

# Assessing Occupational Hearing Loss: Beyond Noise Exposures

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In recent years, findings that exposure to industrial chemicals may affect hearing and interact with noise brought to light a risk that had not been given substantial attention previously. The need for research becomes clear when the magnitude of the population of workers exposed to noise and chemicals and the number of potentially hazardous chemicals found in work environments are taken into consideration. The need for research in this area is further heightened by the fact that there are no guidelines or standards for combined exposures of chemical and physical agents. The present paper reviews the effects of combined exposures to chemicals and noise on hearing and examines study designs, hearing assessment alternatives, and strategies for the analysis of combined effects.

*Key words:* Hearing, noise, chemicals, solvents, combined exposures, interaction, study designs.

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The Occupational Noise Standard from the United States Department of Labor celebrated 25 years on April 27, 1996. Despite increasing efforts towards hearing conservation, occupational hearing loss is still one of the most prevalent work-related conditions in the United States, as in most industrialized countries (Merry et al., 1995). The traditional approach to hearing conservation, directed to manufacturing workers exposed to noise levels equal or greater than 85 dBA and which often relies on personal hearing protection, has not proven itself effective. Nonetheless, there has been a steady progression in scientific knowledge which could lead to novel strategies to ensure effective hearing conservation strategies to all worker populations at risk of hearing loss (Merry et al., 1995). One of the relevant findings related to occupational hearing loss is that the effects of noise in the workplace can be exacerbated by other factors, such as: vibration, heat, individual characteristics and industrial chemicals (Lindgreen, 1987; Phaneuf & Hetu, 1990; Morata et al., 1994; Lang, 1994; Pekkarinen, 1995; Ward, 1995).

The purpose of this paper is to focus on the interaction between noise and solvents, which are two common ototraumatic agents

in the workplace, and to discuss strategies for taking multiple exposures into account when investigating, and ultimately, preventing the occurrence of occupational hearing loss.

## *Ototoxic industrial chemicals and noise*

Industrial chemicals that have been investigated as potential ototoxicants include heavy metals, solvents, and asphyxiants (Ryback, 1992; Fetcher, 1989; Fetcher, 1995; Johnson & Nylén, 1995). The majority of animal investigations on the ototoxicity of industrial chemicals is constituted by studies investigating individual solvents, but some also looked at combinations with noise, medicinal drugs, genetic factors, and solvent mixtures (Johnson & Nylén, 1995). In summary, these studies have demonstrated that toluene, carbon disulfide, xylene, styrene, and trichloroethylene are ototoxic and the evidence indicates, with the exception of carbon disulfide, that the effect is most likely related to cochlear damage (Johnson & Nylén, 1995). When toluene or trichloroethylene exposure was combined with noise, either sequentially or simultaneously, a synergistic interaction was noted in rats (Johnson et al., 1988; Muijsers et al., 1993-

1994). In most of the cases when solvent mixtures were investigated, additive rather than non-additive interactions were indicated (Johnson & Nylén, 1995).

In human studies, voluntary, accidental, or occupational exposures to solvents, asphyxiants or metals have been associated with a variety of symptoms that suggest several possible underlying mechanisms for hearing loss (Fetcher, 1989, 1995). Some of these chemicals are recognized as neurotoxic and can affect hearing or equilibrium by acting primarily at the level of the brainstem or higher central auditory pathways (Möller et al., 1989; Möller et al., 1990; Ödkvist et al., 1987; Ödkvist et al., 1982). The indication that occupational chemicals could alter auditory function by either ototoxicity, neurotoxicity, or a combination of both processes should be taken into account by any investigator especially when selecting the metrics to be used.

### *Evaluating the effects of multiple exposures on hearing*

In general, studies on occupational hearing loss have relied on pure tone audiometry and averaging thresholds as the means to assess noise effects on auditory function. To investigate the effects of combined exposures, this typical approach may not be sufficient nor adequate.

Field studies conducted with styrene, an organic solvent which ototoxicity has been reported in rats (Pryor et al., 1987), used this approach and identified only minimal effects of the solvent on pure tone thresholds (Möller et al., 1989; Muijser et al., 1988; Sass-Kortsak et al., 1995). Workers exposed to low levels of styrene did not appear to have increased age-dependent hearing loss at high frequencies (Muijser et al., 1988). Nonetheless, a comparison within the group of exposed workers between the least exposed and the most exposed revealed a statistically significant difference in hearing thresholds at high frequencies. Audiometric results of workers exposed to styrene in a plastic boat plant did not indicate hearing losses resulting from causes other than exposure to noise (Möller et al., 1990). Seven of eighteen workers, however, displayed abnor-

mal results in central auditory system testing. Styrene and noise exposures were meticulously assessed for 299 workers in the reinforced fiber industry (Sass-Kortsak et al., 1995). Noise levels were found to be in the range between 85 to 90 dBA, while styrene levels were generally below the recommended level of 50 ppm. The association between noise exposure, based on the developed lifetime noise dose estimate, and hearing loss (assessed by averaging pure tone thresholds) was significant. That was not the case for styrene exposure. Styrene exposure approached significance for hearing loss only at some specific frequencies (Sass-Kortsak et al., 1995).

The assignment of audiometric results into categories using various criteria, and the subsequent estimation of prevalence rates and risk ratios (from hearing results being analyzed as a binary variable), are approaches that have yielded more robust indications of the risk posed by occupational exposures to solvents on hearing. Some examples of these alternatives are presented below.

In a 20-year longitudinal study of hearing sensitivity in 319 employees from different departments of industry, the percentage of workers with compensable hearing loss was calculated (Bergström et al., 1986). A large proportion of the workers in the chemical sector showed compensable hearing loss (23%) as compared to groups from non-chemical environments (5-8%). This effect was found despite the lower noise levels in the chemical department (80-90 dBA) when compared to other divisions (95-100 dBA). Thus, the exposure to industrial solvents was implicated as an additional causative factor for those hearing losses.

The hearing function of workers from a printing facility who were exposed simultaneously to noise (88-98 dBA) and toluene (100-365 ppm) were compared with a group of printers exposed to noise alone (88-97 dBA), a group exposed to a solvent mixture in which toluene was the main component, and a control group exposed neither to noise nor toluene (Morata et al., 1993; Morata, 1990). The audiometric thresholds of the four study groups were averaged and compared as the first step in the data analyses (Morata, 1990).

Following that, Analysis of Variance (ANOVA) tests were performed (between and within subjects) comparing the mean thresholds of all subjects (nested in groups), by frequency and by group.

The audiometric threshold averages indicated that the groups exposed to noise alone or in concert with toluene had significantly poorer hearing thresholds than both the non-exposed group and the group just exposed to a solvents mixture. This finding does not offer evidence to discriminate between the effects of noise or toluene, probably due to the overlap of effected frequencies.

Subsequent to the calculation of mean audiograms, the audiogram of each worker was classified as either normal or altered by a conductive or sensorineural hearing loss. The losses were scaled according to different levels (mild to profound), and further classified as either bilateral or unilateral. The use of clinical audiometric classification indicated that most of the hearing losses for the groups exposed to solvents were mild (up to 45 dB HL) and allowed for the estimation of prevalence rates (Morata et al., 1993). The prevalence of sensorineural hearing loss found in the group exposed to noise and toluene simultaneously (53%) was statistically higher than in other groups: 8% in the non-exposed group, 26% in the noise exposed group, and 18% in the group exposed to a mixture of solvents. It should be noted that the prevalence of high-frequency hearing losses observed among those exposed to solvents only (18%) was higher than for those unexposed (8%), although they had equivalent mean thresholds.

For the next analysis, cases of conductive and unilateral hearing losses were excluded, as they could not be clearly related to the occupational exposures. Whenever the period of observation is equal for all study subjects and the outcome of interest is a binary factor, logistic regression is a powerful statistical tool for the estimation of risk ratio adjusted for confounding variables and for the systematic appraisal of effect modification (Kelsey et al, 1986; Miettinen, 1985). The dummy variables were the groups that represented different exposure conditions. The variables considered for inclusion in the model were: age, length of

employment, previous occupational exposure to noise or to chemicals, and exposure to non-occupational noise. By assessing the predictive power of the logistic regression model, only age, length of employment, and group contributed significant information to the model. Other variables were eliminated by stepwise addition or subtraction to model. Age and length of employment were highly correlated. So, since the study population was relatively young (median age 33), the investigators opted for the model that included length of employment, as an exposure variable, instead of age. This provided estimates of adjusted relative risk for hearing loss, four times greater (95% confidence interval, 1.4 to 12.2) for the noise group; eleven times greater (95% confidence interval, 4.1 to 28.9) for the noise and toluene group; and five times greater (95% confidence interval, 1.4 to 17.5) for the solvents group.

These results are powerful indicators of the effects of solvents on hearing, but these effects could only be clearly identified by treating the hearing data as a binary variable. If only audiometric threshold averaging had been performed, the association between solvent exposure and hearing loss would not have been noted. In fact, the opposite conclusion would have been reached (Morata et al., 1993; Morata, 1990).

Acoustic reflex threshold measurements also performed in the same investigation suggested the hearing losses found in the group exposed to both agents might be due to lesions with a central auditory system component.

Inasmuch as the reported prevalence of hearing loss among solvent exposed workers was surprisingly high, it is still likely that those were underestimations, since the field studies may have failed to detect some of the hearing disorders because of insufficient testing (Bergström & Nyström, 1986; Morata, 1990). Furthermore, the auditory retrocochlear disorders due to solvent exposure could represent a more debilitating impairment than the one caused by noise, or expected from the pure tone audiogram.

In the study on printers, the acoustic reflex results contributed to a better appraisal of the

risk and indicated that the administration of complementary audiologic tests is needed to adequately assess the impact of chemicals on hearing (Morata, 1990).

A similar approach was used with petrochemical workers who were exposed to various levels of noise and solvents mixtures (Morata et al., 1997). The ideal study design would have a comparison group with neither noise nor chemical exposure, i.e., the baseline nonexposed group, a group with only noise exposure and another with only chemical exposure. Preferably these latter two groups will have similar levels of exposure as the group with both noise and chemical exposure. This configuration allows for the clearest delineation of the additive or synergistic effects that may be related to combined exposures. A further requirement is similarity among groups with respect to age, gender, and socioeconomic status. Often the ideal is difficult to attain and probably the most difficult problem is to identify a population with similar exposures. Data from a group with exposure to a compound with a similar chemical structure and exposure level could be used, and in the case of noise exposure, comparing the results with ISO estimates for noise exposure and age is an option. This was the approach used in the study with petrochemical workers. The study groups included workers exposed to various concentrations of organic solvents and noise, and unexposed controls (Morata et al., 1997). Since no group was exposed exclusively to noise, mean audiometric thresholds of the groups were compared to estimates from ISO 1999, databases B and E (ISO 1999, 1990). Each of the studied groups had poorer thresholds at the frequencies of 1 and 2 kHz than the ISO estimates for their age, and some of the exposed groups also had poorer thresholds than ISO 1999 databases B and E at higher frequencies (3 to 6 kHz). Again, from this analysis only, it was difficult to reach a conclusion on which exposures were associated with hearing loss. Evidence on the association of exposure to various combinations of solvent and noise became clear after the estimation of prevalence rates and risk ratios. Despite measurements which suggested most exposures to noise and solvents were below

recommended limits, the prevalence for hearing loss within the exposed groups ranged from 42 to 50%, significantly exceeding the 30% prevalence observed for the unexposed group. 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. Finally, the results of acoustic reflex decay test contributed to the differentiation of the causes of some of the observed disorders.

The effects of toluene on the auditory system were studied in a group of rotogravure printers through the use of brainstem auditory evoked responses (Abbate et al., 1993). Forty workers with normal hearing ability (assessed by pure tone audiometry), who had been exposed to an average of 97 ppm for 12 to 14 years, were selected to participate. Their results were compared with those from a group of workers of the same age but not occupationally exposed to solvents. The study indicated that exposure to toluene was associated with a statistically significant alteration in the evoked responses, visible for all waves and all the intervals studied. The auditory brainstem evoked responses demonstrated auditory nervous system modifications before the occurrence of clinical signs due to chronic exposure to toluene.

Clinical studies have been conducted on auditory and vestibular functions of workers exposed to mixtures of unspecified alcohols, jet fuels, and aromatic solvents (Möller et al., 1989; Ödkvist et al., 1987). The test battery included pure-tone audiometry, speech reception threshold, maximum speech discrimination score, discrimination of interrupted speech, acoustic reflex thresholds and decay, phase audiometry, auditory brainstem responses, and cortical response audiometry. The findings of pure-tone audiometry and speech discrimination testing essentially were normal for age and noise exposure history, and did not indicate measurable cochlear damage due to solvent exposure. However, a significant abnormality was found in tests that assessed

more central portions of the auditory pathways, specially in discrimination of interrupted speech and evoked cortical potentials in response to frequency glides (Möller et al., 1989; Ödkvist et al., 1987).

The association between hearing disorders and occupational exposure to solvent mixtures have also been studied through the use of self-assessment scales in a cross-sectional design with 3284 male subjects (Jacobsen et al., 1993). Exposure to solvents for 5 years or more resulted in an adjusted relative risk for hearing impairment of 1.4 in men without occupational exposure to noise. A sub-sample of 51 men was examined with pure-tone audiometry and 20 of the 21 men who reported abnormal hearing also fulfilled an audiometric criterion for hearing impairment. Occupational exposure to noise had an effect twice that of solvents and in the case of combined exposures the effects from noise dominated.

Auditory brainstem responses (ABR) and auditory event-related potentials were recorded in workers exposed occupationally to lead who had their blood lead levels monitored (Discalzi et al., 1992; Discalzi et al., 1993; Araki et al., 1992). Blood lead levels were significantly correlated with abnormalities in the recorded evoked potentials. Although less pronounced than the alterations caused by lead exposure, significant alterations in the ABR were also observed in the case of occupational exposure to mercury (Discalzi et al., 1992).

## Discussion and conclusion

Occupational and non-occupational factors that may interact in causing a hearing loss should be assessed when planning a field study in order to minimize the risk of potentially confounding the relation between exposure and hearing loss. Factors like age, gender, race, medical history, non-occupational, and occupational exposures to noise and chemicals can be assessed by using a questionnaire or by reviewing records.

The selection of study designs and plan for analysis needs to be scrutinized more carefully in studies which assess the effects of multi-

ple occupational exposures than in studies in which the only hazardous agent considered is noise. Currently, ototoxic properties of industrial chemicals have only been investigated for a very small number of substances. When specific ototoxicity information is not available on the chemical under consideration for study, the investigator should gather information on the agent's general toxicity, neurotoxicity (since most of the chemicals that were found to affect the auditory system are neurotoxic), and common complaints from exposed populations.

A crucial decision to be made concerns metrics. Various parts of the auditory system have been reported to develop lesions in association with industrial chemicals. This variability of site of lesion implies that performing exclusively pure tone audiometry and averaging threshold results may be inadequate and result in underestimation of the outcome. The ideal situation would be to administer a complete audiological battery; however, this is often not feasible in occupational studies because of the cost and time involved. In such cases, the use of tests that complement pure tone audiometry and evaluate more central portions of the auditory system are essential.

The evidence of the ototoxic effects of some industrial chemicals has far-reaching implications for hearing conservation. Whether current practices are meeting the needs of workers exposed to chemicals needs to be further evaluated, as does the hearing assessment used when monitoring these workers. A greater understanding of the effects of combined exposures on hearing is needed so that more effective strategies can be developed for the prevention of hearing loss.

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