Auditory effects of chronic exposure to carbon monoxide and noise among workers

Tony Leroux[1*], Adriana Lacerda[2], Jean-Pierre Gagné[1]

1 School of Speech-Language Pathology and Audiology, University of Montreal, Montreal, Quebec, Canada

2 School of Speech-Language Pathology and Audiology, University of Tuiuti do Paraná, Curitiba, Paraná, Brazil

*corresponding author: e-mail adress: tony.leroux@umontreal.ca

INTRODUCTION

For more than a century, scientific publications have discussed the numerous harmful consequences of noise exposurte on hearing (Berglund & Lindvall 1995). However, in addition to the presence of noise in working environments, other environmental factors represent a potential risk of acquiring a noise-induced hearing loss (NIHL) (Fechter 2004).

The risk of acquiring a hearing loss in the presence of moderate exposure to noise associated to the presence of asphyxiant chemical substances has been evaluated mostly in rats (Fechter et al. 1987, 1988, 1997, 2000a, b, 2002; Fechter 1989, 1995; Young et al. 1987; Chen et al. 1999, 2000, 2001; Chen & Fechter 1999; Rao & Fechter 2000; Rao et al. 2001). These studies investigated the effects of acute simultaneous exposure to high concentrations of carbon monoxide (CO) and to moderate levels of noise. As a whole, the results show the emergence of a NIHL from the exposure of CO in rats exposed to noise levels which, alone, do not produce any significant changes to hearing detection thresholds. Effects of chronic combined exposure to CO and noise on human hearing in a working environment were investigated in only two studies (Sulkowski & Bojarski 1988; Ahn et al. 2005).

While the results of the previously mentioned studies suggest a significant interaction between CO and noise, the specific effects of chronic combined exposure to these contaminants on hearing remain largely unknown. Considering the large distribution of CO and noise in the working environment and the large number of exposed workers, it is of utmost importance to confirm a potential effect of chronic exposure to both CO and noise on human hearing. The aim of this study was to determine if workers chronically exposed to CO and noise, in the workplace or during non-occupational activities face a greater risk of acquiring NIHL.

METHODOLOGY

The data used in this study were extracted from the database developed and maintained by the *Centre d'expertise en dépistage* of the *Institut national de santé publique du Québec* (CED-INSPQ) between 1983 and 1996. This database contained information from 49,495 workers who have completed a questionnaire about their hearing history, including personal information (gender, age, extraprofessional noise exposure, etc.), medical (surgery, middle ear problems, vertigos, etc.) and occupational history (occupation, noise dose at the current work position, number of years at current position, total number of years of employment, etc.), and who had undergone an audiometric examination in a mobile laboratory used by the CED-INSPQ across various industrial settings in Quebec. The audiometric examination procedure used by the CED-INSPQ is a conventional air-conducted pure tone test, using a Békésy-

automated method. The evaluation is carried out under supraaural or inserts earphones in a standard audiometric room, which complied with the ANSI S.31-1999 standard recommendations (ANSI 1999), using a clinical instrument.

The CED-INSPQ's database did not contain direct information regarding occupational exposure to CO. Indirect information about occupational exposure to CO was obtained through a panel of five experts used to assess potential CO exposure for each professions included in the Canadian Classification and Dictionary of Occupations (CCDO) also available in the CED-INSPQ's database. The members of the panel individually reviewed each occupation listed in the CCDO and ascertain a value to a dichotomized CO occupational exposure variable (present/absent). A Kappa test was then used to measure intra-judge agreement on the dichotomized CO variable (Landis & Koch 1977). The results showed good to excellent intra-judge agreement ($0.4 \leq K \leq 0.75$ and $K > 0.75$) for 82% of the occupations listed in the CCDO. Two additional experts were recruited for a second analysis to conciliate the differences obtained for the remaining 18% of the occupations. The dichotomized variable was then incorporated to the original CED-INSPQ's database.

Two studies were conducted. First, a case-control study was design to estimate the risk of acquiring NIHL for workers exposed either to noise alone or in combination with CO. The only cases retained were those where the individual only work in one single noisy workplace and where the number of years worked in that environment and the corresponding noise exposure levels were documented. Workers that presented with a contributing medical or personal history (vertigo, Menière's disease, middle ear problem or abnormal tympanogram, sudden or congenital hearing loss, extraprofessional noise exposure, military career) were excluded from this study. Due to the very small number of cases, women were also excluded from the study.

After exclusions, data from 6,812 audiometric assessments were retained for analysis and were divided among four groups: (1) CO plus noise ≥ 90 dB(A)-8h (exposed cases); (2) noise alone ≥ 90 dB(A)-8h (non-exposed cases); (3) CO plus noise < 90 dB(A)-8h (exposed controls); and (4) noise alone < 90 dB(A)-8h (non-exposed controls). Table 1 presents the summary of the composition of the four groups according to the sample size, the means and standard deviations for: age, number of years of noise exposure at the current occupation and total number of years of occupational noise exposure.

Table 1: Groups composition of first study according to sample size, age, number of years at current occupation and total number of years of employment

	CO & NOISE ≥ 90 dB(A)-8h Exposed Cases	**NOISE ≥ 90 dB(A)-8h Non-Exposed Cases**	**CO & NOISE < 90 dB(A)-8h Exposed Controls**	**NOISE < 90 dB(A)-8h Non-exposed Controls**
Sample size	1872	2383	1031	1526
Age (mean ± SD)	29.2 ± 9.6	30.4 ± 9.8	30.2 ± 9.7	31.0 ± 9.8
Years at current occupation (mean ± SD)	6.1 ± 7.2	6.6 ± 7.6	6.7 ± 7.4	6.8 ± 7.2
Years of employment (mean ± SD)	6.3 ± 7.1	6.8 ± 7.5	7.0 ± 7.3	7.1 ± 7.2

The independent variables used for the analyses were: frequency (0.5, 1, 2, 3, 4 and 6 kHz), dose of noise at current workplace (< 90 dB(A) and ≥ 90 dB(A) $L_{Aeq\text{-}8h}$), and exposure to CO. The dependent variable used for the analyses was the auditory threshold averaged across ears. To control for age, the 90th percentile for presbyacousia provided by ISO-7029 standard (ISO 2000) was used to decide whether a

significant hearing deficit existed. Odds ratios [*OR= (exposed cases / non-exposed cases) / (exposed controls / non-exposed controls)*] were determined for three groups of workers: (1) exposed to CO and noise ≥ 90 dB(A)-8h; (2) noise alone ≥ 90 dB(A)-8h; and, (3) CO and noise < 90 dB(A)-8h.

A second study examined the effects of non-occupational combined exposure to CO and noise. The aim of this study was to verify if a combined, non-occupational exposure to noise and CO could affect the hearing thresholds of workers with occupational noise exposure. The samples were constructed with 6,395 workers that reported non-occupational noise exposure including or not concomitant CO exposure. Workers who reported snowmobile, motorbike, farm vehicles, snow blower, and/or chainsaw use as a non-occupational activity were described as having been exposed to non-occupational noise and CO exposure. Workers who reported electrical power tools and/or loud music used is non-occupational context were described as having been exposed to non-occupational noise only. Inclusion in one or the other category is mutually exclusive, e.g. a worker that reported electrical power tools and snowmobile use were excluded from the study. Table 2 shows the distribution of mean age per study group according to the mean number of years of occupational noise exposure.

Table 2: Mean age distribution according to groups (non-occupational CO & Noise; non-occupational Noise) and years of occupational noise exposure (from 0 to 30 years)

Groups non-occupational exposure	**Mean age (± SD) of the subjects as a function of years of occupational noise exposure in 5-year clusters**					
	≥ 0 - < 5	**≥ 5 - < 10**	**≥ 10 - < 15**	**≥ 15 - < 20**	**≥ 20 - < 25**	**≥ 25 - < 30**
CO & Noise (n=3306)	27.4 ± 7.4	31.7 ± 6.7	35.3 ± 6.5	40.3 ± 6.1	44.0 ± 5.7	49.1 ± 5.3
Noise (n=3089)	24.4 ± 5.0	29.2 ± 5.6	33.3 ± 4.6	38.1 ± 5.0	42.1 ± 4.1	47.9 ± 5.3

For the second study, a multivariate analysis of variance (MANOVA) using repeated measures was used and the appropriate Greenhouse-Geisser adjustment was applied. The independent variables for this test were: the frequency (0.5, 1, 2, 3, 4, and 6 kHz), the non-occupational CO exposure (non-occupational Noise+CO exposure and non-occupational Noise exposure), years of occupational noise exposure (7 categories, based on 5-year clusters and ranging from no occupational noise exposure to 30 years of occupational noise exposure), and current occupational noise exposure level (8 categories, ranging from exposure < 80 dB(A) $L_{Aeq-8hr}$ to exposure > 100 dB(A) $L_{Aeq-8hr}$). The dependent variable for this test was the average hearing threshold. Age, a potential confounding variable, was used as a covariate in the analysis.

RESULTS

In the first study, odds ratios were determined for three groups of workers: (1) exposed to CO and noise ≥ 90 dB(A)-8h; (2) noise alone ≥ 90 dB(A)-8h; and, (3) CO and noise < 90 dB(A)-8h. The results of those calculations are shown in Table 3.

Table 3: Results of clinical thresholds analysis according to age – Risk factors for the groups

1) Clinical thresholds analysis according to age – Risk factors: CO and noise ≥ to 90 dB(A)

Frequency Hz	Normal	Hearing loss	Odd Ratio	95% CI	p
500	2797	601	1.158	0.969-1.385	0.11
1000	3014	384	1.311*	1.055-1.628	0.01
2000	3068	330	1.232	0.978-1.552	0.08
3000	2834	564	1.348*	1.121-1.622	0.002
4000	2557	841	1.388*	1.184-1.627	< 0.001
6000	2227	1171	1.419*	1.229-1.639	< 0.001
At least one	1508	1890	1.347*	1.175-1.543	< 0.001

2) Clinical thresholds analysis according to age – Risk factor: noise ≥ to 90 dB(A)

Frequency Hz	Normal	Hearing loss	Odd Ratio	95% CI	p
500	3228	681	1.110	0.936-1.317	0.24
1000	3473	436	1.251*	1.015-1.542	0.04
2000	3541	368	1.146	0.917-1.432	0.24
3000	3256	653	1.329*	1.113-1.586	0.002
4000	3011	898	1.155	0.990-1.348	0.07
6000	2646	1263	1.178*	1.025-1.353	0.02
At least one	1795	2114	1.180*	1.037-1.342	0.01

3) Clinical thresholds analysis according to age – Risk factors: CO and noise < 90 dB(A)

Frequency Hz	Normal	Hearing loss	Odd Ratio	95% CI	p
500	2113	444	1.157	0.941-1.423	0.18
1000	2283	274	1.254	0.975-1.614	0.08
2000	2333	224	1.014	0.767-1.340	0.94
3000	2178	379	1.014	0.879-1.368	0.43
4000	1987	570	1.131	0.936-1.366	0.21
6000	1763	794	1.110	0.937-1.317	0.24
At least one	1203	1357	1.147	0.979-1.345	0.09

Elevated ORs were observed at 4 frequencies for the combined exposure to CO and noise (≥ 90 dB(A)-8h). Significant ORs were obtained at 1, 3, 4 and 6 kHz (95% CI ranged from 1.055-1.628 (1 kHz) to 1.229-1.639 (6 kHz). The OR remained significant when its computation was restricted to a deficit at a single frequency (95% CI = 1.175-1.543). Noise exposure alone (≥ 90 dB(A)-8h) was associated to the hearing deficit at 1, 3 and 6 kHz (95% CI ranged from 1.015-1.542 (1 kHz) to 1.113-1.586 (3 kHz). The OR remained significant when its computation was restricted to a deficit at a single frequency (95% CI = 1.037-1.342). The effect of CO exposure with moderate noise exposure (< 90 dB(A)-8h) was not significant at all frequencies. No significant effect on hearing threshold could be demonstrated even when considering a deficit at a single frequency (95% CI = 0.979-1.345).

The MANOVA applied to the second dataset showed a significant interaction ($F_{[122,19183]}$ = 1.36; p = 0.005; Greenhouse-Geisser adjustment = 0.61) for frequency *

non-occupational CO exposure * years of occupational noise exposure * occupational noise exposure levels. Figure 1 depicts the hearing thresholds at 0.5, 1, 2, 3, 4, and 6 kHz according to years of occupational noise exposure (a: ≥ 0 and < 5 years; b: ≥ 5 and < 10 years; c: ≥ 10 and < 15 years; d: ≥ 15 and < 20 years; e: ≥ 20 and < 25 years; and f: ≥ 25 and < 30 years) and for the two study groups (non-occupational exposure to noise; combined non-occupational exposure to CO and noise). Based on the analysis of the confidence intervals around group means (95% CI), significant differences between groups were observed for 3, 4 and 6 kHz for the workers with ≥ 15 and < 20 years of occupational exposure (Figure 1, panel d). For the workers having ≥ 20 and < 25 years of occupational exposure, significant differences were noted only for 3 and 6 kHz (Figure 1, panel e). For the group of workers having ≥ 25 and < 30 years of occupational exposure, significant differences were also observed at 3 and 6 kHz but also extend at the frequency of 2 kHz (Figure 1, panel f). These results suggest that the hearing thresholds for the high frequencies are affected first by the non-occupational combined CO and noise exposure. As the number of years of exposure increases, the hearing loss progressively extends towards low frequencies. The impact of non-occupational CO and noise exposure on hearing thresholds across the frequencies tested is especially striking for workers having ≥ 25 and < 30 years of occupational noise exposure. There was no significant difference between groups at 4 kHz for workers having the longer occupation noise exposure (≥ 20 and < 25 years, ≥ 25 and < 30 years).

Figure 2 depicts hearing thresholds at 0.5, 1, 2, 3, 4, and 6 kHz according to the current occupational noise exposure level (a: no significant occupational noise exposure; b: $L_{Aeq\text{-}8hr}$ ≥ 80 and < 85 dB(A); c: $L_{Aeq\text{-}8hr}$: ≥ 85 and < 90 dB(A); d: $L_{Aeq\text{-}8hr}$: ≥ 90 and < 100 dB(A); and e: $L_{Aeq\text{-}8hr}$: ≥ 100 dB(A)) and for the two study groups.

A significant difference between groups was observed only at 2 kHz when the subjects had no occupational noise exposure. The differences noted between groups at 3 and 4 kHz were close to the significant level in the same condition (Figure 2, panel a). Intersubject variation is larger among subjects in the CO+Noise group, (range from 151 to 228 %) when compare to the variation observed in the Noise group thus reducing the statistical power. As the level of occupational noise exposure increases, the difference between groups disappears (Figure 2, panels b-e). These results highlight the effect of non-occupational combined noise and CO exposure on workers' hearing thresholds even when the workers have no occupational noise exposure.

CONCLUSION

Two main conclusions may be drawn for the first study. First, CO interacts with noise to increase the risk of hearing loss in workers exposed to dose levels that are superior to 90 dB(A)-8h. Second, a chronic exposure to CO and noise should be considered when the risk for acquiring a NIHL is being assessed.

For the second study, the results indicate that non-occupational noise and CO exposure interacts with occupational noise exposure to worsen hearing thresholds. A long history of non-occupational noise and CO exposure as well as occupational noise exposure is a risk factor for NIHL. Combined non-occupational noise and CO exposure and low level occupational noise exposure is a risk factor for NIHL which should be clinically assessed.

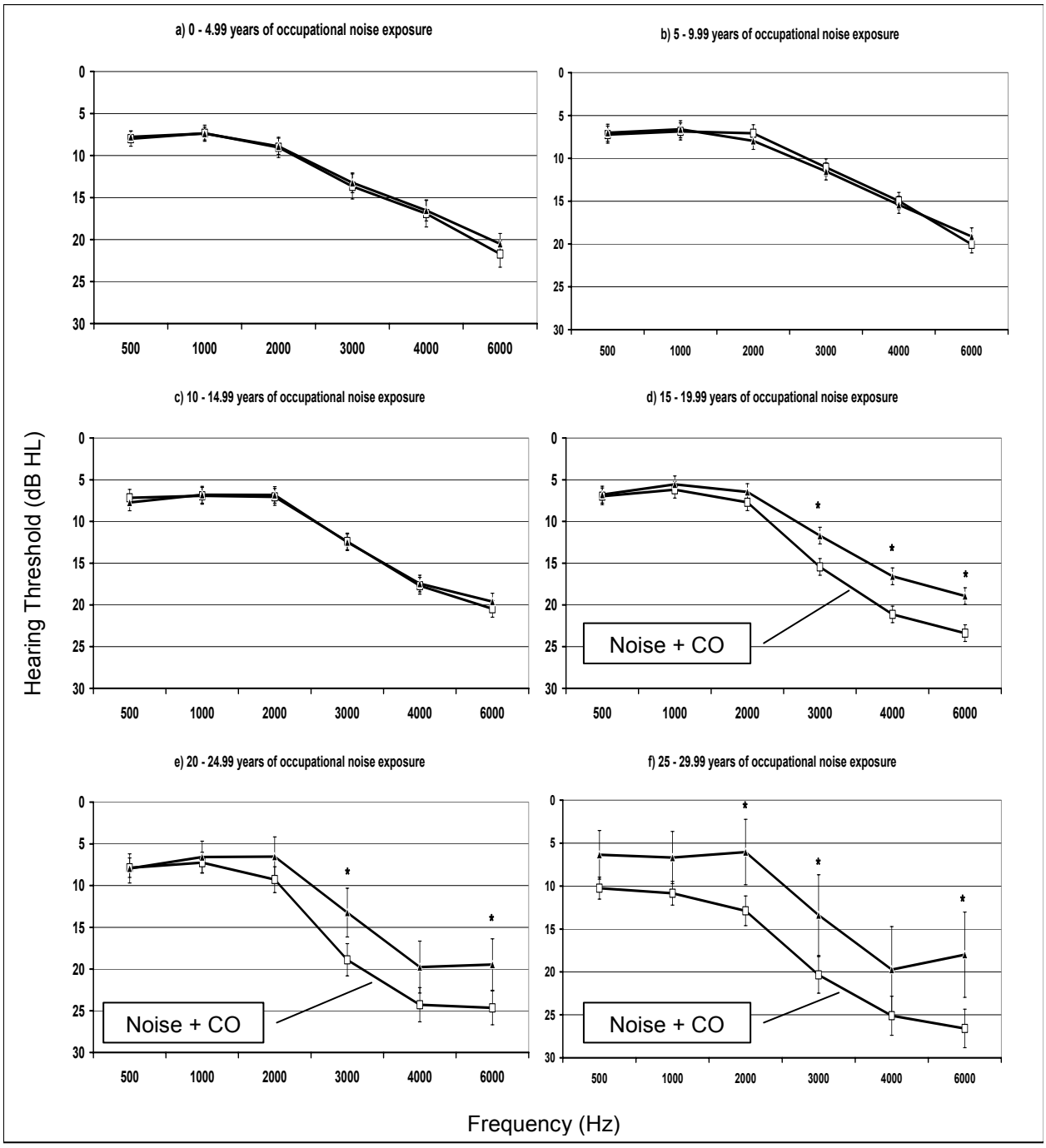

Figure 1: Mean of hearing thresholds (0.5, 1, 2, 3, 4, and 6 kHz) for workers according to years of occupational noise exposure (panels a to f) taken from the CED-INSPQ database

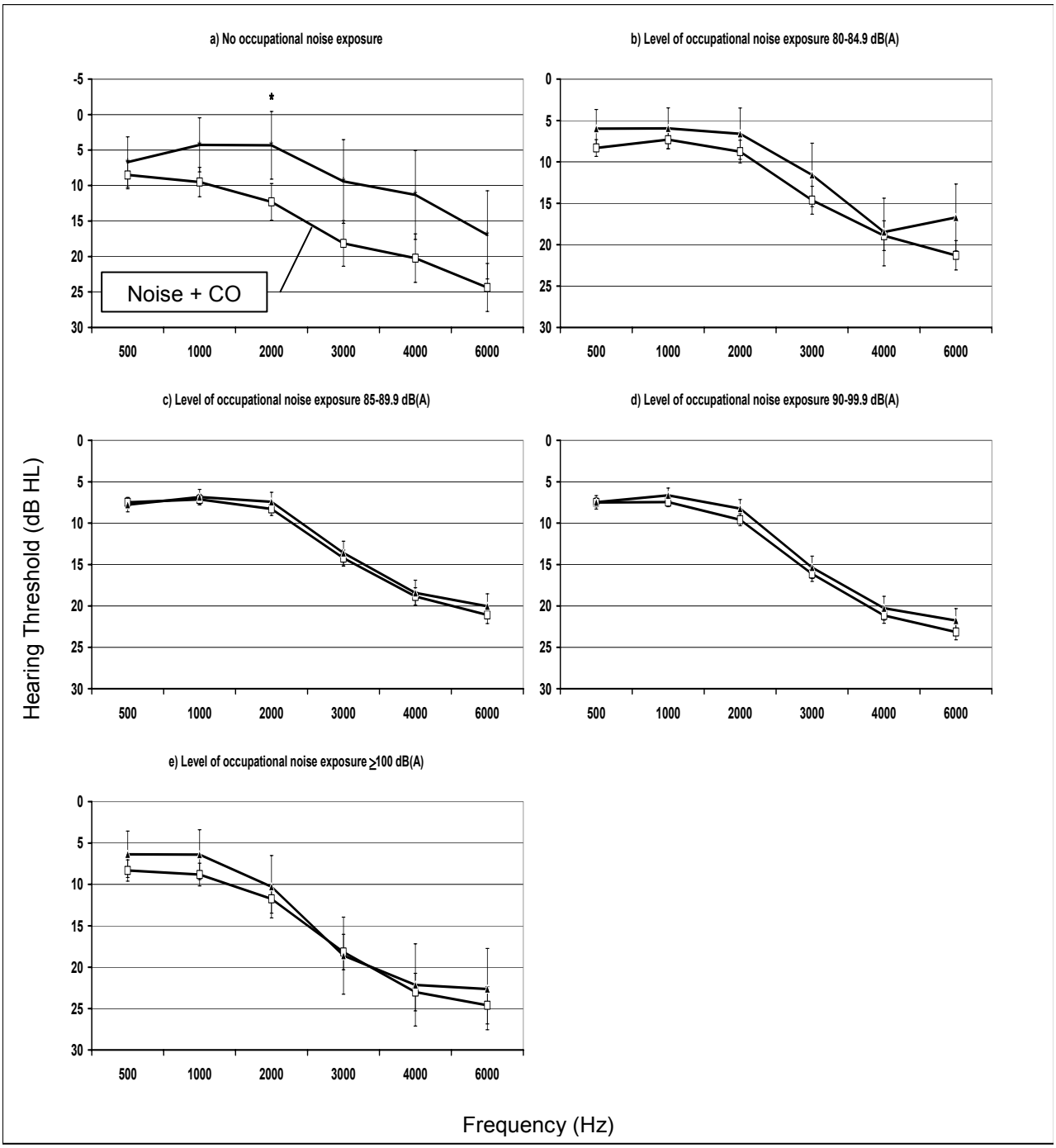

Figure 2: Mean of hearing thresholds (0.5, 1, 2, 3, 4, and 6 kHz) for workers according to level of occupational noise exposure (panels a to e) taken from the INSPQ database

Based on our findings we recommend: (1) that field studies be undertaken to continue to evaluate the combined effect of noise and CO on hearing sensitivity among exposed workers; (2) the identification of the minimal dose of CO (over a worker's career) that can safely co-exist with noise without any deleterious effects on hearing; 3) that studies be undertaken to elucidate the effects of simultaneous exposure of CO and noise in combination with other ototoxic agents; and, 4) in addition to pure-tone audiometry, hearing assessments administered in the workplace should incorporate test procedures (i.e. otoacoustic emissions) that could be more sensitive to the physiopathologic process occurring within the cochlea when noise and chemical asphyxiants are present in the working environment.

REFERENCES

Ahn YS, Morata TC, Stayner LT, Smith R (2005). Hearing loss among iron and steel workers exposed to low levels of carbon monoxide and noise. Presentation at the International Symposium on Neurobehavioral Methods and Effects in Occupational and Environmental Health, September 26 - 29, Gyeongju, Korea.

ANSI (American National Standards Institute) 1999. Maximum permissible environment noise levels for audiometric test rooms. ANSI S 3.1-1999, New York.

Berglund B, Lindvall T (eds.) (1995). Community noise. Document prepared for the World Health Organization. Arch Center Sensory Res 2: 1-195.

Chen GD, Fechter LD (1999). Potentiation of octave-band noise induced auditory impairment by carbon monoxide. Hear Res 132: 149-159.

Chen GD, Mc Williams ML, Fechter LD (1999). Intermittent noise-induced hearing loss and the influence of carbon monoxide. Hear Res 138: 181-191.

Chen GD, Mc Williams ML, Fechter LD (2000). Succinate dehydrogenase (SDH) activity in hair cells: a correlate for permanent threshold elevations. Hear Res 145: 91-100.

Chen GD, Kong J, Reinhard K, Fechter LD (2001). NMDA receptor blockage protects against permanent noise-induced hearing loss but not its potentiation by carbon monoxide. Hear Res 154: 108-115.

Fechter LD (1989). A mechanistic basis for interactions between noise and chemical exposure. Arch Commun Environ Stud 1: 23-28.

Fechter LD (1995). Combined effects of noise and chemicals. Occup Med: State of the Art Rev 10: 609-621.

Fechter LD (2004). Promotion of noise-induced hearing loss by chemical contaminants. J Toxicol Environ Health 67A: 727-740.

Fechter LD, Thorne PR, Nuttall AL (1987). Effects of carbon monoxide on cochlear electrophysiology and blood flow. Hear Res 27: 37-45.

Fechter LD, Young JS, Carlisle L (1988). Potentiation of noise induced threshold shifts and hair cell loss by carbon monoxide. Hear Res 34: 39-48.

Fechter LD, Liu Y, Pearce TA (1997). Cochlear protection from monoxide exposure by free radical blockers in the guinea pig. Toxicol Appl Pharmacol 142: 42-55.

Fechter LD, Liu Y, Herr DW, Crofton KM (1998). Trichloroethylene ototoxicity: evidence for a cochlear origin. Toxicol Sci 42: 28-35.

Fechter LD, Chen GD, Rao D (2000a). Characterising conditions that favour potentialization of noise induced hearing loss by chemical asphyxiants. Noise & Health 3(9): 11-21.

Fechter LD, Chen GD, Rao D, Larabee J (2000b). Predicting exposure conditions that facilitate the potentiation of noise-induced hearing loss by carbon monoxide. Toxicol Sci 58: 315-323.

Fechter LD, Chen GD, Rao D (2002). Chemical asphyxiants and noise. Noise & Health 4(14): 49-61.

ISO (International Standard Organization) (2000). ISO-7029. Acoustics. Statistical distribution of hearing thresholds as a function of age. Geneva, Switzerland.

Landis JR, Koch GG (1977). An application of hierarchical kappa-type statistics in the assessment of majority agreement among multiple observers. Biometrics 33:363-374.

Rao DB, Fechter LD (2000). Increased noise severity limits potentiation of noise induced hearing loss by carbon monoxide. Hear Res 150: 206-214.

Rao DB, Moore DR, Reinke LA, Fechter LD (2001). Free radical generation in the cochlea during combined exposure to noise and carbon monoxide: an electrophysiological and an EPR study. Exposure Res 161: 113-122.

Sulkowski WJ, Bojarski K (1988). Hearing loss due to combined exposure to noise and carbon monoxide – A field study. In: Noise as a public health problem: Proceedings of 5th International Congress on Noise as a Public Health Problem (p 179).

Young JS, Upchurch MB, Kaufman MJ, Fechter LD (1987). Carbon monoxide exposure potentiates high-frequency auditory threshold shifts induced by noise. Hear Res 26: 37-43.