 years and the range of the noise index was 4.5–64), as shown in figure 10 in the results and discussion chapter on page 63.

Table 7. Principal component analysis of items included in occupational noise index.

Variables	**Rotated factor loadings***		
	1	**2**	**3**
Exposed to loud noise, have to raise own voice	0.96		
No. of years in obstetrical care	-0.77	0.47	
No. years worked with ABC-method		0.93	
Proportion of time in labour ward vs. post-partum ward		-0.79	
Use of hearing protection at work **			-0.92
Exposed to loud noise, difficult to hear conversation	0.64		0.71

* Showing only factor loadings >0.40. A fixed extraction of 1 factor revealed loadings >0.5 for all items.
** The item hearing protection was reversed in the index.

QUESTIONNAIRE ITEM ASSESSING NOISE ANNOYANCE

Noise annoyance was defined by the responses "rather", "very" or "extremely" to the question: "Are you annoyed by sounds/noise at your work place?". The item was adapted to be suitable for an occupational setting from the standard ISO/TS 15666 used in studies of annoyance from environmental noise. A similar item was also included in the survey of the preschool and population control cohorts, but was not analysed in Paper III. It is, however, reported in the thesis.

QUESTIONNAIRE ITEMS ASSESSING STRESSFUL WORKING CONDITIONS

In Paper I, we analysed stressful working conditions by assessing two items representing a measure of work-related stress, thus the effects of stressful working conditions, rather than the working conditions themselves. Work-related stress was defined by responses "often" or "always/almost always" to the items: "I experience a high degree of stress" and "I feel unwell due to stress at work". These items have previously been used in noise research (Ryberg et al. 2007).

In Paper III, stressful working conditions were assessed using the Effort-Reward Imbalance (ERI) model (Siegrist et al. 2004), and the emotional demands subscale from the Copenhagen Psychosocial Questionnaire (COPSOQ), which was based on the two-item short questionnaire (Kristensen et al. 2005). The emotional demands subscale was used in a Swedish version from 2003. The longer Swedish version has been validated (Berthelsen et al. 2013). For ERI, the short version questionnaire was used (ERI-S) including 3 items in the effort subscale and 7 items in the reward subscale, which has been validated in Swedish (Leineweber et al. 2010). A standard procedure was used to calculate the ERI ratio by dividing the sum score of the effort subscale by the sum score of the reward subscale with a correction factor for the difference in number of items in the subscales: $\sum e/(\sum r*0.42857)$ (Siegrist et al. 2004). A ratio above 1 was defined as imbalance and thus representing stressful working conditions. Scale reliability was acceptable, with Cronbach's alpha of 0.791 for the effort subscale, and 0.731 for the reward subscale. Responses from COPSOQ emotional demand items were combined and dichotomised such that responses of "often" or "always" on both items were defined as excessive emotional demands contrary to responses of "sometimes" or "never/rarely" on either or both items. Scale reliability was acceptable, with Cronbach's alpha of 0.779.

Job-Exposure Matrix for Occupational Noise (Paper IV)

In using JEM for occupational noise (Sjöström et al. 2013) in Paper IV, exposure was assessed for each occupation held for more than six months throughout the working-life, as reported in the questionnaire. Job titles were initially assigned a 5-digit occupational code according to the Nordic Occupational Classification system from 1983 and used in the Swedish census in 1985. Two research assistants and one occupational hygienist coded the occupational history in collaboration with the author. Each occupational description occurring in the raw data was coded only once, and later transferred to individual records. Job content and titles were used to assign occupational codes without regards to or assuming noise exposure levels. However, in 40 instances, where more than one occupational code could fit the job description equally well, the occupational code with the highest exposure was chosen. This small number of instances should not influence the overall result much by overestimating of exposure. However, misclassification in both directions (i.e. individuals receiving higher or lower exposure than the true exposure) is possible when using the JEM in combination with reported job titles. One important aspect relating to our data is that the JEM assigns exposure level from sound level measurements only when those were available, which is less common in female-dominated occupations. In other cases expert judgement is used. Importantly, the coding of job titles, and hence of exposure assessment, was done blinded to the outcome.

Each occupation reported for each individual in our data was matched to the noise level intervals provided by the JEM. For some job families, such as cleaners, the noise exposure interval assigned by the JEM differs depending on calendar year (e.g. higher exposure during earlier 5-year periods than later). Thus, the reported years in these job families were considered when assigning noise level intervals to individual occupational records.

The analysis reflects two aspects of noise exposure. Primarily, we assessed the occupation, and thus the exposure, at the year when hyperacusis onset was reported, or, if hyperacusis was not reported, the occupation held at the survey year. This was the main exposure variable, which categorised each subjects into one of the four exposure groups based on the three noise intervals in the JEM and with preschool teachers as a separate fourth occupational category. Preschool teachers are assigned to the equivalent sound level interval 75–85 dBA by the JEM. Secondly, occupational exposures preceding onset of hyperacusis, or the occupation held at the year of the survey if hyperacusis was not reported, were assessed based on the full occupational history for each individual. This variable was analysed as a repeated time-varying variable using the shared frailty in the survival model (see further in the section on statistical analysis). The effect of prior exposure was hypothesised based on the notion of an accumulating effect of noise exposure on the risk of adult-onset hyperacusis. The initial analysis, without the use of shared frailty due to prior exposure, showed that the data had significant heterogeneity in the survival time assessed by the theta. Such heterogeneity may underestimate the individual hazard if a standard cox regression model is used, which assesses the population hazard instead of the individual hazard. Thus, the availability of longitudinal occupational exposure for all held occupations is a major strength in our analysis. However, a limitation is that we did not include as measure of impulse exposure. The choice not to include it was based on the information that many female-dominated occupations had low validity in the assessment of impulsiveness (Sjöström, personal communication, January 2018).

In our analysis, we were able to assign exposure categories based on the occupation held at the year of symptom onset. This is a strength, as current exposure (i.e. at time of survey) may differ from the exposure at the time of onset. However, a limitation is the uncertainty about the exact year of onset, as this was reported retrospectively.

Clinical hearing tests (Paper II)

The standard clinical hearing tests for Paper II, were conducted during February through to April 2012. The tests were performed by a licensed audiologist (the author), and two occupational health care nurses trained for the project. The participants were informed that they should not be exposed to high sound levels for 16 hours prior to testing.

BACKGROUND NOISE LEVELS IN THE TEST ROOM

All the hearing tests were performed in a quiet room at the obstetrical ward. The A-weighted equivalent sound level measured over 6 hours in the empty test room was 30 dB. Measurement was done using the stationary sound level meter Brüel & Kjaer 2260, with the microphone placed at the position of the test subjects head. Intermittent loud sounds were detected in the frequency range 0.25–1.6 kHz in 1/3 octave maximum level ($_{LFmax}$) 1–9 dBA higher than recommended levels for performing pure tone audiometry (ISO 8253-1, 1994), but only for short intervals, at most during three connected 30-second logs. Measurement of hearing thresholds was not conducted when the operator heard intermittent loud sounds.

HEARING TESTS AND DIAGNOSTIC CUT OFFS

Otoscopy was performed to avoid effects of cerumen. If cerumen was present, participants were rescheduled for a test after having had cerumen removed. The hearing assessment included three standard hearing tests: pure-tone audiometry, distortion product otoacoustic emission (DPOAE) and Hearing in Noise Test (HINT), and middle ear status was also assessed by tympanometry.

Otometrics MADSEN OTOflex 100 was used for tympanometry. For pure-tone audiometry and HINT, a Grason-Stadler GSI 61 was used with a DVD-player connected to the audiometer. As a precaution against background noise affecting the test results, dampening insert earphones were used for DPOAE and Sennheiser HDA200 circumaural headphones were used for pure-tone audiometry and HINT. Audiometer calibration was done according to international standards (ISO 389-8, 2004) because HDA200 was used. DPOAE was measured using custom equipment. Technical specifications have been presented in published Paper II.

We measured air-conduction pure-tone hearing thresholds at the standard audiometric frequencies 0.25, 0.5, 1, 2, 3, 4, 6 and 8 kHz. Masking of the opposite ear was not done. However, only one individual had measured thresholds ≥40 dB difference between each ear. HINT was measured binaurally using the Swedish version (Hällgren et al, 2006), with noise fixed at 65 dB SPL and the speech signal adaptively adjusted in 2 dB steps, starting at 0 dB signal-to-noise ratio (SNR). DPOAE was measured by generating two stimulus tones at 65 and 55 dB SPL (L1 and L2) with a frequency ratio (f2/f1) fixed at 1.23. DPOAE was registered as the cubic distortion product at the frequency calculated as 2f1-f2, from 32 sets of primary input tones with f2 ranging from 0.707–10.374 kHz.

Two cut-off values for failing each hearing test were used. Both were set with the intention of capturing a mild hearing disorder, and the strict cut-off more so ("mild disorder"), than the less strict one ("fairly mild disorder"). The less strict cut-off for each test was: one or more pure-tone thresholds at ≥40 dB HL in the

0.25–8 kHz range in either ear (labelled 40 dB HL), DPOAE SNR <3 dB in either one or both of the f2 range 2–3.9 kHz and 4–10 kHz in either ear (labelled 3 dB SNR) and HINT SNR >-3 dB (labelled -3 dB SNR). The strict cut-off for each test was: two or more pure tone thresholds ≥25 dB HL or one or more pure tone thresholds ≥30 dB HL in the 0.25–8 kHz range in either ear (labelled 25/30 dB HL), DPOAE SNR <6 dB in either one or both of the f2 ranges 2–3.9 kHz and 4–10 kHz in either ear (labelled 6 dB SNR) and HINT SNR >-4 dB (labelled -4 dB SNR).

The main reasons for choosing these test methods were the feasibility considering training of operators and the time constraints of the participants. There were also additional restraints' by availability of testing equipment. As the analysis required categorising subjects into two groups, cut-offs for each test was required. When choosing the cut-offs, we relied on experience from clinical assessment, such as the use of an SNR-based criteria for DPOAE. However, for pure-tone audiometry we could not use the common method of pure-tone averages because we had applied a screening level at 10 dB HL. For HINT, we considered the reference data presented for the Swedish test (Hällgren et al. 2006). However, as we used a slightly different method (e.g. binaural instead of monaural), we had to rely on common sense in choosing the cut-offs. Because the calculation of diagnostic performance rely heavily on the chosen cut-offs, the results should be interpreted with consideration to these cut-offs.

Main outcome measures, risk estimates and statistical methods

Here, the main outcome measures, risk estimates and statistical methods used in each paper are described in brief. Further details can be found in Papers I–IV.

The main outcome measure of symptom occurrence in Papers I and III was symptom prevalence. One limitation is that prevalence reflects both the duration of disease and the rate of disease onset (incidence rate). If the duration is long, such as for a chronic non-fatal disease, prevalence may be high even if the rate of disease onset is low. Symptom prevalence from Paper I was also used in the selection of participants in Paper II. In Paper III and IV, symptom occurrence was also assessed as retrospectively reported incidence rates, with onset reported to have occurred either after age 24 (Paper III) or after the first reported occupation (Paper IV) (i.e. adult-onset). This was done to focus on onset relating to occupational exposures, rather than on symptoms occurring due to hereditary factors or environmental factors during childhood.

The main risk estimate assessed in Paper I, was the odds ratios (OR) estimated in binary logistic regression models. We used a manual stepwise selection of variables in accordance with a predefined hypothesised order of importance. Thus, occupational noise was assessed first, then stress, then annoyance and, if variables in previous steps were significant, an interaction effect. Models were adjusted for smoking and leisure noise exposure if there was a considerable change in the estimated coefficient. Due to multi-collinearity between age and the occupational noise index, age was analysed in separate regression models.

In Paper II, the main purpose was to assess diagnostic performance by calculation of sensitivity, specificity and predictive values. Because of the method used in selecting participants, the calculations were weighted to reflect the underlying population. Approximate confidence intervals were computed using the percentile bootstrap method, because of the use of weighted calculations.

In Paper III, we assessed both the risk ratio (RR), which was estimated using log-binomial regression, and manually calculated incidence rate ratios (IRR). The log-binomial regression models were adjusted for age, socioeconomic status, smoking, current use of hearing protection at work and leisure noise, and we also assessed age-stratified RR. A sub-sample including only women currently working with data on current occupational exposure to noise and stress was assessed in log-binomial regression models by stratifying on exposure status. Models were adjusted for age, socioeconomic status, smoking, current use of hearing protection at work and leisure noise.

In Paper IV, we assessed hazard ratios (HR) estimated in frailty regression survival models. The final regression model was adjusted for the following variables measured at the year of survey: age, education, household income, family history of hearing loss, history of ear infection, smoking and reporting to have changed jobs due to noise. The best-fit model was chosen based on the Akaike's information criterion (AIC).

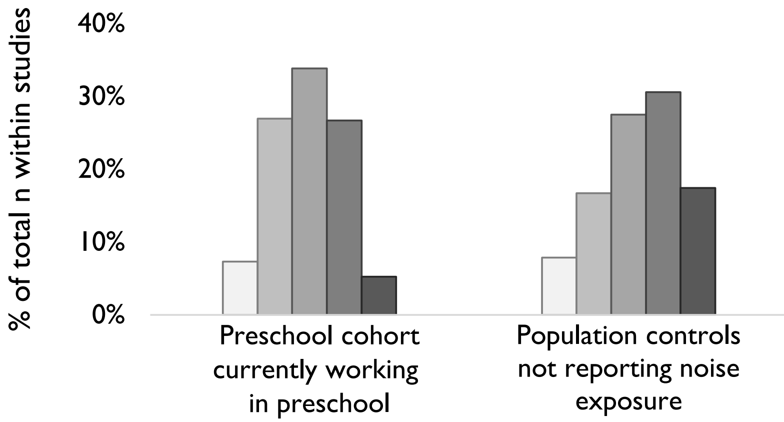
In addition, parametric and non-parametric tests of differences were used where applicable (e.g. to analyse differences in average sound levels, differences in proportion of subjects reporting noise exposure, or similar assessments of demographic variables).

In all statistical analysis, the a priori criterion for the probability of falsely rejecting the null hypothesis (the alpha level) was .05, unless stated otherwise. The statistical software used in Paper I and II was SPSS Statistics (IBM Corp. Version 20). In Paper II we also used SAS (Intel Corp. Version 9.3 and 9.4) and MatLab (The MathWorks, Inc.). In Paper III, we used SAS (Intel Corp. Version 9.4). In Paper IV, we used STATA (Stata Corp. Version 14).

Additional analysis

Symptom prevalence in Paper I and sub-populations from Paper III

An additional analysis presented in this thesis included sub-populations from the two cohorts presented in Paper III and the complete obstetrical personnel group presented in Paper I. From the preschool cohort, a sub-sample was selected including only women currently working in preschool when responding to the questionnaire survey (n 3525). From the population control cohort, a sub-sample was selected including only controls who did not report exposure to occupational noise when responding to the survey (n 2611). Currently not exposed to noise was defined by responses "never/almost never" to the question: "How often is the sound level at your workplace so loud that you have to raise your own voice to be able to talk to other people?". Because this item relate to the work environment, women in the control cohort who were not currently working (e.g. on leave of absence, sick leave or other reasons) were not included in this sub-sample of controls. The mean age of the sub-sample from the preschool cohort was 44 years (SD 10) range 24–65. The mean age of the sub-sample from the control cohort was 48 years (SD 11) range 24–65. Numbers and proportion by age groups of participants in these sub-populations are shown in figure 7. Additional analysis included crude estimates of RR. The analysis was performed using STATA (Stata Corp. Version 14).



N within studies	Preschool cohort currently working in preschool	Population controls not reporting noise exposure
20–29	258	205
30–39	950	436
40–49	1192	717
50–59	941	798
60–65	184	455
Total	3525	2611

Figure 7. Number and proportion per age category in the sub-sample analysed in additional analysis: preschool teachers working in preschool when responding to the survey and controls who did not report noise exposure.

Exploring mediating and moderating effects

A second additional analysis, which has been presented at the 12th ICBEN Congress in Zurich, Switzerland (Fredriksson et al. 2017), analysed the study population in Paper III (n 8840) described in previous sections.

The analysis included the previously described hearing-related symptoms (hearing loss, tinnitus, difficulty perceiving speech, hyperacusis and sound-induced auditory fatigue), as well as noise annoyance and stressful working-conditions (ERI and COPSOQ), as described for Paper III. In this analysis, ERI and COPSOQ were treated as separate variables. In addition, we assessed occupational noise exposure by calculation of a cumulative occupational noise exposure index, similar to the one used in Paper I. The main difference is that we have not included numbers of years at work. The index was derived from the questionnaire items described for Paper III.

The index included: key items assessing loud noise at work, use of hearing protection at work and ever having changed job due to noise, but also included questions on whether any acoustic interventions had been taken at the workplace or not (e.g. sound absorbents). In contrast to Paper III, the items assessing loud noise at work and hearing protection included responses both relating to the current workplace and to the work held five years earlier. A higher score on the noise index indicate a higher total exposure dose. Finally, we also assessed stress response using a scale measuring symptoms of long-lasting stress (LLS), which was adapted from Hasson et al (2011). The assessment of LLS included questionnaire items such as "experiencing heart palpitations without physical exertion", "feeling tense", "being stressed out".

Based on our hypothesised causal model shown in figure 8, we assessed whether noise annoyance, stressful working conditions (COPSOQ or ERI) or stress response (LLS) acted as mediators or moderators in the relationship between occupational noise exposure and hearing-related symptoms. We employed the causal steps approach to assess the mediation effect. This method, popularised by Baron and Kenny (1986), is widely used and have been described in detail by Preacher et al (2007). Each causal path was estimated and mediation was assessed only when evidence of a total effect in the association was found (i.e. significant effect of noise exposure on the hearing-related symptom). Bootstrapping method was used to produce unbiased standard errors and confidence intervals for examining the indirect, direct and total effects caused by the mediator. In parallel steps, noise annoyance, stressful-working conditions (COPSOQ or ERI) and stress response (LLS) were also assessed for moderating effect (i.e. interaction). To assess whether the interaction term was significant, a Wald test was used with a significant level of 5% to reject the null hypothesis (i.e. no interaction). The final adjusted model included moderators and mediators from previous steps as well as potential confounders following the forward stepwise approach. The following confounders were assessed: age, leisure noise exposure, hearing protection at work, smoking, socioeconomic status (education and household income) and employment status (currently working or not). The best-fit model was chosen based on the likelihood ratio test. Statistical analyses were performed using STATA (StataCorp. Version 14).

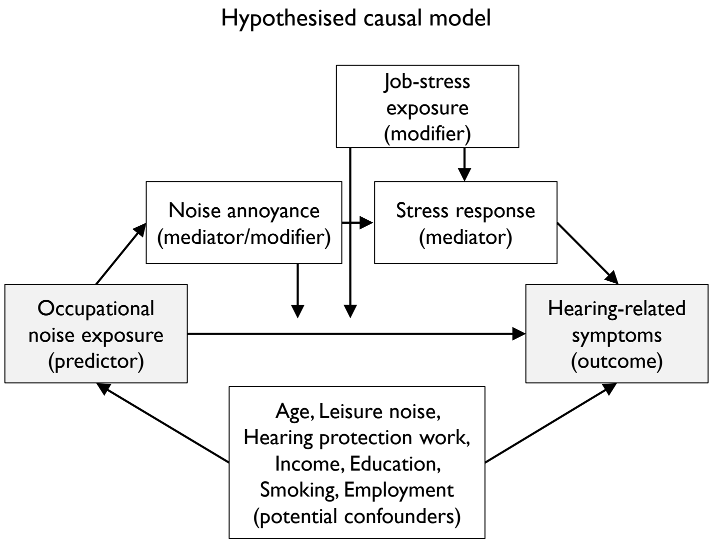


Figure 8. Hypothesised causal model for hearing-related symptoms in relation to occupational noise exposure, noise annoyance, stressful working conditions and stress response.

Ethical considerations

The Regional Ethics Board in Gothenburg approved the studies (reference numbers 788-11 and 060-13).

Information and consent

Detailed written information was sent to each subject. In addition, oral information was given to all personnel at the obstetrical ward (Papers I and II). In the study for Papers I and II, all the subjects gave their informed consent to participation when completing the survey and by signing up for hearing tests. Five individuals, who participated in the questionnaire study, asked not to be included in the selection of participants for hearing testing. In the study for Papers III and IV, participants received written information together with the postal questionnaire. They gave their consent by returning a completed questionnaire. Subjects could ask to have their personal data (personal identity number and postal address) removed from the database and to not receive reminders. All the participants were given the contact information of the researchers responsible for the studies (telephone, e-mail and postal address).

Confidentiality

Data has been anonymised using an individual identification number so it could not be traced to an individual. The number is stored together with personal information separate from the data collected. For the web survey reported in Paper I, data was stored in a secure Structured Query Language database encrypted according to AES256.

The results should not be possible to trace back to an individual because the data and results were reported on a group level. In reporting which groups we studied, we did not identify which obstetrical ward in which we had performed our study, though enough information may have been given that the ward would be easy to identify. Moreover, while we did publish an individual sound level measurement, we did not state at what day or time this was collected. Furthermore, while we stated that all subjects with a certain academic degree from certain universities issued during certain years were selected for the study reported in Papers III and IV, we did not include details for those who participated.

Retrieving personal information from registries

In the collection of the data reported in Papers III and IV, we had ethical approval for collecting personal numbers of preschool teachers from the universities and to select a random sample from the general population. In both cases, the subjects could not decline being sent the study information and questionnaire, unless they had protected identity. Thus, everyone was contacted at least once without having actively given prior consent.

The current addresses were retrieved a few weeks before the study information was sent out, which had the unfortunate consequence that some in the study population had died after their address had been retrieved from the tax registry. This may have caused distress among family and relatives.

Sound level measurements

After evaluating the sound levels at the workplace (Paper I), all personnel were given information about the results and potential risks of working in noise that exceeds the regulated action levels and exposure limits. Hearing protectors were made available to everyone through the occupational health care unit (after the survey was completed). In addition, the personnel and head of the ward were informed of the current regulations (AFS 2005:16) and the importance of risk assessment and systematic work environment surveillance.

Furthermore, the mothers who were admitted to the obstetrical ward during the period when sound level measurements were performed, and their partners, were informed in writing about the measurement when admitted to the ward. None of the measurements included recordings of sounds that could be listened to, and none of the measurements contained or could be connected to any personal information. However, as the mothers and their partners could not choose to go somewhere else to give birth, participation was not strictly voluntary.

Hearing tests

Five subjects were referred to the Occupational Health Care for further testing or were directly referred to the audiological clinic for assessment and follow-up. These subject had been identified with a hearing disorder which was deemed to require further medical evaluation or audiological rehabilitation. The disorders were identified through diagnostic test results, symptoms and anamnesis.

Questionnaires

Care was taken in preparing the questionnaires to avoid intrusive questions that might cause distress or invade subject's privacy. However, questions related to health may have such unfortunate effects and may be difficult to avoid completely. We made sure to assess these aspects during the cognitive interviews performed as validation.

Think-aloud interviews

The questionnaire used for Papers III and IV was evaluated and validated using cognitive interviews. The participants were recruited via fliers and contacted us if they wanted to participate. They received a movie ticket. This reimbursement was considered low enough not be an incentive causing involuntary consent, but high enough to be considered a reasonable compensation for the time spent.

Experimental animal studies

As noted in the discussion of study design, certain experiments are not considered ethical to perform on humans due to the potential health risks of the exposure. Often, such experiments are performed instead in “animal models”. This usually mean that animals are not only exposed to hazardous agents, but are also euthanized. I have struggled with the ethics of having to cite and refer to findings from such experiments.

Responsibility in dissemination of research findings

The university has a responsibility to share knowledge gained within research (Swe. “tredje uppgiften”), and so does state-financed researchers. In doing so, however, ethics should be considered in relation to how results and potential risks are communicated and explained. We want to stress the importance of our findings at a population level. However, consideration should be taken to how individuals might interpret the risk concerning themselves. This care is not always easy to balance in relation to demands for catchy headlines.

Results and Discussion

The main results relating to the aims of each paper are reported in this section and discussed in relation to methodological issues. Then, the results from the papers are combined and discussed in relation to the overall aim and some additional analyses.

Sound levels in the labour ward

In Paper I, we found that the equivalent level measured in the labour ward ranged from 56 to 87 dBA (mean 70.3, SD 6) and the maximum level with time weighting FAST ranged from 83 to 122 dBA (mean 106.3, SD 6). No significant differences were found between the different shifts or between professional groups.

As shown in table 8, we found that the lower action value for the equivalent level 80 dBA was reached or exceeded in 45% of the shifts and the exposure limit for equivalent level 85 dBA in 5% of the shifts. Because the measurements were taken during the full shift (7–10 hours), and equivalent levels were similar regardless of shift, we assume that the equivalent levels are comparable to the 8-hour daily exposure level in the occupational noise regulation (AFS 2005:16). In addition, the exposure limit for maximum level (L_{AFmax}) 115 dB was exceeded in almost a third of the shifts. Six instances were verified with high certainty, using written logs and time history graphs, to have occurred during a delivery and most likely due to screaming, as reported by the personnel. These six instances showed a particular pattern of repeatedly high sound levels lasting about 15 minutes, an example of which is shown in figure 9. Instances that occurred during other work tasks (e.g. cleaning) often had a single registered maximum level (L_{AFmax}) >115 dBA. Since we did not observe the measurements being taken, we cannot rule out that impact noise may have caused some of these instances.

The large number of measurements performed, which covered several weeks, provides a good representation of the sound levels in the labour ward. However, the exposure and risk assessment cannot directly be transferred to other wards within obstetrical care, such as the post-partum ward, where personnel are likely exposed to a lesser degree. Moreover, the exposure limit levels should be assessed in relation to the dampening effect of hearing protections. However, in the survey of the personnel, only 8% on the general obstetrical ward reported using hearing protection "always/almost always" or "sometimes" (table 9 next section). Thus, most personnel in the labour ward were likely exposed to the levels measured, and as such, at risk of hearing damage. However, because we have not estimated the exposure dose over many years, we cannot directly draw conclusions on the level of risk of hearing damage, but it should be noted that NIHL has been estimated to develop in about 3–15% among subjects exposure to these levels over a 40-year lifetime (Prince et al. 1997). In addition, particularly high sound levels may cause immediate damage. For example, a study has reported persistent tinnitus from exposure to impulse noise from gunfire (Metternich et al. 1999), and another study has reported tinnitus among subjects directly after attendance in nightclubs with loud music (Johnson et al. 2014). Although sound levels emitted from gunfire is likely higher than screaming in the obstetrical care, the risk of frequently and repeatedly being exposed to such high maximum sound levels should not be ignored. We chose to use the maximum A-weighted level with time weighting FAST to capture the high sound levels during labours. Impulsiveness is otherwise commonly measured as C-weighted instantaneous sound pressure level (Cpeak). However, because the peak represent the instantaneous level, it was assumed that it would not properly reflect the high sound levels of a scream. In addition, the Cpeak could also be more difficult to interpret due to the risk of impact noise. More research is needed to ascertain the possible risk of high sound levels from screaming as well as to ascertain which acoustic parameter best reflect this type of exposure.

We found few studies to which we could compare our measurements within the obstetrical care, but our results were similar to those from a work inspection performed within an obstetrical ward in Skövde, Sweden. The inspection found that the lower action value for equivalent levels 80 dBA was exceeded in 7% of the shifts measured and the exposure limit for maximum level (L_{AFmax}) 115 dBA was exceeded in 25% of the shifts (Tenenbaum et al. 2010). Thus, a similar proportion of maximum levels as found in our study. The reason for a higher proportion of shifts exceeding the equivalent levels in the Gothenburg study than in the Skövde study may be the larger size of the ward in Gothenburg, and thus possibly a busier ward with more communication-intense noise. The only published study found in refereed journals was one from India, which reported slightly lower equivalent levels compared to those in our study, ranging from 62 to 73 dBA (Vinodhkumaradithyaa et al. 2008). However, the measurements were only performed during one hour in the morning and one hour in the evening using a stationary sound level meter instead of dosimeters and the aim of that study was to assess the general sound levels in the hospital, not the exposure of the health care personnel. Moreover, dosimeter levels are usually higher compared to stationary sound level measurements, partly due to the contributions of own voice (Ryherd et al. 2008). We consider the contribution of own voice to the overall equivalent levels negligible in our measurements, partly because the overall level is high and partly because each individual is likely not speaking more than a fraction of the measured time. These two factors influence the amount of contribution from own voice (Ryherd et al. 2012).

It is remarkable that we have found few to none previous study, considering that the sound levels in the labour ward were so high. Thus, there is a clear indication that more studies are needed to assess the extent of exposure in other labour wards. Moreover, as the levels were found to exceed the action levels and exposure limits in the occupational noise regulations, set in order to prevent hearing damage, our data clearly indicate that noise-mitigating and hearing preventive measures are needed. The data suggest that hearing protection should be used during labours when high sound levels are expected. In addition, because personnel reported that they were often crowded in a small nurses' office when discussing, making telephone calls and during shift changes, room acoustic and organisational measures could likely be implemented to reduce the high equivalent levels of communication-intense noise.

Table 8. Percentage and number of sound level measurements at the labour ward reaching or exceeding the occupational noise exposure regulation AFS 2005:16 (Paper I).

	Reaching or exceeding per	
	Work shifts	**Dosimeter measurements**
Equivalent and maximum sound levels		
Lower action value 80 dB ($L_{Aeq\ 7\text{-}10\ h}$)	45% (n 28)	6% (n 30)
Upper action value and exposure limit 85 dB ($L_{Aeq\ 7\text{-}10\ h}$)	5% (n 3)	0.6% (n 3)
Exposure limit 115 dB (L_{AFmax})	27% (n 17)	8% (n 41)

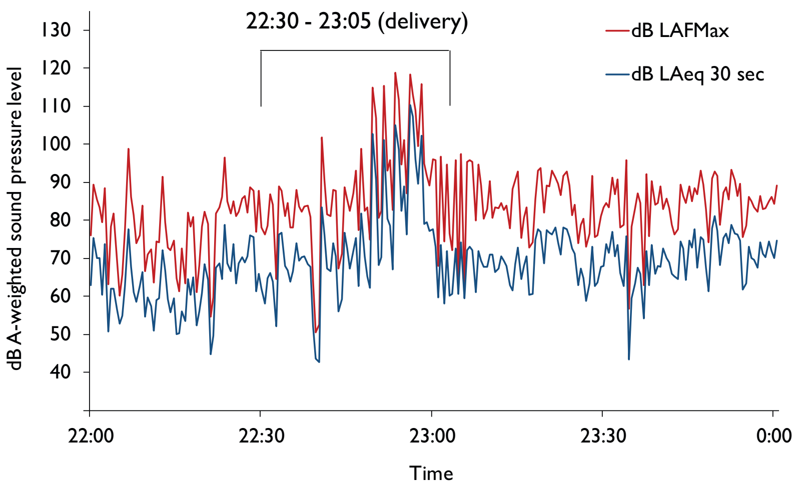


Figure 9. A 2-hour section time history graph from a sound level measurement in the labour ward where the exposure limit for maximum level $_{(LAFmax)}$ 115 dB was exceeded during a delivery (Paper I).

Hearing-related symptoms among obstetrical personnel

The survey responses from obstetrical personnel showed that loud noise and noise annoyance as well as work-related stress was commonly reported (table 9). Sound-induced auditory fatigue and difficulty perceiving speech was the most common symptoms (table 10). The main result of the analysis showed a significant increased OR for tinnitus and sound-induced auditory fatigue in relation to a cumulative occupational noise exposure index (table 10). In addition, both noise annoyance and work-related stress were significantly associated with sound-induced auditory fatigue when assessed in separate models with the main predictor variable occupational noise exposure. However, when all three variables were added in one model, the estimated effect of stress was reduced (p=0.053). This may have been a result of multi-collinearity between noise annoyance and work-related stress, which were weakly yet significantly correlated (r=0.249, p=0.008). There were no statistically significant interaction effects between the occupational noise index and work-related stress (p=0.718) or between noise index and annoyance (p=0.881), but they were all commonly reported by the personnel (table 9). Neither noise annoyance nor work-related stress were significantly associated to tinnitus when assessed with noise exposure.

A positive correlation between "sound fatigue" (i.e. a similar symptom assessed with a slightly different questionnaire item) and noise annoyance has previously been found in a small sample of preschool personnel, but the symptom was not found to be correlated to measured sound levels present at the time of survey (Sjödin et al. 2012). Thus, our result, showing an association between sound-induced auditory fatigue and the noise index, could suggest that the effect of noise exposure on sound-induced auditory fatigue is cumulative. Contrary to that interpretation, an intervention study has shown that room acoustical improvements can have a positive effect in decreasing the reports of a similar symptom termed "hearing fatigue" (Persson Waye et al. 2009). Because the latter study also showed improved ratings of the sound environment after the intervention, such as decreased reports of noise annoyance, it is possible that the perception of sound quality characteristics, which are not represented by sound level measurements, may be more important for sound-induced auditory fatigue compared to the sound level *per se*. This is also indicated in our analysis as noise annoyance was associated with this symptom. We were unable to assess whether sound-induced auditory fatigue was associated to measured sound levels, because measurements in the labour ward were not available on an individual level.

Furthermore, the significant association found between occupational noise and tinnitus is important considering the high sound levels measured in the labour ward. Noise exposure as a cause of tinnitus is rather well accepted (Axelsson et al. 2000, Henry et al. 2005). Studies have found that tinnitus prevalence is higher among subjects who report occupational noise exposure compared to those who do not report noise exposure (Shargorodsky et al. 2010, Masterson et al. 2016, Feder et al. 2017). Impulse noise is considered to pose a greater risk of hearing loss compared to continous noise (Starck et al. 2003), and tinnitus is likely to arise after acoustic trauma (Mrena et al. 2002). Even though these studies refer to extremely high noise levels, it migh be conceived that the exposure to loud screaming is particularly important for our finding of increased risk of tinnitus among obstetrical personnel, rather than the moderately high equivalent sound levels from communication-intense noise.

However, there are also other possible risk factors for tinnitus. A large study from Norway found a high prevalence ratio of tinnitus among women who were occupationally inactive and also in occupations considered to be less noise exposed (e.g. clerks) (Engdahl et al. 2012). This could suggest that different aetiologies underlie tinnitus within different populations, which is also suggested in the literature and reviews (Møller et al. 2010, Langguth et al. 2013, Henry et al.

2014). One possible risk factor for tinnitus, other than noise exposure, is temporomandibular disorder (TMD), which is a joint and muscle disorder in the jaw (Bürgers et al. 2011). In the previously reported analysis, this risk factor was not found to be significantly associated with tinnitus in a logistic regression model including the noise exposure index. We also found no significant correlation between TMD and tinnitus in a post hoc analysis (Spearman's rho .078, p=0.407). Furthermore, studies have also indicated that depression may be associated with tinnitus severity (Holgers et al. 2000, Langguth et al. 2007), and a large population study in Norway also reported a weak, yet significant, association with anxiety and depression regardless of tinnitus intensity (i.e. frequency and duration of tinnitus) (Krog et al. 2010). We had no measure of symptom severity, but in a post hoc analysis we assessed whether symptom frequency (i.e. how often the symptom was reported to occur) correlated with self-reported depression assessed by affirmative responses to the question "Do you currently have or have you had mental illness, depression?". The correlation was not significant (Spearman's rho -.174, p=0.175). It should, however, be noted that this is a crude assessment of mental health and the results should be interpreted with some caution. Moreover, we found that age was not significantly association with tinnitus. As seen in table 11, age was not significantly associated to any of the hearing-related symptoms reported by the obstetrical personnel. Due to multi-collinearity, age and noise index could not be included in the same model. The significant correlation between these two variables (Pearson r=0.706, p=<0.001), was most likely an effect of the cumulative characteristic of the noise index resulting from the inclusion of number of years worked in obstetrical care.

Concerning the magnitude of the effect in our main analysis, it is important to note that noise annoyance and work-related stress were binary variables, whereas the noise index was a continuous variable. Thus, the 1.04 OR found for the noise index represents a 4 % increase in risk per point in the noise index, as compared to a fivefold OR for those defined as annoyed by noise at work compared to not being annoyed. Above a certain point on the noise index, between 4 and 13 points, which mainly represents current exposure, each additional point can be interpreted as one year of working in obstetrical care (figure 10). Thus, the increase over a longer time-period could be substantial even if the OR was only slightly increased. Moreover, because risk was estimated by the OR derived from logistic regression models, the high prevalence of the outcome sound-induced auditory fatigue (32 % in total) might inflate the OR, which could lead to an overestimation of the risk, as compared to estimates of RR (Schmidt et al. 2008).

Therefore, we initially calculated the RR manually at a number of different points along the noise index, as reported in Paper I, and found only slight differences. In an additional analysis analysing instead log-binomial regression models, we found very similar results with only a slight decrease in RR compared to OR both for tinnitus and for sound-induced auditory fatigue in association with the noise index, as well as for sound-induced auditory fatigue in association with noise annoyance. The associations were still statistically significant ($p<0.05$).

None of the other symptoms were associated with the occupational noise index (table 10). Importantly though, a post hoc power analysis indicated that about 800 subjects would have been necessary in order to detect significant association of the niose index with hyperacusis and 1000 subjects would have been necessary for difficulty perceiving speech. These calculations, however, assume that the estimates found in the regression models were accurate. Nonetheless, as in all hypothesis testing, a non-significant result should be interpreted such that we could not find evidence for an association between noise exposure and other hearing-related symptoms among obstetrical personnel in this study, not that it has been proved that there is no association.

In summary, the high sound levels measured in the labour ward, together with the non-significant association to age, but the significant association to noise exposure and noise annoyance, as well as the finding that only 8% of the personnel wore hearing protection, strengthens the indication that obstetrical personnel may be at risk noise-induced hearing disorder. However, the cross-sectional design limits the possibility of ascertaining causal effects. Moreover, because the analysis assessed self-reported symptoms there are limits to the conclusion regarding definite physiological disorder. Interestingly though, Paper II showed that self-reporting of sound-induced auditory fatigue correctly identified 89% and tinnitus 78% of subjects with fairly mild hearing disorder diagnosed by clinical hearing tests.

Table 9. Selected descriptive data on work-related factors reported by obstetrical personnel (Paper I).

		% of n 115	(95% CI)
Exposed to loud noise	Have to raise own voice	58	(49–67)
	Difficulty hearing a conversation	52	(43–61)
Use hearing protection at work		8	(3–13)
Noise annoyance		58	(40–58)
Work-related stress		42	(33–51)

Table 10. Selected results from binary logistic regression models analysing hearing-related symptoms in association with occupational noise exposure (noise index), noise annoyance and work-related stress in obstetrical personnel (Paper I).

Symptom (prevalence, %)		OR (95% CI)	*p*-value
Sound-induced auditory fatigue (32%)			
Noise model:	Noise index	**1.04 (1.01–1.07)**	**0.031**
Stress-model:	Noise index	**1.04 (1.01–1.08)**	**0.027**
	Work-related stress	**2.62 (1.15–5.98)**	**0.022**
Annoyance model:	Noise index	**1.04 (1.01–1.08)**	**0.026**
	Noise annoyance	**5.67 (2.25–14.27)**	**<0.001**
Full model:	Noise index	**1.04 (1.01–1.08)**	**0.025**
	Work-related stress	2.39 (0.99–5.79)	0.053
	Noise annoyance	**5.25 (2.05–13.42)**	**0.001**
Tinnitus (13%)	Noise index	**1.04 (1.00–1.09)**	**0.049**
Hyperacusis (sound sensitivity) (13%)	Noise index	1.03 (0.97–1.06)	0.570
Poor hearing (16%)	Noise index	1.00 (0.96–1.04)	0.985
Hearing loss (9%)	Noise index	1.00 (0.95–1.06)	0.995
Difficulty perceiving speech (32%)	Noise index	1.01 (0.98–1.05)	0.461
Any symptom (one or more) (55%)	Noise index	1.02 (0.99–1.05)	0.273

OR, Odds ratio, CI: confidence interval. Bold indicate statistical significant association ($p<0.05$).

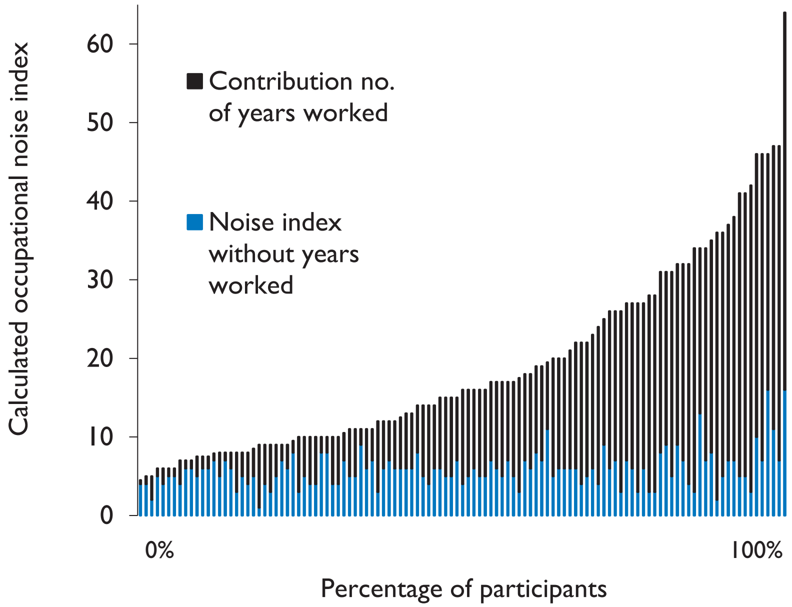


Figure 10. Calculated occupational noise index and the contribution of the variable years worked in obstetrical care (Paper I).

Table 11. Results from binary logistic regression models analysing hearing-related symptoms in association with age in obstetrical personnel (Paper I).

		OR (95% CI)	*p*-value
Hearing loss	Age	1.03 (0.97-1.10)	0.296
Tinnitus	Age	1.05 (0.995–1.11)	0.071
Difficulty perceiving speech	Age	0.998 (0.962–1.04)	0.921
Hyperacusis (sound sensitivity)	Age	0.999 (0.95-1.05)	0.976
Sound-induced auditory fatigue	Age	1.03 (0.996–1.07)	0.092
Poor hearing	Age	0.999 (0.95–1.05)	0.957

OR: Odds ratio, CI: confidence interval

Diagnostic performance of questionnaire items

The main finding of Paper II was that the questionnaire item assessing sound-induced auditory fatigue correctly identified 89% of subjects with at least a fairly mild hearing disorder diagnosed by pure-tone audiometry (one or more threshold ≥40 dB HL in either ear) and 85% of those diagnosed by distortion product otoacoustic emission (<3 dB SNR in either ear) while simultaneously correctly dismissing 70% who were not diagnosed with a disorder (table 12). In addition, the item assessing tinnitus and the item assessing hearing loss also showed a fairly good sensitivity (around 70%) and specificity (almost 90%) in relation to pure-tone audiometry (40 dB HL cut-off), although the sensitivity estimates had wide confidence intervals (table 12). Thus, caution in the interpretation is necessary.

For predictive values, the only estimate that had a confidence interval above 50% was the item assessing sound-induced auditory fatigue in relation to DPOAE (6 dB SNR cut-off). The positive predictive value (PPV) was 71% (95% CI 50–90) and negative predictive value (NPV) 71% (95% CI 54–87). Mild hearing disorder diagnosed by pure-tone audiometry (25/30 dB HL cut-off) was best predicted by self-reported hearing loss (PPV 71%), and disorder diagnosed by DPOAE (6 dB SNR cut-off) was next best predicted by tinnitus with a PPV of 70%. However, these estimates were uncertain with wide confidence intervals (38–100% for hearing loss, 36–100% for tinnitus).

The estimates for sound-induced auditory fatigue may have been influenced by the selection of study participants, who could all report this symptom and it was also one of the most commonly reported symptom in the underlying study population (Paper I). The selection of the study sample was, however, corrected for by weighting the calculations based on the prevalence in the population.

Because the item assessing sound-induced auditory fatigue had a fairly good diagnostic performance in relation to pure-tone audiometry and DPOAE, it could be argued that the symptom is a sign of auditory dysfunction. Moreover, because we found a significant association with the occupational noise index in Paper I, our studies points to the importance of including other symptoms than hearing loss when assessing the risks of auditory damage from noise exposure, leastwise among women working in communication-intense noise. The selected and restricted study sample limits the generalisability of the results in this study, but opens up for future research within the field.

The diagnostic validity of the items assessing other self-reported symptoms (difficulty perceiving speech, hyperacusis, poor hearing and the combination "any symptom") was, however, poor. The estimates generally had sensitivity below 50% regardless of diagnostic hearing test and diagnostic cut-off. In contrast, we found that a combination of items (i.e. reporting one or more hearing-related symptom) had a sensitivity of 100% in relation to pure-tone audiometry. However, the concurrent specificity was only 56%.

It could be argued that the clinical tests were not apt to diagnose some of the reported symptoms. However, we found that subjects reporting any hearing-related symptom (i.e. one or more symptom) on average had worse results on all three hearing tests. For example, figure 11 shows the distribution of pure-tone thresholds in the left ear. In the paper, we reported significant difference in mean thresholds at 6 and 8 kHz in the left ear and 6 kHz in the right. In an additional analysis of difference in median thresholds, assessed due to the skewed data, we found that the differences were still significant (p <0.013, Mann-Whitney U Test).

The hearing tests were chosen mainly on the basis of feasibility. For example, pure-tone audiometry was chosen because it is the most widely used method to assess hearing thresholds and because the operators were familiar with the method. An additional incentive was that it allowed for screening of the participants hearing, which was requested in the initiation of the project. However, pure-tone audiometry may not be sensitive enough to capture slight hearing dysfunction or early signs of NIHL. Nevertheless, the sensitivity of self-reported hearing loss in relation to pure-tone audiometry (40 dB HL cut-off) was similar to that found in a larger study (Nondahl et al. 1998). Furthermore, we also included measurement of DPOAE, as it has shown some promise in detecting effects of noise exposure (Desai et al. 1999, Attias et al. 2001). In our analysis, we did not assess a combined diagnostic cut-off. It could perhaps be considered for pure-tone audiometry and DPOAE, as studies have showed that OAE is probably most valid as an addition to pure-tone audiometry, rather than a substitute, in detecting auditory effects of noise exposure (Engdahl et al. 2013, Helleman et al. 2018). We found that self-reported symptoms other than sound-induced auditory fatigue generally had low sensitivity in relation to DPOAE. One possible explanation could be that we used a signal-to-noise ratio cut-off instead of assessing other parameters, such as the amplitude of the emission. Moreover, assessment of efferent suppression of OAEs could be considered in future studies, as it has been hypothesised that the efferent system may play a protective role during exposure to noise by controlling cochlear function (Fuente 2015).

Regarding the use of HINT as a diagnostic tool for hearing disorder, the study indicate that self-reporting difficulty perceiving speech did not perform well. Instead, tinnitus and sound-induced auditory fatigue had a higher sensitivity in relation to HINT. One of the reasons of choosing HINT over the standard clinical diagnostic speech audiometry test using phonemically balanced words (PB) presented in speech-weighted noise (Magnusson 1995), was that HINT is an internationally recognised test. Moreover, it was assumed that HINT could better represent the individuals perception of everyday hearing difficulties assumed to be captured in self-report, as compared to the PB test. HINT uses speech stimuli with sentences, which is slightly more comparable to everyday communication compared to PB word-lists. However, this also implies that the test involve more top-down processes, such as cognitive functions and language ability, and may thus be less specific to effects of the peripheral auditory system. More specific tests of active peripheral processing, such as frequency selectivity, intensity discrimination and temporal resolution could be suggested, but was out of scope for this study.

While we considered measuring ULLs to predict the diagnostic performance of the questionnaire items assessing hyperacusis, we did not. The main reason was the potential risk of causing distress and discomfort for subjects with hyperacusis and because trained, albeit inexperienced, nurses and not licensed audiologists would be testing many of the participants. Moreover, other researchers have explicitly cautioned about the use of this test (Baguley et al. 2011).

Furthermore, it would have been interesting to analyse results from electro-physiological tests such as auditory brainstem responses (ABR), which assess the transmission of sounds from the cochlea to the auditory nerve, since it has been used to identify synaptopathy in experimental studies (Kujawa et al. 2015). However, the results from a recent study suggest that ABR may not be sensitive to this pathology in humans (Prendergast et al. 2017). Moreover, it would have required considerably lengthier test sessions, and was thus to feasible in this study. Other studies have suggested that electrocochleography may be used to detect so-called “hidden hearing loss” (Liberman et al. 2016). This method was not considered when designing this study. While the technique giving the most clear response is invasive, which would not have been ethical to perform with inexperienced operators, a non-invasive method could be considered in future studies.

Table 12. Selected results of diagnostic performance of questionnaire items in relation to the less strict diagnostic cut-offs representing fairly mild hearing disorder (Paper II).

	Audiometry, 40 dBHL	**DPOAE, 3 dB SNR**	**HINT, - 3 dB SNR**
Sound-induced auditory fatigue			
Sensitivity, % (95% CI)	89 (60–100)	85 (56–100)	75 (0–100)
Specificity, % (95% CI)	70 (57–82)	70 (55–84)	63 (50–76)
Tinnitus			
Sensitivity, % (95% CI)	78 (43–100)	33 (0–67)	75 (0–100)
Specificity, % (95% CI)	88 (78–96)	84 (72–95)	84 (73–93)
Hearing loss			
Sensitivity, % (95% CI)	67 (0–100)	36 (0–75)	50 (0–100)
Specificity, % (95% CI)	87 (77–96)	88 (76–97)	84 (73–94)

DPOAE: Distortion product otoacoustic emission, HINT: Hearing in noise test, CI: confidence interval

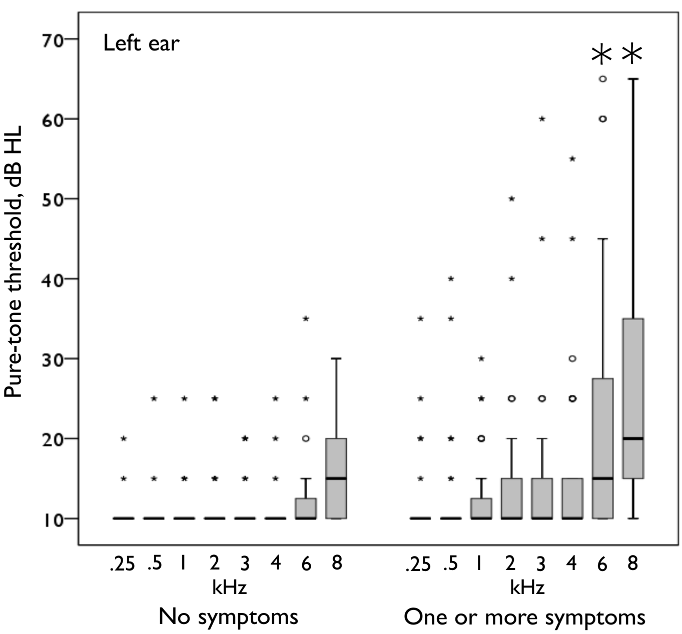


Figure 11. Distribution of pure-tone thresholds for subjects reporting hearing-related symptoms (right) or not reporting any symptoms (left) (Paper II). * indicates $p<0.013$

Relative risk of hearing-related symptoms, comparing preschool teachers and population controls

The main finding of Paper III was that the preschool cohort had an increased risk of self-reported hearing-related symptoms relative to women in the general population, both when assessing symptom prevalence and incidence rates (table 13). The increased relative risks reflects that a larger proportion of the preschool cohort reported symptoms compared to the population control cohort, and that they reported symptom onset earlier during the working-life (i.e. after age 24). The most notable relative risk, more than twofold, was seen for sound-induced auditory fatigue, hyperacusis and difficulty perceiving speech. The relative risk of hearing loss and tinnitus was increased albeit less pronounced.

Although the current analysis has limitation with regards to causal inference, the notably high relative risks found in this study should not be ignored regardless of the cause of the reported symptoms. Contrarily, the result clearly indicate that more research is needed to better understand the cause and our data suggest that work-related factors are of importance and should be considered. As seen in table 14, we found significant differences between the two cohorts in the reports of work-environment factors, which could explain the significant relative risks. A larger proportion of the preschool cohort reported noise exposure, noise annoyance and emotional demands, while fewer reported effort-reward imbalance compared to women in the general population who have not worked in preschools.

In an exposure-stratified analysis, we found that the relative risk of hyperacusis was pronounced among those reporting current exposure to occupational noise, RR 2.1, 95% CI: 1.6–2.8 (figure 12), which is explained by the markedly higher prevalence of hyperacusis among preschool teachers compared to women in the control population reporting similar noise exposure (figure 13). This could suggest that the communication-intense noise environment found in preschools is a more important risk factor for hyperacusis than noise exposure in other occupations. The opposite seems likely for the relative risk of hearing loss and tinnitus, as it was not significantly pronounced. Thus noise regardless of type might have an effect of these symptoms, indicated by the increased prevalence among women reporting noise exposure. The direct effect of noise exposure on hearing-related symptoms is discussed further in subsequent sections.

Numerous studies have found sound levels in preschools around the equivalent level 80 dBA. In a Danish study, which included 38 day care personnel, average equivalent levels in preschools were even as high as 84 dBA, but the study did not find a parallel in measured pure-tone hearing loss (Rubak et al. 2006). The latter corresponds to a study in Norway showing that nursery workers did not have pure-tone hearing thresholds worse than teachers in primary and vocational schools, with the latter being used as a reference category (Engdahl et al. 2010). Moreover, a study including 101 preschool teachers has found that pure-tone thresholds are generally within the normal range (better than 20 dB HL), but hearing thresholds were still slightly worse when compared to age-matched reference data (Sjödin et al. 2012). The latter study also showed, similar to ours, that hearing-related symptoms are commonly reported by preschool personnel. Slightly different self-report questions and symptom definitions were used compared to our study, which may explain why tinnitus prevalence (31%) was higher than in our study. The prevalence of hyperacusis, however, was comparable (45%) to our study, when considering those responding "sometimes" and "quit often" in the Sjödin study. Thus, it might be concluded that the risk of pure-tone hearing loss is not particularly high in preschool personnel, but that other symptoms such as hyperacusis is. Interestingly, a study among subjects with normal or near-normal pure-tone thresholds who reported hearing-related symptoms, including tinnitus and hyperacusis, has showed that a group of preschool teachers and teachers had hearing test results indicating inner ear dysfunction (e.g. forward masking and speech recognition in noise) and had dysfunctions similar to a group of noise exposed industry workers (Lindblad et al. 2014). Taken together, these studies are interesting in the light of research on "hidden hearing loss", which is thought to reflect disorder that does not show as pure-tone hearing loss, as discussed earlier. It could even be argued that the long-standing paradigm of pure-tone thresholds as gold standard indicator for noise-induced auditory effects may be questioned. At least with regard to subjects exposed to communication-intense noise.

It could be hypothesised that the particular characteristics of communication-intense noise explains the increased risk of hyperacusis, sound-induced auditory fatigue and difficulty perceiving speech found in our study. Possibly, the risk of reporting these symptoms relate to the high demands of perceiving speech and the constant exposure to sounds that "trigger" the perceptual consequences of hyperacusis (i.e. discomfort or pain from sounds). Thus, it might be that the specific characteristics of the noise exposure rather than the sound level is of importance. However, it could also be argued that preschool teachers are in fact more noise exposed than controls. Firstly, this is indicated by the prominent difference in self-reported exposure to loud noise at work (table 14). Secondly, even when the same degree of exposure is reported, women in the preschool cohort reports less use of hearing protection as compared to controls (figure 14). The hypothesis is further strengthened by Paper IV, which shows a significant effect of occupational noise on adult-onset hyperacusis. Because not wearing hearing protection when exposed to noise *per se* means more exposure, the increased risk could be interpreted as an effect of the noise exposure. The perceived difficulties in using hearing protection in preschools has been documented by other researchers, who showed also that it may depend not only on the fear of missing out on information in conversations, but also that it is perceived as unpleasant to wear hearing protection in the presence of parents, and that it is not considered reasonable (Koch et al. 2016). These factors should thus also be considered when recommending preventive measures and the goal should rather be to decrease the sound levels and improve the sound environment, than to merely promote the use of hearing protection among personnel.

Moreover, the exposure-stratified analysis of relative risks also showed that the risk of sound-induced auditory fatigue was pronounced within the stress only strata (RR 2.0, 95% CI: 1.7–2.4) (figure 12). Notably though, symptom prevalence was generally much lower among women reporting only exposure to stressful working conditions, in both cohorts, as compared to those reporting noise exposure, and in many cases even lower than among those who were defined as unexposed (figure 13). Thus, we interpret these results such that exposure to stressful working conditions do not increase self-reported prevalence of hearing-related symptoms in general, but that sound-induced auditory fatigue is more common among preschool teachers who report stressful working conditions as compared to controls reporting stress. It is possible that the results indicate that working in a communication-intense sound environment with high demands on attentive listening and speech perception may provoke listening fatigue, and that this in turn is related to stress. Similar hypothesises have been discussed by others with regard to the mental exertion required to understand speech in sub-optimal listening conditions (McGarrigle et al. 2014).

Other cross-sectional studies have found associations between occupational stressors and the outcomes difficulty perceiving speech and tinnitus (Hasson et al. 2011). Effects of long-term stress have been hypothesised to negatively affect the auditory system on a neuro-endocrine level and has therefore been hypothesised as harmful to the auditory system (Canlon et al. 2013). As the current analysis focused on comparing the two cohorts, we did not assess the direct effect of stress in Paper III, but we did not find that the prevalence was particularly high in the stress-only strata. In a following section, we present results from additional analyses which explore the association with stress further.

If we assume that the preschool cohort (who have been exposed to the preschool work environment) is otherwise comparable to the control population (who have not worked in preschool) with regard to risk for hearing-related symptoms, we can compare measures of disease occurrence to assess the effect of the exposure (i.e. having worked in preschool) (Rothman et al. 2008). Our data suggest that, if anything, the control population had higher occurrence of other risk factors for hearing disorder, such as higher median age, more leisure noise exposure, smoking being more common and having lower socioeconomic status ($p<0.001$). In contrast, the reports of current noise exposure at work as well as emotional demands stood out as being more common within the preschool cohort (table 14), which was also expected based on other studies (Wieclaw et al. 2006, Sjödin et al. 2012). In addition, a larger proportion of women in the preschool cohort reported to have changed jobs due to noise (7%), compared to women in the general population (2%). This could either be interpreted as more overall exposure, or it could imply lower current exposure. As have been shown, the preschool cohort report significantly more current noise exposure. Furthermore, we can note that a majority of the women in the preschool cohort currently worked in preschool when responding to the survey (n 3525, 75%). In addition, almost a third of the women in the preschool cohort had only worked in preschool throughout their entire working life (n 1390, 29%), and thus had not been exposed to other occupational hazards. This strengthens our interpretation of the preschool work-environment affecting the occurrence and risk of reporting hearing-related symptoms among the women in the preschool cohort.

The potential adverse health effect of the preschool work environment should not be neglected. Especially considering that it is one of the largest workplaces in Sweden, employing more than 150000 individuals, and in which also more than 90% of children in Sweden today spend most of their waking time.

Table 13. Results from log-binomial regression models analysing risk ratio and results from manual calculation of incidence rate ratio of hearing-related symptoms comparing the preschool cohort (n 4718) to population controls(n 4122) (Paper III).

	Prevalence, %		Risk ratio (adjusted*)		Incidence rate ratio (crude)	
	Preschool	**Controls**	**RR**	**(95% CI)**	**IRR**	**(95% CI)**
Hearing loss	19	15	1.6	(1.5–1.8)	1.7	(1.5–1.9)
Tinnitus	18	14	1.7	(1.5–1.9)	1.8	(1.6–2.0)
Difficulty perceiving speech	46	26	1.9	(1.7–2.0)	2.4	(2.2–2.6)
Hyperacusis	39	18	2.3	(2.1–2.5)	3.1	(2.8–3.4)
Sound-induced auditory fatigue	71	32	2.4	(2.2–2.5)	NA	

* Adjusted for: age, education and household income, smoking, hearing protection at work and leisure noise exposure, CI: Confidence interval, RR: Risk ratio, IRR: Incidence rate ratio, NA: Not available

Table 14. Selected descriptive variables relating to the work-environment reported by the preschool cohort and population controls (Paper III).

	Preschool cohort		Population controls		
	%	**(95% CI)**	**%**	**(95% CI)**	
Exposed to loud noise at work (≥25% of time)					
Difficulty hearing a conversation	75	(73–76)	32	(30–33)	*
Have to raise own voice	75	(73–76)	29	(28–31)	*
Wear hearing protection at work (often/always)	3	(2–3)	5	(4–5)	*
Noise annoyance (rather, very, extremely)‡	70	(68–71)	27	(25–28)	*
Effort-reward imbalance (ratio >1)	17	(16–18)	35	(33–36)	*
Emotional demands (often or always)	49	(48–51)	28	(26–29)	*

* Difference were significant (p<0.001) as assessed by the chi-square test.
‡ Additional data, not included in Paper III.

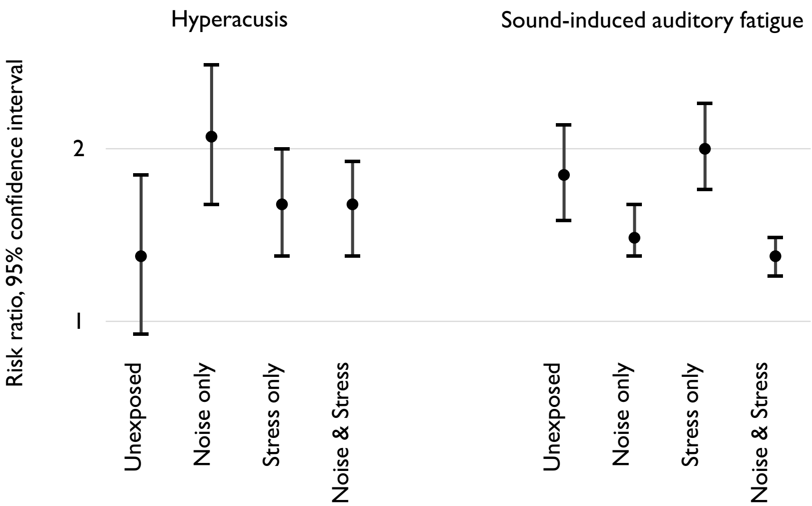


Figure 12. Relative risk of hyperacusis and sound-induced auditory fatigue within strata of current exposure to occupational noise and stressful working conditions (Paper III).

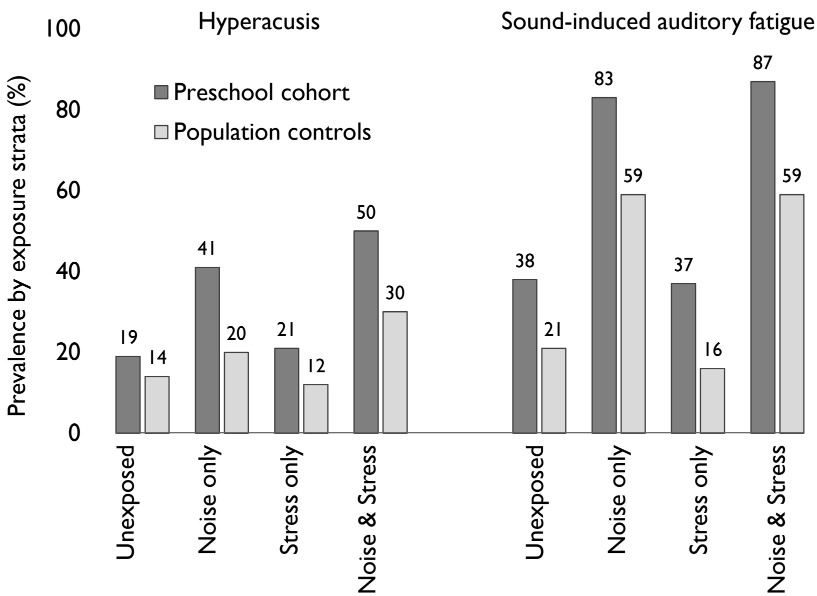


Figure 13. Prevalence of hyperacusis and sound-induced auditory fatigue within strata of current exposure to occupational noise and stressful working conditions (Paper III).

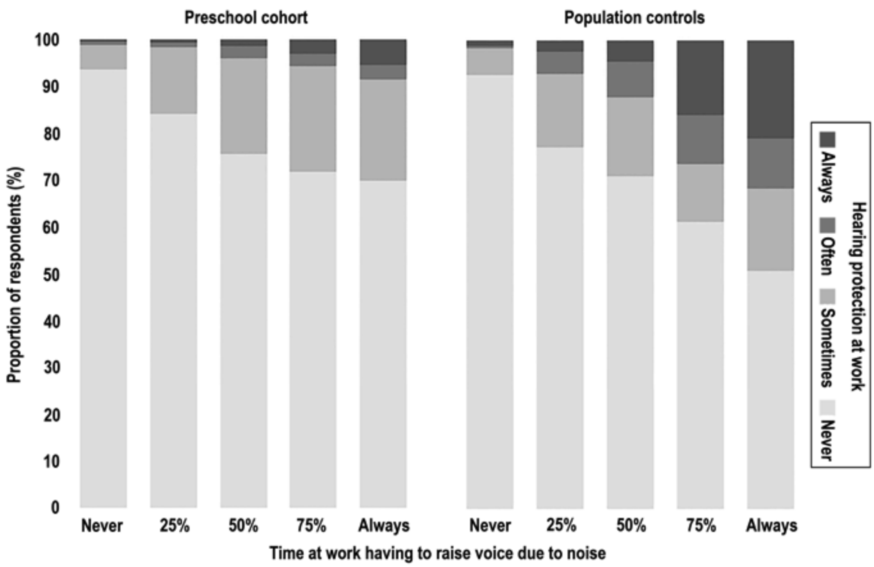


Figure 14. Proportions reporting use of hearing protection at work (frequency of use shown in different shades of grey) in relation to different degree of occupational noise as reported by the preschool cohort and population controls (Paper III).

Adult-onset hyperacusis in relation to occupational noise

The main finding of Paper IV was that the HR of adult-onset hyperacusis was significantly increased among women working in equivalent sound levels in the range of 75–85 dBA and substantially increased among preschool teachers working in preschools, also assigned to the 75–85 dBA interval, compared to the reference category <75 dBA (table 15). The HR in the highest exposure interval, >85 dBA, was increased, but not significant and the CI was wide. This was most likely due to the few events occurring in this exposure group (n 6).

We also found that the HR was still significant for working in preschool noise when including both preschool teachers and child caretakers in the preschool group (HR 3.2, 95% CI: 2.9–3.5). The HR for the other occupations within the 75–85 dBA interval was still significant when child caretakers had been reassigned to the preschool exposure group (HR 1.5, 95% CI: 1.3–1.8). The exposure interval <75 dBA was used as the reference category.

The particularly infrequent use of hearing protection among preschool teachers compared to its use among women in the general population (Paper III), could explain the substantially higher HR compared to women in other occupations in the same exposure interval. Exposure to loud screaming may provide an additional explanation for the substantially higher HR found in the preschool exposure category, than in other occupations in the same exposure interval. An additional analysis of female preschool teachers, showed that a majority of those who currently worked in preschools when responding to the survey (n 3525) reported to have been exposed to screaming in the ears several times (72%) or a few times (25%). Whereas only a small proportion reported to never have been exposed to screaming in the ear (3%). However, as this question was not asked of women who have not worked in preschools, we were unable to compare this exposure between the groups. Similarly, a study has shown that preschool personnel are frequently exposed to 1-minute events of equivalent sound levels exceeding 85 dBA, up to 100 such events were detected per hour in preschools (Sjödin et al. 2012).

The statistical analysis indicated that exposure prior to symptom onset also played an important role for the analysis of time to an event (hyperacusis onset). When initially performing the survival analysis using standard Cox-regression, heterogeneity in survival time was observed by the frailty parameter theta ($\theta \neq 0$), which indicated that there were unmeasured factors influencing the survival times. For our data, this means that subjects working in the same exposure interval when an event occurred had different survival times. Thus, the assigned exposure group at time of event did not fully explain the risk of hyperacusis onset. If not corrected for by using frailty regression, which can address the difference in individual hazard, the analysis could have been biased as the population hazard would not be able to account for this heterogeneity. When we accounted for previous exposure (i.e. having worked in an occupation assigned to a different exposure interval prior to onset), the model showed that we no longer had significant heterogeneity. Thus, we can hypothesise that not only noise exposure at the time of symptom onset is important, but also prior noise exposure.

An important limitation in the analysis is the possibility of exposure misclassification due to the fact that the JEM assigns exposure levels to job families, which comprise occupations that may have different exposures. Moreover, there is also a question of how well the JEM assigns the correct exposure to female-dominated occupations, as these have been studied far less.

It may thus be expected that exposure assignment in these occupations are more often based on consensus judgment than on actual measurements. There is also a possible misclassification of exposure due to subjects' uncertainty when recalling the specific year of symptom onset. In the development of the questionnaire, it was noted in the think-aloud interviews that subjects expressed some uncertainty about the exact year of symptom onset. The low rate of missing data was also supported by the interviews, as most subjects reported being confident enough to give a response in almost all cases. It might be conceived that specific events could influence the recall. We have not been able to assess whether this affects self-reported onset differently in different occupations. We did, however, note that recall in general had a slight effect, but not different among women in the preschool cohort compared to the control cohort. Results of these evaluations are presented in Paper III.

Moreover, the wide range of the exposure interval of equivalent levels ranging from 75–85 dBA hindered an evaluation of whether the current regulation of noise at work (AFS 2005:16) is sufficient in preventing hyperacusis, as the interval in which we found a significantly increased hazard ratio includes the lower action value for equivalent levels 80 dBA. In addition, as noise levels in preschool are considered to be in the range of equivalent levels 80–85 dBA in the forthcoming updated JEM, while some other occupations in the 75–85 dBA interval may actually have an exposure closer to 75 dBA, this could possibly further explain the pronounced HR in the preschool exposure group. Additionally, a limitation of our study was that we did not fully account for repeated exposure to sudden high sound levels. This is not consider fully by the noise regulation either. It would be valuable to study further whether exposure to screaming in the ear can explain the pronounced risk for women working in preschool.

Clinical experience and research indicate that preschool teacher is as a common profession among hyperacusis patients (Anari et al. 1999, Jüris et al. 2013). Although research is limited regarding causal effects of noise on hyperacusis, noise exposure has been proposed as a likely cause (Axelsson et al. 1987, Aazh et al. 2014, Tyler et al. 2014). In addition, experimental studies suggest that hyperacusis may be an outcome of synaptopathy caused by noise exposure even when hearing loss is not present (Kujawa et al. 2015). However, further research is needed to develop understanding of physiological mechanisms relating to hyperacusis in humans and further assess dose-response relationship between noise exposure and hyperacusis.

Table 15. Hazard ratio of adult-onset hyperacusis in relation to occupational noise exposure assessed by JEM (Paper IV).

	Incidence rate per 1000 person-years		**Adjusted* survival model**	
	IR	**(95% CI)**	**HR**	**(95% CI)**
<75 dBA	6.9	(6.4–7.5)	(reference)	
75-85 dBA	7.8	(6.9–8.8)	1.6	(1.3–1.8)
75-85 dBA (preschool teachers)	23.0	(21.6–24.4)	3.4	(3.0–3.7)
>85 dBA	6.4	(2.9–14.3)	1.3	(0.6–3.0)

* Adjusted for variables measured at time of survey: age, education, household income, family history of hearing loss and reported to have changed jobs due to noise and prior noise exposure as frailty component. IR: incidence rate, HR: hazard ratio, CI: confidence interval

Prevalence of hearing-related symptoms

In an additional descriptive analysis, we compared the overall and age-stratified prevalence of hearing-related symptoms from the different study populations. We included obstetrical personnel (n 115, Paper I), a sub-sample of the preschool cohort who currently worked in preschool when responding to the survey (n 3525, from Paper III), and a sub-sample of the population control cohort who did not report current occupational noise exposure (n 2611, from Paper III). Symptom prevalence in the control population is also discussed in relation to other studies.

The main finding of the additional comparison of the overall prevalence of hearing-related symptoms was that obstetrical personnel generally had lower prevalence and lower RR compared to preschool teachers, except for for tinnitus, and that obstetrical personnel had a significantly higher overall prevalence and risk of difficulty perceiving speech and sound-induced auditory fatigue compared to the "unexposed" control cohort (table 16). The differences between the sub-sample of preschool teachers and the "unexposed" population cohort showed, similar to the results in Paper III, a higher prevalence among preschool teachers compared to controls and significantly increased overall RR for all symptoms (table 16). In this additional analysis, it can be noted compared to the analysis in Paper III that when comparing preschool teachers who currently work in preschool to "unexposed" controls, the RR is more pronounced than the RR in the complete cohort in Paper III, in which we had not excluded noise exposed controls. However, as we calculated only crude RRs in this additional analysis, it is possible that the estimates are confounded. Notably though, in Paper III, we found that the RR in adjusted models were generally higher rather than lower compared to the crude models.

Figure 15 shows age-stratified prevalence in the three groups. Descriptive comparison indicate that symptoms were generally reported already at a young age. Most notable was difficulty perceiving speech among young obstetrical personnel and preschool teachers, as well as sound-induced auditory fatigue and hyperacusis among preschool teachers. The exceptionally high prevalence of difficulty perceiving speech among young obstetrical personnel should be interpreted with caution because there were only 10 subjects in the strata 22–29 years. Interestingly though, the result has some similarity to a large study in the general Swedish population. The study showed that the prevalence of difficulty perceiving speech ("sometimes a bit difficulty to hear when talking to one person in a quiet room") among young women (ages 18–25 years) was as high as that of older women (ages 40–50 years), but lower in the ages between (Pierre et al. 2015).

Furthermore, the prevalence of sound-induced auditory fatigue in our two larger cohorts had almost equal prevalence regardless of age (figure 15). The smaller group of obstetrical personnel showed a slight increase by age for sound-induced auditory fatigue, however, we did not find a significant association with age in a logistic regression model (p=0.092), as reported earlier. This could imply that sound-induced auditory fatigue is a temporary outcome, as prevalence seems not to accumulate over the lifetime. This hypothesis is, as discussed, in line with an intervention study which showed a decrease in reports of "hearing fatigue" after room acoustic improvements had been done in a preschool (Persson Waye et al. 2009). However, the hypothesis is perhaps conflicting with Paper I, which showed that a calculated cumulative noise dose (accumulation by number of years worked in obstetrical care) was significantly associated to sound-induced auditory fatigue among personnel. Hence, more studies are needed in order to determine the pattern of symptom occurrence over time. Unfortunately, we did not have information on symptom onset of sound-induced auditory fatigue, which hinders us from assessing incidence rates.

Hyperacusis also showed a rather constant prevalence across age-strata in the control cohort. A similar prevalence of hyperacusis in different age groups has been found among respondents to a postal survey, but not in a group who responded to a web survey (Andersson et al. 2002). The latter group had increasing prevalence from 6% among 16–30 year olds to 15% among 51–79 year olds. In another study, subjects who had self-reported hyperacusis had a lower mean age than a group who did not report hyperacusis, while a group who reported to have "physician diagnosed hyperacusis" had a higher mean age (Paulin et al. 2016). Generally, most studies do not report age-stratified prevalence of hyperacusis. This could perhaps imply that age is not an important factor, but it could also be due to the fact that most studies on hyperacusis have so far mostly been concerned with specific patient groups rather than being epidemiological population studies.

In contrast, the prevalence of hearing loss, difficulty perceiving speech and tinnitus generally increased by age in our data and in all three study populations, albeit to a lesser extent in the control cohort. Age is perhaps the most commonly reported factor associated with acquired hearing loss. Measured pure-tone hearing thresholds generally show a trend of worse hearing with increasing age. For example, large population studies in Sweden and Norway, have showed that thresholds increased with age both in screened and unscreened populations (Johansson et al. 2002, Engdahl et al. 2005). Age itself is, however, most likely only partly the cause of the increase in prevalence. As noted in a review of age-related hearing loss, intrinsic genetic factors may play an important role in individual susceptibility, but extrinsic and preventable factors, such as accumulating noise exposure dose, may also explain the association with age (Yamasoba et al. 2013). From comparing our two larger cohorts, it seems unlikely that preschool teachers would have an underlying intrinsic susceptibility to age-related hearing loss, tinnitus or hearing disorder in general. If anything, the data rather suggest that the control cohort has a higher baseline risk (i.e. a higher proportion of the control cohort reports other known risk factors), such as a larger proportion of ever smokers and lower socioeconomic status. Thus, it could be hypothesised that the higher prevalence in the preschool cohort compared to controls is a result of exposure to the preschool work-environment. This hypothesis is strenghtened by an age-stratified analysis of relative risk of the data in Paper III, which showed that the RR was not significantly increased for hearing loss and tinnitus among women younger than 30 years of age. This is also visible in figure 15 as a similar prevalence in the youngest age-strata. This could be explained by the fact that the youngest group of preschool teachers have only been exposed to this work environment for a short duration.

Comparing the prevalence in the sub-sample of controls who did not report current noise exposure (n 2611, from Paper III) to the prevalence in the complete control cohort (n 4122), we found a slight decrease in the former group. The largest decrease, was seen for the symptom sound-induced auditory fatigue. This strengthens the hypothesis of an effect of currently reported noise exposure for this symptom. It was, however, not possible at this stage to control for type of exposure (e.g. intermittency, information content or demanding speech perception) among women in the control cohort. Thus, further research is needed to assess whether the symptom is specific for communication-intense sound environments, or whether it is associated to noise exposure in general.

When comparing the complete control cohort (i.e. including also those who report noise exposure) to prevalence rates reported in other studies, we found both similarities and differences. Hearing loss in our larger control cohort was identical to a recent Swedish study reporting that 15% among women 18–50 years old responded that their hearing was slightly or very impaired (Pierre et al. 2015). For tinnitus, our control cohort had a slightly higher prevalence compared to an older study among women age 20–79 years in the general Swedish population, which reported an overall prevalence of 12% (Axelsson et al. 1989). A more recent Swedish study has reported a prevalence of tinnitus at 22%, among working women age 16–64 years and 23% among non-working women (Hasson et al. 2010), which is higher than in our control cohort. The same study also reported a 10% prevalence of difficulty perceiving speech in conversation between several people (referred to as hearing loss in that study) among working women and 11% among non-working women, which is lower than in our study by comparing to our symptom difficulty perceiving speech. Another study has reported a prevalence of 25% for difficulty perceiving speech with several people and 20% for tinnitus, among women in the general population age 18–50 years (Pierre et al. 2015). Those data are comparable to our control cohort for difficulty perceiving speech, while prevalence of tinnitus was higher than in our data. For hyperacusis, a recent study reported that 220 out of 1898 women in the ages 18–79 years had self-reported hyperacusis (12%) and 44 (2%) reported physician diagnosed hyperacusis (Paulin et al. 2016). Combining these two groups, the prevalence is only slightly lower than in our control cohort. Obviously, differences in questionnaire items, response alternatives and symptom definitions make comparisons between studies difficult. Moreover, we have not found reports of sound-induced auditory fatigue in the general population to compare to our control cohort.

Table 16. Prevalence and crude risk ratio of hearing-related symptoms in obstetrical personnel (Paper I) and preschool teachers currently working in preschool (from Paper III), compared to women in the general population control cohort who did not report current occupational noise exposure (from Paper III).

	Obstetrical personnel		**Preschool teachers currently in preschool**		**Population controls not reporting noise exposure**	
	n 115		**n 3525**		**n 2593**	
	% RR‡	**(95% CI)**	**% RR‡**	**(95% CI)**	**%**	**(95% CI)**
Hearing loss						
Prevalence	9*	(4–14)	18	(17–20)	12	(11–14)
Crude risk ratio	0.8	(0.4–1.5)	**1.5**	**(1.3–1.7)**	Reference	
Tinnitus						
Prevalence	13	(7–19)	19	(17–20)	11	(10–13)
Crude risk ratio	1.2	(0.7–1.9)	**1.6**	**(1.4–1.9)**	Reference	
Difficulty perceiving speech						
Prevalence	33*	(23–41)	47	(45–48)	22	(20–23)
Crude risk ratio	**1.5**	**(1.1–2.0)**	**2.1**	**(2.0–2.3)**	Reference	
Hyperacusis						
Prevalence	13*	(7–19)	41	(39–43)	14	(12–15)
Crude risk ratio	1.0	(0.6–1.6)	**3.0**	**(2.7–3.4)**	Reference	
Sound-induced auditory fatigue						
Prevalence	32*	(23–41)	76	(75–78)	19	(18–21)
Crude risk ratio	**1.7**	**(1.3–2.2)**	**4.0**	**(3.7–4.3)**	Reference	

RR: Risk ratio (manually calculated), CI: Confidence interval
‡ Bold RR >1 indicates significant Chi-square test (p<0.05).
* Indicate crude RR with 95% CI <1 for obstetrical personnel compared to preschool teachers, and significant Chi-square test (p<0.05).

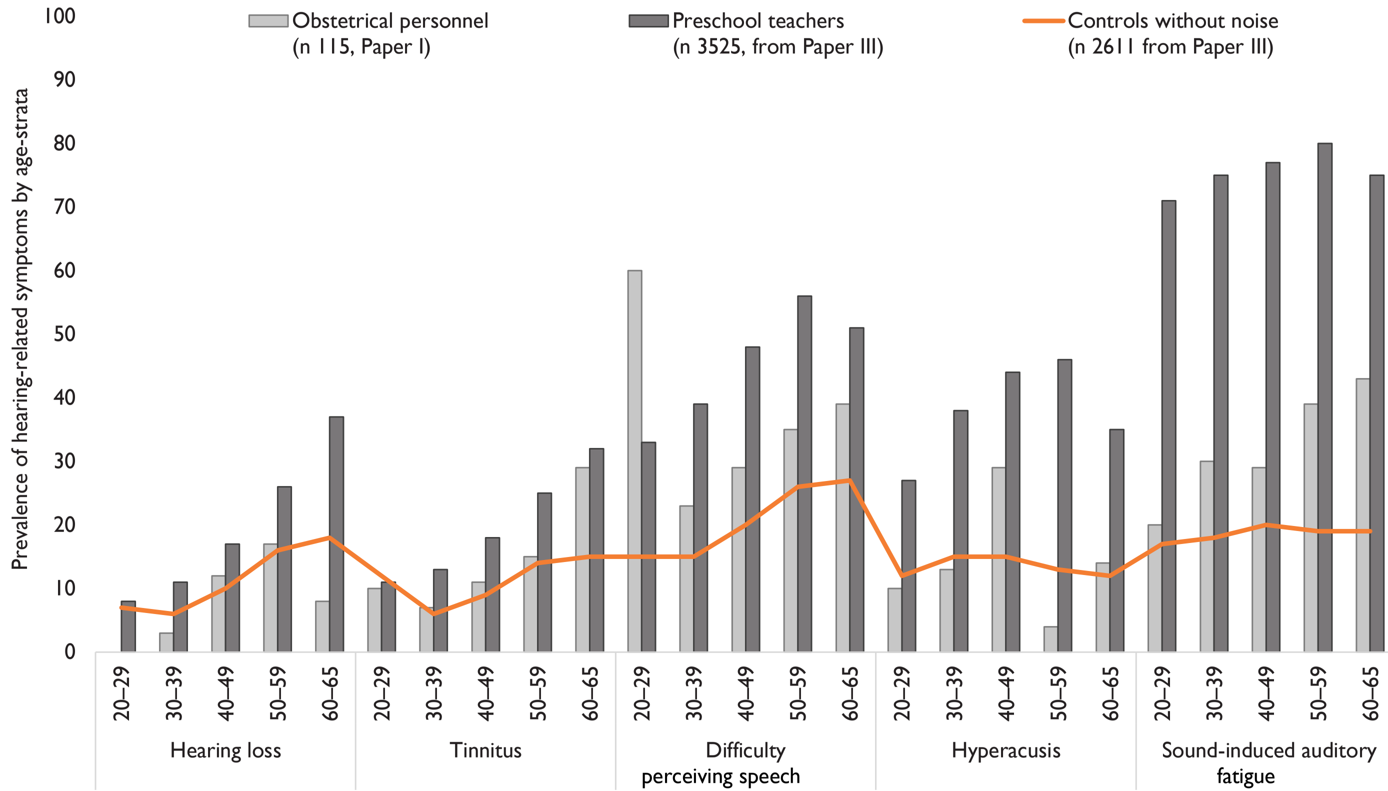


Figure 15. Prevalence of by age-strata among obstetrical personnel (paper I) and preschool cohort (from paper III) compared to control population (from paper III).

Exploring direct, mediating and moderating effects

Additional explorative analysis of the data from Paper III, has been performed and were presented at the 12th ICBEN Congress (Fredriksson et al. 2017). These analyses focus on exploring whether stress and noise annoyance has a mediating or moderating (i.e. interaction) effect on the association between noise exposure and hearing-related outcomes.

The analysis showed significant direct effects of noise exposure at work on hearing-related symptoms in the final models, which included stress and noise annoyance according to the results described in the following paragraphs. The final models were adjusted for possible confounding by age, leisure noise exposure, smoking, education, income and employment status where appropriate, as assessed by model fit (AIC). The association and direct effect of noise was strongest for the symptom sound-induced auditory fatigue ($\beta=0.31$), then difficulty perceiving speech ($\beta=0.29$) and hyperacusis ($\beta=0.27$). The direct effect of noise was lower for hearing loss ($\beta=0.17$) and tinnitus ($\beta=0.11$), yet still significant.

The analysis of possible mediating or modifying effects of stressful working conditions (ERI, COPSOQ) and stress-response (symptoms of long-lasting stress, LLS) showed that the different measures of stress acted differently in relation to different hearing-related symptoms. For example, both stressful working conditions and stress-response showed a modifying effect on sound-induced auditory fatigue and hyperacusis, and significantly interacted with noise exposure ($p<0.05$), while both factors had a very small mediating indirect effect on difficulty perceiving speech ($\beta<0.04$). For hearing loss, ERI showed a significant interaction effect ($p=0.029$), while LSS did not. For tinnitus, LLS showed a very small indirect effect ($\beta=0.03$).

In addition, noise annoyance, like stress, had different effects on the models assessed for the different symptoms. Noise annoyance had a mediating indirect effect on sound-induced auditory fatigue ($\beta=0.28$), but a significant interaction effect with noise exposure in the model for hyperacusis ($p=0.03$) and difficulty perceiving speech ($p=0.004$). Noise annoyance also had a very small indirect effect in the model assessing tinnitus ($\beta=0.07$), but did not show any effect on self-reported hearing loss.

Thus, the results indicate that different models explain the different hearing-related symptoms. Thus the potential effects, based on the hypothesised causal model, should be re-evaluated and developed further for each symptom separately. Nevertheless, the results indicate that noise exposure, stressful working conditions and stress response has importance for hearing-related symptoms and it should be studied further whether these effects are specifically related to certain types of noise exposure, such as communication-intense noise.

Previous research has showed an association between occupational stressors, such as burnout and LLS, and hearing-related symptoms (difficulty perceiving speech and tinnitus) (Hasson et al. 2011). Studies have also found that mental health is associated to tinnitus (Holgers et al. 2000, Krog et al. 2010). One study has also found that women with emotional exhaustion had decreased ULLs, indicative of hyperacusis, when exposed to an acute stress test (Hasson et al. 2013), which could imply that abnormal functioning of the stress response is an important factor for experiencing hyperacusis when exposed to stress. However, studies have also shown that subjects with hearing-related symptoms report a more demanding and stressful work environment, and report worse health outcomes under stressful working conditions (Danermark et al. 2004). This effect may be greater in communication-intense environments, as suggested from interviews among preschool personnel with hearing loss (Danermark et al. 2003). In the exposure-stratified analysis of symptom prevalence reported in Paper III, we found that symptom prevalence was generally low among subjects who reported only stressful working conditions, which could imply that stress, measured by effort-reward imbalance or emotional demands at work, do not cause hearing-related symptoms in general. However, the reported studies as well as ours have limitations in interpreting causal effects. Thus, the role of stress in relation to hearing disorders and symptoms need to be studied further. Regardless, the significant associations found in different studies suggest that experiencing stress or working in stressful conditions is important. Either as it contributes to hearing-related symptoms or as a condition in which subjects who experience hearing-related symptoms are affected more by stress.

Gender perspective

As discussed earlier, men and women traditionally work in different occupations and sectors (i.e. occupational gender segregation), and may thus be exposed to different occupational hazards (Eng et al. 2011). Although more men than women report exposure to noise, it should be noted that the proportion of women reporting work-related disorder due to noise in Sweden has increased significantly in recent years, according to official statistics (figure 16). In addition, data from the national health survey in Sweden show that the prevalence of difficulty perceiving speech (termed hearing loss in the report) has increased slightly among women, especially among women in working age (ages 35–64 years), when comparing data from the years 1990-1995 to 2000-2005 (Danermark et al. 2012). This could suggest that hearing prevention is lacking in female-dominated occupations. The lack of risk assessment for female workers, particularly within the education and health care sector has been emphasised by the European Agency for Safety and Health at Work (EU-OSHA 2013). These are sectors in which large numbers of women in Sweden work. It is possible that traditional noise-mitigating measures (such as installing sound absorbents) are not efficient enough to reduce the effects of communication-intense noise and most likely not for loud screaming, or that they are not suitable or acceptable (such as wearing hearing protection) and are thus not being implemented.

The sound environment and noise exposure is different in traditionally male-dominated occupations within the industry sector, compared to female-dominated human service occupation where speech communication, human activity and screaming are dominating noise sources. As such, the extensive research on the risk of noise exposure on hearing derived from studies on male industry workers, cannot be assumed to directly translate to risks in communication-intense sound environments. A consequence of the narrow focus on industrial settings within noise research may have implications for the general view of what constitutes noise exposure and what should be considered a significant noise-related health outcome. This potential bias caused by gender blindness in research should be discussed more within the research community. Within noise research, there has been a long standing focus on NIHL, while symptoms such as hyperacusis have been research far less. It is possible that differences in the noise exposure itself, both regarding physical characteristics and perceptual qualities and regarding the necessity of attending to the information contained in the noise, in addition to the appropriateness of available preventive measures, may all have an effect on which hearing-related outcomes arise and which outcomes are perceived as most important, and thus reported, by workers. However, this has so far been research to very little extent.

In general, contemporary knowledge about diseases and risk factors is constructed mainly based on studies among men (Hamberg 2008), and thus are more likely to be representative for outcomes reported by men. A recent review of 210 experimental studies has showed that bias relating to biological sex also apply in the area of basic pre-clinical research on NIHL (Lauer et al. 2017). Thus, the knowledge on physiological mechanisms of the effects of noise exposure on hearing may be biased and may potentially be less applicable to women and female workers. Although differences in hearing-related outcomes between men and women, such as men generally showing worse pure-tone hearing thresholds, may be a result of men generally being more exposed to noise, studies also indicate that men might be more sensitive to noise. The female sex hormone oestrogen have, for example, been indicated to have a protective effect on hearing (Hederstierna et al. 2010). Both gender differences relating to where men and women traditionally tend to work, as well as biological differences relating to sex hormones may thus be important. These factors are something to observe and consider in studies, rather than something to ignore.

Furthermore, the effect of gender bias may also have implications on the individual worker. For example, The European Agency for Safety and Health at Work has noted that physicians may fail to link cases of hearing loss in women to occupational exposures because of the lack of research among female workers, and the authors discuss the necessity of risk assessments to be "*based on looking at real exposure and not making assumptions based on job titles*" (Kauppinen et al. 2003), page 76. This is interesting in relation to a study on acceptance rate of work-related disease claims performed by the Swedish Social Insurance Agency (Mattsson 2011). The study showed that women were less likely to have a disease accepted as work-related, especially if they worked in traditionally female-dominated occupations. Only about 15–24% of the studied cases between 2005 and 2010 were approved among women, compared to 32–40% among men. In addition, questions regarding competing risks, often factors unrelated to the work environment, were more often asked in cases concerning women compared to cases concerning men (Mattsson 2011). These statistics could be an effect of how the insurance regulation is constructed or by gender prejudices, but could also be explained by the fact that stronger evidence is generally available within traditionally male-dominated occupations. This is evident in most fields of medical research (Hamberg 2008).

Addressing not only the work environment that many men face, but also that which many women face, is an important responsibility of researchers and of the research community in general, such that both women's and men's realities are equally considered (European Commission, report 23857, 2009).

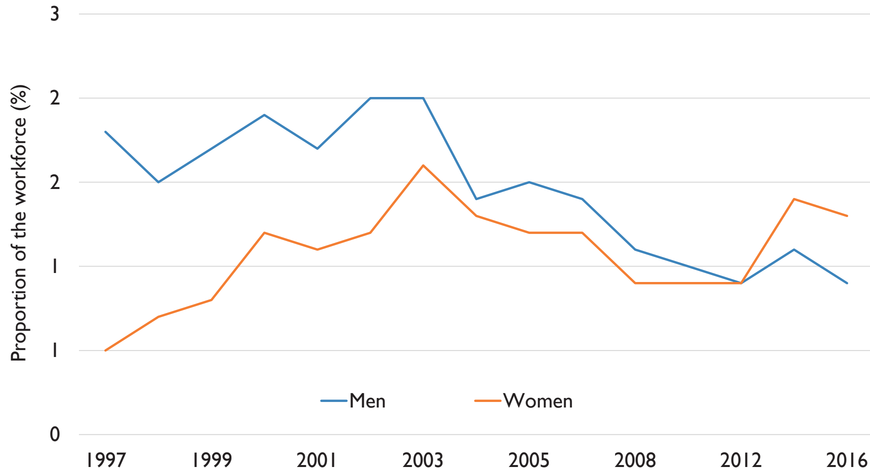


Figure 16. Reported work-related disorders due to noise shown as the proportion of all men and the proportion of all women in the Swedish workforce 16–64 years old (graph produced based on official data from Statistics Sweden).

Strengths and limitations

A strength in Paper I is the large number of sound levels measurements performed in the labour ward. However, a limitation is that only one labour ward was measured and that the measurements were unobserved. This limits the generalisability and limits the certainty in the evaluation of maximum sound levels. Another strength of Paper I was the rather high response rate (72 %) in the questionnaire survey. However, a limitation is the cross-sectional design, which restricts us from assessing causal effects. As we calculated a cumulative noise exposure index we were, to some degree, able to assess long-term effect of exposure from working in the obstetrical ward, but we may have underestimated the risk as we did not assess prior exposure. Although the study population included a majority of the personnel, the power was probably too low to determine effects on some hearing-related symptoms, such as hyperacusis, and may have influenced the analysis of interaction effects.

A limitation of Paper II is the selection of study participants and the limited sample size. We were able to account for the unbalanced sampling of subjects with and without symptoms in the analysis, but the restricted selection limits the generalisability of our findings. The limited sample size resulted in wide confidence intervals, causing uncertainty in the estimates. Moreover, the study indicated that more sensitive diagnostic tests for detecting mild hearing disorder may be needed. Also, longitudinal studies are required for actual predictive values.

A strength of Papers III and IV is the large sample size and the ability to assess relative risk in comparison to a randomly selected control cohort. However, the response rate was rather low, especially among controls (38%), but slightly higher among preschool teachers (51%). In a non-response analysis, we did not find major indications of selection bias with regard to the risk of hearing loss and tinnitus, but we did not have data to assess other outcomes. This analysis is presented in Paper III. A limitation of the analysis of relative risk in Paper III is that data was based on the baseline survey in a newly initiated cohort study, and as such cross-sectional in design. This limits the ability of drawing conclusions on causality. The retrospectively reported symptom onset did however strengthen the study by means of assessing incidence rate and incidence rate ratio. These results showed a similar trend of the risk as that found for RR with regards to the different symptoms. Retrospective report does however entail a risk of recall bias. When assessed in Paper III, we did not find major influence with regards to comparing the two cohorts. However, uncertainty in the exact reported year may still have influenced the analysis in paper IV. A strength in Paper IV was that we assessed noise exposure using a JEM, which decrease the risk of common method variance. The exposure assessment was also fully blinded to the outcome. However, the use of a JEM may introduce misclassification of exposure such that individuals with different job tasks with different exposure are assigned to the same exposure within a job family. Misclassification of exposure is also a limitation in Paper III, where only current exposure could be assessed. A strenght in Paper IV was that we could include a measure of prior exposure by means of a frailty component in the survival model. As the noise categories assigned by the JEM are wide, we were unable to fully assess a dose-response relationship. Moreover, the number of events occurring in the highest exposure category were few, which limited the power in the analysis of risk to high noise exposure and gave a wide confidence interval for the estimated hazard ratio.

One important strength in the overall conclusion of the thesis is that we have used different methods to assess occupational exposures in relation to hearing-related symptoms.

Conclusions and Implications

The overall finding of this thesis was that women working in obstetrical care and preschools had an increased risk of hearing-related symptoms. These human service occupations are characterised not only by stressful working conditions, but also by communication-intense noise and screaming. While longitudinal studies are required to ascertain causality, the notable level of risk suggest that hearing preventive measures should be taken.

Main findings:

- Equivalent sound levels in the labour ward exceeded 80 dBA (45%) and 85 dBA (5%). High maximum sound levels occurred during ongoing labours.
- Obstetrical personnel had increased risk of tinnitus and sound-induced auditory fatigue in association with calculated occupational noise exposure. Sound-induced auditory fatigue was also associated with noise annoyance.
- The questionnaire item assessing sound-induced auditory fatigue correctly identified more than 85% of women with fairly mild diagnosed hearing disorder and correctly dismissed 70% of women without disorder.
- Preschool teachers had more than twofold risk of sound-induced auditory fatigue, hyperacusis and difficulty perceiving speech and increased but less pronounced risk of hearing loss and tinnitus relative to the general population.
- Working in equivalent sound levels in the range of 75–85 dBA significantly increased the hazard of adult-onset hyperacusis, and particularly among women working in preschools who had a threefold hazard ratio compared to women working in exposure to equivalent sound levels below 75 dBA.
- No interaction between noise exposure, noise annoyance or work-related stress was found for obstetrical personnel. However, explorative analysis of the preschool and population cohorts indicate that these work-related factors likely have different effects on different hearing-related symptoms (mediating or moderating).
- Hearing protection is rarely used by obstetrical personnel and preschool teachers even though they report exposure to loud noise.

Future Perspective

As there is still less research on hearing-related outcomes among female workers compared to male workers, and within female-dominated occupations compared to male-dominated occupations, numerous questions relating to the aim of this thesis still remain to be answered.

Concerning the obstetrical care, no previous internationally published research investigating occupational noise and hearing have been found. Thus, replications of our study is needed to assess the extent of exposure and the generalisability of our results. Maximum sound levels should be measured under observation to gain further understanding on the sources of the high sound levels. Further research should also examine effects on the auditory system in more detail and in a larger sample, and diagnostic tests capable of capturing very mild signs of noise-induced hearing disorder should be developed further. In addition, studies should investigate if acoustical and organisational measures can reduce the noise exposure in obstetrical care.

Concerning the preschool work environment, cross-sectional studies clearly show a risk of self-reported hearing-related symptoms. Prospective longitudinal studies are now needed to improve understanding of causal and long-term effects of noise exposure and the role of stress. Studies should be directed both at detection of physiological mechanisms and at the individual experiences and consequences of suffering from hearing-related symptoms. Eligibility of work-related disease claims should also be evaluated. Hearing preventative and noise-mitigating measures should be studied further, not only for the sake of the personnel, but also for the children who spend most of their waking time in preschool.

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