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VIBRATION-INDUCED WHITE FINGER AS A RISK FACTOR FOR HEARING LOSS AND POSTURAL INSTABILITY

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ABSTRACT

Effect of vibration-induced white finger (VWF) on the hearing was examined in 289 Japanese forest workers. From 51 subjects suffering from VWF and 228 with no history of VWF, 37 pairs were formed, matched for age and hours of noise exposure. The cases with VWF had a significantly higher hearing threshold at 4 and 8 kHz than their matched controls. This result was corroborated by the follow-up study which showed significant deterioration of hearing at 2 and 4 kHz only in subjects with VWF during five-year follow-up period. The possible effects of VWF on the postural stability were investigated in 71 Finnish forest workers. Postural stability was evaluated by an average velocity of the body-sway (ASV) measured with a force platform technique. Neither age nor exposure duration to chain saw noise and vibration correlated with ASV. A significant positive correlation was found between ASV and hearing level at 4 kHz after allowing for the effects of the exposure. Multiple regression analysis of ASV on age, exposure hours, hearing level at 4 kHz and prevalence of VWF showed that the hearing level and VWF had significant and almost significant effects on ASV, respectively. Thus, the workers suffering from VWF developed greater hearing loss and the hearing loss correlated with ASV. VWF explained some variance of ASV in the regression analysis. VWF seemed to play some role in hearing deterioration and possibly in genesis of balance disorder.

Key Words: Combined effects, Noise-induced hearing loss, Postural stability, Posturography, Raynaud's phenomenon, Vibration-induced white finger

INTRODUCTION

Forest workers are exposed to the risk of vibration syndrome and noise-induced hearing loss (NIHL) simultaneously. Pyykkö et al.[1] first reported that forest workers suffering from vibration-induced white finger (VWF) had developed significantly greater hearing loss at 4 kHz than healthy workers. This interesting finding has been followed by several papers in this decade. Our cross-sectional study[2] clarified this association after the elimination of confounding due to age and noise-exposure. Miyakita et al.[3] reported a similar result from a cross-sectional study in a larger scale. These findings have been corroborated by longitudinal studies of Pyykkö et al.[4] and our own.[5] Thus, VWF has come to be regarded as one of the probable risk factors for NIHL.

Several authors have reported a high rate of complaints on balance disturbances in connection with exposure to hand-arm vibration.[6,7] Some otologists also presented the case-reports of the patients with vibration syndrome involved in vestibular dysfunctions.[8–10] Krejcova et al.[11] found abnormal vestibulo-ocular findings in as high as 82% of the miners who had been chronically exposed to noise and hand-arm vibration. People impaired severely by the exposure to hand-arm vibration could be involved in vestibular dysfunctions. All of these studies, however, lacked the control groups for comparisons. Recently, Wakaba et al.[12] have done a case-control

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study showing that the compensated patients with vibration syndrome showed more frequent pathological nystagmus and worse postural stability than controls did. VWF might be a risk factor for vestibular dysfunctions in addition to NIHL.

In this paper, I am presenting the gist of our cross-sectional[2)] and follow-up[5)] studies showing the association between VWF and NIHL, and the results of our recent posturographic study investigating possible effects of VWF on the postural control.[13)]

VWF AND HEARING LOSS[2,5)]

From a population of forest workers in Nara, Japan, 289 males were recruited as the subjects for this study. They had no history of ear diseases nor exposure to ototoxic factors except noise exposure in forestry. Their mean age was 48.0 ± 8.2 (mean ± SD) years, and mean hours of exposure to noise from chain saws were 4762 ± 4613 in 281 workers, those from bush cutters were 3531 ± 4478 in 124 and those from winches were 7518 ± 8162 in 112. Fifty-one (17.6%) subjects suffered from VWF and 228 men (78.9%) had no history of VWF. Pure-tone audiometry was conducted in a sound-proof chamber after the absence of occupational noise exposure at least for eighteen hours. The hearing levels of the left ear were analyzed.

Median audiogram of the subjects showed 4 kHz-dip, a typical NIHL. Hearing levels grew with the ageing and with the hours of exposure to noise after correction of age-effects. Subjects with VWF had developed significantly greater hearing loss than those without it. However, the former were significantly older and had been exposed to noise for longer periods of time than the latter.

We formed 37 pairs from subjects with and without VWF, matched for age and hours of noise exposure, to examine the net effect of VWF on hearing. Table 1 shows the mean age and operating hours with the three types of the tools for the subjects with VWF and the controls. These two groups were closely matched for age and hours of work with chain saws. VWF subjects, however, had worked significantly fewer hours with winches than had their paired controls. On the other hand they had used bush cutters for more hours than the controls, so that the total hours of work with the three types of tools were considered to be adequately matched between the pairs.

Table 1. Age and the working hours with each type of tool in the subjects with vibration-induced white finger (VWF) and their matched control workers.

Groups	Sample size	Age	Working hours with; Chain saws	Bush cutters	Winches
VWF	37	49.9±5.8	6057±3475	1193±2389	3063±5723
Control	37	50.1±6.2	6052±3455	843±1667	4633±7323*

*: p< 0.01 by two-tailed Student's t-test for paired samples.

Fig. 1 illustrates the median audiograms of VWF subjects and controls. VWF subjects had a greater median hearing loss than controls at every frequency. These differences were not as large as those before the matching, which suggested that the confounding effects of age and exposure to noise had been eliminated in this analysis. The differences remained significant at 4 and 8 kHz ($p<0.05$) and were almost significant at 2 kHz ($p \fallingdotseq 0.06$) by Wilcoxon's signed rank test.

To establish this association between VWF and hearing loss, 108 workers had been followed for 5 years. We excluded 22 subjects from the analyses because of their exposure to ototoxic factors during the follow-up period. Among the remaining 86 subjects, 15 men (17.4%) had been suffering from VWF throughout the study period and 62 (72.1%) had remained without VWF. Again, case-control pairs were formed from the subjects with and without VWF, matched for the hearing level and age at the baseline study and exposure hours to noise during the follow-up. This pairing was done for each of the audiometric frequencies independently, because the sample size was too small to form pairs matched for the initial hearing levels at all the test frequencies simultaneously.

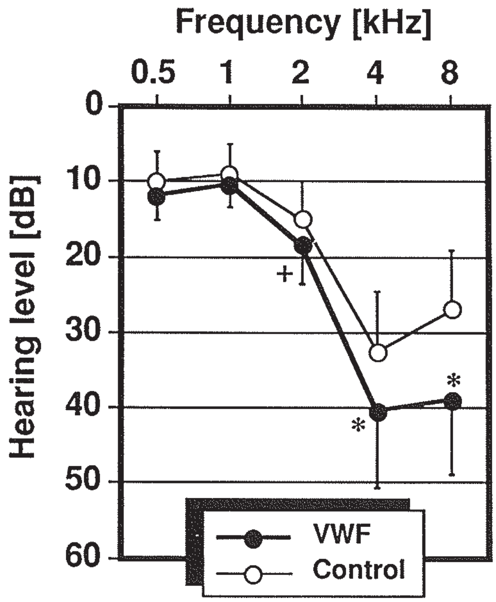

Fig. 1. Median audiograms of cases with VWF and their matched control samples in the cross-sectional study.
Vertical bars denote 95% confident limits of the medians.
*,+: Significant difference at $p<0.05$ (*) or almost significant (+; $p \fallingdotseq 0.06$) by Wilcoxon's signed rank test.

Table 2 shows the mean age and work hours with each type of tool during the study period for the VWF-affected cases and controls at 2, 4 and 8 kHz. No significant difference in age was observed between VWF cases and controls at any frequency. At 4 kHz, the mean working hours with the bush cutters were less and those with winches were greater in the VWF subjects than in the controls. However, these differences were not significant, and the total hours of exposure to all the tools were nearly the same between these groups. Thus, good matching between VWF subjects and controls was achieved for age and total hours of noise exposure.

Fig. 2 represents the initial median audiogram and the median hearing threshold shifts during the study for VWF subjects and controls. Vertical bars originating from the initial audiogram denote the change of heating levels during the study. Both subjects with and without VWF showed a significant increase of hearing loss at 8 kHz during the follow-up ($P<0.05$ by Wilcoxon's signed rank test). Significant deteriorations of the hearing at 2 and 4 kHz were seen in the subjects with VWF ($p<0.05$), whereas no change was observed in the men without VWF.

Table 2. Initial age and hours of work with each type of tool during the follow-up period for the subjects with vibration-induced while finger (VWF) and their matched control workers.

Frequency [kHz]	Groups	Number of subjects	Age [years]	Hours of work with; Chain saws	Bush cutters	Winches	Total exposure [hours]
2	VWF	14	50.3±4.9	774±963	271±663	605±913	1650±1485
	Control	14	49.7±5.6	627±414	372±542	152±418	1151±912
4	VWF	10	50.1±5.8	899±985	391±779	706±1000	1996±1200
	Control	10	49.7±6.7	829±730	1228±1831	91±189	2148±1782
8	VWF	11	49.5±5.3	929±1055	332±752	708±1024	1969±1464
	Control	11	49.4±6.8	963±863	156±247	219±415	1338±886

Each pair of values represents the mean ± standard deviation

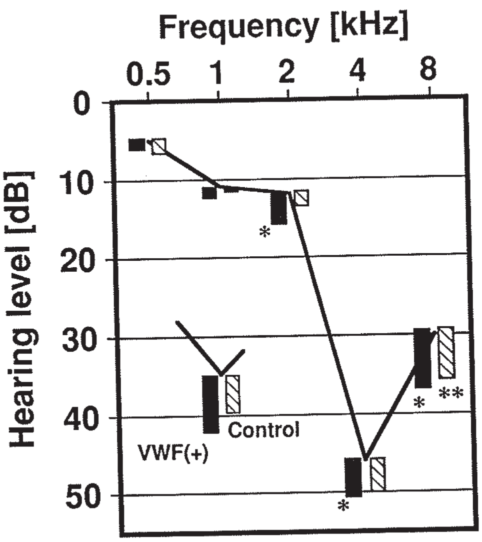

Fig. 2. Initial audiogram and development of hearing loss during the follow-up period in subjects with VWF and their matched controls.
Vertical bars represent the development of hearing loss during the follow-up.
*,**: Significant development at $p<0.05$(*) or $p<0.01$(**) by Wilcoxon's signed rank test.

VWF AND POSTURAL STABILITY[13]

We examined 71 men recruited from a cohort of professional forest workers in Suomussalmi, Finland, which had been followed in a longitudinal study since 1972, where the history of work with chain saws and past history of illness had been recorded.[14] They had no possible diseases affecting the vestibular system according to the medical records in the longitudinal study or the otological examinations in this study. Their mean age was 42.9±9.2 years, and the mean exposure to chain saw noise and vibration was 12,360±9,460 hours. The number of subjects with VWF was four (5.6%) at the time of the survey. Postural stability was measured with a force platform technique. This system was controlled by a microcomputer and recorded the sway of the center of the force on the platform surface, and calculated the average velocity of this sway (ASV [mm/s]).[15] Stability was measured during 30 seconds with eyes closed for four times in each subject with a 3-to 5-minute rest interval. The mean value of ASV in the four measurements was used in the following analyses. ASV values were converted logarithmically to form a normal distribution when a statistical method required it. Pure-tone audiometry was carried out in an acoustically treated room after the absence of occupational exposure to noise for 15 to 48 hours. The hearing levels of the left ear were analyzed.

Table 3 gives Spearman's correlation coefficients of the age, exposure hours and hearing levels to ASV. Neither age nor exposure correlated significantly with ASV. We found a significant correlation coefficient between the hearing level at 4 kHz and ASV ($p<0.05$), and a near significant one between the hearing level at 6 kHz and ASV ($0.05<p<0.1$). The former correlation remained significant even after eliminating the effect of age and exposure by calculating a partial correlation coefficient ($p<0.05$).

Table 3. Spearman's rank correlation coefficients of age, exposure hours and hearing levels to average sway velocity.

	Correlation coefficients	
	Simple	Partial
Age	0.157	--
Exposure hours	0.037	--
Hearing level at;		
0.5 kHz	0.177	0.116
1 kHz	0.195	0.138
2 kHz	0.061	-0.031
3 kHz	0.169	0.109
4 kHz	0.299*	0.257*
6 kHz	0.201+	0.142
8 kHz	0.141	0.082

Pearlized variables are age and exposure hours.

*: $p<0.05$, +: $0.05<p<0.1$

The subjects were divided into three groups according to their hearing level at 4 kHz; 26 subjects whose hearing level was lower than 20 dB, 22 men whose level was between 20 to 40 dB, and 23 subjects with the level higher than 40 dB. Fig. 3 illustrates the mean ASV among the groups. Dunnett's t-test for multiple comparisons indicated a significant difference in ASV between the groups with the highest and lowest hearing levels ($p<0.05$).

We performed a regression analysis of ASV on age, exposure hours, hearing level at 4 kHz and VWF. VWF was represented by a binomial variable where 1 and 0 denote with and without VWF, respectively. The result is shown in Table 4. Stepwise selection of independent variables ($P_{in}=0.15$, $P_{out}=0.15$) eliminated age and exposure hours from the regression equation. The equation obtained was statistically significant ($p<0.05$) and explained 10.3% of the total variance of ASV. The hearing level at 4 kHz had a significant regression coefficient ($p<0.05$) and VWF had an almost significant one ($0.05<p<0.1$).

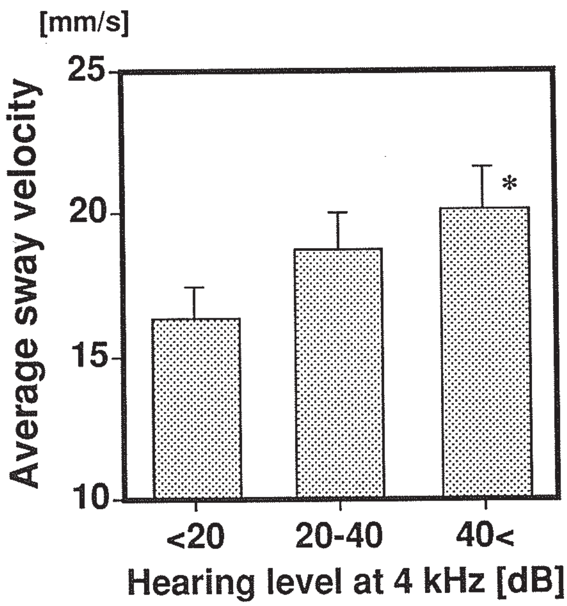

Fig. 3. Comparisons of average sway velocity among subjects according to hearing level at 4 kHz.
<20: 26 subjects whose hearing level at 4 kHz was lower than 20 dB.
20–40: 22 subjects whose hearing level at 4 kHz wasl between 20 and 40 dB.
<40: 23 subjects whose hearing level at 4 kHz was higher than 40 dB.
Vertical columns and bars denote the means and standard errors of the means, respectively.
*: Significant at $p<0.05$ by Dunnett's t-test in comparison with workers whose hearing level was lower than 20 dB.

Table 4. Multiple regression analysis of sway velocity on age, exposure hours, hearing level at 4kHz and vibration-induced white finger (VWF).

Independent variables	Standardized partial regression coefficients
Age	--
Exposure hours	--
Hearing level at 4 kHz	0.254*
VWF	0.185+

*: $p<0.05$, +: $0.05<p<0.1$

--: Rejected by step-wise selection of independent variables.

DISCUSSION

In the present series of studies on the hearing of forest workers, we observed that workers suffering from VWF developed a greater hearing loss than controls. This result was similar to the original findings of Pyykkö et al.,[1] but was obtained after more strict allowance for confounding variables. VWF is now demonstrated to be one of the risk factors of NIHL.

One of the most probable mechanisms of NIHL is that vasoconstriction in the inner ear caused by noise-exposure and increased oxygen demand due to strong and prolonged excitation of the receptor cells give rise to ischemic damage to the hair cells.[16] This hypothesis was corroborated by scanning electron microscopic observations which showed vasoconstriction and sludging of the blood cells in the cochlear blood vessels after noise exposure,[17] and by laser-Doppler flowmetry which indicated fluctuation of blood-flow in the cochlea in synchrony with noise-exposure.[18] The mechanism of such change in the cochlear blood flow is not known. However, the sympathetic nervous system probably plays some role in this change since remarkably dense adrenergic innervation was observed in the inner ear,[19] and sympathectomy caused an increase in cochlear blood flow.[20] Thus, higher tone in the sympathetic nervous system may decrease the blood flow in the cochlea.

The sympathetic nervous system has an important role in the genesis of VWF even though some local factors such as organic narrowing of the digital arteries[21,22] and hyperresponsiveness of the arteries to noradrenaline[23] have been proposed. Several authors have pointed out that the sympathetic nervous system of the subjects with VWF showed higher tone[24] and was excited more intensely by noise exposure[25] or simultaneous cooling of the fingers and body[26] than that of healthy people. Such conditions of the sympathetic nervous system in subjects with VWF might influence the susceptibility to noise in the hearing process through the decrease of the blood flow in the cochlea as well as in the fingers.

Another series of our study failed to show directly that the exposure to hand-arm vibration and noise from chain saws affected the postural stability. However, hearing level at 4 kHz correlated with ASV after allowance for the effect of age and exposure. Subjects with cochlea sensitive to noise might have a vestibule vulnerable to noise as well.

Occupational noise exposure has been speculated to have harmful effects on the vestibular labyrinth since the middle of this century.[27,28] However, Hinchcliffe et al.[29] reviewed the publications on this issue and concluded that the evidence was not strong enough to regard it as probable. More recently, there have been some evidences of the effects of impulse noise from firearms on balance control.[30,31] The mechanism of this effect has been postulated as a direct mechanical damage caused by pressure waves of high-energy impulses.[32] Noise from chain saws, however, is not impulsive and dose not have the high energy of noise from firearms. Direct mechanical damage dose not seem to be an apt mechanism for the debilitating posturographic results found among subjects with a higher hearing threshold.

In this respect, the effects of VWF on the posturographic results in this study is interesting. Even though the number of subjects with VWF was small, VWF explained some variance of ASV in the regression analysis, and it seemed to play some role in the genesis of the balance disorder. A similar mechanism might underlie the effects of VWF on body-balance control and hearing loss. Thus, noise exposure induces ischemia more severely in the vestibular labyrinth as well as in the cochlea in men with VWF, thereby causing worse posturographic results. To establish VWF as a risk factor for postural instability, further studies on a larger scale are necessary.

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