*NOISE-INDUCED HEARING LOSS AND HEARING PROTECTIVE DEVICES**

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ABSTRACT

Longitudinal studies of hearing in workers in selected industries in Canada have shown that the effect of continuous high-level noise exposure is an increase in detection threshold of about 1 1/2 decibels per year. This is in contrast to 1/2 dB per year for non noise-exposed office workers in the same plants. Personal hearing protectors, in the form of ear plugs and muffs, have been chosen as an effective, inexpensive and easily implemented method of hearing conservation. However, behavioural experiments simulating the noise background in the industrial environment have shown that the use of these devices may give rise to difficulties in detecting warning signals and defects in the materials worked on, as well as in the perception of speech. This is particularly true in the case of individuals who have already sustained a moderate to severe sensorineural hearing loss, either through noise exposure or aging. To improve both hearing and comfort, many try to alter the device physically. This, of course, will result in a decrease in its sound attenuating capabilities. An experiment in progress is investigation the possibility of prescribing protectors on an individual basis, taking into account both hearing status and shape and size of the ear canal. Relatively little information is available on ear canal morphology. It appears that some types of widely used insert devices are less effective in reducing sound for women because of poor fit to their relatively smaller ear canals.

SOMMAIRE

Des études longitudinales sur l'ouïe de certains ouvriers canadiens ont indiqué que l'exposition continue à un niveau sonore élevé se traduit par une élévation du seuil de détection d'environ 1 1/2 décibel par an. Quant à eux, les employés de bureau des mêmes entreprises (non exposés au bruit) obtiennent un résultat de 1/2 dB par an. On a pu constater l'efficacité à cet égard des protecteurs d'oreilles et des protège-tympan, moyens peu onéreux et faciles à utiliser. Par contre, des expériences ont prouvé que le recours à ces protecteurs peut causer des problèmes lors de la détection des signaux avertisseurs et des défectuosités caractérisant des matériaux manipulés, ainsi que dans la perception de la parole. Ceci s'avère particulièrement dans le cas des personnes qui ont déjà subi une perte d'ouïe (moyenne à grave) du fait du vieillissement ou de l'exposition au bruit. Aussi, afin d'améliorer l'audition et le confort, nombre de personnes modifient les caractéristiques physiques des appareils. Bien sûr, ces derniers perdent alors une partie de leur efficacité sur le plan de la réduction du bruit. Une expérience est actuellement entreprise qui vise à

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déterminer la faisabilité de protecteurs personnalisés tenant compte de l'acuité auditive et de la forme du canal auditif de chacun. En ce qui concerne la morphologie de ce dernier, les informations disponibles sont relativement rares. Il semble que certains des appareils les plus fréquemment utilisés seraient moins efficaces dans le cas des femmes car ils s'insèrent moins bien dans la canal auditif de celles-ci.

Permanent hearing loss with continuous exposure to high-level noise has been well documented.[1-4] My work includes longitudinal studies of noise-induced hearing loss among workers in Canadian industry and evaluation of the effectiveness of hearing conservation programs. Experiments have measured the attenuation realistically provided by routinely used hearing protective devices and the drawbacks associated with their use. These drawbacks include interference with communication on the job and the perception of warning signals or changes in the material worked on. Work in progress focuses on difference in the success of hearing conservation programs based on personal hearing protection for males and females, and the relationship of these differences to ear canal morphology.

PROGRESSION OF NOISE-INDUCED HEARING LOSS

In order to study the progression of hearing loss, we enlisted the support of three Canadian industries, Ontario Hydro, Falconbridge Nickel Mines and DOFASCO, Inc.[5] Each industry provided us with the results of hearing tests routinely conducted on employees. The database for Ontario Hydro comprised one audiogram (a plot of the intensity required for detection of pure tones ranging from 500 Hz to 8 kHz) recorded in 1977 for each of 1191 workers in four different jobs. Falconbridge Nickel Mines contributed 2 to 13 audiograms measured at intervals of 1 to 2 years for each of 121 individuals employed in two job categories for a period of 4 to 11 years. DOFASCO provided 7 to 13 audiograms for 100 individuals employed in three job categories for a continuous period ranging up to 15 years. All, except for a control group of 343 office workers at Ontario Hydro, had been exposed to noise exceeding 85 dBA, a level considered injurious to hearing in the long-term.

Where only a single audiogram was available, cross-sectional analyses were carried out to assess the effects of job type, number of years of exposure and age on noise-induced hearing loss. Within-subject comparisons were made of hearing loss for the various test frequencies. The availability of several successive audiograms for individual workers allowed an investigation of the rate of hearing loss with time on the job.

The results for a group of 63 Falconbridge drillers employed in the mining industry since the age of 21 or younger are typical of the overall findings. A comparison was made of the most recent audiogram measured (1977-80) and the earliest on record, taken on average 6 years earlier. We looked first at risk of impairment, i.e., the number of individuals whose hearing thresholds exceeded a defined critical value of 25 dB relative to normal. For the earliest test the results of only 4 of 26 individuals, 35 years of age or younger, exceeded the fence for risk at 1 kHz and 10 of the 26 exceeded the fence at 4 kHz. Six years later the figures were 4 and 15 respectively for these two frequencies. No changes in risk had occurred for the lower frequency. At the higher frequency, 5 more individuals had crossed the line. Seven of the 15 had a moderate to severe loss of 50 dB HL or greater. An analysis of the

slope of the hearing loss over time within individuals indicated that the rate of change at 4 kHz was about 1.5 dB per year. This was in contrast to a rate of 0.5 dB per year for non-noise exposed office workers employed at Ontario Hydro.

Each of the industries included in the survey had had a hearing conservation program based on the use of personal hearing protection in effect at the time the measurements were made. Yet noise-induced hearing loss was evident in even the youngest workers sampled, i.e., those for whom the wearing of protectors had been mandatory since the onset of employment. In order to better understand this negative effect we surveyed a sample of 57 individuals at one Ontario Hydro work site. For these there had been no change in exposure over the total period of employment and no known noise exposure outside of the work environment.

Responses to the survey questionnaire indicated that 20 subjects in the sample under age 25 had all been provided with protectors on starting employment. Of these, 16 (80%) admitted to wearing the muffs or plugs less than 50% of the time on the job. In a second subgroup of 25 workers aged 25 to 34 years only 11 had first worn protection at the start of employment. Again, we found that virtually the entire subgroup (70%) wore protection less than 50% of the time. Looking at the benefits for those who consistently wore protection more than 50% of the time (about 8 of the 57 or 14%), we found no clear trend in the direction of less risk for hearing impairment.

WHY HEARING PROTECTORS FAIL

One of the reasons why hearing protectors may fail to protect against the harmful effects of high-level noise is that the actually achieved attenuation may fall short of the manufactuer's specification. In order to test this hypothesis, we measured the attenuation provided by ten commonly used plugs and muffs in 350 workmen who had been referred for clinical assessment of noise-induced hearing loss by the Workmen's Compensation Board of Ontario.[6] Most were miners and steelmakers aged 35-65. Each was asked to bring the protectors he normally used and to fit them personally. The number of individuals tested for the various devices ranged from 15 to 58.

Thresholds for hearing were measured free-field with and without the protector worn at eight narrowband frequencies ranging from 125 Hz to 8 kHz. The difference between the protected and unprotected scores gave the attenuation for each frequency. Regardless of the protector type (i.e., muffs or plugs) the model (e.g., expandable foam or pre-molded vinyl) or the frequency tested, the achieved attenuation varied by as much as 45 dB across individuals. To take an example, for one plug, purported to provide 40 dB of attenuation at 4 kHz, 84% of the 49 individuals tested achieved less than 35 dB.

An examination of the devices used by the workers[7] indicated that these had often been modified for greater comfort. Many individuals had difficulty fitting the device correctly. A later study[8] indicated that if the protectors were fitted by an audiologist rather than by the subjects the standard deviation in attenuation scores associated with a particular protector and test frequency decreased by about 5 dB. Achieved attenuation was not related to the amount of hearing loss or age of subjects.

COMMUNICATION AND SIGNAL DETECTION IN NOISE

Misuse and deliberate abuse of the protector in many cases reflects concern by the worker that attenuation of sound will interfere with the perception of speech, warning signals, machinery malfunctions and defects in the material worked on. In the first experiment of a series to study this problem[8] we compared speech intelligibility in noise with and without protectors worn in three groups of subjects with screened normal hearing, bilateral noise-induced high-frequency hearing loss, (i.e., normal hearing at 500 Hz), and bilateral flat loss (i.e., hearing loss throughout the range of audible frequencies).

At the time of the study census data indicated that at least 1/4 of the workforce in Ontario had acquired English as a second language. We wondered whether poor comprehension and a hearing loss would act orthogonally in determining speech perception in noise with ear protectors. Thus, half the subjects recruited for each of the three groups were fluent in English and half were poorly conversant. Each of the subgroup with high-frequency loss were further subdivided into two age categories, 35 to 50 years and 51 to 65 years. Aging apart from hearing loss has been shown to affect central neural processing.

Intelligibility of word lists was assessed in quiet and in background of white noise and crowd noise of 85 dBA for speech level of 80 and 90 dBA. The results showed that intelligibility decreased with signal to noise ratio and was poorer in speech-like crowd noise than in steady-state white noise. The wearing of protectos had no effect for the normal listener but caused a substantial decrement in individuals with hearing loss. For all three major groups, non-fluency contributed an additional loss of 10% to 20%. Age of subjects was not a significant factor. Significant differences were found for different plug and muff types used.

In order to simulate the detection in noise problem in the laboratory, we taped samples of mill house and drilling noise at Falconbridge Nickel Mines, and subsequently measured detection thresholds for narrowband signals centred at 1 kHz and 3 kHz in quiet and superimposed on each of these noise backgrounds set at levels of 85 dBA.[9] Signals and noise were presented using headphones. Thresholds were measured both with and without insert protectors worn.

Subjects with three configurations of audiogram were tested: normal hearing; bilateral high frequency loss of at least 35 to 85 dB HL at 3 kHz and normal hearing at 1 kHz; and bilateral hearing loss of 35 to 85 dB HL at both 1 kHz and 3 kHz. Within each of the groups with noise-induced hearing loss we studied two subgroups: workers who had been exposed mainly to steady-state noise (e.g., machinists and millers employed in pulp and paper mills) and workers exposed mainly to impulsive or intermittent noise, (e.g., riveters and rock drillers).

For unprotected listening, all subjects regardless of hearing status showed a detection threshold of about 80 dBA when listening for a 3 kHz narrowband signal superimposed on noise of 85 dBA. Detection in quiet was well predicted by the audiogram. Using insert protectors in noise, normal subjects showed an advantage of 3 dB. Those with moderate to severe hearing loss at 3 kHz were virtually totally deafened by the use of the protector when listening in quiet or in noise. Analysis of the results for detection of 1 kHz indicated that the deleterious effets of wearing hearing protection was confined to the frequency of hearing loss. Impaired listeners

with near-normal hearing at 1 kHz performed like subjects who had normal hearing throughout the range of audible frequencies. For neither of the hearing-impaired groups was noise exposure history a significant factor.

The results of the detection study were conclusive in showing that individuals with a moderate to severe hearing loss are at risk when wearing protectors. A model of the detection process was described for choosing a level of attenuation that would optimize detection while at the same time affording the listeners reasonable protection. The recommendation made was that noise reduction to a standard of 85 dBA through the use of attenuating devices was not necessarily suitable for all workers. For those who already have a moderate to severe impairment, Class B or C protectors, as described by the new Canadian Standard[10] would likely be far more appropriate.

MORPHOLOGY OF THE EAR CANAL

An experiment in progress is investigating the possibility of prescribing ear protectors on an individual basis, taking into account both hearing status and shape and size of the ear canal. The attenuation of three commonly used insert protectors having different physical characteristics is being measured in one hundred and twenty young males and females with normal hearing. The protectors include the EAR expandable foam, the Willson premolded vinyl and Bilsom polyethylene encapsulated glass fiber. All have similarly high noise reduction ratings. Headphone detection thresholds are being measured with and without the protectors worn for five one-third octave bands centred at 250, 500, 1000, 3150 and 6300 Hz.

The question of interest is whether the achieved attenuation found for each type of protector is related to the size and shape of the ear canal. To this end bilateral full ear canal molds are being made in the same subjects. Various parameters characterizing size and shape will be correlated with the attenuation data within individuals for each protector in order to establish whether particular types of devices may be inappropriate for certain individuals. Few objective data are available regarding human ear canal morphology. This aspect of the study is designed to provide new basic information.

A concern which is often raised with regard to the use of hearing protective devices is the effect of wearing time on attenuation. Workers often report that insert protectors may work their way out of the ear canal, requiring frequent re-fitting. In order to study this problem in the laboratory, we have begun an investigation in which attenuation is measured in young normal subjects before and after they eat lunch. The protectors are not re-fitted prior to the second measurement, thereby allowing us to assess the affect of head and jaw movement on attenuation.

Twelve subjects will be tested at each of two narrowband stimuli with centre frequencies of 500 Hz and 3150 Hz. Each subject will be required to participate on three separate days for testing of the three protectors used in Experiment I, i.e., the EAR expandable foam plug, the Willson sound silencer premolded vinyl plug and Bilsom encapsulated glass fiber. Order of presentation of protectors (across days) and test frequency (within days) will be counterbalanced across subjects so that we may assess possible practice effects.

CONCLUSION

The results of these investigations indicate that noise-induced hearing loss continues to be an important problem for occupational health. Every province has a regulation for safe levels of noise exposure, and large industries have viable hearing conservation programs, yet claims for compensation for hearing loss continue to rise. Part of the problem is nonoccupational noise exposure associated with leisure activities. On the worksite, failure of personal hearing protectors appears strongly related to poor fitting techniques, maintenance, and inadequate monitoring of usage. If protectors continue to be the method of choice for noise reduction, then our experiments strongly point to the need for prescription on an individual basis with special attention paid to such variables as hearing loss, ear canal morphology and characteristics of the noise background in which the devices are used.

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