Occup Environ Med 2000;**57**:218–228

Prevalence and pattern of occupational exposure to hand transmitted vibration in Great Britain: findings from a national survey

Keith T Palmer, Michael J Griffin, Holly Bendall, Brian Pannett, David Coggon

MRC Environmental Epidemiology Unit, Community Clinical Sciences, University of Southampton, UK
K T Palmer
H Bendall
B Pannett
D Coggon

Institute of Sound and Vibration Research, University of Southampton, UK
M J Griffin

Correspondence to:
Dr Keith Palmer, MRC Environmental Epidemiology Unit, Southampton General Hospital, Southampton SO16 6YD, UK
email ktp@mrc.soton.ac.uk

Accepted 20 December 1999

Abstract

***Objectives*—To estimate the number of workers in Great Britain with significant occupational exposure to hand transmitted vibration (HTV). Also, to identify the occupations and industries where such exposures arise, and the main sources of exposure.**

***Methods*—A questionnaire was posted to 22 194 men and women aged 16–64, comprising 21 201 subjects selected at random from the age-sex registers of 34 general practices in England, Scotland, and Wales, and a further 993 subjects selected at random from the central pay registers of the three armed services. Among other things, the questionnaire asked about exposure to sources of HTV in current and earlier employment. Responses were assessed by occupation and industry, and prevalence estimates for the country as a whole were derived from census information on occupational and industrial populations nationally. Estimates were also made in exposed workers of the average daily dose of vibration (A(8) root mean squared (rms) for the past week, based on their reported sources and durations of exposure.**

***Results*—Usable questionnaires were returned by 12 907 subjects (overall response rate 58%). From these it was estimated that some 4.2 million men and 667 000 women in Great Britain are exposed to HTV at work in a 1 week period, and that personal daily exposures to vibration exceed a suggested action level equivalent to 2.8 ms^{-2} for 8 hours (A(8) >2.8 ms^{-2} rms) in at least 1.2 million men and 44 000 women. High estimated doses (A(8) >5 ms^{-2} rms) arose most often in bricklayers and masons, gardeners and groundsmen, carpenters and joiners, electricians and electrical maintenance fitters, and builders and building contractors. The industries where high A(8) values most often arose were construction, motor vehicle repair and maintenance, manufacture of basic metals, and agriculture. The most common sources of exposure were hammer drills, hand held portable grinders, and jigsaws.**

***Conclusions*—Exposure to HTV is surprisingly prevalent, and preventive measures and health surveillance may be warranted for many men in Britain. Control strategies should focus on prevention at source, with priority accorded to the common sources of exposure and the occupations in which significant exposures tend to arise. Many vibratory tools that are common in Britain have been overlooked in previous surveys, highlighting an important focus for future research.**
(*Occup Environ Med* 2000;**57**:218–228)

Keywords: hand transmitted vibration; population; prevalence; exposure

Exposure to hand transmitted vibration (HTV) has been linked with several health effects, the best known being Raynaud's phenomenon—vibration induced white finger (VWF).[1 2] Sensorineural impairment in the fingers[2 3] and carpal tunnel syndrome[4 5] are other reported hazards from use of vibratory tools, and osteoarthritis of the wrist and elbow have also been associated with HTV in some studies.[6–9] The term hand-arm vibration syndrome (HAVS) has been used to define collectively the disorders thought to be associated with exposure to HTV.[10 11]

Exposure to HTV arises from many sources, including powered percussive hammers, concrete breakers, sanders, powered drills, grinders, polishers, burring tools, chain saws, and even motorcycle handlebars. The range and extent of these exposures has increased steadily over the 20th century, and HTV now represents one of the commonest of occupational hazards in British industry.

One major national survey of occupational exposure, undertaken by the Health and Safety Executive (HSE) in the 1980s, suggested that more than 400 000 British workers were exposed on a weekly basis to the potentially injurious effects of HTV,[12] but several limitations to the data were acknowledged. Sampling was based on a narrowly selected list of industries and a restricted range of exposure patterns (emphasis was placed on tools and occupations covered by United Kingdom statutory reporting arrangements); no detailed information was collected by occupation or on the types of tool giving rise to exposure; for practical reasons establishments were sampled rather than employees, and the exposure histories of workers were obtained by proxy, by questioning their managers; the survey, which was restricted to premises registered with the HSE, almost certainly underrepresented small employers and self employed business people; and practical difficulties were encountered in obtaining a head count in some industrial sectors, notably in the building industry. Some

Figure 1 Locations of the general practices that participated in the survey.

important industries were not included in the survey, and later supplementary surveys were carried out among railway, mine, and quarry workers[13 14] which raised the estimated number of exposed workers to nearly 500 000.

To target control measures appropriately at the national level, better information is required about the extent, sources, and distribution of exposure to HTV. Recognising this, the HSE commissioned a postal survey to collect information on exposures and relevant symptoms in a large community based sample. Responses were assessed by occupation and industry, and prevalence estimates for the country as a whole were derived from census information on occupational and industrial populations nationally. This paper focuses on the prevalence, extent, and distribution of exposures in Great Britain. The associations between exposure and health complaints will be reported elsewhere.

Methods

SAMPLE SELECTION

The study sample comprised 21 422 men and women selected from the patient lists of 34 general practices, and 993 members of the armed services. The practices were chosen to give a broad coverage of Great Britain and to ensure that industries with known exposure to vibration but a restricted geographical distribution were adequately represented in the sample. They were identified from lists of general practitioners with a known interest in research (provided by the Royal College of General Practitioners and the Primary Care Rheumatology Society) and in a few cases from the Medical Directory. The locations of the practices are shown in figure 1.

To assess seasonal differences in reporting, the posting was split into two tranches. The first, in May and June 1997, was sent to a one in eight sample of men and women aged 16–64 years who were randomly selected from the lists of 18 practices. The second, in January 1998, was sent to a random sample of one in six men and one in 12 women in the same age range from the remaining practices. A few subjects (1%) were excluded from the posting on the advice of their general practitioners, generally because of terminal illness or recent bereavement.

Members of the armed forces were unlikely to be included in these groups, as primary care for the services is provided by military doctors rather than civilian practitioners. To ensure their representation, there was a separate posting in January 1998. The sampling frame was restricted to members of the armed forces resident in Britain, and a simple random sample of men and women aged 16–64 years was taken from each service, from central pay records for serving members as an enumeration list. Altogether 993 names were selected (297 subjects from the Royal Air Force, 220 from the Royal Navy, and 476 from the Army).

STUDY QUESTIONNAIRE

Each subject was sent a postal questionnaire with a covering letter from his or her general practitioner (or in the armed forces from the director of general medical services). Nonresponders were sent a single reminder after 5 weeks.

The questionnaire was developed in consultation with health and safety professionals, vibration specialists, trades unions, trade associations, and members of a former working group of the Royal College of Physicians Faculty of Occupational Medicine. It underwent several rounds of field testing and refinement, the details of which have been published.[15] Among other things, it included questions about current occupation and industry; exposures to HTV at work in the previous 7 days (sources and durations of exposure); and any occupational exposure to HTV (for more than 1 hour a week) in previous employment. The occupations of respondents were coded to the latest revision of the standardised occupational classification (SOC 90)[16] and industries were coded according to the standard industrial classification scheme (SIC 92).[17]

Information on current exposure to HTV was obtained principally from a question about use in the past week of 39 listed tools and machines. Also, some subjects reported other sources of occupational exposure to HTV in the past week in response to an open question. These reports were reviewed independently by a vibration specialist (MJG), an occupational hygienist (BP), and an occupational physician (KTP), to decide whether they represented substantive exposures, and if so whether the source belonged to the predefined list of tools and machines, or whether new categories of tool should be created to accommodate them. Differences of opinion were resolved by consensus. As a result, 11 new categories were added to the original list.

STATISTICAL ANALYSIS

To derive estimates of exposure for the population of Great Britain, and to allow for the possibility of differential sampling and response rates between occupations and industries, account was taken of the relative frequency of occupations and industries among those who answered the questionnaire compared with the national population. Tables from the latest available (1991) national census[18] were obtained from the Office of National Statistics giving the estimated national populations by occupation and industry in men and women of working age. For most national estimates of exposure, the number of exposed people in the sample in each occupation was multiplied by a scaling factor as follows:

$$\text{Estimated number with exposure in an occupation nationally} = \text{number with exposure in occupation in sample} \times \frac{\text{number in occupation nationally}}{\text{number in occupation in sample}}$$

In the analyses of national exposure by industry, a similar method was used but with the scaling based on industrial rather than occupational populations.

PERSONAL EXPOSURES TO HAND TRANSMITTED VIBRATION

From published measurements and other information held by the Institute of Sound and Vibration Research, dominant axis frequency-weighted vibration accelerations (a_{hw} values) were assigned to each of the categories of vibratory tool or machine that were distinguished in the questionnaire. Average personal daily vibration exposures (A(8)) for the past week were then estimated for exposed subjects by assuming the time dependency in the International Standards Organisation (ISO) 5349, 1986[19] and summing the partial doses arising from each source. Further details are provided in an appendix.

For a few sources, representative a_{hw} values could not be assigned with confidence; and in a substantial minority of cases estimates of the duration of exposure were missing. In such cases total dose could not be calculated, but for subjects who had several sources of exposure sufficient information often existed to estimate a minimum A(8).

Table 1 Most common sources of exposure to hand transmitted vibration in the past week

Source	Subjects reporting exposure in the sample: n	%*	Estimated numbers with exposure in Great Britain (in thousands): n	95% CI
Men†:				
Hammer drill	651	11.9	1723	1600 to 1847
Hand held portable grinder	600	10.9	1560	1443 to 1677
Jig saw	412	7.5	1066	968 to 1165
Circular saw	348	6.3	926	833 to 1020
Hand held sander	298	5.4	804	715 to 892
Pedestal grinder	266	4.8	641	566 to 717
Impact wrench	233	4.2	541	473 to 609
Impact screwdriver	223	4.1	541	471 to 610
Hand guided mower	176	3.2	478	409 to 547
Chipping hammer	170	3.1	418	356 to 480
Concrete breaker	166	3.0	470	400 to 541
Chain saw	165	3.0	405	344 to 466
Nailing or stapling gun	157	2.9	375	317 to 433
Metal drill	156	2.8	369	312 to 427
Unclassified	119	2.2	233	192 to 275
Women‡:				
Floor polisher	81	2.1	278	218 to 338
Nailing or stapling gun	51	1.3	142	104 to 181

*Employed respondents who used a given tool in the week (%).
†All others <2.1% of male employed respondents.
‡All others <0.5% of female employed respondents.

Results

QUESTIONNAIRE DISTRIBUTION AND RETURNS

A total of 22 415 subjects were selected for study, but 221 were excluded on their general practitioners' advice, so that 22 194 questionnaires were posted. Of these, 1028 questionnaires (4.6%) were returned as "address unknown", "moved away" or "deceased", and 56 were completed by someone other than the intended recipient. Usable responses were therefore obtained from 12 907 subjects, giving a response rate of 58% overall or 61% among those who could be contacted.

The overall response rate by practice ranged from 33.1% in Lambeth to 70.2% in Devon, and in the armed services varied from 60.9% (Army) to 72.7% (RAF). The response rate was higher in women than men (67% *v* 52%), and tended to be higher at older ages, but was similar in the summer and winter.

Seventy three per cent of respondents (79% of men and 65% of women) were in a paid job or were self employed in the week preceding completion of the questionnaire, and most of these (9084 out of 9368) were at work in that week.

Some subjects had worked in more than one job, but exposure to HTV in secondary jobs was rare (only 37 men and eight women), so further analysis was confined to the main job held. The relative frequency of occupations in the sample was generally similar to that of the 1991 national census,[18] except that the sampling design led to overrepresentation of the defence sector.

FREQUENCY OF OCCUPATIONAL EXPOSURE TO HAND TRANSMITTED VIBRATION

Altogether, 2945 men (42.6% of all male respondents) reported having been occupationally exposed to HTV at some time, including 1727 who reported exposure to a source of HTV in the week preceding completion of the questionnaire (31.5% of those in employment). The estimated 1 week prevalence of exposure among men of working age in the national population was 20.5% (95% confidence interval (95% CI) 19.7 to 21.3%) overall, and 31.9% (95% CI 30.7 to 33.1%) in those at work.

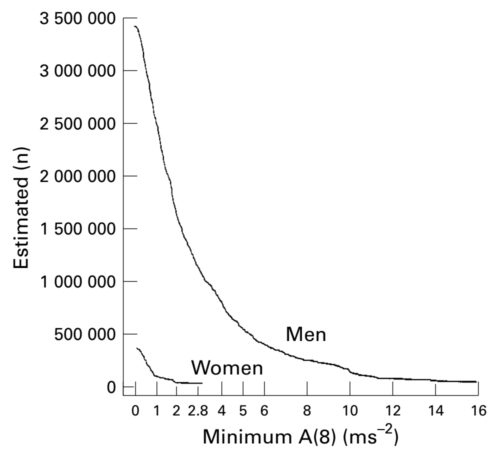

Figure 2 Minimum estimated numbers of men and women in Great Britain whose exposure level (average daily A(8) rms) in the past week exceeded the values indicated.

Among women, exposure was less common: 475 women (7.9% of the sample) had ever been exposed occupationally, and 225 women (3.7%) had been exposed in the past week. In the national population, the 1 week prevalence of exposure was estimated as 2.9% (95% CI 2.6 to 3.3%) of all women and 6.4% (95% CI 5.6 to 7.2%) of those in work.

For all occupations combined, it was estimated that 4 208 000 men (95%CI 4 044 000 to 4 371 000) in Great Britain were exposed to a source of HTV in the past week. The occupations which contributed the largest estimated numbers of exposed men were those belonging to group 5 of SOC 90 (the craft and related occupations major group). These included: metal working production and maintenance fitters (299 000 exposed, 95%CI 272 000 to 324 000), carpenters and joiners (254 000, 95%CI 242 000 to 267 000), electricians and electrical maintenance fitters (194 000, 95% CI 177 000 to 211 000), motor mechanics and autoengineers (157 000, 95%CI 139 000 to 176 000), plumbers and heating and ventilating engineers (141 000, 95%CI 127 000 to 155 000) and builders and building contractors (131 000, 95%CI 119 000 to 144 000). These six occupations accounted for an estimated 28% of the men with exposure nationally.

The industries which contributed the largest estimated numbers of exposed men were: construction (979 000 exposed, 95%CI 907 000 to 1 052 000), motor vehicle maintenance and repair (276 900, 95%CI 234 000 to 320 000), agriculture (219 000, 95%CI 194 000 to 244 000), manufacture of fabricated metal products other than machinery and equipment (218 000, 95%CI 185 000 to 252 000), and defence (162 000, 95%CI 123 000 to 201 000). These five industries included an estimated 49% of the men with exposure nationally.

The 1 week prevalence of occupational exposure to HTV in women corresponded to an estimated 667 000 women (95%CI 582 000 to 751 000) exposed nationally. The occupation with the largest estimated number of exposed women was cleaner or domestic worker (241 000, 95%CI 193 000 to 288 000), followed by hairdresser (12 000, 95%CI 4000 to 20 000). The education sector gave rise to the biggest estimated number of exposed

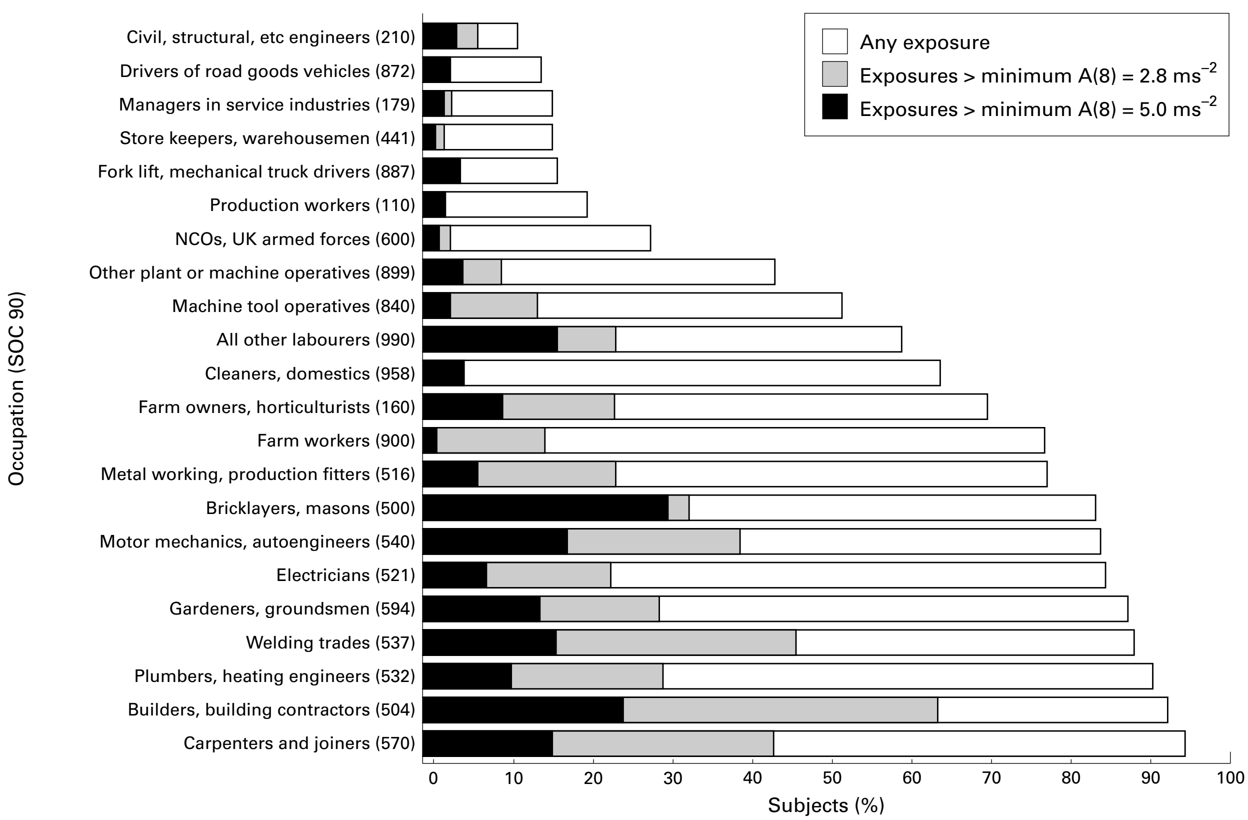

Figure 3 The occupations in which exposures to HTV most commonly arose in the past week among employed men.

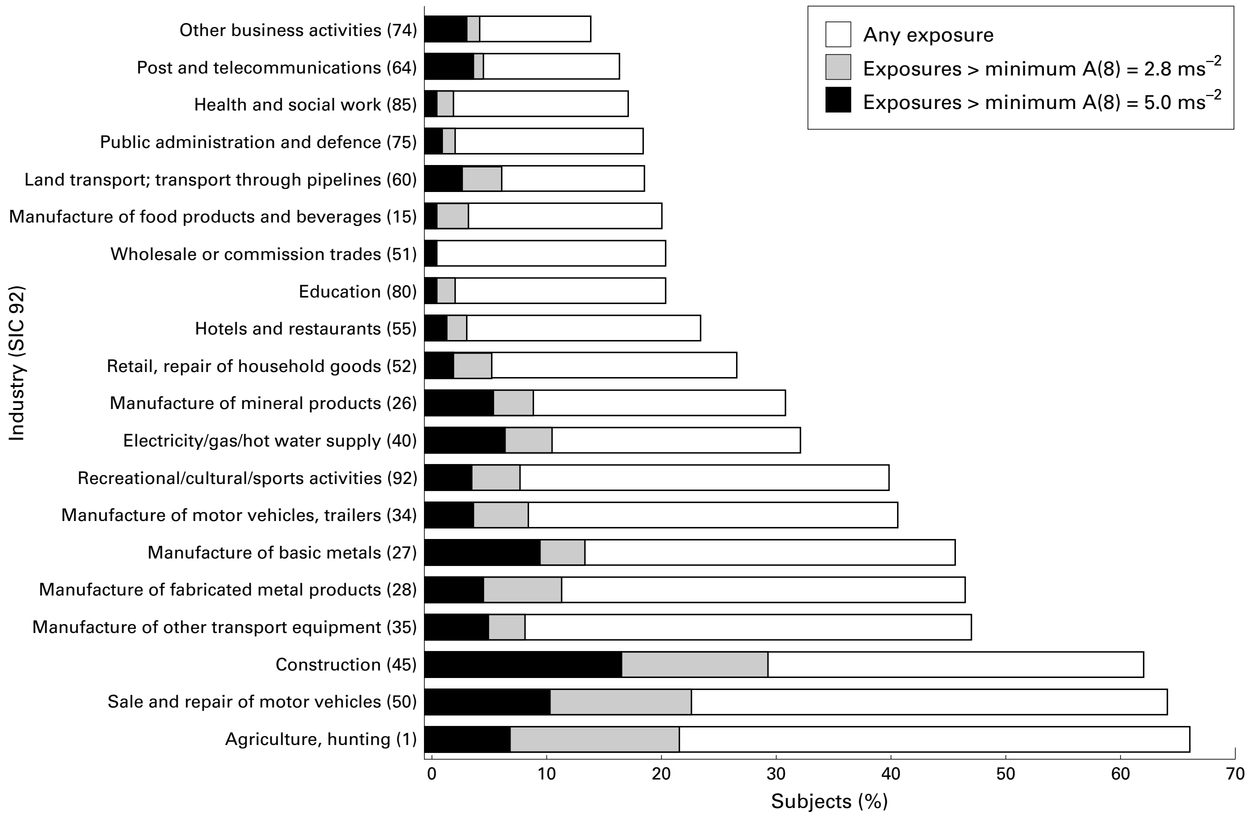

Figure 4 The industries in which exposures to HTV most commonly arose in the past week among employed men.

women by industry (111 000, 95%CI 83 000 to 139 000).

MOST COMMON SOURCES OF HAND TRANSMITTED VIBRATION

Table 1 lists the sources of exposure to HTV in the past week that respondents reported most often, and the estimated numbers of people with such exposure in Great Britain. Among employed men in the sample, the most common exposures were hammer drill (11.9%), hand held portable grinder (10.9%), and jig saw (7.5%). The national estimates for these tools imply that there are more than 1.7 million users of hammer drills, more than 1.5 million users of hand held portable grinders, and more than 1 000 000 users of jig saws. Among women, floor polishers were the source of exposure reported most often, followed by nailing and stapling guns.

Exposure to multiple sources of HTV was fairly common. Thus, 1218 men (22% of employed men in the sample) were exposed to two or more sources of HTV in the week before they completed the questionnaire, including 301 men (5.5%) who reported using six or more vibratory tools. In women, occupational exposure to more than one source of HTV was uncommon (only 39 subjects among 3878 employed respondents).

Table 2 Minimum prevalence of exposure to hand transmitted vibration (A(8) >2.8 ms^{-2} rms) in the past week by occupation

	Sample			Population of Great Britain (in thousands): minimum estimated number with A(8) >2.8 ms^{-2}	
		Minimum with A(8) >2.8 ms^{-2}			
Occupation (SOC 90)	n	n	%	n	95% CI
Men:					
All occupations	5490	445	8.1	1198	1092 to 1304
Carpenters and joiners (570)	103	44	42.7	115	90 to 141
Builders, building contractors (504)	38	24	63.2	90	68 to 112
Metal working, production and maintenance fitters (516)	155	35	22.6	88	62 to 113
Motor mechanics, autoengineers (including road patrol engineers) (540)	55	21	38.2	72	48 to 96
Electricians and electrical maintenance fitters (521)	95	21	22.1	51	33 to 70
Plumbers, heating and ventilating engineers, and related trades (532)	42	12	28.6	44	23 to 66
Welding trades (537)	33	15	45.5	43	27 to 59
Farm owners and managers, horticulturists (160)	36	8	22.2	38	15 to 61
Bricklayers, masons (500)	41	13	31.7	33	18 to 47
Gardeners, groundsmen (594)	46	13	28.3	31	17 to 45
Machine tool operatives (including CNC machine tool operatives) (840)	55	7	12.7	17	5 to 28
All other labourers and related workers (990)	53	12	22.6	15	8 to 23
Women:					
All occupations	3878	9	0.2	44	15 to 73

Analysis has been confined to occupations with ⩾30 in the sample.
CNC = computer numerical control.

Table 3 Minimum prevalence of exposure to hand transmitted vibration (A(8) >2.8 ms^{-2} rms) in the past week by industry

Industry (SIC 92)	Sample n	Minimum with A(8) >2.8ms^{-2} n	Minimum with A(8) >2.8ms^{-2} %	Population of Great Britain (in thousands): estimated minimum number with A(8) >2.8ms^{-2} n	95% CI
Men:					
All industries	5490	445	8.1	1145	1043 to 1246
Construction (45)	428	125	29.2	460	392 to 528
Sale, maintenance, and repair of motor vehicles and motorcycles; retail sale of automotive fuel (50)	89	20	22.5	97	60 to 134
Agriculture, hunting, and related service activities (1)	154	33	21.4	71	49 to 92
Manufacture of fabricated metal products, except machinery and equipment (28)	188	21	11.1	53	31 to 74
Retail trade, except of motor vehicles and motorcycles; repair of personal and household goods (52)	329	16	4.9	42	22 to 62
Land transport; transport via pipelines (60)	137	8	5.8	34	11 to 57
Manufacture of basic metals (27)	77	10	13.0	21	9 to 33
Recreational, cultural and sporting activities (92)	94	7	7.4	21	6 to 35
Manufacture of motor vehicles, trailers, and semitrailers (34)	124	10	8.1	17	7 to 27
Electricity, gas, steam and hot water supply (40)	170	17	10.0	16	9 to 24
Manufacture of other transport equipment (35)	64	5	7.8	15	2 to 28
Public administration and defence; compulsory social security (75)	299	5	1.7	15	2 to 28
Women:					
All industries	3878	9	0.2	42	15 to 70

Analysis has been confined to industries with >60 in the sample.
The totals for all industries differ slightly from those for all occupations (table 2) because different scaling factors were applied.

PERSONAL DAILY EXPOSURES TO VIBRATION IN THE PAST WEEK

The HSE has suggested that when exposures exceed the equivalent of 2.8 ms^{-2} for 8 hours (A(8) > 2.8 ms^{-2} root mean squared (rms)), control measures and a programme of health surveillance are likely to be required.[20] Among 704 exposed men from the sample who supplied full information, 185 (3.4% of male respondents) indicated exposures above this suggested action level, including 77 (1.4%) with estimates of A(8) higher than 5 ms^{-2} rms.

Full information on exposure was missing for 1023 of the 1727 men exposed to HTV (either because exposure times or data on representative vibration magnitudes were missing), but in workers who were exposed to several sources, sufficient information was provided to indicate that at least a further 260 men had a minimum A(8) >2.8 ms^{-2}. On this basis, the minimum number of men in the population exceeding this action level was estimated to be 1 198 000 (95%CI 1 092 000 to 1 304 000). Among women, by contrast, these levels of exposure were uncommon (only nine of 3878 employed respondents had a minimum estimated A(8) >2.8 ms^{-2}). Figure 2 presents further details in the form of a cumulative frequency curve showing the estimated numbers in the population exceeding different values of A(8) in the past week. Curves are drawn separately for men and women, and are minimum estimates, in so far as exposure information was sometimes incomplete.

The prevalence of exposure did not differ importantly between subjects who responded at the first invitation and those who required a reminder. In men, for example, 20.4% of early responders reported an exposure compared with 21.0% of late responders; and among men the corresponding frequencies for a minimum estimated A(8) >2.8 ms^{-2} rms in the past week were 6.0% and 7.6%.

Estimates of exposure were similar in the summer and winter. Thus, among men from the first posting, 24% reported an exposure in the past week and 6.2% had a minimum estimated A(8) >2.8 ms^{-2}; whereas the corresponding figures for wintertime respondents were 26% and 7.5% respectively.

Figures 3 and 4 detail, for occupations and industries where exposures were most common, the prevalence and extent of exposures in the past week. Analysis was confined to occupations with >30 respondents and industries with >60 respondents; and minimum prevalences are presented, to the extent that information on exposure was sometimes missing. Estimated exposures >2.8 ms^{-2} were found most often in builders and building contractors (63%), followed by welding trades (46%), carpenters and joiners (43%), and motor mechanics (38%). The industries where A(8) values most often exceeded 2.8 ms^{-2} were construction (29%), motor vehicle repair and maintenance (23%), agriculture (21%), and manufacture of basic metals (13%). The highest exposures (estimated A(8) >5 ms^{-2} rms) occurred most often in the construction crafts (bricklayers and masons (29%), builders and building contractors (24%), carpenters and joiners (15%), and plumbers (9%)); in motor mechanics (16%); welding trades (15%); labourers (15%); gardeners and groundsmen (13%), and farm owners (8%).

These occupations and industries also contributed the largest numbers to national estimates of the minimum frequency of exposures exceeding the HSE threshold for control measures (A(8)>2.8 ms^{-2}, tables 2 and 3), with some 115 000 carpenters and joiners, 90 000 builders and building contractors, 88 000 maintenance fitters, and 72 000 motor mechanics estimated to receive daily exposures above this threshold.

OCCUPATIONAL EXPOSURE TO HTV AND CURRENT EMPLOYMENT

Among men who reported having a paid job in the past week, 913 (16.6%) described themselves as being self employed. Men in this category were more likely to have used hand held powered tools in the past week than all men in work (47.8% *v* 31.5%), and more commonly belonged to one of the occupations with high exposure: thus, 92% of farm owners and managers were self employed, as were 79% of builders and building contractors, 55% of plumbers and heating and ventilating engineers, 40% of carpenters and joiners, 39% of bricklayers and masons, and 28% of gardeners and groundsmen.

Discussion

This survey indicates that in Great Britain over a given week about 20% (4.2 million) of all men of working age and 3% (0.7 million) of all women of working age are exposed to HTV at work. It further suggests, based on self reports of exposure times, that the daily A(8) in 5.8% of men of working age (1.2 million), and 0.2% of women of working age (44 000) exceeds the HSE suggested action level of 2.8 ms^{-2} rms The occupations and industries contributing most to estimates of exposure prevalence nationally have been identified, as well as those in which high reported levels of exposure were most commonly found; and the vibratory tools most often giving rise to exposure have been identified. The data also provide an estimate of the lifetime prevalence of occupational exposures—42% of men and 8% of women from the sample having worked at some stage in a job that entailed exposure to HTV for more than 1 hour a week.

POTENTIAL BIASES AND LIMITATIONS

In assessing the implications of these findings for policy, it is important to take account of several potential sources of bias. These include the representativeness of the sample, the accuracy of the information supplied in response to the questionnaire, the reliability of the a_{hw} values assigned to tool categories, and the validity of extrapolation from the sample to the national population.

Outside the armed forces, nearly everyone in Britain registers with a family doctor, making the age-sex registers of general practices comprehensive and representative enumeration lists. Around a thousand questionnaires from the survey were returned because patients had moved or died before posting, but the factors that influence non-registration and turnover are unlikely to have importantly biased estimates of contemporary occupational exposure to HTV. Representativeness was further assured by the wide geographical base chosen for sampling and by the process of standardisation, in which census information was used to compensate for oversampling or undersampling and differences in response rate between occupations.

The response rate was higher in older subjects, but a comparison of older and younger responders (those over and under 40 years) among commonly exposed occupations did not indicate that age was systematically related to the frequency of exposure. Also, subjects with exposure could have been more highly motivated to participate, a bias that could lead to overestimation of exposures within occupations. This possibility was explored by comparing the prevalence of exposure in people who responded at the first invitation and those who required a reminder, on the assumption that a greater interest in the survey would be reflected in a higher frequency of exposure in the early responder group than the late responder group: in the event, only minor differences were apparent between the two groups.

Information on current exposure to HTV came principally from closed questions concerning a predefined list of sources, but also from answers to an open question about other sources, which were evaluated by a panel of vibration specialists. Errors may have arisen in answers to the closed questions if respondents did not recognise a tool name or confused it with another that they had used; and in the open response section if they described tools in an ambiguous or misleading way. Such errors could lead to an overestimate or underestimate of the frequency of exposure. Another possibility is that recreational activities were sometimes reported as if they were occupational. This risk might be expected to be higher for some tools, such as hand guided mowers, than for others.

To test these concerns the face validity of common exposures was examined by occupation. This was done for users of hammer drills, hand held portable grinders and jig saws (the three commonest sources of exposure), and for users of hand guided mowers, hedge trimmers, and strimmers (three exposures that may arise recreationally as well as occupationally). Exposures in the hammer drills, hand held portable grinders, and jig saws group largely arose from occupations where use was expected or considered plausible, lending support to their reliability. For example, the leading occupations reporting use of the hammer drill came from the construction industry, whereas hand held portable grinders were used most often by metal working and maintenance fitters, and jig saws by carpenters and joiners. However, only 19%–35% of exposures to hand guided mowers, hedge trimmers, and strimmers among men were specifically in gardeners, so a possible bias due to the false reporting of leisure time exposures cannot be discounted in the case of gardening equipment.

An independent test of the accuracy in reporting sources of exposure was conducted by visiting workplaces and comparing reports of exposure with direct observations. The findings, which are reported elsewhere,[21] provide empirical evidence that self reports are generally accurate as to whether exposure does or does not occur, although workers do sometimes confuse the names of vibratory tools or omit to report some sources of exposure.

Quantitative estimates of exposure are subject to several potential sources of error and bias—in assigning a_{hw}, in self assessment of durations of exposure, and in the method of dose calculation. The task of assigning a_{hw} was based on a qualitative appraisal of data that were available from both published and unpublished reports (see appendix). Generally, several sources of information were consulted for each source of exposure, but a different choice could have been made. One value was ascribed to each family of tools, but in practice variations of up to fivefold have been found in some published series,[22] reflecting differences in the model type, eras of design, and source of manufacture; and differences in the task and fitted accessories. Single values represent a convenient simplification. However, to test the appropriateness of the choices made, we separately made field measurements on sources of exposure that were found to be common in this survey, and have reported our findings.[23] In general, the median measured values were close to the values listed in the appendix and chosen for analysis.

In a few cases the lack of dependable data prevented any value being assigned, and missing exposure details required the calculation of minimum rather than absolute A(8) values in many subjects. Personal daily exposure to vibration was calculated according to a widely promulgated method of dose summation, but there is some uncertainty about the best method.[24–26] Reliance was also placed on self estimates of the duration of daily exposures—an approach traditionally assumed to be adequate, but seldom tested. Elsewhere we report a study showing that workers tend systematically to overreport their exposure durations (by around 2.5-fold),[21] but, because of the assumed square root relation between A(8) rms and daily exposure time according to ISO 5349, 1986[19] this would translate into an exaggeration of calculated A(8) of around 60%, and is comparatively small in relation to the variation in magnitude of vibration between apparently similar sources.

It should be emphasised that the various limitations of quantitative assessment of exposure are not particular to this investigation, but general to the field of inquiry. The epidemiological studies that underlie suggested action levels have been based on a similar means of exposure assessment.

The questionnaire collected information during two calendar periods. The responses included people who were employed but absent from work, and encompassed various typical and less representative exposure patterns. Short cycle variations and periods of atypical exposure might be expected to even out in a large sample, and do in any case contribute to the broad dynamic picture of national exposure. But estimates in occupations where seasonal differences in vibratory tool use exist could convey a misleading impression of the extent of annual exposure. In practice however, these effects are likely to be small: few men and women reported that their exposure in the past week was unusual, and a cross comparison of responses within occupations identified only minor differences between summer time and winter time respondents in the proportions reporting exposures.

With occupational (or industrial) populations to derive national estimates of prevalence of exposure, two simplifying assumptions were made—that there was little heterogeneity between industries within an occupation (and vice versa), and that any geographical variation in exposure within occupations and industries was adequately represented in the broad geographical sampling base, or unimportant as a source of error. Given the small numbers of exposed people in the various occupation-industry combinations (no more than 71 in any occupation-industry pair) the validity of these assumptions cannot readily be tested. However, it seems unlikely that the overall estimates of exposure, and particularly those for larger occupational groups, will have been seriously biased as we found the leading occupations with exposure to be similar countrywide in an analysis that divided Britain into six separate regions.

The aggregated estimates of exposure, by virtue of their large sample size, have narrow 95% CIs, but in other cases population estimates were derived from small sample sizes within an occupation or industry. This represents a limit on precision and results in relatively wide 95% CIs for some occupations.

COMPARISON WITH OTHER STUDIES

This study indicates that exposure to HTV is far more common than estimated previously.[12–14] The discrepancy seems to have arisen mainly because sampling in the earlier studies was selective as to industry and source of exposure. No data were collected from at least 28 of the 38 industries in the SIC 92 code groups where we found exposure; within an industry, often only restricted aspects of exposure were assessed—for example, only chain saws in agriculture and forestry—and many of the sources of exposure that we included in our questionnaire were omitted or incompletely surveyed (including floor polishers, nut runners, impact screwdrivers, jig saws, circular saws, hand guided mowers, hand held hedge trimmers, brush saws, barking machines, stump grinders, tampers, scabblers, hammer drills, needle guns, nibbling machines, motorcycle handlebars, and nailing and stapling guns). The emphasis previously seems to have been on sources reported to cause health problems and exposures that were explicitly reportable and compensatable under statutory rules, but other sources are now considered to be potentially hazardous, and many of these now are in the Industrial Injuries Advisory Committee's revised list of compensable exposures.[27] These extra sources may account for an estimated additional 1.5 million users nationally. Finally, differences also arise because we sampled more completely from small businesses and the self employed, where the proportion of exposed workers was higher.

While our survey was underway, an independent estimate of community exposure was reported in the Office of National Statistics omnibus survey.[28] A questionnaire on self reported working conditions was administered to a sample of adults in private British households, selected from a national post code address file. Face to face interviews were conducted in August and October 1995. A

Table 4 Proportion of workers with exposure to hand transmitted vibration: comparison with the survey of self reported working conditions[28]

Occupational groups†	% exposed Current survey	Working conditions survey 1995[28]
All occupations	21	18
Construction	78	76
Metal processing	73	73
Electrical processing	69	57
Farming, fishing, and forestry	63	53
Other processing	44	42
Repetitive assembly, inspection	38	40
Hair and beauty	17	34
Other transport and machinery operatives	30	29
Textile processing	25	27
Security and protective services	22	26
Cleaners	44	25
Material moving and storing	14	23
Science and engineering	10	18
Managerial	14	12
Teaching	10	8
Road transport operatives	10	8
Nursing	3	7
Literary, artistic, and sports	16	5
Catering	6	6
Selling	7	5
Other education and welfare	9	4
Care workers	6	4
Clerical	1	3
Professional and related supporting management	2	2
Other personal services	20	0
Secretarial	<1	0

†As defined in the study of self reported working conditions in 1995, appendix 2.[28]

question on exposure to HTV was posed as part of a much wider survey of economic activity that had no particular focus on use of vibratory tools, blue collar work or work related illness. Exposure was defined as "the use of power tools which transmitted vibration to the hands", but no predefined checklist of sources of exposure was used, as in our survey. None the less a similar estimate of exposure was obtained. Among 2230 employed people, 27% of men (95%CI 24% to 30%) and 7% of women (95%CI 5% to 9%) reported using hand held powered tools in their job. A more detailed comparison between our survey and the self reported working conditions survey shows striking similarities in the respective estimates of exposure frequency by occupation (table 4). Hence, estimates that were collected independently, during different calendar periods, by different methods, and in a different context, show a high degree of agreement. This provides reassurance about the validity of exposure information in this study and suggests that response and sampling biases have not caused important errors in the numbers estimated to be exposed.

IMPLICATIONS

In the United Kingdom, HSE recommends a programme of preventive measures and health surveillance at an A(8) of 2.8ms^{-2} rms[20] (An annexe to British Standard 6842, 1987 predicts that 10% of the workforce might be expected to develop finger blanching over an 8 year period at this threshold[29]). Elsewhere, it is advised, because of the uncertainty about the exposure-response relation, that it would be prudent to conduct health surveillance on all regularly exposed workers.[30] Such exposures are surprisingly prevalent, and preventive measures and health surveillance may be warranted for many men in Britain. There could, however, be major practical difficulties in providing appropriate health surveillance, especially for the self employed and in small businesses. This emphasises the strategic need to provide technical and engineering solutions that limit exposures at source.

The distribution of exposures to HTV is influenced by Britain's industrial base. Hence, in certain occupations and industries we would expect the pattern to differ from other countries (for example, mining is no longer an important national source of exposure, by contrast with some other nations). However, it seems likely, at least in the industrialised countries, that similar patterns of exposure will prevail in common occupations.

UNDER-RESEARCHED TOOLS

Many sources of HTV that are common in Britain have been overlooked in previous surveys of health and exposure to vibration. These may confer health risks, but the evidence on this is limited. At present it rests almost entirely on the measured vibratory characteristics of a selection of these tools. This has led to proposals for some sources to be included in parts 2–17 of ISO 8662 defining vibration type tests (to demonstrate tool safety standards and relations with safety labelling)[31]; and to such sources being included in the Industrial Injuries Advisory Committee's recent list of potentially compensable exposures.[27] By contrast, there is little direct evidence of adverse health effects arising from some of these sources. A search of the EMBASE (Excerpta Medica) database for 1980–98 and Medline (National Library of Medicine, USA) database for 1966–98 failed to identify any articles in which keywords—such as mower, circular saw, jig saw, impact screwdriver, nailing gun, and stapling gun—were used in conjunction with search criteria for Raynaud's phenomenon and VWF; and very few published studies on health risks from these sources or from metal drills and hammer drills could be discovered in the Institute of Sound and Vibration Research's international library of information. Such common sources of exposure seem largely to have been overlooked in health inquiries, but are worthy of formal study, and some exploratory health analyses will be reported separately.

Conclusions

We conclude that occupational exposure to HTV is surprisingly prevalent in Great Britain, and that average self estimated A(8) exposures in a 1 week period exceed the HSE's suggested action level of 2.8 ms^{-2} in >1 000 000 British men. The scale of exposure, including exposures in small businesses and self employed people, suggests that higher priority should be given to technical and engineering controls. The data provide information on the occupations, industries, and sources which should be the priorities for corrective action, and highlight common exposures in Britain that warrant further investigation.

This study was supported by a grant from the Health and Safety Executive. We are grateful to the Royal College of General Practitioners, the Primary Care Rheumatology Society, HM Armed Forces, and the 34 general practices that assisted in assembling the mailing lists; the companies that helped in the piloting and assessment of the questionnaire; and the MRC staff who were involved in data handling. We are particularly indebted to Ian Bowes and Vanessa Cox for their role in the collection and processing of the data. Paul Brereton and Chris Nelson offered many constructive comments during the course of the study. Denise Gould prepared this manuscript.

Appendix: derivation of personal vibration exposure levels

Dominant axis frequency weighted vibration accelerations (a_{hw} values) were assigned to each category of exposure (table 5), and average personal daily vibration exposures (A(8)) for the past week were then estimated by assuming the time dependency in ISO 5349, 1986[19] and summing the partial doses arising from each source. Hence:

$$A_i = a_{hwi}\left[\frac{t_i}{5 \times 480}\right]^{\frac{1}{2}}$$

where:

A_i = the average 8 hour equivalent magnitude for *i*th source of exposure

a_{hwi} = the frequency weighted acceleration for the *i*th source of exposure

t_i = total duration of exposure in minutes over the whole week.

And for several sources used in combination:

$$A_8 = \left[\sum_{i=1}^{i=n} A_i^2\right]^{\frac{1}{2}}$$

where:

n = the number of sources

A(8) = the average 8 hour equivalent magnitude (personal daily vibration dose) for all *n* tools combined

A_i = the average 8 hour equivalent magnitude for *i*th source of exposure.

In selecting suitable a_{hw} values, several sources of information were consulted and a judgement taken on the quality of available data. The sources included:

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2 Nelson CM. Hand transmitted vibration assessment: a comparison of results using single axis and triaxial methods. *United Kingdom Group Meeting on Human Response to Vibration.* Southampton: Institute of Sound and Vibration Research, University of Southampton, 1997.

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4 Griffin MJ. Measurement, evaluation, and assessment of occupational exposures to hand transmitted vibration. *Occup Environ Med* 1997;**54**:73–89.

5 Hewitt SM. Hand transmitted vibration exposure in shipbuilding and ship repair. *International Congress on Noise Control Engineering, Inter-Noise, Liverpool, United Kingdom, 30th July to 2nd August 1996.* Liverpool, UK: ICNCE, 1996:1707–12.

The range of vibration magnitudes can vary greatly according to the conditions of operation, and higher or lower magnitudes will often occur, but the values in table 5 generally accorded with median values we have recently measured and reported.[23] For a few tools it was not considered possible to assign a representative a_{hw}, either because of insufficient information, or because sources within a group were considered sufficiently dissimilar to negate the approach.

Table 5 Representative a_{hw} values assigned to sources of hand transmitted vibration

Source of exposure	*ms^{-2} rms*	*Source of exposure*	*ms^{-2} rms*
Floor polisher	2.0	Needle gun	16.0
Nut runner	6.1	Nibbling machine	8.0
Impact wrench	5.0	Clinching and flanging tool	13.6
Impact screwdriver	4.0	Concrete vibrothickener	3.5
Jig saw	4.2	Nailing or stapling gun	—
Circular saw	1.7	Pedestal grinder	12.0
Chain saw	10.0	Pedestal linisher	4.0
Hand guided mower	4.0	Hand held portable grinder	5.3
Hand held hedge trimmer	4.0	Hand held polisher	3.5
Brush saw	7.0	Hand held sander	6.0
Barking machine	15.0	Shoe pounding up machine	12.0
Stump grinder	6.0	Vibratory roller	—
Concrete breaker (road breaker)	17.0	Metal drill	3.0
Rock drill	32.0	Surgical tool	—
Tamper	12.0	Disc cutter	3.1
Scabbler	29.2	Hair clipper	—
Stone working hammer	10.7	Strimmer	8.0
Rotary hammer swager	16.7	Screwdriver	1.0
Rotary burring tool	4.1	Metal saw	4.9
Engraving pen	5.0	Planer or planing tool	—
Hammer drill	11.0	Jet wash	—
Riveting hammer or dolly	5.5	Router	2.1
Chipping hammer	11.5	Motor cycle handlebars	1.5
Scaling hammer	21.4	Miscellaneous	—
Caulking hammer	7.8	Unclassified	—
Rammer	32.5		

—No value assigned.

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5 Koskimies K, Farkkila M, Pyykko I, *et al*. Carpal tunnel syndrome in vibration disease. *Br J Ind Med* 1990;**47**:411–16.

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