Vibration-induced White Finger and Auditory Susceptibility to Noise Exposure

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Summary: It is well known that there are wide individual variations in the susceptibility of human hearing to noise exposure. The hearing of male forest workers were examined with vibration-induced white finger (VWF) as an indicator of noise susceptibility of hearing. The results were as follows: 1. Hearing losses at 4 and 8 kHz in subjects with VWF were greater than those of unaffected men in a matched pair case-control study allowing for confounding due to differences of age and noise exposure. 2. The hearing loss at 4 kHz on the ipsilateral side of the hand with VWF was greater than the loss on the contralateral side in subjects with VWF in one hand. 3. The hearing loss at 4 kHz in subjects with VWF progressed more rapidly during a five-year follow-up period than the loss in men with no history of VWF. These results indicate that the hearing of subjects with VWF was more vulnerable to noise than the hearing of subjects without VWF. It was suggested that a pathological change causing VWF, such as enhanced vasoconstriction due to elevated sympathetic nervous tone, could also cause this additional auditory vulnerability to noise exposure.

Key words: noise-induced hearing loss — auditory susceptibility to noise — sympathetic nervous system — vibration-induced white finger — combined effects

Introduction

There is no doubt about the noxious effects of intense noise on hearing. However, individuals of the same age and sex, working for the same length of time in the same occupational environment, do not always present the same audiological picture. A large individual variation in noise susceptibility of hearing exists (Kawata, 1988). Previous studies have suggested several factors which could influence this variation, such as race (Jerger et al. 1986), age (Humes, 1984), smoking habits (Barone et al. 1987), prevalence of hypertension (Talbott et al. 1985), administration of ototoxic drugs (Boettcher et al. 1987), previous noise exposure (Humes, 1984), threshold of acoustic reflexes (Miyakita et al. 1983) and sympathetic nervous function (Kawata, 1988).

Recently, Pyykkö et al. (1981) reported that lumberjacks with vibration-induced white finger (VWF) had greater hearing losses at 4 kHz than those with no history of VWF. It is interesting to consider the possibility that increased noise susceptibility of hearing could be related to VWF. Similar results have been observed in
other studies (Iki et al. 1985; Pyykkö et al. 1986; Miyakita et al. 1987). To confirm the association between VWF and hearing loss, and to evaluate its temporal relationship; a group of forest workers was followed for five years with special reference to the relationship of VWF to the progression of hearing loss (Iki et al. 1987).

In this paper, results are presented from revised analyses on previous cross-sectional study data and the present follow-up study.

**Subjects and Methods**

1. **Subjects**

   Forest workers, consisting of 524 males and 19 females, voluntarily underwent annual medical examinations for vibration syndrome in 1980 in Nara, Japan. From this group, 360 men were selected as the subjects for the cross-sectional study. They had no history of ear diseases, vertigo, head injury, or the intake of ototoxic drugs; no continuous use of hearing protectors; no noisy hobbies; and no conductive hearing loss detected by otoscopy and audiometry in this study. Among the 360 men examined, 289 had no history of occupational noise exposure other than that from chain saws, bush cleaners or winches, and their total hours of work with each type of tool was evaluated.

   Among the 289 subjects for the cross-sectional study, 108 workers were selected and studied for five years. They were interviewed, annually, during the follow-up period, regarding working hours with vibrating tools and exposure to the ototoxic factors described above. In this group, 22 subjects were eliminated from the analyses because they had one or more ototoxic factors during the study period. Consequently, 86 subjects (88.1%) remained.

2. **Audiometry**

   Pure tone air- and bone-conduction hearing levels were measured at frequencies of 0.5, 1, 2, 4 and 8kHz with a diagnostic audiometer (RION AA-64N). The audiometer was calibrated based on the Japanese Industrial Standard (JIS T 1201-1982), which has the same zero levels as the international standard (ISO 389-1975). The audiometry was conducted in a portable sound-proof chamber (RION AT-4C) located in a quiet room, where the background noise level was always lower than 40 dBA. Each subject had been free from the noise of tools for at least 18 hours prior to the audiometry.

3. **Diagnosis of VWF**

   A diagnosis of VWF was reached when two doctors in the laboratory judged from detailed interviews that a subject had a typical history of VWF, such as clear blanching of the digits followed by cyanosis and then by flushing, most commonly induced by acute body cooling.

4. **Chain Saw Noise and Vibration**

   The noise and vibration from recent models of chain saws were analyzed. The noise was measured with a precise sound level meter (RION NL-10) with a condenser microphone located near the ear of a worker. The vibration acceleration was measured as the root mean square value in meters per second², (0 dB ref. 10⁻⁵m/sec²) from a vibration level meter (RION VM-50) connected to triaxial acceleration pick-up (RION PV-93) mounted rigidly on the front handle of a chain saw. Both noise and vibration signals were tape-recorded with a data recorder (TEAC R-61). The recorded signals were analyzed into one-third octave band levels in the frequency range from 50Hz to 10kHz for the noise and from 8 to 1000Hz for the vibrations with a one-third octave band analyzer (RION SA-59A). Fig. 1 and 2
Auditory Susceptibility to Noise Exposure

Fig. 1. Noise spectra from a chain saw (Stihl 041AV) analyzed in one-third octave bands, including the permissible standards for 30 (PS 30), 60 (PS 60) and 120 (PS 120) minutes of daily exposure recommended by the Japanese Association of Industrial Health.

Fig. 2. Vibration spectra from a chain saw (Stihl 041AV) analyzed in one-third octave bands, including the permissible limit for 4 to 8 hours of daily exposure recommended by the International Standardization Organization (ISO/DIS 5349, 1979).

Fig. 3 represents the median values of the audiograms for each age group. Twenty-five men who were younger than 30 years of age or older than 60 were excluded. The older the subjects, the higher the hearing thresholds, especially at 4 and 8 kHz. The greatest hearing loss, however, in most of the groups was observed at 4 kHz, and this type of audiogram is typical of a noise-induced hearing loss. The hearing levels of all the age groups at 4 kHz were significantly lower than those from the normal Japanese population of the same age and with no exposure to noise (Yokouchi, 1964). Therefore, the hearing of the subjects was affected by noise, as well as by aging.

Results

1. Cross-Sectional Study

(1) General features of the subjects

Table 1 shows the mean age of the subjects and the hours of work using the three types of tools. Among 289 subjects whose exposure history was evaluated, 60 men had worked only with chain saws and 8 only with bush cleaners. The rest had used two or three different types of tools.

(2) VWF and hearing loss

Of the 289 men, 51 (17.6%) had VWF (+) group, and 228 (78.9%) had no history of VWF (+) group; the remaining 10 (3.5%) had atypical symptoms.

Fig. 4 illustrates the median audiograms of the VWF (+) and VWF (−) groups. The greatest hearing loss was at
TABLE 1
Mean age and working hours with each type of tool for the subjects in the cross-sectional study

<table>
<thead>
<tr>
<th>Subjects</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>All subjects</td>
<td>360</td>
<td>48.1</td>
<td>8.2</td>
</tr>
<tr>
<td>Subjects with whom the hours of tool use were evaluated</td>
<td>289</td>
<td>48.0</td>
<td>8.2</td>
</tr>
<tr>
<td>Age (years)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating hours</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chain saws</td>
<td>281a</td>
<td>4762</td>
<td>4613</td>
</tr>
<tr>
<td>Bush cleaners</td>
<td>124a</td>
<td>3531</td>
<td>4478</td>
</tr>
<tr>
<td>Winches</td>
<td>112a</td>
<td>7518</td>
<td>8162</td>
</tr>
</tbody>
</table>

a: Number of workers who had operated the tool.

4 kHz in both groups. The VWF (+) group had a significantly higher hearing threshold than the VWF (−) group at every frequency. However, the subjects in the VWF (+) group were significantly older (51 ± 7 [mean ± SD] for the VWF (+) group versus 47 ± 9 for the VWF (−) group; p < 0.01) and had used chain saws for a longer time (7929 ± 6360 hrs. vs. 3898 ± 3833 hrs.; p < 0.01) than in the VWF (−) group.

Fig. 3. Median values of the audiograms for each five-year age grouping of the subjects in the cross-sectional study.

Fig. 4. Median audiograms of the subjects without [VWF (−)] and with [VWF (+)] vibration-induced white finger in the cross-sectional study. Significant at p < 0.05 (*), p < 0.01 (**) or p < 0.001 (***) by the Mann-Whitney test.

To determine which of these features (age, operating time, or VWF) was related to the differences in hearing levels, 37 pairs matched for age and exposure duration were formed from the VWF (+) and VWF (−) groups. The controls were matched by age groups with the VWF
TABLE 2
Age and the working hours with each type of tool in the subjects with vibration-induced white finger and controls

<table>
<thead>
<tr>
<th>Groups</th>
<th>Sample size</th>
<th>Age</th>
<th>Working hours with;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>VWF</td>
<td>37</td>
<td>49.9</td>
<td>5.8</td>
</tr>
<tr>
<td>Controls</td>
<td>37</td>
<td>50.1</td>
<td>6.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chain saws</td>
<td>Bush cleaners</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>VWF</td>
<td>6057</td>
<td>3475</td>
<td>1193</td>
</tr>
<tr>
<td>Controls</td>
<td>6052</td>
<td>3455</td>
<td>843</td>
</tr>
</tbody>
</table>

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

subjects, and their operating time with each type of tool was almost equal to or larger in some instances than those for the VWF subjects.

Table 2 shows the mean age and operating hours with the three tools for the VWF group and the controls. The two groups were closely matched for age and hours of work with chain saws. The VWF subjects, however, had worked significantly fewer hours with winches than had their paired controls. On the other hand, they had used bush cleaners for more hours than the controls, so that the total hours of work with the three tools were considered to be adequately matched for the pairing.

Fig. 5 illustrates the median audiograms of the VWF subjects and the controls. The VWF subjects had a greater median hearing loss than the controls at every frequency. These differences were not as large as in Fig. 4, since the confounding effects of age and exposure to noise had been eliminated in this analysis. However, the differences remained significant at 4 and 8kHz (p<0.05) and were almost significant at 2kHz (p=0.06).

The relationship between VWF and hearing loss was examined by a multiple regression analysis. Table 3 shows the multiple regression function for the hearing level at each test frequency with age, working hours with each type of tool and
TABLE 3

Results of the multiple regression analysis of hearing levels to age and working hours with each type of tool and the prevalence of vibration-induced white finger

<table>
<thead>
<tr>
<th>Dependent variables</th>
<th>Standard partial regression coefficients of independent variables</th>
<th>Multiple regression coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Working hours with;</td>
<td>VWF</td>
</tr>
<tr>
<td></td>
<td>Age</td>
<td>CS</td>
</tr>
<tr>
<td>Hearing level at .5 kHz</td>
<td>0.143*</td>
<td>0.177**</td>
</tr>
<tr>
<td>1 kHz</td>
<td>0.243***</td>
<td>0.118***</td>
</tr>
<tr>
<td>2 kHz</td>
<td>0.271***</td>
<td>0.136*</td>
</tr>
<tr>
<td>4 kHz</td>
<td>0.363***</td>
<td>0.143*</td>
</tr>
<tr>
<td>8 kHz</td>
<td>0.318***</td>
<td>0.104</td>
</tr>
</tbody>
</table>

CS: Chain saws  BC: Bush cleaners  W: Winches
+: P<0.1  *: P<0.05  **: P<0.01  ***: P<0.001

TABLE 4

Laterality of vibration-induced white finger and hearing loss

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Side of the ear</th>
<th>Hearing levels [dB] at test frequency [kHz] of;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td>Subjects with no history of VWF (N=245)</td>
<td>Right</td>
<td>11.9</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>11.2</td>
</tr>
<tr>
<td>VWF in both hands (N=28)</td>
<td>Right</td>
<td>15.0</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>14.8</td>
</tr>
<tr>
<td>VWF in one hand (N=16)</td>
<td>VWF(−)</td>
<td>17.0</td>
</tr>
<tr>
<td></td>
<td>VWF(+)</td>
<td>16.7</td>
</tr>
</tbody>
</table>

VWF (−): The ear on the contralateral side of the hand with VWF.
VWF (+): The ear on the ipsilateral side of the hand with VWF.
+: P=0.06

The prevalence of VWF was represented by a binomial variable which had a value, 1, for the subjects suffering from VWF or 0 for the men without the symptoms.

A statistically significant regression function was obtained for the hearing level at every frequency. The age of the subjects had a significant positive regression coefficient for every hearing level, and the working hours using chain saws was also a significant independent variable at every test frequency except 8kHz.

The prevalence of VWF had a significant regression coefficient with the hearing level at 4kHz. Thus, the hearing of the subjects was affected by the age of the subjects and the noise from the chain saws. In addition, VWF correlated positively to the hearing loss at 4kHz independent of the age and noise exposure.

(3) Laterality of VWF and hearing loss

From the total group of 360 workers, 313 pairs of hearing level data were obtained to examine the laterality of the
TABLE 5
Mean working hours with each type of tool for the subjects in the follow-up study

<table>
<thead>
<tr>
<th>Working hours with;</th>
<th>Chain saws</th>
<th>Bush cleaners</th>
<th>Winches</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Up to the beginning of the study</td>
<td>83</td>
<td>4372</td>
<td>3238</td>
</tr>
<tr>
<td>During the follow-up</td>
<td>79</td>
<td>978</td>
<td>761</td>
</tr>
</tbody>
</table>

N: Number of subjects using each type of tool.

hearing loss. Among these available subjects, 50 men had VWF and 245 had no history of VWF. Among the subjects with VWF, 16 males suffered from the symptom in one hand and 28 men had VWF of an equal Taylor-Pelmear scale and equal Rigby-Cornish scale (Taylor, 1983) in both hands.

Table 4 shows the median hearing levels for each ear in the three groups of subjects, that is, those without VWF, with VWF in both hands and with VWF in one hand. The Wilcoxon’s signed rank test indicated no significant differences in the hearing levels between the right and left ears in the former two groups. In the latter group, however, the hearing loss at 4kHz on the ipsilateral side of the hand with VWF was greater than that on the contralateral side, and this difference was nearly significant (p<0.06).

2. Follow-up Study

(1) General features of the cohorts

The mean age of the subjects included in the cohort group was 48±7 years at the beginning of the study. Table 5 shows the hours of use of three types of tools up to the beginning and during the course of the five-year follow-up period. The most commonly used vibrating tool was the chain saw. Every worker had used at least one of the vibrating tools.

![Fig. 6. The median audiogram at the beginning of the follow-up study (line graph) and the median hearing threshold shift during the study period (vertical bar) in the 86 subjects. Significant at p<0.05 (*) or p<0.001 (***)) by the Wilcoxon’s signed rank test.](image)
els at 2, 4 and 8kHz grew significantly worse during the five years.

(2) VWF and hearing loss

Among 86 subjects, 15 men (17.4%) suffered from VWF which did not improve during the study period and 62 (72.1%) had no history of VWF. The rest (10.5%) had atypical blanching of the fingers or had VWF which developed or ceased during the follow-up period.

At the beginning of the study, the subjects with VWF had significantly lower hearing levels at 4kHz (47.5 [median] in the men with VWF vs. 28.5 in the men without VWF; p<0.001) and were significantly older (51±5 vs. 47±7; p<0.05) than those without VWF. To eliminate the effects of such differences on the analyses of threshold shifts, case-control pairs were formed from the subjects with and without VWF. They were matched for age and hearing level at the beginning of the study and for total hours of work with the tools during the follow-up period. However, the sample size was too small to obtain a sufficient number of subjects with similar ages, similar hearing levels at all the test frequencies and similar working hours with each type of the tool. Therefore, matching was performed independently at each of the test frequencies. Five groups of case-control pairs were obtained for five test frequencies.

Table 6 shows the mean values and standard deviations of age and work hours with each type of tool during the study period in the VWF-affected cases and controls at 2, 4 and 8kHz. No significant difference in age was observed between the VWF cases and controls at any frequency including 0.5 and 1kHz. At 4kHz, the mean working hours with the bush cleaners were less and the working hours with the winches were greater for the VWF subjects than for the controls. However, these differences were not significant (p>0.05), and the total hours of operation of all the tools were nearly the same for both groups. Thus, good matches between VWF subjects and controls were achieved for age and total hours of noise exposure.

Fig. 7 represents an initial median audiogram and the median hearing threshold shifts during the study for the VWF subjects and the controls. The median decreases of hearing levels were 3.8 dB in the VWF subjects vs. 1.3 dB in the controls at 2kHz, 4.6 dB vs. 4.4 dB at 4kHz, and 8.5 dB vs. 5.8 dB at 8kHz. The Wilcoxon’s signed rank test indicated that

<table>
<thead>
<tr>
<th>Frequency [kHz]</th>
<th>Groups</th>
<th>Number of subjects</th>
<th>Age</th>
<th>Hours of work with;</th>
<th>Total hours of operation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CS</td>
<td>BC</td>
</tr>
<tr>
<td>2</td>
<td>VWF</td>
<td>14</td>
<td>50.3±4.9</td>
<td>774±963</td>
<td>271±663</td>
</tr>
<tr>
<td></td>
<td>Controls</td>
<td>14</td>
<td>49.7±5.6</td>
<td>627±414</td>
<td>372±542</td>
</tr>
<tr>
<td>4</td>
<td>VWF</td>
<td>10</td>
<td>50.1±5.8</td>
<td>899±985</td>
<td>391±779</td>
</tr>
<tr>
<td></td>
<td>Controls</td>
<td>10</td>
<td>49.7±6.7</td>
<td>829±730</td>
<td>1228±1831</td>
</tr>
<tr>
<td>8</td>
<td>VWF</td>
<td>11</td>
<td>49.5±5.3</td>
<td>929±1055</td>
<td>332±752</td>
</tr>
<tr>
<td></td>
<td>Controls</td>
<td>11</td>
<td>49.4±6.8</td>
<td>963±863</td>
<td>156±247</td>
</tr>
</tbody>
</table>

Each pair of values represents the mean±standard deviation.
CS: Chain saws   BC: Bush cleaners   W: Winches
Fig. 7. The initial median audiogram and median change of hearing levels during the follow-up study in subjects with vibration-induced white finger (shaded bar) and controls (hatched bar). Significant at p<0.05 (*) or p<0.01 (**) by the Wilcoxon's signed rank test.

The changes in hearing levels at 2, 4 and 8kHz were significant for the VWF subjects and only the change at 8kHz was significant for the controls.

Discussion

Several previous studies (Pyykkö et al. 1981, 1986; Iki et al. 1985; Miyakita et al. 1987) have proposed an association between VWF and hearing loss. In the present cross-sectional analyses, a similar association was obtained after allowance for age and noise exposure by matching these factors in the VWF subjects and controls or by using multiple regression analyses. However, a cross-sectional study can not give an evaluation of the temporal relationship of the association (MacMahon and Pough, 1970). The present follow-up study clarified that the hearing loss progressed more rapidly in men with VWF than in healthy men even after allowance for several contributing factors. A temporal relationship has been established by this work.

The effect of aging on hearing initially develops as a hearing loss in the higher frequency bands (Corso, 1976). The threshold shift at 8kHz in the present subjects was mainly a function of age. On the other hand, hearing at 4kHz is typically impaired by noise exposure, and audiograms display a "4-kHz dip" with noise-induced deafness (Robinson, 1976). The subjects in this study had this type of audiogram indicating that they were affected by noise exposure. However, the hearing loss at 4kHz was much greater in the men with VWF than in those without VWF, although no difference existed in the exposure times to noise between these two groups of subjects (Fig. 7). This difference in the hearing level at 4 kHz can account for the difference in the noise susceptibility of the two groups. The cause of this additional vulnerability of hearing due to VWF remains obscure. A pathological change causing VWF might also play a role in the development of the hearing loss.

Organic narrowing of the digital arteries (Ashe et al. 1962; Walton, 1974) and hyperresponsiveness of the arteries to noradrenaline (Azuma et al. 1978) have been proposed as local factors bringing about VWF. However, an important factor in the induction of VWF is the sympathetic nervous system hyperactivity (Hyvärinen et al. 1973; Matoba et al. 1975; Olsen et al. 1985). Several authors have pointed out that the sympathetic nervous system in patients with vibration syndrome has a higher tone (Matoba et al. 1981) and is excited more intensely by noise exposure (Matoba et al. 1975) or simultaneous cooling of the fingers and body (Olsen et al. 1985) than in healthy people.
Some hypothetical mechanisms for the noise-induced hearing loss have been introduced. One of the most probable mechanisms is that vasoconstriction in the inner ear causes ischemic changes in the cochlea. These ischemic changes are enhanced by the increased oxygen demand due to strong and prolonged excitation of the receptor cells by intense noise exposure, resulting in damage to the hair cells (Hawkins, 1971). This hypothesis was corroborated by more recent scanning electron microscopic observations which indicated that there was a vasoconstriction and sludging of blood cells in the cochlear blood vessels during noise exposure (Nakai and Masutani, 1988). According to this hypothesis, some factor which produces vasoconstriction in the inner ear raises the noise susceptibility of hearing.

The control of cochlear microcirculation is not conclusively established. A large amount of work has focused on the role of the sympathetic nervous system (Lawrence, 1980). Morphological observations indicate that the inner ear has a remarkably dense adrenergic innervation (Maass, 1981). Unilateral sympathectomy in animals increased cochlear blood flow (Hultcrantz, 1979) and reduced hearing damage due to noise exposure (Borg, 1982) on the operated side. One may speculate that sympathectomy decreases the effect of noise exposure on hearing by inhibiting the sympathetic vasoconstriction in the inner ear. This speculation is supported by an observation in human by Sanden and Axelsson (1981). They stated that an increased excitability of the sympathetic nervous system may be one of the physiological features of noise-resistant men in comparison with noise-resistant men. A higher tone in the sympathetic nervous system of subjects with VWF may increase the noise susceptibility of their hearing.

Concerning the effects of the sympathetic nervous system on hearing, the laterality of the hearing loss related to VWF is interesting. In general, no laterality occurs with noise-induced deafness (Robinson, 1976). Laterality was also not observed in the present study in the subjects without VWF or with VWF of equal severity in both hands. Laterality was present in men with VWF in one hand.

One possible mechanism for the laterality of the hearing loss is a difference in the exposure to noise between the right and left ears. With a usual posture of an chain saw operator, the right ear is nearer the tool than the left ear. However, the distances from the chain saw to the right and left ears vary with the posture of an operator which changes while cutting down a tree. From the measurements of chain saw noise under actual working conditions, there was little difference in the sound levels (Leq) at the right and left ears during the time a subject was cutting down a tree. It is unlikely that the laterality of the hearing loss observed in men with VWF in a unilateral hand was due to a difference in the level of noise between the ears.

The different noise susceptibilities of the ears on the ipsilateral and contralateral sides of the hand with VWF may cause the laterality of the hearing loss. In the men with VWF on one side, vibrations from chain saws were probably transmitted to the affected hand more intensely than to the unaffected hand (Färkkilä, 1979). Noise exposure could induce more intense sympathetic vasoconstriction in the inner ear on the side with the higher transmission of vibration, resulting in a higher noise susceptibility of hearing on the ipsilateral side.

This laterality of hearing loss related to VWF should have been examined in a prospective study. However, the sample size of the present follow-up study was too small for such analyses, thus further studies are necessary.

In this paper, some new knowledge on the relationship between VWF and hearing
loss was presented. In the study design, factors due to subject age and exposure time to noise were eliminated. However, there may be uncontrolled biases, for instance, differences in noise and vibration levels of the tools used during the study period, or differences between subjects with and without VWF in the ways the tools are handled. It is important, but very difficult, to assess the exposure levels to vibration and noise on an individual basis. For this reason highly controlled studies are necessary.

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References


