Aalto University School of Science and Technology
Department of Signal Processing and Acoustics
Espoo 2010 Report 16

HEARING CONSERVATION AMONG CLASSICAL MUSICIANS; NEEDS, MEANS AND ATTITUDES

Heli Koskinen

Dissertation for the degree of Doctor of Science in Technology to be presented with due permission of Faculty of Electronics, Communications and Automation for public examination and debate in Auditorium S4 at the Aalto University School of Science and Technology (Espoo, Finland) on the 9th of April 2010, at 12 noon.

Aalto University School of Science and Technology
Faculty of Electronics, Communications and Automation
Department of Signal Processing and Acoustics

Aalto-yliopiston teknillinen korkeakoulu
Elektroniikan, tietoliikenteen ja automaation tiedekunta
Signaalinkäsittelyn ja akustiikan laitos

Distribution:
Aalto University School of Science and Technology
Faculty of Electronics, Communications and Automation
Department of Signal Processing and Acoustics
P.O. Box 13000
FI-00076 AALTO
Tel. +358 9 47001
Fax +358 9 460224
E-mail heidi.koponen@tkk.fi

ISBN 978-952-60-3073-9 (Printed)
ISBN 978-952-60-3074-6 (Electronic)
ISSN 1797-4267

Multiprint Oy
Espoo, Finland 2010

ABSTRACT OF DOCTORAL DISSERTATION	Aalto University School of Science and Technology P.O. BOX 1000, FI-02015 TKK http://www.tkk.fi

Author Heli Koskinen (née Laitinen)

Name of the dissertation Hearing Conservation Among Classical Musicians; Needs, Means and Attitudes

Manuscript submitted 27.11.2010	Manuscript revised 9.3.2010

Date of the defence 9.4.2010

☐ Monograph	☒ Article dissertation (summary + original articles)

Faculty	Faculty of Electronics, Communications, and Automation
Department	Department of Signal Processing and Acoustics
Field of research	Acoustics
Opponent(s)	Doctor Kim Kähäri
Supervisor	Professor Matti Karjalainen
Instructor	Associate Professor EskoToppila

Abstract

Noise is usually defined either unwanted sound or sound that is harmful to the hearing. Earlier studies have shown that musicians are exposed to sound levels that can be harmful to hearing, and thus music can be considered as noise. Studies have also shown that musicians have hearing problems due to prolonged music exposure. This is also the case among classical musicians. According to the new noise directive, hearing conservation programs directed to entertainment sector are needed. However the needs and attitudes of the classical music players are not understood in many perspectives. In this study, the total annual noise exposure including personal rehearsals has been measured and evaluated for the first time. The problems experienced with hearing protective devices, hearing symptoms (self-evaluated hearing loss, tinnitus, hyperacusis and diplacusis), and stress and their interaction were identified and quantified in two countries among large symphony orchestras. The results showed that the use of a hearing protective device was poor, especially in personal rehearsals. The musicians with hearing loss used more often a hearing protective device. All hearing symptoms were related to stress and reduced work satisfaction. Hearing loss was measured with audiometer among a volunteer group. The hearing loss correlated with music exposure but was smaller than predicted by the standard ISO 1999-1990. Room acoustics was improved in a project involving small classrooms for music students. The classrooms correspond to personal rehearsal facilities for musicians. The improvement in room acoustics was minor, but had a beneficial effect on job satisfaction. The thesis provides means to implement personal protection, technical means and training in hearing conservation programs for classical music players.

Keywords music, hearing loss, hearing symptoms, noise exposure, hearing conservation program, hearing protectors

ISBN (printed) 978-952-60-3073-9	ISSN (printed) 1797-4267
ISBN (pdf) 978-952-60-3074-6	ISSN (pdf) 1797-4267
Language English	Number of pages 160

Publisher Multiprint Oy

Print distribution Aalto University School of Science and Technology

☒ The dissertation can be read at http://lib.tkk.fi/Diss/2010/isbn9789526030746

VÄITÖSKIRJAN TIIVISTELMÄ	Aalto-yliopisto teknillinen korkeakoulu PL 1000, 02015 TKK http://www.tkk.fi
Tekijä Heli Koskinen	
Väitöskirjan nimi Klassisen musiikin esittäjien kuulonsuojelu; tarpeet, keinot ja asenteet	
Käsikirjoituksen päivämäärä 27.11.2010	Korjatun käsikirjoituksen päivämäärä 9.3.2010
Väitöstilaisuuden ajankohta 9.4.2010	
☐ Monografia	☒ Yhdistelmäväitöskirja (yhteenveto + erillisartikkelit)

Tiedekunta	Elektroniikan, tietoliikenteen ja automaation tiedekunta
Laitos	Signaalinkäsittelyn ja akustiikan laitos
Tutkimusala	Akustiikka
Vastaväittäjä(t)	Lääketieteen tohtori Kim Kähäri
Työn valvoja	Professori Matti Karjalainen
Työn ohjaaja	Dosentti Esko Toppila

Tiivistelmä

Melu määritellään tavallisesti joko ei-toivotuksi ääneksi tai ääneksi, joka on haitallista kuulolle. Tutkimukset ovat osoittaneet, että muusikot ovat altistuneita äänitasoille, jotka voivat vahingoittaa kuuloa, ja siten musiikkia voidaan pitää meluna. Tutkimukset ovat myös osoittaneet, että muusikoilla on kuulo-ongelmia, jotka johtuvat pitkittyneestä musiikin äänialtistuksesta. Myös klassisen musiikin esittäjien on havaittu altistuvan korkeille äänitasoille, ja heillä on havaittu kuulo-ongelmia. Uuden meludirektiivin mukaan tarvitaan viihdealalle suunnattuja kuulonsuojeluohjelmia. Tästä huolimatta klassisen musiikin esittäjien tarpeita ja asenteita ei ymmärretä riittävän monelta kannalta. Tutkimuksessa mitattiin ja määriteltiin ensimmäistä kertaa koko vuosiannos, mukaan lukien yksilöharjoitukset. Koetut ongelmat kuulonsuojainten käytössä, kuulo-oireet (itsearvioitu kuulonalenema, tinnitus, hyperakusia ja diplacusis) sekä stressi ja näiden vuorovaikutus on tunnistettu ja määritetty kahden maan suurissa sinfoniaorkestereissa. Tulokset osoittivat, että kuulonsuojainten käyttö oli vähäistä, varsinkin yksilöharjoituksissa. Muusikot, joilla oli kuulonalenema, käyttivät kuulonsuojaimia eniten. Kuulo-oireet korreloivat stressin ja vähentyneen työtyytyväisyyden kanssa. Kuulonalenema mitattiin vapaaehtoisryhmältä. Kuulonalenema oli verrannollinen altistukseen, mutta pienempi kuin standardin ISO 1999-1990:n ennustemallin mukainen. Huoneakustiikkaa parannettiin yhdessä projektissa pienissä musiikkiluokkahuoneissa, joita myös käytetään yksilöharjoitteluun, ja jotka ovat täysin vastaavanlaisia kuin orkesterien käyttämät huoneet yksilöharjoituksiin. Huoneakustiikan parannus oli minimaalinen, mutta sillä oli suuri merkitys työssä viihtyvyyteen. Väitöskirja antaa työkaluja kuulonsuojauksen, teknisten keinojen ja valistuksen toteuttamiseen klassista musiikkia esittävien muusikkojen kuulonsuojeluohjelmissa.

Asiasanat musiikki, kuulonalenema, kuulo-oireet, melualtistus, kuulonsuojeluohjelma, kuulonsuojaimet	
ISBN (painettu) 978-952-60-3073-9	ISSN (painettu) 1797-4267
ISBN (pdf) 978-952-60-3074-6	ISSN (pdf) 1797-4267
Kieli Englanti	Sivumäärä 160
Julkaisija Multiprint Oy	
Painetun väitöskirjan jakelu Aalto-yliopiston teknillinen korkeakoulu	
☒ Luettavissa verkossa osoitteessa http://lib.tkk.fi/Diss/2010/isbn9789526030746	

PREFACE

Colorful harmony of the sound

smile ignites

bright glow to the colors

It is not only music but the joy of the performer that creates memorable experience to the audience. It is a circle of joy: the joy of the artist creates music which creates joy in a listener. In this thesis, the circle is broken. Music has become burden, and the joy is lost. I have always loved all kinds of music, and the music has given me such a joy. This is my effort to balance the scales.

This study would not have been possible without the co-operation of the management and musicians of Finnish National Opera, Finnish Radio Symphony Orchestra, Helsinki Philharmonic, the Tapiola Sinfonietta, the Guards Band in Finland, and the management and musicians of South Jutland Symphony Orchestra, Aalborg Symphony Orchestra, Aarhus Symphony Orchestra in Denmark, and the management and music teachers of Espoo Music Institute. I owe them more than words can say.

The relationship between teacher and student has always been important to me. I have been fortunate to meet some great teachers in the course of my life. First one of them, Mr. Eero Huovila, pulled a mathematician out of me, and for that I am grateful. Second one, Dr. Esko Toppila has influenced me the most. It is difficult to overstate my gratitude to him, as a teacher, a colleague, and the instructor of this thesis. With his enthusiasm, his inspiration, his intelligence, and his ability to explain things clearly and simply, he helped to change impossible into possible. Throughout my study period (which was not a short time), he provided encouragement, sound advice, good teaching, and lots of good ideas. I would have been lost without him. He believed in me when even I did not.

I am also indebted to Prof. Matti Karjalainen, my supervisor for his invaluable comments, patience and support, especially during my stay at Helsinki University of Technology. Ms. Lea Söderman, helped me in practical matters, and encouraged me to continue the effort, a big thank to you. From that period I also thank my “roommates”, Hannu and Heidi-Maria, it was fun to stay with you. I also would like to thank Ms. Heidi Koponen, who helped me with the final stage of the thesis.

I would like to show my deep gratitude to official reviewers, Dr. Miikka Peltomaa, and Dr. Per-Anders Hellström, who provided me many useful and insightful comments on the thesis.

I would like to express my special gratitude to MSc. Pekka Olkinuora (Finnish Institute of Occupational Health) who enabled and performed many measurements, helped me a great deal, and informed me about possibilities to participate interesting projects.

During my study process I have been given the opportunity to work at two excellent workplaces, and it is a pleasure to thank the personnel of Finnish Institute of Occupational Health, and Helimäki Acoustics, especially there MSc. Heikki Helimäki, who kindly shared his knowledge for helping me to complete my thesis. Mikko, I hope you get eligible answers to your questions.

I owe my deepest gratitude to Associate Professor Torben Poulsen who relentlessly encouraged me, helped in practical matters, gave ideas, and taught me so much about acoustics. I would also like to express my gratitude to the staff of Acoustic Technology and Hearing Systems at Technical University of Denmark. In particular, I wish to thank Associate professor James Harte, who besides being a true friend, did fantastic job in proofreading and commenting my thesis, and Associate Professor Finn Jacobsen who helped me organizing my stay in Denmark.

I had the honor to co-operate with Professor Yôiti Suzuki at Tohoku University, where I studied and worked during 2002-2004. Professor Suzuki has made available his support in a number of ways, and I am truly grateful for that. I would also like to thank his staff, especially Assistant Professor Shuichi Sakamoto, Research Expert Ryuichi Nishimura, and Technical Officer Fumitaka Saitoh.

In addition, I would like to thank most sincerely my colleagues Dr. Jaana Jokitulppo (Akukon Consulting Limited), Dr. Kim Kähäri (Sahlgrenska academy at Göteborgs University), Dr. Beat Hohmann (Swiss Accident Insurance Institution), and Ms. Iiris Turunen-Rindel, who all have given me their valuable time and support. I also wish to thank MSc. Olli Salmensaari (Akukon Consulting Limited) and Docent Tapio Lokki (Helsinki University of Technology) for giving me permission to utilize their results to complete one of my research projects.

I would like to thank also my excellent co-authors from Finnish National Opera, Ms. Kaarina Kuisma and Ms. Katja Perälä.

I wish to acknowledge the financial supporters of the thesis: The Finnish Work Environment Fund, EC Marie Curie Host fellowships program 'Early Stage Research Training' (EST), Academy of Finland, and Finnish Concordia Fund.

Friends are the salt of the earth. There would be so many names but only to name a few: my maid of honors, and dearest friends, Sarri and Tiina, you have been there for me, always. When the world gets too complicated, the joy of a child of simple things brightens the day: my godsons Otso and Jouka, thank you for existing. The rest of the core gang: Ego, Kahko, Kirsi, Konsta, Janne, and Outi, what would I do without you.

Chan, your sense of humor and your continuous support over borders has carried me through some tough times. We are so different, and yet so alike. Marina, my dear neighbor and wonderful friend, I am indebted to you. Angela, I thank you for all the fun times (quite many) we had. My beloved extended Sendai family: karaoke and friends are forever. Oikawa san, thank you for your visits, they were precious. Akama family, and Mikiko san, you helped me to adjust to Japanese way of living. Sara and James, you came a long way to be there in our celebration, cannot thank you enough.

I wish to thank my gaming groups and GMs (you know who you are), and always welcomed visitors, Pauliina, Rami, Eija, Kirsi, Irina, Sanna (our private cook), and Rasmus.

We choose our friends, fate chooses our relatives. Fate has been truly kind to me by providing amazing relatives. Especially I wish to thank you my godparents Liisa and Arvi, and my cousins Lea and Ari for their love and support. I also would like to thank most warmly my godmother Liisukka, who has been like a second mother to me throughout times, and has ensured to have my own haute couture.

I would like to express my deepest gratitude and love to my parents. My mother wished to see the day when I graduate but the time simply run out. I hope that you still will be able to see this, even though you are not longer with us. I miss you every day.

Patience is required from the spouse of a researcher. I have been lucky to have such a husband. Sami, my love, my light, I thank you for all your support and love, and also giving me new family members, your family, to whom I am also most grateful.

Lastly, I offer my gratitude and blessings to all of those who supported me in any respect during the completion of the project.

Espoo, 9th of March 2010

Heli Koskinen

CONTENTS

LIST OF ORIGINAL PUBLICATIONS

I. Laitinen H., Toppila E., Olkinuora P., Kuisma K. “Sound exposure among the Finnish National Opera personnel.” Applied Occupational and Environmental Hygiene 2003;18(3):177-82.

II. Koskinen H., Toppila E., “Hearing Loss Among Classical Orchestra Musicians”, submitted for publication in 2009. Material presented also in the technical report: “Hearing Among Classical Orchestra Musicians”, Technical Report no. 17, Aalto University School of Science and Technology, Department of Signal Processing and Acoustics. Espoo, Finland 2010. ISBN 978-952-60-3084-5, ISSN 1797-4267.

III. Laitinen H. “Factors Affecting the Use of Hearing Protectors among Classical Music Players.” Noise and Health. 2005 Jan-Mar;7(26):21-9.

IV. Toppila E., Laitinen H., Olkinuora P., Kuisma K., Perälä K. “Development of Hearing Conservation Program for Finnish National Opera”, The 2001 International Congress and Exhibition on Noise Control Engineering, The Hague, The Netherlands, 2001 August 27-30.

V. Laitinen H., Poulsen T. “Questionnaire investigation of musicians’ use of hearing protectors, self reported hearing disorders, and their experience of their working environment”. International Journal of Audiology 2008; 47 (4): 160-168.

VI. Koskinen H., Toppila E., Olkinuora P. “Facilities for music education and their acoustical design”. International Journal of Occupational Safety and Ergonomics, accepted for publication in 2009.

LIST OF ABBREVIATIONS AND SYMBOLS

HPD = Hearing protective device

NIHL = Noise induced hearing loss

PTS = Permanent threshold shift

HL = Hearing loss

OAE = Otoacoustic emission

SOAE = Spontaneous otoacoustic emission

EOAE = Evoked otoacoustic emission

TEOAE = Transiently evoked otoacoustic emission

DPOAE = Distortion product otoacoustic emission

TTS = Temporary threshold shift

OSHA = Occupational Safety and Health Administration

HCP = Hearing conservation program

NIWL = National Institute for Working life

Ammot = Artists and Musicians Against Tinnitus

CIEH = Chartered Institute of Environmental Health

HSE = Health and Safety Executive

FNO = Finnish National Opera

RSO = Finnish Radio Symphony Orchestra

HP = Helsinki Philharmonic

TS = The Tapiola Sinfonietta

GB = The Guards Band

FIOH = Finnish Institute of Occupational Health

T = time (hours)

Y = time (years)

L_{Aeq} = A-weighted equivalent continuous sound pressure level

$L_{Aeq,a}$ = average sound exposure for a year

$L_{Aeq,pr}=L_{AeqH}$ = measured average A-weighted sound level in personal rehearsals

$L_{Aeq,gr}= L_{AeqP}$ = measured average A-weighted sound level in performances and orchestra rehearsals

$L_{Aeq,8h}$ = measured A-weighted equivalent continuous sound pressure level normalized to 8 hours work shift

$L_{Ex,8h}$	= A-weighted equivalent continuous sound pressure level normalized to hours work shift over life time
L_{ni}	= noise immission, total energy entering the ear over life time
z	= z-transformation
x	= is the observed threshold shift
μ	= expected mean threshold shift obtained from ISO 1999 (1990) database A
σ	= standard deviation of the threshold shift obtained from ISO 1999 (1990)

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

The question whether music is noise or not, can be approached from many perspectives. Music is appreciated by many and is also used as one kind of therapy to ameliorate pain and suffering (Guzzetta, 1989; Chlan L, 1998; Magill-Levreault, 1993). On the other hand, there are many professional musicians whose hearing problems are known to be caused by music. Still there are musicians that think that hearing problems are an occupational hazard that are dealt with when they occur. They find it offensive to speak about music as noise. The word noise is of Latin origin, the word nausea means seasickness, and is often defined as unwanted or harmful sound (The Canadian Hearing Society, 2008). In this thesis these unwanted effects of music to hearing are in the focus and thus terms music and noise are used in parallel.

The most important tool of a musician is their hearing sense, which must of course be conserved. Musicians have been noted to suffer from hearing symptoms like hearing loss, tinnitus, hyperacusis, diplacusis. Tinnitus is especially common, and consists of ringing in the ears. It has been noted, that tinnitus occurs both continuously (Niemi, 2000; Häkkinen, 1997; Hagberg et al., 2005; Ostri et al., 1989) and after rehearsals and performances (Häkkinen, 1997).

The special character of musicians' occupation has been recognized. A separate field of medicine called performing arts medicine has existed a fairly short time (Harman, 1993). Though the problems of performing artists have been dealt with before, the beginning of performing arts medicine is considered as late as in the end of 70's. The journal of arts medicine, Medical Problems of Performing Artists, was established in 1986. Nowadays, the emphasis of performing arts medicine is prevention. Occupational health care has an obligation to reach musicians, administration, and surrounding co-workers.

When introducing the new directive (2003/10/EC) to protect the workers from the harmful effects of noise, the needs of the entertainment sector were recognised by the European union. All member states were required to make a Code of Conduct to provide practical guidelines, to help workers and employers in those sectors, to attain the levels of protection established in the directive. In Finland the Code of Conduct (Ministry of Social Affairs and Health, 2006) identifies several groups like musicians, technical staff, restaurant staff which belong to the entertainment sector. For each group different measures of hearing conservation have been proposed. The proposals are presented in a form of a four-by-three matrix, where the four columns are performers, music educators, technical staff, and service workers, and on the three rows there are steady job, one-time job, and self-employed. From the matrix, the cell that suits best for the musician is sought. The cell contains procedures for the hearing conservation. The code separates means to reduce the exposure to quick and slow means. Quick means include usage of mutes, quieter arrangements, silencers to theatre guns, sound reduction in sound reproduction, in-ear monitors, absorbent materials, and plexiglasses, as secondary mean hearing protective devices (HPDs). In slow means there are among others development of quieter instruments, acoustic redesign of the facilities, and the most optimal selection of HPDs. Application of the code into reality has been difficult to musicians and the administration. Thus more thorough advice is needed.

In addition to the entertainment specific requirements, the general requirements are still in force. The general requirements consist of limiting the daily exposure, evaluating the risk of combined exposure to noise and vibration, ototoxic chemicals, and the effect of noise to accident risk. In addition the new directive also requires that the employer shall give particular attention (when performing the risk assessment) to the effects on the health and safety of those workers who belong to sensitive risk groups. The recognition of those risk groups is a difficult task and requires the monitoring of risk factors known to affect individual susceptibility (Pyykkö et al., 2007).

According to the directive (2003/10/EC), the employer shall give particular attention to the level, type and duration of exposure, including any exposure to impulsive noise. Many researchers have speculated that if the type of noise is music then the risk is smaller than predicted by exposure evaluation (Burén et al., 1992) in children and youngsters. If true this would require a redefinition of the risk assessment of noise induced hearing loss (NIHL). In some countries, like in Brazil, musicians are not protected by any legislation concerning loud sound levels (Mendes et al, 2007). Thus there is no obligation for the employer to provide hearing conservation to musicians. The researchers in these countries can benefit from the pioneering work done in other countries, in order to bring the matter to the attention of legislators, employers and employees.

The noise directive requires that group level protection measures should be considered first. This means all actions focused on premises, sources and work organisation should be made first followed by technical means. Nevertheless, it is often impossible to reduce sound levels to the extent that usage of hearing protectors would be unnecessary. Musicians' acknowledge the need to use HPDs, however, the usage rate is often low (Curk & Cunningham, 2006; Emmerich et al., 2008; Harper, 2002). In order to improve the usage rate, more knowledge is needed of the current HPD usage and reasons for the negligence.

Already small changes in the exposure would have a dramatic impact to the risk, which is proportional to sound energy entering to the ear (ISO 1999, 1990). Thus a small reduction of 3 dB reduces the risk to half. In addition, the risk of other staff surrounding musicians (lighting crew, sound crew, roadies etc) is reduced at the same extent. Nowadays both musicians and audience wear hearing protectors in many concerts. Hopefully, educated music teachers will pass on the message to their students, and the hearing of a starting, prominent musician is protected at early age, and she/he will be an example to co-workers and colleagues. And perhaps even more also the music students who might have music as a hobby, learn to protect their hearing, and pass on the knowledge to their surroundings. It is also usual that if a person is aware of the dangers of loud sound, she/he protects her/his hearing in noisy leisure time activities as well.

Chapter 2 summarises the current knowledge of noise related hearing problems among classical musicians and their effect on performance. Chapter 3 gives the principles of sound exposure measurement and the state of art of exposure evaluation in classical music. Chapter 4 deals with room acoustics of neglected facilities, i.e. small practise rooms for musicians. The means of protection for musicians are presented in Chapter 5, and drawing up a hearing conservation program (HCP) in general is described in Chapter 6. The noise legislation that involves musicians is given in Chapter 7.

The purpose of the present study is to determine the need for hearing conservation for classical musicians, the current situation, and to investigate whether the hearing conservation principles of industrial noise can be applied to music noise.

Hearing symptoms and stress and their interaction with noise exposure were identified and quantified. Hearing symptoms were evaluated using audiometry and questionnaires. Noise exposure was measured in accordance with ISO 1999 (1990). Although hearing protectors are a simple method to reduce exposure, their use was sporadic according to questionnaire because of the suspected effect to performance. Improving the premises (classrooms, training rooms) did not reduce exposure but increased job satisfaction.

2. HEARING RELATED PROBLEMS OF MUSICIANS

2.1 Definitions and used methods

When talking about hearing problems, the terms are often used quite carelessly, which causes difficulties in trying to follow the presentation. In this thesis the following definitions are used in a consistent way:

Permanent threshold shift (PTS) is the difference between measured audiogram and standard population (ISO R 389, 1964).

Hearing loss (HL) is a permanent threshold shift exceeding a predefined limit. The limit value is not a standard. According to WHO, the HL is disabling when the average PTS in the better ear is more than 41 dB for an adult. According the standard ISO 1999 (1990), the range for normal hearing is 0-25 dB. Sataloff and Sataloff (1993b) suggest, however, that a subject with a 15 dB HL at most frequencies has a hearing deficit.

Noise induced hearing loss refers to a hearing loss caused by noise.

Hearing impairment refers to alteration in auditory system, such as HL, tinnitus, or decreased frequency resolution (WHO, 1980).

Hearing disability refers to the functional limitations caused by impairment in everyday activities, primarily where communication is concerned (WHO, 1980).

Hearing symptoms refer to any subjective evidence of disease. It is closely related to hearing impairment, which refers to physiological changes corresponding to symptoms (MedicineNet, 2009).

Hearing disorder refers to any disruption in the normal hearing process, where sound waves are not converted to electrical signals or nerve impulses are not transmitted to the brain for interpretation (The McGraw-Hill Companies, 2002).

In research and in evaluation of hearing handicap the current golden standard is the audiogram. However, the correlation of the audiogram with subjective evaluation and handicap varies between 0.2 and 0.5 (Barrenäs & Holgers, 2000). The subjective evaluation of hearing disability correlated somewhat better with the audiogram than the handicap. In audiometry the hearing of an individual is tested using pure tone at standard frequencies, usually from 250 to 8000 Hz. The standard IEC 60645-1 (2001) gives the specifications to the audiometer. Audiometers can be used with different types of earphone (Arlinger, 2007). The audiometers are standardized so that 0 dB corresponds to the normal hearing of an average 18 year old subject.

The audiometric data is affected by the type of instrument, technician and background noise level. The types of audiometers used are a clinical audiometer and a screening audiometer. The type of audiometer can cause different variation in the recorded hearing threshold values. Melnick (1984) has proposed that a 10 dB shift at any frequency is significant when using clinical audiometer, and a 15 dB shift when using screening audiometer.

The measurement conditions can be sometimes insufficient. The soundproof room can have background noise levels exceeding the permissible sound levels, or there is only quiet room but no soundproofing. The latter facility is used especially in industry, and results that 0 dB hearing threshold levels cannot be measured. Also, calibration may not be adequate, and the results can be thus biased (Royster & Royster, 1986). The authors suggest that in addition to adequate calibration, normal controls with stable hearing are to be used among noise-exposed population. Also the person taking the audiogram can affect the results (Hinchcliffe, 1997).The variation can be as large as 10 dB.

High-frequency audiometry tests frequencies from 8000 Hz to 20 kHz. Though it is not often tested, it has been considered to be a tool in early detection of NIHL. It can also be used to separate NIHL and presbyacusis. In presbyacusis, higher frequency thresholds (at 10 kHz, 12 kHz and 14 kHz) are decreased whereas in NIHL they are inaffected (Sataloff & Sataloff, 1993d). If the noise exposure is not of a long duration, and the tested persons are young (not over 30 years), high-frequency audiometry shows a hearing threshold shift (Bartsch et al., 1989). In normal audiometry this threshold shift is not seen. In older test subjects the effect disappears and it is impossible to tell the difference between the effects of age and noise on hearing. In another study (Hallmo et al., 1994) the age of rapid decrease high frequency hearing starts from 24 years.

Risk of NIHL is determined by performing audiograms to the examined group, ruling out other possible causes and comparing results to the tables of same age group. The tables are based on studies of industrial workers exposed to noise. If no HL is detected, the risk is negligible. ISO 1999 (1990) standard gives means to calculate expected HL for a population, when noise exposure level, age, and the gender are known. However, the percentiles of the estimations vary a great deal. In reality, the variation is due to individual differences. The question why some people get HL very easily, and even when exposed to safe levels, and others have no problems while exposing themselves to exceedingly loud levels, has been occupied researchers (Pyykkö et al., 2007; Prasher, 2007). Prasher (2007) lists among others the relative strength of the acoustic reflex, levels of melanin and magnesium, and relative protection from sound conditioning as contributing factors to individual differences. Pyykkö et al. (2007) found that smoking and cholesterol can make an individual more susceptible to HL. Ageing can be a confounding factor when other risk factors are present.

Otoacoustic emissions (OAEs) are sounds produced by the cochlea in the normal ear. They can be measured with a miniature microphone directly from the ear and they reflect the functioning of the hearing. Spontaneous otoacoustic emissions (SOAEs) are result of normal functioning of the cochlea, and are present in 30-50 per cent of normal ears. Evoked otoacoustic emissions (EOAEs) can give information about weakened function of cochlea before the problems are seen in audiogram. The EOAE response decreases, or even disappears as the NIHL proceeds. Transiently evoked otoacoustic emissions (TEOAEs) are measured as response to transient stimuli like clicks. Distortion product otoacoustic emissions (DPOAEs) are recorded otoacoustic emissions from the ear in response to two pure tone stimuli. DPOAEs respond better than TEOAEs at high frequencies. They are also less sensitive to HL. They are shown in an ear with HL up to 45 dB. It is also assumed that OAEs can be used for evaluation of noise-induced tinnitus and hyperacusis (Borka, 2007a).

2.2 Noise induced hearing loss

2.2.1 Noise and hearing loss

Noise induced hearing loss (NIHL) can be divided into two classes: acute acoustic trauma and chronic trauma due to prolonged exposure to noise.

Acute acoustic trauma refers to PTS and tinnitus caused by a single event. It may be seen in young people even after short term or incidental noise exposure, e.g. toy pistol firing (Fleischer et al., 1999) and loud amplified music (Metternich & Brusis, 1999). Typically in acute acoustic trauma there is tinnitus involved (Nicolas-Puel et al., 2006). Although typically ignored in health promotion initiatives, tinnitus and acoustic trauma are important health hazards (Borchgrevink, 2003).

Chronic trauma is first seen at frequencies between 3 kHz and 6 kHz at most (Burns, 1973). The important frequencies for understanding speech are at 0.5-2 kHz, and as the HL advances, the speech frequencies are affected too. NIHL profoundly affects person’s everyday life. Hétu et al. (1995) describes the following symptoms that can be present in hearing impairment: the individual threshold of sound detection is increased, the increase in loudness is distorted when the sound level increases, difficulties in resolving the neighboring sounds, ability to detect gaps in an ongoing sound is reduced and persistent tinnitus is present.

The time period for the development of chronic trauma can be long, from 20 to 30 years. With the same noise exposure there is a large variation in HL. The safe level of noise exposure where no one gets NIHL is considered to be 75 dB(A) (ISO 1999, 1990). In the European noise directive it is regarded that 80 dB(A) is the safe limit for minor non-significant changes in hearing levels. Only the most susceptible ones get HL if the noise exposure is less than 85 dB(A). If persons are exposed to sound levels of 85 dB(A) for many years, 5-10 per cent of the exposed will get NIHL (ISO 1999, 1990).

2.2.2 Music and hearing loss

The affects of music on hearing have been noted first in classical music in 1960 (Arnold & Miskolczy-Fodor). The research was set off by a single case. A concert pianist with sudden HL and different ear symptoms after a treatment of aspirin (which is known to be deleterious to hearing; ototoxic, Myers & Bernstein, 1965) raised a discussion about harmfulness of music to hearing, and the matter was decided to be investigated. At that time, it was difficult to get musicians to participate and only 30 elderly pianists participated into investigation. They concluded that they had better hearing than the average of the general population.

Some researchers have studied the hearing of music students, but especially among young students no HL could be determined (Fearn & Hanson, 1989). However, elevated hearing thresholds, and dip in audiograms similar to NIHL have been reported in older groups of music students (Fearn, 1993; Phillips et al., 2008), and beyond noise exposure individual genetic risk factors have been estimated to contribute to observed differences in hearing with students exposed similar sound levels (Phillips et al., 2008).

Research has not come to unanimous opinion on music exposure causing HL. There are studies that conclude that musicians of classical music have NIHL due to music exposure (Royster et al.,1991; Axelsson & Lindgren, 1981; Ostri et al., 1989) and studies that conclude just the opposite (Kähäri et al., 2001b; Obeling & Poulsen, 1999; Karlsson et al., 1983). Even rock musicians have been noted to have better hearing than one would expect (Axelsson et al., 1995). The definition of HL varies. The hearing thresholds that are better than noise exposure level would lead us to assume (if compared to ISO 1999 model) have been explained by different characteristics with music than with industrial noise, variation between quiet and loud sound, toughening effect, use of stapedius reflex (Karlsson et al., 1983; Kähäri et al., 2001b; Axelsson et al., 1995). Also, positive attitude towards music has been assumed to be a protecting element for musician’s hearing (Axelsson et al., 1995).

Though NIHL is usually bilateral and of same magnitude in both ears, among musicians there can be differences between ears. Violin players (Ostri et al., 1989; Axelsson & Lindgren, 1981), and percussionists (Pride & Cunningham, 2005) have been noted to have worse hearing in the left ear. The difference is explained by larger exposure from the instrument on one side and with percussionist by the location of the high-hat cymbal.

Relationship between HL and location in the orchestra and instrument type has been investigated by Johnson et al. (1985) in the Minnesota Orchestra. Audiograms were measured from 60 musicians including high frequencies (9 to 20 kHz). The comparison of different relationships was made among a group of musicians that do not differ from normal individuals (Johnson et al., 1986). No differences in hearing sensitivity were found when comparing between different instruments, or between different locations at stage (Johnson et al., 1985). Also Westmore and Eversden (1981) found no relationship between different types of instrument and hearing.

In self-reported problems with HL, there were differences in the study by Chesky and Henoch (2000) where 3292 musicians replied via WWW. The percentages of those with problems varied from 37 per cent of electric bass players to 4 per cent of harp players. Chesky and Henoch (2000) also found a difference between classical and non-classical music players, where 20 per cent of classical musicians reported problems whereas the corresponding figure for non-classical players was 33 per cent.

Kähäri et al. (2001a) measured audiograms from 140 orchestra musicians. They did not find any severe HL due to music exposure. Female musicians had significantly better hearing than male musicians, percussion players had somewhat yet still significant worse hearing than other instrument group players. However, all age and gender groups up to 40-49 age group had hearing thresholds within 20 dB. The study was made with volunteer musicians.

Music students have not been measured often in the literature. Since HL develops slowly, it is unlikely that young students' hearing would be deteriorated. Schmidt et al. (1994) studied the hearing of students in Netherlands, and found that though there were dips in audiogram they were similar in the control group and thus deducted that there is no effect yet caused by music studies. They also concluded that extended high-frequency audiometry cannot be used as early indicator to detect NIHL.

Studies with professional singers are rare. Steurer at al. (1998) measured hearing thresholds of 62 opera choir singers and found significant degrees of NIHL among them. However, they also found HLs at lower frequencies larger than HLs at higher frequencies. They hypothesized that the reason might be increased endolymph pressure which would cause the low-frequency HL. It has been speculated that the hearing threshold at the singer's formant at 2800-3500 Hz might be affected by NIHL, and thus singer couldn't monitor the sound quality of her/his voice (Teie, 1998).

Whether TEOAEs or DPOAEs can be used as a diagnostic tool for musicians or not has not been adequately established. Lapsley Miller et al. (2004) concluded that either of the measurement types was considered to be valid, reliable or measurable enough to be used in HCP monitoring individuals. However, some audiologists use DPOAEs as a method of monitoring and diagnosing HL or possible future HL (Chasin, 1996; Hall & Santucci, 1995; Emmerich et al., 2008).

Reuter and Hammershøj (2007) measured hearing thresholds and DPOAEs of symphony orchestra musicians before and after the rehearsals. They could not find any differences in hearing or DPOAEs before and after rehearsals where the sound level L_{eq} varied from 70 to 90 dB(A). The authors suggest three reasons for this: 1) the exposure is too low to detect any changes, 2) the recovery time is too fast and test time for DPOAE fine structure is too long to detect the changes, or 3) none of the methods is sensitive enough to detect the effects of overexposure.

Emmerich et al. (2008) measured 109 musicians of different ages and found that both PTSs and OAEs declined with duration of employment, and exceeding age matched presbyacusis in the age group of 40-49 years. Hamdan et al. (2008) measured TEOAEs of professional singers and though they speculate that TEOAEs can be used for monitoring singers, they suggest further study as the number of singers investigated was small.

The time period between detection of DPOAE change and actual detection of the HL is short, only 4 to 5 years. All musicians do not have their hearing checked that often, with three years between check-ups being typical in Finland (FIOH, 2006). In the worst case, the benefit of using DPOAE comes too late.

Other, not often used method is loudness-discomfort level measure where pure-tone stimuli is presented in 5 dB steps, and stopped when discomfort level is reached (Axelsson & Lindgren, 1981; Woolford et al., 1988). The method gives information about the level of sound tolerance of a musician. The information is needed for the diagnosis and treatment of hyperacusis.

2.3 Tinnitus, hyperacusis, diplacusis, and performance

In addition to NIHL other hearing symptoms exist: tinnitus, hyperacusis, or diplacusis. These symptoms can also exist without NIHL, or at worst case musicians can suffer from all symptoms at the same time.

Tinnitus is defined as a subjective sound sensation without any real acoustic sound present. Tinnitus can be heard in one ear, or both, changing sides from one ear to another, or in the middle of the head. Most people experience tinnitus at least sometimes. The origin of the tinnitus is not certain. It has been assumed as a malfunctioning of the hearing system either in the cochlea or in the afferent pathways to the cochlea. Usually the cause is not visible in otoscopy (ear examination). The ear can be affected to such a minor degree that it cannot be discovered in the audiogram. Later on another factor can trigger tinnitus, for example stress. It is also possible that a person can cause tinnitus to him/herself consciously (Borka, 2007b). Tinnitus is measured by questionnaires. Unfortunately there is no consensus on one particular questionnaire as a meter of the annoyance (Henry et al., 2005). Tinnitus can be measured with comparison to given stimulus but it is not as reliable as for example an audiogram (Tyler & Erlandsson, 2003).

The relationship between NIHL and tinnitus is problematic. Literature typically deals with tinnitus in relation to noise exposure, but not to diagnosed HL. In a literature review by Axelsson and Prasher (2000) patients exposed to occupational noise, tinnitus (minimum duration 5 minutes) was present in 20-40 per cent of the cases.

In addition to NIHL, tinnitus is related to presbyacusis (age-related HL), Ménière’s disease, head injury, and tumours etc (Lockwood et al., 2001). Drugs that can cause temporary tinnitus include quinine, aspirin and other salicylates. Streptomycin, and platinum-containing chemotherapeutic agents damage cochlea can cause tinnitus (Lockwood et al., 2001). Tinnitus is usually worsened by infections, tiredness, muscle tension, weakened general condition, and declined spirits. Tinnitus is relieved by relaxation, rest, good general condition, positive mood, functional human relations, etc. Tinnitus is not usually permanent condition. It often diminishes with time, and the effects are soothed or even disappear completely (Sataloff & Sataloff, 1993a).

Hyperacusis is abnormal sensitivity to sound. The sound can be of low level, and not always a specific one (Baguley, 2003). Usually a subject with hyperacusis is extremely disturbed by some daily sounds, for example plates clanging together (Sataloff & Sataloff, 1993b). Hyperacusis is a rather common symptom with tinnitus patients, 40 per cent of tinnitus patients complain also having hyperacusis (Baguley, 2003). And vice versa, hyperacusis as major complaint, 86 per cent of the patients have also tinnitus.

There are different questionnaires to evaluate the hyperacusis and its effects. It is rare to find any medical condition causing hyperacusis. In such a case, it is usually either of peripheral or central origin. However, usually no medical condition can be found, and other explanations for hyperacusis have been presented: 5 hydroxytryptamine dysfunction, auditory efferent dysfunction, possibility of some central hyperexcitability. As with tinnitus, hyperacusis is sometimes worsened with tiredness, anxiety and stress (Baguley, 2003).

Both tinnitus and hyperacusis (with some modifications) are treated with tinnitus retraining therapy (Baguley, 2003). After medical examination, the patient is taught about tinnitus (hyperacusis) and hearing. Only then sound therapy is given; continuous wide band noise is fed to both ears. This continuous stimulus helps the patient to cope with tinnitus (hyperacusis) as the ear gets used to sounds.

Table 2.1. Hearing disorders with musicians in literature.

	Temporary tinnitus	Continuous tinnitus	Diplacusis	Distortion	Hyperacusis
Niemi, 2000 Students	10 % often, 60 % sometimes	12.5 %	-	-	-
Häkkinen, 1997 Students	16 % after rehearsals, often or always 18.2 % after performances often or always	2.5 %	-	9 % often or always	38% often or always
Hagberg et al., 2005 Students	-	incidence of 10.6/1000 practise years	-	-	-
Ostri et al., 1989 Professionals	-	4 %	-	-	-
Emmerich et al., 2008 Professionals	over 50 % after stress or loud performances	-	-	-	-
Miller et al., 2007 Students	63% after exposure to loud music	-	-	-	-
Phillips et al., 2008 Students	12 % after exposure to loud noise, 2 % after instrumental practise	0 %	-	-	-
Kähäri, 2002 Professionals, rock/jazz	43%, more frequent among men than women	-	4% of men, none in women	17% , more frequent among men than women	56% of women, 31% of men
Zeigler and Taylor, 2001	51 %, bigger college, 28 % smaller college, tinnitus of more than 5 minutes	1 student of 179 students	-	-	-
Perälä, 1998 Professionals	44 % sometimes, 15 % often or always	-	-	-	-
Pang-Ching, 1982 school band directors	46% intermittent or constant	-	-	-	-
Wright Reid, 2001 professionals	35-40% frequent or occasional	-	-	-	25% of woodwind players

Diplacusis is a distortion of pitch (Sataloff & Sataloff, 1993c). For musicians it means that when a sound is heard, the pitch is different in two ears. Tuning an instrument and playing can be difficult, if not impossible. Besides NIHL, it can be one symptom of Meniere's disease (Sataloff & Sataloff, 1993b).

Tinnitus is the hearing symptom that has been researched most among musicians besides HL. Even music students have reported temporary tinnitus and continuous tinnitus and other hearing symptoms (Table 2.1.).

Hearing symptoms seem to be connected with psychosocial parameters. This subject is not widely studied. Notable exceptions include Kähäri (2002) made a study among rock/jazz musicians. Musicians seem to be very satisfied with their job. Male musicians having hyperacusis had higher psychological demands, greater difficulty in relaxing after work, higher stress during individual preparation, not getting enough sleep and higher perceived sound level. Female musicians were noted to have association between tinnitus and greater difficulty in relaxing after work and less energy during musical performances.

2.4 Other hearing related problems

It is assumed that absent temporary threshold shift (TTS) after noise exposure means that the noise in question is safe for the exposed (Colvin & Luxon, 2007). Also, it is assumed that if noise exposure causes TTS, it will also cause HL if the exposure continues. The relationship between TTS and PTS has not been firmly established (a certain amount of TTS will cause certain amount PTS). In general, the higher the sound level is, the greater the TTS will be. Classical music has been found to cause lesser TTS than industrial noise (Strasser et al., 2003). A difference in TTS's was found also in other studies between music and noise (Lindgren & Axelsson, 1983; Swanson et al., 1987) with music causing lesser TTS than noise. The first study used only test subjects that liked the music they listened, and the second one had both 'like' and 'dislike' groups, and the conclusion was that liking the sound you are exposed to decreases TTS compared to the sound you dislike. However, no differences in TTS after music and noise exposure have also been found (Hellström et al., 1998).

TTS was experienced by 38 per cent of the musicians occasionally after performance (Ostri et al., 1989). Especially when musicians had to play under the overhang of the orchestra pit, they experienced different symptoms during and after performances: headache, dizziness, tinnitus, and hearing problems. Axelsson and Lindgren (1981) also found TTS in orchestra musicians. The amount of TTS was reported to be mostly less than 15 dB. TTS has also been found in heavy metal musicians after the performance (Drake-Lee, 1992). In spite of the loud sound levels, Drake-Lee considers the risk of HL due to rock music definite but small.

Even if musicians are satisfied with their work, there is a lot of stress involved. Hearing problems and stress are connected. Musician's stress is caused by multiple factors. Sternbach (1993) divides these into three categories: environmental hazards, psychological pressures and intrinsic factors. Environmental hazards include shift work, travelling, frequent swapping of leadership, and economic insecurity. Psychological pressures consist of performing anxiety and ability to cope with it, and how to handle the lack of artistic control as a member in an orchestra. Intrinsic factors are dealing with the dedication to the art, the sacrifices to be made striving for the perfection.

2.5 Summing up the problems

Noise related hearing symptoms exist in musicians. Musicians have an elevated risk of tinnitus. There is no consensus of opinion on whether music causes NIHL or not. We cannot say for certain that classical music does not cause HL. In occupational health care the safety precaution principle that is used applies to musicians too: unless cannot be proved definitely that music is not harmful to musician's hearing and health, the need for protection cannot be ignored when music exceeds the safety limits set for sound. Naturally, the proofs to either way must be procured by further research.

3. SOUND EXPOSURE MEASUREMENTS

The risk of chronic NIHL is proportional to the total acoustic energy entering the ear during a subject's life time. So it depends on both the sound power and exposure time. All frequencies are not equally harmful, which is corrected by applying A-weighting to the sound level.

As the sound exposure cannot be monitored continuously, it must be evaluated. The standard ISO 9612 provides guidelines how to do this. The measurements must be taken over representative period T or they must be done based on tasks. The continuous equivalent sound pressure level ($L_{Aeq,T}$) is defined as "steady state sound that has the same amount of A-weighted energy as the time-varying noise over the same period of time T" (Knight & Baguley, 2007). To make the results comparable they are normalized to one eight hour work shift ($L_{Aeq,8h}$). The sound pressure level is integrated over the time periods measured, usually by the sound level meter. However this is not always done, which makes comparison of results sometimes difficult especially because the authors omit the time subscript.

The noise directive gives the limit values in $L_{Ex,\,8h}$, which is the average daily noise exposure (ISO 1999, 1990). Both $L_{Ex,\,8h}$ and $L_{Aeq,8h}$ present daily exposure. The difference is that $L_{Aeq,8h}$ presents the measured present average exposure as $L_{Ex,\,8h}$ presents the average daily exposure over lifetime. The total energy entering to the ear is expressed (ISO 1999, 1990) as

$L_{ni} = L_{Ex,\,8h} + 10 * \log_{10}(Y)$, where Y is the years of exposure and L_{ni} is the called the noise immission.

The equal energy principle, which means that by every 3 dB of decrease sound energy entering the ear decreases by half, applies only to reasonable sound levels. For example under 85 dB (A) sound level for 8 hours is considered safe to hearing, and 88 dB(A) for 4 hours, 91 dB(A) for 2 hours and so on. A single event can damage hearing when the peak level of the sound exceeds 120 dB (A) (Strasser et al., 2003). The noise directive (10/2003/EC) states that the preventive actions start at 112 Pa (peak) (135 dB(peak)) and becomes intolerable at 200 Pa (peak) (140 dB(peak)). The equal energy principle seems to apply to continuous noise only, intermittent noise has been found to overestimate, and impulse noise to underestimate the HL risk (Colvin & Luxon, 2007). Impulse noise is characterized as a signal of short duration with high intensity. As examples of impulse noise, explosions, gun fire, and fireworks can be mentioned (Burns, 1973). In noise control, different definitions of impulse noise are presented. Burns (1973) suggests that most important factors when one considers the risk of NIHL, are peak level, rise time, and principle wave duration (simple waveforms) or pressure envelope duration (complex waveforms). Pekkarinen (1989) lists peak sound pressure level, time domain and repetition rate as the most usual factors when impulse noise is defined.

The concept of equivalent continuous sound was first introduced by Burns and Robinson (1970). It was normalised into 8-hour exposure. At that time, music was not considered continuous because of its large fluctuation, and for example Schneider in 1976 doubted whether music ever can be equated with continuous industrial noise though acknowledging that loud music can be a risk to hearing. The human voice was not considered to be a risk to hearing in its all forms.

The sound exposure measurement for musicians of classical music is laborious as the situations, and the music played varies a great deal. In order to get a sufficiently comprehensive sample of the sound exposure experienced by typical musicians, the experimental conditions require careful planning. This is due to the fact that classical musicians are exposed to musical pieces that vary a great deal in their sound exposure (i.e. types of musical pieces). They also play in many different facilities, they have a variable number of performances and rehearsals, the size of the orchestra differs, and musician's location in the orchestra differs. Musicians' exposure should be measured in rehearsals with the full orchestra, at personal rehearsals and at performances. The working hours that are included to the calculation of annual exposure can be received from musician her/himself, or from the representative of the musicians. Usually the figure is not the usual number of office working hours as the hours vary with musician, and not all the working hours are spent at playing. The figure is not always the truth about musician’s actual exposure. Many orchestral musicians teach at music conservatories and institutes as their second occupation, and the hours when teaching are not included to the annual exposure, as the employers are different. Naturally, many musicians practise on their own time a great deal and these hours are also not always included to the calculations. This all makes the sound exposure difficult to generalise and determine a mean value for a 'typical' musician.

After the first measurements were carried out on pianists in 1960 (Arnold & Miskolczy-Fodor), the topic was somewhat forgotten. The question about popular music, and its sound levels rose, and research begun more vibrantly than with classical music (Fluur, 1967; Rintelmann & Borus, 1968; Lebo & Oliphant, 1968; Axelsson & Lindgren, 1978). Lebo and Oliphant did measure the sound levels of a symphony orchestra but came to the conclusion that the sound levels are safe for the hearing even at forte passages for the whole orchestra. Interestingly enough the sound levels they measured in 1968 would today exceed the level that is considered safe.

Many musicians still believe they can judge sound levels subjectively. For example, the type of music affects the judgement (Westmore& Eversden, 1981). In their study, ballet Romeo and Juliet was determined excessively loud even though the sound levels did not differ from the average.

The exposure measurement is usually performed by using a personal dosimeter on each musician (Sabesky & Korczynski, 1995; Early & Horstman, 1996). The dosimeter is attached on the shoulder of musician so that it doesn’t hinder the movement of the musician but as close to ear as it is possible. The easiest choice is to measure the sound levels from violin players from the right side but it is also possible to attach microphone to the left side using a band on the head. Tripod-mounted sound level meters have also been used in the measurement of musicians (Westmore & Eversden, 1981; Jansson & Karlsson, 1983; Axelsson & Lindgren, 1981) but it doesn’t give enough information about musician’s instrument and of the exposure they receive from other instruments, that is, the location in the orchestra is an important factor.

In Europe and in the USA different methods to report the noise exposure are used. In Europe usually L_{Aeq} is used and in the USA the concept of dose in percentages is also used. The 100 per cent dosage is received when the L_{Aeq} for 8-hour working day is 90 dB(A). Some of the results of sound level measurements are presented in literature by using only dosage (Henoch & Chesky, 2000), which also makes it difficult to compare different measurements. At present, Occupational Safety and Health Administration (OSHA) noise standard consists of two stages (McCammon & Sorensen, 1996). When an employee is exposed to sound levels 85 dB(A) or more in 8 hour workday, a HCP must be implemented. If the sound levels exceed also 90 dB(A), engineering or administrative noise controls are required.

In Europe the action level used to vary from 90 dB(A) to 80 dB(A) (86/188/EEC, 1986). Since the new directive (2003/10/EC) there are three different action levels which each require different measures to be taken by the employer, and also by the employee.

Conductors decide largely the overall sound level of an orchestra. Measurements can for example reveal that acoustics at the conductor’s podium are such that she/he experiences the lowest sound levels, and thus requires orchestra to play louder even though from the audience point of view this is not necessary. There are some recorded sound level measurements made on conductors (Harding & Owens, 2003). Depending on the study, conductors either are or are not exposed to harmful sound levels. The acoustics of the facility, size of the orchestra and the musical works at hand contribute to the sound level of a conductor.

Royster et al. (1991) measured sound levels and hearing thresholds of Chicago Symphony orchestra. 68 sound level measurements with a dosimeter were performed. The sample was collected from different kind of repertoire, and both at orchestral rehearsals and performances. Personal rehearsals were measured with two musicians (violin and viola), and the results were not combined with other exposure though it was noted that for louder instruments personal practise increases the sound exposure significantly. They conclude from the measured peak sound levels that the chance of an acoustic trauma is small from orchestral music. However, there are other sources of sound that have been noted to cause acoustic trauma for musicians, for example fireworks that are sometimes used to add festivity to the performance (Esko Toppila, personal information).

There are very few studies that take into account annual sound exposure $L_{Aeq,a}$. Lee et al., 2005 measured the sound exposure of Canadian Opera Company and calculated also musicians' annual sound exposure. They came to the conclusion that musicians are not at risk on annual level. The sound levels are not that different from other studies but the working hours used were relatively low and the personal rehearsals were not included to the study. The annual exposure varied from conductor's 74 dB(A) to trumpet's 85 dB(A). The authors themselves also present a third reason for low levels, that the types of the operas measured are considered average and light. The study could not determine whether the sound exposure is worse for musicians in the orchestra pit than for example rehearsal hall. However in other studies the greater sound levels in the pit have been discovered (Emmerich et al., 2008).

Babin (1999) measured sound levels with orchestras in Broadway shows. The orchestra is playing in the pit with various layouts, and the pit could be enclosed in different ways. It turned out that the more enclosed the pit was, the more difficulties musicians experienced. The most liked layout was when the brass section was around the conductor and the sound escaped through the open section of the pit. Other factors that added sound exposure was the loudspeakers' orientation that were meant for transferring sound to the audience but ended up also exposing the musicians in the pit, and gunshots occurring at the stage. Also, no acoustical absorption was allowed to install to the pit as producers wanted the sound to reflect from the wooden walls to the audience.

Within classical music, also type of music played has been researched. Subjectively musicians have considered modern classical music the loudest (Axelsson & Lindgren, 1981). However, this is not true when sound pressure levels are considered. There is no question that sound levels vary with music pieces but the factors affecting are more than just the music played: size of an orchestra, location (pit, stage), conductor etc. Operas composed by Wagner have been brought up as the worst case scenario (Camp & Horstman, 1992), and they have proved to be loud. Nevertheless one should not draw the conclusion that Wagner by default would be any louder than other operas or compositions with "heavier" content. It has been recommended that the high exposure pieces are recognised from the performance schedule and placed to the schedule so that they do not cause extreme exposure to musicians (Mikl, 1995), by for example keeping the rest of the day quiet or not having two loud performances the two following days. This will give the ears some recovery time and thus might lessen the affect of sound exposure to hearing (Campo & Lataye, 1992).

Besides players of classical music, also professional singers of classical music have been noted to be exposed to excessive sound levels (Niemi, 2000). Choirs are exposed to high sound levels (Lindblad, 1986). Unfortunately, the study will not give precise figures but percentages of the overall time at different sound levels to which singers are exposed.

Music teachers are also known to be subjected to sound levels exceeding the limits (Mace, 2006). Though there were more teachers exposed to sound levels over 85 dB(A) after group activities, the greatest average sound levels alternated between group and individual teaching activities. Also, the relation between number of students and sound level was weak as was the relationship between experience level and sound levels. Behar et al. (2004) calculated L_{EX} of Canadian music teachers and found that 39 per cent of the teachers were exposed to sound levels over 85 dB(A), and others were at the limit or close to it. High school band directors are exposed to levels over 85 dB(A) (Owens, 2004).

Previous studies will give us an approximate range of sound levels for different instruments (Fearn, 1993; Mc Bride et al., 1992; Obeling & Poulsen, 1999, Sabesky & Korczynski, 1995) but as the range of the results is very wide, and depends on the size of an orchestra, playing facilities, working hours, whether all different types of playing situations are recorded, they give us only idea of the situation. In addition, most of the measurements are performed only in orchestral rehearsals and performances. However, it has been shown that the sound levels are high also in personal rehearsals and the hours spent in them is considerable (Fearn, 1993). In many cases the sound levels are above the national action limit (Jansson & Karlsson, 1983; Royster at al., 1991, Sabesky & Korczynski, 1995; Harding & Owens, 2003 among others), and thus it can be said musicians are exposed to sound levels that can be considered harmful to hearing.

The exposure measurements made and presented above often lack sufficient information in order to compare the results with other studies, or with action levels. L_{Aeq} is sufficient information for starting a noise control program but not for risk evaluation. The evaluation is a strenuous process and for example the estimation of real working hours can be extremely difficult. This might be the reason why annual exposures are rarely used. Musicians themselves might not always tell the truth about the working hours. Behar et al. (2006) recommend in their review that in further studies the results should include the full description of measurement technique, raw data, and the explanation how the calculation was handled, and more precise analysis of data. They give recommendations for the future studies: complete measurement of the exposure period, measurements details given, explanation of the calculations and raw data offered, preferably annual exposure or other long term exposure calculated, and whenever possible, combined with audiometries compared to ISO 1999 (1990).

4. ROOM ACOUSTICS AND MUSICIANS

When room acoustics is considered in music, it usually involves large music halls where music is being performed to an audience. Historically, the focus of classical studies was in the audience and their experience. Room acoustics from the view of reduction of the sound exposure in music and music education is surprisingly insufficiently studied. One of the few guides, namely Wenger planning guide (Wenger Corporation, 2001) charts quite extensively all the aspects in building music institutes and their facilities. In Finland there is also a guide on the acoustical design of buildings: schools, auditoriums, spaces for sports and libraries (Kylliäinen et al., 2007), which has a chapter on music facilities. It might be said that when the facility has good acoustical planning, it is also good from the point of view of reduction of the sound exposure. One exception can be the spaciousness of the facility: if a loud instrument is placed to a small room, in spite of good acoustics, the sound level is too high, and musician may feel the situation uncomfortable. Also, there is little information about the reality that students, teachers and professional musicians are facing, and what can be done if the requirements are not met.

Musicians, while performing at a stage, have been researched more extensively since the 80's (Gade, 1981), but mostly from the point of view musicians hearing each other in the assemble. Also, some attention has been paid to the rehearsal halls, but for small, one or at most five musicians' practice rooms are hardly ever considered. The room acoustics of great halls is of course very important but also the proper planning of rehearsal rooms for orchestra and individual musicians is required.

The new directive (2003/10/EC) was an important reason for the study of new opera house in Copenhagen (Gade, 2007). The acoustics of the opera house was considered good but the volume of the house caused an increased demand for sound levels from orchestra musicians and singers. The questionnaire study revealed that brass players disliked the screens in front of them (used to protect other musicians from the direct sound from brass) due to strong reflections back at them. The measurements with different types of screens showed that a screen with absorbent side towards brass would be most beneficial for the musicians. Concerning the acoustics of the orchestra pit the Danish working group (aims for finding solutions for complying with the directive in music and entertainment business) recommends the following:

- Suitable area for a musician is 2 m^2, minimum 1,5 m^2 in rehearsals and performances
- If electrical amplification is not going to be used, volume of the hall must be designed with care: not too big and not too small, both will increase the sound levels.
- Background noise of technical equipment should be low and the sound insulation of the facilities should be good.
- Performances should be selected so that they fit into the hall in question.
- There should also be acoustically reflective surfaces near the orchestra, situated so that they help the orchestra to hear each other.
- Screens must have sufficient attenuation but small enough to keep the connection between orchestra and musicians behind them.

The working group also had to set up guidance for directors and stage set designers to make it easier for the singers to perform. The guidance deals mostly getting a proper reflective wall behind and to the side of the singers in order to reduce the volume of the stage and to convey the sound better to the audience. The guidance to the directors concerns mostly the placement of the singers: they should be more in the front than at the back of the stage.

Behar et al. (2004) compared music teachers in two similar spaces of different volume. Their measurements showed a decrease in sound levels by 2 dB which was within measurement error.

The rooms had absorption only at ceiling, and authors describe them subjectively as not too reverberant. They found the increase of the absorption ineffective since absorption works only when teacher and a student are far away from each other. They recommend use of carpet to reduce noise from moving furniture and walking.

The use of basements with hard reflecting walls for practise rooms has been noted in the 70's by Flottorp (1973) and a concern for the high sound levels was raised. However, basements are still used and absorption is rarely sufficient leading to high sound levels, and acoustically poor facilities.

The Code of Conduct (Ministry of Social Affairs and Health, 2006) gives requirements for the space needed for the instruments: grand piano and drum set at least 80 m^3/person, wind instruments at least 20 m^3/person, and other instruments at least 10 m^3/person. Wenger planning guide (Wenger Corporation, 2001) for secondary school music facilities gives values for area and by person: one student; 3-4 m^2, two students, 5-6 m^2, four students 7-7.5 m^2, and six students 9-9.3 m^2. Chasin (1996) recommends a minimum volume of 17 m^3 for a rehearsal room.

The Code determines the acoustic properties of the facilities by using SFS 5907 (2004), Acoustic classification of spaces in buildings, where the reverberation time for special class rooms is smaller than 1 s, and sound isolation R'_w (ISO 140-4, 1998) is bigger than 57 dB. When building new or renovating old facilities, the Code provides class B to be used for music facilities (reverberation time 0.8-0.9 s and the sound isolation R'_w bigger than 65 dB). A Class B is a very demanding facility to achieve in sound insulation, especially when renovating old. Class B almost always requires an acoustician to plan it. However, even Class B is not enough when band practise facilities are built.

Mehta et al. (1999) and Teuber and Voelker (1993) give the essential requirements for modern design of practise rooms. Good sound insulation is necessary, and principles for structures and requirements for materials are given. Sound insulation must be built for preventing sound to proceed from the room and to the room, also from outside the building. Sound transfer from one room to another through HVAC systems is prevented with silencers in ducts. Sound level limits for the background noise in practise rooms are given. Absorption time for small room varies depending on the volume from 0.2 s to 0.6 s for smaller rooms. Carpets are to be used, and lighting should be preferably even, not fluorescent. Mehta gives area and volume requirements for band halls and choral rooms. Mehta et al. (1999) and Kemp (2000) bring also forward the possibility to use prefabricated practise rooms. Prefabricated rooms that are modules ready to be placed into the building are not often used in Finland.

It has been noted by several authors that adjustable room acoustics is beneficial for practise rooms as the opinions changes with the individual musician (Lane & Mikeska, 1955; Wilkes, 1998; Teuber & Voelker, 1993).

The cost of appropriate premises is negligible when taking the demands into account in the planning phase. Renovation is always expensive. Musicians practise a great deal. Their practise places vary from facilities built for the purpose to the dressing rooms with ceramic tiled floor and walls. Needless to say, it feels quite different to play in these two extremes.

Again, education plays an important role too. Musicians need to know what they can expect from acousticians and learn to ask for it. According to Gade, only 28 per cent of the musicians had talked about acoustic problems with an acoustician or similar expert ever (Gade, 1981).

5. PROTECTING THE PROFESSIONAL EAR

Musicians' hearing protectors are a contradiction in terms. However, acoustical improvements and other measures to decrease the sound level exposure have limits. More often than not musicians have to face the fact that HPDs are to be used. There are different kinds of HPDs on the market and the selection for the musicians has been increasing. HPDs designed for industrial use are often not used by musicians because their attenuation is strongest at higher frequencies and small at lower frequencies. This kind of uneven attenuation is felt by many musicians to be unacceptable.

Generally speaking, the types of HPDs are passive and active (Starck et al., 2007). Passive HPDs are divided into earmuffs that have a head- or neckband or they are attached to a helmet, and to earplugs that are either disposable or reusable. Active HPDs comprises sound generation systems and noise cancellation systems.

When hearing protectors are selected they are required to be suitable for the work in order to ensure high usage rate. Thus the selection of musicians' HPDs demands skilful and careful planning. In accordance to standard EN 458 (selection, use and maintenance of HPDs, 1993) the HPDs shall be selected so that they protect adequately but not too much. There are different methods in EN 458 varying from rough estimate to precise in order to determine what kind of HPDs are the best. The usage time is important, the protection efficiency decreases rapidly when HPDs are not used when they are supposed to: for 8 hour exposure the usage time of 4 hours means about 3 dB protection even with the most efficient HPDs at the market (Starck et al., 2007). The protection decreases also if the HPDs are old, fitted incorrectly, or the person moves at work.

Musicians use hearing protectors but most do not use them continuously (Landau Goodman, 2001; Cunningham et al., 2006; Hoffman et al., 2006). Studies have shown that even if hearing protectors would be used only sometimes, severe HL cases are more uncommon with occasional users than with those who do not use them (Starck et al., 1996). The effect has been studied among certain groups of percussionists. In a study of 315 percussionists (Cunnigham et al., 2006; Hoffman et al., 2006; Pride & Cunnigham, 2005), those who used foam earplug always or sometimes had significantly better hearing thresholds than those who used them never. The effect did not reach statistical significance for all percussionists that used any type of HPDs, but when DPOAEs were compared (group of 86 percussionists), HPD users had significantly better DPOAE amplitudes. The usage rate for those who used HPDs sometimes or always was 33 per cent in practise and 44 per cent in performances (Curk & Cunnigham, 2006).

Musicians' earplugs; which are custom-moulded earplugs with special filters that provide flat attenuation at all frequencies measured were introduced to the market in 1985 (Killion et al., 1988). In reality, the attenuation is not strictly flat but it is the best option for hearing sounds unaltered, only quieter. There are three kinds of filters with different attenuation levels. Before these specially designed hearing protectors, musicians used all the available types of hearing protectors if any. Also researchers had the opinion in the 1980's that earplugs are not suitable for musicians, partly for image reasons (Westmore & Eversden, 1981; Axelsson & Lindgren, 1981). Despite the development of musicians' earplugs, many musicians still dislike the custom-moulded earplugs (Emmerich et al., 2008). The custom moulded earplugs are expensive and especially freelancers sometimes consider the expenses too high. Because the custom moulded earplugs lose their ability to protect with time (the seal becomes loose), they should be replaced every second or third year.

Chasin and Chong (1992) have presented a so-called tuned/vented earplug that attenuates only at higher frequencies. This type of earplug is not often used in Europe, because at present the prerequisite for hearing protectors to be sold at European market is that a hearing protector shall attenuate certain level at every frequency tested (EN-352-2).

Classical musicians usually do not wear in-ear monitors (Hall & Santucci, 1995), but they are also one type of hearing protector when other sounds must be monitored while performing amplified music. They are essentially loudspeakers that are fitted into an ear mould which seals the ear canal, and protects from outer sounds, and enables lower sound level in the loudspeakers. The monitors can be conventional loudspeakers on the floor but usually they lead to high sound levels from the loudspeakers on top of other surrounding sounds.

The use of hearing protectors increases when hearing symptoms occur (Häkkinen, 1997). Some musicians use hearing protectors only in one ear (Häkkinen, 1997). In Häkkinen's study music student groups that used only one hearing protector were violinists, cellists and a flutist.

Many studies mention the occlusion effect in the context of hearing protectors (Østergaard Hansen, 1997; Oberdanner et al., 2002; Berger, 1994). The occlusion effect occurs when the ear is completely sealed by the hearing protector. The sound through bone conduction is clearer, and low frequencies below 2000 Hz are enhanced (Berger, 1994). The effect has been studied among hearing aid users (Østergaard Hansen, 1997) but research among musicians has been small (Oberdanner et al., 2002).

A wrong type of hearing protectors or a faulty usage of HPDs can lead to the symptoms that have nothing to do with hearing: pressing the voice of a singer, overplay resulting to pains in neck, wrists etc (Chasin & Chong, 1992).

The usage of HPDs and characteristics of usage have been studied but not to great extent. In the 1995 study of Sabesky and Korczynski, 10 per cent of the musicians wore HPDs. The types varied from premoulded earplugs to custom moulded ones.

Landau Goodman (2001) studied musicians in the USA where musicians of an orchestra were given free custom moulded musicians' earplugs but out of 102 musicians 60 declined the offer. Even though musicians who rejected the earplugs felt that their hearing was decreased, they did not feel that the cause would be music. The musicians who took the offer reported reasons for not using musicians earplugs earlier on: inconvenience and the expense of a doctor, never took the opportunity, not available, didn't know about them, not worried about damage yet, already using foam earplugs etc. This group also reported higher a usage rate for foam earplugs in loud selected pieces: 45 per cent used them occasionally, 29 per cent on a consistent basis. After the trial of musicians's earplugs, a survey was made again. Musicians seemed to be satisfied with musician's earplug though 12 per cent of the respondents did not use them at all during the trial period and 12 per cent still kept using foam plugs more the custom moulded ones. Most of the respondents found sound quality through earplugs better than anticipated, and they were happy to have tried them and would recommend them to other musicians.

A study in the UK and Germany (Harper, 2002) among musicians showed that in the UK, of the 78 per cent that used some sort of preventive measures, 77 percent had used hearing protectors, and 60 per cent screens. In Germany of the 73.7 percent that used some sort of preventive measures, 52.6 percent had used hearing protectors, and 62 per cent screens. This of course does not give the actual figure for usage, or if it is continuous. In fact, 10.8 per cent noted that they cannot play at all with hearing protectors on. In another study in Germany (Emmerich et al., 2008), 60 per cent of the musicians never used HPDs, 18 per cent used them rarely, 17 per cent often and 2 per cent always. When asked about having their hearing tested (Harper, 2002), 44.2 per cent of the UK musicians have had their hearing tested while the same percentage for German musicians was 90.3 per cent. In Germany the hearing tests were given by the employer and were often obligatory for musicians.

Music students use hearing protectors too. In Niemi's (2000) study, 27.5 per cent of the responded students used hearing protectors sometimes. Häkkinen (1997) found out that music students use hearing protectors while rehearsing as follows: 24 per cent used them rarely, 5 per cent often and 6 per cent always. In performances the percentages were slightly lower. Students do not use custom moulded hearing protectors; only 2 per cent used musicians' earplugs. This is probably due to high price of the earplugs and students' low economy. In 2007 study by Miller et al., 78 per cent of the students wore no HPDs at all, and of those who wore HPDs none reported 100 per cent usage. Foam plugs were mostly used. Zeigler and Taylor (2001) found that students wore HPDs occasionally 12, 4 and 29 per cent, and regularly 3, 1, 7 per cent in rehearsals, concerts and leisure time activities respectively.

Though the topic concentrates mainly on the professional musician, the measurements among people surrounding musicians and music have shown that there is a risk of HL, and usage of HPDs is minor. Sadhra et al. (2002) measured British student employees working in university entertainment venues. They found that, although the limits were exceeded, the workers did not have knowledge about hearing protection, and did not even think loud noise a risk to their hearing.

In addition to hearing protectors, different products are developed to protect the hearing of a musician. Hearwig® (Hearwig®, 2008) is an adjustable shield that surrounds musicians head when in use, and can be pulled back without using hands. Though the attenuation of Hearwig® is not that extensive, especially at lower frequencies, there are many satisfied users for it. Hearwig® requires musician's own judgement of the music and it does not protect from musician's own instrument.

Different kinds of plastic shields are used. They protect the ear at high frequencies but very little at low frequencies (Camp & Horstman, 1992). Some musicians find them useful. Shields are sometimes criticized for their visibility to the audience. James (2006) has studied the effect of both visibly and acoustically transparent shield, and found that the reflections from the shield to the musician in front of it are small compared to reflective shield. Musicians' feedback has been generally positive over the absorbent shield. James recommends the usage of reflective shields only in the closed orchestra pits, where the reflective energy can be directed onto the overhang covered with absorbent material.

Chasin and Chong (1992) suggests humming as protective measure to the instrumentalists who know a particularly loud sound is about to occur. Humming would trigger the stapedial reflex which stiffens the auditory ossicles and thus prevents the transfer of the sound into inner ear.

6. HEARING CONSERVATION PROGRAM

An effective hearing conservation program (HCP) is designed to prevent NIHL at work. It has been shown that if a HCP is developed merely to comply with the regulations, it is not efficient (Royster at al., 1982). Only if the whole workplace is motivated and committed, can the HCP work as it was intended.

The components of an effective HCP are as follows (Stewart, 1994):

1. Measurement of work-area noise levels
2. Identification of over-exposed employees
3. Reduction of hazardous noise exposure to the extent possible through engineering and administrative control
4. Provision of HPD if other controls are inadequate
5. Initial and periodic education of workers and management
6. Motivation of workers to comply with HCP policies
7. Initial and periodic evaluation of worker hearing levels
8. Professional audiogram review and recommendations
9. Follow-up program for audiometric changes
10. Detailed record-keeping system for the entire HCP
11. Professional supervision of HCP

There are however, several other HCPs with slightly different emphasis, or classification. Royster at al. (1982) presents five stages essential for an HCP: education, sound surveys, engineering and/or administrative controls, and audiometric testing. One of the problems in HCPs is the interpretation of audiometry. Franks et al. (1989) suggested that besides audiometry, companies should gather other information that might affect the employee's hearing, such as medical history and off-work noise exposure. He also recommends that employees are informed about risks of noisy hobbies or other factors that might affect hearing. The knowledge of other risk factors affecting hearing is increased and more comprehensive models, that take into account more than an ISO 1999 model, have been developed (Pyykkö et al. 2007, Toppila et al. 2000).

Royster et al. (1982) found that in the most effective HCPs, the program was run by one person who was committed and had the management's total support. Melnick (1984) investigated three methods for evaluation of the effectiveness of an HCP, but concluded that the information that was available was insufficient. He necessitates, however, the need for the evaluation of the effectiveness of HCPs.

When in doubt, sound level measurements should be performed. Musicians cannot determine harmful sound levels by themselves (Niemi, 2000).

When HCPs are made in large orchestras, a committee consisting of all the representatives of the organisation should be formed: orchestra members, administration, technical staff, conductors etc. Especially conductors are the key group since they decide how the orchestra sounds and more important, how loud they are. The committee in particular should be well educated about hearing problems, hearing protectors and noise control.

Education is important, as shown. In an American study (Cunnigham et al., 2006; Hoffman et al., 2006), where researchers gave first a brief education about risks of music induced HL and HPD use to 400 percussionists. 300 of them received free Etymotic ER-15 musician-quality earplugs. 350 participants received a survey after 6 months to their home, and 172 returned the survey. Of these respondents, 77 per cent used HPDs more often after the given information. The reasons for the behaviour were stated as "were more aware of the dangers of loud music (78 per cent), were made aware of benefits of musician-quality HPDs (76 per cent), received a free pair of Etymotic ER-15 earplugs (77 per cent), or learned that they were at risk for music induced HL (44 per cent)". 27 per cent of the percussionists even bought a new pair of earplugs after the information was received.

A study among British music students showed that they would most likely seek advice from their instrumental teacher, who is not necessarily always an authority in providing the exact information on health problems (Williamon & Thompson, 2006). The study suggests that conservatories and similar institutions, should: include knowledge about musician's health and well-being as a part of their educational program. Education has also been noted to be the most effective way into usage of hearing protectors (Landau Goodman, 2001), and to hearing conservation in general (Schmidt et al., 1994).

In some orchestras and music institutes, the preventive measures and education have been taken (Fearn, 1993). Musicians and music students are lectured on hearing, music as noise, and hearing protection. Research has also shown that students are exposed to loud sound levels, already have problems in hearing (Niemi, 2000; Miller et al., 2007). Miller et al. also found that education can be deficient, where 74 per cent of the students had received education on effects of noise but still the protection of hearing was minor. One of the problems is that students are not subject to noise exposure regulations, and thus it is up to the educational institute whether or not health education of music students is given (Miller et al., 2007). This practise differs from country to country, and for example in Finland noise exposure regulations are applied also to students (FIOH, 2007).

A survey was made of musicians in the UK and Germany (Harper, 2002). In the UK, most of the respondents (96 per cent) were concerned about noise. Noise and cramped playing position were the issues that caused the biggest concern among musicians. In instrument groups noise was considered the biggest problem among woodwind players, harpists and percussionists. In Germany musicians were also concerned about noise, but there all instrument groups unanimously considered noise as their biggest problem.

Studies among British orchestras have led to a guide to symphony orchestras how to manage hearing conservation (Wright Reid, 2001, Wright Reid & Warne Holland 2008). Though the guide gives a wide selection of advice on how to handle hearing conservation, and recognizes that HPDs are the last resort, it emphasizes that "personal hearing protection will have to become a part of daily life for large number of musicians".

Zeigler and Taylor (2001) investigated music students in two colleges in Florida, USA. The students were mostly inquired about tinnitus, and the usage of HPDs. The questionnaires were distributed two times, and at first time students were asked if they were more likely to participate in hearing conservation efforts after completing the survey, 64 and 68 per cent said yes, and no significant difference were found among the colleges. The second time they were asked if they were more likely to participate in hearing conservation efforts after completing the preliminary survey, and 74 per cent of the college B said yes, and 46 per cent said yes in college A. The researchers could not explain the difference comprehensively but they assumed that existing NIHL of the professor of the college B, and his usage of HPDs, and his talks about protection acts as a constant exposure to hearing conservation education. They conclude that it might take this kind of constant exposure to get students to change their hearing conservation efforts. Students did not change their noise exposure patterns after the first questionnaire.

Job satisfaction is an important factor also in hearing conservation. Musicians seem to have high job satisfaction and to be more satisfied than some other occupational groups in general (Kivimäki & Jokinen, 1994; Kähäri et al., 2003). However, musicians did report stress and high strain in their work much like the same as other occupational groups. In big orchestras, musicians have very little power over selecting their repertoire. Wright Reid found out that 5 per cent of the brass players played music they disliked all of their time, 18 per cent of the woodwind players played music they disliked half the time, and 10 per cent of the orchestra disliked played music more than half the time they were playing. Studies have also shown that environmental conditions play important role in job satisfaction (Harper, 2002; Axelsson & Lindgren, 1981): poor ventilation, poor lighting, dust, dirt, boxes and cords lying about, dangerous access to pits, special effects (sparks, dry ice, sounds, objects flying etc.).

Regular monitoring of musicians' hearing is recommended (Royster et al., 1991). Santucci (1990) recommends for most of the musicians annual check-ups, and for those who are exposed to very high sound levels, semi-annual check-up.

When musicians are informed, also the affects of leisure time noise exposure should be discussed. In ordinary life, there are many occasions when leisure time activities can cause additional exposure to loud sounds: lawn-mowing, grass trimming, building, visiting concerts, portable MP3 players, big sport events etc. For example Nassar (2001) found aerobics lessons to be very noisy: the average sound level was 90 dB(A). In countries where military service is obligatory another noise exposure is added to musicians. In Finland, the hearing thresholds of noise exposed workers were 9 dB worse at 4 kHz if they were exposed also to shooting noise (Pekkarinen at al., 1993).

We know little of aging musicians. Kähäri et al. (2001b) tried to have retired musicians to participate their study but failed. The reason for the refusal is unknown. Smith (1992) on the other hand found no musician who would have had to retire because of the HL. Henoch and Chesky (1999) have found in their preliminary data that musicians would have higher incidence of reported HL to the fourth decade of life than in National Health Interview Survey for the general US population. After fourth decade the incidence of reported HL decreases among musicians compared with general population. They assume that musicians develop higher levels of auditory sensitivity, and thus do not report noticeable changes so often in later life.

7. LEGISLATION AND PREVENTIVE MEASURES FOR MUSICIANS

Directive 2003/10/EC gives the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise). The Directive was set up by the European Parliament and of the Council, and since then it has been adopted to every member state's legislation. Musicians as a part of the entertainment sector, are for the first time included to the legislation concerning hearing conservation.

The directive requires that all available means to reduce the exposure at source are done in order to eliminate the risks entirely or at least reduce to a minimum. Different action values determine what measures should be taken at the workplace (Table 7.1., Pyykkö et al., 2007). A risk assessment is to be made, and if the Upper exposure action level is exceeded, a HCP has to be established by the employer. In the risk assessment directive, it states that "the employer shall give particular attention to … any effects concerning the health and safety of workers belonging to particularly sensitive risk groups". If the sound levels cannot be reduced to safe level, personal hearing protectors, suitable for the job must be provided without cost. It is in the obligation of the employer to ensure that hearing protection is carried out. The Directive also requests the employer to inform and train the employees, and provide regular screening of the employees' hearing.

Table 7.1. The action and limit values of the directive 10/2003/EU and comparison to the standards ISO 1999 (directive 10/2003/EU, Pyykkö et al., 2007).

Noise level Daily equivalent level and peak level	Relevance in the directive	
75 dB(A)	Not defined	No changes in hearing thresholds (ISO 1999)
80 dB(A) and 135 dB(C) The effect of hearing protectors is not taken into account	Lower exposure action level: -Worker has access to hearing protectors. -Workers have right to test their hearing -Workers should receive information on noise risks and benefit of the use of hearing protectors	No hearing loss over the speech frequencies (500-2000Hz)
85 dB(A) and 137 dB(C) The effect of hearing protectors is not taken into account	Upper exposure action level: Preventive efforts to reduce noise should be made -Employer must establish a noise control program and provide hearing protectors -Employer must promote the use of hearing protectors by all possible means -Workers must use hearing protectors -Noise areas must be identified and marked and access to these areas should be restricted	Five percent of workers will get NIHL
87 dB(A) and 140 dB(C) The effect of hearing protectors is taken into account	Exposure limit value must not be exceeded	Eight percent of workers will get NIHL

The Code of Conduct for the entertainment sector is mandatory in EU countries. European Agency for Safety and Health at Work (2005) has published recommendations for the entertainment sector. In these recommendations it is identified that noise reduction can be obtained by organisational measures, through technical and architectural measures and by using hearing protection. For practice rooms a size of 17 m^3 is recommended. Good acoustic design and proper absorption are recommended to reduce the sound levels. The European agency has also conducted a survey on the methods used to implement the Code of Conduct (Augustyńska et al., 2007). Out of sixteen countries from which information was returned in this survey, eleven countries put in force new law implementing directive's requirements. Two countries are awaiting new regulations in year 2007. Seven countries introduced two-year transitional period (typically period ending early in 2008).

In addition there are many laws and regulations in the Member States, which can be applied to control sound levels in the music and entertainment sectors. For example in the German Technical Direction on the Protection against Noise, Federal Immision Protection Law, Sport Facilities Noise Protection Directive for sport facilities, and certain regulations coming from accident insurers (BGV B3 Noise regulations) or other industrial sectors as the Gaststättengesetz (restaurant law). Also regulations to protect the audience limit the exposure of workers. As an example, regulations limiting the level to 85 or 90 dBA, and demanding control of the settings to be conducted by a competent technician, and certain environmental laws on noise control.

The recommendations come both from various governmental (federal or local) and non-governmental social partners. Governmental agencies mentioned in the report include the German Federal Institute for Occupational Safety and Health, the Finnish Institute for Occupational Health, the Swedish National Institute of Working Life (NIWL), the governments of Land Bremen, and city of Hamburg. Examples of non-governmental groups include the Danish Musicians' Association, the German Federal Medical Doctors Chamber (Bundesärztekammer), the Institute of Music Medicine of University of Music in Freiburg, and the Swedish Artists and Musicians Against Tinnitus. Various projects have arisen due to a close co-operation between governmental and non-governmental partners.

Other initiatives of various kinds have been started by diverse social partners. In Germany, Länder committees started cross-departmental working groups dealing with the noise problem in the entertainment sector. In Austria, due to the co-operation of different social partners, a website containing information on risks in the music and entertainment sectors was started. Seminars, on problems related to risk of hearing damage by music, were initiated in Great Britain and France. Promotions and campaigns, publications and lectures on required policies on harmful effects of loud music were started in Great Britain, Sweden, and Poland, as well as certain research leading to HCPs (Finland) or acoustic projects for discos and music clubs (Finland, Sweden).

Examples of large scale initiatives include establishing indicators showing protection of the audience in discos by Land Sachsen in Germany, seminars organized by French Acoustical Society, and a campaign "Hein" launched across France by the French National Modern Music Forum AGI-SON. There are also a HCP among workers and artists of Finnish National Opera, and a website by the Swedish NIWL, and Artists and Musicians Against Tinnitus (Ammot). A number of awareness raising campaigns have been run, such as 'Don't Lose the Music' by Royal National Institute for the Deaf, and seminars organized by Chartered Institute of Environmental Health (CIEH) with a co-operation with Health and Safety Executive (HSE) in the United Kingdom.

As shown by the report, the recommendations are typically given to different branches of entertainment sector separately. The Finnish approach is different. The Code of Conduct is intended to be used as a checklist by labour inspectors. It does not provide any practical solutions, how to achieve the goal, but it provides an overall view of the requirements and possibilities. Also the HSE provides a similar overall view in their webpage (HSE, 2007). The instructions are given by the type of music: concert halls and theatres, amplified music, studios, schools and colleges, pubs and clubs and marching bands. Also the needs of different worker groups, like technicians and freelancers, are identified in a similar way to the Finnish Code of Conduct. In practise, the problems in hearing conservation have been recommended to be solved with various methods. Ever since it was suspected that music could be harmful to hearing, suggestions for protection have been made.

Before musicians' earplugs were invented, researchers even suggested clarinettists not to wear HPDs because of the bone conduction and for the rest of the orchestra, **Westmore and Eversden** (1981) did not consider them as aesthetically desirable. Instead, they suggest use of risers, increasing the distance, and decreasing reverberation time in the halls if possible.

Mikl (1995) suggested that all the musicians will not participate the performance the whole time, only when they have to, and not all the members participate each performance, and that each musician has at least one opera that he/she does not participate.

Teie (1998) presents couple of questions directed to musician with what can be determined whether music is too loud. The questions portray the symptoms of temporary HL, distortion, and tinnitus in a more understandable form. An audiogram, and if possible, measurement of OAEs should be performed if any of the answers is positive. For prevention he suggests: avoid any exposure over 85 dB, reduce noise at source, increase distance, and rest for 24 to 48 hours after exposure to high sound levels. HPDs should be used as last option. Musicians' earplugs are the foremost optimum solution among HPDs, but he warns about the difficulties with the occlusion effect.

Camp and Horstman (1992) have the following remedies: use of risers, redesigning of the orchestra pit, use of sound shields and chair baffles, HPDs, and having breaks between high sound level exposure.

Royster et al. (1991) researched the NIHL among orchestra musicians and suggest regular audiometric monitoring, and the usage of HPDs.

Santucci's (1990) answer to the protection of musicians is usage of HPDs, suitable distance from high sound levels, use of Plexiglas shields, personal baffles and education.

Sataloff (1991, 1997) proposes that usually appropriate counselling would be sufficient for the musicians. The musician should be provided with audiogram and an explanation of its correspondence with the piano keyboard. In this way, the musician is able to make the adjustment of the HL to her/his playing providing that the HL is not severe.

Niemi (2000) studied church music students and suggested that students should play quieter. A plex should be placed above organist head to protect from the sound from the pipes above, and using closed lid of the piano and grand piano when possible. He also suggested using quieter instruments, clavichord and cembalo for technique practise and when singing, avoidance of music stands, singing far away from the reflecting wall and unaccompanied. In choir singing risers should be used. In overall, students should have less loud free time hobbies, and their hearing should be monitored regularly.

McBride et al. (1992) consider plexiglass baffles as means to reduce loud sound levels, and in the long term they suggest programming of performances by a proper mixture of loud and not so loud works.

Kähäri et al. (2001b) recommend that the employer should provide musicians with free custom moulded earplugs. They also recommend the usage of baffles, shields and risers.

Hall and Santucci (1995) list the following important measures in protecting the musicians: education, hearing assessment, monitoring sound levels and hearing, distance to high level sound source, usage of HPDs, rest after high sound exposures, and where needed, the usage of in-ear monitors.

Chasin (2006) and **Chasin and Chong** (1995) suggest that speakers/amplifiers are elevated from the floor, treble bass instrument should be on risers, 2 m of unobstructed floor space in front of the orchestra, and that small stringed instruments never play under overhangs in pits. In practise the use of mutes in the instruments is recommended. Two devices for the musicians have been developed: an acoustic monitoring device that amplifies bass frequencies for large string instruments, and helps musician to keep healthy sitting posture, and seat shakers for drummers that gives them low frequency vibration feedback and reduces the sound level played and the risk of overplay. For school band directors they recommend acoustical improvements of the classrooms, use of risers, movable thick curtains, carpeting of the front room, 3-D relief art, breaks between exposures, and HPDs.

Harding and Owens (2003) studied conductors and recommend the following: monitoring their sound levels, allow rest time for the recovery, adjustment of room acoustics if necessary, usage of HPDs, and limiting personal exposure time.

Sabesky and Korczynski's (1995) sound level measurements lead to hearing conservation/audiometric program and to the improvement of facilities with acoustical treatments and they also recommend the usage of HPDs.

An extensive medical evaluation of the musician is the basis for satisfactory evaluation (**Hart et al.,** 1987). All hearing symptoms, history of exposure, patient history, family history etc. is collected with an extensive questionnaire. In audiometric evaluation audiometry, preferably every year, speech discrimination test, and objective measures of middle ear function are performed. Tinnitus is aimed to be treated by any known means. As prevention measures authors suggest HPDs, plexiglas shields, baffles, acoustical treatment of orchestra pits, use of risers and if possible, increasing the distance between musicians.

Early and Horstman (1996) recommend acoustical treatment; sound absorption material on walls and ceilings and heavy carpet on floors in practise areas as the first measure. They urge to pay special attention to small practise rooms. They also realize that HPDs are necessary and that musicians' earplugs should be used.

Ostri et al. (1989) suggest for opera orchestra that musicians would not have to play under overhangs in orchestra pits, the usage of plastic screens and suitable earplugs, and to increase the distance between the musicians. They also recommend regular audiograms, and access to a noise dosimeter for the musicians. The musicians whose exposure exceed the permitted limits, or have notched audiogram would be advised to use HPDs.

Pride and Cunnigham, (2005) and **Curk and Cunnigham** (2006) find that the prevention is the only treatment for NIHL. They demand a protocol for the prevention of HL in musicians. This education should be started at the early stages of musician's career. Regular monitoring of the hearing is also required, with otoacoustic measurements. In education they specify that musicians should be made aware of that musician-quality HPDs do not muffle or distort the sound, they are not expensive neither troublesome or they do not affect the optimal performance.

Babin (1999) measured sound levels and hearing thresholds of orchestra musicians playing in the pit in Broadway shows. She suggests the following remedies: volume of the monitor speakers turned down, overall playing volume turned down (tried and succeeded), acoustical padding, baffles, PPE, and seating positioning in the pit.

In addition to the improvements in the room acoustics of the new opera house in Copenhagen, **Gade** (2007) recommends also other measures to comply with new directive: hiring conductors with moderate playing style, quieter instruments, varying evenly between loud and quiet performances, varying orchestra layout, rotating seating order, rehearsals placed sensibly to the schedule, first rehearsal should be played more quietly, preferably musicians should not play under overhang of the pit and provision of HPDs.

Owens (2004) necessitates that all the music teachers should be aware of the risks. Teachers should undergo regular monitoring of hearing, should be provided with musicians' earplugs, and their noise exposure should be monitored with sound level meters in the classes. He also urges to the improvements of room acoustics in rehearsal rooms when sound levels exceed the limits. He also sees consultation with an acoustician necessary. Other measures include reduction of sound exposure time if necessary, rest periods, and the decrease of leisure time exposure.

Nodar (1993) found a HL from a professional organist, and recommended that all musicians should know at what sound level they play, and thus they should protect themselves, have their hearing tested regularly and be informed about hearing problems.

Lee et al. (2005) recommend firstly technical means to reduce noise levels: use of risers (though in the case of the opera orchestra this is not possible in the pit), and sound barriers (also difficult to be used in the pit). Next step is the HCP with distributing information to musicians, the usage of HPDs and training for the usage, audiograms and their follow-ups.

Emmerich et al. (2008) find the annual monitoring of musicians' OAE levels beneficial. They also recommend after **Ostri et al.** (1989) recommendations rest between rehearsals or performances. Researchers also recommend that the facilities for the practise should have proper sound insulation and room acoustics. The usage of HPDs should be started from the beginning of musical education at academies of music.

Behar et al. (2004) studied music teachers and found the engineering noise controls scarce. They recommend cost-effective measure of covering floors with carpets to remove noise from dragging chairs and walking and decrease reverberation. Also, a HCP was suggested.

Performing arts medicine has a lot to offer to a musician. Physicians need to be educated as well. The use of ototoxic treatment for musician should be avoided if possible and the patient should be informed of the possible effects of the treatment (**Bianco**, 1993). Audiograms shall be taken before and after the treatment. Small injuries that do not affect the work of an office worker might make the musician unable to work (**Sternbach**, 1993). Musician in turn should try to find time to consult the physician face-to-face, be more active to go to the doctor and not to wait until the symptom goes away, talk to colleagues with the same problem for support, and campaign for prevention (**Fetter**, 1993).

Petterson (2007) lists measures to be taken to educate groups relating to music. He necessitates music teachers to incorporate education about the risks of high sound levels to music teaching. The education for musicians could be give via different associations for musicians with NIHL and tinnitus. Petterson recommends this approach due to varying groups of musicians. Disc jockeys should be educated about the hearing conservation. Sound guard ensures that the music is at sufficiently low levels (otherwise levels is automatically lowered or shut off completely). Other groups that should be affected are young people, children, decision-makers, authorities, organizers/owners, sound engineers, gym instructors etc.

There is a great deal of means to reduce sound exposure in Sound Ear II by **Wright Reid and Warne Holland** (2008). They emphasize the importance to get the conductors and new composers favourable to the cause. Noise should be considered as one factor when programmes are developed. Quieter instruments should be used. Projection should be improved by risers, noise sections at sides and front, noisy instruments with direct sound lines to audience, standing up/playing bells up, deflecting sound from horns to the audience and more space to the orchestra. Correct stance while playing is important; head straight and playing bells up. One suggested option is to have two musicians instead of one halving the exposure which means only 3 dB decrease against fairly expensive expenses. Rotation of seating positions, marking the noisy passages to the score, placing brass to one row, balancing the schedule, acoustical treatment, screens, appropriate acoustics are among tried measures. They mention orchestra that tried to move noisy instruments somewhere else and miked them, but the time delay was significant. As a last advice they suggest to try to stay out of the line of fire.

Though **Lockwood (1989)** does not give advice on prevention of HL, he demands the overall good physical condition for the musician. He emphasizes the strengthening exercises in order to reduce overuse problems. In another paper **Lockwood et al.** (2001) recommends change of seating in orchestras, use of risers, sound shields, ear plugs, and avoidance of leisure time noise exposure. Particularly HPDs should be used in accordance to Lockwood et al. by musicians with already compromised hearing, and those who use medicine that can cause HL combined to noise exposure.

One “method” that rises above all is the education. In USA a project called Health Promotion in Schools of Music has been launched (Chesky et al., 2006). HPSM aims to assist schools of music to prevent occupational injuries and one of the declarations of the project is for the schools to recognise NIHL and inform their students about it: “Prevention education is the foundation for injury prevention”. At another American university school of music a hearing conservation policy that will include mandatory annual hearing tests will come into effect (Phillips et al, 2008).

It is clear that preventive technical measures cannot always reduce the sound to a safe level but hearing protectors must be used. The usage increases when knowledge increases among musicians and administration. Education is thus the most important key to hearing conservation. Thus education should be performed at most early stage of the career, preferably already at school, music institutes and universities. Old habits die hard, and it is the task of music education to ensure that they are good, old habits.

8. PURPOSE OF THE STUDY

The purpose of the present study is to determine the need for hearing conservation for classical music musicians, the current situation, and to investigate whether the hearing conservation principles of industrial noise can be applied to music noise. In addition, the purpose is to find out how hearing conservation can be made and what topics among the essential stages (evaluation of exposure, risk assessment, reduction of exposure, and residue risk accompanied by hearing protector usage) of the HCP should have particular attention.

In particular, the following topics are studied in detail:

1. To determine the total annual sound exposure of musicians, including personal rehearsals (I, IV)

2. To determine hearing thresholds, and other hearing symptoms and study how problems in hearing affect musicians’ work and life (II, III, IV, V)

3. To investigate how small practice rooms for musicians are experienced and how they should be designed (VI)

4. To determine musicians’ usage of hearing protectors, their attitudes towards hearing protection, and to understand the problems involving the usage of hearing protectors (II, III, V)

9. SUBJECTS

9.1. Sound level measurements (I), Finland

Sound level measurements were made in the Finnish National Opera among performing staff. The orchestra (65-88 members) was divided into ten groups based on their instruments. In total 87 measurements were made. The choir was divided into bass, tenor, alto and soprano singers. In total 66 measurements were made. In addition one rehearsal pianist rehearsing with soloists was measured along with the soloists, and conductor was measured with single measurements.

9.2 Hearing threshold measurements (II), Finland

The sample consisted of the members of four major orchestras from the Helsinki metropolitan area, the Finnish National Opera orchestra (20/112 musicians), the Tapiola Sinfonietta symphony orchestra (12/40), the Radio Symphony Orchestra (21/98), and a military brass band called the Guards Band (14/40). Inclusion in the sample was based on voluntary participation, the subjects' audiometry corresponding to normal NIHL audiometry with the notch at 3-6 kHz, and their having no ear or central nervous system infections.

Altogether, 67 musicians participated in the study, of which four were excluded because of their audiometer pattern, with 38 males with a mean age of 41 (±9) years, and 25 females with a mean age of 40 (±6) years. The members of the sample were informed about the purpose of the study before presenting them with the questionnaire.

9.3. Questionnaire study (III, IV), Finland

There were five orchestras that participated into Finnish study:

1. Finnish National Opera (FNO),112 musicians
2. Finnish Radio Symphony Orchestra (RSO), 98 musicians
3. Helsinki Philharmonic (HP), 93 musicians
4. The Tapiola Sinfonietta (TS), 40 musicians
5. The Guards Band (military brass band, GB), 40 musicians

Orchestras were visited, lectures about sound levels and HL were given, and the questionnaires distributed. The musicians filled them on their own time and posted the answers to researchers. Total percentage of the answered was 51 per cent of the musicians.

9.4. Questionnaire study (V), Denmark

A Danish study, was made, the participants were three symphony orchestras:

1. South Jutland Symphony Orchestra (66 musicians)
2. Aalborg Symphony Orchestra (65 musicians)
3. Aarhus Symphony Orchestra (72 musicians)

Orchestras were visited and lectures given on hearing conservation. The collection of answers differed: musicians filled questionnaires on location, and thus everyone who attended the lecture answered the questionnaire. There were some missing however from lectures and thus answer rate was 71 per cent (one reply rejected due to insufficient data) of all members in the orchestras.

9.5. Questionnaire study and measurements determining room acoustics (VI), Finland

A music institute in Espoo participated to the study. 7 music classes were renovated and/or measured. The number of responses for the first part of the questionnaire were 31 respondents (53 distributed), and for the second part of the questionnaire 8 respondents (teachers working in renovated facilities).

10. METHODS

10.1. Sound level measurements (I), Finland

The personnel's sound exposure was initially evaluated by measuring A-weighted equivalent continuous sound pressure level (L_{Aeq}) (either an equivalent sound level of measurement, or for the group, the arithmetic means of the equivalent sound levels were calculated). The average sound exposure level for a year ($L_{Aeq,a}$) was evaluated as follows:

$$L_{AEq,a} = 10\log_{10}(\frac{1}{T}\sum_{i=1}^{2}10^{L_{Ai}/10}t_i),$$

where T is 1500 hours, i=1 group rehearsals and performances, and i=2 personal rehearsals, and t_i exposure time respectively. Selected individuals were provided with dosimeters and taught the proper use. Each subject kept a record about their daily schedule.

The orchestra was divided into ten groups based on their instrument. The sound level for each group was measured during personal rehearsals, group rehearsals, and performances.

The choir was divided into bass, tenor, alto, and soprano singers. The sound level was measured during personal rehearsals, group rehearsals, and performances. During one opera, also fixed measurement points were placed on the main and side stages in locations that correspond to typical working zones during the performance.

Single measurements were done among soloists, rehearsal pianist, and conductors. Sound levels of one rehearsal pianist were measured during two rehearsals in different rooms while training the soloists.

The microphone was located on middle of the left or right shoulder of the test subject. In the case of string instruments and harps, the microphone was positioned on the opposite shoulder. The fixed-point measurements were conducted using the dosimeter (Larson & Davis 705). Dosimeters were mounted on a stand at the height of 1 meter (m). The location of each dosimeter was selected to give a representative sample of the area.

10.2. Hearing threshold and sound level measurements (II), Finland

10.2.1. Audiometry

Audiograms were measured using a Madsen Midimate 602 clinical audiometer, starting with the subjects' right ears in the sequence of 1000 Hz, 2000 Hz, 3000 Hz, 4000 Hz, 6000 Hz, 8000 Hz, 500 Hz, and 250 Hz, and then repeating the process with their left ears. All audiometer measurements were made in the audiometric booth of the occupational-health care unit, except for the members of the Guard band, who were measured in a booth at the Finnish Institute of Occupational Health.

As the threshold shift is highly dependent on age and gender (ISO 1999, 1990), their effects were removed by using Z-scoring techniques, which involved the following transformation:

$$z = \frac{x - \mu}{\sigma} \ ,$$

where x= is the observed threshold shift, μ= expected mean threshold shift obtained from ISO 1999 database A, and σ= standard deviation of the threshold shift obtained from ISO 1999 (1990).

The ISO 1999 (1990) models consist of two Gaussian distributions, one for over the 50th percentile and another for under the 50th percentile. Age, gender, and noise exposure are the input parameters (16). As a result, the Z-score distribution of observed threshold shifts has zero means and standard deviations of one.

The Z-scoring was applied to the audiograms twice. To compare the musicians' hearing to the hearing of the non-noise-exposed population the noise-exposure term is set to zero. The noise-exposure term was inserted in the second transformation, which enabled comparison to noise-exposed industrial workers. The Z-scores were calculated using Matlab 7 rev 3, made by Mathworks Inc., USA, and sent the results to SPSS 16, made by SPSS Inc, USA. The comparisons were made using t-test and ANOVA.

10.2.2. Tinnitus and Hyperacusis

This study's data about the presence of tinnitus and hyperacusis after rehearsals and performances were obtained with, questionnaire items with a five-point Likert scale of never, seldom, sometimes, often, always.

10.2.3. Exposure Evaluation

These measurements were conducted by instrument group in one to four different sessions each using a dosimeter (Larson & Davis 705, 706), placing the microphone on each musician's shoulder in such a way that it could not disturb the performance. Each dosimeter recording took place over an entire training or performance session, providing a total of 130 measurements from performances, group rehearsals, and personal rehearsals. The average annual daily exposure (ISO 1999, 1990) was calculated using the following formula:

$$\mathrm{L}_{\mathrm{Ex,8h}} = 10\log_{10}(\frac{1}{T}(10^{L_{AEq,pr} * T_{pr}/10} + 10^{L_{AEq,gr} * T_{gr}/10}) \, ,$$

where T_{pr} = Time spent in personal rehearsals (hours/8), T_{gr}=Time spent in group rehearsals and performances (hours/8), T= 1500 hours = average working hours/year, $L_{Aeq,gr}$ = Mean A weighted noise level in group rehearsals and performances, $L_{Aeq,pr}$ =Mean A weighted noise level in personal rehearsals.

To evaluate the life time exposure a standard questionnaire (Kuronen et al., 2004; Pyykkö et al., 2000) was used. The questionnaire provided the total number of years and information of noisy hobbies and teaching and about the use of hearing protectors. The musicians of the FNO were measured in the earlier study I.

10.3. Questionnaire study (III, IV), Finland

The questionnaire comprised of 35 questions, six with open answers, and the rest multiple-choice questions. First age, gender, instrument group and playing experience were asked, then questions about job satisfaction, ear symptoms, and stress. Stress was defined as “a situation when person feels him/herself tense, restless, or anxious or he/she has difficulties to sleep when things bother him/her”. Hearing problems and annoyance were asked using questions like “Have you had temporary ringing in the ears after the performances and rehearsals? “, “Has loud music caused pain in your ears at work?” and “Do you find the rehearsals and performances noisy?” Usage of hearing protectors was separated into usage in personal rehearsals, orchestra rehearsals, and performances. Also the type of hearing protectors tried and used was queried. Open questions concerned with problems of usage, and playing facilities.

10.4. Questionnaire study (V), Denmark

Three major Danish orchestras participated in the investigation. The questionnaire used in this study was designed based on questionnaires from a previous study in Finland (Laitinen, 2003), a study in Sweden with rock musicians (Kähäri, 2002), and a questionnaire about the occlusion effect (Østergaard Hansen, 1997).

There were 91 questions; 27 were open answered, and the rest were multiple-choice. The questionnaire was divided into sections that included (1) General, (2) Hearing protection and sound level reduction, (3) Occlusion effect, (4) Health related questions (questions about hearing disorders), (5) Work surroundings, and (6) Rehearsal and performance facilities. The questionnaire incorporated questions pertaining to age, gender, instrument group, and playing experience. One section included questions about how often and in which work situations hearing protectors were utilized as well as which kind of hearing protector the musician used and the reason for choosing that particular hearing protector. Another question asked for other means to reduce the sound levels in the orchestra. The musicians answered questions about different hearing disorders (tinnitus, hyperacusis, diplacusis, and distortion), job satisfaction, and a possible feeling of stress (note that this is self reported stress; no physiological or behavioral measures of stress symptoms are made in the present investigation). The musicians were asked about their physical playing facilities and the possible need for quiet facilities at work.

10.5. Questionnaire study and measurements determining room acoustics (VI), Finland

A music institute in Espoo participated in the study. The facilities there were measured earlier for reverberation time and sound insulation (Lokki & Salmensaari, 2007). Those facilities that did not meet with the requirements of the code for reverberation time, or were otherwise considered difficult to teach in, were scheduled for renovation by adding more absorption. The amount of material to be added was calculated using the Sabine formula. The opinions of teachers were sought through a questionnaire before and after the renovation. In addition, teachers who were using the facilities that met the requirements of the code were also included in the study. The questionnaire had questions about hearing protector usage and possible hearing symptoms. The questionnaires were distributed to the teachers, who then returned them to the institute.

After the renovation, the reverberation time of the facilities was measured again. Sound exposure measurements were performed for teachers before and after the renovation in order to establish the actual sound level decrease through the additional absorption. Unless otherwise stated, the equivalent sound level measurements were performed using a dosimeter (Larson & Davis 705, USA). The microphone was located in middle of the left or right shoulder of the teacher. Teachers recorded the style of music that they taught. Unfortunately, the pieces used were different in each classroom.

11. RESULTS

11.1. Sound level measurements (I), Finland

The sound levels at the conductor's location varied between 80 and 88 dB(A). The mean sound level for the rehearsal pianist was 95 dB (A) and for the soloists, the tenor, 97 dB(A), and the soprano 105 dB(A).

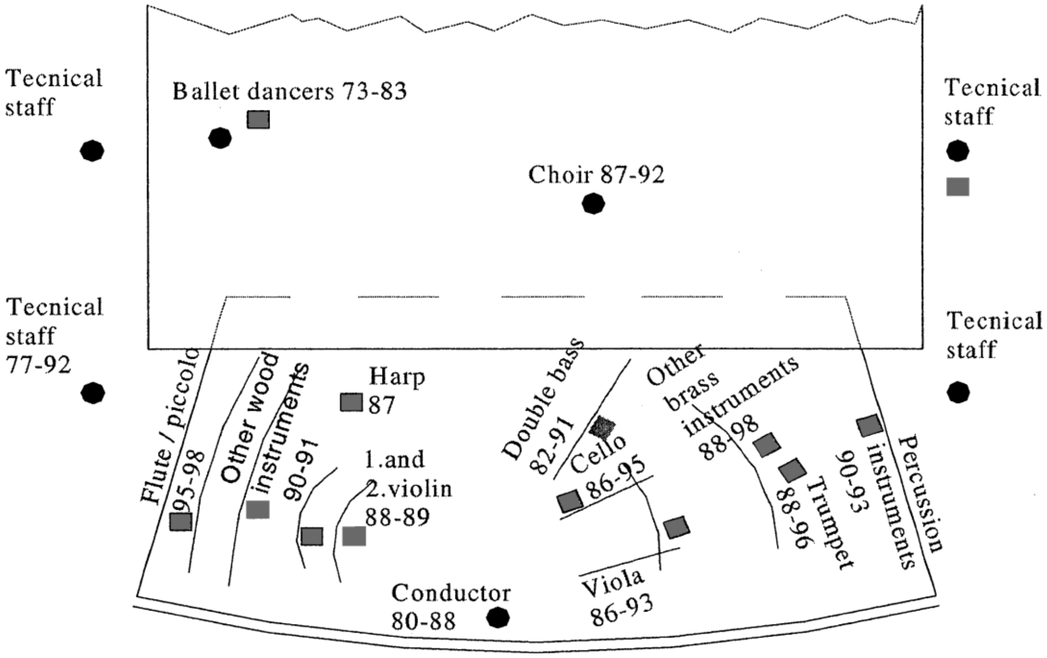

Figure 11.1. Measurements during performances/group rehearsals. The figure shows the location of groups, measurement techniques (circle = fixed-point; box = dosimeter), and typical measurement results. The drawing is not to scale.

The sound levels and sound exposure level of the choir are provided in Table 11.1. The sound levels during the personal rehearsals were considerably higher than during group rehearsals and performances (Figure 11.1).

Table 11.1 Sound levels during rehearsals and performances: sound exposure level for the choir.

Group	Sound pressure level (SPL): group rehearsals and performances [dB(A)]	Sound pressure level (SPL): personal rehearsals [dB(A)]	Sound exposure level [dB(A)] $L_{Aeq,a}$
Tenors	87	100	92
Basses	87	100	92
Sopranos	92	100	94
Altos	88	100	92

Sound levels, and sound exposure levels for different instrument groups of the orchestra are shown in Table 11.2. During performances and group rehearsals, sound levels varied between groups from 82 dB(A) for the double bass players to 98 dB(A) for flute/piccolo players (Figure 11.1). For personal rehearsals, the highest levels were found among percussionists and flute/piccolo players. During personal rehearsals, the lowest sound level was found among double bass players (79 dB(A)).

Table 11.2. Summary of musician's sound levels and exposure levels.

Instrument group	L_{AeqP} [dB(A)] Die Walküre	L_{AeqP} [dB(A)] Insect Life	L_{AeqP} [dB(A)] Don Giovanni	L_{AeqP} [dB(A)] Swan Lake	L_{AeqH} [dB(A)] (range)	$L_{Aeq,a}$ [dB(A)]
1. and 2. Violin (4)	89	88	88		86	86
Viola (3)	92	90	86	93	86 (84-88)	87
Cello (4)	90	95	86	88	88	86
Double Bass (4)	88	91	82		79	83
Flute/Piccolo (4)	95	98	97		96	95
Other wood instruments (6)	90	91	91		91 (91-92)	89
Trumpet(2)	96	93	88		97 (93-99)	94
Other brass instruments (9)	93	93	88	98	95 (92-99)	92
Harp(1)				87	89 (89-90)	87
Percussion instruments (3)	93	91		90	99	95

Note: L_{AeqP} is the average sound level for performances and orchestra rehearsals; L_{AeqH} is the average sound level for personal rehearsals; and $L_{Aeq,a}$ is the annual sound exposure level. If no range is provided, only one subject was measured. The total number of test subjects is indicated in parentheses following the group name.

11.2. Hearing thresholds and sound level measurements (II), Finland

Table 11.3 shows the results of the sound exposure measurements. Most of the musicians are exposed to sound levels over 90 dB(A). Those in GB received the highest exposure and those in the TS, the smallest orchestra, received the lowest.

Based on the questionnaire it was evaluated whether during a period there is a probability of higher exposure in previous occupations. As the type of orchestra or the instrument did not change during the professional career, it was assumed that the exposure measurements are representative for the whole professional career. The exposure time was long, with 12 % of the subjects having started their professional career before age 20, the mean starting age being age 23. The total exposure was somewhat higher among men (102 ± 5.3dB) than among women (98 ± 5 dB). The difference was due to higher weekly exposure (90 ± 5 dB vs. 87 ± 3 dB) and longer exposure time (19± 10 vs. 15 ± 8).

Table11.3 Weekly exposure by orchestra and instrument group. $L_{Aeq,gr}$ is the mean weekly exposure during group rehearsals and performances, T_{gr} is the time spent in this activity, $L_{Aeq,pr}$ is the exposure during personal rehearsals, T_{pr} is the time spent in this activity, and $L_{Aeq,8h}$ is the total average exposure based on the measurement week.

Orchestra	Instrument	$L_{Aeq, gr}$ (dB(A))	T_{gr} (h)	$L_{Aeq,pr}$ (dB(A))	T_{pr} (h)	**$L_{Aeq, 8h}$ (dB(A))**
GB	alto saxophone	95.9	30			**95**
GB	baritone saxophone	93.6	30			**92**
GB	baritone horn	96.2	30			**95**
GB	bass clarinet	91.6	30			**90**
GB	flute-piccolo	91.5	30			**90**
GB	clarinet	92.4	30			**91**
GB	french horn	91.9	20	93.3	10	**91**
GB	percussion instruments	92.4	20	90.5	10	**91**
GB	trombone	92.3	30			**91**
GB	saxophone	95.4	30			**94**
GB	conductor	95.4	30			**94**
GB	conductor	82.5	30			**81**
GB	trumpet	96.1	20	96.6	10	**95**
RSO	viola	87	23	90.9	10	**88**
RSO	bassoon	89.4	23	94	10	**91**
RSO	flute	86.7	23	97.5	10	**92**
RSO	clarinet	93.4	23	94.5	10	**93**
RSO	contrabassoon	87.2	23	78.3	10	**85**
RSO	french horn	92	33			**91**
RSO	oboe	87.9	33			**87**
RSO	cello	90	33			**89**
RSO	trumpet	92.1	33			**91**
RSO	violin	86.4	23	85.7	10	**85**
TS	viola	84.7	19	84.6	10	**83**
TS	bassoon	87	29			**86**
TS	flute-piccolo	92.8	29			**91**
TS	clarinet-piccoloclarinet	89	19	93	10	**89**
TS	double bass	83.1	29			**82**
TS	french horn	91.6	29			**90**
TS	percussion instruments	88.5	19	95.2	10	**91**
TS	oboe-cor anglais	86.3	29			**85**
TS	cello	83.9	19	87	10	**84**
TS	trumpet	91.8	19	95.4	10	**92**
TS	violin	86.1	19	88	10	**86**

Free time exposure consisted of teaching. Most of the musicians had taught in some stage of their life, and at present 36 per cent was teaching during the study. However for everyone teaching took only couple hours every week and thus it was negligible compared to exposure during work activities. For this reason teaching was omitted from the exposure evaluation.

The mean HL was remarkably symmetric, but somewhat higher in the left ear (Figure 11.2). The HL was tuned to the higher frequencies, which is typical for NIHL and presbycusis. The greatest HL was typically found at 6 kHz, as shown in Figure 11.2.

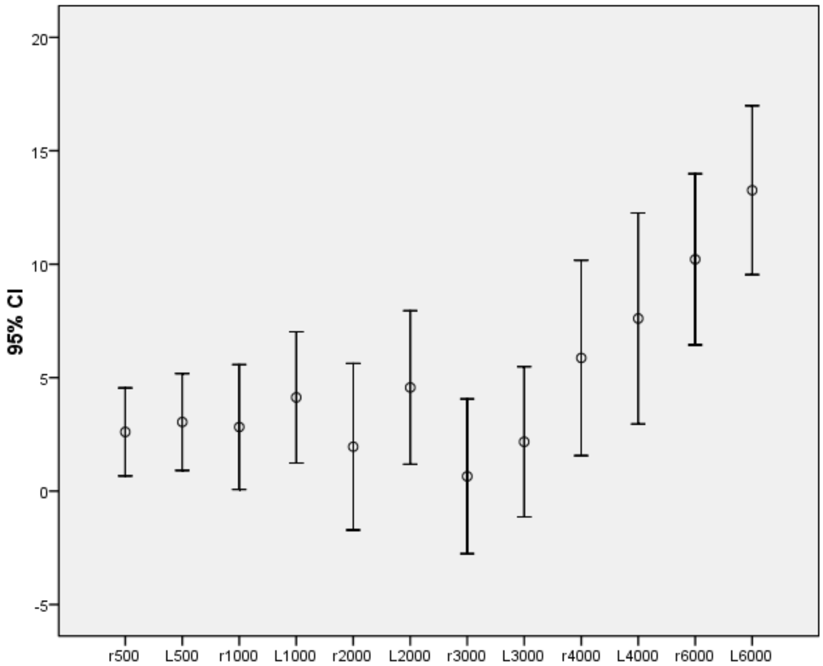

Figure11.2. Mean hearing loss by frequency and its 95 % confidence interval (CI) in right (r) and left (L) ear.

To test whether this HL depends on exposure, we divided the musicians into a high-exposure class (L_{EX}>100) and a low-exposure class (L_{EX}<100). In the high-exposure class the HL was significantly higher in both ears at frequencies of 3000 and 6000 Hz, as shown in Table 11.4.

Table 11.4. Mean difference between low and highly exposed groups by frequency.

Frequency (Hz)	Right ear		Left ear	
	Difference (dB)	Significance	Difference (dB)	Significance
500	0.6	NS	0.7	NS
1000	1.6	NS	0.2	NS
2000	2.1	0.041	1	NS
3000	2.7	0.03	2.1	0.02
4000	3.8	NS	1.8	NS
6000	5.8	0.04	3.1	0.05

Comparing the musicians to a non-exposed population using Z-scoring revealed that their HL corresponded to the expected HL of that non-exposed population, except for at 3000 Hz and 6000 Hz. At 6000 Hz the HL was higher than predicted, as shown in Figure 11.3.

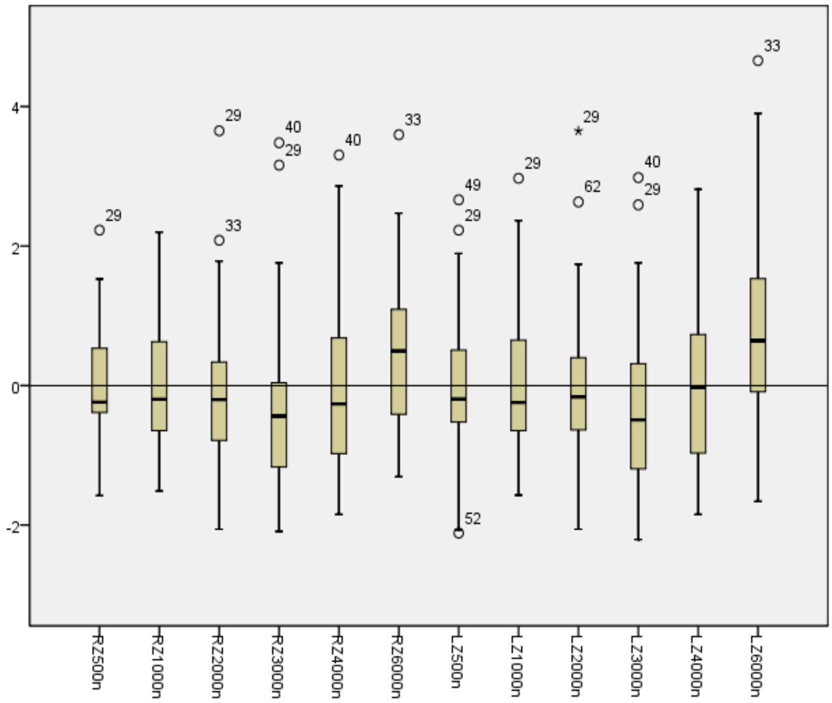

Figure 11.3 Comparison of the musicians' hearing loss to that of a non-exposed population. The zero corresponds to the expected value.

The musicians' HL can be seen to be smaller than expected for the frequencies of 2000, 3000, and 4000 Hz (sig <0.04), with an expected value of 6000 Hz (sig NS), when compared to an industrial population having also had lifetime exposure, as shown in Figure 11.4.

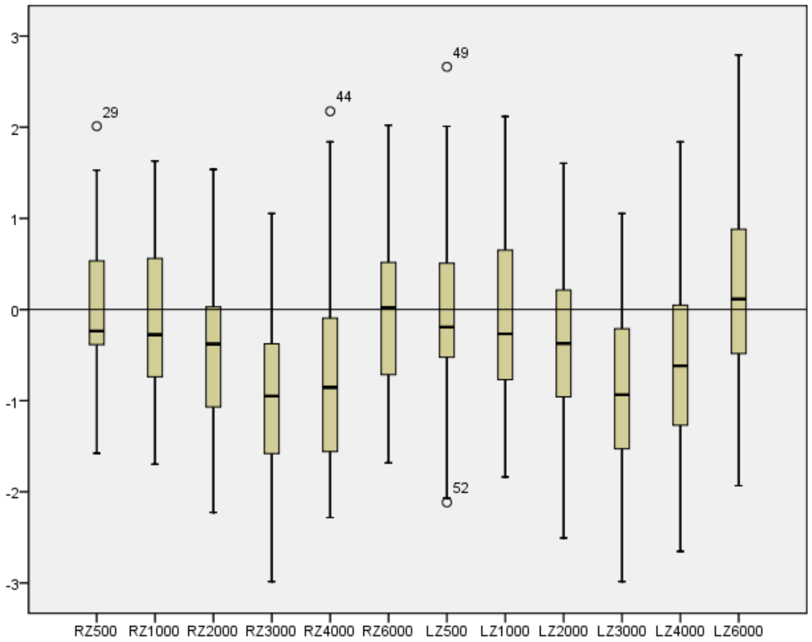

Figure11.4 Comparison of the musicians' hearing loss to a population with the same lifetime exposure. The zero corresponds to the expected value.

Tinnitus and hyperacusis were relatively frequent, as shown in Table 11.5, with 60 per cent of the musicians having never or seldom experienced tinnitus after group rehearsals and performances. A greater number, 78 per cent, reported never or seldom experiencing it after personal training. Only 16 per cent of the musicians reported never having experienced hyperacusis.

Table11.5. Percentage of musicians having experienced tinnitus or hyperacusis.

	Tinnitus after performances and group rehearsals	Tinnitus after personal rehearsals	Hyperacusis
Never	26	40	16
Seldom	34	38	43
Quite often	30	16	37
Often	6	2	2
Always	4	4	2
Total	100	100	100

11.3. Use of hearing protectors (III, IV, V)

11.3.1. Usage rates, Finland

HPDs were mainly used in orchestra rehearsals and performances (Figure 11.5). There were no significant statistical differences between orchestras except personal rehearsals. In personal rehearsals, very few used HPDs. In RSO, only some musicians used HPDs, and HPDs were used to some degree in GB (Fig 11.6). The difference between RSO and GB was statistically significant (t=0.012). The difference between GB and the other orchestras was also statistically significant (t=0.033).

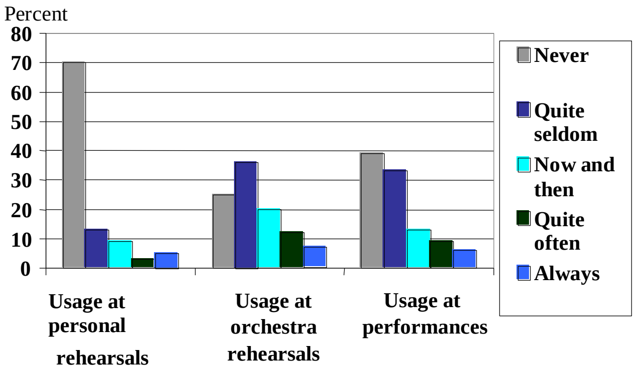

Figure 11.5. Hearing protector usage in work.

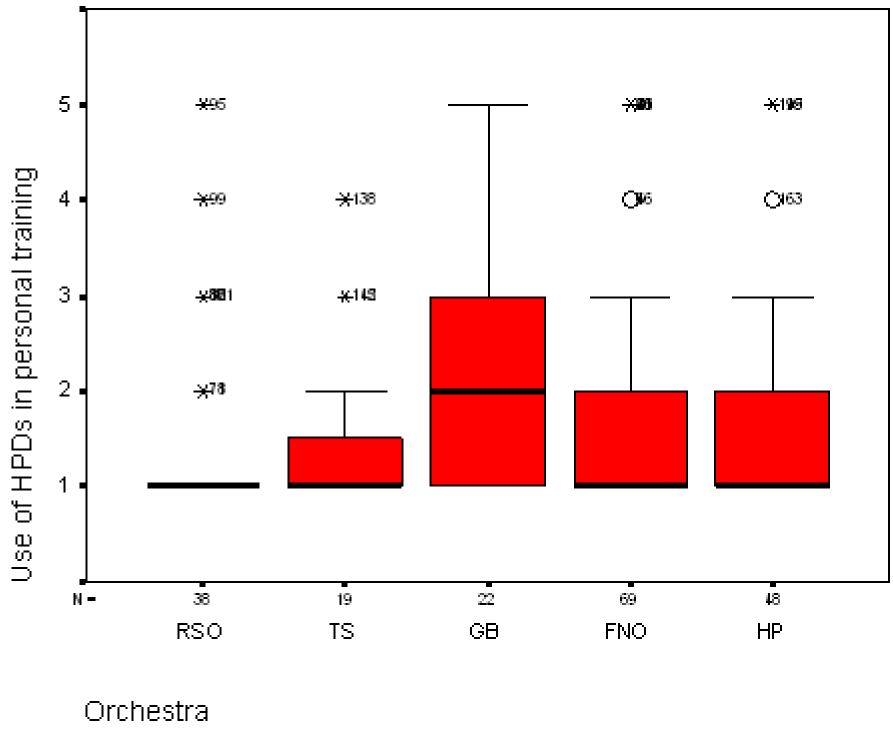

Figure 11.6. The usage of hearing protectors at personal rehearsals by orchestra. (1=never, 2= seldom, 3=sometimes, 4=often, 5=always; numbers mark the outliers)

11.3.2. Usage rates, Denmark

The usage rates are lowest at personal rehearsals and teaching and slightly higher at orchestra rehearsals and performances (Table 11.6.). Only 13 per cent of the respondents adjusted to hearing protectors right away, 15 per cent required time to adjust, 43 per cent were not used to hearing protectors (but used them anyway), and 29 per cent stopped using hearing protectors because it was too difficult.

Table 11.6. Per cent of respondents using hearing protectors at personal rehearsals, orchestral rehearsals, performances, and while teaching.

	Never	**Seldom**	**Sometimes**	**Often**	**Always**
At personal rehearsals	84	7	6	2	2
At orchestral rehearsals	39	31	18	8	5
At performances	48	31	11	7	4
While teaching	94	1	5	0	0

Hearing protectors were used in both ears by 49 per cent of the participants, as many as 35 per cent used them in only one ear, and 16 per cent said that it depended on the situation. Whether the left or right ear was protected depended mostly on the location of the loudest sound source. Only violinists reported using hearing protection on their left ear more often.

The majority of the musicians responded that they use HPDs only during loud passages or when sitting near loud instruments. The participants responded that they are more likely to use hearing protectors when they are tired or when playing contemporary music.

11.3.3. Hearing symptoms and usage rates, Finland

Usage rate of HPDs was clearly affected by the hearing symptoms (Figure 11.7.). In personal rehearsals, HPDs were used often or always by 2 per cent of musicians without hearing symptoms, and by 12 per cent of musicians with hearing symptoms. The same tendency was shown in orchestra rehearsals (9 per cent versus 22 per cent) and performances (7 per cent versus 20 per cent).

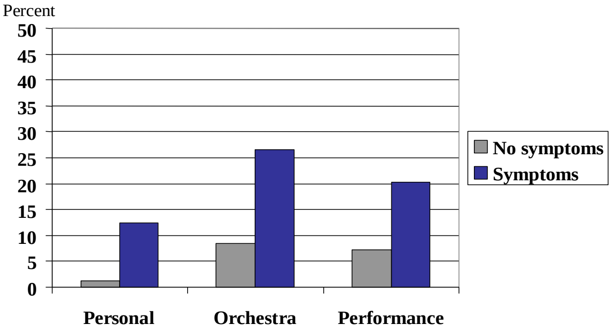

Figure 11.7. Effect of hearing symptoms to the use of HPDs.

11.3.4. Hearing symptoms and usage rates, Denmark

The use of hearing protectors was to some extent related to temporary ringing in the ears (tinnitus). The correlation coefficients were in the range of 0.2 to 0.4.

A Kendall’s tau_b analysis was used. The hearing disorders were combined into one variable where one disorder adds one unit to the variable. For example, if a person has tinnitus and hyperacusis, the variable would have the value of two. No disorders would have a value of zero, and all of the disorders would create a value of five; however, none of the musicians reported all of the disorders. The analysis showed that the more hearing disorders a musician has, the more worried the musician is about hearing, there is more self-reported stress, the musician perceives the working conditions as noisier, and the musician uses hearing protectors more often at rehearsals and performances. This is shown in Figure 11.8. for hearing protector use at different playing conditions.

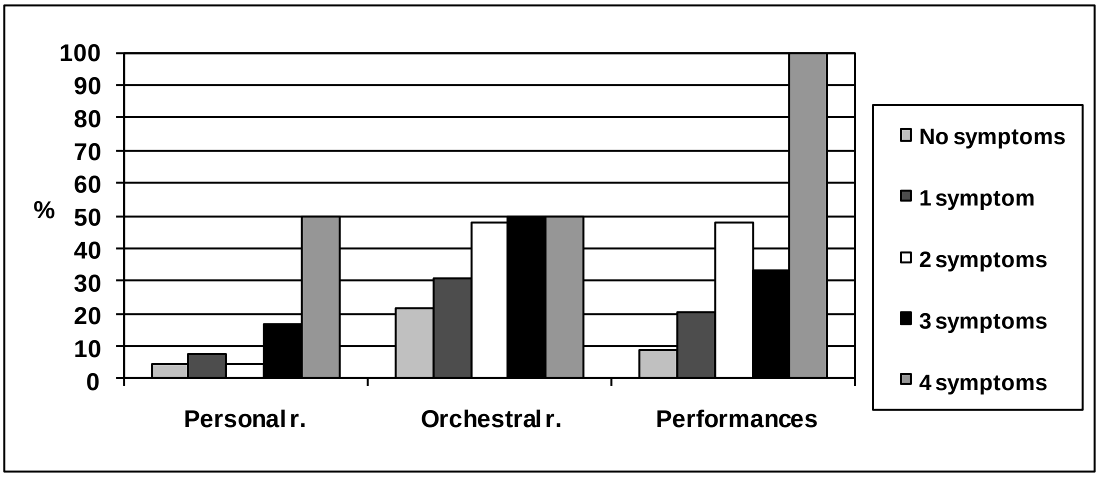

Figure 11.8. Hearing protector use at personal rehearsal (Personal r.), orchestral rehearsal (Orchestral r.), and performances, divided into the number of hearing disorders. The percentages are a sum of the responses to the usage question, comprising those musicians who used hearing protectors 'sometimes', 'often', and 'always'.

11.3.5. Type of hearing protectors, Finland

The most popular type used was custom moulded earplugs (47 per cent), followed by disposable earplugs (25 per cent). There were other combinations like regular cotton, tissues and hands, accounting for 12 per cent. There were no statistical differences between genders, but orchestras differed in the sense that custom moulded earplugs were not used in TS, but custom moulded earplugs were used by the majority of musicians using HPDs in GB. From different instrument groups, brass players used almost exclusively custom moulded earplugs.

11.3.6. Type of hearing protectors, Denmark

Types of hearing protectors used (or tried) included disposable foam earplugs (39 per cent), custom moulded musicians' earplugs (35 per cent), and hi-fi earplugs (16 per cent). Ten percent of the musicians used other protection means: shield behind the chair (one player), electronic hearing aid (two players), rubber plugs (one player), cotton wool (four players), ear muffs (one player), and paper towels (one player).

11.3.7. Problems in usage, Finland

The most common reason for usage was that musicians were afraid of HL and tinnitus. Other often mentioned reasons were to avoid pain, to protect their ears from fatigue, to decrease stress, irritation, and fatigue, and due to already existing HL and tinnitus. Hindrance and other problems with usage were listed as follows:

- Hinders own performance (N=155)
- Difficult to hear others play (N=88)
- Sensation from hearing protectors is unpleasant (N=15)
- Difficult to insert (N=12)
- Existing HL makes usage difficult (N=3)
- Communication problems in rehearsals (N=4)

11.3.8. Problems in usage, Denmark

Forty percent of the musicians answered that they have changed from one hearing protector type to another. The musicians who preferred the custom moulded protectors to the other types liked them because of their frequency independent attenuation, better fit, and better protection. Disposable earplugs were criticized for being too visible. Musicians who changed from the custom moulded devices to the disposable plugs found the fitting of the custom moulded earplugs more time consuming. In addition, they reported that the custom moulded earplugs changed the perceived sound quality, were warm and sweaty, and the disposable earplugs attenuated less than the custom moulded earplugs.

The musicians reported itching, infection in the ear canal, pain, and hearing their own breathing as problems that caused them to stop using hearing protectors. The hearing protectors were seldom cleaned.

The participants were provided with six possible problems in connection with using hearing protectors. Problems were as follows: difficult to hear others playing (82 per cent of the responses); hindering own performance (76 per cent); uncomfortable (52 per cent); difficult to put into the ears (30 per cent); feeling of pressure from the earplugs (23 per cent); other (10 per cent, comprising occlusion, ear disease, other musicians' comments, and bone conduction from the mouth to the ear (same as the occlusion effect)).

Participants were also asked to list any problems in connection with hearing protector use; the responses included 'hindering own performance', 'lack of control', 'lack of sound quality', 'problems in intonation', and 'occlusion effect'. One musician had no problems at all in connection with hearing protectors. Infections bothered 5 per cent of the hearing protector users and 23 per cent had a tendency to create a large amount of ear wax. Seventy-nine percent reported an 'enclosed feeling' while wearing hearing protectors.

In total, 89 participants (of 145) responded to the questions about the occlusion effect. The distribution of the results included 88 respondents reporting their own instrument sounds different, 63 respondents reporting their own voice sounds different, 35 respondents reporting they can hear their own breathing more clearly, and 34 participants reporting a blocked feeling of their ears. The occlusion effect caused 43 per cent of the users to stop wearing hearing protectors. Hollow sound quality was experienced and found to be annoying by 20 per cent of the respondents, and very annoying by 50 per cent of the respondents.

The reduced use of hearing protectors at personal rehearsals and classes supports the conclusion that musicians find their own instrument less noisy than other instruments regardless of the instrument group.

11.4 Hearing conservation program for the Finnish National Opera (IV)

Possibilities to reduce the sound exposure by technical means were evaluated by an experienced industrial hygienist. The evaluation revealed that the rooms for personal rehearsals were not appropriate for this purpose. They were too small and the reverberation time was too long. The orchestra pit was very small. Orchestra rehearsal hall was large and the distances between players were considerably longer than in the pit, up to 2.5 m.

Based on the findings of the study, a HCP of the Finnish National Opera was built of four modules:

- Motivation and training: An information package was made for the use of occupational health care and safety engineers.
- A tutorial how to take in use HPDs in the orchestra. The tutorial gives recommendations, which plugs to choose, how to start to use them gradually and what kind of problems can be expected and how to avoid them.
- In every production, a check to ensure that no unnecessary exposure occurs.
- Possibilities to make changes in rehearsal rooms and design of the stage are checked periodically to reduce the exposure
- The group rehearsals are timed in such a way that the larger rooms can be used

Activities are supervised by Hearing Protection committee, composed of the representatives of different artist group and safety engineers.

11.5. Working conditions and hearing symptoms (III, IV, V)

11.5.1. Working conditions and stress, Finland

The job satisfaction of the musician was found to be high. The claim: “work is inspiring and meaningful” was *completely agreed* with by 43 per cent, and *almost agreed* with by 35 per cent. The work was considered to be *strenuous to some extent* by 50 per cent, *quite strenuous* by 36 per cent, and *very strenuous* by 4 per cent.

One of the orchestras, TS, was more stressed than the others. The stress was also related to health in general. In the same orchestra, those musicians who had more stress also felt that their health was worse than those who had less stress. Musicians were worried about their hearing: 34 per cent were *quite worried* or *very worried* and 35 per cent were *worried to some extent* about their hearing.

Rehearsals and performances were found *quite noisy* by 32 per cent, and *extremely noisy* by 26 per cent of subjects. In TS, performances and rehearsals were found *quite noisy* or *extremely noisy* by 21 per cent, and in GB the corresponding figure was 91 per cent. However, personal rehearsals were not found so noisy: 13 per cent thought they were *quite noisy* and 2 per cent *extremely noisy*. Again results from GB differed, 27 per cent found their personal rehearsals *quite noisy*.

11.5.2. Working conditions and stress, Denmark

The musicians in this study reported they were happy with their work, 55 per cent completely agreed that their work is inspiring and meaningful, and 29 per cent almost agreed with this statement. Figure 11.09. shows the percentage of self-reported stress responses.

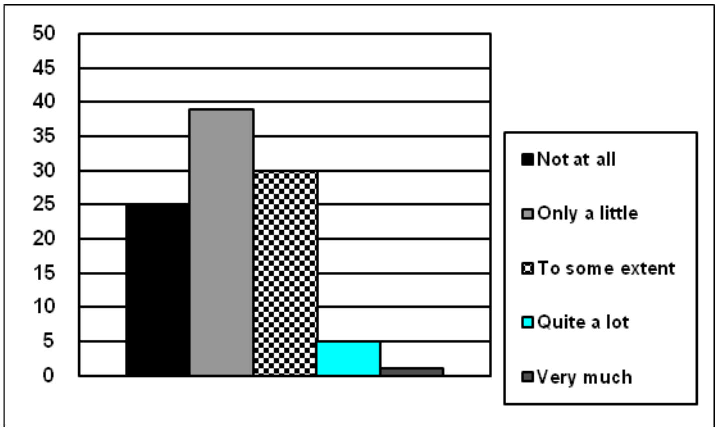

Figure 11.09. Self-reported stress as indicated by musicians.

Musicians felt that they could influence the working conditions by having improved communication with colleagues and management, by having a positive attitude themselves, and by playing well. There were also personal comments about seating arrangement, playing softer, and spending (more) time on personal rehearsals.

Most musicians did not consider personal rehearsals noisy, 3 per cent found them quite noisy, and no one found them extremely noisy. Orchestral rehearsals were considered quite noisy by 27 per cent and extremely noisy by 7 per cent of the participants. Performances were considered quite noisy by 25 per cent and extremely noisy by 5 per cent of the participants.

Other comments from the musicians included the following: (1) a wish for quiet rest facilities, (2) the negative effects of stress, fatigue, or general dissatisfaction with work, (3) good concert halls are pleasant working surroundings, (4) halls with bad acoustics increase the sensation of having hearing problems, (5) individual attitude is important, (6) some instrument groups could reduce their sound levels, (7) playing with lower sound levels is possible only if all agree to do so, (8) instruments today were built to play louder than before, and (9) the general tendency is to play louder.

Almost half of the musicians were satisfied with the sound level reduction in the orchestra. Those musicians who were not satisfied suggested acoustic improvements (including other rooms/facilities; 9 respondents); lower playing style (6 respondents); greater distance between players (5 respondents); more co-operation from conductors (5 respondents); change of seating arrangement (5 respondents); less talk, more action (4 respondents); reduction of sound from some instrument groups (4 respondents); moderate sound levels at rehearsals (3 respondents); and use of Hearwig® (2008), use of risers, removal of screens, instruments with less sound, co-operation of all (each suggested by 2 respondents).

11.5.3. Hearing symptoms, Finland

Hearing symptoms are shown in Table 11.7. Temporary ringing in the ears was experienced *sometimes* by 17 per cent, *quite often* by 8 per cent, and *always* by 6 per cent after orchestra rehearsals. The corresponding figures after personal rehearsals were 10 per cent, 5 per cent, and 3 per cent. In GB, temporary ringing in the ears was experienced a bit more in orchestral rehearsals. It was reported that 15 per cent of women, and 18 per cent of men had permanent tinnitus.

Musicians experienced hyperacusis sometimes in 27 per cent of the case, quite often in 13 per cent of the cases, and always in 3 per cent of the cases. There were no significant differences between the orchestras. The pain was described as smart, sharp pain (N=36), ripping, grating, jarring pain (N=19), sense of pressure (N=8), distortion of sounds (N=8), humming in the head (N=4), stuffed ears (N=3), nausea (N=2), and warming feeling in the ear (N=2). Single comments included descriptions like crackle, feeling of panic, jamming feeling, and feeling of weakness, torture, booming inside the head and sense of ear infection.

Table 11.7. Hearing symptoms reported, sorted according to orchestra. (Ringing 1 is temporary ringing in the ears after rehearsals, or performances, and Ringing 2 is temporary ringing in the ears after personal rehearsals. The cases included to Ringing 1, Ringing 2 and Pain are musicians who are suffering from these symptoms sometimes, quite often or always. Superscripts indicate the number of missing answers.)

	HL (yes) n (%)	**HL (no) n (%)**	**Tinnitus n (%)**	**Ringing 1 n (%)**	**Ringing 2 n (%)**	**Pain n (%)**
GB (n=22)	6 (27)	13 (59)	6 (27)	13 (59)	9 (41)	10 (45)
Gender separation was not made due to protection of privacy						
TS (n=19)	11 (58)	8 (42)	1 (5)	3 (16)	3 (16)	8 (42)
Women (n=11)	6 (55)	4 (36)	0 (0)	1 (9)	1 (9)	3 (30)
Men (n=8)	5 (63)	2 (25)	1 (13)	2 (25)	2 (25)	5 (63)
FNO (n=69)	24 (35)	37 (54)	14 (20)	18 (26)	10 (14)	27 (39)
Women (n=28)	9 (32)	16 (57)	8 (29)	9 (32)	6 (21)	14 (50)
Men (n=41)	15 (37)	21 (53)[1]	6 (15)	9 (22)[1]	4 (10)[1]	13 (32)
HP (n=48)	10 (21)	31 (65)	6 (9)	9 (13)	5 (7)	19 (28)
Women (n=12)	2 (17)	9 (75)	1 (9)[1]	4 (33)	1 (9)[1]	4 (33)
Men (n=36)	8 (22)	22 (61)	5 (14)	5 (14)[1]	4 (11)	15 (42)
RSO (n=38)	9 (24)	23 (61)	6 (16)	16 (42)	8 (21)	20 (53)
Women (n=10)	5 (50)	5 (50)	0 (0)	4 (40)	1 (10)	6 (60)
Men (n=28)	4 (14)	18 (64)	6 (21)	12 (44)[1]	7 (27)[2]	14 (50)
Total (n=196)	**60 (31)**	**112 (57)**	**33 (17)**	**59 (30)**	**35 (18)**	**84 (43)**

Musicians experienced hyperacusis *sometimes* in 27 per cent of cases, *quite often* in 13 per cent of cases, and *always* in 3 per cent of cases.

Hearing symptoms were compared to stress and working environment with odds ratios (Figure 11.10). Hearing symptoms had a clear impact on job satisfaction and stress. There were three times more who experienced stress than among those who had HL, and nine times more among those who had pain in the ear.

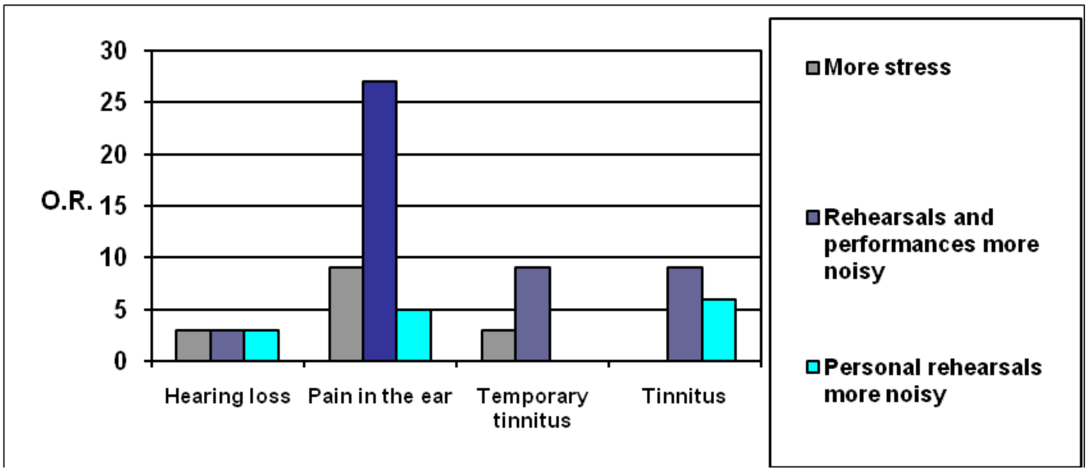

Figure 11.10. Effect of hearing symptoms to job satisfaction and stress (odds ratios).

11.5.4. Hearing symptoms, Denmark

The hearing disorders tinnitus, hyperacusis, distortion, and diplacusis were included in the questionnaire, and the distribution of the responses is shown in Table 11.8.

Table 11.8. Number of hearing disorders in the orchestras (N = number of musicians who answered affirmative to the specific question. The percentages are calculated from the number of respondents who gave a response (yes or no) to the specific question).

	Tinnitus **N (%)**	**Hyperacusis** **N (%)**	**Distortion** **N (%)**	**Diplacusis** **N (%)**
ALL	34 (24)	33 (25)	15 (12)	6 (5)
Women	10 (18)	16 (31)	7 (14)	3 (6)
Men	24 (27)	17 (21)	8 (11)	3 (4)

Thirty four respondents (of 145, i.e. 24 per cent) reported that they experience tinnitus according to the definition. Of these, 42 per cent reported it was always present, and 24 per cent reported it affects their sleep. Tinnitus is exacerbated mainly by loud sounds and stress.

Nine percent of the participants have tried a form of treatment for their tinnitus. Seven percent of the respondents tried hyperacusis treatment, and eight percent of the respondents had tried a treatment for distortion.

11.6. Questionnaire study and measurements determining room acoustics (VI), Finland

11.6.1. Reverberation time

The reverberation times measured before and after the renovation in the facilities are given in Table 11.9. Classrooms I, II and III are located in a bomb shelter facility with concrete walls, floors and ceilings. Classroom IV also has concrete walls, floor and ceiling. The music playschool hall has one wall mirror, while Classrooms V and VI are regular rooms with minor absorption. One facility was not renovated, but was measured nevertheless, and this showed very good repeatability in spite of different instrumentation and personnel. The reverberation time is given at 1 kHz. The measurements at low frequencies were disturbed in Classroom II due to timpani. The absorption material added was mineral wool, with a thickness of 50mm.

Table 11.9. Reverberation time measured before and after renovation. Bass element means the large triangle-shaped absorption material in the cross-section of ceiling and wall.

Rooms	*Area (m^2)/ volume (m^3)*	Reverberation time(s), before	Reverberation time(s), after	Change of reverberation time (s)	Absorption
Classroom I	40 /110	0.5	0,4	-0.1	Bass element, 10 metres
Classroom II	38 / 103	0.6	0.3	-0.3	Increased by 7 per cent + bass element, 10 metres
Classroom II	90 / 246	0.7	0.5	-0.2	Increased by 30 per cent
Classroom IV	35 / 120	0.6	0.3	-0.3	Increased by 70 per cent
Music playschool hall	111 / 311	1.2	0.7	-0.4	Increased by $20m^2$
Classroom V	48 / 116	0.6	0.4	-0.2	Increased by 27 per cent
Classroom VI	75 / 209	0.5	0.5	-	No absorption material added

11.6.2. Sound level measurements

The sound exposure measurements of teachers' 8 h sound level exposure (L_{Aeq}) – the average taken before and after renovation – are shown in Table 11.10.

Table 11.10. Sound exposure measurements before and after renovation.

Facilities	*Instrument*	L_{Aeq}, before dB(A)	L_{Aeq}, after dB(A)	Comment
Classroom I	trumpet	85	84	
Classroom II	drums	91	93	
Classroom II	drums	87	85	fixed point
Classroom III	French horn	80	84	
Classroom IV	accordion	84	75	
Classroom IV	accordion	81	71	fixed point

11.6.3. Questionnaire

There were 31 responses to the questionnaire before renovations, and 8 responses after the renovations. No statistical analysis was performed due to the small sample size.

The facilities that were commented on in the questionnaire, besides the renovated facilities mentioned above, were:

- Larger classrooms, volume about 100 m^3
- Smaller classrooms, volume about 35 m^3
- Classrooms in another building, which were office rooms renovated into music facilities
- Orchestral rehearsal room with variable acoustics, volume about 400 m^3
- A classroom used for teaching harp playing

Teachers were asked which teaching facility they used most. The replies were grouped according to the volume and reverberation time, and approximately the same usage. The resulting groups were:

1. Classrooms I, II and III (almost entirely of concrete, some absorbent material)
2. Larger classrooms
3. Smaller classrooms
4. Classrooms in another building
5. Music playschool hall
6. Classrooms V and VI
7. Classroom IV (almost entirely of concrete, with some absorbent material)
8. Orchestral rehearsal room
9. A classroom used for teaching harp playing (over 100 per cent absorbent material)

Teachers were also asked about support, dynamics, sound levels in the room, whether they can hear themselves, whether they can detect mistakes easily and the reverberation in the room. In addition, their overall opinion about the room acoustics was sought.

Table 11.11 contains the questions on which the evaluation key words are based in figures.

Table 11.11 The questions asked seeking evaluation of the facilities.

Key word	Question used	Scale (5 step)
Satisfied	Are you satisfied with the teaching facilities?	Very satisfied – very unsatisfied
Support	Support received from the facility (is it easy to play in the facility)?	Very good – very bad
Dynamics	Dynamics of the facility?	Very large – very small
Sound level	Sound level of the facility?	Too quiet – too loud
Hear self	Can you hear yourself?	Very well – very badly
Mistakes	Can the mistakes of the student can be distinguished?	Very well – very badly
All in all	The overall acoustics of the facility?	Very good – very bad

The questionnaire results show at most improvement in the sound levels of the rooms by two-fold. However, this improvement cannot be confirmed by sound level measurements. One explanation may be that the bass elements decreased low frequency sound, which does not contribute greatly to the A-weighted exposure. Thus, the musicians may have rated their annoyance at the room instead of the sound level.

Questions about the sound insulation asked whether teachers were disturbed by or thought they disturbed others. Most respondents were satisfied with the sound insulation and were not aware if they disturbed others. According to the earlier measurements, most of the facilities did not meet the requirements of SFS 5907 (2004) for the minimum level of sound insulation.

Teachers were asked whether they were satisfied with the teaching facilities, and showed no complete dissatisfaction with the facilities. Teachers were also asked whether the music style affects how they feel about the facilities. Around half of the respondents (12 out of 26) were convinced that music style does not affect their opinion; while the other half (10 respondents) thought that music style matters. Three respondents considered the age and playing ability of students more important than the music style.

Some respondents thought that a hard wall is needed. The instruments that needed a hard surface varied, and teachers of the same instrument had different opinions. Floor material seems to affect the sound of instruments. 16 out of 17 respondents thought that a wooden floor was the best material for an instrument. Only 2 teachers liked concrete floors, and 3 wall-to-wall carpeting.

Teachers had the opportunity to comment freely on the facilities. Twelve teachers felt that the classrooms were too small. Other comments included suggestions that the working position could be better, the room could have more height, there could be better sound insulation, stairs could be improved (one facility had steel stairs), better lighting in some rooms, less reverberation, better ventilation, concrete flooring annoys, and the absorption material should be mounted on the walls instead of the ceiling in order to avoid that the bow breaks when hitting the absorbent.

Teachers also commented on the facilities. An ideal facility for teaching, according to them, would be one that had:

- Ample space
- Large volume
- A high ceiling
- Not too much reverberation, but was also not too dry

In addition, there were a few comments dealing with windows, hard floors, the concert stage, wooden flooring, the need for furniture and freedom from other noise.

Six out of eight teachers were either very positive or positive about the effects of renovation on the facilities. The two teachers who thought it negative both taught woodwind instruments. The following comments were given about the renovation:

- The concrete floor could be covered with wood, which would make the facility even better
- The smearing of sound has reduced
- They are very satisfied with the facility
- The music does not bother their ears as much now
- Listening is easy
- Reverberation and booming has been reduced, but sound insulation did not get any better

Teachers of woodwind instruments did not like the reduced reverberation. This is problematic because the same facility is also used by drums. Teachers of woodwind instruments felt that it is harder to play now and that it is more difficult to hear the mistakes of the student. Volume reduction was also criticised, as well as the impression that the attenuation of the facility is not even. One teacher has stopped personal rehearsals in the classroom. One of the teachers described the volume reduction as shocking, but admitted they have become used to it.

12. DISCUSSION

The current situation of hearing conservation in Finnish and Danish orchestras performing classical music has been presented. Both large and small orchestras participated the study. Though the study does not include all the orchestras and perspectives, (which is impossible to do due to resources) the results can be applied to all orchestras performing classical music in those countries where the problems of the hearing have been acknowledged and musicians are using HPDs as requirement of the directive. The usage of HPDs is still, however, unsuccessful. The usage rates are low and the education is insufficient.

The Code of Conduct and (2006) its applicability to room acoustics has been evaluated in music classroom which are small and hold usually two persons at a time (a teacher and a student). The results can be applied to the facilities of the musicians in general, as they are an example of the best facility available to musicians for personal practice. The facilities of the musicians for personal practice are often neglected in professional orchestras. At its best, there are facilities, but often too few, too small and poorly designed for the purpose. Musicians are known to practice at home, in cleaning supply closets, storage rooms, and bath rooms. All places whose acoustics is not designed for music.

12.1 Total annual exposure of musicians

In the FNO the conductors, and double bass players were not exposed to sound levels exceeding 85 dB(A). For other groups, such as choir, soloists, and orchestra, higher sound exposure levels occurred during personal and group rehearsals, as well as during performances. In addition, results of this study show that personal rehearsals are a significant source of exposure. In fact, it was the main noise exposure source for the choir members, percussionists, woodwind instrument players except for the flute/piccolo players, brass players, and harp players. The largest differences between sound levels at personal rehearsals and performances and group rehearsals were found with the choir. Although only 13 percent of the singing time was utilized at the personal rehearsal, it was the major source of exposure. This was mainly due to the fact that at choir rehearsals the sound power was 6 to 20 times higher than at group rehearsals and performances.

The noise exposure measurements in other orchestras showed the same tendency as in the FNO. Only TS, which is a small symphony orchestra, had couple of players from other instrument groups (one viola and one cello) that did not exceed 85 dB(A). However, even in TS majority of the musicians were exposed to harmful sound levels. Personal rehearsals were also in these measurements contributing to the exposure. Only contra bassoon seems to have significantly low sound levels in personal rehearsals, and thus their total noise exposure depends on the orchestra.

According to the Finnish legislation, if the noise level exceeds 85 dB(A), the employer must develop a HCP. In HCP the first task is to evaluate the sources of noise and the possibilities to reduce the levels by technical means. If reduction of the noise source is not possible, the workers should be provided with HPDs, and the workers should be informed about the risks and the correct use of the selected HPDs in an appropriate way. The use was charted with a questionnaire that was composed by the personnel.

12.2. Hearing thresholds, and other hearing symptoms

The issue of whether musicians tend to have NIHL has been debated for a long time. This study found that orchestra musicians' hearing loss corresponds to that of the non-noise-exposed population, according to ISO-1999 (1990). Still there is dependency of the exposure to noise. Similar low susceptibility to noise have been found also among military pilots (Kuronen et al., 2004). For military pilots the low susceptibility was explained with low presence of personal risk factors (elevated blood pressure, elevated cholesterol, use of painkillers and smoking). In general the ISO 1999 model seems to work well with blue collar workers (Toppila et al., 2001) ,but when a group of workers with low presence of risk factors is selected, the ISO 1999 model overestimates the risk.

Another factor indicating that music can harm musicians' hearing is the sample's elevated prevalence of tinnitus and hyperacusis. The low presence of hearing loss and the high presence of tinnitus can be explained by their etiology. Over-stimulation may lead to cochlear injury either mechanically or metabolically, which are two fundamentally different ways (Ulehlova, 1983).

At sound-pressure levels of less than 125 dB, sound-induced over-stimulation and over-activity of the cochlea can result in disturbed cochlear homeostasis and subsequent functional impairment in the absence of direct and immediate mechanical damage. Experimental evidence suggests a critical level about 125 dB SPL, at which level the cause of damage changes from predominantly metabolic to mechanical (Scheibe et al., 1992). Tinnitus, however, is more common among people exposed to such impulsive noise as music (Alberti, 1987). Impulsive noise's high peak levels indicate that mechanical damage plays an important role in the etiology of tinnitus. It is reasonable to assume that risk factors affect the effects of metabolic trauma but not those of mechanical trauma, which could explain the low prevalence of NIHL and the high prevalence of tinnitus among musicians.

Eighty-four percent of Finnish musicians have had a hearing check within a three year period (Laitinen et al., 2003); whereas, this was the case for only 35 per cent of Danish musicians in the current study. Danish musicians are not as worried about their hearing, have less stress, and are slightly more satisfied with their work than their Finnish colleagues as shown in the Laitinen et al. study (2006).

Musicians have a high prevalence of ear symptoms. In a normal population 15 per cent have tinnitus, whereas 37 per cent of the Finnish musicians, and 24 per cent of the Danish musicians surveyed have tinnitus. Permanent tinnitus seems to be associated with the perception of noise. Musicians in GB had the most cases of permanent tinnitus, while musicians in TS had less than musicians in other orchestras. Similar tendencies were also discovered in noisiness evaluations. Members of GB had more temporary ringing in their ears than members of other orchestras. Because GB consists almost entirely of brass instruments, almost every musician is exposed to high sound levels, and corresponding symptoms were more frequent. TS however is a smaller symphony orchestra, and in which the sound levels are lower.

Musicians are satisfied with their work. However, they are stressed, and one of the reasons for the stress can be pre-existing hearing problems. It is important to remember that other factors can also contribute to stress, and lower a musician's ability to play without additional effort. There are other hearing symptoms to be considered, for example tinnitus and hyperacusis. In the Finnish study a connection between some of these hearing symptoms and stress was found. It is difficult however to say whether the stress increases the incidence of these symptoms, or the existing symptoms increase the stress felt. In the worst case, it can be both and the processes fortify each other. Danish musicians feel that hearing disorders could be reduced by avoiding stress and noise, sufficient rest, and by having a positive attitude.

Musicians are concerned about the acoustics of their working environment. Typically they find the acoustics of the concert hall satisfying, but the rehearsal hall and other playing rooms are not always found appropriate. Further, musicians want a quiet room for rest. The present study did not investigate the acoustics of the halls; thus, the criticism of the rehearsal halls may be a psychological factor. Musicians' evaluation of other playing environments (not their usual concert and rehearsal hall) is always related to poor acoustics in one way or another (e.g. reverberant places, dry halls, orchestra pit, sport halls, small halls, etc.).

Musicians seem to be concerned about their proximity to instruments that are louder than their own or even to instruments that are at the same sound level as their own instrument. Even a small increase of the distance to other instruments can affect the musician's satisfaction.

Danish musicians reported that having good communication with their colleagues and the management, having a positive attitude, and playing their instrument in a correct manner were ways to influence their working conditions. The selection of program, seating arrangements, acoustic changes, and more moderate sound levels are issues that the individual musician cannot influence.

The musicians accuse contemporary music and the composer for increased loudness levels; however, sound level measurements show that this is not necessarily the case (Laitinen et al., 2003). Due to the characteristics of contemporary music, it is only perceived as noisier than classical music. However, job satisfaction, and reduced stress are two of the important keys to the occupational health of musicians; therefore, the repertoire should be carefully considered.

12.3. Small practice rooms

Changing the room reverberation characteristics did not decrease the level of exposure of teachers or students. This result is not surprising because the level of playing can be controlled by the player. Reverberation thus is more related to the quality of sound, and therefore to job satisfaction.

The recommendations regarding room size is hard to achieve in most places. However, this study shows that decent room acoustics can be achieved even in relatively small rooms. The major problem seems to be the amount of the absorption material needed to find proper reverberation which is instrument dependent. Because teachers are using the same classrooms for different instruments, they should be designed such that reverberation time can be easily changed. In addition, the teachers have to get used to utilising the new facility. Another advantage is that, because of tuning possibilities, there is no need for measurements to adjust the acoustics of the room. A sufficient range can be obtained through acoustical modelling.

Reverberation times were shortened in all of the facilities that were renovated. A simple calculation seems to be precise enough to design facilities for both practice and teaching. The decision regarding the amounts of absorption material to be used should be carried out by a professional. However, sound insulation in the bomb shelters is not sufficient, mainly due to insufficient sound insulation for such high demands (the loud instruments used). A common misconception is that thick walls prevent sound travelling from one facility to another, but sound travels both in the structure and through ventilation ducts. A room that is in a room-structure should always be used for loud instruments and band practise. In addition, concrete (or some other extremely hard surface) as the surface material does not provide good acoustics to practice rooms – it is almost always too reverberant for music. If concrete is used, there is a need for highly absorbent, space requiring materials that absorb sound, especially at lower frequencies. In spite of the insufficient sound insulation, teachers generally do not seem to be bothered by weaker sound insulation. There could be two reasons for this: the first is that the sound insulation is quite good, and so it does not cause any great problems in teaching; and the second is that teachers are used to the situation and have learnt to deal with it.

The Code of Conduct (2006) uses SFS 5907 (2004) as a guide for its recommendations for reverberation time and sound insulation. However, SFS 5907 is suitable only when designing a regular music classroom in a school. In addition, the standard does not give any practical means for designing rooms. In Finland, there is a guide entitled “Acoustical design of buildings: schools, auditoriums, spaces for sports and libraries” that can be used (Kylliäinen et al., 2007). This guide follows the SFS 5907 standard. The limits given in SFS 5907 and the advice of the guide are not suitable for small spaces where loud instruments are played, such as band practice or the individual practice of loud instruments. The requirements for sound insulation in these cases are greater, while sound reverberation time must be reduced at such facilities. Planning requires good knowledge of building acoustics. If the proper sound insulation is not achieved, the simultaneous usage of facilities can be impossible (for example, band practice disturbs education in classrooms on the upper floors of the building).

The acoustical design should also be reviewed from the viewpoint of occupational healthcare. If one considers the sound exposure levels, differences in sound reverberation times are usually not significant. However, even small changes and correct reverberation time can be heard and can improve job satisfaction, and thus high quality in acoustical design is important when good occupational healthcare is desired.

The sound levels were considered to be a problem in almost all facilities. These were thought to be decreased in the renovation, although shorter reverberation time did begin to be a problem for some instruments. Some teachers have hearing problems, but the usage of hearing protectors is low.

Sound level measurements before and after the renovation must be compared with care. The reverberation time measurements confirm that the sound level is somewhat reduced at the facilities, but this is not confirmed by the sound level measurements. The variance in teaching situations masks the small reductions in sound level. A large difference can be seen in an accordion class, but even there the effects of different teaching material cannot be excluded. However, when all of the sound level measurements are considered together, it is possible to confirm the prediction of the modelling: that sound levels and therefore sound exposure will not change significantly through changing the room acoustics. Satisfaction in the work environment and teachers’ opinions of the room acoustics does change. For most of the teachers who responded, the situation improved, while for a minority it worsened. It would seem that woodwind instruments suffered the most, since the negative replies were all given by woodwind instrument teachers. The reason for this is probably that useful feedback from the reflective wall decreased. Because many of the rooms still had convertible acoustics, the teachers could adjust each room to their satisfaction. However, the convertible acoustics has been designed so that it is very difficult to use. Even if the exposure is not decreased, the effect on job satisfaction is important, because the sensation of a noisy environment is related to both stress and job satisfaction.

Some of the teachers felt that the skills of students are the major cause of sound exposure. However, Mace (2006) made experiments with university music teachers and found that there was little if any effect on average sound levels. In her study the freshmen had at least some skill while in our study this was not guaranteed. Lack of technique can be a cause of an increased/decreased sound level in some instruments, although music can appear noisier even when sound levels are the same.

Building and renovation are expensive. There are often complaints that the cost of extensive planning and using an acoustician add more cost to an already expensive project. However, these can also save money. In this case, the renovation cost was determined by a call for offers. The initial offers were relatively high, and so the author then went through the offers with builders. The results were significantly lower after the precise needs of the music institute were determined. If the builder has no experience in building this kind of facility, the cost evaluation can be difficult and an hour of consultation can thus save thousands of Euros on an offer.

When totally new facilities are being built, or there is a need for extensive renovation, consulting an acoustician in the early stages of planning when the budget is being estimated and decided on, and later supervision by the acoustician at the construction site, can save on additional correction costs.

The results suggest that practice rooms and classrooms for music require careful planning, although comprehensive measurements are not always necessary. If there are problems with sound insulation and room acoustics, by measuring the worst cases and going through the facilities on site and looking at earlier plans, the condition can be identified and renovations planned. The ideal situation is for planning to be finished well before the facilities are built.

Convertible acoustics is highly recommended. Only if the usage proposed for the room is known well in advance and is not going to be changed, can acoustics be planned for that one particular purpose. Even then, individual preferences may vary and, even though the facility is good for one instrument player, it can be bad for another player of the same instrument. The solutions for convertible acoustics can be simple: a frame with a soft and hard surface that can easily be turned is cheap yet effective. The experiences at the institute showed that if convertible acoustics is thought to be tiresome or too complicated to use, it will not be used, and in the worse case is not even perceived as convertible. The solution is relatively simple, that usage of this kind of acoustics must be taught to users. The principles of How, Why and When should be taught to users at the beginning, and should be included in the orientation of new employees. Using convertible acoustics should be as automatic as turning the lights on when it is dark.

12.4. Hearing protectors

12.4.1. Finnish National Opera and hearing conservation program

The opera allowed everyone to buy hearing protectors of their choice at opera's expense. Still, most of the artists did not use HPDs. About 77 percent of the artists never used HPDs when playing alone. The use was more frequent at group rehearsals where most of the artists sometimes used HPDs. Only less than three percent always used HPDs. The use of HPDs is not related to exposure. 50 percent of the musicians exposed to over 90 dB(A) never used HPDs while over 90 percent of musicians with exposure less than 90 dB(A) used at least some times HPDs in performances/rehearsals. These rates are very low compared to the self-reported symptoms: 19 percent of the orchestra and 41 percent of the choir informed that their hearing had worsened in the latest audiometry performed. These results indicate a serious lack of education and training causing poor motivation in the use of HPDs.

In the opera five types of HPDs were used: Danalink ER-15, Elacin ER-15/25, E.A.R Ultratech, and E.A.R. Classic. The four first types have uniform attenuation, are designed for musicians. Applying the HML check-method of EN 458-1993 (1993), the level inside HPD (Table 12.1) can be evaluated using the M-index, and results in Tables 11.1 and 11.2. According to EN 458, the attenuation is good if the level inside the hearing protector is 75–80 dB(A), and acceptable if the level inside the hearing protector is 70–75 dB(A), or 80–85 dB(A). Table 12.1 shows that best overall products are the E.A.R. Ultratech and the Elacin ER-15. The Elacin ER-25, and the E.A.R Classic are best suited for trumpet, brass, and percussion instrument players, as well as for singers in personal rehearsals. The Danalink ER-15 is best suited for string instrument players.

Table 12.1. *Calculated sound pressure levels (dB(A)) inside the hearing protectors among various groups in the Opera.*

Performer	Danalink ER-15, M=10	Elacin ER-15, M=14	Elacin ER-25, * M=24	E.A.R. Ultratech, M=18
1. and 2. Violin	76-79	72-75	62-65	68-71
Viola	76-83	72-79	62-69	68-75
Cello	76-85	72-81	62-71	68-77
Double Bass	69-81	65-77	55-67	61-73
Flute/Piccolo	85-88	81-84	71-74	77-80
Other wood instruments	80-81	76-77	66-67	72-73
Trumpet	78-87	74-83	64-73	70-79
Other brass instruments	78-88	74-84	64-74	70-80
Harp	77-79	73-75	63-65	69-71
Percussion instruments	80-89	76-85	66-75	72-81
Choir: personal rehearsals	90	86	76	82
Choir: performances	77-82	73-78	63-68	69-74

*These values apply to E.A.R. Classic which has the same M-index.

12.4.2. Finnish and Danish studies

Most musicians do not use hearing protectors on a regular basis. Usage rates strongly agree among both studies. Surprisingly, many musicians in the Danish study use a hearing protector in only one ear, namely the ear with more perceived exposure. The other ear is then used to listen to the music.

Only 15 per cent reported that they constantly use hearing protectors. Most of the musicians wear hearing protectors only occasionally, especially during loud passages. Calculating the musicians' sound exposure level is somewhat complicated due to the dynamic nature of music. In addition, the duration of hearing protector use must be considered (Laitinen et al, 2003). These issues become more important with the new European directive, which states sound exposure must not exceed 87 dBA. The directive assumes that employees use hearing protectors in both ears.

Hearing protectors are not used in personal rehearsals though measurements (Laitinen et al., 2003) have showed that it is essential to use them both during orchestra rehearsals and personal rehearsals. The number of musicians using hearing protectors is larger than what Kähäri (2002) found (10 per cent), but a direct comparison is difficult to make, since scaling has been used and also personal rehearsals were separated as their own group. The results support that musicians feel their own instrument is not noisy, but it is the neighboring instruments that cause the problems.

Musicians need some time to get acquainted to hearing protectors. Ten percent of the Danish musicians adjusted to hearing protectors right away, but for the majority of the musicians, it took some time, months or even years. Many stopped using hearing protectors or never tried them. Development of hearing protectors that are immediately accepted is necessary. It may seem awkward to recommend hearing protectors for musicians; however, it seems to be the only way musicians can be protected and fulfill the EU directive about noise at the workplace. The sound levels in the orchestras are usually not extremely high; thus, a protector with limited attenuation (achieved passively or electronically) is sufficient for many musicians.

The best results are achieved when HPDs are worn by motivated users. Low motivation to wear HPDs is seen in low usage rates and low attenuation values (Foreshaw & Cruchley, 1981). Increasing motivation can be obtained via appropriate education and training. For industrial workers best results are obtained if personal audiometric data is used (Stewart, 1994). For musicians, other hearing symptoms are important and must be taken into consideration when promoting their use. For a musician, hearing is of major importance. Any obstacles to hearing can deteriorate the quality of playing. HPDs deteriorate intelligibility, and if hearing is already deteriorated by HL, the use of HPDs may become impossible. The fact that musicians with hearing symptoms use HPDs more often indicates that it is possible to get used to them. However it can take two to three months to get used to them, and this can vary between individuals.

Also, it seems that those musicians suffering from hearing symptoms more frequently use HPDs than those without symptoms. Musicians were worried about their hearing, yet they seemed to be reclutant to use HPDs, which are often the only solution to protect hearing. It would seem that the musicians with problems start to use HPDs only after the problems appear. This is supported by the comments from musicians themselves when asked about the reasons to use HPDs. Some of them admitted that they use HPDs because of already existing HL and tinnitus, and also to protect the ears from pain. Because of the fact that only very few musicians have used HPDs as music students, the assumption is that hearing symptoms are the major reason for the use of HPDs.

For musicians, disposable foam or cotton earplugs are free of charge. Custom moulded musicians' earplugs are more expensive; however, they are often paid for by the orchestra for the musicians. Two Danish musicians used hearing aids as hearing protection. The hearing aids were modified in such a way that they prevented high peaks to be transmitted into the ear, but otherwise, in principle, they were transparent to the user. These two users expressed great satisfaction with this method, which calls for further study and development of a transparent hearing protector for the music and entertainment sector. In Europe, hearing protectors must have a certain minimum attenuation to be marketed as hearing protectors. A transparent hearing protector does not fulfill these minimum requirements; however, in order to overcome this issue, the designation 'hearing protector' could be avoided.

When HPDs are used, musicians mostly in Finland use the custom moulded earplugs with flat attenuation. However, if the HPDs are not paid for by the employer, musicians can make the decision not to buy them because they consider them to be too expensive. Brass players seem to favor custom moulded earplugs. This is probably due to the valve in the earplug that lowers the pressure in the ear canal of which brass players sometimes complain. Disposable earplugs are also popular among musicians. Some musicians commented that custom moulded earplugs are difficult and slow to use, so they instead use disposable earplugs when they need protection quickly. Because it takes time to properly insert a disposable earplug, the earplug may then only be partly inserted into the ear, reducing the attenuation of the earplug.

Custom moulded hearing protectors are often considered to be the best choice for professional musicians, but some musicians change to other types of protectors. According to musicians, one of the reasons why they consider custom moulded earplugs inferior is the time it takes to insert the earplugs. This issue emphasizes the necessity to train musicians on the fitting of the earplug. It takes only seconds to insert the earplug; however, this must be learned under relaxed conditions, not in the middle of a concert.

Musicians feel that cotton wool preserves a better sound image; however, cotton wool attenuates very little at high frequencies; thus, the protection is mainly psychological. The tendency to change from custom moulded plugs into another form of hearing protection was also observed in a previous study (Laitinen, 2005). The Danish study was the first time that the reason for changing hearing protector type was investigated.

The occlusion effect changes the sound of the musicians' own voice and the sound of their instrument. Hollow sound quality and changes in the sound image are considered very annoying. The general problems of a blocked feeling in the ears, moist ear canals, and an itch in the ear canal are not the worst problems for musicians. Although musicians acknowledge that there are differences between hearing protectors, the occlusion effect has caused almost half of them to stop using hearing protectors. These occlusion effect problems indicate that the individual fitting of musicians earplugs is not optimal in all cases. Another possible explanation is that the musicians have misunderstood the word 'occlusion' or mixed it up with the typical high frequency attenuation from conventional hearing protectors. Thus, the responses might be about hearing protectors in general and not specifically about musicians' earplugs.

Some of the problems in the usage of HPDs can be solved. For example, paying special attention to hygiene can prevent ear infections. For many musicians, the first problems are a reason to quit using the hearing protectors. If it were understood that there are always problems, but they can be dealt with, usage rates could likely be increased.

AUTHOR'S CONTRIBUTION

Publications I-IV were gathered in two projects funded by The Finnish Work Environment Fund. In these projects the author worked as principal investigator. Publication V was performed under the EC Marie Curie Host fellowships program 'Early Stage Research Training' (EST), and was an independent work performed by the author. Publication VI was funded by Academy of Finland. The author was in project the principal investigator.

Publication I: "Sound exposure among the Finnish National Opera personnel."

The author realised the measurements and questionnaires and made the interpretation of results. The actual measurements were made by co-author of the publication, Pekka Olkinuora. Esko Toppila provided comments to the manuscript.

Publication II: "Factors Affecting the Use of Hearing Protectors among Classical Music Players"

The author redesigned the questionnaire used earlier in Opera to provide more practical information. The acquisition of data, and statistical analyses were performed by the author. The manuscript was written by the author.

Publication III: "Development of Hearing Conservation Program for Finnish National Opera"

The author performed part of the sound exposure measurements, and was part of the group who composed the hearing conservation program. The analysis of the questionnaire was performed by the author. The author actively participated in writing the manuscript.

Publication IV: "Hearing Loss Among Classical-Orchestra Musicians"

The author organized in addition to sound exposure measurements the audiometric tests, cholesterol and blood pressure measurements. The author participated to making the manuscript.

Publication V: "Questionnaire investigation of musicians' use of hearing protectors, self reported hearing disorders, and their experience of their working environment. "

The author toured the orchestras with co-author, gave lectures and distributed the questionnaires which were based on earlier studies, and some hypothesis of the author. The author performed the statistical analysis, and wrote the manuscript. Torben Poulsen helped with Danish open answers, and provided comments to the manuscript.

Publication VI: "Facilities for music education and their acoustical design"

The author made the questionnaire, and performed the analysis of the results. The sound exposure measurements were performed by the co-author, Pekka Olkinuora. The author provided the renovation guidance, made reverberation measurements, and wrote the manuscript. Esko Toppila provided comments to the manuscript.

13. CONCLUSIONS AND FUTURE DEVELOPMENT

The study has shown that there is an urgent need for hearing conservation among classical musicians. For majority of the classical musicians, the total noise exposure exceeds the upper exposure action level. Classical musicians suffer from different hearing symptoms (tinnitus, hyperacusis, and diplacusis). The hearing symptoms affect the musicians detrimentally, and reduce their job satisfaction.

The noise directive requires that technical measures (silencing the source, the prevention of spreading the sound, and reducing exposure time) precede always personal protection. This order should also be applied to the entertainment sector. As the product is the sound, there is no sense in reducing the sound levels in classical music. In industry, one of the most often used technical measures, is adding large amount of sound absorption material to the facility. In music, there is a limit how much one can add the absorbent material. Some instruments can use different kind of mufflers, but they are not often used even at personal rehearsals. Screens between instruments are used, but they are not always accepted. The personal protection is the first, and in practice, the only option for the musicians to protect their hearing. Experiences from the Finnish National Opera revealed a huge gap between reality and practise. Musicians do not often use HPDs, although based on measurements, they should. The need to hear one's own and others' performance is too great, and HPDs are neglected. The usage rates are low even though majority of the musicians are well informed about the harmful effects of loud sounds. The measures taken in industry for increasing the HPD usage are not enough in the music sector. Musicians take the risk of HL and hearing symptoms willingly in order to perform perfectly.

The musicians' noise exposure were measured and evaluated as an annual exposure from different music samples, and for the first time including personal rehearsals to total exposure. Every musician practises a great deal, and it is required that they do so. It was shown that personal rehearsals had an additive effect to the annual exposure, and thus they should always be included to the total exposure. The measurements showed that all musicians in all the major orchestras in Finland, excluding double bass players and conductors, were exposed to sound levels exceeding upper exposure action levels. The small symphony orchestra had in addition one viola and cello player who also fell below the upper exposure action level. Still, even in the small symphony orchestra, the majority of the musicians were exposed to sound levels exceeding the upper exposure action level.

The hearing threshold of the musicians exposed to harmful sound levels correspond the hearing thresholds of non-noise exposed population, according to ISO-1999 (1990) model. However, audiograms are dependent on noise exposure. In addition, exceptionally many musicians suffer from other hearing symptoms (tinnitus, hyperacusis and diplacusis).

Most frequent hearing symptoms were tinnitus and hyperacusis. Musicians with hearing symptoms used HPDs more often than musicians without hearing problems, and thus it seems that musicians will start use HPDs only when the problems with hearing appear. The connection between hearing problems and stress could not be demonstrated.

The noise exposure measurements of this study showed that a strongly contributing fact to musician's exposure is their personal rehearsals. Still, the room acoustics of these facilities is often neglected. The affect of improvement was investigated at a music institute in their small classrooms. The room acoustics was not significantly improved but it had a positive effect on job satisfaction. In order to use practise facilities efficiently and by different instruments, easy-to-use variable acoustics is recommended. The Code of Conduct provides limit values for design but does not provide any practical guidance to design the facilities.

The musicians were worried about their hearing. Still, HPD usage was low, especially in personal rehearsals. The biggest problems in the usage were that HPDs hinder own performance, and that it is difficult to hear others' play. Musicians' reluctance to use HPDs in personal rehearsals can partly be explained by experiencing the own instrument less noisy than others'. The HPD usage was not continuous, many musicians wear HPDs only in loud passages, and some of them only in one ear. Despite of the development of musicians' earplugs, disposable earplugs are still used.

As the situation in occupational safety is far from being satisfactory, new techniques to promote the safety are needed. New techniques for further education are one key issue. Though all orchestras have basic knowledge about hearing and HL, it would seem that the knowledge is not affecting to the behaviour but only the problems are. The attitudes need to be changed, preferably at early age, and the acceptance of HPDs is required. Musicians' HPDs have been developed, but it is possible that they are not still optimal. The development and research on new musicians' HPDs is needed. Musicians, and professionals surrounding musicians need to know what they can expect, and demand in the matters of HPDs, hearing conservation, technical solutions, and facilities.

The results of this study are not directly applicable to other music branches like rock and pop, jazz, folk, church music, and other professionals like the music teachers. The methods developed in this study are directly applicable in these fields.

Musicians enjoy greatly their work, but hearing problems may seriously impact the joy. Research and practical work are needed to prevent this impact.

REFERENCES

86/188/EEC (1986) Council directive on the protection of workers from the risks related to exposure to noise at work. Brussels: European Commission.

2003/10/EC (2003) Council Directive on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise). Brussels: European Commission.

Alberti P. (1987) Tinnitus in occupational hearing loss: nosological aspects. *J Otolaryngol*, 16:34-35.

Arlinger S. (2007) Measurement of hearing thresholds, in Noise and its effects. Ed: Luxon L, Prasher D, John Wiley & sons.784p.

Arnold G.E., Miskolczy-Fodor F. (1960) Pure-tone thresholds of professional pianists. *Arch Otolaryngol*, 71:938-947

Augustyńska D., Buffet M. A., Karjalainen K., Kuhl K., Mlynski R., Toppila E., Zera J. (2007) TCWE Task 3.2.2 Report, Noise in the entertainment sector version 5.0 final [Internet]. European Agency for Safety and Health at Work. Forthcoming from: www.osha.eu

Axelsson A., Eliasson A., Israelsson B. (1995) Hearing in pop/rock musicians: a follow-up study. *Ear Hearing*, Jun;16(3):245-53

Axelsson A., Lindgren F. (1978) Hearing in pop musicians. *Acta Otolaryngol (Stockh)* Mar-Apr, 85(3-4):225-31

Axelsson A., Lindgren F. (1981) Hearing in classical musicians. *Acta Otolaryngol Suppl (Stockh)*, 377:3-74

Axelsson A., Prasher D. (2000) Tinnitus induced by occupational and leisure noise. *Noise Health*, 8:47-54

Babin A. (1999) Orchestra Pit Sound Level Measurements in Broadway Shows. *Med Probl Perform Ar*, 14 (4): 204

Baguley D. M. (2003) Hyperacusis. *J R Soc Med*, 96:582–585.

Barrenäs M., Holgers K. (2000). A clinical evaluation of the hearing disability and handicap scale in men with noise induced hearing loss. *Noise Health* 6: 67-78

Bartsch R., Dieroff H., Brueckner C. (1989). High frequency audiometry in the evaluation of critical noise intensity. *Int Arch Occup Environ Health* 61(5): 347-351

Behar A., MacDonald E., Lee J., Cui J., Kunov H., Wong W. (2004) Noise Exposure of Music Teachers. *J Occup Environ Hyg*, April, 1:243-247.

Behar A., Wong W., and Kunov H. (2006) Risk of hearing loss in orchestra musicians: Review of the literature. *Med Probl Perform Ar*, 21 (4): 164-168.

Berger E. H. (1994) Hearing Protectors – Specifications, Fitting, Use and Performance, in Hearing Conservation in Industry, Schools, and the Military. Ed: Lipscomb D. M., Singular Publishing Group, Inc, San Diego, USA. 344p.

Bianco E. A. (1993) Consent to treatment: Application to performing arts medicine. *Md Med J*, Vol 42(3): 293-297.

Borchgrevink H. M. (2003) Does health promotion work in relation to noise? *Noise Health*. Jan-Mar; 5 (18):25-30

Borka C. (2007a) The value of otoacoustic emissions in the investigation of noise damage. *Audiol Med*, 5: 10-24.

Borka C. (2007b) Tinnitus and external sounds, in Noise and its effects Ed: Luxon L, Prasher D, John Wiley & sons.784p.

Burén M., Solem B.S., Laukli E. (1992) Threshold of hearing (0.125-20 kHz) in children and youngsters. *Br J Audiol*, Vol 26(1):23-31.

Burns, W. (1973) Noise and man, 2nd ed., London, John Murray 459 pp.

Burns W., Robinson D. W. (1970) Report on Hearing and Noise in Industry. London: Her Majesty's Stationery Office. 241p.

Camp J.E., Horstman S.W. (1992) Musician sound exposure during performance of Wagner's Ring cycle. *Med Probl Perform Ar*, 7(2):37-39.

Campo P., Lataye P.R. (1992) Intermittent noise and equal energy hypothesis. In: Noise-Induced Hearing Loss. eds.: A.L. Dancer, D. Henderson, R. J. Salvi, R. P. Hamernik. Mosby Year Book. 554p.

The Canadian Hearing Society (2008) The Canadian Hearing Society Position Paper on Noise Pollution. Retrieved October 10th, 2009 from http://www.chs.ca/en/home/chs-position-papers/chs-position-paper-on-noise-pollution/download.html

Chasin M. (1996) Musicians and the Prevention of Hearing Loss. San Diego, London: Singular Publishing Group. 184p.

Chasin M. (2006) Hear The Music Hearing Loss Prevention for Musicians. retrieved 22nd November, 2009 from www.musiciansclinics.com, Canada. 98 p.

Chasin M, Chong J. (1992) A Clinically Efficient Hearing Protection Program for Musicians. *Med Probl Perform Ar*, 7(1): 40-3.

Chasin M., Chong J. (1995) Four environmental techniques to reduce the effect of music exposure on hearing. *Med Probl Perform Ar*, 10 (2): 66-69.

Chlan L. (1998) Effectiveness of a music therapy intervention on relaxation and anxiety for patients receiving ventilatory assistance, *Heart Lung* Vol 27(3)May/June: 169-176.

Chesky K. S., Dawson W. J., Manchester R.(2006) Health Promotion in Schools of Music: Initial Recommendations for Schools of Music. *Med Probl Perform Ar,* 21 (3): 142-144.

Chesky K., Henoch M. A. (2000) Instrument-specific Reports of Hearing Loss: Differences between Classical and Nonclassical Musicians. *Med Probl Perform Ar,* 15(1): 35-38.

Colvin I., Luxon L. (2007) Clinical diagnosis of noise-induced hearing loss, in Noise and its effects Ed: Luxon L, Prasher D, John Wiley & sons.784p.

Cunningham D., Curk A., Hoffman J., Pride J (2006) Despite high risk of hearing loss, many percussionists play unprotected. *Hear J,* 59 (6): 58-66.

Curk A.E., Cunningham D. R. (2006) A profile of percussionists' behaviors and attitudes toward hearing conservation. *Med Probl Perform Ar,* 21(2): 59-64.

Drake-Lee A. B. (1992) Beyond music: auditory temporary threshold shift in rock musicians after a heavy metal concert. *J R Soc Med,* (85),10: 617-619.

Early K. L., Horstman S. W. (1996) Noise exposure to musicians during practice. *Appl Occup Environ Hyg*, 11, 1149-1153.

Emmerich E., Rudel L., Richter F. (2008) Is the audiologic status of professional musicians a reflection of the noise exposure in classical orchestral music? *Eur Arch Otorhinolaryngol*, Jul; 265(7):753-8.

EN 458 (1993) Hearing protectors – Recommendations for selection, use, care and maintenance – Guidance document. Brussels:CEN. 35p.

European Agency for Safety and Health (2005) Reducing the risks from occupational noise. Luxembourg: Office for Official Publications of the European Communities. 88p. Also available from: www.osha.eu.

Fearn R. W. (1993) Hearing loss in musicians. *J Sound Vib,*163(2), 372-378.

Fearn R.W., Hanson D.R. (1989) Hearing levels of student and professional musicians. *J Sound Vib,* 133(1), 173-176.

Fetter D. (1993) Life in the Orchestra, *Md Med J,* Vol 42(3): 289-292.

Finnish Institute of Occupational Health (FIOH) (2006) Health Examinations in Occupational Health Care [in Finnish], Ed. Anna-liisa Karhula, 2nd Ed, Vammalan kirjapaino Oy, Vammala Finland. 524p.

Finnish Institute of Occupational Health (FIOH) (2007) Occupational Safety Act, guide to application [in Finnish], Ed. Rauni Pietiläinen, 6th Ed, Tammer-Paino Oy, Tampere Finland. 149p.

Fleischer G., Hoffmann E., Lang R., Muller R. (1999). Documentation of the effects of child cap pistols. *HNO* 47(6):535-540.

Flottorp G. (1973) Music—a noise hazard? *Acta Otolaryngol,* Apr;75(4):345-7

Fluur E. (1967) Pop music as hearing injury [in Swedish]. *Svenska Läkartidn,* 64: 794–796.

Foreshaw S., Cruchley, J. (1981) Hearing protector problems in military operations, in Personal hearing protection in industry, P. Alberti, ed. New York: Raven Press. 605p.

Franks J. R., Davis R. R., Kreig E. F. (1989) Analysis of hearing conservation program data base: factors other than work place noise. *Ear Hear,* 10:273-280.

Gade A. (1981) Musicians' Ideas About Room Acoustical Qualities. Report no. 31, The Acoustics laboratory, Technical University of Denmark, Lyngby.

Gade A. (2007) Acoustic challenges in large opera houses. In proceedings, International Symposium on Room Acoustics, Seville, 10-12 September 2007.

Guzzetta C.E. (1989) Effects of relaxation and music therapy on patients in a coronary care unit with presumptive acute myocardial infarction. *Heart Lung*. Nov;18(6):609-16

Hagberg M., Thiringer G., Brändström L. (2005) Incidence of tinnitus, impaired hearing and musculoskeletal disorders among students enrolled in academic music education – a retrospective cohort study. *Int Arch Occup Environ Health*, 78, 575-583.

Hall J.W.I., Santucci M. (1995) Protecting the professional ear: conservation strategies and devices. *Hear J,* 48, 37-45.

Hallmo P., Sundby A., Mair I.W. (1994) Extended high frequency audiometry. Air and bone-conduction, age and gender variation. *Scand Audiol* 23(3):165-170.

Hamdan A-L., Abouchacra K.S., Al Hazzouri A. Z., Zayton G. (2008) Transient-Evoked Otoacoustic Emissions in a Group of Professional Singers Who Have Normal Pure-Tone Hearing Thresholds, *Ear Hear*; 29: 360-377.

Harding R. and Owens D. (2003) Sound pressure levels (dB) experienced by conductors in collegiate music rehearsal settings. In proceedings, Hawaii International Conference on Arts and Humanities, Hawaii.

Harman S. E. (1993) Odyssey: The history of performing arts medicine. *Md Med J,* Vol 42(3): 251-253.

Harper B. S. (2002) Workplace and health: A survey of classical orchestral musicians in the United Kingdom and Germany. *Med Probl Perform Ar,* 17(2): 83-92.

Hart C.W., Geltman C.L., Schupbach J., Santucci M. (1987) The musician and occupational sound hazards. *Med Probl Perform Ar*, 2(1):22-25.

Health Safety Executive (2007) Sound Advice - noise at work in music and entertainment. Retrieved 2nd November, 2009 from http://www.soundadvice.info/

Hearwig® (2008) Hearwig®. Retrieved 28 September, 2008 from http://www.hearwig.com/index2.html

Hellström P.A., Axelsson A., Costa O. (1998) Temporary threshold shift induced by music. Scand Audiol Suppl 48: 87-94.

Henoch M. A., Chesky K. (1999) Hearing Loss and Aging: Implications for the Professional Musician. *Med Probl Perform Ar*, 14(2):76.

Henoch M. A., Chesky K. (2000) Sound exposure levels experienced by a college jazz band ensemble - Comparison with OSHA risk criteria. *Med Probl Perform Ar*, 15(1): 17-22.

Henry J.A., Dennis K.C., Schechter M.A. (2005) General review of tinnitus: prevalence, mechanisms, effects, and management. *J Speech Lang Hear Res*, Oct;48(5):1204-35.

Hétu R., Getty L., Hung TQ. (1995) Impact of occupational hearing loss on the lives of the workers in occupational medicine. *State of the art reviews Philadelphia*, Hanlay & Belfus Inc,vol 10:3.

Hinchcliffe R. (1997). Medical examiner variability, *J Laryngol Otol* 111;1:8-14.

Hoffman J.S., Cunningham D.R., Lorenz D.J. (2006) Auditory thresholds and factors contributing to hearing loss in a large sample of percussionists. *Med Probl Perform Ar*, 21(2): 47-58.

Häkkinen M-L. (1997) Tinnitus ja orkesterisoitinten ammattiopiskelijat [Tinnitus and students of orchestral instruments, in Finnish],Thesis, Sibelius Academy, Finland.

IEC 60645-1 (2001). ELECTROACOUSTICS - AUDIOLOGICAL EQUIPMENT - Part 1: Pure-tone audiometers, International Electrotechnical Commission, Geneva. 40p.

ISO 140-4 (1998) Acoustics – Measurement of sound insulation in buildings and of building elements- Part 4: Field measurements of airborne sound insulation between rooms. Geneva, International Organisation for Standardisation. 24p.

ISO - 1999 (1990) Acoustics - Determination of occupational noise exposure and estimation of noise-induced hearing impairment. Geneva, International Organisation for Standardisation. 17p.

ISO R 389. (1964). Standard reference zero for the calibration of pure tone audiometers, International Organization for Standardization, Geneva.

James A. (2006) Research into sound levels on concert hall platforms and the effect of an absorbent acoustic screen for orchestra players. In proceedings of the Institute of Acoustics, Vol 28(2): 330-337

Jansson E., Karlsson K. (1983) Sound levels recorded within the symphony orchestra and risk criteria for hearing loss, *Scand Audiol*, 12(3):215-21.

Johnson D.W., Sherman R.E., Aldridge J., Lorraine A. (1985) Effects of instrument type and orchestral position on hearing sensitivity for 0.25 to 20 kHz in the orchestral musician. *Scand Audiol* 14:215-221.

Johnson D.W., Sherman R.E., Aldridge J., Lorraine A. (1986) Extended high frequency hearing sensitivity: A normative threshold study in musicians. *Ann Otol Rhinol Laryngol* 95: 196-201.

Karlsson K., Lundquist P.G., Olaussen T. (1983) The hearing of symphony orchestra musicians. *Scand Audiol* 12:257-264.

Kemp W. (2000) Music Education Suites. National Clearinghouse for Educational Facilities.

Killion M., DeVilviss E., Stewart J. (1988) An Ear plug with uniform 15-dB attenuation. *Hear J*, May, Vol 41(5):14-17.

Kivimäki M., Jokinen M. (1994) Job perception and well-being among symphony orchestra musicians: a comparison with other occupational groups. *Med Probl Perform Ar*, 9(3): 73-76.

Knight R. D., Baguley D. M. (2007) Physical characteristics of sound, in Noise and its effects Ed: Luxon L, Prasher D, John Wiley & sons.784p.

Kuronen P., Toppila E., Starck J., Pääkkönen R., Sorri M. J. (2004) Modelling the risk of noise-induced hearing loss among military pilots. *Int J Audiol*, 43(2):79-84.

Kylliäinen M., Hongisto V., Helimäki H. (2007) Acoustical design of buildings: schools, auditoriums, spaces for sports and libraries [in Finnish]. Helsinki, RIL Finnish Association of Civil Engineers, RIL 243-2-2007.79p.

Kähäri K., Axelsson A., Hellström P. A., Zachau G. (2001a) Hearing assessment of classical orchestral musicians. *Scand Audiol*, 30, 13-23.

Kähäri K., Axelsson A., Hellström P. A., Zachau G. (2001b) Hearing development in classical orchestral musicians. A follow-up study. *Scand Audiol*, 30, 141-149.

Kähäri K. (2002) The influence of music on hearing. A study in classical and rock/jazz musicians. PhD thesis. Department of Otolaryngology, Faculty of Medicine, University of Gothenborg, Sweden.

Kähäri K., Eklöf M., Sandsjö L., Zachau G., Möller C. (2003) Associations between hearing and psychosocial working conditions in rock/jazz musicians. *Med Probl Perform Ar,* 18 (3): 98-105.

Laitinen H. (2005) Factors Affecting the Use of Hearing Protectors among Classical Music Players. *Noise Health*, Jan-Mar;7(26):21-9.

Laitinen H., Toppila E., Olkinuora P. (2003) A questionnaire about stress and hearing impairment among Finnish musicians. In proceedings, Inter-Noise 2003, Seul, Korea, p. 132.

Laitinen H. and Poulsen T. (2006) Hearing protection and hearing symptoms in Danish symphony orchestras. In proceedings, Euronoise 2006, Tampere, Finland, 6 pages.

Landau Goodman K. (2001) Attitudes and use of musician's earplugs. PhD thesis. Department of Communication Disorders, Central Michigan University, Mount Pleasant, Michigan, USA.

Lane R.N., Mikeska E.E. (1955) Study of Acoustical Requirements for Teaching Studios and Practise Rooms in Music School Buildings. *J Acoust Soc Am* Vol 27(6): 1087-1091.

Lapsley Miller J.A., Marshall L., Heller L.M. (2004) A longitudinal study of changes in evoked otoacoustic emissions and pure-tone thresholds as measured in a hearing conservation program. *Int J Audiol* 43:307-322.

Lebo C.P., Oliphant K.P.(1968) Music as a source of acoustic trauma. *Laryngoscope*, 78 (7):1211-1218.

Lee J., Behar A., Kunov H., Wong W. (2005) Musicians' noise exposure in orchestra pit. *Applied Acoustics,* 66, 919-931.

Lindblad S. (1986) Acoustics for choir and orchestra./Ternström S. (Ed.) Papers Given at a Seminar by the Music Acoustics Commitee of the Royal Swedish Academy of Music. Stockholm, 1986. 76p.

Lindgren F., Axelsson A. (1983) Temporary Thresholf Shift after Exposure to Noise and Music of Equal Energy. *Ear Hear* Vol. 4 (4): 197-201.

Lockwood A. H. (1989) Medical problems of musicians. *N Engl_J Med*, Jan 26; 320(4): 221-7.

Lockwood A. H., Salvi R. J., Burkhard R. F. (2001) Tinnitus and the performer. *Med Probl Perform Ar,* 16(4): 133-135.

Lokki T, Salmensaari O. (2007) Measurement report: Espoon Musiikkiopiston opetusluokat [in Finnish]. Helsinki (Finland): Akukon Oy. Report No: 71119-1. 41p.

Mace, S. T. (2006) A descriptive analysis of university music performance teachers' sound-level exposures during a typical day of teaching, performing, and rehearsing. In proceedings, 9th International Conference on Music Perception and cognition, Bologna, August 22-26 2006.

Magill-Levreault L. (1993) Music therapy in pain and symptom management. *J Palliat Care*, Winter;9(4):42-8.

McBride D., Gill F, Proops D., Harrington M., Gardiner K., Attwell C (1992) Noise and the classical musician, *BMJ*, Dec 19-26;305(6868):1561-3

McCammon C., Sorensen B. (1996) NIOSH Health Hazard Evaluation Report. Retrieved 12th October, 2009 from: http://www.osha.gov/SLTC/autobody/docs/cdc003.html#Noise

The McGraw-Hill Companies (2002) Definition of hearing disorder. in McGraw-Hill Concise Dictionary of Modern Medicine, retrieved 10th October, 2009 from http://medical-dictionary.thefreedictionary.com/hearing+disorder

MedicineNet (2009) Sympton definition. Retrieved 10th October from http://www.medterms.com/script/main/art.asp?articlekey=5610.

Mehta, M., Johnson J., Rocafort J. (1999) Architectural acoustics: principles and design. Prentice-Hall, Inc.

Melnick W. (1984). Evaluation of industrial hearing conservation programs: a review and analysis. *Am Ind Hyg Assoc J*, 45: 459-467.

Mendes M. H., Morata T. C., Marques J. M. (2007) Acceptance of hearing protection aids in members of an instrumental and voice music band. *Braz J Otorhinolaryngol*, 73(6) November/December: 785-92.

Metternich F.U., Brusis T. (1999). Acute hearing loss and tinnitus caused by amplified recreational music. *Laryngorhinootologie* 78(11):614-619.

Mikl K. (1995) Orchestral music: an assessment of risk. *Acoust Aust*, 23, 51.

Miller V. L., Stewart M., Lehman M. (2007) Noise Exposure Levels for Student Musicians. *Med Probl Perform Ar*, 22(4): 160-164.

Ministry of Social Affairs and Health, Finland (2006) Code of Conduct for entertainment sector [in Finnish]. Retrieved October 10th, 2009 from http://www.tyosuojelutietopankki.fi/good_practice/ohjeet/meluntorjuntaohje.pdf

Myers, E.N., Bernstein J.M. (1965) Salicylate ototoxicity; a clinical and experimental study. *Arch Otolaryngol*, Nov 82(5): 483-493.

Nassar G. (2001) The human temporary threshold shift after exposure to 60 minutes' noise in an aerobics class. Br J Audiol, 2001 Feb;35(1):99-101.

Nicolas-Puel C., Akbaraly T., Lloyd R., Berr C., Uziel A., Rebillard G., Puel J. L. (2006) Characteristics of tinnitus in a populations of 555 patients: specifities of tinnitus induced noise trauma. *Int Tinnitus J*, 12(1):64-70.

Niemi T. (2000): The exposure of hearing of church music students [in Finnish].Thesis, Sibelius Academy, Finland.

Nodar R. H. (1993) Hearing Loss in a Professional Organist: A Case Study. *Med Probl Perform Ar*, 8(1): 23-24.

Obeling L., Poulsen T. (1999) Hearing ability in Danish symphony orchestra musicians. *Noise Health*, 2, 43-49.

Oberdanner H., Reintges F. and Welzl-Müller K. (2002) Personal hearing protectors for musicians [in German]. In proceedings, Fortschritte der Akustik, DAGA 02, Oldenburg, 56-57.

Ostri B., Eller N., Dahlin E., Skylv G. (1989) Hearing impairment in orchestral musicians. *Scand Audiol*, 18(4):243-9.

Østergaard Hansen M. (1997) Occlusion effects, Part I. Hearing aid users' experiences of the occlusion effect compared to the real ear sound level. Part 1 of PhD thesis. Department of Acoustic Technology, Technical University of Denmark, Lyngby, Denmark.

Owens D. T. (2004) Sound Pressure Levels Experienced by the High School Band Director. *Med Probl Perform Ar*, 19 (3): 109-115.

Pang-Ching G. K. (1982) Hearing levels of secondary school band directors. *J Aud Res*, 22: 284-288.

Pekkarinen J. (1989) Exposure to impulse noise, hearing protection and combined risk factors in the development of sensory neural hearing loss. PhD thesis. Publ Univ Kuopio 1989-4-Kuopio: University of Kuopio, Finland.

Pekkarinen J., Iki M., Starck J., Pyykkö I. (1993) Hearing loss risk from exposure to shooting impulses in workers exposed to occupational noise. *Br J Audiol*, 27: 175-182.

Perälä K. (1998) Attitudes towards music as noise in Finnish National Opera [in Finnish]. Thesis, Sibelius Academy, Finland.

Pettersson, B. (2007) Target groups in prevention of health effects from listening to music, in Noise and its effects. Ed: Luxon L, Prasher D, John Wiley & sons.784p.

Phillips S. L., Shoemaker J., Mace S. T., Hodges D. A. (2008) Environmental Factors in Susceptibility to Noise-induced Hearing Loss in Student Musicians. *Med Probl Perform Ar*, 23 (1): 20-28.

Prasher D. (2007) Factors determining an individual’s susceptibility to noise damage, in Noise and its effects Ed: Luxon L, Prasher D, John Wiley & sons.784p.

Pride J.A., Cunningham D.R. (2005). Early evidence of Cochlear Damage in a Large sample of Percussionists. *Med Probl Perform Ar*, 20 (3): 135-139.

Pyykkö I. V., Toppila E. M., Starck J. P., Juhola M., Auramo Y. (2000) Database for a hearing conservation program. *Scand Audiol*, 29(1):52-58.

Pyykkö I., Toppila E., Zou J., Kentala E. (2007) Individual susceptibility to noise-induced hearing loss. *Audiol Med* 5(1):41-53.

Reuter K., Hammershøi D. (2007) Distortion product otoacoustic emission of symphony orchestra musicians before and after rehearsal. *J Acoust Soc Am*, 121: 327-336.

Rintelmann W. F., Borus J. F. (1968) Noise-induced hearing loss and rock and roll music. *Arch Otolaryngol*, Oct;88(4):377–385.

Royster J. D., Royster L. H. (1986) Using audiometric data base analysis. *J Occup Med* 28:1055-1068.

Royster J. D., Royster L. H., Killion M. C. (1991) Sound exposures and hearing thresholds of symphony orchestra musicians. *J Acoust Soc Am*, Jun;89(6):2793-803.

Royster L. H., Royster J. D., Berger E.H. (1982) Guidelines for developing an effective hearing conservation program. *Sound Vib*, 16:22-25.

Sabesky I.J., Korczynski R.E. (1995) Noise exposure of symphony orchestra musicians. *Appl Occup Environ Hyg*, 10:2: 131-135.

Sadhra S., Jackson C. A., Ryder T., Brown M.J. (2002) Noise Exposure and Hearing Loss among Student Employees Working in University Entertainment Venues. *Ann Occup Hyg*, Vol, 46(5):455-463.

Santucci M. (1990) Musicians Can Protect Their Hearing. *Med Probl Perform Ar*, 5 (4): 136-8.

Sataloff R. T. (1991) Hearing loss in musicians. Am J Otol, Mar;12(2):122-7.

Sataloff R., Sataloff J. (1993a) Tinnitus in Occupational Hearing Loss, 2nd edition, Marcel Dekker, Inc. Edited by Sataloff R, Sataloff J. New York, USA. 833p.

Sataloff R., Sataloff J. (1993b) Sensorineural hearing loss: Diagnostic criteria, in Occupational hearing loss 2nd edition, Marcel Dekker Inc. Edited by Sataloff R, Sataloff J. New York, USA. 833p.

Sataloff R., Sataloff J. (1993c) Hearing conservation in industry, in Occupational hearing loss 2nd edition, Marcel Dekker Inc. Edited by Sataloff R, Sataloff J. New York, USA. 833p.

Sataloff R., Sataloff J. (1993d) The audiogram, in Occupational Hearing loss 2nd edition, Marcel Dekker Inc. Edited by Sataloff R, Sataloff J. New York, USA. 833p.

Sataloff R. T. (1997) Hearing Loss in Singers and Other Musicians. *Med Probl Perform Ar,* 12(2): 51-56.

Scheibe F., Haupt H., Ludwig C. (1992) Intensity-dependent changes in oxygenation of cochlear perilymph during acoustic exposure. *Hear Res*, 63(1-2):19-25.

Schmidt J. M., Verschuure J., Brocaar M. P. (1994) Hearing loss in students at a conservatory. *Audiology*, 33: 185-194.

Schneider J. (1976) Music, noise and hearing damage, *S Afr Med J*, Nov 6;50(47):1912-4.

SFS 5907 (2004) Acoustic classification of spaces in buildings. Helsinki: Finnish Standards Association. 36p.

Smith D. (1992) Medical Problems of Orchestral Musicians According to Age and Stage of Career. *Med Probl Perform Ar*, 7(4): 132-134.

Starck J., Pyykkö I., Toppila E., Pekkarinen J. (1996) Do the models assess noise-induced hearing loss correctly? *ACES Bull*, 7 (3-4):21-26.

Starck J., Toppila, E., Pyykkö I. (2007) Hearing protectors, in Noise and its effects Ed: Luxon L, Prasher D, John Wiley & sons.784p.

Sternbach D. (1993) Addressing stress-related illness in professional musicians. *Md Med J*, Vol 42(3): 283-288.

Steurer M., Simak S., Denk D. M., Kautzky M. (1998) Does choir singing cause noise-induced hearing loss? *Audiology*, 37: 38-51.

Stewart A. P. (1994) The comprehensive hearing conservation program, in Hearing Conservation in Industry, Schools, and the Military. Ed: Lipscomb D. M., Singular Publishing Group, Inc, San Diego, USA. 344p.

Strasser H., Irle H., Leglre R. (2003) Temporary hearing threshold shifts and restitution after energy-equivalent exposures to industrial noise and classical music. *Noise Health*, (5) 20, July-September, 75-84.

Swanson S. J., Dengerink H. A., Kondrick P., Miller C. L. (1987) The Influence of Subjective Factors on Temporary Threshold Shifts after Exposure to Music and Noise of Equal Energy. *Ear Hear*, October 8(5):288-291.

Teie P. U. (1998) Noise-induced hearing loss and symphony orchestra musicians: risk factors, effects, and management, *Md Med J*, Jan;47(1):13-8.

Teuber W., Voelker E-J. (1993) Acoustical Requirements and Results for Music Rehearsal Rooms, Preprint 3549, AES the 94th Convention 1993 March 16-19, Berlin.

Toppila E., Pyykkö I., Starck J. (2001) Age and noise-induced hearing loss. *Scand Audiol*, 30:236-244.

Toppila E., Pyykkö I., Starck J., Kaksonen R., Ishizaki H.(2000) Individual Risk Factors In The Development Of Noise-Induced Hearing Loss. *Noise Health*, 8:59-70.

Tyler R., Erlandsson S. (2003) Management of the tinnitus patient, in Textbook of audiological medicine – Clinical aspects of hearing and balance. Ed: Luxon L, Taylor&Francis, London. 956p.

Ulehlova L. (1983) Stria vascularis in acoustic trauma. *Arch Otorhinolaryngol*, 237(2):133-138.

Wenger Corporation (2001) Planning guide for secondary school music facilities. Owatonna: Wenger Corporation, USA. 52 p.

Westmore G. A., Eversden I. D. (1981) Noise-induced hearing loss and orchestral musicians, *Arch Otolaryngol*, Dec;107(12):761-4.

WHO (1980) International classification of impairments, disabilities and handicaps. Geneva, World Health Organization.

Wilkes J. A. (1998) Other Places for Speech and Music Activities, in Architectural acoustics Principles and Practice, John Wiley & Sons, Inc. USA. 352p.

Williamon A., Thompson S. (2006) Awareness and incidence of health problems among conservatoire students. *Psychology of Music*, 34(4):411-430.

Woolford D. H., Carterette E. C., Morgan D. E. (1988) Hearing Impairment among Orchestral Musicians. *Music Perception*, Vol. 5, No. 3: 261-284.

Wright Reid A. (2001) A Sound Ear, Exploring the issues of noise damage in orchestras- Report, Association of British Orchestras, London, UK.

Wright Reid A., Warne Holland M. (2008) A Sound Ear II, The control of noise at work regulations 2005 and their impact on orchestras- Report, Association of British Orchestras, London, UK. 51p.

Zeigler M. C., Taylor J. A. (2001) The Effects of a Tinnitus Awareness Survey on College Music Majors' Hearing Conservation Behaviors. *Med Probl Perform Ar*, 16(4): 136-43.