Hearing Loss in Workers Exposed to Carbon Disulfide and Noise

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Simultaneous exposure to carbon disulfide and noise may have a combined effect on hearing impairment. In this study we investigated hearing loss in 131 men with exposure to noise [80–91 A-weighted decibels; dB(A)] and CS_2 (1.6–20.1 ppm) in a viscose rayon plant. These men were compared with 105 men in the adhesive tape and electronic industries who were exposed to noise only and with 110 men employed in the administrative office of the rayon plant who were exposed to low noise and no CS_2. We conducted interviews to obtain sociodemographic information and exposure assessments, and we performed physical examinations, including hearing tests. Results showed that the prevalence of hearing loss of > 25 dB hearing loss (dBHL) in rayon workers (67.9%) was much higher than that in administrative workers (23.6%) and in the adhesive tape and electronic industrial workers (32.4%). Hearing loss occurred mainly for speech frequencies of 0.5, 1, and 2 kHz. When the CS_2 exposure was measured by the product of CS_2 exposure level and employment years, the adjusted odds ratios of hearing loss of > 25 dBHL in rayon workers, compared with administrative workers, were 3.8 [95% confidence interval (CI), 1.5–9.4] for those with the exposure of 37–214 year-ppm, 14.2 (95% CI, 4.4–45.9) with 215–453 year-ppm exposure, and 70.3 (95% CI, 8.7–569.7) with exposure of > 453 year-ppm. The study suggests that CS_2 exposure enhances human hearing loss in a noisy environment and mainly affects hearing in lower frequencies. *Key words:* carbon disulfide, hearing loss, noise, viscose workers. ***Environ Health Perspect*** **111:1620–1624 (2003). doi:10.1289/ehp.6289 available via *http://dx.doi.org/* [Online 22 May 2003]**

Hearing loss is a leading occupational concern in industrial country workers (May 2000; Neitzel et al. 1999; Palmer et al. 2002; Regulations of Labor Safety and Health 1997). Occupational noise exposure is a well-known cause of premature hearing loss for workers in industrial processes. Smoking and ototoxic chemicals exposures are believed to cause hearing impairment (Barregard and Axelsson 1984; Morata et al. 1993, 1994, 1997; Morioka et al. 2000; Sliwinska-Kowalsha et al. 2001; Starck et al. 1999). Studies have indicated that some organic solvents such as toluene, xylene, styrene, *n*-hexane, trichloroethylene, and petroleum are ototoxic and neurotoxic affecting hearing (Barregard and Axelsson 1984; Mortata et al. 1993, 1994, 1997; Morioka et al. 2000; Sliwinska-Kowalsha et al. 2001). In addition, Morata (1989) and Kowalska et al. (2000) also found exposure to carbon disulfide an ototoxic solvent.

CS_2 is widely used in the industry for the production of viscose rayon, rubber, carbon tetrachloride, or other organic materials, and also as a solvent. Occupational exposure to CS_2 has been extensively studied as a cardiovascular hazard (Bortkiewicz et al. 2001; Drexler et al. 1996; Stetkiewicz and Wronska-Nofer 1998; Sulsky et al. 2002; Swaen et al. 1994). However, there have been limited studies on the ototraumatic consequences of CS_2 and noise exposures (Kowalska et al. 2000; Morata 1989). Animal experiments on exposure to CS_2 revealed no consistent effects on auditory function (Clen and Fechter 1991; Robert et al. 1986). A study of CS_2 exposure in a Japan viscose rayon factory suggested an effect on the brainstem auditory-evoked responses, although no hearing loss assessment was carried out (Hirata et al. 1992).

Morata (1989) conducted audiometric and balance tests on 258 workers simultaneously exposed to excessive levels of both noise [86–89 A-weighted decibels; dB(A)] and CS_2 at a viscose rayon plant. Results showed a high percentage of hearing loss: 67.9% in one group with exposure to 30 ppm CS_2 and 60.1% in another group with an unknown CS_2 level. However, no adequate comparison subjects were used in the study. Furthermore, no dose–response study has investigated the combined effects of CS_2 and excess noise on auditory function. Instead, Kowalska et al. (2000) investigated hearing levels among workers 44–65 years of age, employed an average of 20.3 years in a viscose fiber spinning mill. With average exposures of 25.8 mg/m^3 CS_2 and a noise level of 88–92 dB(A), only 22.5% of those investigated had normal hearing.

In this study we investigated hearing loss for workers exposed simultaneously to CS_2 and noise, compared with workers with noise exposure only and workers with low noise and no CS_2 exposure. We also measured exact hearing loss to complement the information from pure tone audiometry. This allows a comparison of one group with a risk for hearing impairment due to CS_2 versus two groups with no CS_2 exposures.

Materials and Methods

Study subjects and data collection. Three groups of study subjects were recruited for this study. The CS_2 exposure group consisted of all of the 131 male workers employed in two plants manufacturing viscose rayon. These subjects were exposed simultaneously to CS_2 and noise. We used two reference groups: a noise-only exposure group and a low-noise exposure group. The noise-only exposure group consisted of 105 randomly selected male workers employed in factories manufacturing adhesive tape and electronics; these men were exposed to noise but not to CS_2. The low-noise exposure group consisted of all of the 110 males employed in the administrative offices of the rayon factories; these men were not exposed to CS_2 and were exposed only to low noise. Written consent was obtained from all participants.

Data collection consisted of interviews in which each subject was asked about birthdate, educational level, marital status, height, weight, occupational history, solvent and noise exposure history, medical history, medication used, and lifestyle (e.g., smoking, drinking, diet, and exercise); on-site exposure measures of CS_2 and noise levels for workers; and physical examinations required by the Taiwan labor laws, including hearing tests.

CS_2 exposure assessment. On-site exposure to CS_2 was measured using both personal sampling methods and environmental stationary measurements for areas including the foremen's office, CS_2 manufacturing, viscose manufacturing, and filament spinning. Tube-type diffusive samplers (10 cm × 0.5 cm i.d.; Perkin-Elmer, Buckinghamshire, UK) were adopted as the passive sampling tubes, using Spherocarb (Foxboro Co., Foxboro, MA, USA) as a solid adsorbent pretreated with 50 mL/min helium (99.9995%)

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at 300°C for 4 hr (Wang et al. 2001). We used an automatic thermal desorption system interfaced with a Q-Mass 910 gas chromatograph/mass spectrometer (Perkin-Elmer Co., Norwalk, CT, USA) to measure the CS_2 level in samples.

Hearing test. All three groups of subjects were given a pure-tone audiometry test (Beltone 2000 audiometer; Beltone Co., Chicago, IL, USA) for hearing thresholds of air conduction to both ears at 1, 2, 3, 4, 6, 1, and 0.5 kHz by the method of ascending and then descending; the test for 1 kHz was repeated. We used a quiet room and frequency spectrum analysis devices [calibrated in decibels hearing loss (dBHL)] that fulfilled the ISO 8253-1 (International Organization for Standardization 1989) criteria to meet the requirement of ANSI S3.6-1969 (ANSI 1970). Hearing tests were conducted 16 hr after the end of the last work day as indicated by the Institute of Occupational Safety and Health, the Council of Labor Affairs, Taiwan (IOSH 1999). The sound pressure measurements were conducted using a sound pressure level meter (model B&K 2260; Bruel and Kjaerca, Naerum, Denmark). Electroacoustic calibration was performed daily before data collection.

Data analysis. Data analyses were conducted first to compare sociodemographic and lifestyle characteristics between rayon workers and control subjects. The prevalence of hearing loss was calculated in percentage distribution for the worse ear (the ear with the greater hearing loss compared with the other ear of the same person) with loss of ≤ 25 dBHL, 26–39 dBHL, 40–54 dBHL, and ≥ 55 dBHL, respectively, for *a*) rayon workers with noise exposure ≤ 85 dB(A); *b*) rayon workers with noise exposure > 85 dB(A); *c*) workers with noise-only exposure in the adhesive tape and electronic industries; and *d*) the rayon plants administrative workers with low noise exposure.

The prevalence of overall hearing loss of > 25 dBHL was calculated for each group, based on measures using a three-division method for sound levels of 0.5, 1, and 2 kHz. The dose–response evaluation for the hearing effect of CS_2 and noise for rayon workers was estimated based on the stratified exposure levels of the chemical and noise obtained from environmental stationary measurements. Odds ratios (ORs) and corresponding 95% confidence intervals (CIs) were calculated. The association between hearing loss and the length of employment (1–9, 10–19, and ≥ 20 years) was observed.

To measure the contribution of hearing loss by exposure status and covariates, including age (< 40, 40–49, ≥ 50 years), smoking, drinking, and the use of noise-proof equipment, multivariate analysis of hearing abnormality was based on logistic regression modeling. In this model, the risk of hearing loss was measured for rayon workers relative to administrative workers. The CS_2 exposure group was stratified into five subgroups based on the cumulative exposure index (CEI), the product of the environmental CS_2 concentration multiplied by years of employment in year-ppm. Cumulative percentage prevalence of hearing loss was used to distinguish the pattern of hearing impairment among study groups for the pure-tone frequencies of 0.5, 1, 2, 3, 4, and 6 kHz. Similar prevalence analysis by the pure-tone frequency was also performed for rayon workers by their noise exposure levels [≤ 85 dB(A) and > 85 dB(A)] to distinguish the difference in hearing loss among associated frequencies.

Results

The average age in viscose rayon workers was 48.3 years, approximately 6 years older than subjects in the two comparison groups (Table 1). The viscose workers were also less educated and had been employed longer in their current work. The noise exposure levels were 80–91 dB(A) for viscose rayon workers,

Table 1. Selected characteristics of CS_2-exposed workers and reference groups.

Variables	CS_2 exposure group (n = 131) No. (%)	Reference group: Noise only (n = 105) No. (%)	Reference group: Administrative (n = 110) No. (%)	p-Value
Age (years)				< 0.001
< 40	24 (18.3)	39 (37.1)	46 (41.8)	
40–49	35 (26.7)	54 (51.5)	51 (46.4)	
≥ 50	72 (55.0)	12 (11.4)	13 (11.8)	
Mean ± SD	48.3 ± 8.7	42.2 ± 5.8	42.0 ± 6.2	
Education (years)				< 0.001
< 6	72 (55.0)	20 (19.0)	12 (10.9)	
7–9	26 (19.8)	34 (32.4)	23 (20.9)	
10–12	31 (23.7)	43 (41.0)	30 (27.3)	
≥ 13	2 (1.5)	8 (7.6)	45 (40.9)	
Employment (years)				< 0.001
1–9	31 (23.7)	35 (33.3)	54 (49.1)	
10–19	10 (7.6)	57 (54.3)	43 (39.1)	
≥ 20	90 (68.7)	13 (12.4)	13 (11.8)	
Mean ± SD	20.8 ± 10.5	12.1 ± 5.7	11.3 ± 6.4	
Body mass index (kg/m^3)				
Mean ± SD	24.6 ± 3.2	24.4 ± 3.7	25.0 ± 2.9	0.318
Smoking				0.104
Yes	59 (45.0)	55 (52.4)	61 (55.5)	
No	60 (45.8)	42 (40.0)	40 (36.4)	
Quit	12 (9.2)	8 (7.6)	9 (8.2)	
Noise exposure range [dB(A)]	80–91	83–90	75–82	
Always use noise-proof equipment (%)	3.8	13.0	0	< 0.001

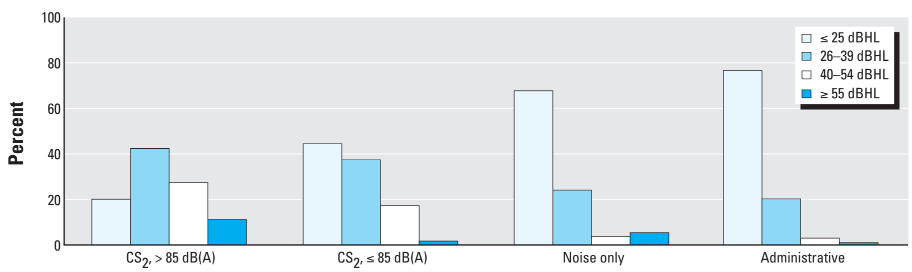

Figure 1. Percentage distribution of hearing loss for CS_2-exposed viscose rayon workers, by noise exposure level, and for reference groups.

Table 2. Percentage hearing loss and age-adjusted ORs (95% CIs) by study group.

Exposure group	No.	Hearing loss: Mean ± SD (dBHL)	Hearing loss: > 25 dBHL No. (%)	OR (95% CI)
Administrative	110	20.5 ± 8.9	26 (23.6)	1.0
Noise-only	105	22.9 ± 14.7	34 (32.4)	1.5 (0.8–2.8)
CS_2 < 14.6 ppm	131	32.8 ± 14.0	89 (67.9)	6.8 (3.9–12.1)
≤ 85 dB(A)	41	22.6 ± 8.4	14 (34.1)	1.7 (0.8–3.7)
> 85 dB(A)	5	22.4 ± 7.3	1 (20.0)	0.8 (0.1–7.5)
CS_2 ≥ 14.6 ppm				
≤ 85 dB(A)	24	39.6 ± 9.7	22 (91.7)	35.5 (7.8–161.3)
> 85 dB(A)	61	37.9 ± 14.5	52 (85.2)	18.7 (8.1–42.9)

83–90 dB(A) for tape and electronic workers, and 75–82 dB(A) for administrative workers. Only 3.8% of the viscose rayon workers and 13.0% of the noise-only exposure group used noise-proof equipment.

Figure 1 shows that hearing loss was greatest for workers exposed simultaneously to CS_2 and noise > 85 dB(A). Approximately 80% of them had a hearing loss of > 25 dBHL, whereas only 32.4% of adhesive tape and electronic workers and 23.6% of administrative workers had this level of hearing loss. Workers in the rayon industry with noise exposure ≤ 85 dB(A) exhibited a higher prevalence (18%) of hearing loss of 40–54 dBHL than did subjects with noise exposure (4%).

Table 3. Prevalence of hearing-loss of > 25 dBHL by years of employment and study group.

	CS_2 exposure group (n = 131)	Reference group	
		Noise only (n = 105)	Administrative (n = 110)
	No. (%)	No. (%)	No. (%)
Employment (years)			
1–9	9 (29.0)	14 (40.0)	7 (17.1)
10–19	6 (60.0)	17 (29.8)	14 (25.0)
≥ 20	74 (82.2)	3 (23.1)	5 (38.5)
Study group total	89 (67.9)	34 (32.4)	26 (23.6)

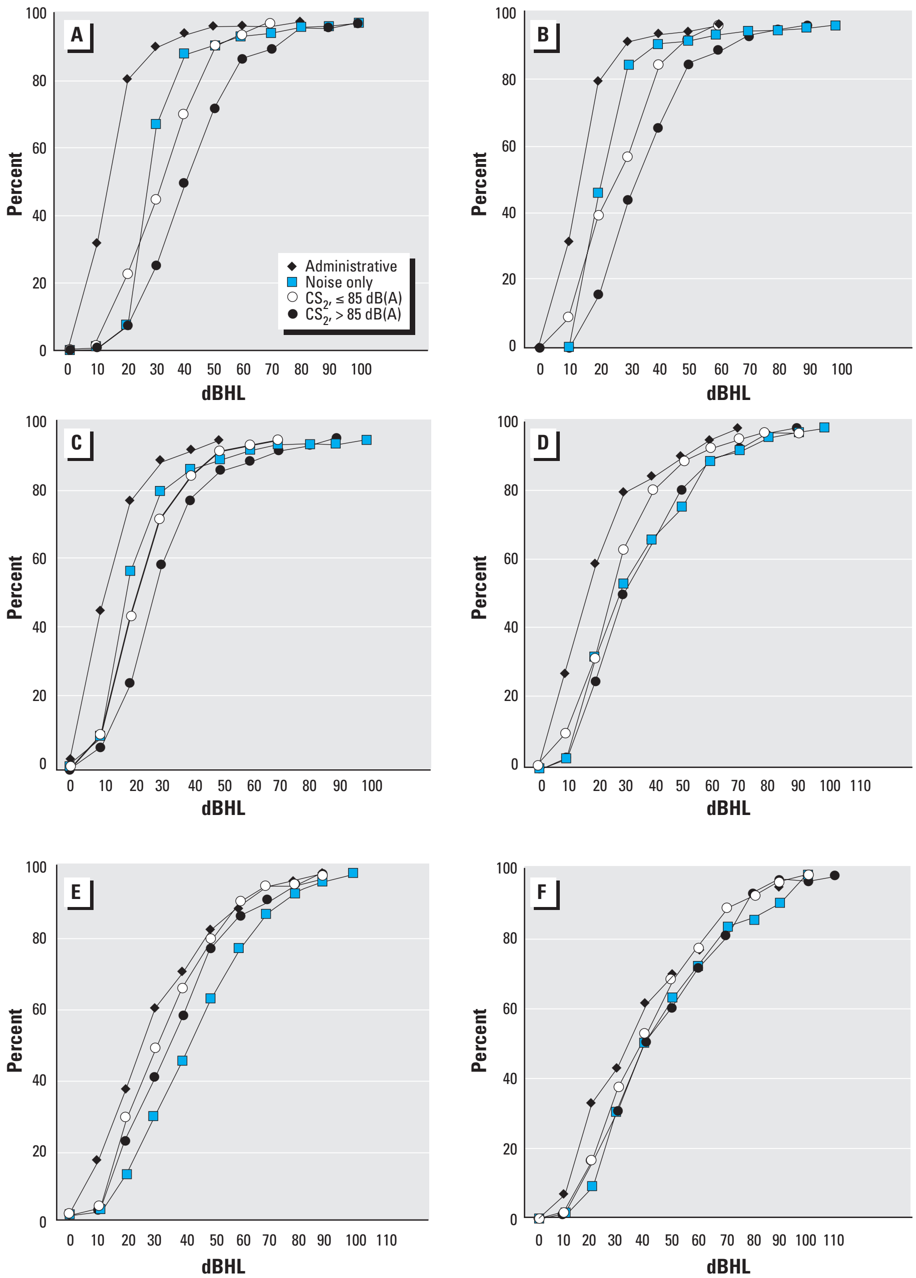

Figure 2. Cumulative percentage distribution of hearing loss by exposure status of study group at pure tone frequencies of (*A*) 0.5, (*B*) 1, (*C*) 2, (*D*) 3, (*E*) 4, and (*F*) 6 kHz.

The average CS_2 levels in the environmental samples were 1.6 ppm in the foremen's office area, 8.9 ppm in the CS_2 manufacturing area, 14.6 ppm in the viscose manufacturing area, and 20.1 ppm in the filament spinning area. Table 2 shows an apparent dose–response association: CS_2 exposure ≥ 14.6 ppm enhanced the hearing loss effect of noise exposure. Compared with the administrative personnel, the overall OR for hearing loss of > 25 dBHL was 6.8 (95% CI, 3.9–12.1) for all workers with CS_2 exposure. This risk increased greatly for workers with average CS_2 exposures of ≥ 14.6 ppm. ORs were 35.5 for those with noise exposure ≤ 85 dB(A) and 18.7 for those with noise exposure > 85 dB(A). Table 3 shows that the impact was the greatest for those with CS_2 exposure for ≥ 20 years.

Hearing loss at specific pure-tone frequencies showed that impairments differ among the measured frequencies—0.5, 1, 2, 3, 4, and 6 kHz—for the four groups of subjects [administrative workers, noise-only exposure, CS_2 plus ≤ 85 dB(A), and CS_2 plus > 85 dB(A)]. Figure 2 shows that workers exposed to both CS_2 and noise had greater hearing impairment than did the noise-only exposure group, at pure tones of lower frequencies of 0.5, 1, and 2 kHz, the "speech frequencies." The noise-only group had a stronger effect at 4 kHz. Both groups had similar hearing loss at a sound frequency of 6 kHz. However, Figure 3 shows that the impairments in viscose rayon workers were most severe at the frequency of 6 kHz and the least severe at 2 kHz.

When rayon workers were stratified into five subgroups by the CEI of CS_2, the estimated risk levels still demonstrated a dose–response association after controlling for age, smoking, drinking, and the use of noise-proof equipment (Table 4). The OR increased to 3.8 (95% CI, 1.5–9.4) for workers with 37–214 year-ppm of CS_2 exposure and further increased to 70.3 (95% CI, 7.9–521) for those with 454–483 year-ppm of exposure. The risk increased slightly more with CEIs > 483 year-ppm.

Discussion

Previous human studies indicate that occupational exposure to some organic solvents may increase hearing loss. Sulkowski (1979) found workers exposed to noise of 86 dB(A) and 100–900 mg/m^3 CS_2 (lowered to 30–35 mg/m^3 later) had an increased incidence of pathologic vestibular symptoms and sensorineural hearing loss. Morata (1989) found a high proportion of elevated prevalence of hearing loss of ≥ 25 dBHL in São Paulo, Brazil, rayon workers exposed to CS_2 and noise.

CS_2 exposure levels for viscose rayon workers in the present study ranged widely, with the environmental average values between 1.6 ppm and 20.1 ppm among the four working areas, lower than that in the previous studies. Noise exposure levels varied between 80 and 91 dB(A), with a mean value slightly higher than the permissible value of 85 dB(A); this level was exceeded for approximately one-half of the workers studied. The prevalence of hearing loss of ≥ 25 dBHL in the group with simultaneous exposure to noise and CS_2 in our study (67.9%) was similar to the findings (60.1–67.9%) of Morata (1989), considerably higher than that in the two comparison groups, the noise-only group (32.4%) and the administrative group (23.6%). Compared with the noise-only–exposed workers, the excess portion (35.5%) among rayon workers suffering hearing loss of ≥ 25 dBHL may imply an aggravating effect of CS_2 on hearing loss. The rayon workers studied by Morata (1989) were exposed to high levels of noise [86–89 dB(A)] and higher levels of CS_2 (30 ppm) than were the rayon workers in the present study. Also, the workers in Morata's (1989) study had an average work history of 3 years, much shorter than the workers in our study. More than half of the viscose rayon workers in our study have worked for 20 years or longer.

The overall prevalence of hearing loss of > 25 dBHL for viscose rayon workers exposed to both CS_2 and noise in this study was 12.2% higher for the worse ears than for the better ears (55.7%). For the purpose of disease prevention, we used the hearing loss in the worse ears to measure the impact. At the average CS_2 exposure level of < 14.6 ppm, the risk of hearing loss was not significantly higher than that for the reference group. Further multivariate analysis showed a dose–response association between increased CS_2 exposure and the effect of hearing loss in a noisy environment. This dose–response effect showed that there might be a threshold for hearing impairment caused by CS_2. The prevalence of hearing loss shows an association with years of exposure. When the product of exposure dose of CS_2 and year of employment was included in the multivariate analysis and rayon workers were stratified into five subgroups based on the CEI, exposures of 37–214 year-ppm were required to develop significant hearing impairment. We also found that the exposure of 132–465 year-ppm were required when the workers were stratified into three groups. Therefore, exposures to 132–214 year-ppm of CS_2 may be critical for hearing impairment to reach a significant level. With the CS_2 exposure of ≥ 450 year-ppm, rayon workers are at an extreme risk of hearing loss.

Taiwan's standards for permissible exposure to chemicals in industry (Regulations of Labor Safety and Health 1997) have a threshold limit for CS_2 of 10 ppm. Our results imply that this average threshold limit value may be low enough to protect workers from significant aggravated hearing impairment due to CS_2 exposure in a noisy working condition. Unfortunately, the permissible standard was not adhered to in the industry. Among the 131 viscose rayon workers exposed to CS_2, 64.9% were exposed to an average of ≥ 14.6 ppm. The estimated risk analysis shows significant hearing loss. This finding strongly suggests that chronic exposure to CS_2 > 10 ppm should be avoided in order to prevent a toxic effect on auditory function.

Another important finding of this study is that the enhanced effect of CS_2 on hearing loss affects a wide range of sound frequencies. Among the tested frequencies, the impact seems to be greatest for the sound frequency of 6 kHz, followed by 0.5 and 5 kHz. However, the impact occurs mainly in the speech frequencies of 0.5, 1, and 2 kHz, as shown in Figure 2. Hearing loss ≥ 4 kHz may be mainly due to noise exposure. We have further analyzed data by CEI and noise exposure level [≤ 85 dB(A) and > 85 dB(A)] to observe the interaction between these two factors and found that the impact on hearing loss caused by exposure to CS_2 is much greater than that caused by noise.

Two major limitations in this study should be considered. First, we were unable to identify workers with CS_2 exposure only,

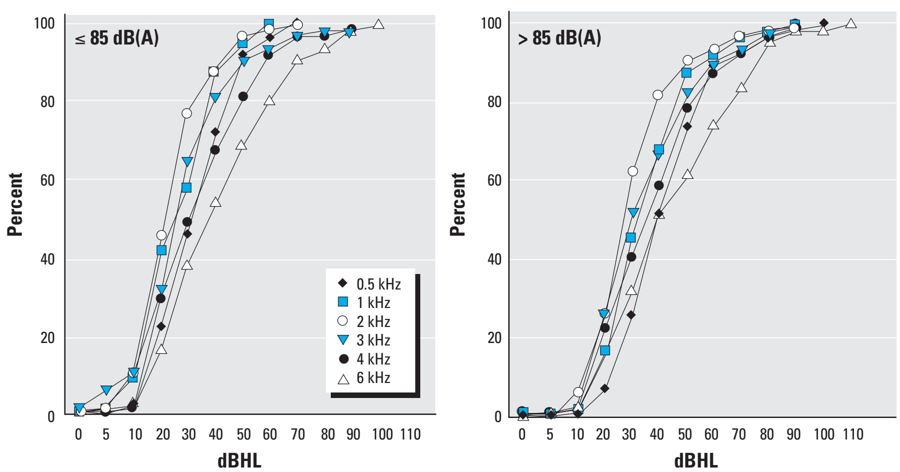

Figure 3. Cumulative percentage distribution of hearing loss by pure-tone frequency (0.5, 1, 2, 3, 4, and 6 kHz) for rayon workers exposed to CS_2 by noise exposure category.

Table 4. Multivariate-adjusted OR and 95% CIs of hearing loss of > 25 dBHL.

Variables	No.	Hearing loss > 25 dBHL No. (%)	OR (95% CI)
Exposure group			
Administrative	110	26 (23.6)	1
Noise-only	105	34 (32.4)	1.4 (0.7–2.5)
CS_2 by CEI (year-ppm)	131	89 (67.9)	
< 37	27	5 (18.5)	0.8 (0.3–2.2)
37–214	27	14 (51.9)	3.8 (1.5–9.4)
215–453	27	22 (81.5)	14.2 (4.4–45.9)
454–483	26	25 (96.2)	70.3 (8.7–569.7)
> 483	24	23 (95.8)	74.5 (8.7–634.5)
Age (years)			
< 40	109	26 (23.9)	1
40–49	140	57 (40.7)	1.6 (0.9–2.8)
≥ 50	97	66 (68.0)	1.2 (0.5–2.8)
Smoking			
No	142	65 (45.8)	1
Yes	175	71 (40.6)	1.1 (0.6–2.0)
Quit	29	13 (44.8)	1.0 (0.4–2.7)
Drinking			
No	184	86 (46.7)	1
Yes	129	48 (37.2)	0.8 (0.4–1.3)
Quit	33	15 (45.5)	1.0 (0.4–2.6)
Always use noise-proof equipment			
Yes	19	11 (57.9)	1
No	327	138 (42.2)	0.5 (0.2–1.6)

although some of the workers had noise exposure level < 80 dB(A). However, most of the workers studied had a long employment history in the industry, exposing them to different areas of the work site as they walk around. Their noise exposures may have been higher than we measured.

Second, the age, education level, and length of employment of the study subjects were not homogeneous among the three studied groups. The viscose rayon workers were much older than workers in the other two comparison groups. They also had received less education, and 68.7% had worked in the industry for ≥ 20 years. However, the differences in social status of the examined subjects have no significant influence on the findings of hearing loss.

Because only approximately one-third of viscose rayon workers had an employment history of < 20 years, stratified analysis by age and years of employment was difficult, with too few workers in the younger group with shorter employment history. We were unable to precisely differentiate the effect of CS_2 exposure for < 20 years of employment. It is possible that some employees with an employment history of < 20 years left because of hearing loss or other health effects such as cardiovascular disorder and other neurotoxic effects. Therefore, the risk estimation of interaction between CS_2 exposure and noise exposure may be somewhat limited to workers with long exposure to the environment.

Despite these limitations, the present study still clearly established a significant ototraumatic dose–response interaction relationship between CS_2 and noise exposures. Workers exposed to CS_2 higher than the permissible level have an increased aggravated risk of hearing loss, mainly at the lower frequencies of spoken sound. Protective measures for these workers should be considered.

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