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ORIGINAL ARTICLE

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Hand-arm symptoms related to impact and nonimpact hand-held power tools

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Abstract Hand and arm symptoms among workers using impact and non-impact hand-held power tools were investigated in a cross-sectional study and a 5-year follow-up study. The study population consisted of concrete workers ($n = 103$), truck assemblers ($n = 234$), electricians ($n = 101$), platers ($n = 140$) and lumberjacks ($n = 102$). Of the original 680 subjects, we followed up 312 after 5 years. A questionnaire concerning ongoing hand and arm symptoms, daily exposure to hand-held power tools, type of tool used, and individual factors was administered. More workers using low-frequency impact tools than workers using non-impact tools reported symptoms in the elbows and shoulders. Elbow symptoms were accentuated in the cross-sectional study, while shoulder symptoms were accentuated in the follow-up study. Wrist symptoms were reported by more of those working with high-frequency impact tools than of those using only non-impact tools when the analyses were controlled for age, years in the occupation and smoking habits. A possible explanation of the results found in this study is that low-frequency impact vibration is transmitted to the upper arm, and thus the elbow and shoulder are at risk, while high-frequency impact vibration is attenuated in the hand and wrist and may predominantly cause symptoms there.

Key words Hand-arm vibration syndrome · Impact tools · Nonimpact tools · Epidemiology · Follow-up study · Hand-held power tools

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Introduction

Risks of hand and arm disorders such as carpal tunnel syndrome (CTS), tendinitis and vibration white finger (VWF) have been reported among workers using hand-held power tools [3, 6, 21]. Work with hand-held power tools exposes the users, among many other factors, to hand-arm vibration. The vibration can be of two types, depending on the operating method of the tools, with either impact or non-impact (harmonic) characteristics. The assessment of these two types of vibration has been discussed ever since the international standard for the measurement and evaluation of hand-arm vibration was first published [19]. The standard included the statement that impact vibration can be provisionally assessed with the standard. Prevalence data for VWF among workers using impact tools and among those using non-impact tools, compared with the predicted prevalence according to the Appendix to the standard, seem to challenge that statement.

High impulsiveness, a vibration characteristic not accounted for in the ISO method, was claimed by Starck [32] to contribute to the high prevalence of Raynaud's phenomenon in a group of pedestal grinders. It has also been suggested [11, 12] that a large content of frequencies outside the range of the ISO weighting curve (well above 1 kHz) may contribute to the prevalence of VWF observed in workers using impact tools (riveting hammers). However, other studies [25, 30] found no differences between exposures to impact vibration and exposure to harmonic vibration in either acute effects or prevalence of VWF.

The studies cited have mostly investigated the prevalence of VWF. Recently laboratory studies [16, 22, 23] found that grip and push forces, as well as the fundamental frequency of the exposure, greatly influence response parameters such as hand-arm impedance, dissipated power, vibration transmission, muscle activity (EMG), vibration perception threshold changes, and discomfort ratings. Lower frequencies ($\leqslant 50$ Hz) are transmitted unattenuated up to the elbow and may therefore affect the elbow and shoulder more than higher frequencies, while frequencies > 100 Hz are largely absorbed in the hand and wrist. This indicates a relationship between frequency and site of vibration effect as well as type of symptom. One simple frequency-weighting method therefore seems to be insufficient for all the different symptoms found in workers using hand-held vibrating tools.

The present study addressed the following hypotheses.

1. Work with impact tools is related to more symptoms than is work with non-impact tools.
2. Work with low-frequency impact tools is related to more proximal symptoms than is work wigh high-frequency impact tools.

Subjects and method

Study groups

The study group consisted of 103 concrete workers, 234 truck assemblers, 101 electricians, 140 platers and 102 lumberjacks. Every fourth concrete worker from a local division of the Construction Labour Union, every fourth electrician from a local division of their Labor Union, all platers in a company for manufacturing machines for the paper-mill industry, all assemblers on an assembly line for trucks and all lumberjacks belonging to an industrial health center in central Sweden were asked to participate in the studies. The number approached ($n = 853$) and the actual number participating ($n = 680$) in the study are shown in Table 1. Forty-six percent of the workers ($n = 312$), all still in the same job 5 years later, participated in a 5-year follow-up study.

Method

All the subjects answered a questionnaire, validated by Johansson and Hagberg [20], concerning their daily exposure time to hand-held power tools and symptoms. The subjects reported how many minutes they had worked with each specific tool during their latest working day. One set of different tools was specified for each of the five occupations. Thus, the set for the lumberjacks, included only tools used by lumberjacks. The subjects were grouped according to the type of tools they used. The tools were grouped by operational function of impact or non-impact (NI) origin (Table 2). The impact tools were further divided into low-frequency impact (LFI) tools and high-frequency impact (HFI) tools (Table 2). The tools with impact frequency $\leqslant 50$ Hz (rock drills, concrete breakers, drill hammers and chipping hammers) were categorized as LFI tools and the other impact tools (impact drills, impact wrenches and scalers) were categorized as HFI tools. The 50 Hz limit was chosen because at frequencies up to 50 Hz the vibration is transmitted almost unattenuated to the elbow [22].

Very few subjects worked solely with LFI tools, making it impossible to study workers using solely that type of tool. In the LFI tool group, subjects also using other tools were therefore included. The only criterion was that they had been exposed to one LFI tool at some time during the working day.

The questions on musculoskeletal symptoms were presented, together with a map of the body (Fig. 1) on which the subjects marked their answers "no" or "yes" concerning current ache, pain,

Table 1 The number of subjects approached and the number of subjects included in the cross-sectional and follow-up studies subdivided, by occupation

Job titles	Cross-sectional Approched	Included	(%)	Follow-up Included (*n*)	(%)
Concrete workers	143	103	72	72	70
Platers	165	140	85	76	54
Assemblers	258	234	91	6	3
Electricians	146	101	69	78	77
Lumberjacks	141	102	72	80	78
Total	853	680	80	312	46

Table 2 The division of tools into nonimpact (*NI*), high-frequency impact (*HFI*) and low-frequency impact (*LFI*) tools. Occupations in which the tools are used are marked brackets after the tools (*C* concrete workers, *E* electricians, *A* assemblers, *P* platers, *L* lumberjacks)

NI	HFI	LFI
Concrete vibrators (C)	Impact drills (C, E)	Rock drills (C)
Powered screw drivers (E)	Impact wrenches (A)	Concrete breakers (C)
Nutrunners (A)	Scalers (P)	Drill hammers (C)
Grinders (P)		Chipping hammers (P)
Drills (P)		
Chain saws (L)		
Bruch saws (L)		

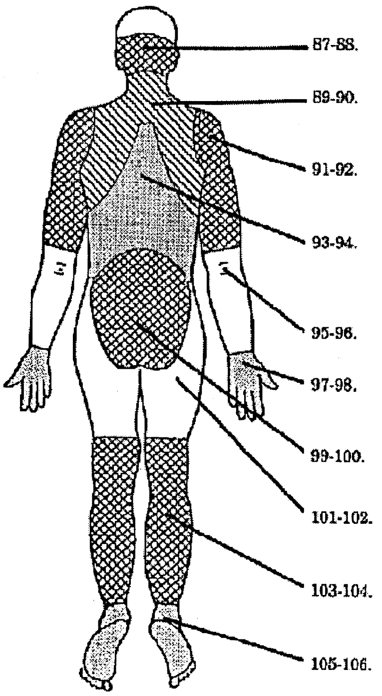

Fig. 1 Body map defining the different parts of the body used in the section on musculoskeletal symptoms in the questionnaire

numbness or other disorders. The present study only considers the answers for the forearm and elbow ("elbow"), questions 95–96, and the upper arm and shoulder-joint region ("shoulder"), questions 91–92, plus those pertaining to circulatory and neurological symptoms in the hand and wrist. The question regarding circulatory symptoms was, "Do you at present have symptoms of white fingers such as one or more fingers become white in cold or damp weather." The question on neurological symptoms was, "Do you at present feel numbness or tingling in the hand or fingers during day or at night." The question concerning the wrist was "Do you right now have pain in the wrist." These answers were categorized according to a four-grade scale with "no", "insignificant," "some" and "rather a lot" as alternatives. Subjects answering "some" or "rather a lot" were considered to be reporting symptoms; the others were considered to be symptom-free.

The questionnaire also contained items concerning age and smoking habits.

Statistical analysis

Bivariate

The prevalence and 95% confidence intervals (CI) of symptoms of white fingers (WF), tingling, pain in the wrist, elbow and shoulder symptoms were calculated separaetly for workers using the three types of tools (LFI, HFI and NI tools) [13].

The crude prevalence rate ratios (PRR) between subjects working with impact tools and subjects working with non-impact tools were calculated for each type of symptom with test-based confidence intervals. These calculations were made with the SAS/STAT software package, procedure Freq (SAS Institute, Cary, N.C., USA).

Multivariate

A multiple logistic regression analysis was performed concerning different aspects of exposure to vibration from hand-held powered tools. The model for the cross-sectional study was built using Maximum Likelihood Technique adding variables [24]. Fit to the data was tested with the 'goodness-of-fit" test according to Hosmer and Lemeshow [17] included in the JMP ver 3.1 statistical software package (SAS Institute). The final model included exposure to LFI and HFI tools in two classes, 1 = no exposure, 2 = exposure. Number of years in the occupation (continuous variable) was also included in the model. The individual factors included in the model were age (continuous variable) and smoking habits (dichotomized as "no" or "yes"). The adjusted odds ratios (OR) were calculated for an increase of one unit of each factor included in the model, while for age and years in the occupation the ORs were transformed to 10-year periods. For the follow-up study we used the same model for simplicity.

The logistic model used was as follows:

$$\begin{aligned}\ln(p/(1-p)) &= \alpha + \beta_1 * \text{LFI tools (1 or 2)} + \beta_2 * \text{HFI tools (1 or 2)}\\ &\quad + \beta_3 * \text{age} + \beta_4 * \text{years in occupation}\\ &\quad + \beta_5 * \text{smoking (1 or 2)}\end{aligned}$$

Results

Prevalences

Cross-sectional study

The prevalences of elbow and shoulder symptoms were much higher (38% in each region) for the LFI tool group than for the other two groups (Fig. 2). The prevalences of hand and wrist symptoms were around 20% for all three tool groups.

Follow-up study

The prevalences of white fingers and tingling were all between 20% and 30% among those participating in the follow-up study after 5 years (Fig. 3). Among those using LFI tools the prevalences of wrist, elbow and shoulder symptoms were higher than among users of the other two tool types.

Bivariate analysis

Cross-sectional study

There was no increase in reports of wrist pain among workers using impact tools compared with workers

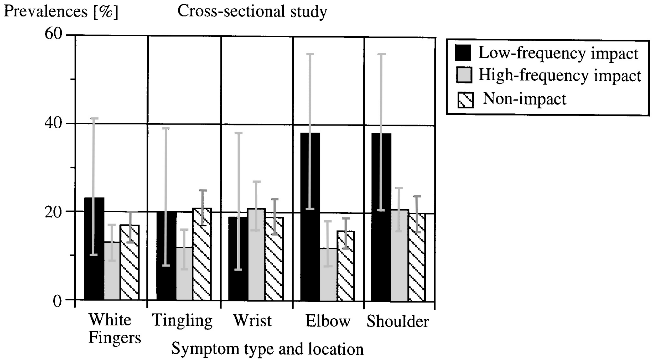

Fig. 2 The prevalences with 95% confidence intervals of white fingers (*WF*), tingling and symptoms in the wrists, elbows and shoulders among workers using nonimpact and high- and low-frequency impact tools in the cross-sectional study

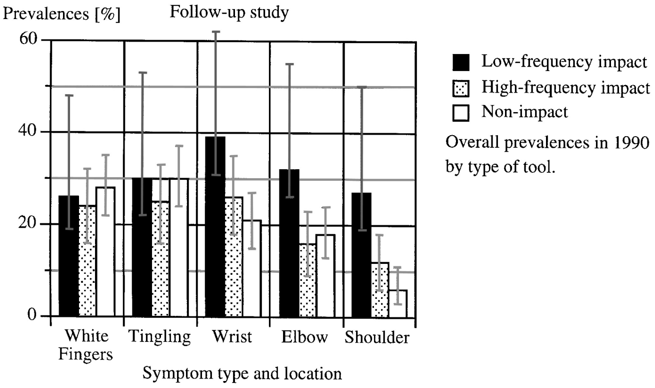

Fig. 3 The prevalences with 95% confidence intervals of white fingers (*WF*), tingling and symptoms in the wrists, elbows and shoulders among workers using nonimpact and high- and low-frequency impact tools in the follow-up study

using NI tools (Fig. 4). The frequency of symptoms in the elbow and shoulder was higher for those using LFI tools than for those using NI tools (PRR = 2.4 and 1.9). For those using HFI tools there was no such increase.

The reports of WF and tingling were not higher among workers using impact tools than among workers using NI tools (Fig. 4).

Follow-up study

More workers using LFI tools reported symptoms in the shoulder than workers using NI tools (PRR = 3.2; Fig. 5). There was no difference in shoulder symptoms between those using HFI tools and those using NI tools. For wrist symptoms there was only a small increase in symptom prevalence among LFI and HFI tool users. For white fingers and tingling there was also only a tendency to more frequent reports among those using LFI tools (Fig. 5).

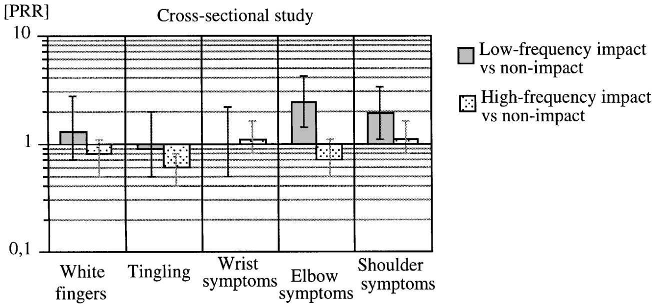

Fig. 4 The prevalences rate ratios (*PRR*) with 95% confidence intervals of white fingers, tingling, and symptoms in the wrist, elbow, and shoulder among workers using low- and high-frequency impact tools compared with workers using nonimpact tools in the cross-sectional study

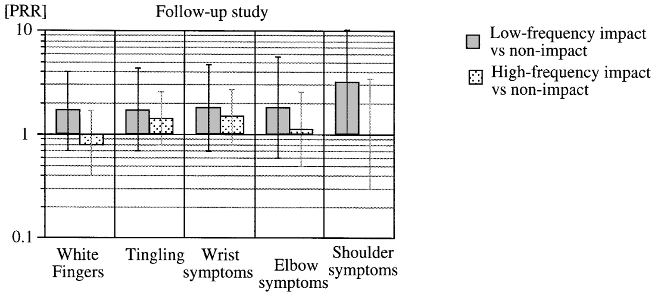

Fig. 5 The prevalences rate ratios (*PRR*) with 95% confidence intervals of white fingers, tingling, and symptoms in the wrist, elbow, and shoulder among workers using low- and high-frequency impact tools compared with workers using nonimpact tools in the follow-up study

Multivariate analysis

Cross-sectional study

The "goodness-of-fit" (sometimes called "lack-of-fit") test showed that the model used was not rejected at the 5% level. An acceptable fit to the observed data was therefore obtained with this model.

The factor associated with risk in the bivariate analyses, work with LFI tools, was also found in the multivariate analysis that controlled for age, years in the occupation, and smoking habits. Exposure to LFI tools resulted in an OR of 0.9, 2.9, and 1.6 for reporting symptoms in the wrist, elbow and shoulder respectively (Table 3). In the same analyses work with HFI tools resulted in ORs of 1.5, 1.2, and 1.6 for wrist, elbow and shoulder symptoms.

Age transformed to 10-year periods was associated with all three symptom locations, and smokers reported symptoms in the wrist less often than nonsmokers.

Follow-up study

Multiple logistic regression, when age, years in the occupation and smoking habits had also been included, gave results similar to those of the bivariate analysis. Exposure to LFI tools had an OR of 3.7 for shoulder symptoms (Table 4). For symptoms in the elbow, exposure to LFI tools and an OR of 2.0. For wrist symptoms, exposure to HFI tools had an OR of 1.6.

Incidence

The 5-year incidence of white fingers, tingling, wrist and shoulder symptoms were all around 20% (Fig. 6). For elbow symptoms it was around 10%. The widest difference between the three tool group users was found for shoulder symptoms; 20% incidence for those using LFI tools and less than 10% for the other two tool group users. The incidence ratio for shoulder

Table 3 Individual factors and physical work factors (exposure to low- and high-frequency impact tools) related to wrist, elbow and shoulder symptoms by multiple logistic regression for the cross-sectional study. The ORs for the factors age and years in the occupation are calculated for 10-year increments

Factor	Wrist symptoms OR (CI)	Elbow symptoms OR (CI)	Shoulder symptoms OR (CI)
Low-frequency impact	0.9 (0.4–2.4)	2.9 (1.2–6.8)	1.6 (0.7–3.8)
High-frequency impact	1.5 (1.0–2.3)	1.2 (0.8–2.0)	1.6 (1.0–2.6)
Age	1.4 (1.1–1.7)	1.9 (1.5–2.4)	2.2 (1.7–2.7)
Years in occupation	0.9 (0.7–1.2)	0.7 (0.5–0.9)	0.7 (0.5–0.9)
Smoking	0.5 (0.3–0.7)	0.7 (0.4–1.2)	1.2 (0.8–1.9)

Table 4 Individual factors and physical work factors (exposure to low- and high-frequency impact tools) related to wrist, elbow and shoulder symptoms by multiple logistic regression for the follow-up study. The ORs for the factors age and years in the occupation are calculated for 10-year increments

Factor	Wrist symptoms OR (CI)	Elbow symptoms OR (CI)	Shoulder symptoms OR (CI)
Low-frequency impact	1.0 (0.3–4.1)	2.0 (0.5–7.9)	3.7 (0.8–16.6)
High-frequency impact	1.6 (0.8–3.4)	1.2 (0.5–3.1)	1.0 (0.3–3.3)
Age	0.7 (0.5–1.2)	1.2 (0.8–1.9)	0.7 (0.3–1.6)
Years in occupation	1.5 (0.9–2.5)	1.1 (0.6–1.7)	1.9 (0.7–4.8)
Smoking	1.1 (0.5–2.3)	1.2 (0.5–2.8)	1.0 (0.5–2.8)

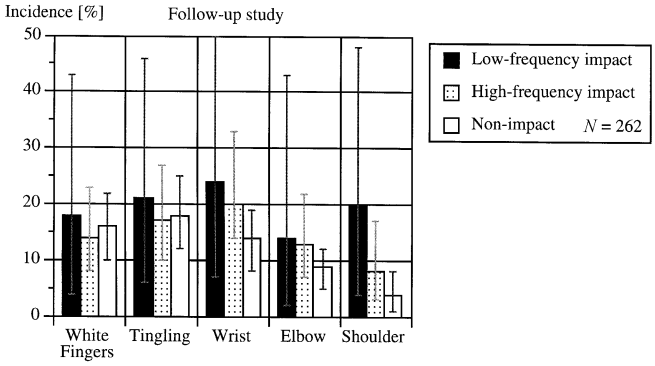

Fig. 6 The incidences with 95% confidence intervals of white fingers tingling and symptoms in the wrist, elbow, and shoulder among workers using nonimpact and low- and high-frequency impact tools in the follow-up study

symptoms between workers using LFI tools and workers using NI tools was 3.2 (CI = 1.0–10.3).

Discussion

Impact vs NI tools

In the cross-sectional study workers using LFI and HFI tools had about the same prevalence ratios of pain in the wrist as workers using NI tools (Fig. 4). In the follow-up study, however, there was a tendency for a higher prevalence of pain in the wrist among workers using impact tools than workers using NI tools (Fig. 5). Controlling for other factors, such as age, years in the occupation and smoking habits, indicated that work with HFI tools was a risk factor for pain in the wrist.

HFI vibration is attenuated in the hand and wrist. The vibration from such tools could therefore only affect the hand and wrist. LFI vibration, however, is transmitted to the elbow, and could therefore affect the whole arm, including the wrist. High forces, repetitive movements, powerful grip and vibration have been reported as risk factors for CTS and other wrist symptoms [1, 15, 27, 31]. The grip and push forces also effect the transmission of vibration to the hand-arm system [16, 22]. A firm grip increases the vibration transmission from the handle to the hand-arm system.

Impact vibration or impact forces also create elastic wave propagation in the bones. Several authors have used such waves for the measurement and study in vivo of bone characteristics [7–10] The impulse forces are distributed to different joints and bones in the wrist [29]. If the total impact force is large enough, an overload in one of the joints or bones in the wrist could occur and cause a micro-fracture.

Some epidemiological studies support these findings. Hunting et al. [18], for example, found a prevalence of about 50% for reports of symptoms in the hand and wrist among electricians, but only 15% reported symptoms in the elbow. Electricians often use impact drills, which are HFI tools.

Exposure to impact power tools contributes to complaints of pain and stiffness in the hand, arm and shoulder, and particularly in the wrist [5, 26].

Some authors have reported higher prevalences of VWF among workers using impact tools than among workers using NI tools with the same vibration level according to the ISO 5349 standard [11, 12, 32]. We found no such difference between impact and NI tools in the present study (Fig. 4). In the follow-up study we found a tendency to increased reports of tingling among those using LFI and HFI tools. Among those using LFI tools we found a tendency for increased white finger symptoms compared with those using NI tools (Fig. 5).

Low-vs high-frequency impact tools

Work with LFI tools was found in both the cross-sectional and the follow-up studies to be a risk factor for symptoms in the elbow and shoulder, in comparison with work with NI tools used as a reference (Figs. 4, 5). Work with HFI tools, however, was a risk factor only for shoulder symptoms in the cross-sectional study, while for elbow symptoms it did not differ from work with NI tools. An explanation of this may be that low frequencies ($\leqslant 50$ Hz) are transmitted almost unattenuated up to the elbow [22] and would therefore affect the forearm and upper arm more than high frequencies, which are attenuated in the hand and wrist. This is also shown by the higher incidence, in the follow-up study, of shoulder symptoms (Fig. 6) among workers using LFI tools.

Furthermore, LFI tools are often ergonomically more strenuous to the upper extremities than HFI tools, because they are usually heavier than the HFI tools. This will have contributed to the difference in symptoms between LFI and HFI tools. Many of the NI tools used in the study were also heavy (grinders, shut-off nut runners, etc.), requiring high handling forces. Another reason is that workers using LFI tools are exposed to other ergonomic factors that are strenuous to the upper arm. Miners and construction workers are exposed to strong static joint loading, with joints in extreme positions, to heavy lifting, other heavy manual work and repetitive hand movements [14, 33, 34].

In an experimental study [23], the muscle activity in the hand, forearm and upper arm increased with exposure to vibration as opposed to non-vibratory exposure. In the forearm and upper arm, exposure to vibration from a chipping hammer (impact frequency = 50 Hz) resulted in a greater increase in muscle activity than exposure to vibration from a grinder (fundamental frequency = 137 Hz). The discomfort ratings for the forearm and upper arm were also higher during exposure to the chipping hammer than during grinder vibration exposure. This constitutes experimental evidence of physiological effects of the transmission of impact vibration from the hand to the wrist, elbow and shoulder.

The differences in physiological effect and transmission to different parts of the hand-arm system for the type of vibrations could explain the difference in reported symptoms between workers using LFI tools and workers using HFI tools. This means that some of the acute effects studied could be used as predictors of the reported findings in the present study.

The hypothesis that low-frequency vibration may affect the upper arm and shoulder is supported by the following studies:

Work with jack-hammers (LFI tools) increased the risk of shoulder tendinitis [34]. A significant dose–response relationship between range of movement in elbow flexion as well as radiographic changes in the right elbow was found among stone quarry workers under the age of 60 years using chipping hammers and rock drills [28]. Coal mine workers using LFI tools had a slightly increased prevalence of elbow osteoarthrosis [14]. Other radiological changes in the right elbow have also been seen among those using chipping hammers [3]. Therefore, the repetitive impacts transmitted to the elbow can be a cause of human degenerative joint changes associated with osteoarthrosis.

Aging seemed to be associated with all three symptoms in the cross-sectional study (Table 3), but not in the follow-up study (Table 4). These contradictory results were also found in the literature. Some studies show that age basically affects the elbow [28], while others [26], found that age was not an important risk factor for reporting symptoms in the back, neck or upper limbs. In one study [4], age was a risk factor for reporting at least one symptom in the upper extremities.

Consideration of study design, and bias

In the bivariate analyses in this study, PRRs were used instead of the more common prevalence ORs, for two reasons. With this method it is easier to interpret differences between exposures, and as Axelson et al. [2] have pointed out, the OR is a poor measure of risk in cross-sectional studies. This is so because, for instance, the sensitivity of the OR to disease duration is higher in that type of study. We tried to use the method Axelsson et al. suggested, PRRs and an analysis by means of a proportional hazards model (Cox regression) to control for confounding, but it was not suitable for the present study.

The PRRs and ORs in the present study were all calculated with workers using NI tools as a reference. The reason for this was that the difference in symptoms between working with impact tools and working with NI tools was the object of study, and the workers using NI tools also performed manual work of about the same kind as the workers using impact tools. If non-exposed subjects, included but not reported in the study, had been used as controls, the PRRs would have been much larger. For the LFI tool group workers, the PRR would have been between 4 and 20, depending on the symptom.

There were many drop-outs in the follow-up study: only 312 of 680 workers still worked in the same company after 5 years. The largest drop-out was among the assemblers, only 6 remaining in the same job. An explanation for this could be that in the late 1980s and the early 1990s, employee turnover was high. The assembly industry had replaced 20–30% their work force each year. This could be explained by the healthy worker effect: only those who can adapt to work on an assembly line with its controlled pace stay, and the others get new jobs. Another explanation is that the workers stayed only a couple of years until they found better jobs.

Because of the relative low number of subjects in the LFI tool groups, the confidence intervals, especially in the follow-up study, became relatively wide. In many cases they included unity, so no certain conclusion could be drawn. In summary, work with LFI tools was associated with more reports of symptoms in the elbow and shoulder than was work with NI tools. Elbow symptoms were accentuated in the cross-sectional study, while shoulder symptoms were accentuated in the follow-up study. These results were in agreement with the results from earlier biomechanical and psychophysiological studies about acute effects of exposure to vibration from a chipping hammer and a grinder on the hand-arm system. Low-frequency vibration was transmitted almost unattenuated to the elbow, causing a larger increase of muscle activity in the arm and more discomfort in the upper arm than high-frequency vibration did.

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