Man & Sound Environment 2010.

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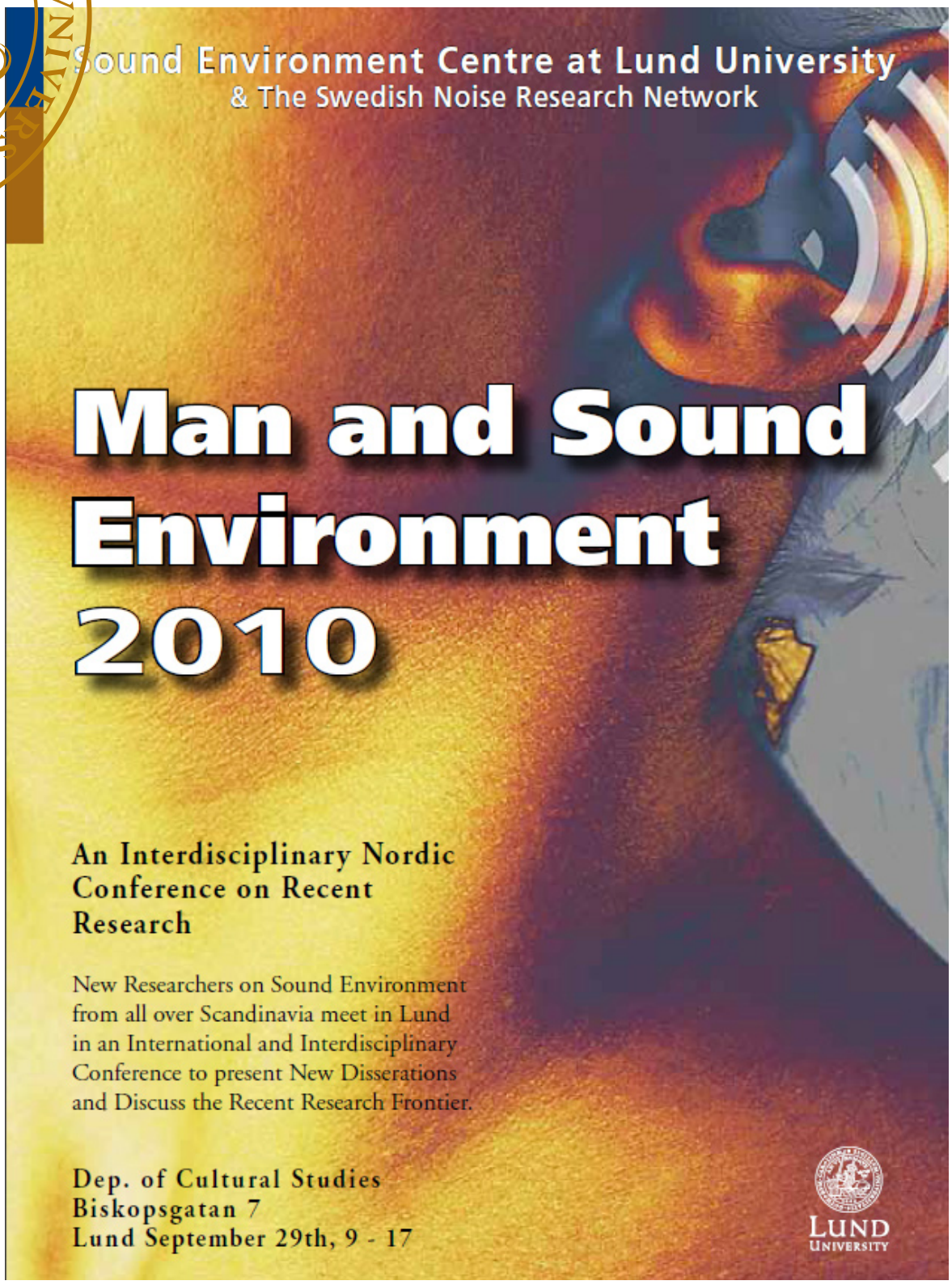
Proceedings



Editors: Ulf Landström and Frans Mossberg

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UNIVERSITY OF GÄVLE

MAN AND NOISE

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Contents

Symposium “Man and Sound Environment 2010”

The prevalence of noise problems

Despite measures carried out, noise is still considered as one of the most widespread social and work place environmental problems. Its consequences and the need of measures are frequently described in the debate, statements, plans of action and directives.

The consequences of exposure are observed in terms of hearing damages, tinnitus, increased sound sensitivity, changes in hearing sensations, masking, annoyance, reduced working capacity, increased effort, fatigue, stress and related effects on physiology and health. The indirect consequences of a noise exposure are often difficult to describe and explain. Besides the individual un-health, the consequences of a noise exposure often also will be connected to loss in production and cost for the society related to prevention, insurances and rehabilitation. At the same time, sound is also a fundamental agent for information and orientation and can provide us with pleasure and entertainment. How it affects man however yet has to be fully understood. The need of research and knowledge to explain and measure the noise problems of today are big.

Scientific issues

The reports of unhealth related to noise exposure are still dominated by environments with high noise levels, mostly industrial working places. The society and the working places however have been undertaken both rapid and dramatic changes during the last centuries. New noise exposures gradually can be pointed out due to the technical development, new machines, tools, processes and environments. The development of new noise exposures in some case also can be linked to factors as social patterns and attitudes, changes in organization at working places and development of new industrial and business areas. In many industrial areas the noise exposures have been measured with the result of lower noise levels and hazards. In some cases however, not at least outside our working environments, eg. music and entertainment environments, the noise exposures have increased. In many working places, eg. offices and school environments, the number of people exposed to annoying and stressful noise has increased.

In many cases the effects of a noise exposure is complicated due to a number of combined physical and psychological exposures. In order to explain the hazards of a noise exposure, there is often a strong need of multidisciplinary approaches to the problems. The need of co-operation between medical, technical and behavioral sciences is big. The need of interdisciplinary approach to the noise problems, in the research and plans of action, is increasing.

The perspectives described above are reflected by a number of new research projects, ongoing and recently carried out. The findings are documented in scientific articles and a number of new theses. The support to distribution and use of the new noise research and knowledge is important.

Aims of the symposium

A fundamental aim of the noise symposium is to announce theses newly published at the Nordic institutions and to support the introduction of booth the work, findings and the new researchers. An overall aim is also to support the exchange of knowledge, connections and future co-operation between the new researchers. Speakers invited to the symposium thus have been selected among researchers with theses defended during the last two years.

Support and organization

The symposium is supported by grants from the Swedish Council for Working Life and Social Research and AFA Insurance.

Besides the proceedings, including the abstracts of the speakers, the Power Point pictures of the lectures as well as the proceedings will be documented on the web sites www.noise-network.se and www.ljudcentrum.lu.se.

The symposium is organized and arranged in co-operation between the Swedish Noise Research Net Work “Man and Noise” at the University of Gävle and The Sound Environment Centre at the University of Lund.

Lund 2010-09-01

Ulf Landström and Frans Mossberg

Coordinators of the symposium

Program

08.30-09.00	Registration	
09.00-09.10	Opening of the symposium	Frans Mossberg The Sound Environment Centre at Lund University
09.10-09.40	Effects of transportation noise on sleep - Assessment of nighttime noise exposure from railway and road traffic and effects on self-reported sleep and sleep assessed by polysomnography	Gunn Marit Aasvang Nasjonalt Folkehelseinstitutt, Norway
09.40-10.10	Traffic noise and cardiovascular disease	Jenny Selander Karolinska Institutet Sweden
10.10-10.30	Pause	
10.30-11.00	Non occupational noise - Sources, exposure and effects on hearing	Jaana Jokitulppo University of Kuopio, Finland
11.00-11.30	Annoyance from low frequency noise	Christian Sejer Pedersen Aalborg University Denmark
11.30-12.00	Urban noise and strategies of silencing	Jacob Kreutzfeldt University of Kopenhagen Denmark
12.00-13.00	Lunch	
13.00-13.30	Hearing conservation among classical musicians – Needs, means and attitudes	Heli Koskinen Technical University of Helsinki, Finland
13.30-14.00	Room acoustics and cognitive load when listening to speech	Robert Ljung University of Gävle, Sweden
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14.20-14.50	Hearing in young men - The influence of military noise and epidemiological aspects	Per Muhr Karolinska Institutet och Försvarsmakten Sweden
14.50-15.20	Sensing the environment – Development of monitoring aids for persons with profound deafness or deafblindness	Parivash Ranjbar University of Örebro, Sweden
15.20-15.50	Coffee-break	
15.50-16.20	Communication Acoustics in Classroom Environments - On the Use of Assistive Listening devices	Johan Odelius University of Luleå, Sweden
16.20-16.50	Assessment of speech intelligibility in background noise and reverberation	Jens Bo Nielsen Technical University of Denmark, Denmark
16.50-17.00	End of the symposium	Frans Mossberg The Sound Environment Centre at Lund University

Effects of transportation noise on sleep - Assessment of night time noise exposure from railway and road traffic and effects on self-reported sleep and sleep assessed by polysomnography.

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The thesis can be read at: http://www.med.uio.no/disputaser/a-c/aasvang-gunn-marit.xml

Abstract

In this thesis the effects of residential railway noise, both airborne and structurally radiated noise, on sleep were investigated. A main objective was to examine different noise exposure descriptors, such as the equivalent and the maximum noise level and their associations with effects on sleep. Furthermore, the possible differential effects on sleep from railway and road traffic noise were examined.

Data on self-reported sleep disturbances was collected from two surveys, in 2000 and 2003, from a total of 4500 residents, mainly in and around Oslo, Norway. Noise exposures from rail and road traffic were calculated both outside and inside of the bedroom façade. Forty subjects exposed to either prevailing railway or road traffic noise were further examined with polysomnography during two nights in their own bedroom. Noise measurements were conducted concurrently in the bedroom and outside the bedroom façade.

A main finding was that both the equivalent and the maximum noise levels from rail traffic were significantly associated with the proportion of subjects reporting sleep disturbances due to traffic noise. The maximum noise level was significantly related to noise annoyance and self-reported sleep disturbance due to structurally radiated noise from railways. Furthermore, road traffic noise was found to give a higher proportion of self-reported sleep disturbances than railway noise at the same nighttime equivalent noise level. However, this difference was reduced when the bedroom was oriented away from the most exposed façade.

When effects on physiological sleep parameters were examined, the results suggest that sleep is more severely affected by railway noise. The time spent in REM sleep decreased

and wake time increased with increasing maximum level of railway noise. The results suggest that the maximum noise level may be of special importance at lower equivalent noise levels, since even a few noise events with maximum levels above 50 dB may negatively influence sleep.

Traffic noise and cardiovascular disease

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Abstract

Traffic noise is an increasing problem in urban areas worldwide, but health effects in relation to traffic noise exposure are not well understood. Several studies show that noise may give rise to acute stress reactions, possibly leading to cardiovascular effects, but the evidence is limited on cardiovascular risks associated with traffic noise exposure. Cardiovascular effects have been indicated for other environmental stressors such as occupational noise exposure and job strain. However, interactions between these factors in relation to cardiovascular disease have not been investigated. Furthermore, studies regarding interactions between air pollution and noise from road traffic in relation to cardiovascular disease are lacking. The overall aim of this thesis was to investigate the association between traffic noise exposure and cardiovascular disease, including interactions with other factors.

The thesis is based on one case-control study and one cross-sectional study. The population based case-control study on risk factors in relation to first time myocardial infarction was conducted 1992-1994 in Stockholm County. The participants answered a questionnaire and underwent a physical examination. Exposure assessments were made of residential road traffic noise exposure, occupational noise exposure and air pollution between 1970 and 1992-94. Job strain was defined based on questionnaire data regarding the last employment. An increased risk of myocardial infarction was suggested in participants exposed to road traffic noise at the residence. The risk appeared particularly high among participants exposed to a combination of road traffic noise, occupational noise and job strain (OR 2.27, 95% CI 1.41–3.64). The association between road traffic noise and myocardial infarction did not seem to be affected by air pollution.

The cross-sectional study was carried out in six European countries. All participants were interviewed at home and blood pressure measurements were made by a field nurse. An association was found between night-time aircraft noise exposure and hypertension. In a subgroup of study participants cortisol was assessed through saliva samples as an indicator of stress. We observed an elevation in morning saliva cortisol level among women exposed to high levels of aircraft noise at the residence of 34%, corresponding to 6.07 nmol/L (95% CI 2.32-9.81). No clear association was seen in men.

It may be concluded that long-term traffic noise exposure at the residence seems to give rise to cardiovascular effects. Our results support the hypothesis that exposure to a combination of noise and job strain increases the risk of myocardial infarction substantially. In addition, our results suggest that exposure to aircraft noise increases the risk of hypertension, as well as morning saliva cortisol levels in women, which may be of relevance for noise-related cardiovascular effects.

Non occupational noise - Sources, exposure and effects on hearing.

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Abstract

The objective of the study was to evaluate the total risk for hearing loss related to leisure time noise activities during the lifetime in Finland. The total combined lifetime leisure time noise exposure of all the activities was calculated and the hearing thresholds of conscripts at the beginning and at the end of the military service was measured. Furthermore, the effect of military service to hearing was evaluated. Also the aim of the study was to find those leisure time activities, which had most effect on total leisure time noise exposure. In addition, the effects of personal leisure time noise exposure on hearing thresholds and self-reported auditory symptoms related to noise exposure was determined.

This study was performed among teenagers, conscripts and adults with the use of a leisure time noise exposure questionnaire. The weekly noise exposures of a single activity and all activities combined was calculated and compared to occupational noise legislation (EU 10/2003), because there is no separate evaluation model for leisure time noise.

The most leisure time noise exposures occurred during high volume music related activities, such as discotheques and concerts. In addition, shooting, motor sports, home tools and playing in a band had an effect on the total weekly noise exposure among all the age groups. Total weekly noise exposure exceeded 85 dB in one third of the teenagers and the conscripts and in one fifth of the adults. One out of five conscripts had already reached the noise exposure similar to the noise exposure of 85 dB for 40 years by the end of their conscription. Most of this noise was gathered from military noise exposure during the conscription. Teenagers and young adults spend similar amount of hours as 40 hour working week at noisy activities during their leisure time.

Approximately one in five of the conscripts had a hearing impairment (HI) of over 20 dB in either ear in the frequency range of 0.5-6 kHz during the arrival examination. Most of the hearing losses were mild types (class 2). By the end of the military service the prevalence of hearing loss was increased into one in three of the conscripts. Tinnitus and temporary hearing impairment were common auditory symptoms in subjects of all investigated groups. These symptoms were most common in individuals with high personal weekly noise exposure.

The results seem to confirm the hypothesis that the most probable cause of HI in young men is related to the leisure time noise exposure. In addition, although the time of the military service is short, the exposure to very high noise levels during that time has further deleterious effects on the hearing of the young men. The high incidence of hearing symptoms and hearing loss with noise high exposure levels seems to confirm the assumption that leisure-time noise exposure is a significant factor of the development of NIHL.

The auditory symptoms such as tinnitus and temporary hearing loss should be regarded as warning signals of exposure to too high levels of noise. These symptoms should be routinely asked in the health examination of all age groups. The legislation to protect especially the young peoples' hearing from the effect of too high volume music should be proceeded. It is suggested that hearing conservation programs that consider the leisure time noise should be a part of a health education.

The method performed in this study is usable for evaluation of the total leisure time noise exposure of several people. In addition, possible risk groups of high leisure-time noise exposed subjects could be screened for further health examinations. Early screening of hearing loss is important for avoiding further development of hearing loss at any age.

Human hearing at low frequencies, with focus on noise complaints

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Abstract

The human hearing is generally not sensitive at low-frequencies and relatively high sound pressure levels are needed before the sound is audible. However, if the sound is audible then slight changes in the level gives relative large changes in the perception of the sound which is reflected in the compression of the equal-loudness-level contours at low-frequencies. Combined with individual differences in the hearing function with possible extraordinary low-frequency hearing this could explain cases where only one person in the household complain about a low-frequency sound which is not audible to the rest of the household. However, there are cases where no apparent sound source is found and noise measurements are not able to show any sound that could be causing annoying. This raises the fundamental question if it is a physical sound that causes the annoyance. To answer this question a selection of twenty-one cases of low-frequency noise complaints were investigated with sound recordings in the home and laboratory experiments in a new low-frequency test facility which allows for great control of the sound exposure with low background noise and low distortion. The facility uses digital signal processing in order to create a homogeneous sound field for the entire low-frequency region. The low-frequency hearing threshold and an equal-loudness contour were measured for each complainant. The sound recordings were played back to the complainant in blind tests in order to reveal if the physical sound in the home is audible to the complainant. In cases of audible sound recognition tests provided information whether the sound was similar to the annoying sound. The audible sounds were filtered into four different frequency ranges which were presented to the complainant in another series of blind tests and recognition tests in order to find the audible and annoying frequency components. Finally a matching experiment was used to approximate the frequency and level of the annoying sound.

No cases of extraordinary hearing were found among the complainants. The results shows that in seven cases the complainant is annoyed by a physical sound in the home, while in six cases low-frequency tinnitus is responsible. In the remaining eight cases the complainants could hear the recorded sound but it is not clear whether it is physical sound or low-frequency tinnitus that is responsible for the annoyance. In none of the cases is infrasound responsible for the annoyance. It is not audible even at 10 dB above the recorded level. Comparisons between results obtained by the Danish, Swedish and a three-dimensional corner measurement procedure show that especially the Danish method gives much variation and both the Swedish and the Danish method gives lower values than the three-dimensional corner method. For the seven cases clear cases with annoyance from a physical sound only three of the cases had levels exceeding the Danish limits for low-frequency noise even if the three-dimensional corner method is used. This shows that further research is needed on finding acceptable limits for low-frequency noise.

Urban noise and strategies of silencing

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Abstract

This dissertation presents an investigation of the methodology of sound environment analysis with specific concern to its relevance in modern urban space. Inspired by a growing interest in urban acoustics it investigates how sounds contribution to the urban life world is articulated within existing complexes of theory, and it outlines perspectives for alternative descriptional categories.

A major step in the tradition of sound environment analysis is the work of composer and music educator R. Murray Schafer in relation to the World Soundscape Project, where

Schafer developed methods for registration, description, analysis, assessment and design of *soundscapes*. In the second chapter of the present dissertation a throughout reading of Schafers publications in relation with the World Soundscape Project is presented. The reading identifies cultural theoretical and normative aesthetic positions within Schafers work through which the soundscape analysis develops a distinct anti-urban perspective. In particular Schafers more or less reflected inspiration from contemporary American thinkers like Marshall McLuhan and John Cage is investigated.

In chapter three, as an alternative way into the auditory field of experience, the concept of territoriality is introduced. Konrad Lorenz' ethological concept of territoriality is investigated taking his *Das sogenannte Böse* as a point of departure, and a loosely founded hypothesis about territoriality's reliance on aggression is deconstructed using Lorenz' own concepts. Following is a presentation of Gilles Deleuze and Felix Guattari's reconstruction of etology along a similar path displacing the substantial end aggression reliant concept of territoriality into a field of practise, which has to do with the interchanging of–primarily sonic–marks.

Following Deleuze and Guattari's rich theory about territoriality and the ritornello, chapter four introduces another theoretical complex specifically related to the analysis of sound environments: Jean-François Augoyard's and the research centre CRESSON's work on *the sonic effect* as specific interpretations of contextual sound. By looking at Augoyard's former work, connections are established both to theories of everyday life and Deleuze and Guattari's work on territoriality. The concept of sonic effect is then interpreted as a way in which the environment is (re-)marked.

In a final analytical chapter the presented theory complexes are tested in the analysis of a specific suburban area in the outskirts of Osaka in Japan. A particular accentuation of sensual qualities of urban space in Japan is outlined through Roland Barthes, Robert Venturi, Botond Bognar and Toyo Ito. It may be that the sound here takes more prominence in shaping flexible and dynamic urban space, though it is hardly a culturally specific phenomenon. The case material is rather thought of as a relevant generator for the development and testing of the potential of sound environment analysis in an urban context.

Hearing conservation among classical musicians - Needs, means and attitudes

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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.

Room acoustics and cognitive load when listening to speech

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Abstract

The present thesis investigated the effects of background noise or a long reverberation time in learning situations. All studies used spoken texts that were presented above the speech intelligibility threshold, but were degraded enough to make listening more effortful. The basic hypothesis for the whole project was that listening to speech in a bad acoustic environment should increase the cognitive load for the listener, which should impair memory of the text. In Paper I the auditory stimuli were lists of words and sentences that were degraded by a background noise. Paper II was a replication of the experiment from paper I, but the independent variable was changed from the level of the background noise to reverberation time. Paper III included two experiments where the stimulus material was 10 minutes lectures. Paper IV included two studies. The first experiment investigated whether serial recall performance is affected when words are presented in long reverberation time (Exp 1a). In experiment 1b word lists were presented in long or short reverberation time or with a background noise. The stimuli were recorded in one classroom with extremely good and one with very bad acoustic design. In experiment 2 word lists with many or few phonological neighbours were presented with long or short reverberation time. In all studies some measure of working memory capacity was included. Taken together, the overall results could be summarized in two sentences: Hearing what is said is a necessary but not a sufficient criterion for people to remember what is said, which means that spoken information should be heard without special effort, otherwise proper learning is jeopardized. No consistent relation was found between working memory capacity and the learning effect in the unfavorable listening conditions.

Hearing in young men - the influence of military noise and epidemiological aspects

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Abstract

During compulsory military service, the hearing capacity of the conscripts is at risk, because of exposure to excessive continuous and impulse noise. In young adult life, a multitude of other risk factors also might result in auditory symptoms and hearing impairment. A Military Hearing Conservation Program is of the utmost importance to prevent auditory complications caused by the military noise exposure.

Aims: To assess the prevalence values of hearing impairment in young men at conscription in the period 1971-1995. To analyse relations between causative factors and hearing symptoms/hearing impairment before military service. To estimate the incidence and relative risk of hearing decline during military service (the efficacy of the Hearing Conservation Program)**.**

Methods: In Paper I we obtained cross-sectional data on prevalence values of hearing impairment at conscription, at age 18, from six complete age cohorts born in 1953-1977, in all 337 986 men. Of these, 89.3% were tested with screening audiometry. In Paper III, a group of 747 conscripts from three regiments performed mandatory screening audiometry at reporting to training in 1999 and at discharge in 2000. In Paper II and IV, a group of 839 men from three other military units performed mandatory screening audiometry, and filled in a questionnaire at reporting to training in 2002-2004. The same procedure was repeated at discharge. In Paper II, III, and IV the cross sectional data were evaluated as prevalence values and the longitudinal data as incidence values. The comparison groups with no military noise exposure made the first audiometric test at the Centre of Conscription and the second at the army unit at reporting for training.

Results: The prevalence values of hearing impairment decreased in the period 1971-1981 from 15.7% to 8.3% and increased in 1986-1995 from 9.8% to 16.3%. This pattern was caused by changes of mild high frequency elevations. The threshold elevations of 45 dB HL or more decreased over the entire study period. Most often only one ear was affected. High frequency hearing impairment was more common in the left ear. Before military service 6.8% of the conscripts reported one or more auditory symptoms often or always.

The most common noise exposure was rock concerts or discotheques. TTS after noise exposure was related to elevated prevalence values of hearing impairment and auditory symptoms. Playing loud music was related to an elevated risk for tinnitus but not for hearing impairment. Prevalence values of hearing impairment, tinnitus and sensitivity to noise were elevated at discharge compared to at reporting to service. At discharge from military service we observed a relative risk of hearing decline of 2.7 in 2000 and of 1.8 in 2003-05. In 2000 we observed an elevated risk of hearing decline during military service for those of the conscripts who had a mild hearing impairment already at reporting to training. This effect was not observed in the stricter screened group in 2003-2005.

Conclusions: High prevalence values of hearing impairment and auditory symptoms were observed before military service. These impairments were related to different causative factors. Elevated relative risk of hearing decline during military service was observed.

Sensing the environment – development of monitoring aids for persons with profound deafness or deafblindness

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Abstract

Earlier studies of persons with deafness (D) and/or deafblindness (DB) have primarily focused on the mobility and communication problems. The purpose of the present study was to develop technology for monitoring aids to improve the ability of persons with D and/or DB to detect, identify, and perceive direction of events that produce sounds in their surroundings.

The purpose was achieved stepwise in four studies. In Study I, the focus was on hearing aids for persons with residual low frequency hearing. In Study II-IV, the focus was on vibratory aids for persons with total D.

In Study I, six signal processing algorithms (calculation methods) based on two prin-

ciples, transposition and modulation, were developed and evaluated regarding *auditory* identification of environmental sounds. Twenty persons with normal hearing listened to 45 environmental sounds processed with the six different algorithms and identified them in three experiments. In Exp. 1, the sounds were unknown and the subjects had to identify them freely. In Exp. 2 and 3, the sounds were known and the subjects had to identify them by choosing one of 45 sounds. The transposing algorithms showed better results (median value in Exp. 3, 64%-69%) than the modulating algorithms (40%-52%) did, and they were good candidates for implementing in a hearing aid for persons with residual low frequency hearing.

In Study II, eight algorithms were developed based on three principles, transposition, modulation, and filtration – in addition to No Processing as reference, and evaluated for *vibratory* identification of environmental sounds. The transposing algorithms and the modulating algorithms were also adapted to the vibratory thresholds of the skin. Nineteen persons with profound D tested the algorithms using a stationary, wideband vibrator and identified them by choosing one of 10 randomly selected from the list of 45 sounds. One transposing algorithm and two modulating algorithms showed better ($p<0.05$) scores than did the No Processing method. Two transposing and three modulating algorithms showed better ($p<0.05$) scores than did the filtering algorithm. Adaptation to the vibratory thresholds of the skin did not improve the vibratory identification results.

In Study III, the two transposing algorithms and the three modulating algorithms with the best identification scores in Study II, plus their adapted alternative, were evaluated in a laboratory study. Five persons from Study II with profound D tested the algorithms using a portable narrowband vibrator and identified the sounds by choosing one of 45 sounds in three experiments (Exp. 1, 2, and 3). In Exp. 1, the sounds were pre-processed and directly fed to the vibrator. In Exp. 2 and 3, the sounds were presented in an acoustic test room, without or with background noise (SNR=+5 dB), and processed in real time. Five of the algorithms had acceptable results (27%-41%) in the three experiments and constitute candidates for a miniaturized vibratory aid (VA). The algorithms had the same rank order in both tests in the acoustic room (Exp. 2, and 3), and the noise did not worsen the identification results.

In Study IV, the portable vibrotactile monitoring aid (with stationary processor) for detection, identification and directional perception of environmental sounds was evaluated in a field study. The same five persons with profound D as in Study III tested the aid using a randomly chosen algorithm, drawn from the five with the best results in Study III, in a home and in a traffic environment. The persons identified 12 events at home and five events in a traffic environment when they were inexperienced (the events were unknown) and later when they were experienced (the events were known). The VA consistently improved the ability with regard to detection, identification and directional perception of environmental sounds for all five persons.

It is concluded that the selected algorithms improve the ability to detect, and identify sound emitting events. In future, the algorithms will be implemented in a low frequency hearing aid for persons with low frequency residual hearing or in a fully portable vibratory monitoring aid, for persons with profound D or DB to improve their ability to sense the environment.

Communication acoustics in classroom environments - On the use of assistive listening devices

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Abstract

Assistive listening devices (ALDs) are used in classrooms to assist communication for students with hearing loss. An ALD, a system of external microphones, transmits sound directly to the students' hearing aids. The signal is coupled to the hearing aid using a radio frequency (FM) or an induction loop (IL) system. Using a switch on the hearing aid, the students can listen to the signal from the hearing aid microphone or the ALD signal received by a FM-receiver or a telecoil. An interest in the impact of ALD solutions on student communication and interaction prompted the work reported in this thesis. The thesis evaluates how the quality of classroom ALDs can be optimized in terms of the concept communication acoustics. Aspects of room acoustics, sound quality, and binaural hearing were explored.

The methodical approach was based on self-assessment using questionnaires, interviews and listening tests. The empirical data in Paper I, II, and III consisted of responses from 25 students (10-20 years old) who were attending classes for the hard-of-hearing. In Paper I**,** the hearing aid microphone (M) and telecoil (T) mode were assessed using a questionnaire. When the hearing aid was in T mode, *audibility* increased: speech intelligibility was improved and less listening effort was required. Better *awareness* was achieved using M mode. The students could better hear sounds in the environment around them and participate in conversations – classified as non-teaching – when the ALD was not used. An important feature of sound quality was the distinction of sounds, which is the ability to recognize additional characteristics of a speech sample, e.g., the ability to identify students by voice and judge the mood of students from their voice.

Hearing aids also offer a combined mode where the signals from the internal microphone and the telecoil/FM are mixed. In Paper II, different hearing aid mode combinations were assessed using a combined approach where the different combinations were self-rated in a questionnaire and compared in a listening test. The result supports the finding that a combination of M and T mode is a feasible compromise between *audibility* and *awareness*. The students were active in their use of different hearing aid modes and aware of the advantages and disadvantages of the alternatives. The hearing strategies varied in different classroom settings and for different degrees of hearing loss, findings that emphasize the importance of individual adjustments. In Paper III, binaural aspects of hearing and ALDs were assessed in a listening test. A binaural model was compared to an omni-directional microphone. No advantage in speech intelligibility and listening effort was found using a binaural ALD.

ALD design and characteristics can be evaluated using room acoustic modelling and auralization in different room acoustic conditions. In Paper IV and V, auralization and binaural reproduction techniques used in Paper II and III were investigated. Aspects of binaural and spatial hearing were assessed in normal-hearing subjects. Auralization is a reliable method to render a binaural listening experience in a classroom environment: the performance was equal to that of using artificial head recordings. The method used for binaural reproduction – a two-loudspeaker cross-talk cancellation system – introduces distortion in reproduced interaural differences. The binaural advantages in speech intelligibility were reduced when compared to headphone reproduction. The interaural differences were sufficiently reproduced in the frequency region of ALDs (300-4k Hz); the use of cross-talk cancellation for hearing aid and ALD evaluation is to be further studied.

High sound quality matches students' expectations and demands. To take an active part in the communication in the classroom, students expect to hear sounds in the classroom that they perceive as adequate. However, the students with hearing loss required speech signals with significantly reduced noise and competing speech levels. Today, students have to make a compromise between *audibility* and *awareness*. Any alternative, however, could make communication in the classroom difficult. Different classroom settings and sound environments as well as individual factors of preference and degree of hearing loss affect their decision.

Assessment of speech intelligibility in background noise and reverberation

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Abstract

Reliable methods for assessing speech intelligibility are essential within hearing research, audiology, and related areas. Such methods can be used for obtaining a better understanding of how speech intelligibility is affected by, e.g., various environmental factors or different types of hearing impairment. In this thesis, two sentence-based tests for speech intelligibility in Danish were developed. The first test is the Conversational Language Understanding Evaluation (CLUE), which is based on the principles of the original American-English Hearing in Noise Test (HINT). The second test is a modified version of CLUE where the speech material and the scoring rules have been reconsidered. An extensive validation of the modified test was conducted with both normal-hearing and hearing-impaired listeners. The validation showed that the test produces reliable results for both groups of listeners. An important deviation between the two new tests and the original HINT is a new procedure used for equalizing the intelligibility of the speech material during the development process. This procedure produces more accurately equalized sentences than achieved with the original HINT procedure.

This study also investigates a fundamentally different method for assessing speech intelligibility. This method is based on the identification of the stop-consonant [t] in a short test-word. The method was originally developed in order to measure the impact of reverberation on speech intelligibility and, in particular, to measure whether the intelligibility of the test-word depends on the reverberation added to a surrounding speech carrier. It has been shown that the intelligibility of a reverberant test-word increases when the same amount of reverberation is also added to the carrier. In the literature, this observation has been interpreted as evidence of an *extrinsic compensation mechanism* for reverberation in the human auditory system. However, in the present study, it is shown that the listener's perception of the test-word is not only related to the carrier reverberation but also to other

of the carrier's acoustic-phonetic properties. The evidence of the extrinsic compensation mechanism is therefore questionable.

Overall, the results from the present study may contribute to the development of future speech intelligibility tests in Danish and other languages. The two developed sentence tests are expected to be useful for assessing speech intelligibility with Danish normal-hearing and hearing-impaired listeners.

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