Chapter 27

Hearing loss after exposure to styrene and noise: a pilot study

ANN-CHRISTIN JOHNSON[1], THAIS C. MORATA[2], ING-MARIE ANDERSSON[1], PER R. NYLÉN[1], BJÖN HAGERMAN[3], TOMAS LINDH[1], EVA B SVENSSON[1], [1]National Institute for Working Life, Department of Work and Health, Solna, Sweden; [2]National Institute for Occupational Safety and Health, Division of Biomedical and Behavioural Science, Cincinnati, USA; [3]Karolinska Institute, Unit of Technical Audiology, Stockholm, Sweden;

The aim of this pilot study was to investigate the feasibility of an epidemiological study on the effects of occupational exposure to styrene and noise on the auditory system. An audiological test battery, styrene and noise exposure assessment protocols and a questionnaire were evaluated by testing 14 exposed workers and a group of 10 unexposed controls. The questionnaire included questions on work history, non-occupational solvent and noise exposure and medical history. The test battery comprised pure-tone audiometry, immittance audiometry, distortion product otoacoustic emissions, psycho-acoustical modulation transfer function, interrupted speech, speech recognition in noise, and cortical response audiometry. Exposure assessment included gathering data from interviews and company records, site-measurements for different work tasks and divisions of the company and videotaping using the PIMEX-method.

Introduction

The effects of combinations of environmental factors on workers' health are receiving increasing attention due to a demand for an approach that more closely reflects work conditions (NIOSH 1996). Still, little is known about how individual agents in mixed exposures may interact to increase or otherwise modify the likelihood of adverse health effects. Among the initiatives in the area of combined exposures are studies investigating the effects of occupational exposure to noise and other factors on hearing. In particular, the potential interaction between noise and chemicals poses a new and important challenge to investigators and occupational health professionals, due to the ubiquity of use of these agents (Hétu et al. 1987; Phaneuf and Hétu 1987; Manninen 1993; Johnson 1994; Morata et al. 1994; Nylén 1994; Lang 1995; Sass-Kortsak et al. 1995).

The indication that occupational chemicals can alter auditory function by either ototoxicity, neurotoxicity, or a combination of both processes, has far reaching implications. It has been demonstrated that if these chemicals occur in sufficiently high concentrations they can affect hearing despite the lack of occupational exposure to intense noise, as indicated by recent reports (Bergström and Nyström 1986; Ryback 1992; Jacobsen et al. 1993; Morata et al. 1993).

Current testing used in the study of noise-induced hearing loss, limited to pure-tone audiometry, has proven insufficient for the examination of hearing loss from mixed exposures. A comparison of hearing loss caused by noise or ototoxic substances reveals how difficult differential diagnosis may be (Morata and Lemasters 1995). It may also explain why the effects of occupational exposure to chemicals have been long overlooked.

Comprehensive audiological test batteries have been used to assess the effects of solvents in small groups of workers (Ödkvist et al. 1982; Ödkvist et al. 1987; Möller et al. 1990). Abnormalities were found in tests that assessed more central portions of the auditory pathways. The results indicated the need for tests to complement pure-tone audiometry when evaluating the effects of solvents.

In order to investigate the auditory effects of combined exposures to noise and solvents, a study was designed to test a sample of Swedish workers (N = 300) with a comprehensive battery of hearing tests and have their exposures to both agents assessed. The objective of this pilot study on a limited number of workers was to investigate the feasibility of the proposed epidemiologic study.

Material and methods

Styrene is used in large amounts in the glass-fibre reinforced plastics (GRP) industry (Arlien-Søborg 1992), particularly in the construction of glass-fibre reinforced plastic boats. An audiologic battery, styrene and noise exposure assessment protocols, and a questionnaire, were evaluated by testing 14 styrene and noise-exposed workers from a GRP industry and a group of 10 controls. Participants were selected for the pilot study because of their exposure conditions. Sixteen were invited to participate but only 14 met the eligibility criteria. These criteria were:

- at least one year of employment in the production of GRP;
- no apparent history of hearing loss from other causes.

The questionnaire included questions on demographic data, health information that focused on events that could be related to hearing status, and non-occupational noise and solvent exposure data. The self-reported medical history included data on diabetes, prior ear surgery, head injury, high fever, mumps, ear infections, history of hearing loss in the family, use of ototoxic medication and tinnitus. Hobby history included questions about diving, hunting, shooting, repairing cars, and using power tools. A work history was collected that included job descriptions, exposure to noise and chemicals, and hearing protector and respirator usage. The questionnaires were distributed to potential participants three weeks before the testing began. The participants were instructed to return the questionnaire by mail within one week and the questionnaires were then used to select the participants that met the eligibility criteria for inclusion in the study. During the testing, interviewers checked the questionnaire for invalid answers or unanswered questions.

Table 27.1: Contents of questionnaire

Present work tasks	type of work noise exposure solvent exposure
Previous jobs	work task noise exposure solvent exposure
Hobby exposures	noise solvent
Military service	noise exposure solvent exposure
Medical history	trauma tinnitus related illnesses medications family hearing problems skin type eye colour
Present hearing status	self perception

Testing the auditory system

A bus, modified into a mobile laboratory, was equipped with a soundproof booth and technical instruments. The test battery comprised otoscopy, pure-tone audiometry, immittance audiometry, distortion product otoacoustic emissions (DPOEs), psycho-acoustical modulation transfer function, interrupted speech, speech recognition in noise, and cortical response audiometry (see Table 27.2)

Table 27.2: Auditory test battery used in the pilot study

Test	Parameters tested	Ear tested
PTA	Békésy thresholds at 0.5–8 kHz	both
Tympanometry		both
Stapedius reflex	0.5, 1, 2, 3 and 4 kHz, contra & ipsi	best[1]
Stapedius decay	0.5 and 1 kHz, contra & ipsi	best[1]
PMTF	Thresholds at 2 kHz and 4 kHz	best[1]
DPOEs	Input/output at 1, 2 and 4 kHz, DP-gram at 45 and 65 dB SPL	best[1]
Speech in noise	50% recognition threshold of Hagermans sentences	
Interrupted speech	Percentage correct of 25 sentences of speech with seven interruptions/second	best[1]
CRA	Latency of CR of frequency glide of 1000 Hz tone	both

1 = the best ear was identified by comparing mean threshold values of the pure tone audiometry between 1 and 8 kHz.

Equipment

For pure-tone audiometry, speech audiometry and psychoacoustical modulation transfer function, a technical audiological measurement processor (TAMP3, Unit of Technical Audiology, Karolinska Institute) was used. TAMP3 is controlled by a personal computer, based on the signal processor Texas TMS32010 with a 96 kB memory, A/D- and D/A-converters, a real time clock, antialiasing filters, controllable attenuators, amplifiers with controllable gain and an output amplifier suited for the headphone type TDH-39 with MX41AR cushion.

The speech material was stored on a compact disc (CD). A CD-player was connected to the TAMP3 equipment. The output speech level was 70 dB SPL referring to the calibration tone in a 6 cc coupler. If the subject requested a speech level higher than the fixed speech level of 70 dB SPL the speech materials were presented at higher levels. For speech recognition in noise, a programmable attenuator and a mixer were added to the TAMP3 to mix noise with the speech signal.

For immittance measurements a clinical immittance audiometer (GSI-33, Grason-Stadler, Tegner AB) was used.

Tucker–Davis Technologies units (signal processing board, microphone probe, signal sources and preamplifier) were used for measuring DPOEs. They were controlled by a personal computer with software developed at TA. The microphone (Etymotic Research ER-10) was inserted in the subject's ear canal using a soft foam ear tip.

For cortical response audiometry (CRA) the equipment from Tucker–Davis was used with a different preamplifier (Entomed 510) and a separate software program (developed by TA).

Pure-tone audiometry

Pure-tone thresholds were measured with the fixed-frequency Békésy method for both ears at the frequencies 0.5, 1, 2, 3, 4, 6 and 8 kHz. The subsequent tests were performed only on one ear, with the exception of immitance measurements and CRA. For tests performed on one ear only, the best ear was used. This was identified by comparing the mean thresholds values of the pure tone audiometry between 1 and 8 kHz.

Immittance audiometry

Immittance audiometry consisted of tympanometry, stapedius reflex testing and a stapedius reflex decay test. Tympanometry was performed on both ears to check the condition of the middle ear. Stapedius reflex thresholds of the better ear were measured at the frequencies 0.5, 1, 2, 3 and 4 kHz, registering the reflex at both the contralateral side and the ipsilateral side. The stapedius reflex decay was measured, at the contralateral and the ipsilateral side, at the frequencies 0.5 and 1 kHz, by 10 seconds stimulation 10 dB above the reflex threshold.

Psychoacoustical modulation transfer function (PMTF)

Psychoacoustical modulation transfer function shows the ability of the ear to follow the natural slow modulations of the intensity of speech (Lindblad et al. 1992; Lindblad et al. 1993). This ability is essential for speech recognition. An octave noise band with a 2 kHz or 4 kHz centre frequency that was amplitude modulated at 2.5 kHz or 10 kHz respectively, was used as a masking noise in this experiment. A four millisecond (ms) short probe tone with the same frequency as the centre frequency of the noise was presented at the peak or at the valley of the noise envelope. The threshold of the probe tone was measured by a Békésy method for both presentations of the probe tone. The threshold for the probe tone without masking noise was also measured. The measurements were carried out at eight noise intensities ranging from 35 to 105 dB SPL, in steps of 10 dB, for the octave bands 2 kHz (2.5 Hz modulation) and 4 kHz (10 Hz modulation). The difference between the peak and the valley thresholds forms a curve with a maximum at about 55 dB SPL for normal hearing subjects. A hearing impairment will cause a decrease in the height of the peak, and shift it towards higher sound pressure levels.

Distortion product otoacoustic emissions (DPOAEs)

DPOAEs are produced by the cochlea during the simultaneous presentation of two tonal signals of different frequencies, f1 and f2, to the ear. The frequency ratio of the primary tones was $f2/f1 = 1.225$ and the levels of f1 and f2 were $L1 = L2 + 10$ dB. The microphone was fitted in the subject's ear canal and the subject was instructed to sit quietly for the duration of the testing. The distortion product input/output function was collected in 10 dB steps from 35 to 75 dB SPL for the frequencies 1, 2 and 4 kHz corresponding to the geometric mean (GM) of the primary tones. Furthermore, so-called DP-grams were measured for GM frequencies 0.5, 1, 2, 3, 4, 6 and 8 kHz at levels of $L1 = 45$ and 65 dB SPL.

Speech recognition in noise

The aim of this test is to check the ability of speech discrimination in noise. Lists of Hagerman's sentences in noise (Hagerman 1982) were used. Lists of sentences were presented together with noise. Each list consisted of 10 five-word sentences. Each word was scored as missed or identified. One training list was used to familiarize the subject with the test. For the training list the noise level was gradually increased to a level where about half of the words were correctly identified. Then two test lists were presented. Between the two test lists the noise level was changed by 3 dB, to achieve one result below and one above a 50% recognition threshold. From these two results the 50% threshold, in terms of a speech-to-noise ratio, was calculated by linear interpolation.

Interrupted speech

Various methods of speech distortion have been used to assess the central hearing pathways and the auditory cortex. Korsan-Bengsten (1973) has shown that the most efficient distortion for this purpose is to interrupt the speech signal with seven interruptions/second. The lists by Korsan-Bengsten were used. They consist of 25 sentences containing 100 key words each. Five sentences from one list are presented at 70 dB SPL for familiarization to the test. If the subject indicates the need of a higher presentation level, further sentences are presented at higher intensity levels until an appropriate level is found. Subsequently, another test list is presented. The percentage of correctly repeated key words is registered.

Cortical response audiometry (CRA)

The test stimuli are based on a 1000 Hz continuous pure tone at 60 dB HL. The actual stimulus was the frequency glide of this tone. The frequency is linearly increased to 1050 Hz in 20 ms. It remains at 1050 Hz for 480 ms and then returns linearly to 1000 Hz in the next 600 ms interval. The inter-stimulus interval varies from 2 seconds and up with a mean of 4 seconds. Cortical responses from 50 × 500 ms sweeps were averaged. The latency of the dominating vertex-negative N1-component was used as the parameter for comparison. CRA was made on both ears and the latency of N1 was compared between the ears.

Exposure assessment

The assessment of the workers' exposure to styrene and noise included questionnaires and interviews focusing on work tasks in the company combined with relevant technical information and information about changes – e.g. production technology, type of polyester used. Type of tools used and ventilation conditions were also obtained from the workers and the supervisor. These data were also used to modify the exposure assessment.

Styrene exposure assessment

After interviewing participants, a list was made of the jobs each subject had held and their respective duration. Subjects were grouped according to different work tasks and divisions of the company. Five different subgroups were identified as working in three departments in the company. Exposure to styrene was measured during one day, on at least one worker in each subgroup. The background concentrations of styrene in the three different departments of the company were also assessed. Specific work operations were mapped with short time measurements. Exposure to styrene was measured according to the PIMEX-method and the charcoal method (Rosén 1993; NIOSH 1994). In the PIMEX method, a worker is followed with a video camera; simultaneously his exposure is recorded with a personal direct-reading measurement instrument, in this case a photo ionization instrument (TIP, 10.2 eV, Photovac Inc., Thornhill, Canada). The measurement signal is sent to a receiver by means of telemetry. The video image and measurement signal are merged with a special video mixer and then displayed in a TV image. Exposure is depicted as a bar at the left edge of the frame. The results are recorded by a video tape recorder. Subsequently, data from the videotape are transmitted to a computer file. For each piece of data stored in the computer file, the corresponding work step is identified from the video. Exposure data could thereafter be sorted according to the work task to which they were ascribable. With these data, each work task's duration and relative importance to total exposure could be easily calculated (Andersson and Rosén 1995).

The charcoal method includes samples collected in a charcoal tube containing 150 mg of charcoal (50 mg control layer) with a personal pump (flow 50-200 ml/min). The tubes were elutriated with carbon disulphide and analysed through gas chromatography.

The exposure assessment was based on a calculated mean value from exposure measurements from the years 1985–1995 combined with a detailed analysis of present work and use of personal protectors. Every defined work group had its own mean value estimates from the previous 10-year measurements. Proper use of respirators in different work tasks was assumed to reduce the exposure to styrene by 90% (Kawai et al. 1994). The amount of time the respirators were used was estimated for every worker based on information from the questionnaire.

Noise exposure assessment

Noise exposure was assessed with a direct reading instrument B&K 2218 with a 0.5 inch microphone 4165 mounted on an extension rod. Personal exposure measurements were made with a Quest Q-400 dosimeter. The Quest dosimeters stored the mean sound level every 10 seconds. The microphone was mounted pointing upwards on the worker's right lapel. All instruments were calibrated before measurements. Estimates of exposure to noise were based on 20 full shift and 4 half shift dosimeter measurements taken on 13 of the 14 study subjects during a three-day period. In addition, sound pressure levels from different power tools were measured 10 cm outside the worker's right ear, with the B&K instrument. Background noise levels were measured during a walk-through survey and sound level decay with distance from sources was measured 1, 4 and 8 meters away from a high intensity source in each of the three different departments.

To estimate the effect of using hearing protectors 'always', 'often' or 'sometimes', information collected in the questionnaire and the dosimeter files from the assembly departments was used. The word 'often' indicated that hearing protectors were used for about 75% of the time they were needed. The word 'sometimes' stood for approximately 50% of usage time. Earmuffs were assumed to offer a 25 dB attenuation. Earmuffs were assumed to be used predominantly when sound level was 95 dBA or more – that is, when the worker performed noisy tasks, such as grinding.

Exposure assessments were based on measurements conducted in groups with similar exposure. A specific individual was assigned the group mean value modified according to his usage of hearing protectors. Measurements conducted with individuals who did not fit in a group had, if needed, their exposure value adjusted to average usage of power tools etc. A time-weighted average was calculated for individuals who worked, or had been working, in different groups with homogeneous exposures.

Estimates of occupational exposure at previous jobs were calculated based on information from the worker, for example, if it was 'quiet' or 'very noisy'. In a few cases, information on typical noise levels in certain industries was found in the literature and included in the estimation of past exposure.

Results

The aim of this paper was primarily to describe the methods used and the feasibility of the proposed study. The number of subjects in the two groups is small and insufficient to provide power for statistical analyses. However, some attempts were made to compare the exposed group with the controls. A Student's T-test and a Fisher test were used for comparison between group means in some variables. A multiple regression analysis, with exposure to noise and styrene as independent variables, was conducted to estimate the effect of exposure. The pure-tone hearing threshold levels were age adjusted according to Passchier-Vermeer (1988) for median (50 percentile) hearing threshold levels. Significant differences between exposed and non-exposed groups were observed in the PMTF and speech recognition in noise tests, and trends towards differences were seen in interrupted speech, CRA and DPOEs. The regression analyses showed no clear association between the exposures and impaired hearing, even if some tendencies to correlation were found in the test variables speech in noise and PMTF. However, the small number of subjects made it unlikely that such an association would be found.

Audiological test battery

The total time spent with the audiologic test battery was three hours per subject, divided into two sessions. This time was considered too long for the proposed study, especially for the recruitment of companies and subjects. After the analyses of the pilot results, a decision was reached to limit the testing and interviewing time as follows. A second soundproof booth will be installed in the mobile unit, so two workers can be tested at the same time. The pure-tone audiometry will be carried out as before. PMTF will be tested in one frequency (4 kHz) with an addition of two stimulation levels at 2 kHz. DPOAEs input/output functions will be measured at one primary frequency (4 kHz, 35-85 dB stimuli) and no DP-grams will be measured. The CRA will be measured in both ears. Both speech tests will be done as they were done in the pilot. The immittance audiometry will be omitted since the other tests provide the lesion site information desired. This will limit the testing time to approximately 2 hours.

Questionnaire

This pilot study was of particular importance for the evaluation of the questionnaire. For the development of an adequate instrument it is important to have discussions with individuals similar to the future subjects in order to acquire a thorough understanding of the employees' work activities, health concerns, and literacy level.

In general, workers did not have difficulties in answering the questionnaire. The only sections that did not provide the information expected were the sections on previous employment and past exposures. Some questions in these sections will be rephrased and some questions will be added (see details in the noise exposure assessment below).

Exposure assessment – styrene

Assessing workers' exposure at the chosen company was relatively simple since there were:

- no major technical changes during the last 10 years, except in one workstation;
- annual styrene exposure measurements records were available since 1985, except for 1993;
- adequate periods of tenure at the company;
- almost no cases of previous occupational exposure to solvents.

Moreover, workers were interested in the study and willing to co-operate with the research team. Finally, the PIMEX-method was used, which allowed the determination of the time a worker devoted to each work task and the use of personal respiratory protector.

The methods used in the pilot study to assess styrene exposure allowed for a detailed evaluation of current and past exposure. In the studied company average exposure levels ranged, in the past 10 years, from 11 to 48 mg/m^3. This average exposure level of the studied group is lower than typical levels of this industry in Sweden. A recent examination of reported exposure levels from some of those factories (17–35 factories) indicates an average exposure level between 50 and 94 mg/m^3 (yearly average) between 1985 and 1994 and no tendency towards changes over time was observed. The Swedish occupational limit value is exceeded in a third of the reported exposure measurements. The Swedish National Board of Occupational Safety and Health reported (Arbetarskyddsstyrelsen 1991) that 42% of 57 studied companies exceeded 25 ppm (110 mg/m^3) during the period 1987 to 1989. In the present study the exposure levels were adjusted for the use of respirators in contrast to the literature data where no such adjustment were made. This may partly explain the lower levels of exposure found in this study.

Air contaminant concentrations are usually considered to be log-normally distributed (Kromhout et al. 1987). Typical geometric standard deviations are around 2.0. This means that a daily average exposure of twice the mean value is likely to occur every fourth day. The exposure variation during the workday is even larger. Andersson and Rosén (1995) reported geometric standard deviations over 3.0 measured with real time monitoring instruments with a short response time (less then a second). This corresponds to frequently occurring exposure peaks exceeding 300-400 mg/m^3 in the group in the present study. Most, but not all of those exposure peaks, occur when the worker is using a respirator.

Exposure assessment – noise

At the studied company the background sound levels were approximately 70 dBA in the assembly departments and 65 dBA in the spray- and thermo plastic departments. The sound level was approximately 5 dB higher in a few work zones where fans and local exhausts were used. Tasks that required power tools (i.e. pneumatic grinders, electrical saws) were responsible for the highest sound pressure levels measured, ranging from 94 to 105 dBA. The comparison between the B&K and the Quest dosimeter were made at two different grinders, one saw and one polyester spray gun with an internal glass fibre cutting device. The results showed that the Quest dosimeter gave readings that were 0.3 to 0.8 dB higher than the B&K instrument. This difference was within the margin of the uncertainty of the test situation and the instruments used. As the noise levels expected in the proposed study range from below 80 to above 90 dBA ASK, the Quest dosimeter was considered to be adequate.

The dosimeter results indicated that the highest noise values were found on the assembly departments. The mean level for all workers on assembly departments 1 and 2 were 86.2 and the mean level for the workers on the thermo department was 86.6 dBA. Calculations showed that the observed usage (reported as 'often' or 'sometimes') of hearing protectors lowered the full shift mean exposure by a few dBs (3 or 1 dB respectively). After the dosimeter results were corrected for hearing protector usage, levels in the assembly departments were reduced to 77–86 dBA, and in the thermo department, exposures were reduced to 75–86.6 dBA.

Discussion and conclusions

To study the combined effects of noise and solvents on the auditory system it is critical to select an industrial setting where the solvent exposure can be thoroughly characterized both historically and presently. Styrene was the chemical selected for this investigation. The selection of styrene and the GRP industry took into consideration styrene's potential neurotoxicity, available evidence of ototoxicity, accessibility and reliability of industry exposure records, accessibility to workers and magnitude of occupationally exposed population. Moreover, the solvent exposure in the GRP industry is almost a mono-exposure to styrene (small amounts of acetone are used for cleaning tools) and this is a clear advantage when evaluating the solvent effects. Noise can also be easily monitored in this industrial setting. The noise levels (as well as the styrene exposure levels) vary depending on different tasks, which will allow the investigators to study the effect of combinations on hearing. In Sweden, companies producing GRP products are required to measure exposure to styrene annually since 1976. The pilot study indicated that the choice of solvent and industry was appropriate for the proposed study, due to the solvents and noise exposure characteristics and availability of retrospective exposure records.

An important element of most epidemiologic studies that purport to investigate occupational associated illness is the development of a quality survey instrument. Before constructing the instrument it is incumbent upon the investigator to become thoroughly acquainted with all facets of the study, understanding both exposure conditions and health outcomes. In order to evaluate exposures, a walk-through survey of the work site should be made to assist in the development of the work history portion of the instrument. Work histories collected from the employees have been shown to be reliable and a valid source of information but are dependent on several factors including number of jobs held, length of time since employment, short tenure on the job and level of education (Stewart et al. 1987; Bourbonnias et al. 1988). Questions should be worded in a clear, unambiguous, and understandable manner for both the respondent and the interviewer (Morata and Lemasters 1995). The testing of the questionnaire in the pilot study offered valuable input for improving the instrument.

The combined use of the PIMEX method and point estimates of styrene offered an excellent estimation of exposure for specific work tasks. This information, together with the use of the questionnaire, individual interviews and diaries kept during data collection, comprised a very comprehensive exposure assessment method. This enabled the research team to estimate the exposure of work groups without having to rely on non-representative results of samples taken from individual workers during a single workday. However, since measurements of chemicals in air do not reflect the total exposure of the individual, biological monitoring of styrene in urine is planned in the proposed study, in addition to the methods described earlier.

The noise measurements performed were comprehensive and allowed for a characterization of the workers' noise exposure. The analyses of the results have revealed some weaknesses in the questionnaire. Some of the questions on noise exposure, such as amounts of time spent on different work tasks and the use of hearing protection, will be modified to better recognize present and past noise exposures.

The information on noise exposure obtained in the pilot study will be used in the selection of a noise-only group in the proposed study. Attempts will be made to locate this cohort in the same industry in which styrene and noise exposed workers are selected. Probably this can only be achieved if larger companies agree to participate in the study, since there were no workers just exposed to noise in the small company studied in this pilot.

The audiological battery used in the pilot study was selected with the objective of appraising the effects of solvents in different sites of the auditory system. The use of pure-tone audiometry has proven insufficient for the examination of hearing loss from mixed exposures. Noise-induced hearing losses (NIHL) are caused by lesion to the sensory cells of the cochlea, characterized by a dip in the audiogram around 4 kHz. This feature permits the distinction between this and other kinds of hearing loss (i.e. infections, presbyacusis) that have a different audiometric configuration. If, after solvent exposure, lesions are found in humans as they are in rats (cochlear), the solvent effects could be virtually indistinguishable from those of noise, as reflected in auditory tests. This possibility indicates the need for studies comparing the distribution of hearing losses in large groups of workers exposed to different conditions (Morata and Lemasters 1995).

Researchers in Sweden (Ödkvist et al. 1987; Möller et al. 1990; Laukli and Hansen 1995) have used comprehensive audiological test batteries to investigate workers exposed to mixtures of solvents in different work settings. The findings of pure-tone audiometry and speech discrimination testing did not permit the distinction between the effects of age, noise exposure or solvent exposure. However, a significant abnormality was found in tests that assessed more central portions of the auditory pathways, especially in discrimination of interrupted speech and evoked cortical potentials in response to frequency glides, which the authors suggested resulted from solvent exposure. In summary, the use of tests to complement pure-tone audiometry when evaluating the auditory effects of solvents is imperative.

Although ideal, the use of an extensive audiological test battery in occupational studies may be prohibited by both time and cost constraints. In the face of such constraints, the selection of a minimum battery of tests with proven validity and reliability, as well as availability and ease of administration, becomes crucial for making possible the precise identification of the solvent effect. With the information obtained in the pilot study the research team was able to abbreviate the original test battery but only after the completion of the proposed investigation will it be possible to recommend a minimum battery of tests. The proposed battery of tests should be directly transferable to occupational health services.

In conclusion, the pilot study demonstrated that with minor changes in methodology, the proposed study is feasible and will offer answers to the devised research questions.

References

Andersson I-M, Rosén G (1995) Detailed work analysis for control of exposure to airborne contaminants in the workplace. Appl Occup Environ Hyg 10: 537–44.

Arbetarskyddsstyrelsen (1991) Arbetarskyddsstyrelsen, Swedish National Board of Occupational Safety and Health. Hygieniska gränsvärden – Konsekvensbeskrivning.

Arlien-Søborg P (1992) Styrene. In Arlien-Søborg P (ed.) Solvent Neurotoxicity. Boca Raton FL: CRC Press, pp. 129–53.

Bergström B, Nyström B (1986) Development of hearing loss during long-term exposure to occupational noise. Scand Audiol 15: 227–34.

Bourbonnias R, Meyer F, Theriault G (1988) Validity of self-reported work history. Br J Ind Med 45: 29–32.

Hagerman B (1982) Sentences for testing speech reception threshold in noise. Scand Audiol 11: 79–87.

Hétu R, Phaneuf R, Marien C (1987) Non-acoustic environmental factor influences on occupational hearing impairment: a preliminary discussion paper. Canad Acoust 15: 17–31.

Jacobsen P, Hein HO, Suadicani P, Parving A, Gyntelberg F (1993) Mixed solvent exposure and hearing impairment: an epidemiological study of 3284 men. The Copenhagen male study. Occup Med (Oxf) 43: 180–4.

Johnson A-C (1994) The ototoxic effect of toluene and influence of noise, acetyl salicylic acid or genotype. Scand Audiol 23 (Suppl 39): 1–40.

Kawai T, Mizunuma K, Yasugi T, Horiguchi S, Ikeda M (1994) Effective prevention of styrene monomer exposure by protective respirators in fiber-reinforced plastics work. Occup Hyg 1: 153–61.

Korsan-Bengsten M (1973) Distorted speech audiometry. Acta Otolaryngol (Sthlm) (Suppl) 310.

Kromhout H, Oostendorp Y, Boleij JSM (1987) Agreement between qualitative exposure estimates and quantitative exposure measurements. American Journal of Industrial Medicine 12: 551–62.

Lang L (1995) Strange brew: assessing risk of chemical mixtures. Environ Health Perspect 103: 142–5.

Laukli E, Hansen P (1995) An audiometric test battery for the evaluation of occupational exposure to industrial solvents. Acta Otolaryngol (Stockh) 115: 162–4.

Lindblad A-C, Olofsson Å, Hagerman B (1992) Karolinska Institutet. Tone thresholds in modulated noise. I. Level dependence and relation to SRT in noise for normal-hearing subjects. 125: Technical Audiology Reports.

Lindblad A-C, Olofsson Å, Hagerman B (1993) Hearing aid fitting using psychoacoustical modulation transfer functions. Fifteenth Danavox symposium. Recent Developments in Hearing Aid Technology. Odense, pp. 491–6.

Manninen O. Synopsis of Studies on Combined Effects. Sixth International Congress on Noise as a Public Health Problem. Nice, France, pp. 511–18.

Morata T, Lemasters G (1995) Epidemiologic considerations in the evaluation of occupational hearing loss. In Morata T, Dunn D (eds) Occupational Medicine: State of the Art Reviews 10: 641–56.

Morata TC, Dunn DE, Kretschmer LW, Lemasters GK, Keith RW (1993) Effects of occupational exposure to organic solvents and noise on hearing. Scand J Work Environ Health 19: 245–54.

Morata TC, Franks JR, Dunn DE (1994) Unmet needs in occupational hearing conservation. Lancet 344: 479.

Möller C, Ödkvist L, Larsby B, Tham R, Ledin T, Bergholtz L (1990) Otoneurological findings in workers exposed to styrene. Scand J Work Environ Health 16: 189–94.

National Institute for Occupational Safety and Health (NIOSH) (1994) Manual of Analytical Methods. 4th. DHHS/NIOSH Pub. 94-113. NIOSH: Cincinnati.

National Institute for Occupational Safety and Health (NIOSH) (1996) National Occupational Research Agenda. Pub. 96-115. NIOSH: Cincinnati.

Nylén P (1994) Organic solvent toxicity in the rat; with emphasis on combined exposure interaction in the nervous system. Arbete und Hälsa 1–50.

Passchier-Vermeer W (1988) TNO Institute of Preventive Health Care. Occupational noise exposure and hearing. An analysis of recent publications on age-related hearing threshold levels and on hearing threshold levels of occupational noise-exposed populations. Report 88056: 1-34. The Netherlands.

Phaneuf R, Hétu R (1990) An epidemiological perspective of the causes of hearing loss among industrial workers. J Otolaryngol 19: 31–40.

Rosén G (1993) PIMEX. Combined use of air sampling instruments and video filming: Experience and results during six years of use. Appl Occup Environ Hyg 8: 344–7.

Ryback LP (1992) Hearing: the effects of chemicals. Otolaryngol Head Neck Surg 106: 677–86.

Sass-Kortsak AM, Corey PN, Robertson JM (1995) An investigation of the association between exposure to styrene and hearing loss. Ann Epidemiol 5: 15–24.

Stewart W, Tonascia J, Matanoski G (1987) The validity of questionnaire-reported work history in live respondents. J Occup Med 29: 795–800.

Ödkvist LM, Arlinger SD, Edling C, Larsby B, Bergholtz LM (1987) Audiological and vestibulo-oculomotor findings in workers exposed to solvents and jet fuel. Scand Audiol 16: 75–81.

Ödkvist LM, Bergholtz LM, Åhlfeldt H, Andersson B, Edling C, Strand E (1982) Otoneurological and audiological findings in workers exposed to industrial solvents. Acta Otolaryngol (Stockh) Suppl 386: 249–51.

ADVANCES IN
NOISE RESEARCH

VOLUME 1

BIOLOGICAL EFFECTS OF NOISE

EDITED BY
DEEPAK PRASHER
AND
LINDA LUXON

1998

WHURR PUBLISHERS' BOOKS ON AUDIOLOGY AND COMMUNICATION

ADVANCES IN NOISE RESEARCH
The series entitled Advances in Noise Research has developed from the European Commission Concerted Action Programme on Protection Against Noise (PAN), which is a project within the EC Fourth Framework Biomedical and Health Research Programme in the Occupational and Environmental Health Area.

These volumes report the latest research and developments in the area of noise and its auditory and non-auditory effects on health.

VOLUME 1: BIOLOGICAL EFFECTS OF NOISE
Editors: Deepak Prasher and Linda M. Luxon

The first volume in the series is devoted to the biological effects of noise and covers six main topics: physiological mechanisms, diagnosis, otoacoustic emissions, tinnitus, pharmacology and non-auditory effects in relation to noise.

The section on physiological investigations includes auditory sensitivity modulation by sound conditioning, central nervous system reorganisation after acoustic overstimulation, and the role of stapedial reflex and pigmentation in noise-induced hearing loss. The section covering diagnosis considers the difficulties encountered and the new techniques available, and also looks at the specific issues relating to noise in military life. The discussion of otoacoustic emissions in relation to noise exposure provides insight into their possible use in the assessment of individuals exposed to noise and their role in early identification of impairment. Tinnitus following noise exposure is considered both from the assessment and neurophysiological aspects. The pharmacology section examines the protective and preventative aspects of free radical scavengers and magnesium, and also discusses the synergistic effect of solvent and noise. The non-auditory effects included are sleep disturbance and stress effects on the cardiovascular system, and context and coping as moderators of potential health effects.

ADVANCES IN NOISE RESEARCH
VOLUME 2: PROTECTION AGAINST NOISE
Edited by Deepak Prasher, Linda M. Luxon and Ilmari Pyykkö
1 86156 076 1 cased 1998

HANDBOOK OF VESTIBULAR REHABILITATION
Edited by Linda M. Luxon and Rosalyn A. Davies
1 86156 021 4 paper 1998

PROFOUND DEAFNESS AND SPEECH COMMUNICATION
Edited by Geoff Plant and Karl-Erik Spens
1 897635 45 1 paper 1995

SPEECH AUDIOMETRY
Edited by Michael Martin
1 897635 12 5 paper 1997 2 ed

COCHLEAR IMPLANT REHABILITATION IN CHILDREN AND ADULTS
Dianne J. Allum
1 897635 54 0 paper 1996

GENETICS AND HEARING IMPAIRMENT
Edited by Alessandro Martini, Dai Stephens and Andrew Read
1 897635 29 X paper 1996

PSYCHOPHYSICAL AND PHYSIOLOGICAL ADVANCES IN HEARING
Edited by Alan Palmer, Adrian Rees, Quentin Summerfield, Ray Meddis
1 86156 069 9 cased 1998

AUGMENTATIVE AND ALTERNATIVE COMMUNICATION: EUROPEAN PERSPECTIVES
Edited by Stephen von Tetzchner and Mogens Hygum Jensen
1 897635 59 1 paper 1996

DEVELOPMENTS IN GENETIC HEARING IMPAIRMENT: VOLUME 1
Edited by Dai Stephens, Andrew Read and Alessandro Martini
1 86156 058 3 paper 1998

A copy of Whurr Publishers' catalogue is available on request.

ISBN 1-86156-075-3

9 781861 560759

Contents