Samuli Hannula

HEARING AMONG OLDER ADULTS — AN EPIDEMIOLOGICAL STUDY
SAMULI HANNULA

HEARING AMONG OLDER ADULTS
–AN EPIDEMIOLOGICAL STUDY

Academic dissertation to be presented with the assent of the Faculty of Medicine of the University of Oulu for public defence in the Auditorium of the Department of Anatomy, on 9 December 2011, at 12 noon

UNIVERSITY OF OULU, OULU 2011
Abstract

Age-related hearing impairment is the most common type of hearing impairment among adults. Adult-onset hearing impairment is one of the leading causes of disease burden worldwide and it is associated with social isolation and depression. As the proportion of older people is increasing in Western countries, the socioeconomic importance of adult hearing impairment will increase notably.

The aim of the present contribution was to study the epidemiological aspects of hearing and related factors among older adults. The prevalence of hearing impairment, defined either by audiometry or by a self-report, and the differences between these two were analyzed. Tinnitus and hyperacusis were also studied. Furthermore, the prevalence of ear diseases, otological risk factors, and noise exposure and their association with hearing thresholds were analyzed. In addition, audiogram configurations and certain subject-related factors and their relation to hearing were assessed.

The subjects were randomly sampled from the population register and they responded to an extensive questionnaire. Otological status was examined and pure tone audiometry was conducted. Data on 850 subjects aged 54–66 years were analyzed.

Hearing impairment was found to be a highly common condition with a prevalence of 26.7% when defined by better ear and 42.2% when defined by worse ear. Men had worse hearing than women. High-frequency sloping audiogram configurations were common. Self-reported hearing difficulty and measured hearing impairment seem to be associated at high frequencies. At least one ear disease or otological risk factor for hearing impairment was found among 18.4% of the subjects and noise exposure among 46%, more often by men. Interestingly, noise exposure did not seem to associate with hearing levels among subjects screened for ear disease or otological risk factors.

The results of the present study suggest that hearing impairment is a highly common condition among older adults and this should be taken into account when future hearing healthcare is planned. Furthermore, it seems that most of the subjects reporting hearing difficulty had no measured hearing impairment according to the criteria applied for eligibility for hearing aid fitting in Finland. Based on the results of the present study, the criteria for hearing impairment entitling persons for hearing aid fitting should be reconsidered.

Keywords: adult, hearing impairment, population, prevalence, self-report
Hannula, Samuli, Ikääntyvän kuulo–epidemiologinen tutkimus.
Oulun yliopisto, Lääketieteellinen tiedekunta, Kliinisen lääketieteen laitos, Korvaa- nen- ja kurkutaudit, PL 5000, 90014 Oulun yliopisto
Oulu

Tiivistelmä

Ikäkuulo on yleisin aikuisten kuulovian aiheuttaja, ja aikuisiin kuulovika on merkittävä terveydellinen haittatekijä. Kehittyneiden maiden ikäjakauman painottuessa vanhempiin ikäluokkiin aikuisten kuulovikoista tulee merkittävä sosioekonominen rasite yhteiskunnille.


Tutkimustulokset osoittavat, että kuulovika on hyvin yleinen löydös tämän ikäisillä aikuisilla. Vanhenevat ikäluokat ovat merkittäviä haaste kuulonhuollolle, ja tämä olisi otettava huomioon päätettäessä kuulonhuollon rahoituksesta. Useat niistä aikuisista, jotka kokivat kuulo-ongelmia, eivät kuulokäyrälöysksiä mukaan täyttäneet Suomen kriteereitä kuulokojosivitukselle. Tämän tutkimuksen perusteella näyttääkin siltä, että kuntoutustarvetta arvioitaudessa kuulovian kriteereitä tulisi kansalliseen tarkistaa ottamalla huomioon myös huononmaan korvan kuulokynnysten sekä kuulon alennema korkeilla taajuuksilla.

Asiasanat: aikuinen, kuulovika, oma ilmoitus, vallitsevuus, väestötutkimus
Acknowledgements

This study was carried out at the Department of Otorhinolaryngology, University of Oulu, during the years 2003–2011. The clinical work was mainly executed in the hearing center of Oulu University Hospital.

I am grateful to the heads of the department, Professor Olli-Pekka Alho M.D., Ph.D., Docent Jukka Luotonen M.D., Ph.D., and Docent Petri Koivunen M.D., Ph.D., for giving me the opportunity to conduct this academic project along with my work as clinical teacher. In addition, I am sincerely grateful to the former head of the department Professor Kalevi Jokinen M.D., Ph.D., for his encouragement to choose otorhinolaryngology as my medical specialty.

My deepest gratitude goes to the supervisors of my thesis: Emeritus Professor Martti Sorri M.D., Ph.D., for leading me to the world of audiology and for the unique possibility to get acquainted with the international audiological forum; Docent Elina Mäki-Torkko M.D., Ph.D., for the numerous Skype counsellings and swift e-mail answers whenever I needed help, and special thanks for your encouragement in those moments when anguish and exhaustion overtook the young researcher; Professor Kari Majamaa M.D., Ph.D., for your prompt and accurate comments which often gave a new point of view to the traditional concepts of audiology. It was against all odds, but still you managed to create a researcher out of a simple man. I am most indebted to the three of you.

The official reviewers of this thesis, Professor Einar Laukli M.Sc. (Tech.) Ph.D., University of Tromsø, and Docent Hannu Valtonen M.D., Ph.D., University of Helsinki, deserve my deepest respect for their encouraging and professional comments which helped me to revise the manuscript into a more focused form.

I express my appreciation to Pekka Aikio M.Sc., Dr.H.C., for his assistance during my expeditions in Lapland. I am deeply thankful to my co-author and statistical consultant Risto Bloigu M.Sc., for teaching me how to solve statistical problems faced during this study. I express my gratitude to the former head of the hearing center Professor Heikki Löppönen M.D., Ph.D., for administrative support during the clinical studies. In addition, warm thanks go to the personnel of the hearing center, especially to the audiological assistants who helped us in the clinical work. Keith Kosola, authorized translator, deserves commendation for his expertise in the language of the original articles and the final manuscript of this thesis. I owe particular thanks to all my European colleagues, especially in Antwerp, for their interesting collaboration in the ARHI project. My special thanks
go to the former secretary of our department Mrs. Raili Puhakka for her general and economic assistance and care during the ARHI project.

I feel very privileged to be a part of our excellent ORL department and thus wish to give my praise to all of my present and former colleagues and fellow workers for their friendship and help, especially to Docent Kyösti Laitakari M.D., Ph.D., for being my otological mentor, Heino Karjalainen M.D., Ph.D., for setting an example of a good clinical teacher, and Docent Kerttu Huttunen M.Sc. Ph.D., for her supporting opinions and comments concerning different aspects of the research.

During these past years this project has taken over my life and I have unforgivenly neglected my friends, relatives, and family, still you have not forgotten me. I am sincerely grateful for your support and friendship; I hope you can forgive me. My deepest thanks belong to my dear old friends Jukka, Jukka, Lotta, Mikko, Outi, and Samuli and their families and to many other friends, including my colleagues infected by Botrytis Cinerea.

I extend my love to my brother Teemu and his family: Annukka, Joonas, and Juuso, I am cordially grateful for your care and love.

To my beloved parents, Saara and Herman, thank you for believing in your firstborn and helping him to find his own place in the world.

Pauliina, your infinite love keeps me alive; I love you.

This research project has been supported by the European Union ARHI project, by KEVO funding of Oulu University Hospital, and by the Korvatautien tutkimussäätiö foundation.

Oulu, October 2011

Samuli Hannula
# List of abbreviations and definitions

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARHI</td>
<td>age-related hearing impairment</td>
</tr>
<tr>
<td>ANOVA</td>
<td>analyses of variance</td>
</tr>
<tr>
<td>BEHL</td>
<td>better ear hearing level</td>
</tr>
<tr>
<td>BMHS</td>
<td>Blue Mountain hearing study</td>
</tr>
<tr>
<td>CI</td>
<td>confidence interval</td>
</tr>
<tr>
<td>COM</td>
<td>chronic otitis media</td>
</tr>
<tr>
<td>dB</td>
<td>decibel</td>
</tr>
<tr>
<td>EHLS</td>
<td>epidemiology of hearing loss study</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>FLAT</td>
<td>flat audiogram configuration</td>
</tr>
<tr>
<td>HFGS</td>
<td>high-frequency gently sloping audiogram configuration</td>
</tr>
<tr>
<td>HFSS</td>
<td>high-frequency steeply sloping audiogram configuration</td>
</tr>
<tr>
<td>HI</td>
<td>hearing impairment</td>
</tr>
<tr>
<td>HL</td>
<td>hearing level</td>
</tr>
<tr>
<td>ISO</td>
<td>International Organization for Standardization</td>
</tr>
<tr>
<td>kHz</td>
<td>kilohertz</td>
</tr>
<tr>
<td>LFA</td>
<td>low-frequency ascending audiogram configuration</td>
</tr>
<tr>
<td>MFU</td>
<td>mid-frequency u-shaped audiogram configuration</td>
</tr>
<tr>
<td>NPV</td>
<td>negative predictive value</td>
</tr>
<tr>
<td>NSH</td>
<td>national study of hearing</td>
</tr>
<tr>
<td>OR</td>
<td>odds ratio</td>
</tr>
<tr>
<td>PPV</td>
<td>positive predictive value</td>
</tr>
<tr>
<td>PTA</td>
<td>pure-tone average</td>
</tr>
<tr>
<td>SD</td>
<td>standard deviation</td>
</tr>
<tr>
<td>UNCLA</td>
<td>unclassified audiogram configuration</td>
</tr>
<tr>
<td>WEHL</td>
<td>worse ear hearing level</td>
</tr>
<tr>
<td>WHO</td>
<td>World Health Organisation</td>
</tr>
</tbody>
</table>
List of original publications

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


Table of contents

Abstract  
Tiivistelmä  
Acknowledgements 7  
List of abbreviations and definitions 9  
List of original publications 11  
Table of contents 13  
1 Introduction 17  
2 Literature review 19  
2.1 Hearing and the auditory system ............................................................19  
2.1.1 Hearing and its importance .......................................................... 19  
2.1.2 Definitions ....................................................................................20  
2.2 Etiology of hearing impairment among older adults ..............................22  
2.2.1 Presbyacusis and age-related hearing impairment .......................... 22  
2.2.2 Otological factors ........................................................................23  
2.2.3 Trauma .........................................................................................26  
2.2.4 Systemic disease ..........................................................................26  
2.2.5 Otoxic treatment ........................................................................26  
2.2.6 Environmental factors ..................................................................27  
2.2.7 Genetic factors .............................................................................28  
2.3 Tinnitus and hyperacusis ....................................................................29  
2.3.1 Tinnitus .......................................................................................29  
2.3.2 Hyperacusis ................................................................................29  
2.4 Prevalence of hearing impairment .......................................................29  
2.5 Comparison of self-reported and measured hearing impairment ........33  
2.6 Prevalence of tinnitus and hyperacusis .............................................34  
2.7 Prevalence of audiogram configurations ...........................................34  
2.8 Prevalence of ear diseases ..................................................................35  
3 Aim of the study 37  
4 Subjects and methods 39  
4.1 Subjects ............................................................................................39  
4.1.1 Sample collection .........................................................................39  
4.1.2 Analysis of non-participants .......................................................41  
4.2 Methods ............................................................................................41  
4.2.1 Data collection .............................................................................41
1 Introduction

The prevalence of hearing impairment (HI) is high among older adults in Western countries (Moscicki et al. 1985; Cruickshanks et al. 1998a). Worldwide, adult-onset HI is one of the main causes of disease burden, and it is the most important sensory impairment among men and second most important among women (Beaglehole et al. 2003).

Age-related hearing impairment (ARHI) is a multifactorial process including genetic, medical, and environmental factors (Fransen et al. 2003; Van Eyken et al. 2007b). Some of the risk factors associated with HI are preventable or treatable, such as smoking, high body mass index, occupational noise (Fransen et al. 2008), cardiovascular disease (Hull & Kerschen 2010), and diabetes (Bainbridge et al. 2010). Consequently, in the future ARHI might be considered a condition which can be altered and even prevented to some extent.

The age distribution of the population in Western countries is shifting towards older age (OECD 2009). The prognosis in Finland is that 23% of the population will be 65 years old or older in 2020 (Statistics Finland 2009). ARHI already is an important socioeconomic issue and is becoming even more so as its diagnosis and rehabilitation will require vast amounts of financing (Sorri et al. 2001a; Sorri et al. 2001b). The lack of good epidemiological studies on HI has been noticed by the World Health Organization (WHO), and a databank containing available epidemiological studies has recently been established (Pascolini & Smith 2009).

Hearing impairment has many adverse effects on an individual’s daily life (Cacciatore et al. 1999; Ishine et al. 2007; Lopez-Torres Hidalgo et al. 2009). A large proportion of adults who would benefit from hearing aids do not possess one (Sorri et al. 2001a; Davis et al. 2007) and have not even discussed their hearing difficulty with their family practitioner (Wensing et al. 2001). Hearing-impaired persons have to overcome several obstacles in order to get access to audiological services (Kiessling et al. 2003). Such obstacles include negative attitudes and a lack of knowledge, not only in society and among significant others, but also among medical professionals. To solve this problem of under-diagnosis and under-treatment, the public should be made aware of ARHI and its consequences. Moreover, screening tests for older adults are suggested (Davis et al. 2007), as several interventions are available after screening failure, such as hearing aid rehabilitation, alternative amplification strategies, hearing tactics, and education (Pronk et al. 2011).

Planning of hearing healthcare requires population-based epidemiological data on hearing in adults. Evidence-based decision-making calls for data on the
prevalence of HI and associated problems. In addition, information about risk factors for HI is needed, especially in planning programs that aim to prevent HI.

The aim of the present study was to produce population-based epidemiological data on hearing among older adults.
2 Literature review

2.1 Hearing and the auditory system

The auditory system is comprised of the outer ear, middle ear, inner ear, auditory nerve, central auditory pathways, and auditory cortex. Sounds are caught, sensed, and processed in a complex way and finally interpreted by the brain. Human beings sense and process sounds with the auditory system, and the entire central nervous system forms a unique sensation that together with auditory input is altered and modified by many psychological aspects and also by the input of our other senses. This process is called hearing (Yost 2000).

2.1.1 Hearing and its importance

From the developmental point of view, it is clear that hearing is a vital sense for human beings, as the fetus’s cochlea is ready at about mid-pregnancy, and there is evidence that human babies can hear sound in the uterus (Birnholz & Benacerraf 1983; Gerhardt & Abrams 1996). Hearing plays an essential role in the development of speech and spoken language. Different general aspects of hearing (Levine 1960) are illustrated in Figure 1.

When considering ARHI and other adult-onset HIs, there are plenty of reports on the adverse effect of HI on individuals’ well-being and quality of life, which can lead to depression, loneliness, anxiety, somatisation, social isolation, and dementia (Mulrow et al. 1990b; Cacciatore et al. 1999; Dalton et al. 2003; Chia et al. 2007; Lopez-Torres Hidalgo et al. 2009; Saito et al. 2010; Lin et al. 2011). Many of these adverse effects are reversible with hearing aids (Mulrow et al. 1990a).
Figure 1. Hearing and its importance.

### 2.1.2 Definitions

**Type of hearing impairment**

*Sensory* HI is caused by damage in the inner ear, whereas *sensorineural* HI includes also retrocochlear and central HI. Sensorineural HI is the most common type of HI (Davis 1995; Cruickshanks et al. 1998a) and is seen in conditions such as ARHI, noise-induced HI, sudden sensorineural hearing impairment, and a majority of congenital HIs. The range of severity varies from mild to profound HI.

*Conductive* HI is caused by a process in the outer or middle ear that leads to impaired transduction of sound vibration to the inner ear. In conductive HI the inner ear functions normally but the sound waves do not reach it properly. A classical example is otosclerosis. The maximum conductive HI is 60 dB HL.
Mixed HI is a combination of sensorineural and conductive HI. An example of a mixed type of HI could be ARHI and adhesive otitis media in the same ear in an older person.

Retrocochlear or central HI is a less common condition than the previous three. As the term itself indicates, the outer, middle, and inner ear are all fully functional, but the disease affects the auditory system at the level of the auditory nerve or more centrally in the mid brain or even in the auditory cortex. An example of a condition causing retrocochlear HI is vestibular schwannoma, resulting in reduced neural transmission in the auditory nerve.

Degree of hearing impairment

There is no generally accepted definition for the degree of HI. Many definitions have been proposed, which has led to difficulty in comparing results from different studies and prevalence figures (Pascolini & Smith 2009). Despite different definitions, it is common to separate HI into four groups according to severity, i.e. mild, moderate, severe, and profound HI.

The degree of HI is usually defined on the basis of the average of thresholds calculated over a certain frequency range, i.e. pure-tone average (PTA). This PTA can be calculated for the left and/or right ear, but usually the degree of HI is reported as either better ear hearing level (BEHL) or worse ear hearing level (WEHL).

It has become more common to apply BEHL calculated over 0.5, 1, 2, and 4 kHz (BEHL_{0.5,1,2,4 kHz}), as recommended by an EU expert group (Stephens 1996) and the WHO (Pascolini & Smith 2009) (Table 1). Although the same frequency range is applied, these two definitions differ in terms of the hearing level used to define the severity of HI (Table 1).

<table>
<thead>
<tr>
<th>Degree of HI</th>
<th>BEHL dB HL</th>
<th>Present study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild</td>
<td>20&lt;HI&lt;40</td>
<td>20&lt;HI&lt;41</td>
</tr>
<tr>
<td>Moderate</td>
<td>40&lt;HI&lt;70</td>
<td>40&lt;HI&lt;61</td>
</tr>
<tr>
<td>Severe</td>
<td>70&lt;HI&lt;95</td>
<td>60&lt;HI&lt;81</td>
</tr>
<tr>
<td>Profound</td>
<td>HI≥95</td>
<td>PTA≥95</td>
</tr>
</tbody>
</table>

A modified table reprinted with permission from Informa Healthcare.
Audiogram configurations

Several ear diseases are traditionally associated with a typical audiogram shape, i.e. configuration. One example is Ménière’s disease, which affects low-frequency thresholds or presents with a peaked audiogram configuration (Ries et al. 1999; Halmagyi et al. 2003). Another good example is noise-induced hearing loss, which is associated with a 3–6-kHz dip (Pyykkö et al. 2003). Yet, an association between audiogram configurations and ear pathologies has been questioned, as notched audiograms have been found among subjects with no history of noise exposure (Nondahl et al. 2009). Interestingly, over half of the 3430 US veterans (age range 20–89 years) complaining of HI did not present a 4 kHz notch (Wilson 2011). Furthermore, mid-frequency U-shaped audiograms classically interpreted to be associated with hereditary HI can have other etiologies (Wong & Bance 2004). Different audiogram shapes have been linked to pathological findings of presbyacusis already in the 1960s (Schuknecht 1964). Audiogram configurations have also been applied in genetic presbyacusis studies (Demeester et al. 2010) and phenotype-genotype association studies (Liu & Xu, 1994; Salvinelli et al. 2004).

The early methods of classifying audiograms encountered problems due to the large variety of configurations, which restricted their clinical use (Guild 1932; Carhart 1945). The same problem still exists, and that is why a computer-based classification system has been developed to make it easier for clinicians and researchers to define and interpret audiogram configurations (Margolis & Saly 2007).

2.2 Etiology of hearing impairment among older adults

2.2.1 Presbyacusis and age-related hearing impairment

Presbyacusis refers to degenerative changes in the aging auditory system, but these physiological effects are hard to distinguish from other factors affecting hearing (Glorig & Nixon 1962). Studies on the temporal bone of an aged cochlea (Schuknecht 1964; Schuknecht & Gacek 1993) have enabled the well-known classification of human presbyacusis, which is 1) Sensory presbyacusis with a loss of hair cells and supporting cells, leading to abrupt high-frequency HI, 2) Neural presbyacusis with a loss of afferent neurons in the cochlea, leading to progressive loss of word discrimination but stable pure-tone thresholds, 3) Strial or metabolic presbyacusis with atrophy of the stria vascularis and the lateral wall of the cochlea, leading to HI with a flat audiogram configuration, and 4) Cochlear conductive presbyacusis
with stiffening of the basilar membrane, leading to HI gradually sloping towards high frequencies. In addition, a mixed presbyacusis type, defined as a combination of two or more of the four main types and indeterminate presbyacusis, referring to cases that do not fit into the main definitions, have been added (Schuknecht & Gacek 1993).

Schuknecht’s (1964) classification is based on only 21 cases of human temporal bones and has since been tested by other scientists. A later study on presbyacusis investigated a sample of six temporal bones with a flat audiogram configuration and compared their stria vascularis volume with that of temporal bones (n=10) with no HI and found that only one of six temporal bones had significantly reduced stria vascularis volume (Nelson & Hinojosa 2003). Outer hair cell loss and ganglion cell loss have been found in all tested subjects with presbyacusis (21/21), and most of them also had inner hair cell loss (18/21) (Nelson & Hinojosa 2003). In addition, subjects with a downward sloping audiogram configuration showed degeneration of stria vascularis, spiral ganglion, and both inner and outer hair cells (Nelson & Hinojosa 2006). Schuknecht’s (1993) study has been criticized because most of the male subjects had a history of noise exposure, possibly biasing the results (Gates & Mills 2005). It has been suggested that age-related degeneration in the cochlea appears mainly in stria vascularis (Gates & Mills 2005), as well as a loss of hair cells and spiral ganglion neurons (Bao & Ohlemiller 2010). Furthermore, Schuknecht’s theory leaves out possible age-related changes more centrally in the auditory system, an interesting issue as some of the hearing problems among older adults are due to degeneration in the medial olivocochlear efferent pathway and generally in the central auditory system (Chisolm et al. 2003; Ohlemiller 2004).

Instead of presbyacusis, it has become more common to talk about ARHI, which is a complex disease (Van Eyken et al. 2007b) and represents the cumulative result of various factors affecting hearing, i.e. subject-related, environmental, and genetic factors. Most of these factors are discussed in the following.

2.2.2 Otological factors

Otological diseases can lead to various forms and degrees of HI. This chapter concentrates on clinically prevalent ear diseases in adults. Thus, some pathologies, such as tumors, rare infections, and processes of the temporal bone, are deliberately ruled out of this review, as are complications of ear diseases. Instead, the focus is on chronic otitis media (COM), otosclerosis, Ménière’s disease, sudden sensorineural HI, and herpes zoster oticus.
Chronic otitis media (COM) includes a variety of ear diseases, both inactive and active, including infections and cholesteatoma. In some classifications, persistent but inactive perforations of the tympanic membrane are classified as COM even though infection does not necessarily appear, at least in the middle ear. The etiology of such perforations can be trauma or infection, for example. Depending on the size of the perforation, hearing may be normal or reach up to conductive HI of 60 dB HL and may be accompanied by sensorineural HI when the inner ear is affected, too. Chronic or recurrent middle ear infections and persistent otitis media with effusion are included in the definition of COM. Problems with middle ear gas exchange and Eustachian tube dysfunction can lead to middle ear atelectasis, and in the end to adhesive otitis media, where the tympanic membrane is retracted to the middle ear cavity and the pneumatic space disappears, leading to maximal conductive HI. In addition, there may be erosion of the middle ear ossicles and risk of a cholesteatoma. Cholesteatomas can be either acquired or congenital. The pathogenesis of acquired cholesteatomas is discussed to a great extent in the literature, and several different theories exist. According to one theory, cholesteatomas are epidermal inclusion cysts of the middle ear and/or mastoid, i.e. retraction pockets containing keratin debris. A cholesteatoma can erode bone and it has a destructive nature. The HI can be of different types and degrees. Although it usually presents conductive HI, a cholesteatoma can also lead to mixed HI when chronic infection or ototoxic substances affect the inner ear. In some cases a cholesteatoma creates an inner ear fistula, which can lead to sensorineural, even total hearing loss. The treatment of choice is surgery, and hearing rehabilitation is often needed, as well. (Chole 2010)

The most common clinical picture of otosclerosis is a progressive conductive HI caused by abnormal resorption and remodelling of bone, leading to ossicular fixation of the third middle ear ossicle, i.e. stapedial fixation to the oval window (Cureoglu et al. 2006). However, in about 10% of otosclerosis cases, sensorineural HI is also present. Histopathological studies have shown that the majority of otosclerosis cases do not present clinical signs, referred to as histological otosclerosis (House & Cunningham 2010). The etiopathogenesis of otosclerosis is complex, including both genetic and environmental factors (Schrauwen & Van Camp 2010; Karosi & Sziklai 2010). The most common treatment today is surgery (Meyer & Lambert 2004). Hearing aids are an alternative or conjunctive intervention to surgery. In addition, fluoride therapy may be applied in rare cases of inner ear affection (Cureoglu et al. 2010).
The classical symptoms of Ménière’s disease are episodic vertigo, fluctuating sensorineural HI, aural fullness, and tinnitus (AAO-HNS 1995). The pathology behind the symptoms is probably perturbation of normal ionic transduction, leading to well-known endolymphatic hydrops (Semaan & Megerian 2010). Hearing fluctuates and deteriorates over time, stabilizing at a mean level of 50–60 dB HL after 5–10 years (Huppert et al. 2010). There is no clear consensus on the treatment of Ménière’s disease, but life style adjustment together with medication such as betahistine, diuretics, corticosteroids, or vasodilators are usually included. In addition, intratympanic gentamycin and steroids are used (Martin Gonzalez et al. 2010). Different surgical treatments have been presented, but a recent Cochrane review does not support surgery as a treatment of Ménière’s disease (Pullens et al. 2010).

Sudden idiopathic sensorineural hearing impairment is an attack of rapid HI where both the affected frequencies and the severity of HI vary. There is no universally accepted definition for the condition, but the most common definition is hearing impairment ≥30 dB at three contiguous frequencies within 72 hours. (Chau et al. 2010). The cause of sudden idiopathic sensorineural hearing impairment remains unclear, but suspected etiologies include infections or vascular or hematologic diseases (Chau et al. 2010). The estimated annual incidence varies between 13–20/100,000 (Byl, 1984; Nakashima et al. 2000). No treatment of choice is known (Conlin & Parnes 2007), but promising results have been reported after treatment with corticosteroids, systemically or intratympanically (Seggas et al. 2011).

Herpes (Varicella) zoster oticus or Ramsay-Hunt Syndrome is a clinical entity where infection is caused by reactivation of Varicella zoster virus in geniculate ganglions, leading to mucosal and cutaneous lesions in the auricle. In addition to HI, facial paralysis and vertigo are often seen. Treatment with antiviral medication is important (Ohtani et al. 2006; Gupta et al. 2007). In a study including 15 subjects, some degree of HI was found in most of the patients and it seemed that the auditory system can be affected at the cochlear, retrocochlear, or multiple sites (Kaberos et al. 2002).

Another rare cause of HI is bacterial meningitis, and the median risk for HI as a sequela of meningitis is reported to be 6.1% in a recent worldwide meta-analysis (Edmond et al. 2010).
2.2.3 Trauma

Among patients with a skull fracture, 14–22% sustain a temporal bone fracture (Brodie 2010). Temporal bone fractures can tear the tympanic membrane or disrupt the ossicular chain in the middle ear, leading to a conductive HI (Chujo et al. 2008). Fractures that disrupt the otic capsule produce severe to profound sensorineural HI (Brodie 2010). Direct trauma to the ear can also produce a pressure effect big enough to rupture the tympanic membrane, ossicular chain, or even the round window (Brodie 2010). The same injury can be associated with barotraumas, for example in diving accidents (Rozsasi et al. 2003; Shupak 2006) or blast accidents (Darley & Kellman 2010).

2.2.4 Systemic disease

Cardiovascular diseases have also been associated with HI (Rosen & Olin 1965; Susmano & Rosenbush 1988; Gates et al. 1993). Population-based studies have shown that subjects with diabetes have poorer hearing than those without (Dalton et al. 1998; Bainbridge et al. 2008; Gopinath et al. 2009; Bainbridge et al. 2010). This was also found in a case-control study from the UK (Tay et al. 1995).

Autoimmune HI is another clinical entity usually presented as bilateral sudden or progressive sensorineural HI (within weeks or months) and with possible vestibular involvement. The etiology of organ-specific autoimmune HI is unknown. However, it is known that sensorineural HI can be associated to many systemic autoimmune diseases, i.e. Wegener’s granulomatosis, rheumatoid arthritis, polyarteritis nodosa, Sjögren’s syndrome, Cogan’s syndrome, systemic lupus erythematous, progressive systemic sclerosis, relapsing polychondritis, ulcerative colitis, and Hashimoto’s thyreoiditis, to mention a few. (Mathews & Kumar 2003; Bovo et al. 2006)

2.2.5 Ototoxic treatment

Aminoglycosides, known to be irreversibly toxic to the inner ear, are commonly prescribed antibiotics worldwide, although in developed countries they are nowadays used only for severe infections and against multi-resistant bacteria. In the past, the most common indication for aminoclygosides was tuberculosis (Rizzi & Hirose 2007). The incidence of sensorineural HI is reported to vary from a few percent to 33% of cases, and vestibular toxicity is found in 15% of subjects treated with aminoglycosides (Rybak & Ramkumar 2007). Aminoglycosides enter
hair cells and launch cell apoptosis through an active signal pathway, leading to unpreventable injury (Warchol 2010). HI is usually in the high-frequency range and might be associated with tinnitus (Rizzi & Hirose 2007).

Another important ototoxic drug is *cisplatin*, a chemotherapeutic agent used to treat various malignancies. Studies have reported HI among 75–100% of patients, with elderly and pediatric patients being at the highest risk. Cisplatin causes high-frequency HI, and the target cells seem to be hair cells, spiral ganglion cells, and lateral wall tissue where apoptosis is launched (Rybak & Ramkumar 2007).

A third ototoxic treatment worth mentioning is *radiotherapy*, which is commonly applied in head and neck tumors and brain malignancies. Radiotherapy may affect all the structures of the ear, and about 30% of patients develop late-onset sensorineural HI, which may be severe or profound (Jereczek-Fossa *et al.* 2003).

Reversible HI has been reported to be associated with the use of diuretics, salicylates, non-steroidal anti-inflammatory drugs, and quinine (Martini & Prosser 2003).

### 2.2.6 Environmental factors

The most common environmental factor causing HI is noise. The three most common types of exposure causing *noise-induced hearing loss* (NIHL) are occupational noise, leisure time noise, and gunfire noise. Impulse noise is considered to be more harmful than steady-state noise. Exposure to noise and *organic solvents* as well as exposure to noise and smoking or use of analgetics may have cumulative effects on hearing (Pyykkö *et al.* 2003).

Exposure to noise is one factor behind ARHI. Among 70-year-old Swedish men, those exposed to occupational noise have 10–15 dB HL poorer hearing in the high-frequency area than those not exposed (Rosenhall *et al.* 1990). Furthermore, occupational noise has been found to be a risk factor for ARHI in a European multicenter study (Fransen *et al.* 2008).

*Smoking* was an independent factor for HI in two large population-based studies with more than 3000 participants each (Cruickshanks *et al.* 1998; Fransen *et al.* 2008; Agrawal *et al.* 2009) and in a large US study among over 2000 Medicare beneficiaries (Helzner *et al.* 2005). A large multicenter study among over 4000 Europeans has found an association between smoking and HI after accounting for cardiovascular diseases and body mass index (Fransen *et al.* 2008).
The Human Field Studies Working Group has provided a list of chemicals that may cause HI and need further research. These chemicals include solvents (toluene, styrene, xylene, spirits/stoddard, carbon disulfide, fuels, perchloroethylene), asphyxiants (carbon monoxide, hydrogen cyanide), metals (lead, mercury), and pesticides/herbicides (paraquat, organophosphates) (Morata 2003). Toluene, styrene, and n-hexan have been shown to be ototoxic in rats, but in humans the dose-response/effect is not so clear (Hoet & Lison 2008; Vyskocil et al. 2008).

2.2.7 Genetic factors

The genetics of ARHI is a rather new research area, but several genetic factors have been identified which contribute to ARHI in inbred mouse strains (The Jackson Laboratory 2011). The heritability of ARHI varies between 0.35–0.75 (Karlsson et al. 1997; Gates et al. 1999; Christensen et al. 2001; Viljanen et al. 2007). A family history of HI is associated with moderate or severe ARHI (McMahon et al. 2008) and familial aggregation of ARHI is stronger among women than among men (Gates et al. 1999). Studies seeking to identify genes for ARHI among humans are few, but some promising candidate genes have been reported. For example, there is a significant association between KCNQ4, a voltage-dependent potassium channel gene, and ARHI (Van Eyken et al. 2006). An association between NAT*6A, a detoxification enzyme, and ARHI has been found in two studies (Unal et al. 2005; Van Eyken et al. 2007a). In addition, associations with ARHI have been reported for GRLH2 (Van Laer et al. 2008) and GRM7 (Friedman et al. 2009). Moreover, mutations in mitochondrial DNA are associated with various forms of HI (Fischel-Ghodsian 2003), and acquired mitochondrial mutations are found in ARHI subjects (Bai et al. 1997; Dai et al. 2004). However, a recent study analyzing the entire mitochondrial genome did not find any association between inherited mitochondrial variants and ARHI (Bonneux et al. 2011).

Oxidative damage caused by reactive oxygen species has been suggested to be one of the etiologies for ARHI. Mitochondria are the major source of reactive oxygen species, and their production increases with age (Someya & Prolla 2010). In addition, it has been suggested that mitochondrial apoptosis is related to ARHI (Someya & Prolla 2010). Furthermore, there is an association between ARHI and polymorphism in genes that encode enzymes involved in detoxification of reactive oxygen species and other cytotoxic molecules (Van Eyken et al. 2007a).
2.3 Tinnitus and hyperacusis

2.3.1 Tinnitus

Tinnitus is a common symptom and is defined as perception of sound without an external acoustic stimulus. Tinnitus has multiple etiological hypotheses, such as aberrant neural activity from the cochlea to the auditory cortex, damaged unregulated hair cells leading to over-stimulation of the auditory nerve, or a lack of suppressive actions in the auditory cortex (Seidman et al. 2010). At the moment there is no single therapy suitable for all patients, and a large variety of different treatments have been proposed. For individuals with tinnitus and HI, a hearing aid may be a good alternative for treating tinnitus. Tinnitus retraining therapy and cognitive behavioral therapy are other choices of treatment worth mentioning (Phillips & McFerran 2010).

2.3.2 Hyperacusis

A person with hyperacusis has increased sensitivity to sounds that would not normally trouble other individuals. In most cases there is no underlying medical condition, and many potential mechanisms for this symptom have been suggested (Anari et al. 1999). However, there are some medical conditions that are associated with hyperacusis, as 90% of patients with William’s syndrome (deficits in motor control, conceptual reasoning, problem solving, spatial cognition, and arithmetic ability) report hyperacusis. Hyperacusis is also associated with migraine, depression, head injuries, Lyme disease, and post-traumatic stress disorder. A modified version of tinnitus retraining therapy has been suggested as one choice of treatment (Katzenell & Segal 2001; Baguley 2003). In addition, cognitive behavioral therapy has been proposed as a treatment option (Baguley 2003).

2.4 Prevalence of hearing impairment

Various definitions of HI have been applied in different studies. Some of the earlier epidemiological studies on HI are based on self-reported hearing difficulty (Rosenhall et al. 1987; Rosenhall et al. 1999). Questions that screen for hearing difficulty differ between studies, and in some studies several questions or a questionnaire has been used (Table 2). Furthermore, different questions will produce different results (Davis 1995). Other important aspects to consider when evaluating prevalence
estimates are the demographics of the population, geographical locations, changes over time, and the structure of the questionnaire (Stephens et al. 2004).

When defining HI based on hearing levels measured by pure tone audiometry, the problem of definitions is faced again. As seen in Table 2, many definitions of HI have been used. Some studies are based on the BEHL and others on the WEHL when defining the degree of HI. In some studies mean binaural calculations have been applied, which will bias the figures for unilaterally hearing-impaired subjects (Gomez et al. 2001). There are also differences in the frequency ranges of PTAs used and differences in the hearing levels chosen (Table 2).

The sampling of the study subjects is another critical point of the study design. A method of choice is a population-based random sample, as only this allows generalization of the study results to the general population, as recently pointed out by the WHO (Pascolini & Smith 2009). There are some studies presenting prevalence figures of HI among older adults in Western countries (Table 2), and only three of these reported analyses of non-participants, an important aspect for generalization of the results. The Epidemiology of Hearing Loss Study (EHLS) reported 45.9% prevalence in the US population aged 48–92 years (Cruickshanks et al. 1998a), while 18.9% prevalence among 51–60-year-old subjects was reported by the National Study of Hearing (NSH) in Great Britain (Davis 1989). Both of these studies applied measured hearing levels, whereas in an Italian study the prevalence of self-reported difficulty was 27% (Cacciatore et al. 1999). A slightly higher prevalence of 31.2% has been reported by the NSH for self-reported hearing difficulty in a noisy background (Davis 1989).

The prevalence of HI increases with age (Davis, 1989; Uimonen et al. 1999), and a longitudinal study from the US reported a five-year incidence of 21% for HI (worsening of $\text{PTA}_{0.5,1,2,4\,\text{kHz}} > 5\,\text{dB HL}$) (Cruickshanks et al. 2003). A British study has shown that the rate of deterioration among persons older than 55 years is 9 dB per decade (Davis et al. 1990). The WHO databank of the prevalence of HI currently includes 53 studies conducted in 31 countries around world (Pascolini & Smith 2009).
Table 2. Population-based studies on the prevalence of hearing impairment (HI) among older adults in Europe, North America, and Australia. When possible, the results are presented for a subsample of the study population and according to gender, men (m) and women (w).

<table>
<thead>
<tr>
<th>Study Country</th>
<th>Subjects</th>
<th>Sampling</th>
<th>Prevalence of HI among genders (%)</th>
<th>Definition of HI (dB HL)</th>
<th>Analyses and proportion of non-participants (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lopez-Torres Hidalgo et al. 2009</td>
<td>1162 (44)</td>
<td>Random Albacate</td>
<td>m &amp; w 44</td>
<td>1 kHz and/or 2 kHz ≥40</td>
<td>None (16)</td>
</tr>
<tr>
<td>Spain</td>
<td>65–96</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agrawal et al. 2008*</td>
<td>970 (unknown)</td>
<td>Random US representative</td>
<td>m &amp; w 29</td>
<td>WEHL0.5-4 kHz ≥25</td>
<td>None (unknown)</td>
</tr>
<tr>
<td>US</td>
<td>50–59</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chia et al. 2007*</td>
<td>3498 (44)</td>
<td>Census Blue mountains</td>
<td>m &amp; w 51</td>
<td>Self-reportc</td>
<td>None (25)</td>
</tr>
<tr>
<td>Australia</td>
<td>≥49</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hietanen et al. 2005*</td>
<td>286 (34)</td>
<td>All in age range Jyväskylä</td>
<td>m 92 w 66</td>
<td>BEHL0.5-4 kHz ≥20</td>
<td>None (26)</td>
</tr>
<tr>
<td>Finland</td>
<td>75</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sindhusake et al. 2001 Australia</td>
<td>2015 (43)</td>
<td>Census Blue mountains</td>
<td>m &amp; w 39</td>
<td>BEHL0.5-4 kHz ≥25</td>
<td>None (25)</td>
</tr>
<tr>
<td></td>
<td>≥55</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wiley et al. 2000 US</td>
<td>1236 (46)</td>
<td>Census Beaver Dam</td>
<td>m 18 w 10</td>
<td>HHIES ≥8</td>
<td>None (unknown)</td>
</tr>
<tr>
<td></td>
<td>48–59</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1043 (46)</td>
<td>60–69</td>
<td>m 24 w 11</td>
<td>HHIES ≥8</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cacciatore et al. 1999 Italy</td>
<td>1332 (42)</td>
<td>Random Campania</td>
<td>m &amp; w 27</td>
<td>Self reportc</td>
<td>Yes (25)</td>
</tr>
<tr>
<td>Study Country</td>
<td>Subjects</td>
<td>Sampling</td>
<td>Prevalence of HI among genders (%)</td>
<td>Definition of HI (dB HL)</td>
<td>Analyses and proportion of non-participants (%)</td>
</tr>
<tr>
<td>---------------</td>
<td>----------</td>
<td>----------</td>
<td>-----------------------------------</td>
<td>--------------------------</td>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>Finland</td>
<td>420 (45)</td>
<td>Random Northern Ostrobothnia</td>
<td>m &amp; w 16</td>
<td>BEHL$_{0.5-4 kHz}$ &gt;20</td>
<td>None (28)</td>
</tr>
<tr>
<td></td>
<td>430 (44)</td>
<td>m &amp; w 37</td>
<td>BEHL$_{0.5-4 kHz}$ &gt;20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td>163 (unknown)</td>
<td>Selected households South of Australia</td>
<td>m &amp; w 16</td>
<td>BEHL$_{0.5-4 kHz}$ &gt;25</td>
<td>None (unknown)</td>
</tr>
<tr>
<td></td>
<td>174 (unknown)</td>
<td>m &amp; w 48</td>
<td>BEHL$_{0.5-4 kHz}$ &gt;25</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>174 (unknown)</td>
<td>m &amp; w 58</td>
<td>WEHL$_{0.5-4 kHz}$ &gt;25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>US</td>
<td>1246 (46)</td>
<td>Census Beaver Dam</td>
<td>m 32</td>
<td>WEHL$_{0.5-4 kHz}$ &gt;25</td>
<td>Yes (17)</td>
</tr>
<tr>
<td></td>
<td>3753 (42)</td>
<td>w 10</td>
<td>HHIES &gt; 8</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2506 (unknown)</td>
<td>m &amp; w 35</td>
<td>BEHL$_{0.5-4 kHz}$ &gt;25</td>
<td>None (unknown)</td>
<td></td>
</tr>
<tr>
<td>Italy</td>
<td>~200 (unknown)</td>
<td>Random Milano, Padua, Florence, Bari, Palermo</td>
<td>m &amp; w 19</td>
<td>BEHL$_{0.5-4 kHz}$ &gt;25</td>
<td>None (42)</td>
</tr>
<tr>
<td></td>
<td>m &amp; w 30</td>
<td>m &amp; w 22</td>
<td>WEHL$_{0.5-4 kHz}$ &gt;25</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>m &amp; w 22</td>
<td>Self-report e</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UK</td>
<td>682 (50)</td>
<td>Random Cardiff, Glasgow, Nottingham, Southampton</td>
<td>m 38</td>
<td>BEHL$_{0.5-4 kHz}$ &gt;20</td>
<td>Yes (20)</td>
</tr>
<tr>
<td></td>
<td>675 (50)</td>
<td>w 37</td>
<td>WEHL$_{0.5-4 kHz}$ &gt;20</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5679 (unknown)</td>
<td>m &amp; w 31</td>
<td>Self-report e</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Study Country</td>
<td>Subjects</td>
<td>Sampling</td>
<td>Prevalence of HI among genders (%)</td>
<td>Definition of HI (dB HL)</td>
<td>Analyses and proportion of non-participants (%)</td>
</tr>
<tr>
<td>---------------</td>
<td>----------</td>
<td>----------</td>
<td>-----------------------------------</td>
<td>-------------------------</td>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>Moscicki et al. 1985 US</td>
<td>2293 (40)</td>
<td>Cohort study Framingham</td>
<td>m &amp; w 47</td>
<td>BEHL&lt;sub&gt;0.5 kHz&lt;/sub&gt; &gt;25</td>
<td>None (11)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>m 49</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>w 35</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* No otological examination. HHIES: The hearing handicap inventory for the elderly.

* Screening threshold ≥40 dB HL of 1 kHz and 2 kHz in one ear or 1 kHz or 2 kHz in both ears.

b Do you feel you have hearing loss?

c Not able to usually hear and understand what a person says without seeing his face if that person talks to you in a normal voice in a quiet room.

d Do you think your hearing is normal?

* Very difficult to follow conversation in background noise?

1 Hearing problem now?

### 2.5 Comparison of self-reported and measured hearing impairment

Is there an association between self-reported HI and measured HI? An Australian study among subjects older than 49 years applied the question: “Do you feel you have hearing loss?” and reported a prevalence of 51%, but only half of the subjects had bilateral HI verified by audiometry (Chia et al. 2007). A study among US subjects over 60 years old applied the question “Do you have a hearing problem now?” and 41% of the subjects responded positively, whereas the prevalence of measured HI (BEHL<sub>0.5 kHz</sub> >26 dB HL) turned out to be 29% (Gates et al. 1990).

Only a few large population-based studies have examined the association between self-reported hearing impairment and measured pure-tone thresholds. Among 48–64-year-old subjects, a sensitivity of 81% and a specificity of 67% has been reported for the question “Do you feel you have hearing loss?” when HI was defined as WEHL<sub>0.5,1,2 kHz</sub> >25 dB HL (Nondahl et al. 1998). The same question was applied in another study among 55-year-old subjects with a sensitivity of 78% and a specificity of 67%, but with a slightly different definition of HI (BEHL<sub>0.5,1,2,4 kHz</sub> >25 dB HL) (Sindhusake et al. 2001).
2.6 Prevalence of tinnitus and hyperacusis

Tinnitus and hyperacusis are common hearing problems at older age. The prevalence of tinnitus in the age group of 51–60 years is 15.2% in the UK (Davis 1995), and a similar figure (16.8%) among subjects aged over 60 years has been reported in the US (Gates et al. 1990). Another US study among subjects aged 48–59 years has reported the prevalence of severe tinnitus (causing difficulty in falling asleep) as 7.3% (7.8%, men; 6.8%, women) (Nondahl et al. 2002). A higher prevalence, 25.4% among men and 11.3% among women, has been reported among 50–59-year-old Swedish subjects (Axelsson & Ringdahl 1989). In addition, 71% of those reporting tinnitus also reported HI (Axelsson & Ringdahl 1989). An Australian study found that subjects reporting tinnitus have poorer hearing thresholds, as \( BEHL_{0.5,1,2,4\ kHz} \) was 24.7 dB HL among those reporting tinnitus and 21.4 dB HL among those not, and the same trend was found for \( BEHL_{4,6,8\ kHz} \), the corresponding figures being 48.0 dB HL and 40.6 dB HL (Sindhusake et al. 2003).

2.7 Prevalence of audiogram configurations

Epidemiological studies on the prevalence of audiogram configurations are few. Only two unscreened population-based epidemiological studies, both applying different definitions, were found (Gates et al. 1999; Ciletti & Flamme 2008). The early definition put forth by Lloyd and Kaplan (Lloyd 1978) has been applied in the Framingham study among subjects over 60 years old, and the reported prevalences are 6% for rising, 29% for flat, 36% for gradually sloping high-frequency, and 29% for sharply sloping high-frequency audiogram configurations (Gates et al. 1999). The classification of audiograms in the second study applied cluster analysis among subjects over 18 years of age. Although the method differs greatly from the one used in the first study and produced up to 20 different configurations for men and 9 for women, the deeply sloping configuration still dominated (25%) among men and the gently sloping (13%) among women (Ciletti & Flamme 2008).

Four studies have reported prevalence figures for audiogram configurations among screened populations. The prevalence of the most common configurations among Belgian subjects aged 55–65 years with ARHI were 37% for flat, 35% for high-frequency gently sloping, and 27% for high-frequency steeply sloping configurations (Demeester et al. 2009). The distribution of audiogram configurations were 50% for sloping, 23% for U-shaped, 13% for tent-shaped, 8% for flat, 0% for rising, and 7% for other configurations in a US study based on a survey of an
audiological database among 60–61-year-old subjects (Pittman & Stelmachowicz 2003). In a Swedish study, the distribution of configurations were 47% for high-frequency gently sloping (HFGS), 14% for high-frequency steeply sloping (HFSS), 9% for mid-frequency U-shaped (MFU), 14% for high-frequency U-shaped, 0% for rising, 1% for flat, and 13% for unspecified (Hederstierna et al. 2007). In that study, the configurations were defined according to a modified audiogram classification defined the EU expert group (Stephens 1996), and only women aged 47–53 years with sensorineural HI were included (Hederstierna et al. 2007). In a large US study using automated classification of audiograms drawn from the database of an academic health center audiology clinic, a sloping configuration was the most common (40%) and the next most common configuration was normal (33%), followed by flat (16%), peaked (5%), rising (3%), other (2%), and trough (1%) configurations (Margolis & Saly 2008).

As seen in many recent descriptive population-based studies, high-frequency sloping audiograms are common among older adults, although configurations per se are not reported (Johansson & Arlinger 2003; Engdahl et al. 2005; Hoffman et al. 2010). Even though comparison of studies is complicated by different definitions of audiogram configurations, it still seems that the high-frequency sloping shape is the most common audiogram configuration among adults.

2.8 Prevalence of ear diseases

Only a few population-based studies reporting prevalence figures for COM were found, and the definitions of COM vary between studies. A prevalence of 4.1%, including both active and inactive COM and tympanic membrane perforations, was reported among British adults (Browning & Gatehouse 1992). In a Swedish study defining COM as perforations, adhesions, retractions, cholesteatoma, and ear polyps, prevalence was 4.1% among 50-year-old men and 5.1% among 60-year-old men (Rudin et al. 1983).

Population-based studies report a high prevalence of Ménière’s disease: 513/100,000 among subjects 12 years old or older (Havia et al. 2005) and 120/100,000 among adults (Radtke et al. 2008). In the Framingham cohort the frequency of self-reported history of Ménière’s disease is very high (1.48%) among 2293 subjects aged 57–89 years (Moscicki et al. 1985). A US study has reported the frequency of Ménière’s disease as 190/100,000 among health-insured subjects (Harris & Alexander 2010). Clearly lower prevalence estimates for Ménière’s disease are reported in hospital data: 16/100,000 (no age range given) (Watanabe et
al. 1995) or 43.2/100,000 (no age range given) (Kotimäki et al. 1999). In addition, a low incidence of 46/100,000/year among both children and men has been reported (Stahle et al. 1978).

The prevalence of clinically defined otosclerosis is 2.2% in a population-based study among subjects aged 41–60 years in the UK (Browning & Gatehouse 1992). Furthermore, two population-based studies have reported a history of otosclerosis of 0.52% among subjects aged 57–89 years (Moscicki et al. 1985) and 0.2% among subjects with an age range of 48–92 years (Cruickshanks et al. 1998a). However, several hospital-based series have reported otosclerosis prevalence of about 0.8% among adult patients (Pearson et al. 1974; Gristwood & Venables 1984; Sakihara & Parving 1999). The prevalence of histologically-defined otosclerosis was 3.4% in a post mortem sample of 118 pairs of temporal bones (Declau et al. 2007).
3  Aim of the study

Age-related hearing impairment is the most frequent reason for HI among older adults. As the population structure in Finland and in other Western countries is shifting towards older, data on hearing among older adults are needed in order to plan hearing healthcare. The aim of the present study was to provide epidemiological data about hearing among older adults. Each of the four original publications forming the present thesis concentrates on a specific issue of hearing. The specific aims of the study were:

1. To investigate the prevalence of HI in older adults. In addition, differences between left and right ears and between genders were examined.
2. To investigate the prevalence of self-reported hearing problems, defined as hearing difficulty, difficulty in following a conversation amidst noise, tinnitus, and hyperacusis, and the relationship between hearing difficulty and measured hearing in older adults.
3. To investigate the prevalence of audiogram configurations in older adults. Furthermore, audiogram configurations among subjects reporting hearing difficulty were examined.
4. To study the prevalence of ear diseases, otological risk factors, and noise exposure among older adults and their association with hearing.
4 Subjects and methods

4.1 Subjects

4.1.1 Sample collection

Background of the sample collection: the ARHI project

The subjects for the present study were collected in conjunction with the European Union (EU) ARHI Project (QLRT-2001-00331) conducted between 2003–2007 in seven European countries (Belgium, Denmark, Finland, German, Italy, the Netherlands, and Great Britain). The aim of the EU ARHI project was to investigate environmental, medical, and genetic factors contributing to age-related HI (Van Eyken et al. 2007a; Van Eyken et al. 2007c). The original inclusion criteria for the EU ARHI project were very strict, aiming at a highly selected sample of subjects with only age-related HI, thus leading to a large amount of excluded subjects. However, the continuation of the research in Oulu, Finland, focused on epidemiological studies and enabled inclusion of subjects who were excluded from the original EU ARHI project.

Present study

The inclusion criteria for the present study were more relaxed than those for the original EU ARHI project. It must also be emphasized that the present study is independent and executed apart from that of the ARHI project, thus it also includes subjects who were excluded from the ARHI project. Here the subjects were included on the basis of ethnicity (native Finnish) and age. People born from the year 1938 to the year 1949 and living in the city of Oulu or in the surrounding areas (defined by postal code) in 2003 were eligible for the study (9,417 men; 10,094 women). A random sample of 500 men and 500 women was drawn from the population register in the first phase. As the first sample turned out to be too small due to an unexpectedly high number of non-responders, a second sample (n=2001) was drawn in 2004. A review of the subjects in the second sampling revealed 77 double ascertainments (40 men, 37 women), which were excluded, leaving 960 men and 964 women in the second sample (Figure 2).
A total of 1428 invitation letters were mailed (Figure 2). The invitation letter included information about the study, a questionnaire, and a pre-scheduled invitation to a study appointment. No reminder letters were sent. Five persons were excluded prior to the mailing because they were not Finnish judging from their names, and one because the person was known to have multiple sclerosis, an exclusion criterion of the original EU ARHI project. A total of 570 (40%) subjects did not participate in the study, including 17 subjects with an incorrect address and 4 subjects who had died between the sampling and the mailing of the letter. Altogether 858 subjects arrived to the study appointment, out of which 6 subjects were excluded afterwards because of incomplete data and 2 subjects were excluded because they had a severe acute ear infection and were referred to an ear, nose, and throat outpatient clinic. The study includes data on 850 subjects; 383 men (45.1%) and 467 women (54.9%). The participants were 54–66 years old (median 62, mean 60.9, SD 3.4). Among the subjects included in the present study there were 324 (38.1%) subjects who were excluded from the original sample of the EU ARHI project (155 men and 169 women).

Figure 2. Sample collection.
Figure reprinted with permission from Informa Healthcare.
4.1.2 Analysis of non-participants

As 40% of the subjects invited to the study did not participate, an analysis of non-responders was conducted by mailing a short questionnaire to 400 (73%) of the 549 non-participants. After two rounds of reminder letters, 246 (62%) replies were received. There were three clear differences between the participants and non-participants. The proportion of men was higher among the non-participants (55.8%) than among the participants (45.1%), and the non-participants were slightly younger (mean age 57.5 years) than the participants (mean age 60.9 years). In addition, answers to the question “Do you have any difficulty with your hearing?” suggested hearing difficulty among 21.5% of the non-participants and among 37.1% of the participants. No marked differences in general health, smoking habits, and ear diseases were found between the participants and the non-participants.

4.2 Methods

4.2.1 Data collection

Otological examination and questionnaire

All the subjects were examined by one of two study physicians (Samuli Hannula or Elina Mäki-Torkko). All the participants underwent an otological examination, including pneumatic otoscopy, and otomicroscopy when necessary, and completed an extensive questionnaire covering otological background, general medical history, information about occupation, and possible audiological risk factors, including noise exposure at work or during leisure time and exposure to gunfire noise. In addition, several questions dealt with subjective hearing problems. The patients’ medical files were reviewed when necessary. All the replies in the questionnaire were checked during an interview by the study physician (SH or EM-T) in order to resolve possible misinterpretations of the questions by the participants. When the material was collected for the original EU ARHI project, the original language of the questionnaire was English. The questionnaire was translated into Finnish and then back-translated into English, and these two English versions were then compared to ensure the validity of the translation.
Audiometry

Pure-tone air conduction thresholds (0.125, 0.25, 0.5, 1, 2, 3, 4, 6, 8 kHz) and bone conduction thresholds (0.25, 0.5, 1, 2, 4 kHz) were measured in a sound-insulated booth by a trained audiological assistants using the ascending method according to ISO 8253-1 (1989). Madsen Midimate 602 (Otometrics, Denmark) and Madsen Orbiter 922 (Otometrics, Denmark) clinical audiometers were used and calibrated according to ISO 389-1 (1998) and ISO 389-3 (1994). Supra-aural TDH-39 earphones with MX-41/AR cushions and a Radioear B-71 bone vibrator were used with both audiometers and calibrated according to ISO 389-1 (1998) and ISO 389-3 (1994). The study was conducted in the audiological unit of the Oulu University Hospital, using its facilities, instruments, and sound-insulated booths, which meet the criteria of ISO 8253-1 (1989).

Bone conduction measurements were missing for 16 subjects (13 right ears, 16 left ears). As none of these subjects showed any signs of middle-ear problems in the otological examination, and as 14 out of the 16 had left and right ear PTA$_{0.5,1,2,4\text{ kHz}}$<20 dB HL and the remaining two had <32 dB HL, the subjects’ audiograms were considered sensorineural.

4.2.2 Audiological Criteria

The degree of HI was defined on the basis of average hearing thresholds over the frequencies 0.5, 1, 2, and 4 kHz (PTA$_{0.5,1,2,4\text{ kHz}}$) as recommended by an EU expert group (Stephens 1996). The definitions of the degree of HI used in the present study are shown in Table 1. For the prevalence figures the criterion for HI of average hearing thresholds ≥20 dB HL in the better hearing ear (BEHL) was used. The same averaged frequencies were applied when the prevalence of WEHL was estimated. If pure-tone thresholds exceeded the maximum output of the audiometer, a value of 130 dB was used according to the recommendation of the British Society of Audiology (1988). A HI was considered asymmetrical if the difference between the left and right ear air conduction thresholds was 20 dB or more for at least 2 frequencies out of 0.5, 1, and 2 kHz. A conductive HI was defined as an air-bone gap averaged over 0.5, 1, and 2 kHz≥15 dB HL in one or both ears and a mixed HI as a conductive HI and mean bone conduction over 0.5, 1 and 2 kHz≥20 dB HL in one or both ears. Different PTAs such as PTA$_{0.125,0.25,0.5\text{ kHz}}$, PTA$_{0.5,1,2,4\text{ kHz}}$, and PTA$_{4,6,8\text{ kHz}}$ were applied for the analyses.
4.2.3 Self-reported hearing problems

The questionnaire included four questions identifying self-reported hearing problems among the subjects:

Q1. Do you have any difficulty with your hearing?
Q2. Do you find it very difficult to follow a conversation if there is background noise, e.g. TV, radio, children playing?
Q3. Nowadays, do you ever get noises in your head or ears (tinnitus) which usually last longer than five minutes?
Q4. Are you particularly sensitive to loud sounds?

Each subject answered all four questions, and there were no missing data. A self-reported hearing problem was defined as a positive answer to any of the four questions (Q1–Q4). Question Q1 was used in screening the non-participants.

4.2.4 Audiogram configurations

Audiogram configurations were calculated based on air conduction thresholds. The configurations were determined as recommended by the EU expert group (Stephens 1996; Stephens 2001), however applying the less stringent definition of a FLAT configuration, i.e. <15 dB difference between the mean of 0.25 and 0.5 kHz, the mean of 1 kHz and 2 kHz, and the mean of 4 kHz and 8 kHz (Stephens 2001). The less stringent definition was chosen because preliminary results indicated that the more stringent definition of FLAT audiograms (Stephens 1996) led to a high proportion of unclassified audiograms (UNCLA) (Sorri et al. 2000). Comparison of the definitions of the audiogram configurations between the present study and some previous studies is shown in Table 1 of Work III. When analyzing the prevalence estimates of audiogram configurations for subjects reporting different hearing problems, better and worse ear audiograms were applied.

4.2.5 Ear diseases and otological risk factors for hearing impairment

Responses in the questionnaire and during the interview identified subjects with a history of risk factors that could result in HI. These factors include both ear diseases (infections, otosclerosis, Ménière’s disease, and sudden deafness) and other factors potentially affecting hearing (traumas, ototoxic treatments). The definitions of ear
diseases and different otological risk factors are presented in Table 9. Ear diseases and otological risk factors were analyzed as one entity, and noise exposure was considered and analyzed as a separate factor for HI.

Two subjects had a suspicion of an ear disease but did not fulfill the clinical criteria for diagnosis of a specific ear disease: one man with indications of otosclerosis who also had a history of ear infections and one woman with audiological symptoms of Ménière’s disease without vertigo. However, these two individuals were included in the group of subjects with ear diseases or otological risk factors.

4.2.6 Noise exposure

History of noise exposure was screened with three questions in the questionnaire. If any of the following criteria was fulfilled, the subject was defined as exposed to noise:

i. Occupational noise exposure: “Have you ever worked for more than 1 year in a place where you had to raise your voice to make yourself heard by someone standing 1 m away from you?”

ii. Leisure time noise exposure: “During your leisure time, are you/have you been regularly (more than once a week) exposed to intense sounds or noises (so that you have to shout to make yourself heard by someone who stands more than 1 m away from you)?”

iii. Exposure to gunfire noise: “Have you ever fired a gun?” Exposure was defined as more than 100 rounds with light weapons (i.e. rifles or shotguns, etc.) and/or more than 10 rounds with heavy weapons (i.e. artillery or bazookas, etc.).

Information concerning rounds fired was missing for one man who reported that he had fired a gun. As the majority of men in this generation have completed military service in Finland, he was considered as having been exposed to gunfire noise.

The use of hearing protection was asked for each question screening noise exposure: “Did you use noise protection?” Possible answers were as follows:

1. Always
2. Most of the time
3. More than 50% of the time
4. Less than 50% of the time
5. Never
For the analyses, those reporting noise protection always or most of the time were categorized as having sufficient protection and the others as having insufficient protection. There were missing data from 5 subjects reporting occupational noise exposure and from 3 subjects reporting exposure to firearm noise.

4.2.7 Statistical analyses

Statistical analyses were done using SPSS for Windows, Rel. 16.0 (SPSS Inc., Chicago, IL, U.S.A.) and Confidence Interval Analysis version 2.0.0. (Statistics with confidence 2nd edition. London: BMJ Books.). Confidence intervals (95% CI) were calculated when appropriate. A professional medical biostatistician was consulted for each original publication to confirm accurate statistical methodology.

The Chi-squared test and Fisher’s Exact Test, (significance level p<0.05) were applied to evaluate differences between genders (I, II, III, IV), between self-reported hearing problems (II, III), when comparing PTAs (I, II, III, IV), to determine the prevalence of HI and audiogram configurations (I, II, IV), for differences between left ear and right ear hearings and between better and worse ear hearings (I, II, III, IV), and for the difference between subjects with or without ear disease or otological risk factors for HI, with or without noise exposure (IV). Subjects reporting hearing problems were tested using multiple Pearson Chi-Square tests (III). A Wilcoxon signed rank test was applied as a non-parametric test when comparing differences between ears (I).

The independent samples t-test and the paired samples t-test were applied when comparing hearing levels among the subjects (I, II, IV), to evaluate gender differences between self-reported hearing problems, to compare PTAs, and to determine the prevalence of HI (II).

Positive predictive value (PPV), negative predictive value (NPV), sensitivity, and specificity were calculated when comparing self-reported hearing difficulty and measured hearing (II).

Analyses of variance (ANOVA) were used when interactions between responses and questions Q1–Q4 were analyzed and when the mean differences between WEHL and BEHL were analyzed (II), and when the association between PTAs, self-reported hearing difficulty (Q1), and audiogram configurations were analyzed (III). Age and gender were applied to the models as confounding factors.

Logistic regression was applied to study the odds ratio (OR) between the questions (Q1 and Q2) and measured HI (II) and when analyzing the association between self-reported hearing problems, PTAs, and audiogram configuration (III). Age and gender were applied to the models as known confounding factors for HI.
4.3 Ethical considerations

Written informed consent including permission to check the subjects’ medical records was obtained from all the subjects, and the study was approved by the Finnish National Advisory Board on Healthcare Ethics. The subjects were not given any financial compensation for participating.
5 Results and comments

5.1 Prevalence of hearing impairment among older adults (Work I)

5.1.1 Prevalence of HI

The prevalence of HI (BEHL_{0.5,1,2,4 kHz}≥20 dB HL) in the present randomly sampled population of older adults was 26.7% (36.8% among men, 18.4% among women) (Pearson Chi Square, p<0.05). As some of the ear diseases and HI are unilateral, BEHL as a definition of hearing impairment will exclude these subjects. When defining HI according to the worse ear (WEHL_{0.5,1,2,4 kHz}≥20 dB HL), the prevalence estimate was 42.2% (53.8% among men, 32.8% among women) (Pearson Chi Square, p<0.05). The prevalence figures according to degree of HI are shown in Table 3.

Table 3. Prevalence of hearing impairment (HI) based on better ear hearing level (BEHL) and worse ear hearing level (WEHL) averaged over 0.5, 1, 2, and 4 kHz among men (n=383) and women (n=467).

<table>
<thead>
<tr>
<th>Degree of HI dB HL</th>
<th>Men</th>
<th>Women</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n (%)</td>
<td>n (%)</td>
<td>n (%)</td>
</tr>
<tr>
<td>BEHL&lt;20</td>
<td>242 (63.2)</td>
<td>381 (81.6)</td>
<td>623 (73.3)</td>
</tr>
<tr>
<td>20≤BEHL&lt;40</td>
<td>125 (32.6)</td>
<td>77 (16.5)</td>
<td>202 (23.8)</td>
</tr>
<tr>
<td>40≤BEHL&lt;70</td>
<td>14 (3.7)</td>
<td>9 (1.9)</td>
<td>23 (2.7)</td>
</tr>
<tr>
<td>70≤BEHL&lt;95</td>
<td>2 (0.5)</td>
<td>0 (0.0)</td>
<td>2 (0.2)</td>
</tr>
<tr>
<td>BEHL≥95</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td>WEHL&lt;20</td>
<td>177 (46.2)</td>
<td>314 (67.2)</td>
<td>491 (57.8)</td>
</tr>
<tr>
<td>20≤WEHL&lt;40</td>
<td>160 (41.8)</td>
<td>131 (28.1)</td>
<td>291 (34.2)</td>
</tr>
<tr>
<td>40≤WEHL&lt;70</td>
<td>37 (9.7)</td>
<td>18 (3.9)</td>
<td>55 (6.5)</td>
</tr>
<tr>
<td>70≤WEHL&lt;95</td>
<td>4 (1.0)</td>
<td>2 (0.4)</td>
<td>6 (0.7)</td>
</tr>
<tr>
<td>WEHL≥95</td>
<td>5 (1.3)</td>
<td>2 (0.4)</td>
<td>7 (0.8)</td>
</tr>
</tbody>
</table>

Fisher’s Exact Test for both BEHL and WEHL: p<0.001
A modified table reprinted with permission from Informa Healthcare.
5.1.2 Type of HI

Worse ear hearing was used to define the types of HI, thus ensuring that subjects with unilateral HI were included in the analyses. Among hearing-impaired subjects, 93.9% had a sensorineural HI (WEHL0.5,1,2,4 kHz≥20 dB HL) and 6.1% had a conductive or mixed HI. The prevalence of conductive or mixed HI among all the subjects was 2.6% and that of asymmetrical HI, 4.6%.

5.1.3 Hearing thresholds

Hearing thresholds were analyzed for three different PTAs, and in each of these, comparisons were made between left and right ears and between genders.

Pure-tone average (0.5–4 kHz)

Among all the subjects (n=850), the mean PTA0.5,1,2,4 kHz was 18.4 dB HL in the left ear and 18.2 dB HL in the right. Hearing was symmetrical in the frequency range of 0.5, 1, 2, 4 kHz and also within genders.

Nevertheless, there was a clear difference between genders, as men had 6.2 dB HL (95% CI 4.5;8.0) poorer hearing in the left ear and 5.2 dB HL (95% CI 3.3;7.0) poorer hearing in the right ear than women.

High-frequency average (4–8 kHz)

In contrast to the PTA0.5,1,2,4 kHz, there was a difference of 4.4 dB HL (95% CI 3.4;5.5) between ears for high frequencies in PTA of 4, 6, 8 kHz (PTA4,6,8 kHz) (left ear 40.7 dB HL and right 36.3 dB HL). Men had poorer hearing (left ear 49.9 dB HL and right 44.1 dB HL) than women (left ear 33.1 dB HL and right 29.9 dB HL), giving a difference of 16.8 dB HL (95% CI 14.1;19.5) for the left ear and 14.2 dB HL (95% CI 11.5;16.8) for the right ear.

Low-frequency average (0.125–0.5 kHz)

For the low-frequency range in PTA of 0.125, 0.250, 0.5 kHz (PTA0.125,0.25,0.5 kHz) the difference between ears was minimal. The PTAs for men were not different from those for women. The mean hearing threshold levels are presented in Table 4.
Table 4. Mean and median air conduction thresholds for the right and left ears (dB HL) for all subjects and for both genders. Standard deviation in brackets. M=men, W=women.

<table>
<thead>
<tr>
<th>Gender</th>
<th>n</th>
<th>Ear</th>
<th>Frequency (kHz), mean (SD), median</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.125</td>
</tr>
<tr>
<td>M</td>
<td>383</td>
<td>R</td>
<td>14.8 (13.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>15.0</td>
</tr>
<tr>
<td>L</td>
<td>13.0 (11.0)</td>
<td>9.1 (11.7)</td>
<td>10.8 (12.2)</td>
</tr>
<tr>
<td></td>
<td>10.0</td>
<td>5.0</td>
<td>10.0</td>
</tr>
<tr>
<td>W</td>
<td>467</td>
<td>R</td>
<td>13.6 (10.4)</td>
</tr>
<tr>
<td></td>
<td>10.0</td>
<td>10.0</td>
<td>10.0</td>
</tr>
<tr>
<td>L</td>
<td>13.1 (12.7)</td>
<td>9.5 (11.4)</td>
<td>10.6 (11.5)</td>
</tr>
<tr>
<td></td>
<td>10.0</td>
<td>5.0</td>
<td>10.0</td>
</tr>
<tr>
<td>All</td>
<td>850</td>
<td>R</td>
<td>14.2 (11.9)</td>
</tr>
<tr>
<td></td>
<td>10.0</td>
<td>7.5</td>
<td>10.0</td>
</tr>
<tr>
<td>L</td>
<td>13.1 (12.0)</td>
<td>9.4 (11.5)</td>
<td>10.7 (11.8)</td>
</tr>
<tr>
<td></td>
<td>10.0</td>
<td>5.0</td>
<td>10.0</td>
</tr>
</tbody>
</table>

A modified table reprinted with permission from Informa Healthcare.
5.1.4 Comments

Prevalence

In the present study, the prevalence of HI (BEHL<sub>0.5,1,2,4 kHz</sub>≥20 dB) was 26.7% (36.8% among men, 18.4% among women). These figures are close to those of the NSH (Davis 1995) and to those of a previous population-based study conducted in the 1980s, which included the sampling area of the present study (Uimonen et al. 1999). The Framingham heart study cohort reports the prevalence of HI (BEHL<sub>0.5,1,2 kHz</sub>≥25 dB) as 31% among 57–89-year-old subjects (Moscicki et al. 1985), while the EHLS reports the prevalence of HI (WEHL<sub>0.5,1,2,4 kHz</sub>≥25 dB) as 20.6% among 48–59-year-old subjects (Cruickshanks et al. 1998a). However, using the definition WEHL<sub>0.5,1,2,4 kHz</sub>≥25 dB for HI would raise our prevalence estimate (28.1%; 39.4% among men, 18.8% among women). The figures are still higher than that of the EHLS, which might be partially explained by the approximately five years older population in the present study compared with the EHLS. It should be noted that comparison of epidemiological studies is difficult and includes obvious risks because of differences in the study populations as well as in the methods and definitions used.

Figure 3. Audiogram comparison between men and women. The present study and two reference studies; Cruickshanks et al. (1998) and Davis (1995).
A modified figure reprinted with permission from Informa Healthcare.
**Hearing thresholds**

There were no differences between left and right ear PTA_{0.5,1,2,4 kHz} in the present study. Similar results have been found in the Framingham Cohort (Gates *et al.* 1990), whereas the EHLS reports slightly poorer left ear hearing thresholds (Cruickshanks *et al.* 1998a). At high frequencies the left ear was poorer and a significant left-right difference was found among both genders (men, 5.9 dB HL; women, 3.2 dB HL), corroborating findings from previous studies (Chung *et al.* 1983; Pirilä *et al.* 1992).

Men had poorer hearing in PTA_{0.5,1,2,4 kHz} and PTA_{4,6,8 kHz} than women. Men's poorer hearing was also found in earlier studies (Gates *et al.* 1990; Davis 1995; Cruickshanks *et al.*1998a; Chung *et al.* 1983).

Comparison of the audiograms of the present study with those of the two well-known population-based studies, NSH (Davis 1995) and EHLS (Cruickshanks *et al.* 1998a), shows that the EHLS thresholds are better than those of the NHS and the present study at almost all frequencies. The results of the NSH show the poorest hearing thresholds at low frequencies among the three studies. However, the trend of all the audiograms is similar, i.e. the high-frequency sloping configuration and hearing levels of men are poorer than those of women in all the compared studies (Figure 3). However, it must be pointed out that the NSH is a nationwide study, while the EHLS and the present study are local ones. Therefore, any conclusions regarding possible differences in prevalence between the countries need to be made cautiously.

No clear methodological differences were found between the studies, other than in coding of out-of-range thresholds. In the present study, 130 dB HL was entered when the hearing threshold was out of the audiometer’s range (British Society of Audiology 1988), for EHLS this method is not known, while Davis (1995) reports these figures coded as missing or an appropriate higher value. Coding of out-of-range thresholds is a potential source of bias. For example, when out-of-range values are entered as missing values, coding will leave out the worst hearing levels, thus shifting the mean values towards better hearing. The same will happen if all values that are out of range are coded only with the maximum output level of the audiometer. The validity of our figures is supported by a previous study conducted in the same area as the present one; it reported similar prevalence figures as the present study in spite of a lower proportion of non-responders (22%) (Uimonen *et al.* 1999). Thus, despite the differences between the participants and non-participants, the present results do not seem to underestimate the prevalence of HI among older adults. Anyhow, it is very difficult to estimate the clear effect of non-participants on the present results.
5.2 Prevalence of self-reported hearing problems and their relationship to measured hearing in older adults (Work II)

5.2.1 Prevalence of self-reported hearing problems

Self-reported hearing problems were common among older adults, as 60.8% (n=517) of the subjects reported at least one type of problem (Q1–Q4), men significantly more often 66.6% (n=255) than women 56.1% (n=262). Hearing difficulty amidst noise (Q2) had the highest prevalence (men 47.3%; women 40.0%), followed by subjective hearing difficulty (Q1) (men 45.4%; women 30.2%). Men more often reported tinnitus (Q3) (men 37.3%; women 22.5%), whereas hyperacusis (Q4) was more common among women (men 11.5%; women 21.8%) (p<0.05).

Altogether 333 subjects (39.2%) did not report any hearing problems. About 10% of the subjects reported both Q1 and Q2, men (14.6%) more often than women (6.6%) (p<0.05). About 9% reported three problems; Q1, Q2, and Q3 (men 14%; women 5.1%) (p<0.05). There were 46 (5.4%) subjects who reported all four hearing problems.

5.2.2 Self-reported hearing difficulty and measured hearing

Hearing levels (BEHL_{0.5,1,2,4 kHz} and WEHL_{0.5,1,2,4 kHz}) among subjects reporting hearing difficulty (Q1 and Q2) were analyzed (Table 5). Subjects reporting hearing difficulty had significantly poorer hearing than those who did not, and men reporting hearing difficulty had poorer hearing than women. Differences in hearing levels between genders were significant, also after adjusting for age.
Table 5. Hearing levels dB HL (SD) among men and women with or without various forms of self-reported hearing difficulty.

<table>
<thead>
<tr>
<th>Hearing level</th>
<th>Men (n=383)</th>
<th>Women (n=467)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Q1 Hearing difficulty</td>
<td>Q2 Hearing difficulty amidst noise</td>
</tr>
<tr>
<td></td>
<td>YES</td>
<td>NO</td>
</tr>
<tr>
<td></td>
<td>n=174</td>
<td>n=209</td>
</tr>
<tr>
<td>BEHL&lt;sub&gt;0.5,1.2,4 kHz&lt;/sub&gt;</td>
<td>23.4</td>
<td>13.7</td>
</tr>
<tr>
<td></td>
<td>(12.6)</td>
<td>(7.3)</td>
</tr>
<tr>
<td>Difference (95% CI)</td>
<td>9.7 (7.6;11.7)</td>
<td>7.2 (5.0;9.3)</td>
</tr>
<tr>
<td>WEHL&lt;sub&gt;0.5,1.2,4 kHz&lt;/sub&gt;</td>
<td>32.8</td>
<td>17.9</td>
</tr>
<tr>
<td></td>
<td>(20.3)</td>
<td>(8.3)</td>
</tr>
<tr>
<td>Difference (95% CI)</td>
<td>14.9 (11.8;17.9)</td>
<td>11.7 (8.5;14.8)</td>
</tr>
<tr>
<td>BEHL&lt;sub&gt;4,6,8 kHz&lt;/sub&gt;</td>
<td>49.8</td>
<td>32.9</td>
</tr>
<tr>
<td></td>
<td>(21.8)</td>
<td>(15.4)</td>
</tr>
<tr>
<td>Difference (95% CI)</td>
<td>16.9 (13.1;20.6)</td>
<td>13.1 (9.2;17.0)</td>
</tr>
<tr>
<td>WEHL&lt;sub&gt;4,6,8 kHz&lt;/sub&gt;</td>
<td>64.2</td>
<td>44.4</td>
</tr>
<tr>
<td></td>
<td>(24.3)</td>
<td>(18.0)</td>
</tr>
<tr>
<td>Difference (95% CI)</td>
<td>19.7 (15.4;24.0)</td>
<td>15.9 (11.5;20.3)</td>
</tr>
</tbody>
</table>

Better ear hearing level (BEHL) and worse ear hearing level (WEHL) averaged over 0.5, 1, 2, and 4 kHz and over 4, 6, and 8 kHz. Values are means (standard deviations). 95% CI, 95% confidence interval. In analyses of variance, for each question the differences between genders are significant (p<0.05). In addition, for each question the differences between BEHL<sub>0.5,1.2,4 kHz</sub> and BEHL<sub>4,6,8 kHz</sub> and between WEHL<sub>0.5,1.2,4 kHz</sub> and WEHL<sub>4,6,8 kHz</sub> are significant (p<0.05). A modified table reprinted with permission from the Journal of the American Academy of Audiology.
Table 6. Prevalence of self-reported hearing difficulty according to hearing level among men and women. Total number of subjects, n=850, men=383 and women=467.

<table>
<thead>
<tr>
<th>Hearing level</th>
<th>Subjective hearing difficulty (Q1) n (%)</th>
<th>Hearing difficulty amidst noise (Q2) n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Men=174</td>
<td>Women=141</td>
</tr>
<tr>
<td>BEHL&lt;20</td>
<td>72 (41.4)</td>
<td>87 (61.7)</td>
</tr>
<tr>
<td>20≤BEHL&lt;40</td>
<td>87 (50.0)</td>
<td>45 (31.9)</td>
</tr>
<tr>
<td>BEHL≥40</td>
<td>15 (8.6)</td>
<td>9 (6.4)</td>
</tr>
<tr>
<td>WEHL&lt;20</td>
<td>43 (24.7)</td>
<td>49 (34.8)</td>
</tr>
<tr>
<td>20≤WEHL&lt;40</td>
<td>89 (51.1)</td>
<td>71 (50.4)</td>
</tr>
<tr>
<td>WEHL≥40</td>
<td>42 (24.1)</td>
<td>21 (14.9)</td>
</tr>
</tbody>
</table>

Better ear hearing level (BEHL) averaged over 0.5, 1, 2, and 4 kHz. Worse ear hearing level (WEHL) averaged over 0.5, 1, 2, and 4 kHz. The differences between men and women are significant (Pearson’s Chi Square or Fisher’s exact test, p<0.05).

A modified table reprinted with permission from the Journal of the American Academy of Audiology.

5.2.3 Self-reported hearing difficulty and hearing impairment

Among the subjects reporting hearing difficulty (Q1), 50.5% had no HI (BEHL<sub>0.5,1,2,4 kHz</sub> < 20 dB HL), while the corresponding proportion for Q2 was 60.3%. Application of less stringent definition for HI (WEHL<sub>0.5,1,2,4 kHz</sub> ≥ 20 dB HL) yielded corresponding proportions, which were Q1, 29.2%, and Q2, 42.1%. The gender differences in prevalence of HI were significant. Men reporting hearing difficulty (Q1 or Q2) had HI more often than women. The prevalence of self-reported hearing difficulty according to hearing level is shown in Table 6.

Analysis of variance showed that Q1 is an independent factor for BEHL<sub>0.5,1,2,4 kHz</sub>, WEHL<sub>0.5,1,2,4 kHz</sub>, BEHL<sub>4,6,8 kHz</sub> and WEHL<sub>4,6,8 kHz</sub> and Q2 is an independent factor for BEHL<sub>0.5,1,2,4 kHz</sub> and WEHL<sub>0.5,1,2,4 kHz</sub>.

Logistic regression analysis showed that Q1 was a significant risk factor (OR 5.1) for HI (BEHL<sub>0.5,1,2,4 kHz</sub> ≥ 20 dB) and (OR 5.7) for HI (WEHL<sub>0.5,1,2,4 kHz</sub> ≥ 20 dB). The corresponding OR figures for male gender were 2.1 and 1.9. For age and BEHL<sub>0.5,1,2,4 kHz</sub> ≥ 20 dB, each year gives an OR of 1.08 (95% CI 1.0;1.1) for having...
HI, and the corresponding figure for \( \text{WEHL}_{0.5,1,2,4 \text{ kHz}} \geq 20 \text{ dB} \) was 1.07 (95% CI 1.0;1.1). The OR for HI at 66 years was 2.54 compared with a 54-year-old subject.

Various pure-tone frequencies and frequency combinations and their association with self-reported hearing difficulty (Q1) were analyzed by using the PPV and NPV of Q1 for HI (Table 7). The PPV of Q1 was 83% for HI defined as \( \text{BEHL}_{4 \text{ kHz}} \geq 20 \text{ dB HL} \) and 89% for HI at high frequencies (\( \text{BEHL}_{4,6,8 \text{ kHz}} \geq 20 \text{ dB HL} \)). The same figures were higher for worse ear HI, as the PPV was 93% for \( \text{WEHL}_{4 \text{ kHz}} \geq 20 \text{ dB HL} \) and 96% for \( \text{WEHL}_{4,6,8 \text{ kHz}} \geq 20 \text{ dB HL} \). The lowest PPV of Q1 was 29% for \( \text{BEHL}_{0.5,1,2 \text{ kHz}} \geq 20 \text{ dB HL} \) (29%) and 50% for \( \text{WEHL}_{0.5,1,2 \text{ kHz}} \geq 20 \text{ dB HL} \). The same analyses were completed for Q2 without finding any major differences, but there was a trend of Q2 producing slightly lower figures than Q1 (data not shown).

<table>
<thead>
<tr>
<th>Frequency (kHz)</th>
<th>PPV (95% CI)</th>
<th>NPV (95% CI)</th>
<th>Sensitivity (95% CI)</th>
<th>Specificity (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5, 1, 2</td>
<td>BEHL</td>
<td>0.29 (0.24;0.34)</td>
<td>0.95 (0.93;0.96)</td>
<td>0.77 (0.68;0.83)</td>
</tr>
<tr>
<td></td>
<td>WEHL</td>
<td>0.50 (0.44;0.55)</td>
<td>0.87 (0.84;0.89)</td>
<td>0.69 (0.63;0.75)</td>
</tr>
<tr>
<td>0.5, 1, 2, 4</td>
<td>BEHL</td>
<td>0.50 (0.44;0.55)</td>
<td>0.87 (0.84;0.89)</td>
<td>0.69 (0.62;0.74)</td>
</tr>
<tr>
<td></td>
<td>WEHL</td>
<td>0.71 (0.66;0.76)</td>
<td>0.75 (0.71;0.78)</td>
<td>0.62 (0.57;0.67)</td>
</tr>
<tr>
<td>4</td>
<td>BEHL</td>
<td>0.83 (0.79;0.87)</td>
<td>0.54 (0.50;0.58)</td>
<td>0.51 (0.47;0.56)</td>
</tr>
<tr>
<td></td>
<td>WEHL</td>
<td>0.93 (0.90;0.95)</td>
<td>0.28 (0.24;0.32)</td>
<td>0.43 (0.40;0.47)</td>
</tr>
<tr>
<td>4, 6, 8</td>
<td>BEHL</td>
<td>0.89 (0.85;0.92)</td>
<td>0.35 (0.31;0.39)</td>
<td>0.45 (0.41;0.49)</td>
</tr>
<tr>
<td></td>
<td>WEHL</td>
<td>0.96 (0.93;0.98)</td>
<td>0.14 (0.12;0.17)</td>
<td>0.40 (0.36;0.43)</td>
</tr>
</tbody>
</table>

95% CI, 95% confidence interval.

A modified table reprinted with permission from the Journal of the American Academy of Audiology.
5.2.4 Comments

The prevalence of self-reported hearing difficulty (Q1) was 37.1% (men, 45.4%; women, 30.2%) in the present study. A slightly higher figure is reported by the Framingham cohort (men, 50%; women, 35%), but the Framingham study population was older (mean age 73 years) (Gates et al. 1990) than that in the present study (mean age 61 years).

In the present study, difficulty in following a conversation amidst noise (Q2) was the most frequently reported hearing problem, with a prevalence of 43.3%. This is higher than reported previously: 31.2% (Davis 1989) or 28.4% among men and 21.6% among women (Hannaford et al. 2005). The differences between the figures might be explained by several factors, such as differences in the demographics of the population, differences in the questions asked, and differences in the study design. In addition, it has been proposed that prevalence estimates tend to be higher when questions specifically address hearing and lower when questions concerning hearing are embedded among questions dealing with general health (Stephens et al. 2004). In addition, the age of the subjects should be taken into account when evaluating the results of self-assessment studies, as older individuals tend to report less disability or handicap for a given level of HI (Gatehouse 1990). Thus, the results of the prevalence of self-reported hearing problems may be somewhat overestimated in the present study.

The prevalence of tinnitus (Q3) was 29.2% in the present study population (n=850), and similar figures are presented in the Blue Mountain hearing study (BMHS) among subjects under 60 years of age (Sindhusake et al. 2003). Meanwhile, the prevalence of tinnitus among 1147 Belgian subjects was lower: 19.3% (Demeester et al. 2007). Although the same ascertainment protocol was applied as in the present study, the subjects were otologically and medically screened in the Belgian study.

The prevalence of hyperacusis (Q4) was 17.2% in the present population, and a similar figure (15%) was reported in a Polish study (Skarzynski et al. 2000), whereas a lower prevalence (9%) was found in a Swedish study (Andersson et al. 2002).

There are only a few studies reporting the relationship between self-reported hearing difficulty and measured HI. Only moderate sensitivity and specificity have been found between the question: “Do you feel you have hearing loss?” and HI (Nondahl et al. 1998; Sindhusake et al. 2001). The EHLS reported a sensitivity of 71% and a specificity of 71% when HI was defined as $BEHL_{0.5,1,2,4\text{kHz}}>25$ dB HL (Nondahl et al. 1998) and the BMHS reported a sensitivity of 78% and a specificity
of 67% when HI was defined as $\text{WEHL}_{0.5,1,2,4\, \text{kHz}}>25$ dB HL (Sindhusake et al. 2001). In addition, a false positive rate of 46% and a false negative rate of 17% have been found for self-reported HI (Wilson et al. 1999).

It was found that the question “Do you have any difficulty with your hearing?” (Q1) had a PPV of 50% for HI (BEHL$_{0.5,1,2,4\, \text{kHz}}$$\geq20$ dB HL) and 29% for low-frequency HI (BEHL$_{0.5,1,2\, \text{kHz}}$$\geq20$ dB HL), whereas the BMHS reported a PPV of 61% for HI (BEHL$_{0.5,1,2,4\, \text{kHz}}$$>25$ dB HL) (Sindhusake et al. 2001). The difference between the BMHS and our figures is probably explained by the older population in the BMHS (70% of the subjects were older than 65 years) and by a more liberal definition of HI, producing a higher (39.1%) prevalence of measured HI. In the present study a PPV of 71% was found for HI defined as $\text{WEHL}_{0.5,1,2,4\, \text{kHz}}$$\geq20$ dB HL, and the figure is higher than that reported in the EHLS (Nondahl et al. 1998). However, the definition of HI in the EHLS was more liberal (WEHL$_{0.5,1,2,4\, \text{kHz}}$$>25$ dB HL), thus explaining at least part of the difference between the studies.

It must be emphasized that in the present study, self-reported hearing difficulty predicts HI at higher frequencies (PTA$_{4,6,8\, \text{kHz}}$). A high PPV of 83% for single-frequency HI (4 kHz$\geq20$ dB HL) was found with a sensitivity of 51% and a specificity of 84%. Only one earlier study reporting a relationship between self-reported hearing difficulty and measured high-frequency HI was found (Pedersen & Rosenhall 1991). The correlation coefficient between self-reported assessment of hearing and BEHL (4 and 8 kHz) was 0.41 for women and 0.47 for men and the correlation coefficient for BEHL$_{0.5,1,2,4\, \text{kHz}}$ was 0.57 for women and 0.60 for men (Pedersen & Rosenhall, 1991). However, it must be pointed out that the high PPV alone is not an adequate finding, as good sensitivity and specificity are also required when dealing with screening tests. However, from the clinical point of view, these results provide some additional insight into the hearing of patients complaining of hearing difficulty.

The analyses between participants and non-participants showed that there were more men among the non-participants and, thus, most of the figures are presented separately for both genders. Still, there might be some bias in the PPV and NPV figures, as more men with normal hearing were missing from the analyses. The age difference between the participants and non-participants was small and should not affect the results, as the rate of hearing deterioration has been found to be 9 dB per decade among people over 55 years (Davis et al. 1990). The non-participants reported less self-reported hearing difficulty than the participants of the present study, and there is a possibility of some bias as the prevalence of self-reported hearing difficulty among the subjects may be somewhat overestimated. However, the validity of the
present study is supported by the fact that the prevalence of HI in the present study (Work I) was similar to that in a previous study conducted in the same area as the present one; it reported a very low non-participant rate (22%) (Uimonen et al. 1999).

5.3 Audiogram configurations among older adults, prevalence and relationship to self-reported hearing problems (Work III)

5.3.1 Prevalence of audiogram configurations

The most common configuration was HFSS, accounting for 46.2% of the left ear and 35.2% of the right ear configurations. The second most common was HFGS (29.2% left, 30.9% right), while a FLAT configuration was found in 12.0% of the left ears and 18.8% of the right. The remaining configurations were rare: MFU 0.1% for the left ear and 0.5% for the right ear, low-frequency ascending (LFA) 0% for the left ear and 0.7% for the right ear. The prevalence of audiograms not fitting into any of the above-mentioned configurations was high – 12.5% for the left ear and 14.7% for the right ear. Despite the relaxed definitions there were also some audiograms with a double classification. Of seven FLAT right ear audiograms, one also fulfilled the criteria of HFGS and six, those of LFA. These seven audiograms with a double classification were included in the prevalence figures.

The most common audiogram configuration among men was HFSS, comprising more than half of the audiograms, whereas among women the three most prevalent configurations (HFSS, HFGS, FLAT) and UNCLA were almost evenly distributed (Figure 4). The most prevalent configuration among women was HFGS, with no difference between ears (33.0% left; 31.5% right). Among men, HFSS was more frequent for the left ear (65.3%) than for the right (51.2%) ear. Women had significantly more FLAT configurations than men. The left and right ears presented the same configuration in 448 audiograms (52.3%).

There were more UNCLA configurations among women than among men (Figure 4). As the UNCLA configuration was so frequent (left ear 106; right ear 125) the relationship between the four most prevalent configurations: (HFSS, HFGS, FLAT, and UNCLA) was further studied by drawing them in same audiogram (Figure 5). As shown in Figure 5, the UNCLA audiogram is located between the FLAT and HFGS audiograms, it resembles the HFGS configuration, and the main differences between the HFGS, HFSS, and UNCLA configurations seem to appear
at the frequencies above 1 kHz. When UNCLA, HFGS, and HFSS all have a sloping
tendency towards high frequencies, the mean audiogram of FLAT configurations
has the poorest thresholds for low frequencies and the best for high frequencies.

Figure 4. Prevalence (%) of audiogram configurations among men and women (n=850).
Seven right ear audiograms fulfill the criteria of two different configurations, thus the
total prevalence for the right ear is 100.5% among men and 101.3% among women. Dif-
ferences between genders are significant (Fisher’s Exact Test <0.05) except for MFU
left, MFU right, LFA right and HFGS right. HFSS: High-frequency steeply sloping, HFGS:
High-frequency gently sloping, FLAT, LFA: Low-frequency ascending, MFU: Mid-fre-
quency U-shaped, UNCLA: Unclassified configuration.
A modified figure reprinted with permission from Informa Healthcare.
5.3.2 Audiogram configurations and self-reported hearing difficulty (Q1 and Q2)

Most of the audiogram configurations were among four classifications (HFSS, HFGS, FLAT, and UNCLA) and, hence, rare configurations were excluded from the following analyses. The four subjects with MFU, the seven subjects with LFA and the seven subjects with audiograms fitting in two different configurations – in total 11 (1.3%) subjects – were excluded.

Subjects reporting hearing difficulty (Q1) (56%) or difficulty in following conversation amidst noise (Q2) (49%) more often presented a HFSS configuration than did subjects not reporting these problems (Q1 25%, Q2 27%) (p<0.05; Chi-Square). Among men reporting hearing difficulty (Q1), 66.9% had a HFSS configuration in their better ear, and among women the same figure was 41.8% (Table 8). Among men and women reporting hearing difficulty (Q1–Q2), the prevalence of the HFSS configuration was higher than among men and women in the whole group.

The distribution of the prevalence of audiogram configurations in the better ear and the worse ear according to self-reported hearing difficulty is presented in Table 8.
The association between self-reported hearing difficulty (Q1), audiogram configurations, and measured PTAs was further analyzed. The subjects’ age and gender were treated as known confounding factors for HI.

Analyses of variance was done with BEHL_{0.5,1,2,4 kHz} as a dependent factor and better ear audiogram configuration, self-reported hearing difficulty (Q1), and gender as fixed factors and age as a covariate (n=839). Better ear configuration and Q1 were both significant factors, and this was also the case when analyzing with the worse ear. In a similar way audiogram configurations and Q1 were significant factors in the same model for high frequencies (BEHL_{3,4,6,8 kHz} and WEHL_{3,4,6,8 kHz}).

In further analyses, self-reported hearing difficulty (Q1) was used as the dependent factor and audiogram configurations, PTAs (BEHL_{0.5,1,2,4 kHz}, WEHL_{0.5,1,2,4 kHz}, BEHL_{3,4,6,8 kHz} or WEHL_{3,4,6,8 kHz}), gender, and age were modeled as covariates in a series of logistic regression analyses. All the above-mentioned PTAs were significant factors in every model and the audiogram configurations remain significant factors in the models together with BEHL_{0.5,1,2,4 kHz}, BEHL_{3,4,6,8 kHz}, or WEHL_{3,4,6,8 kHz} but not with WEHL_{0.5,1,2,4 kHz}. In terms of configurations, HFSS seems to be the main explanatory factor for subjects to report hearing difficulty.

In a similar model with hearing difficulty amidst noise (Q2) as the dependent factor, the audiogram configurations were significant factors when modeled together with either BEHL_{0.5,1,2,4 kHz}, BEHL_{3,4,6,8 kHz}, or WEHL_{3,4,6,8 kHz}.
Table 8. Prevalence of audiogram configurations in the better ear and the worse ear among subjects reporting or not reporting hearing problems. Q1: Hearing difficulty, Q2: Difficulty in following conversation amidst noise. The better and worse ear is defined according to the pure-tone averages of 0.5, 1, 2, 4 kHz. Number of subjects, men (M) 381, women (W) 458.

<table>
<thead>
<tr>
<th>Hearing problem (n)</th>
<th>Audiogram configuration</th>
<th>Better ear % (n)</th>
<th>Worse ear % (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HFSS HFGS FLAT UNCLA</td>
<td>HFSS HFGS FLAT UNCLA</td>
<td></td>
</tr>
<tr>
<td>Q1 M Yes (172)</td>
<td>66.9 22.1 2.9 8.1</td>
<td>76.2 14.0 4.1 5.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(115) (38) (5) (14)</td>
<td>(131) (24) (7) (10)</td>
<td></td>
</tr>
<tr>
<td>No (209)</td>
<td>38.6 42.1 8.1 12.9</td>
<td>58.9 27.8 5.3 8.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(77) (88) (17) (27)</td>
<td>(123) (58) (11) (17)</td>
<td></td>
</tr>
<tr>
<td>W Yes (134)</td>
<td>41.8 27.6 19.4 11.2</td>
<td>44.0 26.9 15.7 13.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(56) (37) (26) (15)</td>
<td>(59) (36) (21) (18)</td>
<td></td>
</tr>
<tr>
<td>No (324)</td>
<td>17.6 31.2 29.9 21.3</td>
<td>22.8 38.3 20.4 18.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(57) (101) (97) (69)</td>
<td>(74) (124) (66) (60)</td>
<td></td>
</tr>
<tr>
<td>M &amp; W Yes (306)</td>
<td>55.9 24.5 10.1 9.5</td>
<td>62.1 19.6 9.2 9.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(171) (75) (31) (29)</td>
<td>(190) (60) (28) (28)</td>
<td></td>
</tr>
<tr>
<td>No (533)</td>
<td>25.1 35.5 21.4 18.0</td>
<td>37.0 34.1 14.4 14.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(134) (189) (114) (96)</td>
<td>(197) (182) (77) (77)</td>
<td></td>
</tr>
<tr>
<td>Q2 M Yes (179)</td>
<td>63.7 26.3 3.9 6.1</td>
<td>73.7 15.1 5.0 6.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(114) (47) (7) (11)</td>
<td>(132) (27) (9) (11)</td>
<td></td>
</tr>
<tr>
<td>No (202)</td>
<td>38.6 39.1 7.4 14.9</td>
<td>60.4 27.2 4.5 7.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(78) (79) (15) (30)</td>
<td>(122) (55) (9) (16)</td>
<td></td>
</tr>
<tr>
<td>W Yes (179)</td>
<td>33.5 29.6 26.3 10.6</td>
<td>35.8 31.8 16.8 15.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(60) (53) (47) (19)</td>
<td>(64) (57) (30) (28)</td>
<td></td>
</tr>
<tr>
<td>No (279)</td>
<td>19.0 30.5 27.2 23.2</td>
<td>24.7 36.9 20.4 17.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(53) (85) (76) (65)</td>
<td>(69) (103) (57) (50)</td>
<td></td>
</tr>
<tr>
<td>M &amp; W Yes (358)</td>
<td>48.6 27.9 15.1 8.4</td>
<td>54.7 23.5 10.9 10.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(174) (100) (54) (30)</td>
<td>(196) (84) (39) (39)</td>
<td></td>
</tr>
<tr>
<td>No (481)</td>
<td>27.2 34.1 18.9 19.8</td>
<td>39.7 32.8 13.7 13.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(131) (164) (91) (95)</td>
<td>(191) (158) (66) (66)</td>
<td></td>
</tr>
</tbody>
</table>

HFSS: High-frequency steeply sloping, HFGS: High-frequency gently sloping, FLAT, UNCLA: Unclassified. M: men, W: women. Better and worse ear figures were tested by Chi-Square test by dividing the subjects into groups by gender, self-reported hearing problems, and audiogram configurations; differences were significant (p<0.05) except for women with Q2 for worse ear configuration. No adjustments were made for multiple comparisons. The subjects (11) with rare configurations and with audiograms fitting into two different configurations are not included in the analyses.

A modified table reprinted with permission from Informa Healthcare.
5.3.3 Comments

Prevalence of configurations

The most prevalent audiogram configuration among men was HFSS. The result is in accordance with the results of the Framingham study, where 53.2% of the better ear audiograms among men were sharply falling (Gates et al. 1990), and with a Belgian study, where 41.1% of the left ear audiograms among men were HFSS (Demeester et al. 2009). The prevalence reported by the Belgian study is lower than that in the present study. As in Work II, the difference might be explained by the screened sample of the subjects in the Belgian study, which included only subjects with ARHI (Demeester et al. 2009), whereas the present study population was unscreened.

Among women, the most prevalent configuration for the better ear was HFGS (30.1%) followed by FLAT (26.9%). A similar finding is reported by the Framingham study, where 39.3% of the women have a gradually sloping and 38.6% have a flat audiogram shape in their better ear (Gates et al. 1990).

The various definitions of configurations used in the studies (Table I of work III) complicate comparison of the prevalence figures between studies. The differences between previous studies and the Belgian study have already been discussed, still the difference between the present results and the Belgian study is difficult to explain, as the Belgian study reports 49.7% FLAT and 34.7% HFGS configurations in women’s left ears (Demeester et al. 2009). Nevertheless, the present results are in accordance with an earlier study among subjects aged 18 years or older, where cluster analysis has shown that a gently sloping audiogram configuration is most prevalent among women and configurations featuring a greater slope dominate among men (Ciletti & Flamme 2008). In addition, half of the configurations in another US study were sloping (Pittman & Stelmachowicz 2003).

Although the configuration itself does not provide information about the degree of HI, some explanations behind the higher prevalence of HFSS configurations among men compared with women should be discussed. Firstly, men are usually more exposed to noise than women, thus leading to the commonly defined 3–6-kHz dip and to a steeply sloping audiogram configuration. Secondly, men in general have poorer hearing than women (Gates et al. 1990; Cruickshanks et al. 1998a; Uimonen et al. 1999). This may contribute to the higher number of HFSS configurations. In the present study, the HFGS or HFSS configurations would probably include a...
major part of the subjects with noise-induced hearing impairments due to the use of 4 kHz and 8 kHz in the definitions of both of these configurations.

The proportion of flat configurations for the better ear are higher in a US study (men, 15.2%; women, 38.6%) than that in the present study (men, 5.8%; women, 26.9%), but the US study applied a markedly different definition for flat configurations (<5 dB rise or fall per octave) (Gates et al. 1990). Anyhow, a flat configuration is reported more frequently also in the Belgian study (Demeester et al. 2009) than in the present one. MFU and LFA configurations were rare in the present study, and similar findings were reported by Belgian and Swedish studies (Hederstierna et al. 2007; Demeester et al. 2009).

Self-reported hearing difficulty

No earlier studies reporting prevalence estimates of audiogram configurations among subjects with self-reported difficulty in hearing or difficulty in following conversation amidst noise were found. In the present study, the subjects who reported hearing difficulty or difficulty in following conversation amidst noise more often presented with HFSS configuration than those not reporting. In addition, HFSS was the most prevalent configuration among the subjects reporting hearing difficulty. This finding is in accordance with our earlier results (Work II) that self-reported hearing difficulty well predicts HI at high frequencies. There is some inconsistency between the present results and those of the earlier Swedish study, where the correlation between self-assessed hearing handicap and $\text{PTA}_{0.5,1,2,4\ \text{kHz}}$ is shown to be better than between $\text{PTA}_{4\ \text{kHz}}$ and $\text{PTA}_{8\ \text{kHz}}$. But, is the association between configurations and self-reported hearing difficulty based on the configuration itself or just on the underlying HI? When audiogram configurations and PTA were analyzed in the same model, they both turned out to be independent factors for self-reported hearing difficulty and among configurations, especially HFSS.

The variety of definitions of audiogram configurations between studies complicates comparison of the results, as clearly demonstrated in the present study. However, combining the information of audiogram configurations together with PTAs might provide a good tool for clinical work involving descriptions of subjects’ hearing.
5.4 Ear diseases and risk factors for hearing impairment among older adults – an epidemiological study (Work IV)

5.4.1 Ear diseases

The prevalence of any unilateral or bilateral ear disease or otological risk factor was 18.4% (n=156), including 75 men (48.1%). The most common ear disease was COM (active or inactive) with a prevalence of 5.3% followed by otosclerosis (1.3%), sudden deafness (0.8%), and Ménière’s disease (0.7%). The prevalence estimates for ear diseases and otological risk factors are presented in Table 9. The WEHL for subjects with or without ear diseases or otological risk factors and/or noise exposure are presented in Table 3 of Work IV.

None of the subjects presented several ear diseases, but some of them had an ear disease together with an otological risk factor or presented only multiple otological risk factors.

5.4.2 Noise exposure

Three hundred ninety subjects (45.9%) had some kind of history of noise exposure; men 83.6%, women 15.0% (Chi-square p<0.05). The prevalence of reported occupational noise exposure was 28.5% (n=242), and men (47.5%) were significantly more often exposed than women (12.8%). Sufficient use of occupational hearing protection was reported only by 28.1%. The prevalence of leisure time noise exposure was 5.7% among men and 1.1% among women (Chi-square p<0.05), and 22.2% of the subjects reported sufficient use of hearing protection. Whereas 64.0% of men reported exposure to gunfire noise, only 1.3% of women reported exposure. Sufficient noise protection was reported by 35.1% of these subjects. In addition, among subjects reporting exposure to occupational and gunfire noise (n=110), 12.3% reported sufficient hearing protection, 15.1% reported only occupational hearing protection, 20.8% only gunfire hearing protection, and 51.9% reported insufficient protection for both exposures. There was no significant difference in the distribution of ear diseases or otological risk factors between those reporting and those not reporting noise exposure.

Among subjects with no history of ear diseases or otological risk factors (men, n=308; women, n=386), there was no difference in worse ear hearing levels (WEHL_{0.5,1,2,4 kHz}^* WEHL_{3,4,6,8 kHz}) between subjects reporting noise exposure and
Table 9. Prevalence and definitions of ear diseases and otological risk factors for hearing impairment (HI) among all subjects (n=850).

<table>
<thead>
<tr>
<th>Ear diseases and otological risk factor for HI</th>
<th>Men (n=383)</th>
<th>Women (n=467)</th>
<th>All (n=850)</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Infection</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chronic otitis media</td>
<td>19 5.0</td>
<td>26 5.6</td>
<td>45 5.3</td>
<td>Chronic middle ear infections (both active and inactive), including cholesteatoma, adhesive otitis media, tympanic membrane perforation, or a history of middle ear infections permanently affecting hearing</td>
</tr>
<tr>
<td>Herpes zoster oticus</td>
<td>1 0.3</td>
<td>0 0.0</td>
<td>1 0.1</td>
<td>Self-reported</td>
</tr>
<tr>
<td><strong>Ototoxic treatment</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Antibiotics</td>
<td>15 3.9</td>
<td>21 4.5</td>
<td>36 4.2</td>
<td>Self-reported</td>
</tr>
<tr>
<td>Radiotherapy (head)</td>
<td>5 1.3</td>
<td>1 0.2</td>
<td>6 0.7</td>
<td>In the area of the head</td>
</tr>
<tr>
<td>Chemotherapy**</td>
<td>1 0.3</td>
<td>8 1.7</td>
<td>9 1.1</td>
<td>Self-reported</td>
</tr>
<tr>
<td><strong>Trauma</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ear trauma*</td>
<td>17 4.4</td>
<td>4 0.9</td>
<td>21 2.5</td>
<td>Including acute pressure trauma or acute acoustic trauma</td>
</tr>
<tr>
<td>Head trauma</td>
<td>12 3.1</td>
<td>10 2.2</td>
<td>22 2.7</td>
<td>Reported brain contusion or skull fracture</td>
</tr>
<tr>
<td>Otosclerosis</td>
<td>4 1.0</td>
<td>7 1.5</td>
<td>11 1.3</td>
<td>Operated or non-operated. Presence of conductive hearing impairment and normal otological status verified with pneumatic otoscopy. No history of middle ear infections.</td>
</tr>
<tr>
<td>Sudden deafness</td>
<td>5 1.3</td>
<td>2 0.4</td>
<td>7 0.8</td>
<td>Self-reported</td>
</tr>
<tr>
<td>Ménières disease</td>
<td>2 0.5</td>
<td>4 0.9</td>
<td>6 0.7</td>
<td>Previously diagnosed or clear clinical suspicion during interview: Attacks including vertigo, hearing loss, tinnitus, and feel of fullness or blockage in the ear</td>
</tr>
<tr>
<td>Other known cause of HI</td>
<td>0 0.0</td>
<td>3 0.6</td>
<td>3 0.4</td>
<td>Hereditary HI or congenital HI</td>
</tr>
</tbody>
</table>

Gender differences were significant with respect to ear trauma* (Chi-Square <0.05) and chemotherapy** (Fisher’s exact test 0.046). Twelve subjects had several risk factors.
those not reporting. Similarly, among subjects reporting ear disease or otological risk factors, there was no difference in worse ear hearing levels between subjects reporting noise exposure and those not reporting (Table 3 of Work IV). Further, there was no significant difference in hearing levels (WEHL<sub>0.125,0.25,0.5 kHz</sub>, WEHL<sub>0.5,1,2 kHz</sub>, WEHL<sub>3,4,6,8 kHz</sub>, or WEHL<sub>4 kHz</sub>) between subjects reporting sufficient noise protection and those reporting insufficient noise protection.

Mean audiograms for men, women, and all subjects were drawn to illustrate the differences in hearing between subjects with different histories of factors affecting hearing, including ear diseases or otological risk factors and a history of noise exposure. Although there were clear differences in the audiograms among all subjects, the differences among subjects with no risk factors disappeared when the audiograms were drawn separately for men and women. Then it seems that a history of noise exposure had no association with hearing levels among subjects with no ear diseases or otological risk factors. The main difference between audiograms among men and women was due to a reported history of ear diseases or otological risk factors, and the worse hearing was seen among subjects with both a history of ear diseases or otological risk factors and noise exposure (Figure 6).
Figure 6. Mean air conduction thresholds at various frequencies among men (n=383), women (n=467), and all subjects (n=850) based on worse ear audiograms among four groups defined on the basis of the presence or absence of otological risk factors for hearing impairment (HI) and a history of noise exposure. 1. No ear disease and no otological risk factors for HI and no history of noise exposure, 2. No ear disease and no otological risk factors for HI but a history of noise exposure, 3. Ear disease or otological risk factor for HI but no history of noise exposure, 4. Ear disease or otological risk factor for HI and a history of noise exposure.

1. n=51, 2. n=257, 3. n=12, 4. n=63.
1. n=328, 2. n=58, 3. n=69, 4. n=12.
1. n=379, 2. n=315, 3. n=81, 4. n=75.
5.4.3 Comments

Ear disease

In the present study, the prevalence of COM (active or inactive) was in accordance with that reported in earlier population-based studies from Sweden (Rudin et al. 1983) and the UK (Browning & Gatehouse 1992).

The prevalence of Ménière’s disease is high in the present study population. However, high prevalence figures were also reported in earlier population-based studies (Havia et al. 2005; Radtke et al. 2008). Furthermore, the prevalence of Ménière’s disease is even higher in the Framingham cohort (Moscicki et al. 1985) than in the present study. Even though Ménière’s disease might manifest with dramatic symptoms, it is not a life-threatening condition and subjects with mild symptoms do not necessarily contact healthcare in the first place, or they are treated outside of public healthcare. Yet, it is possible that, when based on several patient contacts, diagnosis of Ménière’s disease is more accurate in clinic-based studies (Kotimäki et al. 1999), than in population-based studies. However, the present and previous studies demonstrate a clear trend where population-based studies report higher prevalence estimates than do clinic-based studies, although comparison with earlier studies is complicated due to the more narrow age range of the present study. Furthermore, it must be pointed out that both previous population-based studies have high non-participant rates of 37% (Havia et al. 2005) and 48% (Radtke et al. 2008), and neither of them presents any analyses of non-participants. Therefore any generalization of the results must be done carefully. On the other hand, with a wider age range in the risk population, there are several subjects in the younger age groups who will suffer from Ménière’s disease later in life. Thus, the narrow age range of the present study complicates its comparison with earlier studies. Anyhow, the female preponderance of Ménière’s disease is in accordance with the gender distribution reported in previous studies (Shojaku & Watanabe 1997; Havia et al. 2005).

The prevalence of otosclerosis was 1.0% among men and 1.5% among women in the present study population, and similar figures are found in earlier studies (Pearson et al. 1974; Hall, 1974). The figures are again higher than those reported in clinic-based studies. Among Danish subjects aged 40–59 years, the frequency of clinical otosclerosis was 0.7% among men and 1.0% among women (Sakihara & Parving 1999). In an Australian study among subjects aged 50–59 years, the prevalence of surgically treated otosclerosis was 0.5% among men and 1.0% among
women (Gristwood & Venables 1984). This difference between clinic-based and population-based studies is comprehensible, as not all subjects with otosclerosis seek medical help. Thus, under estimation of the prevalence figures in a clinic-based series is an understandable risk.

**Noise exposure**

The prevalence of reported occupational noise exposure was 47.5% among men and 12.8% among women. The prevalence of leisure time noise exposure was 5.7% among men and 1.1% among women, whereas 64.0% of men reported exposure to gunfire noise and only 1.3% of women did. However, a US population-based study reports higher figures for occupational noise exposure (men, 80.5%; women, 39.3%) and noisy leisure time activities (men, 97.7%; women, 53.6%), but the frequency of exposure to gunfire noise was lower (men, 31.0%; women, 1.3%) (Nondahl *et al.* 2009). The US study has more liberal definitions of noise exposure, which might partly explain the differences. In addition, Finnish men are probably more exposed to gunfire noise, as Finland has mandatory military service.

An interesting finding was that among subjects with no ear diseases or otological risk factors, hearing levels were the same regardless of their history of noise exposure, including WEHL_{4 kHz}. Furthermore, the mean audiograms showed the same trend. There are only a few population-based studies which compare hearing levels between noise-exposed and non-noise-exposed subjects and also include other possible risk factors for HI in the analyses. A US study compared veterans and non-veterans and reported no differences in hearing, a finding that corresponds with the present results (Wilson *et al.* 2010). A Norwegian study reported opposite results, where hearing impairment at 4 kHz is associated more with a history of noise exposure than with ear diseases (Engdahl *et al.* 2005). Another population-based study from US reported that after adjusting for several confounding factors, a history of target practice and hunting remained associated with high-frequency HI among men (Nondahl *et al.* 2000).
6 General discussion

6.1 Strengths and limitations of the study

The present study has several methodological strengths. Random sampling of the study subjects from the population register allows generalization of the results into the target population in the area. In addition, the study population was unscreened, as the only inclusion criteria were the subjects’ age and ethnicity. The study was designed according to the original EU ARHI project and this had some effect on the present study protocol, especially regarding the questionnaire which had to be identical in all participating centers. As a consequence, some questions regarding noise exposure, self-reported hearing problems, and ear disease or otological risk factors turned out to be somewhat difficult to understand for the participants. However, this was realized early in the data collection and it was decided that each subject would be interviewed. This made it possible to check the whole questionnaire in case of misinterpretation of the questions. The interview was structural and based on the completed questionnaire, whereby sought to avoid any loaded questions. Nevertheless, it is always possible that the interview situation itself may bring bias to the results. In addition, the subjects’ medical files were reviewed when necessary. Thus, the validity of the responses to the questionnaire was confirmed as thoroughly as possible.

All the subjects underwent an otological examination, including removal of excessive ear wax and pneumatic otoscopy. Two physicians (SH and EM-T) were responsible for the investigation and the interviews of the subjects, and repeated follow-up meetings ensured that interpretation of the responses and clinical findings remained constant. Pure-tone audiometry was conducted by trained audiological assistants in a sound-insulated booth and the study was conducted in the Hearing Center of the Oulu University Hospital, using its facilities, instruments, and sound-insulated booths.

The original EU ARHI study had some restrictions which had an effect on the present study. There was limited time for sample collection, and although the number of subjects was sufficient (n=850), it could have been even higher. Furthermore, a wider age range would have given more possibilities for analyses, but with quite a narrow age range, subjects with early signs of ARHI were reached. A clear limitation of the present study is the high proportion of non-participants (40%), which limits generalization of the results. Afterwards it is easy to point out that we should have
been more vigorous in sending reminder letters or even calling the subjects who did not respond to our first invitation. However, a clear strength is that an analysis of the non-participants was conducted afterwards by means of a short questionnaire. There were no significant differences in general health, smoking habits, or ear diseases between the participants and the non-participants, but the groups differed in terms of three factors. First, fewer subjects reported hearing difficulty among the non-participants than among the participants. One explanation for this could be that the subjects who experienced good hearing were less interested in participating. This is possible, despite the fact that the invitation letter specifically encouraged the subjects to participate, even if they felt good hearing acuity. Furthermore, good hearing was not an exclusion criterion. Thus, it is possible that the present results are biased towards worse hearing than they should be. Second, there were more men among the non-participants than among the study group. A similar trend has been reported in an earlier study, but the difference is smaller (participant men 42.3%, non-participant men 46.1%) (Cruickshanks et al. 1998a). As men generally have poorer hearing, this could have caused a bias towards better hearing results in the present study. In addition, differences between genders might have been affected for the same reason. Third, the participants were slightly older than the non-participants, being different from an earlier study, where the participants were younger (mean age, 64.8 years) than the non-participants (mean age, 68.7 years) (Cruickshanks et al. 1998a). This age difference could produce bias towards worse hearing results. However, the age difference between the participants and the non-participants in the present study is small when compared to the reported 9 dB HL deterioration rate in HI per decade among subjects over 55 years old (Davis et al. 1990). These differences must be taken into account in the interpretation of the present results, as it is obvious that the analysis of non-participants can not resolve all possible effects of the differences on the results. Anyhow, it must be emphasized that among the 14 population-based studies presented in Table 2, only three reported analyses of non-participants (Davis 1995; Cruickshanks et al. 1998a; Cacciatore et al. 1999).

6.2 Hearing impairment among older adults

It was found that the prevalence of HI was high (36.8% among men, 18.4% among women), which is in accordance with previous population-based studies (Table 2). In addition, prevalence was even higher if the HI was defined according to the worse ear (53.8% among men, 32.8% among women). In accordance with previous
studies (Moscicki et al. 1985; Cruickshanks et al. 1998a), the prevalence of self-reported hearing difficulty (Q1) was 37.1% (men, 45.4%; women, 30.2%), whereas the prevalence of self-reported difficulty in following a conversation amidst noise (Q2) was even higher in the present study. It must be pointed out that the age range of the present population was narrow, 54–66 years. Even if the subjects may not be considered elderly, still about one third had HI. Comparison between studies is difficult, because different criteria have been used to define HI. However, it is clear that HI is a highly prevalent condition among older adults and even more so among older men. Based on the present results, adult-onset HI should definitely be considered an important public health issue.

The association between self-reported hearing difficulty and measured HI was not as high as expected, as half of the subjects reporting hearing difficulty had no measured HI. When HI was defined according to the worse ear, the corresponding figure was more accurate but still nearly one third had no HI. Thus, many of the subjects do not have HI based on their audiogram, even though they report hearing difficulty. There are several possible explanations for this. Audiology in a sound-insulated booth is far from the daily hearing situations in everyday life, and pure tones are simpler signals to hear than spoken language. In addition, early stages of hair cell damage cannot be detected with basic audiology. Thus, it is possible that pure-tone audiology is actually an inadequate measurement and the results are underestimated, as some hearing difficulty are due to problems in the central hearing system. It is also possible that self-reported hearing difficulty reflects different aspects of hearing, such as a disability and/or handicap, than HI defined by audiology. In addition, it is possible that unilateral HI causes a more severe handicap than expected, thus it might be sensible to evaluate WEHLs rather than BEHLs.

In the present study, self-reported hearing difficulty predicts HI well at higher frequencies (PTA4,6,8 kHz) but poorly at commonly used PTA0.5,1,2,4 kHz. In addition, it was found that subjects with self-reported hearing difficulty more often had a HFSS audiogram configuration than those not reporting. Based on the present results, it seems that self-reporting of hearing difficulty predicts HI at high frequencies. Again, this might be one explanation for the poor association between self-reported hearing difficulty and measured hearing.

The clinical experience that older adults with subjective hearing difficulty have high-frequency HI is supported by the present study. The traditional criteria for audiological definition of HI based on BEHL0.5,1,2,4 kHz should be re-evaluated, and worse ear hearing and high frequencies shall not be neglected. In addition,
self-reported hearing difficulty should be taken into consideration, especially when there is inconsistency with measured hearing.

6.3 Ear diseases, otological risk factors, and noise exposure

Ear diseases and otological risk factors are obvious factors that need to be considered in epidemiological studies, as they may have adverse effects on hearing thresholds. It was found that COM (active or inactive) was the most common ear disease and the prevalence of COM and otosclerosis was similar to that reported earlier (Pearson et al. 1974; Hall 1974; Rudin et al. 1983; Browning & Gatehouse 1992). The prevalence of Ménière’s disease was one of the highest reported so far, but in accordance with earlier population-based studies (Moscicki et al. 1985; Havia et al. 2005; Radtke et al. 2008).

After excluding subjects with ear diseases or otological risk factors, no differences in hearing levels were found between the subjects, regardless of their history of noise exposure. Similar findings were also noted among subjects with ear diseases or otological risk factors. This is an interesting and unexpected finding and might be due to the uneven distribution of men and women among the noise-exposed. In addition, it is possible that such risk factors for HI that were not considered in this study have some underlying effect, i.e. cardiovascular diseases, diabetes, smoking, etc. However, only a few population-based studies have reported noise-related HI among subjects screened for other possible risk factors for HI, and one of them had similar findings (Wilson et al. 2010) while two reported opposite results (Nondahl et al. 2000; Engdahl et al. 2005) compared with the present study. One explanation for this unexpected result could be the use of hearing protectors. But, only about one-third of the noise-exposed subjects reported sufficient use of noise protection. In addition, some subjects reported use of hearing protectors at work but not when firing a gun. Thus, it appears that use of hearing protection did not have a major protective effect; indeed, no difference in hearing levels between subjects reporting sufficient noise protection and those reporting insufficient noise protection were found. Even though possible misinterpretations of the questionnaire were screened in the interview, self-reporting of noise exposure and hearing protection is still a possible cause of bias. In addition, it might be hard to remember different noise exposures and hearing protections from years ago. It is also true that the classification of risk factors in the present study is somewhat artificial and must be considered when interpreting the results.
6.4 Recommendations for hearing healthcare

It is a well-known fact that the age distribution of the population in Western countries is shifting towards older age (OECD 2009). It is estimated that the proportion of the age group of 65 years or older in Finland will increase from the current 17% to 23% by 2020 (Statistics Finland 2009). In the present study about one-third of the subjects had HI. Adult-onset HI, including ARHI, will become an important socioeconomic issue in the very near future and hearing healthcare will require vast amounts of funding, a fact that has also been pointed out in an earlier Finnish study (Sorri et al. 2001b). The results of the present study clearly point in the same direction, but the state of hearing healthcare for adults in Finland still remains poorly organized and neglected by society. The results of the present study emphasize the importance of adequately increasing resources for audiological diagnostics and rehabilitation of older adults.

Self-reports of hearing difficulty seem to predict HI at high frequencies – 4, 6, 8 kHz – better than in the commonly used frequency range of 0.5, 1, 2, 4 kHz. This is an obvious challenge in Finland, where according to the Ministry of Social Affairs and Health (2010), there is general recommendation that among the elderly, \( \text{BEHL}_{0.5,1,2,4 \text{kHz}} \geq 30–40 \text{ dB HL} \) is considered the limit for hearing rehabilitation. Consequently, many older adults who suffer from HI are not referred to audiological consultation. This same problem is found also in Great Britain, where the delay between the beginning of hearing difficulty and hearing aid rehabilitation is ten years (Davis et al. 2007). Based on the results of the present study it appears obvious that strict hearing level limits for hearing aid provision should be reconsidered and that the association of HI with high frequencies and in the worse ear must be taken into account in clinical work together with subjects’ self-reports of hearing difficulty.

As pure-tone audiometry seems to be inadequate, such a hearing test should be developed that would reflect real hearing situations in everyday life, i.e. hearing tests using word or sentences amidst noise. Such valid tests are not yet available in Finland, but they are already suggested in the European standard for services offered by hearing aid professionals (CEN 2010). Furthermore, as shown in the present study, HI is a highly prevalent condition already in the age range from the mid-fifties to the mid-sixties. Based on the results of the present study, it is also apparent that currently used traditional definitions of HI do not identify individuals with hearing difficulty well enough. That is why it is recommended that a hearing screening program for older adults should be designed and launched.
6.5 Future perspectives

The present cross-sectional study is methodically strong in many ways, but it should be followed by a longitudinal study to further analyze changes in hearing and also to further explore the effect of different risk factors. The present results show that, in addition to aging, several other factors affect the hearing of the older population. Further analyses in this ongoing project will cover risk factors such as cardiovascular and autoimmune diseases, diabetes, tobacco smoking, and alcohol consumption. In addition, the present finding that the association of noise with hearing levels among subjects screened for ear diseases or otological risk factors is minimal should be studied further in a larger study group including also a larger variety of medical risk factors. Moreover, the present data could be used to study possible methods for hearing screening among older adults.
7 Summary

Age-related hearing impairment (ARHI) is the most common type of HI among adults, and according to the WHO, adult-onset HI is one of the leading causes of disease burden worldwide. The age distribution in Western countries is turning towards older age, thus the socioeconomic burden of adult HI will increase notably in the near future. Hearing impairment among adults has been shown to be associated with social isolation and even depression. However, technological progress in the field of audiology has enabled good hearing rehabilitation, thus making it possible to prevent or at least alleviate adverse effects of hearing impairment. Although adult-onset HI is pointed out as a major health problem, good-quality epidemiological studies are still scarce, which fact has also been recognized by the WHO, and a bank of epidemiological studies has recently been established.

The aim of the present contribution was to study epidemiological aspects of hearing and related factors among older adults. The focus was on the prevalence of HI, defined either by audiometry or by a self-report, and the differences between these two were further analyzed. In addition other self-reported hearing problems, i.e. tinnitus and hyperacusis were also studied. Furthermore, audiogram configurations and certain subject-related factors and their relation to hearing were assessed. Finally, the prevalence of ear diseases and otological risk factors and noise exposure and their association with hearing thresholds were analyzed.

This study was conducted in conjunction with the European multicenter study EU ARHI project (QLRT-2001-00331). The subjects were randomly sampled from the population register. The study area included the city of Oulu and the surrounding areas. The subjects answered an extensive questionnaire including aspects of hearing, otological factors, general health, and subject-related factors. Otological status was examined and pure-tone audiometry was conducted in the hearing center of Oulu University Hospital. The study includes data on 850 subjects aged 54–66 years.

Hearing impairment was found to be a highly common condition among older adults, as the prevalence of HI was 26.7% when defined by better ear and 42.2% when defined by worse ear, and men had worse hearing than women. The relationship between self-reported hearing difficulty and measured hearing seems to be associated at high frequencies rather than at 0.5–4 kHz, which is commonly regarded as an indicator of HI. In addition, high-frequency sloping audiogram configurations were common and a high-frequency steeply sloping audiogram configuration was the most common among those reporting hearing difficulty. An
ear disease or otological risk factor for HI was found among 18.4% of the subjects, and noise exposure was reported by 46% of the subjects and more often by men. Interestingly, noise exposure did not seem to associate with hearing levels among subjects screened for ear disease or otological risk factors.

The results of the present study suggest that HI is a highly common condition among older adults and this should be taken into account when future hearing healthcare is planned. Hearing impairment is a major health problem, thus screening for HI among older adults and the elderly should be launched. Furthermore, it seems that most of the subjects in this study group with hearing difficulty had no measured HI according to current definitions in Finland. Thus, a portion of individuals with hearing problems are considered not to have sufficient HI for audiological consultation or hearing rehabilitation. The definitions of HI should be reconsidered and worse ear hearing and high-frequency HI should be included in the definitions.
8 Conclusions

Based on the results of this study, the following conclusions can be made.

1. The prevalence of HI is high (27%) among older adults (aged 54–66 years), especially among men. Differences between the left and right ears were found only at high frequencies, the left ears having worse hearing.

2. Self-reported hearing problems are common in this age group. The prevalence of hearing difficulty was 37%; hearing difficulty amidst noise, 43%; tinnitus, 29%; and hyperacusis, 17%. In addition, it was found that self-reported hearing difficulty predicts HI best at high frequencies.

3. The most prevalent audiogram configuration among men was high-frequency steeply sloping, comprising 50% of the better ear configurations, and among women it was high-frequency gently sloping, comprising 30% of the better ear configurations. It was also found that subjects reporting hearing difficulty and difficulty in following conversation amidst noise more often had a high-frequency steeply sloping configuration than those not reporting.

4. The prevalence of chronic middle ear diseases (active or inactive) was 5.3%, that of otosclerosis, 1.3%, and that of Ménière’s disease, 0.7%. Noise exposure was reported by 46% of the subjects. Reported noise exposure had no association with WEHL and neither did reported use of hearing protection.
References


88


Original publications


Works I and III are reprinted with permission from Informa Healthcare and Work II with permission from the Journal of the American Academy of Audiology.

The original works are not included in the electronic version of this dissertation.
1115. Hakalaiti, Anna (2011) Human β1-adrenergic receptor : biosynthesis, processing and the carboxyl-terminal polymorphism

1116. Peltonen, Jenni (2011) TP53 as clinical marker in head and neck cancer


1118. Suorsa, Eija (2011) Assessment of heart rate variability as an indicator of cardiovascular autonomic dysregulation in subjects with chronic epilepsy


1120. Venhola, Mika (2011) Vesicoureteral reflux in children

1121. Naillat, Florence (2011) Roles of Wnt4/5a in germ cell differentiation and gonad development & ErbB4 in polarity of kidney epithelium


1124. Cederberg, Henna (2011) Relationship of physical activity, unacylated ghrelin and gene variation with changes in cardiovascular risk factors during military service


1126. Tolvanen, Mimmi (2011) Changes in adolescents’ oral health-related knowledge, attitudes and behavior in response to extensive health promotion

1127. Pirilä-Parkkinen, Kirsi (2011) Childhood sleep-disordered breathing – dentofacial and pharyngeal characteristics


1130. Haapsamo, Mervi (2011) Low-dose aspirin therapy in IVF and ICSI patients

Book orders:
Granum: Virtual book store
http://granum.uta.fi/granum/
Samuli Hannula

HEARING AMONG OLDER ADULTS – AN EPIDEMIOLOGICAL STUDY

UNIVERSITY OF OULU, FACULTY OF MEDICINE, INSTITUTE OF CLINICAL MEDICINE, DEPARTMENT OF OTORHINOLARYNGOLOGY