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EFFECT OF HAND-ARM VIBRATION ON INNER EAR AND CARDIAC FUNCTIONS IN MAN

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ABSTRACT

To evaluate distant effects of hand-arm vibration we studied Finnish forestry workers using chain saw during the years 1972 through 1990. The hearing was tested annually and individual regression curves for sensorineural hearing loss (SHL) were calculated. Robinson's model was used in prediction of SHL. The heart rate variation (HRV) indexes at rest and during deep breathing test were analyzed to measure autonomic nervous function. In Robinson's model the measured SHL (17.8 dB) respected the predicted SHL (17.2 dB). The subjects with VWF had on average, 10 dB greater hearing loss than those who did not have VWF. The regression model based increase of hearing loss during follow up correlated with ageing, not to VWF. The intercept differed significantly in those with VWF from those without VWF. We found a significant difference between HRV indexes during deep breathing test in those with the shortest and those with the longest vibration exposure. The HRV decreased with age, but multiple regression analysis showed that the total exposure time to vibration had an independent negative association with HRV indexes. Our results suggest that prolonged exposure to vibration caused by chain saw has negative effects an autonomic functions. The aggravated hearing loss in subjects with VWF may be due to vibration induced changes in the autonomic nervous system or internal factors of the blood vessels.

Key Words: Hearing loss, Noise, Vibration, Heart rate

INTRODUCTION

Prolonged exposure to hand-arm vibration (HAV) may cause adverse effects on health of the workers, which can be local or distant. The HAV syndrome, in which the symptoms are limited to exposed areas, is well recognized.[1,2] HAV may also have distant effects on the workers health. Such effects may include temporary or permanent changes in the tone of the autonomic nervous system,[3] deterioration of the sensory function, as hearing[1,4] or body equilibrium[5] or in animal experiments temporary change the neural activity in the central nervous system.[6,7] The distant effects of HAV are confounded by ageing, since during ageing various degenerative processes are accentuated.[8] They may also be confounded by economical status and social demands of the society.[9,10] Therefore, the distant effects are not generally accepted as a part of HAV syndrome.

We came interested in this problem in 1972 when we observed that subjects with vibration-induced white finger (VWF) had greater hearing loss than their controls.[1] Since this observation might be due to unmatched exposure time to chain saw noise or unmatched use of hearing protectors we conducted later a series of studies to clarify etiology of this SHL among forest workers.[11–13] During the follow up of vibration exposed forest workers we also observed that

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different neurogenic and autonomic symptoms were some of the main complaints. Therefore we conducted measurement and computed analysis of the heart rate variation during standardized breathing test referring to autonomic nervous system function in forest workers exposed to chain saw vibration.[8] The present paper contains a summary of data that is partly presented before.

MATERIAL AND METHODS

The investigation was carried out in connection with a compulsory health survey in Suomussalmi country in North-Eastern Finland during the years 1972 to 1990.[1,10,14] The number of subjects varied in different years from 118 to 217 professional forest workers.

In connection with compulsory health examinations the workers filled a questionnaire focusing on symptoms of HAV syndrome, on autonomic disorders and on factors known to cause SHL. A medical history was done and a general history of working hours and medical symptoms were carried out. Also, the use of earmuffs was asked, as well as the history of vibration syndrome.[2] In all subjects the hearing was annually evaluated with audiometry. In connection with the physical examination the ears were inspected.

To measure individual SHL, a mean hearing threshold of both ears at 4000 Hz was used. To standardize the effect of age, exposure and use of ear muffs Robinson's model[15] for development of SHL was used. In Robinson's model the age corrected hearing level is related to A-weighted equivalent level and exposure time. Individual values were calculated for each worker according to a model published previously.[13]

In addition, a linear regression model was calculated for 98 subjects in whom hearing could be followed up since 1972 so that the deterioration of hearing at 4000 Hz could be followed. For the subjects goodness of fit, regression coefficient and intercept were determined.

The function of autonomous nervous system was eveluated among 217 forest workers by questionnaire, and 88 professionals of them were selected for detailed cardiovascular tests. The subjects lay supine for 5 minutes after which bipolar ECG was recorded. The heart rate variation was studied by asking the subject to breath deep rhythmically according to tape recorded instructions. A rate of 6 respiratory cycles per minute was used.[16] In the analysis the ECG signal was amplified and band-pass filtered, the R-R interval vectors were trend corrected. Among other variables the mean length of R-R interval was measured and coefficient of variation was calculated. Furthermore, the spectral analysis of the R-R interval was calculated.[8]

RESULTS

1. Hearing loss

Age: In 1990 the measured SHL for the group was 27.3 dB at 4000 Hz. The prediction of SHL based on Robinson's model resulted in a SHL of 25.4 dB at 4000 Hz. The effect of age can also be evaluated by Robinson's model and based on the model the ageing alone was responsible for SHL of 7.6 dB. In non-age corrected analysis the ageing was the most important risk factor for the development of SHL and could explain about 25 per cent of the variance in SHL ($r=0.512$, $p<0.001$).

Exposure: A significant correlation existed between SHL and noise exposure ($r=0.317$, $p<0.001$). When the effect of age (7.6 dB as defined by Robinson's model) was subtracted from the measured hearing loss, the resulted SHL yielded for the group an average hearing loss

of 17.8 dB. This calculated value was close to the predicted value derived from Robinson's model, 17.2 dB, that is based on exposure and age controlled data of the workers.

Vibration syndrome: The occurrence of VWF correlated significantly with the SHL ($r=0.201$, $p<0.01$). When the subjects with VWF were removed from the subjects the average gain in the hearing loss at 4000 Hz was 10 dB.

Development of hearing loss: For 98 subject, in whom the hearing loss had been followed at least 10 years a regression line with regression coefficient and intercept was calculated to evaluate to progression of SHL at 4000 Hz as a function of time (Fig. 1). In linear regression analysis we found out that age correlated highly significantly with progression of SHL at 4000 Hz ($r=0.254$, $p<0.05$). In step wise linear regression analysis it was the only significant factor correlating for progression of hearing loss ($F=9.46$, $p<0.05$). Neither the exposure not VWF could explain any progression of SHL.

We also examined whether the initial hearing loss at 1972 would depend on environmental factors. We found out significant correlation of the intercept with exposure ($r=0.259$, $p<0.05$) age ($r=0.40$, $p<0.001$) and with VWF ($r=0.293$, $p<0.01$). In step wise linear regression analysis age and VWF could explain 25% of the variability of the intercept. Thus, when concerning the VWF it determines the initial hearing loss but it does not explain the aggravation of the hearing loss during the follow up.

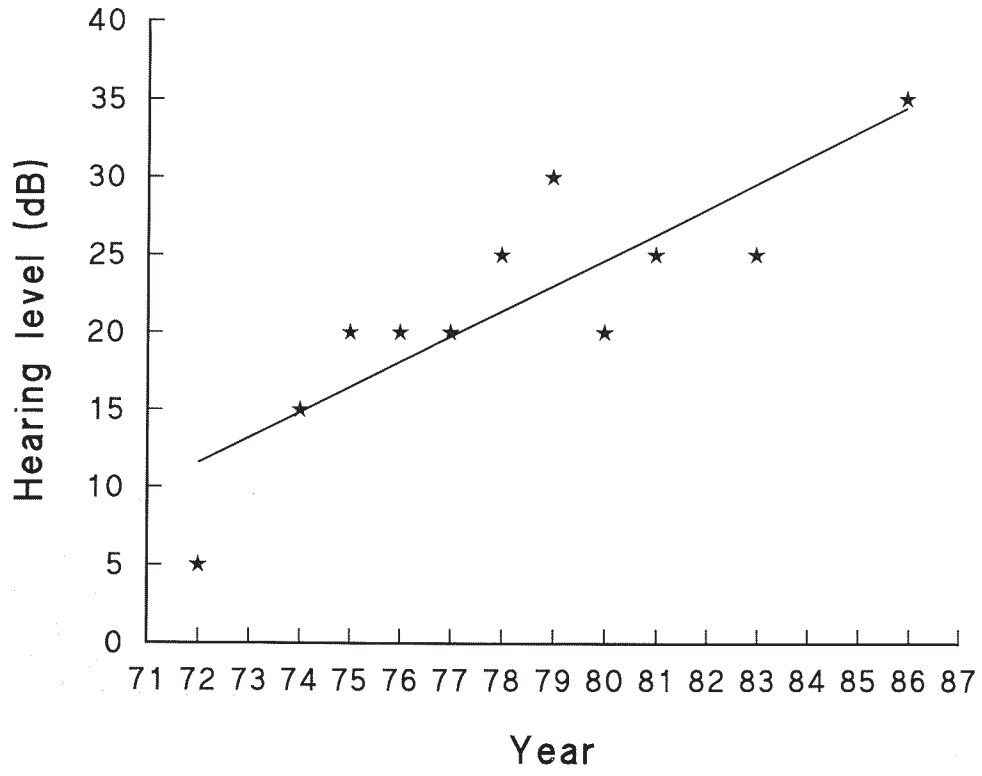

Fig. 1. Hearing loss at 4000 Hz in a forest worker at years 1972–1986. The line represents a linear regression function, y=a+b(x). r=0.854.

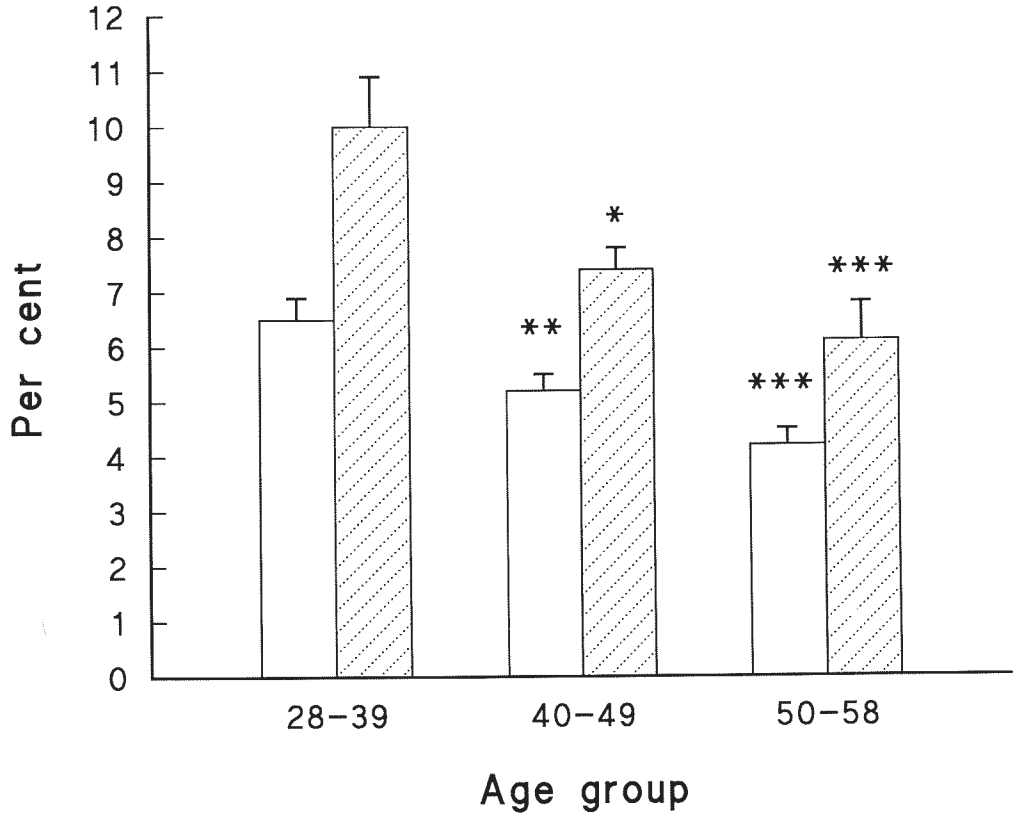

Fig. 2. Coefficient of variation of heart rate at different age groups during rest (open bar) and during guided breathing (shaded bar).
The results are given in percent. The stars indicate probability values when compared with the youngest age groups. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

2. Autonomic nervous function

The HRV decreased with age and there was a significant difference in the HRV during the deep breathing test when correlating the CV with different age groups ($p < 0.001$) (Fig. 2). To examine the effect of the vibration exposure time on the HRV a multiple linear regression analysis was carried out. We found out that both age and total exposure time to vibration had a significant negative correlation with HRV in deep breathing test, but only age had a significant correlation with the HRV in rest condition.

The spectral analysis using the FFT-technique was carried out in HRV data. The frequency range was divided into eight bands each 0.05 Hz wide. The power content (FRP) of each spectra was calculated. The FRPs in the resting state decreased with age at all frequency bands. There was also a significant difference in FRP depending on age group. When the age matched subjects were further divided into three subgroups depending on sawing time we found out significant differences ($p < 0.05$) between FRPs of those with vibration exposure times less than 140,000 h. and those with exposure time of more than 190,000 h. at frequency bands 0.05–0.25 Hz and in the deep breathing test in the frequency bands of 0.05–0.3 Hz. The presence or absence of VWF did not correlate with the outcome of HRV.

DISCUSSION

Advanced hearing loss in population surveys has been explained to arise from ageing, environmental factors and noise exposure. Nevertheless, the data of sensory neural hearing loss (SHL) in carefully controlled studies show remarkable case to case variation indicating that individual susceptibility plays also a significant role. So far the importance of the factors causing individual susceptibility for SHL has not been thoroughly understood. In the present study vascular disorders of fingers arising in HAV syndrome aggregated the development of SHL. Since in individual cases the regression coefficient did not alter significantly during the follow up period it seems that at present the efficacy of hearing protectors with reduced vibration acceleration level do not aggravate SHL in susceptible subjects with VWF.

The reason for the potentiating effect of VWF and SHL is not known. We have earlier speculated that vibration may cause "vasospasm" in the cochlea through autonomic vascular reflexes.[4] Such changes may occur in "susceptible" subjects.[1] Why does then individual ears vary with susceptibility to SHL in vibration exposed workers? One explanation for susceptibility might be that autonomic nervous activity in the subjects with VWF also inflicts with the inner ear circulation. So far this hypothesis is not proved, yet.[17] We have recently developed a measuring system for human cochlear blood flow (stria vascularis) and in the near future we plan to study factors affecting SHL in vibration exposed populations.

A common mechanism might operate on finger circulation and cochlear circulation that will be biased with hand arm vibration. Thus both vascular structures are affected by vibration. Such a mechanism might be hypothesized to be line with faulty endothelin releasing and controlling factors.[18] Thus, excessive vibration of the vessels in stria vascularis, as during loud noise or HAV, may cause vasospasm in the inner ear circulation by releasing endothelin-acting vasoactive substances in the same manner as in finger circulation. Based on this hypothesis the etiology of VWF and SHL would be, in fact, analogous. Proofs for this hypothesis, both in finger circulation and in the inner ear circulations are still lacking.

The observation of stabilization of hearing during the follow up is interesting with regard to VWF. One explanations of the stabilization could be that after damaging the outer hear cells at the apical part of the cochlea, the amplifier function is lost but the inner hear cells are still functioning causing a reduced but stabilized hearing.[19] While the exposure continues the damage of outer hair cells will spread towards the apex of the cochlea as well as to base of the cochlea causing a reduction of the amplifier function at these frequencies.[20,21] We therefore also analyzed 2000 Hz to see whether there would be progression of SHL at this frequency range to demonstrate that the lack of progression of hearing loss (i.e. the stabilization of the hearing) is not a real phenomenon but is due to "burning out" of the outer hair cells in wide area in cochlea. Nevertheless, we could not demonstrate that at 2000 Hz there would be a progression of SHL during the follow up time.

In audiometric evaluation the accuracy of hearing test varies about 5 dB at each frequency due to the psychophysical character of the measurement. Thus, some uncertainty is included in these calculated variables derived from several consecutive audiograms. This variability can be diminished by evaluating the hearing with regression line. We were able to show that ageing is the most significant variable causing progression of the hearing loss at present pace of work. During follow up the presence of VWF did not contribute any significant worsening of the hearing although it was of importance in the onset of the hearing loss. The lack of progression is probably due to two important changes. First, the vibration level of the chain saws have been significantly reduced since introduction of the chain saws in early 1960's.[4] It has reduced the severity of VWF and also secondarily reduced the distant effects of HAV. Second, the general use

of hearing protectors have diminished the noise level perceived by the inner ear.[12)]

In the present study we could demonstrate that HAV may cause also distant effects to autonomic nervous system, that regulates the heart rhythm. These findings are suggestive either to a central autonomic disturbance in the brain stem or to an autonomic neuropathy in the cardiac nerves among forest workers. Same kind of changes were demonstrated previously by Japanese authors.[3,9)] Although the equipments for heart rate variability studies have so far been complicated, the variability itself is a very simple way to identify the function of the autonomic nervous system. Heart rate variability has been previously used in the diagnosis of primary autonomic neuropathy.[22,23)] Although many kinds of autonomic dysfunction symptoms have been reported in workers exposed to HAV the function of autonomic nervous system has not been studied in detail in forest workers. Clinically, the decrease of autonomic reactivity seems to be a part of ageing since elderly subjects commonly have symptoms referring to autonomic nervous system disorder, for example, syncope, anhidrosis, urinary incontinence, constipation, insomnia and weakness.[23)]

The variability of R-R intervals during standardized test pattern has been recommended to quantify the autonomic nervous function.[16,22)] The present finding of reduced variability of R-R interval in forest workers demonstrate an existence of autonomic dysfunction linked to "non-physiological ageing process". The HRV during deep breathing test is associated with the activity of the parasympathetic nervous system and is decreased in autonomic neuropathies. Our results suggest that prolonged exposure to vibration caused by chain saw has depressing effects on an autonomic functions.

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