

A comparison of the effects of solvent and noise exposure on hearing, together and separately

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Abstract

The objective of the present study was to assess the effects of occupational exposure to noise and organic solvents on hearing loss in bus and truck plant workers. Our case control study contained 469 workers from a bus and truck plant divided into three groups. The first group contained workers exposed to only noise; the second group contained workers exposed to both noise and mixture solvents at a permissible level; and the third group included workers exposed to permissible levels of solvents. The control group (Group 4) included 119 individuals selected randomly, persons who were not exposed to noise and solvents. These groups were compared in terms of each individual's frequency hearing loss in both ears. Our study demonstrates that combined exposure to mixed solvents and noise can exacerbate hearing loss in workers. Hence, a suitable hearing protection program is advised that would contain short-interval audiometric examinations and efficient hearing protectors.

Keywords: Combined exposure, hearing loss, noise, occupation, occupational exposure, solvents

Introduction

Hearing loss is a common occupational disorder among industrial workers.^[1,2] The hearing loss of workers can be engendered by several factors, including age, heredity, ototoxic drugs, smoking, and exposure to ototoxic substances in working environments.^[3] Noise exposure has usually been considered as the main hazard for occupational hearing loss.^[4] It is possibly the most abundant of all ototoxic occupational hazards, and besides there is proof for causal links between noise and both auditory and other health effects.^[4] Other ototoxic factors associated with industrial environments are often disregarded.^[5,6] Nevertheless, it was known that several chemicals, including organic solvents such as toluene, xylene, styrene, n-hexane, and trichloroethylene, have neurotoxic and ototoxic effects.^[5]

Several researchers have indicated that occupational exposure to solvents has a toxic effect on the auditory system.^[2,7,8] The first time organic solvent ototoxicity was proven was in rats.^[9-11] The case study reported increased hearing loss when exposed to noise and solvent chemicals, where the hearing

damage was higher than what is expected in cases of exposure to only noise.^[8] In similar studies, more workers verified that the exposure to organic solvents combined with noise, or solvents alone, are associated with hearing loss.^[2,12,13]

The research published is even more alarming, proposing that such solvents may be harmful to hearing at even at concentrations within the limits advised by international agencies.^[13,14] Organic solvents can lead to hearing loss by themselves or elicit noise-induced hearing loss.^[2,15,16] Furthermore, the elevated prevalence of hearing loss has been demonstrated after exposure to organic solvents in the presence of a noise level below the occupational exposure limit value.^[17,18] Therefore, this condition shows a synergistic effect between noise and organic solvent exposure.^[19] Studies have demonstrated that the prevalence of hearing loss found in the combined exposure group is higher than in the noise group, solvent group, and control group.^[12,20] In working environments where organic solvents are used, noise is also common.^[12] Thus, the ototoxicity of organic solvent may interact with noise environments.^[12,21]

The objective of the present study was to assess the effects of occupational exposure to noise and organic solvents on hearing loss in bus and truck plant workers.

Methods

This research is a retrospective case control study. The study contained four groups. Group 1 was comprised of

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223 workers exposed to noise only. These workers were working in the mechanics and assembly department. Group 2 included 131 workers exposed to noise and organic solvents. These workers were working in the paint shop and painting the vehicles. Solvents used in the paint shop included benzene, toluene, xylene, tetrachloroethylene, and acetone. Group 3 was comprised of 115 workers exposed to only solvents. These workers were working in the paint store for the storage and preparation of the paints and solvents. They were also exposed to benzene, toluene, xylene, tetrachloroethylene, and acetone. Group 4 consisted of 119 individuals selected randomly from different administrative clerk sections in the Ankara Occupational Diseases Hospital, who were neither exposed to noise nor exposed to organic solvents. Groups 1, 2, and 3 included the bus and truck plant workers, whose periodic examinations were conducted in Ankara Occupational Disease Hospital. Personal data, such as smoking habits, a detailed history of current and previous occupational jobs, a history of chronic drug intake, and any previous ear operations, pus discharge or hearing problems, was obtained from periodic inspection files. Subjects with a history of chronic illness such as diabetes mellitus or hypertension were eliminated from this study.

Audiometric testing was done using a pure tone manual diagnostic audiometer (Model GSI 61, Grason-Stadler, Inc) by a single audiologist at the Audiology Laboratory, Ankara Occupational Disease Hospital. The subjects were tested in a sound-isolated chamber. Pure tone audiometry was conducted with the subjects at frequencies of 0.5, 1, 2, 3, 4, 6, and 8 kHz using both air and bone conduction. Subjects should try to discriminate low sound levels of different frequency pure tones and respond by pressing a button. The lowest tone heard at each frequency was considered as the hearing threshold level. The thresholds in the frequency range of 0.5-2 kHz were averaged, and average hearing threshold was determined.

Blood solvent levels of subjects who were exposed were measured for one time at periodic examination day in our institute.

An environmental noise assessment using a portable sound level meter standard (CEL-440) was performed at different departments and at different points of exposure during the working shift (8 h). By this way minimum, maximum and average noise level were obtained at each site. The noise

intensities were read out as an equivalent A-weighted sound level in decibel (dBA).

The environmental monitoring of organic solvent levels at different work departments was obtained from the environmental records of the factory maintained by The Republic of Turkey Ministry of Labor and Social Security Institute of Occupational Safety and Health for the same year as the study. To determine the level of exposure to benzene, toluene, xylene, acetone, tetrachloroethylene; a glass adsorption tubes were sealed during the working shift for one time and samples analyzed by gas chromatography (8-h time weighted average).

Hazard index (hygienic effect) is calculated to determine the influence of the different solvents on the total exposure load.

Statistical analysis

The Analysis of Variance and *t*-test were used to compare hearing levels among the groups. Furthermore, Spearman Correlation test was used to investigate whether there is a correlation between exposure time, age, and hearing levels. $P < 0.05$ were considered statistically significant. All the mentioned calculations were performed using Statistical Package for the Social Sciences v.15 (IBM, Chicago, IL) software.

Results

The results of our study are presented as a mean $\pm$ standard deviation and range of quantitative variables. The average age of all workers was 37.56 years. The subjects' age ranged from 19 to 63 years. The average work experience of all workers was 14.78 years (range: 0-40 years). One hundred and thirty-nine workers were smokers (29.6%). Mean age of subjects in Group 1 was 37.52 ± 6.0 years, and their mean duration of exposure was 16.56 ± 6.2 years (8 h/day for 5 days/week). Mean age of subjects in Group 2 was 37.27 ± 4.7 years, and their mean duration of exposure was 12.7 ± 5.8 (8 h/day for 5 days/week). Mean age of subjects in Group 3 was 38 ± 5.1 years, and their mean duration of exposure was 13.7 ± 6.1 years (8 h/day for 5 days/week). Mean age of subjects in Group 4 was 35.76 ± 7.7 years. Table 1 shows that the groups did not exhibit a statistically significant difference in age and smoking. However, there was a significant difference ($P < 0.0001$) in work experience between Group 2 and the other groups.

The concentrations of organic solvents in the paint shop and paint store was demonstrated in Table 2.

Table 1: Comparison between worker groups according to age, work experience and smoking

Variables	Noise $n = 223$; mean $\pm$ SD	Solvent + noise $n = 131$; mean $\pm$ SD	Solvent $n = 115$; mean $\pm$ SD	Control $n = 119$; mean $\pm$ SD	P^*
Age	37.52 ± 6	37.27 ± 4.7	38 ± 5.1	35.76 ± 7.7	0.574
Duration of exposure (years)	16.56 ± 6.2	12.7 ± 5.8	13.7 ± 6.1	—	<0.001
Smoker %	30.04	29	29.56	31.05	0.979

*ANOVA. SD = Standard deviation, ANOVA = Analysis of variance

The average noise level was 84.5 dB (range: 79-86.5 dB) in the mechanical assembly department, and 84 dB (range: 78-87 dB) in the paint shop.

There is a highly statistically significant difference ($P < 0.001$) between all workers (Groups 1, 2, 3) and the control (Group 4) about hearing impairment for 250 Hz, 4000 Hz, 6000 Hz and 8000 Hz in both ears, right and left [Table 3]. Frequencies where there is significantly difference were written bold. There is the difference especially these frequencies between exposed to noise and/or solvents groups and non-exposed group.

As the age and exposure time increased, in both ears of every employee, the hearing level had been determined to increase, especially on 250 Hz, 4000 Hz, 6000 Hz, and 8000 Hz [Table 4]. Frequencies where there is significantly difference were written bold.

There were no statistically meaningful differences between the groups on the average threshold of hearing on both ears

Table 2: Mean levels of organic solvents measured at the study sites

Work station	Concentration (mg/m ³)				
	Benzene	Toluene	Xylene	Acetone	Tetrachloroethylene
Paint shop	1.86	26	411	182	43
Paint store	0.98	33	265	98	51
ACGIH-TLV*	46	75	435	1206	173
EU**	23	192	221	1210	170
TR***	3.25	190	440	—	206

*American Conference of Governmental Industrial Hygienists Threshold Limit Values, **The Commission of the European Communities: Occupational exposure limit values, ***The Republic of Turkey Ministry Of Labor And Social Security Exposure Limit Values

(right $P = 0.26$, left $P = 0.12$). On both ears, only noise exposed group at 250 Hz (Group 1) had increased hearing loss to a statistically meaningful degree when compared with other groups (Groups 2, 3). It was determined that the hearing loss had a statistically significant increase in people who had been exposed to both solvent and noise, in the range of 4000 Hz on the right ear and 2000, 4000, 6000, and 8000 Hz on the left ear. Interestingly at 6000 Hz on right ear we found that hearing loss in Group 1 was more prominent than other groups. In all of the groups, the right and the left ear had been affected the voice equally [Table 5 and Figure 1].

Hazard index of paint shop (where the Group 2 subjects are working) was 1.71. Hazard index of paint store (where the Group 3 subjects are working) was 1.44.

Discussion

Occupational hearing loss has generally been associated with noise exposure, but there is a growing cognizance that industrial solvents can have an adverse effect on the audio vestibular system in humans. Both animal experiments and human studies showed that the solvents would be able to have an ototoxic effect, resulting in some central auditory and vestibular disturbances.^[19] Our study demonstrated that there was elevated hearing loss for workers who were exposed to both solvents and noise compared with those exposed to only noise. This occurred in spite of the fact that the levels measured for both noise and solvents were much lower than those levels suggested by the American Conference of Governmental Industrial Hygienists' threshold limit

Table 3: Comparison of audiogram findings between the control group and all workers

Groups	Mean rank							
	AHT	250 Hz	500 Hz	1000 Hz	1000 Hz	4000 Hz	6000 Hz	8000 Hz
Right ear								
Workers (n=469)	301	310	294	298	295	329	336	327
Control (n=119)	265	232	294	277	291	155	130	163
P	0.03	<0.001	0.974	0.15	0.77	<0.001	<0.001	<0.001
Left ear								
Workers (n=469)	304	316	302	302	302	331	332	321
Control (n=119)	256	207	264	262	261	148	144	186
P	0.005	<0.001	0.014	0.006	0.010	<0.001	<0.001	<0.001

AHT = Average hearing threshold

Table 4: Comparison of audiogram findings for age and work experience, each frequency and both ears. There is a positive correlation between hearing levels at 250, 4000, 6000, 8000 Hz frequencies and exposure time and age

Variables	Ear	AHT	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	6000 Hz	8000 Hz
Work experience (0-40 years)	Right	r:0.08	r:0.14**	r:0.03	r:0.03	r:0.06	r:0.18**	r:0.22**	r:0.16**
		P:0.10	P:0.003	P:0.53	P:0.48	P:0.22	P<0.0001	P<0.0001	P<0.0001
	Left	r:0.07	r:0.14**	r:0.03	r:0.03	r:0.06	r:0.18**	r:0.22**	r:0.16**
		P:0.12	P:0.003	P:0.53	P:0.45	P:0.22	P<0.0001	P<0.0001	P<0.0001
Age (19-63 years)	Right	r:0.08	r:0.10*	r:0.05	r:0.06	r:0.07	r:0.16**	r:0.15**	r:0.15**
		P:0.10	P:0.03	P:0.32	P:0.16	P:0.12	P<0.0001	P:0.001	P:0.001
	Left	r:0.07	r:0.13**	r:0.04	r:0.07	r:0.07	r:0.17**	r:0.16**	r:0.14**
		P:0.12	P:0.006	P:0.44	P:0.22	P:0.06	P<0.0001	P:0.001	P:0.001

r = Correlation coefficient, P = *Correlation is significant at the 0.05 level (2-tailed), **Correlation is significant at the 0.01 level (2 tailed), AHT = Average hearing threshold

Table 5: Comparison of audiogram findings between study groups

Ear	Frequency	Group 1 <i>n</i> = 223 mean $\pm$ SD	Group 2 <i>n</i> = 131 mean $\pm$ SD	Group 3 <i>n</i> = 115 mean $\pm$ SD	<i>P</i>
Right	AHT	7.9 $\pm$ 5.6	8.3 $\pm$ 6.5	9.0 $\pm$ 6.1	0.26
	250 Hz	13.5 $\pm$ 8.1	10.3 $\pm$ 6.9	11.09 $\pm$ 9.0	<0.0001
	500 Hz	7.26 $\pm$ 7	6.87 $\pm$ 6.5	8.39 $\pm$ 7.4	0.2
	1000 Hz	6.5 $\pm$ 4.1	7.56 $\pm$ 5.9	7.78 $\pm$ 6.1	0.05
	2000 Hz	6.86 $\pm$ 6.3	7.94 $\pm$ 8.1	8.78 $\pm$ 7.5	0.05
	4000 Hz	27.13 $\pm$ 18.3	30.69 $\pm$ 20.3	23.74 $\pm$ 17.7	0.01
	6000 Hz	39.6 $\pm$ 21.45	31.64 $\pm$ 19.1	27.3 $\pm$ 19.7	<0.0001
	8000 Hz	30.81 $\pm$ 16.2	32.21 $\pm$ 20.6	28.17 $\pm$ 21	0.23
Left	AHT	8.17 $\pm$ 4.7	8.44 $\pm$ 5.3	9.41 $\pm$ 6	0.12
	250 Hz	16.95 $\pm$ 9.7	10.99 $\pm$ 7	12.87 $\pm$ 7.9	<0.0001
	500 Hz	8.74 $\pm$ 6.3	7.1 $\pm$ 4.6	7.83 $\pm$ 5.3	0.058
	1000 Hz	7.22 $\pm$ 4	7.63 $\pm$ 5.1	8.04 $\pm$ 5.9	0.32
	2000 Hz	7.22 $\pm$ 5.2	9.08 $\pm$ 7.4	9.04 $\pm$ 7.6	0.01
	4000 Hz	23.86 $\pm$ 18	31.41 $\pm$ 19.7	24.22 $\pm$ 16.2	<0.0001
	6000 Hz	30.58 $\pm$ 21.4	33.85 $\pm$ 22.2	25.3 $\pm$ 15.5	0.005
	8000 Hz	26.03 $\pm$ 18.5	33.82 $\pm$ 20.8	27.43 $\pm$ 17.8	0.001

AHT = Average hearing threshold, SD = Standard deviation

values. Consistent with previous studies, our findings are also pointing out currently suggested solvent exposure limit values are insufficient to protect workers at risk from auditory damage.^[13,14] However in this study, there is no single solvent level greater than suggested levels, the hazard index which is representing total exposure load was too high. However, individual solvent level is under limit, cumulative effect of exposure to the solvent mixture is important. Severity of exposure to the solvent mixture is represented by hazard index, and when hazard index exceeds one, this exposure may cause auditory effects.

The main cause of hearing loss among workers is exposure to noise above the allowable level of 85 dBA.^[22] However, hearing impairment can be aggravated by exposure to solvents, even when noise levels are within this limit.^[23] In this study, the groups did not differ in age or rates of smoking. However, there was a significant difference ($P < 0.0001$) in work experience between Group 2 and the other groups. Group 2's exposure time was shorter than that of Groups 1 and 3. However, high frequency (right ear 4000, 6000 Hz and left ear 4000, 6000, 8000 Hz) hearing loss was more common in the paint shop (Group 2) workers (who were exposed to both solvents and noise) than in the paint store (Group 3) workers (who were exposed to only solvents) or mechanics and assembly (Group 1) workers (who were exposed to noise alone), and these differences were significant, which is in line with other studies.^[16,23] Hearing loss in both ears at 250 Hz was more common in the mechanics and assembly workers than in the paint store workers or in the paint shop workers, and these differences were significant too. According to another study that combined exposure to noise and toluene, the combination had a greater effect on hearing loss at speech frequencies than noise alone.^[23]

Rabinowitz *et al.* concluded that solvent exposure was significantly linked with high-frequency hearing loss.^[24]

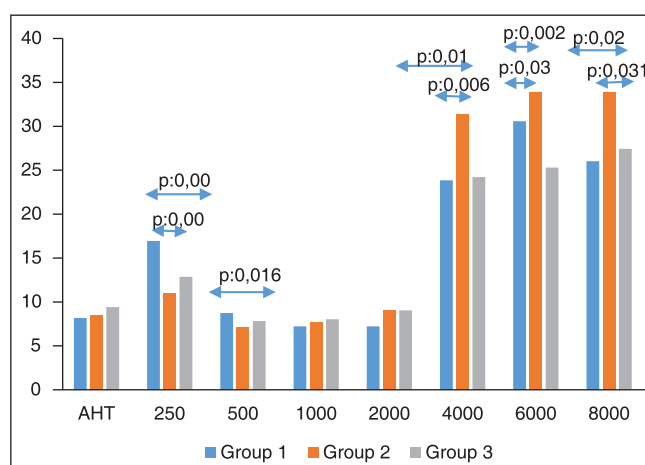


Figure 1: Hearing levels at specific frequencies for each group (left ear). Groups which there is statistically significant difference between them are shown in figure

Although exposures were low, and the time of observation was quite short, workers developed additional hearing loss at high-frequencies.^[24,25] In our study, it was shown that although the solvent and noise exposure time was shorter than in other groups, high frequency hearing loss was more common in the paint shop workers than in the paint store workers or mechanics and assembly workers. Our study showed an earlier onset of effected hearing in workers with simultaneous exposure to noise and solvents. In a study, researchers demonstrated that; the probability of developing hearing loss was over three times higher in the noise-only-exposed group and almost 5 times higher in the noise and solvent-exposed group.^[16]

Kim *et al.* studied workers in the aviation industry and found an association between hearing loss and solvents even within suggested exposure limits of solvents.^[2] Although solvent mixture concentrations and noise levels were low,

a study was demonstrated that there might be a concurrent ototoxicity and neurotoxicity condition.^[26] In contrast, Sliwiska-Kowalska *et al.* demonstrated that workers exposed to solvents at moderate concentrations had a raised risk of hearing impairment, but found no relationship between hearing impairment and the concentrations of the solvent.^[27] The inconsistency between studies may be caused by the type and concentration of the solvent or mixture under study.^[27]

Our study demonstrated a relationship between age and hearing impairment, which is in harmony with similar studies.^[2,28] Having excluded confounding factors like age and smoking, we observed a significant correlation between exposure to noise and solvents and high-frequency hearing loss by the control group, which is consistent with old studies.^[28,29] In a study, it was determined that the odds ratios for hearing loss were 1.12 for each increment of 1 year of age and a significant positive linear relationship between age and hearing loss at almost all frequencies.^[16] Our study verified a positive relationship between age and hearing levels at 250, 4000, 6000 and 8000 Hz frequencies.

In an experimental study, it has been demonstrated that toluene can inhibit the action of the middle ear reflex by modifying the cholinergic receptors. In this instance, it could permit higher acoustic energy penetration into the cochlea exposed to both noise and solvent.^[3] In contrast, some studies reported that combined exposure to noise and solvents did not have a greater effect on hearing impairment than exposure to noise alone.^[2,13,18] Some research proposed a synergistic effect of noise and solvents on hearing.^[30,31] We propose that the exposure to a mixture of solvents and noise, as is the case in our study, is more deleterious to hearing than an individual's exposure to only solvent.

Of all the compounds of the solvent mixture, the influence of xylene and toluene on hearing seems to be the most important, because the ototoxicity of these particular chemicals was

clearly demonstrated in the experiments on animals.^[30,32-34] According to Morata *et al.*, accompanying exposure to noise and a solvents mixture in which toluene was the major component significantly affected hearing thresholds among refinery workers.^[13] In our study, paint shop and paint store workers were exposed to benzene, toluene, xylene, tetrachloroethylene, and acetone. Niklasson *et al.* observed that the distorted speech recognition scores were significantly lower, and the cortical response audiometry latencies were significantly longer in the solvent group than in the control group.^[35] This study showed that not only ototoxicity, solvents are causing also central auditory pathway damage.^[35]

High-frequency hearing impairment was more common in workers exposed to a combination of noise and solvents even at allowable levels than in workers exposed to only noise even after correction for confounding variables.^[36] In our study, high frequency (right ear 4000, 6000 Hz and left ear 4000, 6000, 8000 Hz) hearing loss was more common in the paint shop workers (who were exposed to solvents and noise) than in the paint store workers (who were exposed to solvents alone) or mechanics and assembly workers (who were exposed to noise alone). This suggests that high-frequency audiometry might be the most appropriate method for the evaluation of solvent-induced ototoxicity. Instances of audiograms can be seen in Figures 2 and 3.

This retrospective case control study cannot establish causal relations. However, this can be made in a prospective study. In addition, we were not able to forecast the cumulative dose of exposure, because we did not have information on first exposure levels.

Conclusion

Our results showed that noise and solvents together are more ototoxic than noise individually. In addition to this, solvents even their individual level is below acceptable levels, because

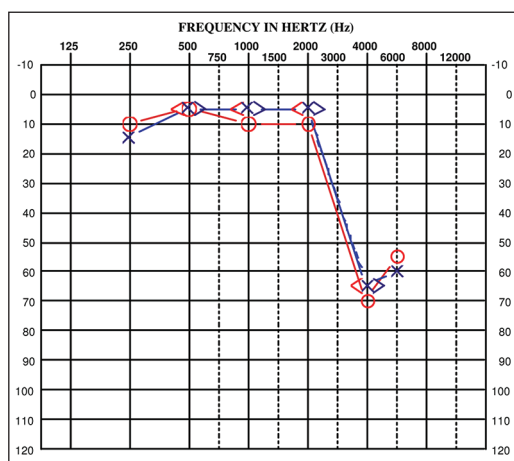


Figure 2: Audiogram of only noise exposed (25 years) 47 years old subject

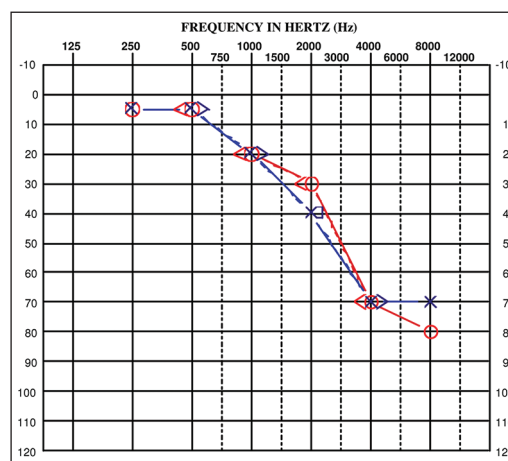


Figure 3: Audiogram of noise and solvent exposed (18 years) 39 years old subject

of they have been found together they cause a cumulative effect and may damage auditory system. In the light of these findings, it can be said that workers at risk should be screened for auditory system damage. Because of damage is mostly recognized at high-frequency levels, workers should be followed with high-frequency audiometry.

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