

Noise-Induced Hearing Loss in Canadian Military Personnel

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ABSTRACT

The escalating cost of claims for noise-induced hearing loss in the Canadian Forces (CF) prompted the review of current hearing conservation practices. As a first step, a prospective study was conducted to assess risk factors for the development of hearing loss in a wide range of military trades. A total of 1,057 individuals working in land, sea and air environments at five CF military bases contributed their current hearing test results and first hearing test results on record. They also completed a 56-item questionnaire relating to demographics, occupational and non occupational noise exposure history, training in and utilization of personal hearing protection, and risk factors other than noise which might affect hearing, including head injury, ear disease, medications, and solvent exposure. Military medical personnel recruited the subjects, distributed the questionnaires and assessed hearing. Apparatus and protocols for the latter conformed to current clinical practice. The results showed that the prevalence of moderate to severe hearing loss progressed with years of noise exposure, with hearing thresholds in those over 45 years ranging broadly from normal to over 70 dB HL. Unprotected exposure to solvents and leisure noise appeared to be significant determinates of adverse outcome, while the effects of head injury, history of ear disease, and the use of medications were minimal. The survey suggested that training on the hazards of noise exposure and the selection and utilization of hearing protection were inadequate. Hearing protection was reported to be incompatible with other gear, uncomfortable and an impediment to communication.

1.0 INTRODUCTION

The Canadian Forces introduced a hearing conservation program in the 1950s [1]. Components include noise measurement, the reduction of noise at the source where possible, education on the hazards of noise exposure, utilization of personal hearing protection and the regular monitoring of hearing. Statistics compiled by Veterans Affairs Canada show that, in spite of these safeguards, the cost of claims for noise-induced hearing loss, is escalating. Currently, the annual payout for a force strength of about 50,000 individuals is more than double the amount cited by the Workplace Safety and Insurance Board of Ontario [2] for a provincial labour force of about 2 million in the manufacturing, construction, agriculture and mining sectors [3]. These data support the need to review and upgrade current hearing conservation practices.

Unprotected exposure to high-level sound results in permanent hearing loss, generally referred to as either noise-induced hearing loss (NIHL) or noise-induced permanent threshold shift (NIPTS). The magnitude of the hearing threshold elevation relative to normal hearing thresholds will depend on the level of the sound to which the individual is exposed, the number of hours of exposure per day, and the use of personal hearing

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protection. For federal employees in Canada the level of continuous steady-state noise that is considered safe for hearing is 87 dBA for an 8-hour work day [4]. Based on the equal energy principal, the exposure duration should be halved for every 3 dB increment in level [5].

According to Franks et al. [6], NIHL is among the most prevalent work-related medical conditions in both the United States and Europe. Biological changes from metabolic stress and mechanical damage following noise exposure are complex and include pathology of neural, sensory, supporting and vascular cells of the peripheral end organ for hearing, i.e., the cochlea [7]. Damage to hearing caused by limited exposures may result in a temporary threshold shift (TTS) that gradually disappears over a number of hours of relative quiet. However, continued or repeated exposures will result in irreversible sensory hair cell loss and concomitant permanent sensorineural, predominately high tone, hearing loss [8]. Although the high-level sounds to which the individual is exposed may have a broad frequency spectrum, the most vulnerable frequency region for hearing loss is 4-6 kHz. This outcome reflects the natural resonance of the ear canal at 3.8 kHz [9]. Hearing loss in this region is clearly evident after 3-5 years of exposure [10]. The hearing threshold “notch” in the audiogram in this frequency region deepens with continued exposure. Hearing loss gradually spreads to lower and higher frequencies. Individual differences are large, denoting a wide range of personal susceptibility [11,12].

High-level impulsive sounds from weapons are a particularly damaging source of noise exposure in military environments [13,14]. Peak levels may be as high as 185 dB SPL. Both the nature of the injury and the pattern of recovery differ substantially from that of continuous noise. The effectiveness of hearing protectors for preventing NIHL from small firearms and large-calibre weapons was investigated by Christiansson and Wintzell [15]. The subjects were 204 infantry officers who instructed conscripts in the use of firearms. Peak exposures levels ranged between 156-185 dB SPL. For the sample as a whole, the maximum loss was observed at 6 kHz. At this frequency the average hearing threshold was 25 dB HL (hearing level, i.e., loss, relative to normal threshold) by 35 years of age, and 40 dB HL at 45 years of age. The prevalence of a moderate hearing loss by mid-life in spite of hearing protector usage suggested that hearing conservation programs developed for application in industrial settings may not be adequate for military trades.

The assessment of hearing loss from occupational noise exposure may be confounded by a number of factors. Studies reported in the literature have focused on the interaction with aging, exposure to potentially ototoxic organic solvents (e.g., toluene and styrene), and exposure to high-level sound from non occupational sources (i.e., leisure noise).

1.1 Aging

The two main causes of hearing loss are aging and noise exposure. The International Standards Organization (ISO) provides databases for males and females who are otologically normal and highly screened for factors that may affect hearing, as well as for males and females from a typical unscreened population of an industrialized country [16,17]. These may be used as baselines against which to assess the effects of noise exposure. Hearing loss is modelled as an accelerating function of age while noise-induced hearing loss is modelled as a decelerating function of the exposure duration [18]. It may be possible to determine the primary cause of the hearing loss, age or noise, from the configuration of the audiogram. The effects of aging start at the highest frequencies and gradually progress to lower frequencies. In contrast, noise-induced hearing loss is initially evident as threshold notch in the region of 4-6 kHz that deepens with exposure and gradually spreads to both lower and higher frequencies [19].

1.2 Solvent exposures

Studies conducted in both animal models and humans suggest that various aromatic hydrocarbons, particularly toluene, xylene and styrene, may be ototoxic [20-23]. Mounting evidence also indicates that exposure to organic solvents potentiates NIHL [24]. In one experiment reported in the literature, Sliwinska-Kowalska et al. [25] compared hearing loss in workers exposed to either a mixture of organic solvents at concentrations below permissible levels in paint and lacquer industries, solvents in combination with noise levels greater than 85 dBA, or neither agent. Hearing loss was defined as an elevated hearing threshold in excess of 25 dB HL at any frequency from 1-8 kHz. The prevalence of hearing loss in the control group was 36% compared with 57.5% for solvent exposure and 61.5% for solvent plus noise exposure. Mean hearing thresholds for the noise plus solvent group were about 5 dB greater than those for the solvent alone group in the range of 2-4 kHz. Research in animal models have demonstrated outer hair cell damage for both solvent and noise, supporting the hypothesis of same site of injury [26].

1.3 Leisure Noise Exposure

There has been increasing concern in recent years about the potentially damaging effect of high-level sound exposure during leisure activities. The sources are diverse and include amplified music at rock concerts and disco/dance bars, motorcycles, snowmobiles, firearms, power and chain saws, and impulse generating toys such as cap pistols. Levels can be in excess of 100 dBA [27]. This concern has been validated by hearing tests conducted as part of medical screening for military recruitment. For example, in a random sample of 500 18-year old Swedish male conscripts, Axelsson et al. [28] found a 14% prevalence of hearing loss, defined as a threshold equal to or greater than 20 dB HL at any test frequency. Most often, the loss was in the region of 4-8 kHz. Seventy-nine percent of the sample reported that they listened to pop music often or very often, and 17% had attended more than 10 rock concerts. Twenty-one percent played a musical instrument. A considerably higher prevalence of high-frequency hearing loss was reported by Borchgrevink [29] for 18-year old Norwegian male conscripts. In the latter study, prevalence increased from 15% to 25% among a sample of about 30,000 individuals over a 10-year period from the early 1980's to the early 1990's. The author argued that the observed increase in prevalence reflected the increase in exposure to leisure noise, particularly rock music.

1.4 Impact on Communication, Task Performance and Health

The impact of noise exposure on human health is wide ranging and includes both auditory and non-auditory outcomes [30]. With respect to communication, studies have shown that individuals with high-frequency hearing loss will have difficulty with speech understanding in noisy backgrounds [31,32]. Smoorenburg [32] found that the speech reception threshold (SRT - the level at which 50% of sentences can be repeated correctly) in quiet was correlated with pure-tone hearing thresholds below 1 kHz and the SRT in noise to the thresholds at 2 kHz and 4 kHz. A noticeable handicap (decrement in SRT in noise) was apparent even when the hearing loss at these frequencies was relatively mild at 30 dB HL.

The presence of high-level background sound is also detrimental to the performance of diverse non-auditory tasks, including vigilance, selective attention, sensory-motor behaviour and recall [33,34]. For example, in a study of vigilance and time-sharing reported by Hockey [35], subjects performed a tracking task (designated high priority) while detecting the presentation of lights at different spatial locations (designated low priority). In a 100 dB-SPL noise background, deficits were observed for the low priority task, particularly for signals presented from peripheral positions. The effect of the noise was a reallocation of attention. Continuous high-level sounds have also been implicated in sleep disorders [36,37], cardiovascular disease [38] and mental

health [39]. In a series of laboratory sleep studies Thiessen and colleagues [40,41] found that, with increases in the level of taped traffic noise, the number of awakenings increased by 40% and the probability of a decrease to a lighter sleep stage increased by 70%. Cantrell [42] reported a rise in plasma cortisol and blood cholesterol levels that persisted for at least a week after the conclusion of an experiment in which subjects were confined to a noisy dormitory for 50 days and nights and exposed to high-frequency sounds ranging from 80 to 90 dB SPL. Research relating to noise and mental health have demonstrated that psychiatric symptoms and mental hospital admissions are more prevalent in the vicinity of airports [43].

2.0 RESEARCH DESIGN

A prospective cross-sectional study was carried out at five Canadian Forces military bases located in Ontario and Nova Scotia [44]. All personnel who were scheduled for a routine hearing test within a designated 12-month period were invited to participate at the time of their clinic visit. No restrictions were placed on age, gender, rank, military trade or length of military service. The only exception was that volunteers had to have completed at least one year of employment in the Canadian Forces prior to the study. No upper limit was placed on the number of participants. Those who volunteered contributed their most recent audiogram, as well as the first audiogram in the clinic chart. The latter was not necessarily the enrolment audiogram. However, at least one year must have elapsed between the first and current assessments.

Volunteers also completed a 56-item survey relating to risk factors for acquiring a hearing loss. The survey included questions about age, gender, previous trades and work-related noise exposure history, current noise and solvent exposures, training in and utilization of hearing protection and respirators, head injury, civilian noise exposure and perceived hearing handicap. Subjects were also asked about their health, and specifically about their history of ear infections and ear symptoms, head injuries, dizziness, and medications prescribed. The responses enabled the investigators to take into account various causes of any observed hearing loss.

3.0 METHODS AND MATERIALS

The study protocol was approved by the Defence Research and Development Canada Human Research Ethics Committee. Upon arrival at the clinic subjects were given the protocol to read. If interested in participating, they provided written consent and then completed the questionnaire while waiting for the hearing assessment. For the latter, subjects were tested individually in a sound proof booth (Eckel Industries, Model AB200). The apparatus included a Beltone audiometer (Model 119) and TDH-39 matched headset. Hearing thresholds were measured by trained clinic personnel once at each of seven pure tone frequencies (0.5, 1, 2, 3, 4, 6 and 8 kHz), in each ear. Thresholds were determined using the standardized method of adjustment [45]. The sound level was systematically increased and decreased in steps of 5 dB to find the critical value (i.e., the threshold) that separated the audible from the inaudible range. Following the hearing assessment, the subject's file (the Consent Form, completed questionnaire, and copies of the current audiogram and first available audiogram) were transferred by clinic personnel to the experimenters.

4.0 RESULTS

4.1 The total sample

4.1.1 Demographics

In all, 1,057 subjects (910 males and 147 females) participated in the study. The distribution of subjects by age is given in Table 1. A comparison of these data with Canadian Forces demographics confirmed that the male/female ratio was virtually identical, as was the ratio of non commissioned members to officers (77% vs 23%). The sample underestimated the population by 10% on average in the two younger categories and overestimated the population by 10% on average in the two older categories. Because there were relatively few subjects older than 55 years, the 46-55 years and 56-65 years categories were combined for subsequent analyses.

**Table 1: The Distribution of Subjects by Age
(N=1057)**

| Age (years) | n | % |
|-------------|------|-------|
| 16 – 25 | 40 | 4.0 |
| 26 – 35 | 246 | 23.0 |
| 36 – 45 | 578 | 55.0 |
| 46 – 55 | 185 | 18.0 |
| 56 – 65 | 8 | 1.0 |
| Total | 1057 | 100.0 |

Table 2 provides summary statistics on the current age, age at recruitment, total years of service and years of service in the current trade. For our sample, just over half the subjects (55%) were aged 36-45 years at the time of the study, the mean age at recruitment was 20 years, subjects had been employed for 19 years on average and had served in the current trade for 15 years. This information suggests that for most of the subjects, the trade (and thus likely the noise exposure profile) had not changed over the course of their military careers. Subjects' age and number of years of military service were highly correlated ($r = +0.872$, $p < 0.001$). Since number of years of service was assumed to be a valid index of number of years of noise exposure, and because of the demonstrated relationship of years of service and age, the decision was made to assess the effects of age on hearing rather than years of service in subsequent analyses.

Table 2: Age at Recruitment, Total Years of Service and Number of Years in Current Trade

| | Current Age (years) | Age at Recruitment (years) | Total Years of Service (years) | Years of Service in Trade (years) |
|--------------------|------------------------|----------------------------------|--------------------------------------|---|
| Mean | 39.59 | 20.38 | 19.20 | 14.60 |
| Standard Deviation | 7.14 | 3.78 | 7.76 | 8.22 |
| Minimum | 20 | 15 | 1 | 0.25 |
| Maximum | 64 | 46 | 47 | 37 |

In all, 107 trades were represented in the sample. In some instances, similar trades were grouped together based on information about the work carried out. The number of subjects in each trade or trade grouping ranged from 1 to 97. Several trades known to be associated with high-level noise exposure, e.g., Infantry, Armoured Soldiers and Artillery Soldiers [46], were poorly represented. This may have been the result of overseas deployment during the period of the study. Land, Sea, Air and Purple (shared by the three environments) trades accounted for 15%, 14%, 36% and 27% of the sample, respectively. Based on a description of their duties and responses to the questionnaire, 9% of the sample were categorized as Controls, i.e., they were not routinely exposed to noise on the job.

4.1.2 Hearing thresholds

Mean current hearing thresholds (dB HL) from 0.5 kHz to 8 kHz are given for left and right ears for each of four age categories in Table 3. A repeated measures analysis of variance (ANOVA) applied to the data from those subjects for whom results were available for all seven frequencies tested (N=948) showed significant effects of age group, ear, frequency, frequency by age group, ear by frequency and ear by frequency by age group ($p < 0.001$). Post hoc pair wise comparisons using the least significant difference (LSD) test [47] indicated that, averaged across frequencies, hearing thresholds for the two younger groups were no different (8 dB HL). Thresholds for both these groups were significantly lower than those observed for each of the two older groups which were significantly different from each other (13 dB vs 20 dB). Averaged across groups, thresholds increased from 8 dB HL to 18 dB HL from 0.5 kHz to 8 kHz. The difference between ears within groups at each frequency was at most 4 dB. Although the mean hearing thresholds were within normal limits, distributions of hearing thresholds observed at 4 kHz and 6 kHz in the left and right ears were positively skewed toward high values, increasingly with age [44]. These data showed that the percentage of individuals with moderate to severe hearing loss increased with years of service. In the oldest group, approximately 17-26% had a moderate to severe hearing, a greater proportion (4-5%) in the left ear than the right at 4 kHz and 6 kHz.

Table 3: Current Hearing Thresholds (dB HL) as a Function of Age

| Age (yrs)** | n | Ear | Frequency (kHz) | | | | | | | |
|-------------|-----|-------|-----------------|-------------|-------------|-------------|-------------|-------------|----------------|--|
| | | | 0.5 | 1 | 2 | 3 | 4 | 6 | 8 ⁺ | |
| 16 – 25 | 40 | Left | 7.4 (6.3)* | 5.9 (5.8) | 7.3 (8.4) | 6.9 (10.2) | 8.3 (9.6) | 10.3 (10.2) | 10.0 (13.8) | |
| | | Right | 9.8 (7.8) | 7.5 (6.7) | 5.6 (8.3) | 6.4 (9.9) | 8.0 (15.7) | 9.4 (14.6) | 11.1 (19.1) | |
| 26 – 35 | 246 | Left | 5.8 (7.1) | 5.6 (7.4) | 5.5 (8.0) | 7.9 (10.2) | 9.2 (11.9) | 12.5 (12.7) | 11.9 (13.7) | |
| | | Right | 6.7 (7.5) | 5.8 (7.0) | 4.5 (7.6) | 5.6 (9.6) | 8.1 (11.6) | 11.8 (11.5) | 11.5 (10.8) | |
| 36 – 45 | 578 | Left | 7.6 (7.9) | 7.6 (8.5) | 7.9 (9.3) | 12.3 (12.4) | 16.0 (14.8) | 20.4 (16.1) | 20.6 (17.5) | |
| | | Right | 8.9 (8.2) | 8.7 (8.5) | 7.4 (8.8) | 10.3 (11.4) | 13.8 (13.2) | 17.7 (15.0) | 18.1 (15.6) | |
| 46 – 65 | 193 | Left | 10.6 (12.7) | 11.2 (13.0) | 13.5 (13.6) | 21.9 (18.6) | 26.4 (18.8) | 30.5 (20.5) | 34.2 (23.3) | |
| | | Right | 11.0 (9.1) | 11.6 (9.9) | 11.6 (11.3) | 17.4 (14.8) | 22.2 (17.4) | 27.6 (18.8) | 29.7 (22.1) | |

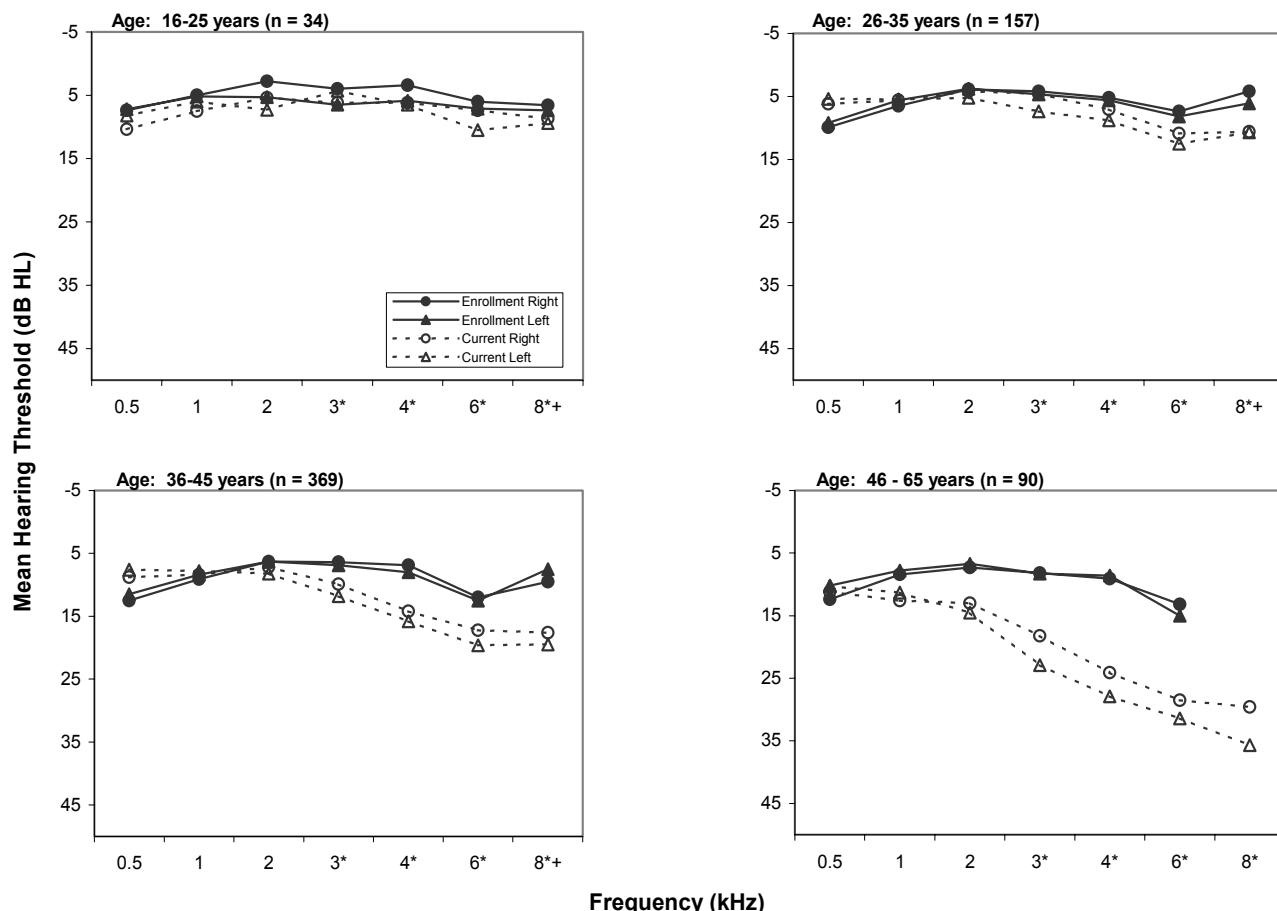
** age range = 20 – 64 years

* mean (standard deviation)

⁺ n for 8 kHz (16 – 25 yrs = 31; 26 – 35 yrs = 227; 36 – 45 yrs = 519; 46 – 65 yrs = 172)

A comparison of mean enrolment and current hearing thresholds is shown in Figure 1. Analyses were based on the data from those subjects in whom the earliest available audiogram was actually the enrolment audiogram (N=650). Results are shown separately for the four age groups. A repeated measures ANOVA applied to the data from those subjects in whom measurements were available for both ears at six frequencies from 0.5-6 kHz (N=647) showed significant effects of age group, time of measurement, ear, and frequency ($p < 0.001$); time by age group, frequency by age group, time by ear, time by frequency, and ear by frequency ($p < 0.001$); time by frequency by age group, time by ear by frequency ($p < 0.001$); and time by ear by age group ($p < 0.04$). Differences due to the time of measurement (enrolment vs current) ranged from 1-2 dB across frequency for the 18-25 year olds, from 0-4 dB for the 26-35 year olds, from 1-8 dB for the 36-45 year olds and from 0-16 dB for the 46-55 year olds. The largest differences were observed at 4 kHz or 6 kHz.

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* n for Enrolment 3 kHz: 26–35=156; 4 kHz: 36–45=368, 46–65=89, 6 kHz: 26–35=156, 36–45=368, 46–65=89

*+ n for 8 kHz Enrolment: 16–25=22, 26–35=36, 36–45=10, 46–65=1; Current: 16–25=26; 26–35=157; 36–45=369; 46–65=81

Figure 1: Enrolment and Current Hearing Thresholds (dB HL) for Four Age Groups (n=650).

As stated above, enrolment audiograms were available for 650 subjects (61% of the sample). Table 4 provides a listing of years of service (in five year bins) for the first available audiogram together with the percentages of subjects who had hearing thresholds less than 20 dB HL (normal or slight hearing loss) and less than 30 dB HL (no more than a mild hearing loss) at 4 kHz and 6 kHz for the left ear. These are the frequencies that have been shown to be most susceptible to the damaging effects of noise. Shown for comparison are the distributions of current hearing thresholds for the same number of years of service. The table shows that for the majority of subjects (84%) the first audiogram was measured within the first five years. In these individuals, 90% had hearing thresholds less than 20 dB HL at 4 kHz and 78% had hearing thresholds less than 20 dB HL at 6 kHz. Regardless of whether the first or current audiogram was examined, the proportion with no more than a mild hearing loss of less than 30 dB HL at these two frequencies remained above 85% over the first 20 years of service, or in terms of age, until the early 40's. Steep declines were then evident.

Table 4: First and Current Hearing Thresholds as a Function of Years of Service

| Frequency | Audiogram | Years of Service | n | Hearing Threshold (dB HL) | |
|----------------------|---------------|------------------|-------------|---------------------------|-----------|
| | | | | < 20 dB | < 30 dB |
| 4 kHz (n = 1043*) | First | 1 - 5 years | 874 (84%) | 784 (90%) | 852 (97%) |
| | | 6 - 10 years | 78 (8%) | 65 (83%) | 77 (99%) |
| | | 11 - 15 years | 37 (4%) | 28 (76%) | 32 (86%) |
| | | 16 - 20 years | 22 (2%) | 17 (77%) | 20 (91%) |
| | | 21 - 25 years | 14 (1%) | 7 (50%) | 11 (79%) |
| | | 26 - years | 18 (2%) | 9 (50%) | 13 (72%) |
| | | Current | 1 - 5 years | 66 (6%) | 52 (79%) |
| | 6 - 10 years | 63 (6%) | 54 (86%) | 61 (97%) | |
| | 11 - 15 years | 180 (17%) | 149 (83%) | 164 (91%) | |
| | 16 - 20 years | 260 (25%) | 184 (71%) | 231 (89%) | |
| | 21 - 25 years | 282 (27%) | 156 (55%) | 230 (82%) | |
| | 26 - years | 192 (18%) | 89 (46%) | 123 (64%) | |

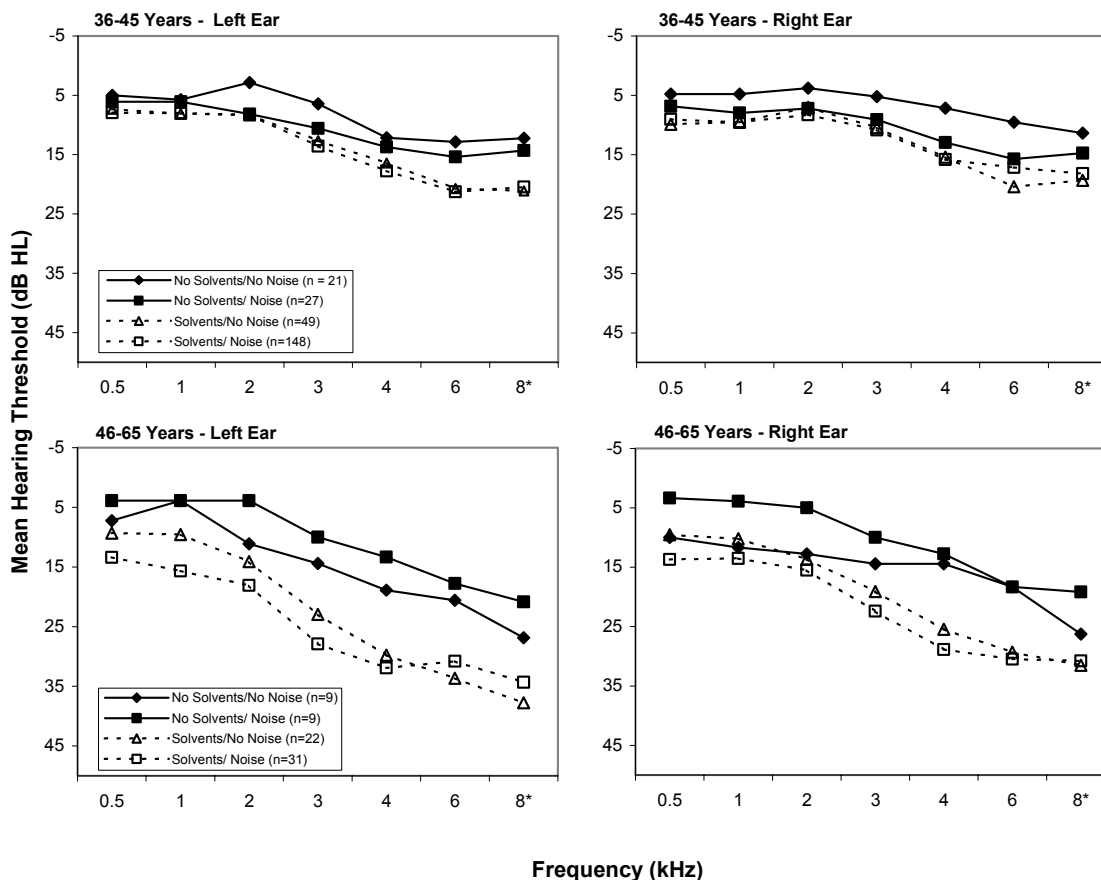
* N = 1057 – 14 participants were not included; 12 did not have a first hearing test or did not have a date for the first hearing test and 2 did not have hearing thresholds at 4 kHz

| | | | | | |
|----------------------|---------------|---------------|-------------|-----------|-----------|
| 6 kHz (n = 1041*) | First | 1 - 5 years | 873 (84%) | 682 (78%) | 811 (93%) |
| | | 6 - 10 years | 77 (7%) | 54 (70%) | 70 (91%) |
| | | 11 - 15 years | 37 (4%) | 26 (70%) | 32 (86%) |
| | | 16 - 20 years | 22 (2%) | 16 (73%) | 18 (82%) |
| | | 21 - 25 years | 14 (1%) | 5 (36%) | 7 (50.0) |
| | | 26 - years | 18 (2%) | 9 (50%) | 12 (67%) |
| | | Current | 1 - 5 years | 66 (6%) | 54 (82%) |
| | 6 - 10 years | 63 (6%) | 44 (70%) | 59 (94%) | |
| | 11 - 15 years | 179 (17%) | 136 (76%) | 161 (90%) | |
| | 16 - 20 years | 259 (25%) | 151 (58%) | 208 (80%) | |
| | 21 - 25 years | 282 (27%) | 123 (44%) | 200 (71%) | |
| | 26 - years | 192 (18%) | 64 (33%) | 111 (58%) | |

* N = 1057 – 16 participants were not included; 12 did not have a first hearing test or did not have a date for the first hearing test and 4 did not have hearing thresholds at 6 kHz

Because a high proportion of subjects indicated that they had been exposed to solvents, a comparison was made of hearing thresholds in those with and without solvent exposure, who had or had not been exposed to noise. Subjects were categorized as solvent exposed if they had responded in the affirmative on the questionnaire and 80% or more of the individuals in their trade had been exposed. In all, 398 subjects met these criteria. Subject were defined as not exposed if they had responded negatively and if less than 20% of the those in their trade had been exposed. In all, 147 subjects met these criteria. From these groups a further selection was made of subjects who had been (1) exposed to noise “often” or “constantly” and the severity of the noise was “moderate” or “severe” and (2) those who were “never” or “occasionally” exposed to noise and the noise was “no noise” or “mild noise” based on the responses to the questionnaire. Mean hearing thresholds plotted as a function of frequency for subjects in each of the four cells are presented in Figure 2 for subjects aged 36-45 years and 46-65 years. These data show that solvents have a relatively greater negative impact than noise on hearing thresholds, particularly in the high frequencies above 3 kHz. The difference increased with age. Because of the wide difference in numbers of subjects across conditions, these trends were not evaluated statistically.

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*n at 8 kHz: 36-45 yrs n = 18, 21, 44, and 131; 46-64 yrs n = 8, 6, 20, and 31

Figure 2: Effect of Solvent Exposures on Hearing in the Two Older Age Categories

4.1.3 Survey of risk factors

Responses to the questionnaire showed the following:

- Perception of changes in hearing and noise levels in the workplace: 27% believed that their hearing had become moderately or much worse since joining the Canadian Forces; 47% reported that their workplace was often or constantly noisy and 59% said that the noise to which they are exposed was moderate or severe.
- Training on hearing loss prevention: The greater proportion of the sample (82%) had either received no training or one hour or less on the dangers of noise exposure. Further, 89% had received either no training or one hour or less on the proper use of hearing protection devices. Finally, 50% judged their training on the dangers associated with noise exposure as either negligible or poor quality.
- Utilization of personal hearing protectors: 80% of the sample were exposed to noise at least some of the time. While relatively few (17%) of those exposed indicated that they never wore hearing protection devices in noise, only 42% wore these devices for more than half the work shift. Most

(77%) said that supervisors advised about the need for hearing protection either occasionally or not at all.

- Drawbacks of hearing protector utilization. On the whole, the participants appeared to understand the utility of wearing hearing protection. Only 19% often or definitely agreed that hearing protectors were *not* beneficial. Only 22% often or definitely agreed that they were uncomfortable but 50% believed that they would interfere with hearing. Only 10% felt that they would pose a danger at work. Concern about auditory impairment, then, seemed to be the major impediment to utilization.
- Few subjects (3%) had moderate to great difficulty listening in a quiet room. By comparison, 32% experienced moderate to great difficulty in noise. Similar outcomes were observed for listening over the telephone. Subjects who had difficulty in noise were likely those with acquired hearing loss. The percentage is similar to the percentage who believed that their hearing had become worse since joining the Canadian Forces. Both distance from the source (i.e., listening across a room) in noise without hearing protection and understanding orders in noise with hearing protection increased the percentage who experienced significant difficulty by about 20%.
- Exposure to Solvents: Over half the sample (61%) were exposed to solvents at work. Of this group, only 19% said that they wore respiratory protective equipment for more than half the work shift.
- Head injury: Relatively few subjects (9%) had a history of work-related head injury. Of these, 10% complained of a moderate or severe permanent hearing loss. In one-third of these cases, both ears were affected.
- Ear infections, non work related head injuries and the use of medications: 41% and 32% of the sample had experienced ear infections during childhood and adulthood, respectively. However, very few individuals (3% of the total sample) believed that they currently had a hearing loss from a previous ear infection. 12% had sustained a head injury outside of work. However, no subject had a permanent hearing loss as a result of the incident(s). No subject reported a permanent hearing loss as a result of medications.
- Tinnitus and dizziness: Previous research has shown that exposure to loud sounds may result in tinnitus (noise in the head or ears) as well as hearing loss. Tinnitus accompanied by both hearing loss and dizziness may be indicative of inner ear disease [48]. Half the sample (52%) reported that they had experienced some tinnitus. Of these, 34% perceived the tinnitus to be moderate or loud, 11% experienced moderate to much interference with their ability to hear, and 3% experienced sleep disturbance often or all the time. 15% of the sample had bouts of dizziness. Of these, only 24% definitely experienced the dizziness as the perception of circling. The latter would be indicative of vestibular involvement. Dizziness rarely interfered with work, and was rarely related to hearing loss.
- Exposure to leisure noise: Of the 1,057 respondents, 53% claimed that they were exposed to loud sounds during leisure activities. The most prevalent sources were power tools (58%), rock music (28%) and disco/dance bars (16%). The number of hours of exposure ranged widely across individuals from 5 minutes to 45 hours. Long durations may have resulted from subjects' inadvertently combining work and non work related exposures in their responses. Only 30% wore hearing protection more than half the time during leisure activities, with muffs and plugs used equally often.

4.2 Selected trades

4.2.1 Demographics

Seventeen trades with 15 or more subjects were selected for individual consideration (see Table 5). These trades accounted for 667 subjects or 63% of the sample of 1,057. A review of the current age, years of service and years in current trade indicated that they were comparable [44]. Mean age ranged from 35 to 43 years and mean total years of service ranged from 13 to 24 years. Mean years in the current trade was somewhat broader, ranging from 7 to 22 years. In most trades, the mean numbers of years in service and years in the current trade were virtually identical, i.e., they differed by 6 years at most. The exceptions were the flight engineers (11 years) and aircraft structures technicians (12 years). Further review indicated that the discrepancies were attributable to the fact that virtually all of the individuals in these two trades had

Table 5: Summary Statistics for Selected Trades

| MOC | Job Title | n | Current Age | Total Years of Service | Years in Trade |
|-----|-----------------------------------|----|-------------|------------------------|----------------|
| 031 | Infantry Soldier | 18 | 41.2 (6.6)* | 21.7 (7.1) | 22.0 (6.9) |
| 091 | Flight Engineer | 33 | 42.9 (5.6) | 23.9 (6.2) | 13.1 (8.1) |
| 215 | Signal Operator | 16 | 37.1 (5.9) | 17.4 (5.9) | 16.3 (6.8) |
| 31 | Air Navigator | 51 | 35.4 (7.3) | 15.2 (7.2) | 12.7 (7.1) |
| 32 | Pilot | 68 | 37.8 (7.2) | 17.3 (7.6) | 14.1 (7.6) |
| 411 | Vehicle Technician | 47 | 38.7 (6.9) | 19.4 (6.8) | 17.3 (7.9) |
| 514 | Aviation Technician | 97 | 38.4 (5.9) | 18.2 (6.3) | 11.8 (6.8) |
| 526 | Avionics Technician | 43 | 40.4 (5.9) | 20.8 (6.1) | 14.5 (8.3) |
| 565 | Aircraft Structures Technician | 17 | 38.3 (7.4) | 18.9 (8.2) | 7.4 (6.1) |
| 71B | Marine Surface and Subsurface | 15 | 40.0 (5.5) | 19.8 (6.4) | 17.2 (7.6) |
| 737 | Medical Technician | 19 | 35.8 (7.9) | 13.4 (8.8) | 10.9 (8.3) |
| 811 | Military Police | 20 | 35.8 (5.9) | 15.5 (7.2) | 12.9 (7.7) |
| 836 | Resource Management Support Clerk | 64 | 40.8 (6.6) | 18.6 (7.8) | 16.2 (8.8) |
| 861 | Cook | 29 | 39.7 (6.1) | 19.5 (6.9) | 17.4 (7.9) |
| 911 | Supply Technician | 53 | 39.3 (5.3) | 18.1 (6.8) | 16.3 (6.8) |
| 933 | Traffic Technician | 40 | 38.8 (8.2) | 18.8 (9.2) | 16.3 (8.7) |
| 935 | Mobile Support Equipment Operator | 37 | 39.9 (6.8) | 19.4 (8.4) | 17.8 (8.6) |

* Mean (Standard Deviation)

previously worked in an engineering technical trade (e.g., Aero Engineering Technician, Airframe Technician or Instrument Electronics Technician). Thus, on balance, it seems safe to conclude that the noise exposure had not changed

4.2.2 Hearing Thresholds

Figure 3 provides a display of the percentage of subjects in each of the selected trades with moderate to severe hearing loss exceeding 40 dB HL at 4 kHz and 6 kHz, ordered by prevalence. The data plotted indicate that the trades in which 15% or more of subjects had sustained a moderate to severe hearing loss were Flight Engineers (left ear at 4 kHz and right and left ears at 6 kHz), Signal Operators (left ear at 6 kHz) and Cooks (left ear at 6 kHz). In Figure 4, the percentages associated with hearing thresholds equal to or greater than 90 dB HL (deafness) to -10 dB HL (normal hearing) are displayed for the Flight Engineers for four frequencies, 0.5 kHz, 2 kHz, 4 kHz and 6 kHz, for all subjects in the selected trade, without respect to age. Mid-frequency (2 kHz) hearing thresholds have been shown to be a good predictor of speech understanding. Since thresholds

at this frequency were generally no more than mildly elevated, it is not expected that subjects would have difficulty with speech understanding in quiet. This outcome is in contrast to the higher frequencies, 4 kHz and 6 kHz, where moderate to severe hearing loss was more prevalent.

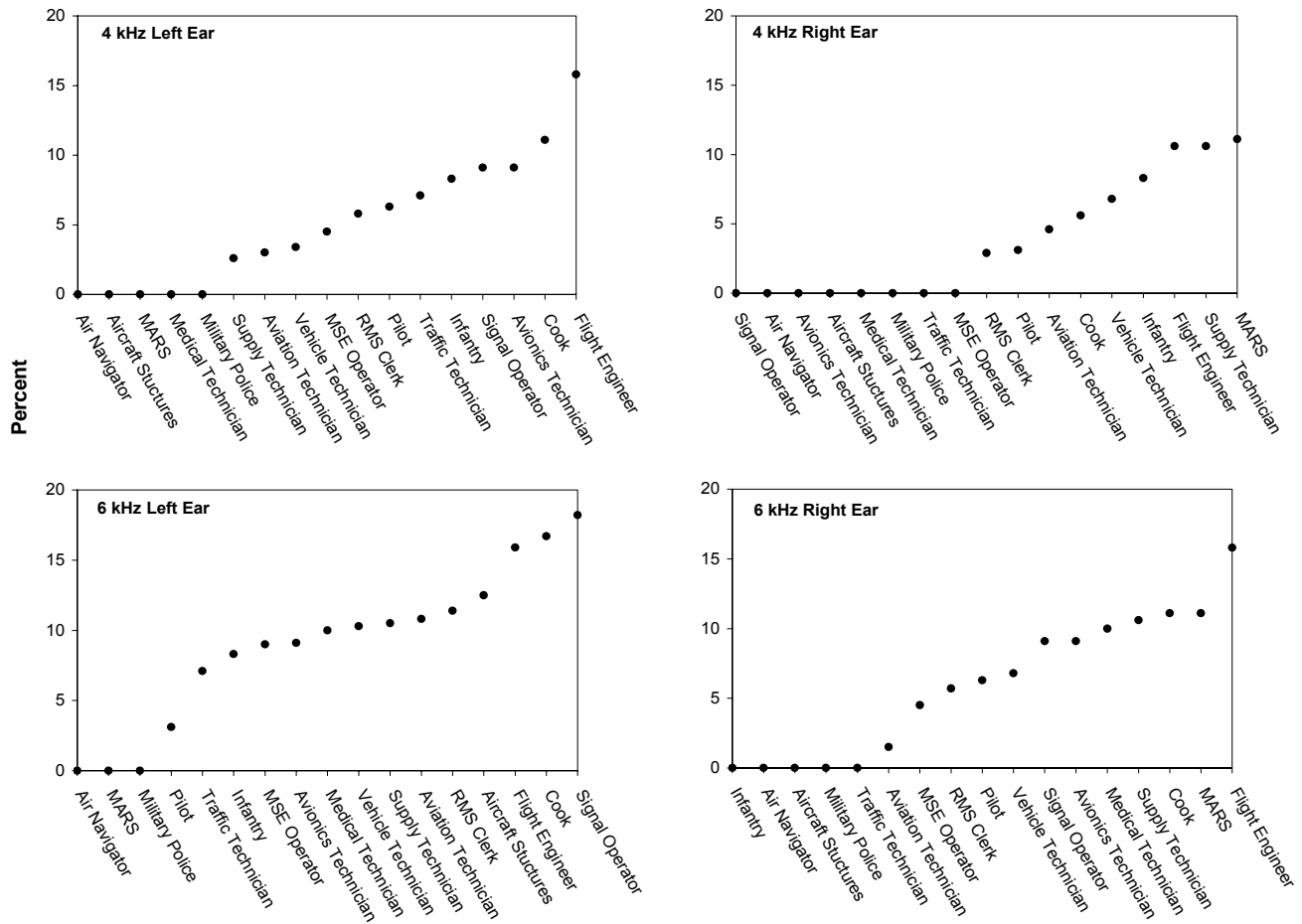


Figure 3: Percentage of 36-45 Year Olds with Moderate to Severe Hearing Loss in Selected Trades

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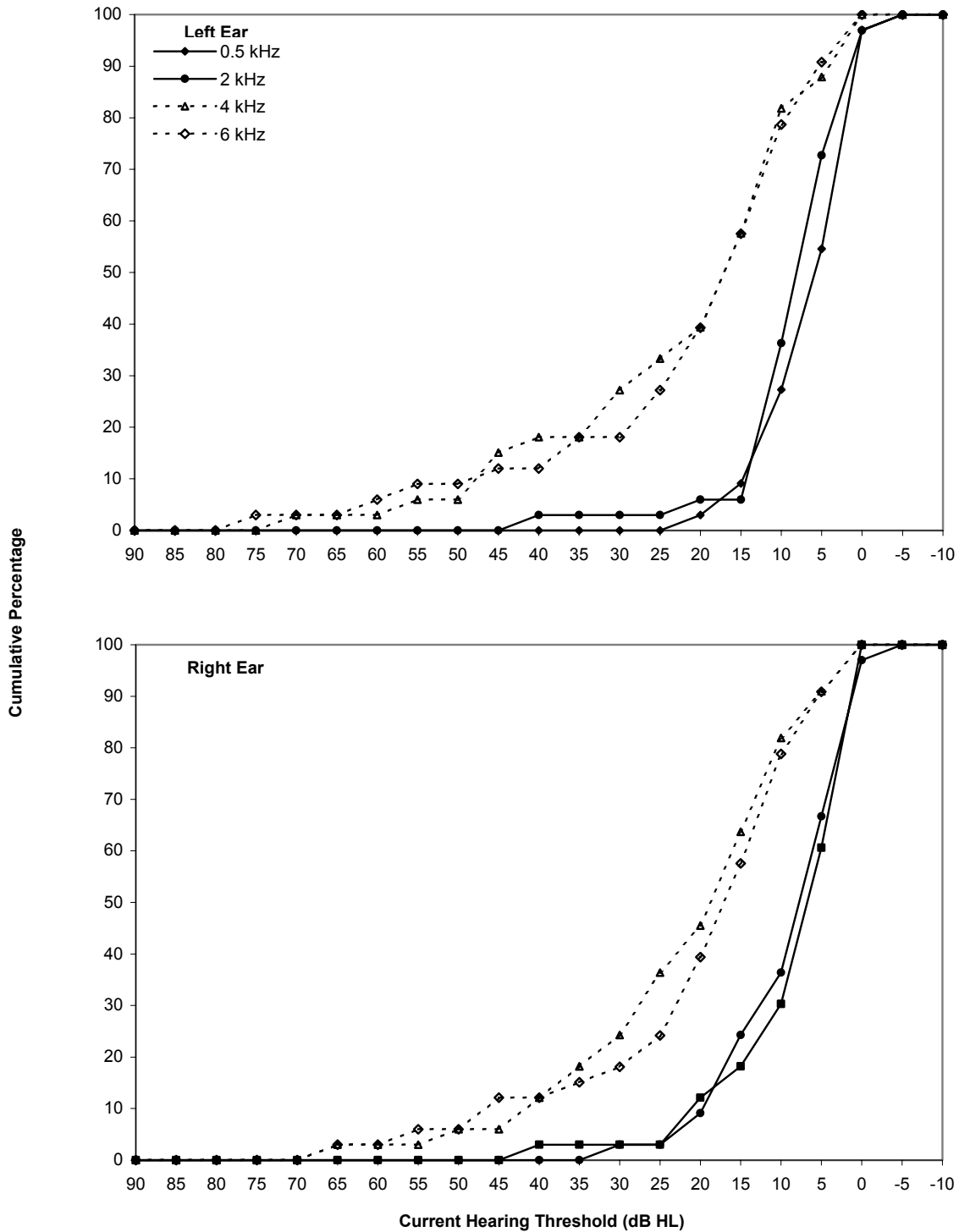


Figure 4: Hearing Loss in Flight Engineers (n=33)

4.2.3 Survey of risk factors

- Perception of changes in hearing and noise levels in the workplace: In approximately half the trades selected, 25% or more believed that their hearing was moderately or much worse since joining the Canadian Forces. Only the Medical Technicians and Military Police had fewer than 20% in these response categories. Trades groups in which more than 50% responded that their workplace was often or constantly noisy included Flight Engineers, Air Navigators, Pilots, Vehicle Technicians, Aviation and Avionics Technicians, Aircraft Structures Technicians, Cooks and Traffic Technicians. More than 40% of Flight Engineers, Air Navigators and Aircraft Structures Technicians said that the noise was severe.
- Training on hearing loss prevention: With the exception of Aircraft Structures Technicians, 68% or more of the subjects in each trade had either received no training or one hour or less on the dangers of noise exposure. Further, more than 75% in every trade had received either no training or one hour or less on the proper use of hearing protection devices. Regardless of trade, fewer than 13% judged their training on the dangers associated with noise exposure to be good.
- Utilization of personal hearing protectors: Except for Military Police, Resource Management Support Clerks and Cooks, at least 65% of individuals in each trade group were exposed to noise. Except for these trades, generally subjects said that they wore hearing protectors in noise. However, in only three trades, Flight Engineers, Air Navigators and Pilots, did more than 50% wear these devices for a full work shift. In only Infantry Soldiers and Aircraft Structures Technicians were more than 40% often or constantly reminded by their supervisors to wear hearing protection.
- Drawbacks of hearing protector utilization. Across trades, only 0-28% often or definitely agreed that hearing protection devices would not be beneficial. However, 25% or more of Flight Engineers, Pilots, Marine Surface and Subsurface personnel, Medical Technicians, Cooks, Supply Technicians and Traffic Technicians often or definitely agreed that they were uncomfortable, and 40% or more of all trades but Air Navigators and Pilots often or definitely agreed that they would interfere with hearing. Cooks (48%), Infantry Soldiers (28%) and Mobile Support Equipment Operators (24%) felt that they would often or definitely pose a danger at work.

In every trade selected, the majority of subjects (more than 70%) did not experience difficulty listening in a quiet room without protectors. The presence of noise resulted in moderate to great difficulty in more than 40% of Infantry Soldiers, Signal Operators, Vehicle Technicians and Supply Technicians. In well over half the selected trades (11 of 17), more than 40% of subjects experienced moderate or great difficulty when answering the telephone in a noisy room. As for the total sample, in every trade distance from the source (i.e., listening across a room) and the use of hearing protection increased the percentage who experienced significant difficulty.

- Exposure to Solvents: Over half the sample (60% or more) in all trades except Air Navigators, Pilots, Military Police, Resource Management Support Clerks, Cooks, Supply Technicians and Traffic Technicians said they were exposed to solvents. For the exposed subjects in each group, with the exception of the Aircraft Structures Technicians, the greater proportion (more than 70%) either did not wear respiratory equipment or did so for less than half the work shift.
- Head injury: Across the selected trades only the Infantry Soldiers, Vehicle Technicians, and Medical Technicians reported more than a 15% incidence of head injury at work. Of the 61 affected individuals in these trades, only 6 had more than a mild permanent hearing loss from the accident.

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- Ear infections, non work related head injuries and the use of medications: At least 30% of the individuals in each trade had experienced ear infections in either childhood or adulthood. Across trades, only 7 individuals had more than a mild permanent hearing loss as a result. Head injuries outside of work occurred in more than 25% of the group for only Infantry Soldiers, Marine Surface and Subsurface personnel and Medical Technicians. There were no reported cases of permanent hearing loss. There was no evidence that any subject in any trade group was suffering from a permanent hearing loss as a result of medications.
- Tinnitus and dizziness: With the exception of Flight Engineers, less than 20% of each trade group believed that they experienced tinnitus often or constantly. In all those who experienced tinnitus in each trade, the tinnitus was perceived to cause moderate to much interference in less than 25% of the group, and often or constant sleep disturbance in less than 20% of the group. Less than 6% of any group experienced dizziness often or all the time. Of those who experienced dizziness, this symptom was definitely felt as the perception of circling in more than 40% in only Medical Technicians, Mobile Support Equipment Operators and Cooks. Dizziness rarely interfered with work or was related to hearing loss.
- Exposure to leisure noise: As in the case of the total sample, at least half the individuals in each trade had been exposed to leisure noise some of the time. The notable exception were Medical Technicians, Military Police and Cooks. In most trades the most likely source was power tools, followed by rock music. Except for Infantry Soldiers less than 50% in each trade wore hearing protection more than half the time during these exposures.
- Sideline work: Relatively few subjects in each trade worked outside the military. Those who engaged in sideline work generally did so occasionally.

5.0 DISCUSSION

A hearing conservation program was introduced by the Canadian Forces about 45 years ago [1]. Yet the cost of compensation claims adjudicated by Veterans Affairs Canada continues to escalate. The goal of the present investigation was to uncover possible oversights in the implementation of the program. Specifically, predisposing risk factors were documented in a relatively large sample of subjects that represented a wide variety of military trades and environments. A cross-sectional study design was used. Current and first available hearing test results were compared within individuals who had been scheduled for a routine hearing test and who had agreed to participate in the study. These subjects were then stratified by age and trade. Subjects were also asked to provide information on diverse factors including age, gender, number of years of military service, history of trades, training on the risks associated with noise exposure and methods of conserving hearing, as well as their history of occupational and leisure noise exposure, solvent exposure, use of protective gear, head injury, hearing health history and use of medications that might impact hearing.

It was estimated that 25% of those who would have been scheduled for a routine hearing test agreed to participate. A comparison of sample and population profiles showed that the ratios of males to females and non commissioned members to officers were closely matched. On average, the four sample age categories under and over estimated comparable population age categories by about 10%. One hundred and seven (107) out of a possible 133 current military trades were represented in the sample: 20 Land, 20 Sea, 15 Air, 23 Purple, and 29 Control (quiet). In only 17 trades, however, were there sufficient subjects for independent analysis. Of these only one (Medical Technicians) might be considered a quiet trade. In the analyses of the data undertaken, differences due to the gender and rank of subjects were not evaluated because of the relatively large disparities in the size of the subgroups that would be compared. Further, since number of

years of service and age were found to be highly correlated, the significance of only age was assessed. This approach had the advantage of allowing for the comparison of outcomes with International standards (see below).

The survey data indicated that about one-half the sample were concerned about noise exposure. Close to one-third perceived that their hearing had deteriorated over the their term of employment. Yet training on the hazards of noise exposure and methods of preventing hearing loss, as well as consistent use of personal hearing protectors was rated as poor. According to the respondents, supervisors rarely reminded personnel about the need to wear hearing protection in noise. Most subjects said that they believed that the use of hearing protection would be beneficial, and relatively few felt that such devices would pose a danger at work. Issues of concern were discomfort and the belief that the wearing of hearing protection might interfere with the performance of auditory tasks. With respect to the latter, half the sample reported moderate to great difficulty understanding orders in a noisy room while wearing hearing protection. Laboratory studies support this observation for subjects with pre-existing high-tone hearing loss [49].

Other risk factors for hearing loss include but are not limited to solvent exposure, head injury, ear infections, the use of ototoxic medications and exposure to noise during side line work or leisure. Well over half the sample (61%) said that they were exposed to solvents at work. Few (less than 20%) wore respirators, perhaps because they or their supervisors believed that the levels were within safe limits. Previous studies provide ample evidence that exposure to solvents alone or in combination with noise may result in hearing loss through injury to the inner ear [25,26]. Dose response curves for human subjects are not yet available. In contrast, the percentages of subjects who had sustained a head injury, suffered ear disease or used medications that might affect hearing were relatively small. Many reported symptoms of inner ear disease, such as dizziness (15%) and/or tinnitus (52%). However, these symptoms did not appear to be severe enough to interfere with auditory perception, the ability to work or sleep. Few subjects (8%) were engaged in sideline work but at least half participated in noisy leisure activities involving power tools, rock music and disc/dance bars. This latter finding is in line with earlier reports [46,50].

The audiometric data showed that for the sample as a whole hearing had deteriorated over time. While mean current thresholds were indicative of no more than a mild hearing loss of about 35 dB HL for the frequencies examined, the distributions of hearing thresholds across subjects were positively skewed to higher values at each frequency. At 4 kHz and 6 kHz, the most susceptible frequencies for NIHL, a hearing loss in excess of 20 dB was evident in approximately 15% of the youngest group (16-25 years). By mid-life (46 years and older) that proportion had increased to 60%, with 20% showing a moderate to severe hearing loss exceeding 40 dB HL [44]. Norms published for otologically normal persons [16] show that the change in hearing over the age range studied should be no greater than 10 dB for 50% of the population at these frequencies. In comparison, in the present study, the difference in mean hearing thresholds observed the youngest and oldest groups of subjects were 16 dB and 18 dB, respectively at 4 kHz and 6 kHz. A post hoc comparison of the effects of solvent and noise exposures either alone or in combination suggested that the solvents might be the more hazardous agent. Hearing thresholds in the oldest group at the higher frequencies, 3-8 kHz, were relatively higher for those subjects exposed to either solvents or solvents and noise than for those not exposed to solvents, with or without noise as a factor.

The 17 trades with sufficient numbers for independent consideration accounted for 61% of the total sample. They ranged widely from Cooks and Medical Technicians to Infantry Soldiers and Pilots. The profiles of subjects in these trades mirrored those of the larger group. Analysis of the survey data showed that the perception that the workplace was noisy was as likely to be reported by Cooks as Pilots or Vehicle Technicians. Generally, it was the air trades that reported that the noise was severe. Except for Aircraft

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Structure Technicians, training on hearing loss prevention was considered poor. A relatively high proportion of only Flight Engineers, Air Navigators, Pilots and Traffic Technicians were likely to wear hearing protection for a full work shift. In most trades hearing protectors were considered to be beneficial. Cooks, Infantry Soldiers and Mobile Support Equipment Operators thought they might pose a danger for their work. A significant proportion in all 17 trades thought they would interfere with hearing. More than half the subjects in 11 of the 17 trades reported that they were exposed to solvents. In each, the use of respirators was not a common practice. As for the total sample, permanent hearing loss from head injury, ear infections and the use of medications were rare. Across the selected trades, the greatest average elevation in hearing threshold at 4 kHz in the left ear by 35-45 years of age was sustained by the Infantry Soldiers. Trades in which 15% or more subjects in this age category had a moderate to severe hearing loss of 40 dB or more in one or other ear at either 4 kHz or 6 kHz included Flight Engineers, Signal Operators, and Cooks. The prevalence of a moderate to severe hearing loss would be expected to increase as these groups aged. Unfortunately, the numbers of subjects available the oldest age category were not sufficient to extend the analysis.

While the results discussed above provide some clues as to some of the underlying factors responsible for the escalating burden of noise-induced hearing loss in the Canadian Forces, subjects' written comments help to identify some of the main problems associated with hearing conservation programs. A representative sample follows.

Aviation Technician: "I've worked on flight line on four different bases...I have made significant efforts to protect my hearing...but the loud screeching sound of turbines and turbine engines still come through..."

Mobile Support Equipment Operator: "As an MSE OP, certain vehicles are very loud inside and as an instructor I am unable to wear hearing protection."

Aviation Technician: "Engine run-ups are extremely loud. It is what causes ringing in my ears. I wear ear plugs and a communications headset, but it doesn't really matter."

Director of Music: "The noise levels during a full band rehearsal are often quite loud.....In order to hear each other, most musicians cannot wear ear defenders."

Aviation Technician: "...inside the hanger 99.8% of the personnel are not wearing hearing protection and concurrent activities...are being carried out outside the hanger which are damaging their hearing abilities."

Traffic Technician: "As it's nearly impossible to carry out a conversation in the back of the aircraft without removing one side of the headset, this practice was and is still common practice amongst in flight check personnel."

Signal Operator: "Monitoring multiple radios plus telephones makes it almost impossible to wear protective equipment. HF radio systems are particularly noisy."

Naval Communicator: "The initial 15 years of going to sea involved noise at levels higher than tolerable. Ignorance toward noise and its effects resulted in my hearing loss....."

Aviation Technician: "I have had trouble wearing earmuffs in winter with a toque."

Search and Rescue Technician: "I do not wear foam ear plugs due to comfort issues."

6.0 CONCLUSIONS

The results of this investigation lead to the following conclusions that the prevalence and escalation of noise-induced hearing loss in the Canadian Forces are due to:

- Insufficient training on the hazards of noise exposure, hearing protection selection and hearing protector utilization.
- Problems with hearing protection use including discomfort with extended usage, incompatibility with gear, and difficulty communicating in noise.
- Unprotected exposure to solvents and leisure noise.

7.0 RECOMMENDATIONS

Comments made by subjects support the creation of end-user focus groups for high-risk trades to capture the impact of hearing conservation programs and practices currently in place on individual workers. Previous studies have shown that these may be used to advantage to supplement and clarify both audiometric and structured survey data [51]. Individual users of personal hearing protection and their supervisors could use these sessions to provide insight into problems with the utilization of hearing protection.

Tailored intervention studies should be conducted to determine the type of hearing protection that would be suitable for individual users in each trade [52]. In particular, the utility of implementing newer hearing protector technologies should be assessed in field studies. Special consideration should be given to both the type of noise and the level of noise to which personnel are exposed, communication capability, comfort and compatibility with other gear [53,54].

Training on the hazards of noise exposure (both occupational and non occupational) must be mandatory for all CF personnel at recruitment and with each new posting. These lectures must include instruction on the proper fitting of the hearing protection that will be used on the job, as well as periodic monitoring to ensure maximum effectiveness.

Strategies for hearing loss prevention must include active surveillance of hearing protection practices by supervisors and flagging by clinic personnel of changes in hearing that exceed strictly defined criteria, immediate and appropriate intervention, and an evaluation of the effectiveness of the intervention [55].

Steps must be taken to control solvent exposures. Although few studies have explored dose response relationships in human subjects, it is clear from the results available that solvents alone or in combination with noise will result in cochlear pathology. The data available demonstrate clearly that even if solvent concentrations meet the criteria set out in regulatory guidelines, they may nonetheless potentiate noise-induced hearing loss [25]. Education on the risks of solvent exposure and training on the use of respiratory equipment should be mandatory for all personnel.

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9.0 REFERENCES

- [1] Neely K. Hearing conservation for the armed forces. *Medical Services J.- Canada* 1959; April: 235-247,
- [2] Vye K. WSIB battles hearing loss: The silent workplace hazard. *Workplace Safety and Insurance Board News Release*, May 15, 2001.
- [3] Statistics Canada. *Canadian statistics - the people: Labour force, employed and unemployed, numbers and rates, 2003*. Excerpted from the official website, www.statcan.ca.
- [4] MOL. *Canada Labour Code, Part VII, Levels of Sound*. Canada Occupational Health and Safety Regulations, Ministry of Labour, Ottawa, ON, Canada, 1991.
- [5] CSA. *Hearing protection devices – performance, selection, care and use, Z94.2-02*. Canadian Standards Association, Rexdale, ON, Canada, 2002.
- [6] Franks JR, Stephenson MR, Merry CJ. *Preventing occupational hearing loss – a practical guide*. US DHHS, PHS, CDC, NIOSH publication no. 96-110, 1996.
- [7] Henderson D, Hamernik RP. Biological bases of noise-induced hearing loss. *Occup Med* 1995; 10(3): 513-534.
- [8] Forge A. Sensory cell regeneration and functional recovery: A review. In: Axelsson A, Borchgrevink HM, Hamernik RP, Hellström P-A, Henderson D, Salvi RJ, eds. *Scientific basis of noise-induced hearing loss*. New York: Thieme, 1996, pp. 3-22.
- [9] Leikin JB, Davis A, Klodd DA, Thunder T, Kelafant GA. Selected topics related to occupational exposures. Part I. Noise exposure. *Diseases of the Month* 2000; 46: 240-255.
- [10] Bauer P, Korpert K, Neuberger M, Raber A, Schwetz F. Risk factors in hearing loss at different frequencies in a population of 47,388 noise-exposed workers. *J Acoust Soc Am* 1991; 90(6): 3086-3098.
- [11] Abel SM, Haythornthwaite C. The progression of noise-induced hearing loss. A survey of workers in selected industries in Canada. *J Otolaryngol*. 1984; 13, Suppl: 2-36.
- [12] Bohnker BK, Page JC, Rovig G, Betts LS, Muller JG, Sack DM. U.S. Navy and Marine Corps hearing conservation program 1995-1999: Mean hearing thresholds for enlisted personnel by gender and age groups. *Military Medicine* 2002; 167: 132-135.
- [13] Smoorenburg GF. Damage risk criteria for impulse noise. In: Hamernik RP, Henderson D, Salvi R, eds. *New perspectives on noise-induced hearing loss*. New York: Raven, 1982, pp. 471-490.
- [14] Dancer A, Buck K, Parmentier G, Hamery P. The specific problems of noise in military life. *Scand Audiol* 1998; 27, Suppl 48: 123-130.
- [15] Christiansson BAC, Wintzell KA. (1993). An audiological survey of officers at an infantry regiment. *Scand Audiol* 1993; 22: 147-152.

- [16] ISO. Threshold of hearing by air conduction as a function of age and sex for otologically normal persons, 7029. Int. Organization for Standardization, Geneva, Switzerland, 1984.
- [17] ISO. Determination of occupational noise exposure and estimation of noise-induced hearing impairment, 1999. Int. Organization for Standardization, Geneva, Switzerland, 1990.
- [18] Dobie RA. Separating noise-induced from age-related hearing loss. *Western J Med* 1994; 160 (6): 564-565.
- [19] Coles RRA, Lutman ME, Buffin JT. Guidelines on the diagnosis of noise-induced hearing loss for medicolegal purposes. *Clin Otolaryngol* 2000; 25: 264-273.
- [20] Pryor GT, Dickinson J, Feeney E, Rebert CS. Hearing loss in rats first exposed to toluene as weanlings or as young adults. *Neurobehav Toxicol Teratol* 1984; 6: 111-119.
- [21] Muijser H, Hoogendijk EMG, Hooisma J. The effect of occupational exposure to styrene on high-frequency thresholds. *Toxicol* 1988; 49: 331-340.
- [22] Fechter LD, Clerici WJ, Yao L, Hoeffding V. Rapid disruption of cochlear function and structure by trimethyltin in the guinea pig. *Hearing Res* 1992; 58: 166-174.
- [23] Morata TC, Dunn DE, Kretschmer LW, Lemasters GK, Keith RW. Effects of occupational exposure to organic solvents and noise on hearing. *Scand J Work Environ Health* 1993; 19: 245-254.
- [24] Barregård L, Axelsson A. Is there an ototraumatic interaction between noise and solvents? *Scand Audio* 1984; 13: 151-155.
- [25] Sliwinska-Kowalska M, Zamysłowska-Szmytko, E, Szymczak, W, Kotyło P, Fiszer M, Dudarewicz A, Wesolowski W, Pawlaczyk-Luszczynska M, Stolarek R. Hearing loss among workers exposed to moderate concentrations of solvents. *Scand J Work Environ Health* 2001; 27(5): 335-342
- [26] Fechter LD, Chen G-D, Rao D. Characterising conditions that favour potentiation of noise induced hearing loss by chemical asphyxiants. *Noise & Health* 2000; 3(9): 11-21.
- [27] Clark WW. Noise exposure from leisure activities: A review. *J Acoust Soc Am* 1991; 90(1): 175-181.
- [28] Axelsson A, Rosenhall U, Zachau G. Hearing in 18-year old Swedish males. *Scand Audiol* 1994; 23: 129-134.
- [29] Borchgrevink HM. Music-induced hearing loss >20 dB affects 30% of Norwegian 18 year old males before military service - the incidence doubled in the 80's, declining in the 90's. In: *Proc Int Congr on Noise as a Public Health Problem, Nice, France, 1993*, pp.25-28.
- [30] Berglund B, Lindvall T. Community noise. *Arch of the Ctr For Sensory Research* 1995; 2(1): 1-195.
- [31] Humes LE. Understanding the speech-understanding problems of the hearing impaired. *J Am Acad Audio* 1991; 2(2): 59-69.

Noise-Induced Hearing Loss in Canadian Military Personnel

- [32] Smoorenburg GF. Speech reception in quiet and in noisy conditions by individuals with noise-induced hearing loss in relation to their tone audiograms. *J Acoust Soc Am* 1992; 91(1): 421-437.
- [33] Davies DR, Jones DM. Noise and efficiency. In: Tempest W, ed. *The noise handbook*. London: Academic, 1985, pp. 87-141.
- [34] Kjellberg A. Subjective, behavioral and psychophysiological effects of noise. *Scand J Work Environ Health* 1990; 16, Suppl 1: 29-38.
- [35] Hockey GR. Effect of loud noise on attentional selectivity. *Quart J Exp Psychol* 1970; 22 : 28-36.
- [36] Vallet M, Gagneux J-M, Simonnet F. Effects of aircraft noise on sleep: An in situ experience. In: Tobias JV, Jansen G, Ward WD, eds. *Noise as a public health problem*. ASHA Reports 10, Rockville, Maryland, 1980, pp. 391-396.
- [37] Griefahn B, Schuemer-Kohrs A, Schuemer R, Moehler U, Mehnert P (2000). Physiological, subjective and behavioural responses during sleep to noise from rail and road traffic. *Noise & Health* 2000; 3(9): 59-71.
- [38] Kent SJ, von Gierke HE, Tolan GD. Analysis of the potential association between noise-induced hearing loss and cardiovascular disease in USAF aircrew member. *Aviat Space and Environ Med* 1986; April, 348-361.
- [39] Tarnopolski A, Watkins G, Hand DJ. Aircraft noise and mental health: I. Prevalence of individual symptoms. *Psychol Med* 1980; 10: 683-698.
- [40] Thiessen GJ. Disturbance of sleep by noise. *J Acoust Soc Am* 1978; 64: 216-222.
- [41] Thiessen GJ, Lapointe AC. Effect of intermittent truck noise on percentage of deep sleep. *J Acoust Soc Am* 1983; 64: 1078-1080.
- [42] Cantrell RW. Prolonged exposure to intermittent noise: audiometric, biochemical, motor, psychological and sleep effects. *Laryngoscope* 1974; 84, Suppl 1.
- [43] McLean EK, Tarnopolsky A. Noise, discomfort and mental health: a review of the socio-medical implications of disturbance by noise. *Psychol Med* 1977; 7: 19-62.
- [44] Abel SM. Risk factors for the development of noise-induced hearing loss in Canadian Forces personnel. External Client Report, DRDC Toronto ECR 2004-116, Toronto, ON, Canada, 2004.
- [45] Yantis RA Pure tone air-conduction testing. In: Katz J. ed. *Handbook of clinical audiology*, 3rd ed. Baltimore: Williams & Wilkins, 1985, pp. 153-169.
- [46] Pelausa EO, Abel SM, Simard J, Dempsey, I. Prevention of noise-induced hearing loss in the Canadian military. *J Otolaryngol*. 1995; 24(5): 271-280.
- [47] Daniel WW (1983). *Biostatistics: a foundation for analysis in the health sciences*, 3rd ed. New York: Wiley, 1983.

- [48] Kruger B. Basic audiologic evaluation. In: Alberti PW, Ruben RJ, eds. *Otologic medicine and surgery*, vol. 1. New York: Churchill Livingstone, 1988, pp. 365-395.
- [49] Abel SM, Armstrong NM, Giguère C. (1993). Auditory perception with level-dependent hearing protectors: The effects of age and hearing loss. *Scand Audiol* 1993; 22(2): 71-85.
- [50] Bray MB Szymanski M, Mills R. Noise induced hearing loss in dance music disc jockeys and an examination of sound levels in nightclubs. *J Laryngol Otol* 2004; 118: 123-128.
- [51] Prince MM, Colligan MJ, Stephenson CM, Bischoff BJ. The contribution of focus groups in the evaluation of hearing conservation program (HCP) effectiveness. *J Safety Res* 2004; 35: 91-106.
- [52] Lusk SL, Ronis DL, Kazanis AS, Eakin BL, Hong OS, Raymond DM. Effectiveness of a tailored intervention to increase factory workers' use of hearing protection. *Nursing Res* 2003; 52(5): 289-295.
- [53] Dancer A, Buck K, Hamery P, Parmentier G. Hearing protection in the military environment. *Noise & Health* 1999; 5: 1-15.
- [54] Abel SM, Sass-Kortsak A, Kielar A. The effect on earmuff attenuation of other safety gear worn in combination. *Noise & Health* 2002; 5: 1-13.
- [55] Helfer TM, Shields AR, Gates, K.E. Outcomes analysis for hearing conservation programs. *Am J Audiol* 2000; 9: 75-83.

