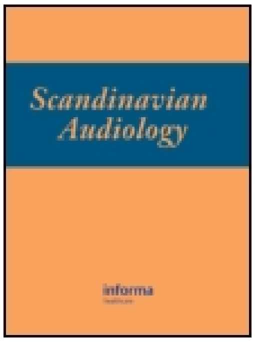

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Workers from a refinery ($n = 438$) were interviewed, had their hearing tested and had their exposures to noise and solvents assessed. Measurements suggested that most exposures to noise and solvents were within exposure limits recommended by international agencies; however, the prevalence for hearing loss within the exposed groups ranged from 42 to 50%, significantly exceeding the 15–30% prevalence observed for unexposed groups. The adjusted odds ratio estimates for hearing loss were 2.4 times greater for groups from aromatics and paraffins (95% CI 1.0–5.7), 3 times greater for the maintenance group (95% CI 1.3–6.9) and 1.8 times greater for the group from shipping (95% CI 0.6–4.9), when compared to unexposed workers from the warehouse and health clinic. The results of acoustic reflex decay tests suggest a retrocochlear or central auditory pathway involvement in the losses observed in certain job categories. These findings indicate that factors in addition to noise ought to be considered when investigating and preventing occupational hearing loss.

Key words: Benzene, cyclohexane, ethyl benzene, hearing, noise, solvent mixture, toluene, xylene.

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Introduction

Exposure to noise continues to be a serious occupational risk, involving approximately 30 million workers in the United States (Ginnold, 1979; Merry & Franks, 1995; NIOSH, 1996*a*). Noise exposure has long been recognized as the major contributor to occupational hearing loss, but an important recent finding in the area is that the effects of noise in the workplace can be exacerbated by other non-acoustic agents, for example extreme temperatures, vibration, and ototoxic drugs (Lindgren, 1987; Phaneuf & Hétu, 1990; Morata et al., 1994*b*; Lang, 1994; Pekkarinen, 1995; Ward, 1995). The interaction of noise and other agents contributes to the large variability observed in a population's response to noise exposure, and if overlooked may undermine the success of traditional hearing conservation programs (Hétu et al., 1987). Among the factors that may interact with noise, occupational exposure to chemicals is one of critical relevance because of the magnitude of workers exposed (Morata et al., 1994*a*) and the evidence that chemicals may affect the auditory system despite the absence of intense noise exposure (Johnson & Nylén, 1995).

Data on the ototoxic effects of chemicals come mainly from animal studies and case reports; however, environmental and occupational exposures to solvents have also been associated with hearing impairments (for reviews see Fechter, 1995; Johnson & Nylén, 1995). Increased prevalence of high-frequency hearing loss has been reported after solvent exposure in the face of noise levels below the threshold limit value (Velasquez et al., 1969; ATSDR, 1993; Morata et al., 1993; Jacobsen et al., 1993). A 20-year longitudinal study of hearing sensitivity of 319 workers indicated that 23% of solvent-exposed subjects from the chemicals' department, who were exposed to noise levels of 80–90 dBA, showed compensable hearing loss, whereas only 5 to 8 percent of workers with a history of noise exposure to higher noise

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levels showed compensable hearing loss in non-chemical environments (Bergström & Nyström, 1986). It has also been demonstrated that exposure to solvents apparently interacts with exposure to noise, so that the combined exposures yield an increased prevalence of high-frequency hearing loss (Morata, 1989; Morata et al., 1993). Moreover, clinical studies in which a comprehensive audiologic battery was performed showed a central component to the observed auditory disorders (Ödkvist et al., 1982; 1987, Möller et al., 1989, 1990). This observation indicates that if auditory retrocochlear disorders due to solvent exposure exist, they could represent a more debilitating impairment than the one caused by noise.

Hitherto, no publication has focused specifically on occupational hearing loss among refinery workers, even though various reports discuss the potential for hazardous exposures to both noise and solvents in that industry (Nelson et al., 1985; McFarland, 1988; Runion, 1988; IARC, 1989).

In the present study we evaluated, using pure-tone audiometry and acoustic immittance measurements, the occurrence of hearing disorders in groups of refinery workers exposed to neither noise nor solvents, and groups of refinery workers exposed to various levels of noise and solvents. Acoustic reflex measurements were performed to obtain information concerning the origin of the observed hearing disorders.

Material and Methods

Study Design

The study was conducted at an oil refinery in South America, with a refining capacity of 200 000 barrels per day. To investigate the effects of occupational exposure to noise and solvents on workers' hearing, workers from different departments of an oil refinery were interviewed, their hearing was tested, and their exposure to both agents was evaluated. Male Hispanic workers, employed for a minimum of 1 year, were included.

Study Population

With the exception of workers with less than 1 year in the company, or workers with ear disorders that prevented them from undergoing immittance audiometry, all the staff from the aromatics plant, paraffins plant, quality control laboratory, maintenance, warehouse, health clinic and shipping departments were invited and agreed to participate in the study. These departments were selected because of their exposures to noise and/or solvents. From the initial 444 workers who volunteered to participate, 438 met the eligibility criteria and were included in the study. Solvent exposure was evaluated as part of a Health Hazard Evaluation conducted by industrial hygienists from the National Institute for Occupational Safety and Health (for details see NIOSH, 1994). During that survey, environmental samples were collected to measure personal exposures and area concentrations of benzene, toluene, xylene, ethyl benzene and cyclohexane in all departments, with the exception of paraffins, which was not operating during the survey period. Their occupational exposures are summarized in Table I and described in more detail below.

Workers were selected from the warehouse and health clinic to serve as an unexposed comparison group ($n = 41$), as they were not occupationally exposed to any known or suspected ototoxicants.

A second group was composed of workers from the aromatics and paraffin plants ($n = 89$). In the aromatics plant, benzene, toluene, xylene, ethyl benzene, and cyclohexane are refined from naphtha. The process is monitored by operators from inside a control room, and some make rounds to monitor parameters, collect samples and inspect the system. In these departments, workers spend most of their shift (around 6 h/day) inside the control room. For an average of 2 h making rounds, aromatics plant workers are exposed to noise levels that range from 78 to 101 dBA, averaging 87 dBA. In the paraffins plant, the noise levels range from 71 to 98 dBA, averaging 88 dBA. The noise levels were provided by the company, which performed the measurements in June 1989. Spot noise measurements performed by an engineer from the research team were in agreement with company records. Considering the report that occasions when workers spent 3 h or more exposed to these noise levels were rare (average of 2 h/day), and that the use of hearing protectors was enforced, the noise doses to which they were exposed should not have posed a risk to their hearing.

A third group of workers was selected from the shipping department ($n = 40$). Personnel in this department supervised the transfer of the finished product from the storage tanks into barges and tankers, and monitored tank levels. Company records from 1994 indicated that noise levels range from 82 to 104 dBA at selected points in the shipping department where operators controlled oil transfer pumps. Considering that the workers reportedly spent up to 3 h on alternate days exposed to these noise levels and that use of hearing protection was enforced, their noise doses should not have posed a risk to their hearing.

A fourth group included workers from a maintenance crew assigned to the aromatics and alkylation plant ($n = 180$). Noise levels in the departments they serviced range from 78 to 101 dBA, averaging 89 dBA. It was reported by the company, by workers and by NIOSH hygienists that these workers spent an average of 50% of their 8-h shift at the plants, so this group was likely exposed to levels equal to or greater than the NIOSH recommended limit of 85 dBA time-weighted average (TWA).

A fifth group was composed of workers who in the past have worked in the aromatics department and were transferred to other departments where they are not exposed to either of the agents ($n = 19$).

A sixth group of workers was selected from the quality control laboratory ($n = 69$). Laboratory personnel worked with samples collected in the aromatic plant and other production plants, using various analytical methods to check the quality of in-process and finished products. This group was not occupationally exposed to noise levels that could have posed a risk to their hearing.

Because of the remote location of the refinery, most workers did not have a history of previous industrial employment nor previous occupational exposure to the studied agents. However, the majority of workers live in the refinery area, and there is a possibility that workers have non-occupational exposure to chemicals through contaminated air and/or water.

To determine whether underlying differences might have

Table I. *Summary of exposures to aromatic solvents and noise, by department*

Department	Noise	Benzene Min.	Benzene Max.	Benzene Med.	Toluene	Xylene	Ethyl benzene	Cyclohexane
Warehouse and Health ($n=41$)	<85 dBA TWA	<MDC	<MDC	NA	<MDC	<MDC	<MDC	<MDC
Aromatics, Paraffins ($n = 89$)	85 dBA TWA (90 dBA/3 h)	<MDC	15 ppm*	0.21 ppm	<MDC to 13.2 ppm	<MDC to 2.6 ppm	<MDC to 0.6 ppm	<MDC to 13.6 ppm
Previously at aromatics ($n = 19$)	NA	NA	NA	NA	NA	NA	NA	NA
Shipping ($n = 40$)	<85 dBA TWA	<MDC	0.12 ppm	NA	<MDC to 18.4 ppm	<MDC to 1.2 ppm	<MDC to 0.3 ppm	<MDC to 0.6 ppm
Maintenance ($n = 180$)	≥85 dBA TWA*	<MDC	32 ppm*	6 ppm*	<MDC to 11 ppm	<MDC to 5.1 ppm	<MDC to 1.1 ppm	<MDC to 1.3 ppm
Laboratory ($n = 69$)	<85 dBA TWA	0.01 ppm	0.87 ppm*	0.03 ppm	<MDC to 0.3 ppm	<MDC to 0.3 ppm	<MDC to 0.1 ppm	<MDC to 0.3 ppm
NIOSH REL/STEL	85 dBA TWA		0.1/1 ppm		100/150 ppm	100/150 ppm	100/125 ppm	300 ppm/NA

Abbreviations: Min, Minimum value measured; Max, Maximum value measured; Med, Median; MDC, Minimum Detectable Concentration; TWA, Time-weighted-average; NA, not available; ppm, parts per million; REL, Recommended Exposure Limits; STEL, Short-term Exposure Limits. Asterisks indicate exposures above NIOSH criteria.

Table II. *Characterization of the study population. Means and standard deviations in parentheses for the variables: age, length of employment, medical and aural history items, hobby history items, and exposure to firearms in the military service, by department*

	Warehouse/ Health		Arom./ Paraffins		Shipping		Maintenance		Prev. Aromatics		Laboratory	
Variable												
Age (years)	44.0	(0.9)	**40.4**	**(0.6)**	41.5	(0.9)	43.9	(0.4)	42.8	(1.4)	**40.7**	**(0.7)**
Tenure (years)	18.4	(4.8)	16.6	(7.0)	**16.0**	**(6.5)**	18.6	(4.5)	19.1	(4.2)	**16.3**	**(5.6)**
Proportions												
Diabetes	0	(0)	0.01	(0.1)	0.02	(0.1)	0.01	(0.1)	0	(0)	0.01	(0.1)
Hypertension	0.07	(0.3)	0.04	(0.2)	0.1	(0.3)	0.08	(0.3)	0.1	(0.3)	0.08	(0.3)
High fever	0.02	(0.1)	0	(0)	0	(0)	0.01	(0.1)	0	(0)	0	(0)
Hearing loss history	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
Ear surgery	0.02	(0.1)	0	(0)	0	(0)	0.02	(0.1)	0.05	(0)	0	(0)
Ear infection	0.10	(0.3)	0.08	(0.3)	0.12	(0.3)	0.17	(0.4)	0.16	(0.4)	0.15	(0.3)
Tinnitus	0.12	(0.3)	0.22	(0.4)	0.05	(0.2)	0.27	(0.4)	0.26	(0.4)	0.17	(0.4)
Ototoxic medic.	0.05	(0.2)	0	(0)	0.02	(0.1)	0.04	(0.2)	0	(0)	0.03	(0.2)
Smoking	0.10	(0.3)	0.19	(0.4)	0.17	(0.4)	**0.24**	**(0.4)**	0.16	(0.4)	0.17	(0.4)
Alcohol consump.	0.76	(0.4)	0.88	(0.3)	**0.95**	**(0.2)**	0.81	(0.4)	**0.47**	**(0.5)**	0.85	(0.3)
Hunting	0.19	(0.4)	**0.04**	**(0.2)**	0.10	(0.3)	**0.04**	**(0.2)**	**0**	**(0)**	**0.07**	**(0.3)**
Shooting	0.02	(0.1)	0.08	(0.3)	0.05	(0.2)	0.04	(0.2)	0.11	(0.3)	0.06	(0.2)
Amplified music	0.02	(0.1)	0.01	(0.1)	0.03	(0.1)	0.03	(0.1)	0	(0)	0.03	(0.2)
Power tools	0	(0)	0	(0)	0	(0)	0.01	(0.1)	0	(0)	0	(0)
Car racing	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)
Motorcycle	0	(0)	0	(0)	0	(0)	0.01	(0.1)	0	(0)	0	(0)
Military	0.29	(0.5)	0.16	(0.4)	0.30	(0.5)	0.22	(0.4)	0.3	(0.4)	0.1	(0.3)

Bold type indicates mean proportions that differ significantly ($p \leq 0.05$) from the non-exposed group from Warehouse and Health Clinic.

existed among the studied groups, previous exposure to noise, previous exposure to chemicals, medical and audiological histories, hobby history, and prior military service were assessed. The characteristics of the six study populations are presented in Table II. The mean proportions, for each of the variables, which differ significantly ($p \leq 0.05$) from the non-exposed group are indicated by bold type.

Questionnaire

All subjects were interviewed for factors such as age, medical history, non-occupational and occupational exposures. The interview protocol included questions concerning demographic data, health information that focused on events that could be related to hearing status, and non-occupational noise exposure data (NIOSH, 1996*b*). The self-reported medical history included data on diabetes, prior ear surgery, head injury, high fever, measles, high blood pressure, mumps, ear infections, history of hearing loss in the family, use of ototoxic medication and tinnitus. Medical history items like diabetes and high blood pressure, were reported as positive if the employee had received or was receiving treatment for the listed condition. Hobby history included questions about diving, hunting, shooting, car racing, motorcycling, listening or playing amplified music, and using power tools. A brief work history was collected which included job descriptions, exposure to noise and chemicals, and hearing protector and respirator usage.

Testing Procedures

Otoscopy, pure-tone audiometry, and immittance measurements were performed to test the workers' auditory functions. Six individuals among the 444 were excluded of the study, based on otoscopy due to of external otitis or perforated tympanic membrane. The tests were performed by audiologists under the principal investigator's supervision.

Pure-tone Audiometry

All the subjects in the present study underwent pure-tone audiometry at the frequencies of 0.5, 1, 2, 3, 4, 6 and 8 kHz for air conduction, before the beginning of their work shift. When there was an indication of conductive hearing loss, bone conduction testing was added. Testing was preceded by a period of at least 14 h without exposure to occupational noise. Subjects were tested in a sound-insulated chamber which met the specifications of ANSI S 3.1-1991 for audiometric testing environments. The audiometer used was a Beltone 2000. Daily biological calibration checks were performed immediately before testing the subjects.

Any high-frequency hearing losses were classified into categories by severity, using a clinical criteria described elsewhere (Morata et al., 1993). Audiograms were classified as normal if no single threshold exceeded 25 dB. The bilateral thresholds in the frequency range of 0.5–2 kHz were averaged, as were the bilateral thresholds of the most affected frequency of the 3–8 kHz frequency range. The results were considered in assigning a classification to the audiograms. A non-occupational category was included to account for those hearing losses that can not be attributed to occupational factors (either severe unilateral or conductive hearing losses, and hearing losses which did not have a high-frequency configuration).

Immittance Measurements

Immittance measurements were performed on all the subjects. It

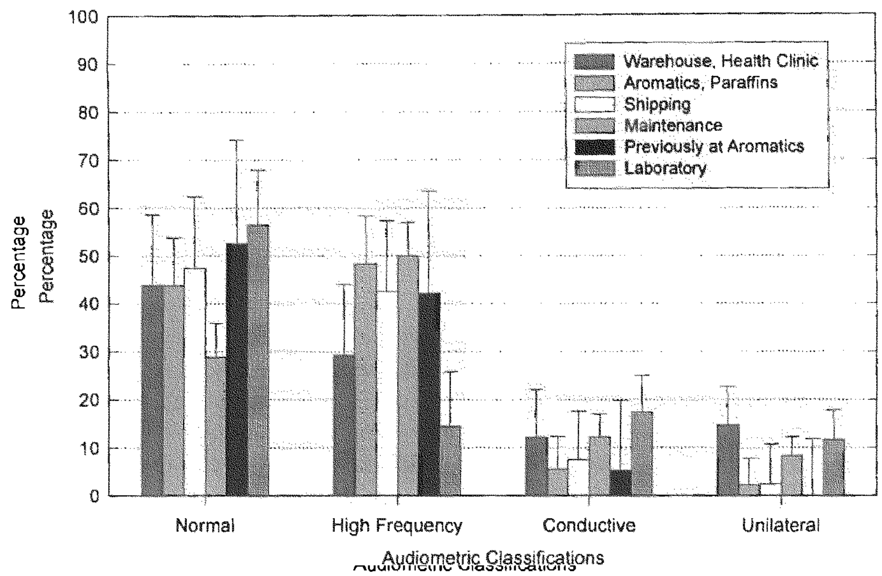

Fig. 1. Classifications assigned to the audiograms of all subjects ($n = 438$) by exposure group (Normal hearing, High frequency hearing loss, Conductive hearing loss and Unilateral hearing loss). T bars indicate upper bounds of 95% confidence intervals.

consisted of tympanometry, static compliance, ipsilateral and contralateral acoustic reflex threshold test (at frequencies 0.5 and 1 kHz), a reflex decay test (at frequencies 0.5 and 1 kHz) and a physical volume test. The acoustic reflex threshold is established by an ascending and descending 5-dB increment bracketing procedure to determine the minimal intensity required to note a change in middle ear compliance (Silman & Gelfand, 1982). Abnormal reflex decay exists when a stimulus is presented at a level of 10 dB greater than the reflex threshold and the amplitude of the reflex decreases to less than half of its original value in 10 s or less (Newby, 1979).

The main objective in performing immittance measurements was to obtain information on lesion site by investigating the acoustic reflex findings in the studied groups. The acoustic reflex tests were chosen because of their reliability, availability and ease of administration. Immittance measurements were accomplished with a Danplex Tymp 83.

Data Analysis Strategies

Data from the questionnaire and test results were entered into dBASE III Plus and into data files using a program written in Clipper. Extensive checks and rechecks were made for invalid codes or consistency errors. After these were corrected a clean data file was ready for analysis. The data were analysed with the Statistical Analysis System (SAS, version 6.08, 1994), using univariate analyses of variance (ANOVA). The data from the questionnaire were analysed using ANOVAs for each of the variables. Tests for contrasts were done using Fisher's least significant difference test. Analyses were done to assess the effect of exposure on hearing status. Logistic regression was used for the estimation of hearing loss rates, adjusted for confounding variables.

Results

Audiometric Results

The percentages of the various audiometric classifications (with T bars indicating upper bounds of 95% confidence intervals) by group are displayed in Fig. 1. All the subjects were included in the analysis.

Results of the analyses of variance indicated that the exposed groups had significantly more workers with high-frequency hearing losses than the groups from the warehouse and health clinic or the group from the laboratory ($p < 0.005$).

Analysis of Association between Hearing Status and Exposure Conditions

The bilateral high frequency sensorineural hearing losses were examined as a binary outcome variable (normal hearing vs high-frequency hearing loss) using multiple logistic regression. Thresholds of 25 dB HL or less were considered normal. For this analysis, conductive and unilateral hearing losses were entered as normal hearing as they could not be clearly associated with the occupational exposures. This analysis was conducted for the estimation of odds ratio, adjusted for confounding variables. Whenever the period of observation is equal for the all study subjects and the outcome interest is a binary factor, logistic regression is a powerful statistical tool for the estimation of odds ratio adjusted for confounding variables and for the systematic appraisal of effect modification (Kelsey et al., 1986). The coefficients of the dummy variables express the relative (log) odds of a problem for each group. In the present study, the dummy variables were the groups that

Table III. *Results of multiple logistic regression for occupational hearing loss, by group*

Variable	Beta	SE	χ^2	p value	Odds ratio (95% CI)
Intercept	−4.314	0.941	21.01	0.000	
Aromatics	0.864	0.452	3.65	0.056	2.4 (1.0–5.7)
Shipping	0.569	0.521	1.19	0.027	1.8 (0.6–4.9)
Maintenance	1.110	0.422	6.91	0.008	3.0 (1.3–6.9)
Prev. Arom.	0.325	0.614	0.28	0.596	1.4 (0.4–4.6)
Laboratory	−0.664	0.527	1.59	0.208	0.5 (0.2–1.4)
Age	0.088	0.019	20.76	0.000	1.1 (1.0–1.1)

represent different exposure conditions. The variables considered for inclusion in the model were the following: age, exposure group, length of employment, previous occupational exposure to noise or to chemicals, exposure to non-occupational noise and medical history which included smoking and alcohol consumption (see Table II for listing of variables included). The approach used was the stepwise logistic regression. That is, at each step, the variable with the lowest p value (<0.05) is added to the model and values of probabilities >0.05 are removed from the model. Only the variables that add appreciably to the predictive power of the model remain in it. The logistic regression model used to test for exposure effects had a dependent variable which indicated presence or absence of hearing loss. The final model included independent variables for group identification, age (the only variables that met the significance level criterion for inclusion in the model) and an intercept. Table III gives the results of the multiple logistic regression model, with the age-adjusted odds ratio estimates for high-frequency sensorineural hearing loss.

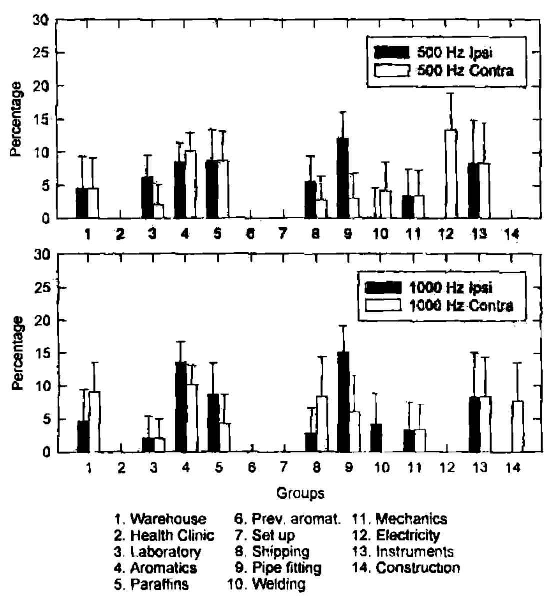

Fig. 2. Percentage of ears with acoustic reflex decay, by exposure group, test frequency, and stimulus presentation ($n = 339$). T bars indicate standard error. Workers from the Maintenance division were divided in subgroups 7–14.

Acoustic Reflex Measurements

The reflexometry measures analysed were: absence or elevation of the reflex (in relation to expectation based on ears with normal sensitivity or ears with cochlear hearing losses), presence of loudness recruitment [observed when the difference between the pure-tone and acoustic reflex thresholds is less than 60 dB SL (Northern et al., 1985)], and the presence of acoustic reflex decay [50% reflex decay before 10 s (Newby, 1979)].

Initially, multivariate analysis of variance (MANOVA) was performed using the following independent variables: group, ear, frequency of the stimulus, and stimulus presentation (contra- or ipsilateral).

No significant difference was observed between the departments for any of the measures analysed. However, subsequent ANOVAs indicated significant differences between the groups regarding reflex decay ($p < 0.05$), but not absence or elevation of reflex. Group contrasts regarding reflex decay showed that the percentage of cases for both frequencies was significantly higher for the workers from aromatics and the subgroup of pipe-fitters from maintenance than for the other groups ($p < 0.05$), and higher when the stimulus was presented ipsilaterally (Fig. 2). The reflex decay test could not be accomplished with 99 of the subjects.

Discussion

Audiometric Findings

To assess the workers' hearing status, pure-tone audiometry and immittance measures were performed. All the subjects underwent a brief interview with regard to health history that focused on hearing, work history, solvent and noise exposure.

From the gathered descriptions of exposures and work routines from the studied groups, maintenance was the only department in which workers were clearly exposed to noise doses considered to be high enough to cause a hearing loss. Regarding solvent exposure, measurements performed during this investigation showed that exposures to toluene, xylene, ethyl benzene and cyclohexane were always below recommended exposure limits. The exception was for benzene levels which exceeded recommended limits in several instances.

Even though measurements suggested that most noise and solvent exposures were within exposure limits, simultaneous exposure to noise and a solvent mixture was found to be associated with elevated prevalences of high-frequency hearing loss. For the group from maintenance it was 50%, 49% in the aromatics and paraffins group, 42% in both the groups from shipping and the group that previously worked in aromatics, 30% in the group from the warehouse and health clinic and 15% in the group from the laboratory. For some unclarified reason, the groups from warehouse and health clinic, that did not have a history of occupational exposure to either of the exposed agents, had an elevated prevalence when compared with the group from the laboratory.

High-frequency hearing losses were examined using multiple logistic regression for the estimation of odds ratio, a risk ratio, adjusted for confounding variables. In this case, age and department were the only variables that met the significance level criterion for inclusion in the regression model. The adjusted odds ratio estimates were 2.4 times greater for the groups from aromatics and paraffins (95% CI 1.0–5.7), 3 times greater for the maintenance group (95% CI1.3–6.9) and 1.8 times greater for the group from shipping (95% CI 0.6–4.9), when compared to the groups from warehouse or the health clinic.

Among the solvents investigated in the study, there is evidence available on the ototoxicity of high concentrations to toluene and xylene, individually, or as components of solvent mixtures (Johnson et al., 1988; Pryor et al., 1987; Morata et al., 1993; Nylén & Hagman, 1994; Nylén et al., 1994; Campo et al., 1997). This is the first study to report an association between exposures below internationally recommended limits and auditory disorders.

Despite the lack of any data on the association of exposure to low concentration of solvents and hearing loss, it is generally assumed that exposure to each of the individual agents below the recommended limits is safe. However, when agents occur in combination, it is conceivable that levels below their recommended limit could still have a deleterious effect. Data on the effects of solvent combinations on the auditory system have shown, in most cases, an additive effect. However, it has been reported that solvents that do not have an effect on the auditory system when presented individually, can enhance the effect of an ototoxic solvent (Nylén & Hagman, 1994; Nylén et al., 1994). Furthermore, a synergistic interaction with noise has been reported for toluene (Johnson et al., 1988; Lataye & Campo, in press) and trichloroethylene (Muijser et al., 1994). It is conceivable that the hearing losses are not associated with the limit-normalized levels of the observed agents but that, peak, non-trivial exposures to either noise or solvents may be contributing to their losses. It is also possible that exposures have been underestimated in this study or that they were higher in the past. Furthermore, we do not know the contribution of non-occupational sources of exposure or the internal doses of their exposures to solvents. Whatever the correct explanations may be, they raise serious concerns regarding workers exposed to combinations of noise and chemical agents. Hitherto, occupational hearing conservation programs have not taken chemical exposures into consideration, whether occupational and/or non-occupational.

Acoustic Reflex Decay Findings

With the workers grouped in departments, no significant difference was observed for the results of the immittance measurement battery. However, the results from sections within the departments revealed significant differences. The subgroups from aromatics and pipe-fitting exhibited a significantly higher percentage of cases of acoustic reflex decay than in the other groups. The acoustic reflex arc involves the pathways up to the lower brainstem level. The results of the acoustic reflex decay test suggest that there might be a retrocochlear involvement in the hearing disorders observed among these workers. Furthermore, the percentage of reflex decay for ipsilateral stimulation was significantly greater than for contralateral stimulation. These findings suggest that the hearing disorders in the two groups have a suspected involvement of the auditory portion of cranial nerve VIII. Contralateral reflex decay has been reported to be abnormal in patients lower brainstem pathology (Stephens & Thornton, 1976; Jerger & Jerger, 1977). The present observations do not eliminate the possibility of the hearing loss having a cochlear component. Although test results do not conclusively uphold such diagnostic statements, they constitute strong evidence about the lesion site. Based on the reflex decay observations, some of the hearing loss observed in the three groups exposed simultaneously to both agents should not be attributed merely to noise exposure effects in the cochlea. The acoustic reflex measurements strongly suggested that the site, as well as the mechanisms underlying the lesions of the group exposed to both physical and chemical agents, may be different from what would be expected from noise exposure alone.

Studies were conducted on auditory and vestibular functions of workers exposed to a mixture of unspecified alcohols, jet fuels and aromatic solvents (Ödkvist et al., 1987; Möller et al., 1989). The findings of pure-tone audiometry, reflex decay and speech discrimination testing did not indicate measurable damage due to solvent exposure that was distinguishable from the effects of noise. However, significant abnormalities were found in tests such as distorted speech discrimination and cortical responses, which assess more central portions of the auditory pathways. A more recent investigation evaluated workers exposed to various solvents with a test battery that comprised both peripheral and central auditory tests. Apart from mild to moderate sensorineural losses observed in some of the workers, the peripheral tests were normal for most subjects. Varying degrees of abnormalities were registered in the tests of filtered speech and cognitive responses, which assess more central portions of the auditory system (Laukli & Hansen, 1995). This evidence indicates that the ideal procedure for studying and assessing the effects of solvents on hearing requires the testing of central portions of the auditory system.

Conclusions

In this study, even though measurements suggested that most exposures were within time-averaged recommended limits, simultaneous exposure to noise and a solvent mixture was found to significantly affect audiometric thresholds and increase the prevalence and odds ratio of hearing loss among refinery workers, when compared with a group of non-exposed workers. This is the first study to associate exposures commonly found in the petrochemical sector with hearing loss.

In addition, the results from the acoustic reflex decay test suggest that there might be a retrocochlear involvement in the hearing disorders observed in some job categories. Even though the prevalence of hearing loss was high among solvent-exposed workers in the present study, it is still likely that these data were underestimations, since the tests conducted may have failed to detect some of the hearing disorders because of their site in the auditory system. More information needs to be made available on the hearing status of petrochemical workers in order to achieve a better understanding of the risk for hearing disorders found in this industry.

Characteristics of hearing loss from industrial chemicals may have such wide variability as to justify more complete testing than in traditional studies of occupational hearing loss. This variability is related to the following: multiplicity of chemicals (with diverse structures) in the occupational environment, non-occupational exposures, limitless possibilities of chemical combinations, and variance in exposure intensity and patterns (i.e. acute, intermittent, chronic). The ideal procedure for studying and assessing the effects of industrial chemicals on hearing ought to include tests that assess central auditory functions, to complement pure-tone audiometry. Nevertheless, the tests used in the present study (pure tone and immittance measures) can be useful screening tools when investigating hearing disorders in industrial populations where complex exposure conditions occur.

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