HAND-ARM VIBRATION AND WORKING WOMEN
Consequences and affecting factors

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Om snöret inte håller, utan går av,
är det bara att försöka med ett annat snöre
A.A Milne
RESULTS

Paper I 14
Paper II 15
Paper III 15
Paper IV 16

DISCUSSION 17

Consequences 17
Affecting factors 18
HAV exposure 19
Other occupational factors 20
Biological factors 21
Personal characteristics 22
Double burden 23
Work injury 23
Knowledge 26

Comments on methods 27
Register study 27
Inclusion criteria 27
Self reported symptoms 27
Vibration exposure 28

CONCLUSION 29

FURTHER RESEARCH 30

SVENSK SAMMANFATTNING 32

TACK 35

REFERENCES 37
ABSTRACT

The use of hand-held vibrating tools may lead to hand-arm vibration syndrome (HAVS), a condition with vascular, neurological and musculoskeletal symptoms. Vibrating tools are used in several occupations in which women can be found, e.g. by metal- and wood workers, drivers, and dental personnel. The risk of women developing HAVS is hard to estimate, as little research has been done on women exposed to hand-arm vibration. The overall aim of this thesis has been to fill this gap of knowledge. It is based upon one questionnaire study and one interview study on women who have reported an occupational injury related to hand-arm vibration. The thesis also comprises two laboratory studies of female and male subjects exposed to hand-arm vibration from a handle.

The questionnaire and the interview study showed that the women had a high prevalence of symptoms, such as numbness, weakness, pain and white fingers. Neurological symptoms were more common and developed after shorter time of exposure compared to vascular symptoms. The symptoms had a considerable impact on all domains of the women’s lives, not only on their physical functioning, such as the ability to work, to participate in leisure activities and to do household activities, but also on their relationships and identity. Forty per cent of the women had retired or retrained due to the injury. Dental personnel had the highest relative risk of vibration injuries.

In one of the laboratory studies 12 female and 12 male subjects were exposed to vibration in two vibration directions, (X_h and Z_h) and at two vibration levels. The absorbed power was higher in the Z_h direction and at the higher vibration level. The volumes of the subjects’ arms affected the power absorption in the Z_h direction. There were no indications of a gender difference in the absorption of power.

In the other laboratory study, the effect of handle size, vibration level, anthropometric measures and maximal grip force on the ability to perform a precision task was studied in 20 female and 20 male subjects. Ratings of difficulty and discomfort were made after each test round. The results indicate that the male subjects per-
formed better in all the tests, but no gender difference was seen in the ratings. The higher vibration level resulted in higher ratings of discomfort. In the female subjects, the handle size, the anthropometric measures and maximal grip force affected both the performance and the ratings.

In conclusion, the studies indicate that vibration injuries are severely disabling and influence many parts of the sufferer’s life. Vibration injuries are preventable, and the extensive consequences found underscore the importance of preventive action. This can be done by informing employees about the risks, and by giving them the opportunity to choose suitable machines and to practice work tasks when starting a new job.

*Key words; HAV, vibration, women, injuries, power absorption, handle, gender.*
This thesis is based on the following papers, which will be referred to by the corresponding Roman numerals:


III Bylund SH, Ahlgren, C. Experiences and consequences in women with hand-arm vibration injuries (Submitted).

IV Bylund SH, Burström L. Hand-arm vibration. Handle size and performance (Manuscript).

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INTRODUCTION

Vibration exposure
Vibrating machines are used daily or occasionally in a variety of occupations, e.g. in industrial, agricultural, building, logging and construction work, but also in dental and medical work. The machines involved are for example grinders, drills, chain saws, and nut runners.

Exposure to hand-arm vibration, HAV, may lead to a variety of medical symptoms. The disease is more commonly known as hand-arm vibration syndrome, HAVS. Documentation of the association between exposure to HAV and symptoms in the hands dates from the early 20th century (Hamilton 1918; Loriga 1911). Apart from physical suffering, HAVS affects daily life and causes economic consequences for the sufferer, the employer and insurance systems.

Recent estimations suggest that in Sweden, 14% of the men and 3% of the women are exposed to HAV for more than ¼ of their working time (Statistics Sweden 2001). The amount of women exposed to vibration has increased compared to earlier years. Furthermore, a survey on work-related disorders in 2003 revealed that 0.6% of working men and 0.2% of working women describe disorders related to HAV exposure (Statistics Sweden 2003b). This means that approximately 12,000 men and 4,500 women have symptoms related to HAV exposure. The number of injuries related to HAV reported to the Social Insurance Office is shown in Table 1. The decrease in reports after 1993 might be due to a new definition of occupational injuries.

Table 1. Numbers of reported vibration injuries to the Social Insurance Office during the years 1990-2003.

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<tbody>
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<td>Men</td>
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<td>888</td>
<td>105</td>
<td>124</td>
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<td>3</td>
<td>7</td>
<td>8</td>
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</table>
Human response to HAV depends on the magnitude of the vibration, most often expressed in terms of acceleration in the SI-unit m/s$^2$, and on the frequency (Hz). The exposure time is also of importance for possible consequences. The vibration is also expressed in terms of direction ($X_h$, $Y_h$ and $Z_h$).

The control of adverse health effects from HAV has been approached by the International Standards Organisation, ISO, which has drawn up guidelines for measurements and assessment of the exposure (ISO 2001). The standard setting involves the frequency range 4-2000 Hz with a frequency weighting, in order to separate more damaging frequencies from those considered to be less detrimental. Vibration in the frequency range of about 6-20 Hz is considered to be the most harmful, while the effect progressively decreases with higher frequency (ISO 2001). Vibration in the range above 1000 Hz is considered to affect the body only to a low degree. The total vibration value is established by combining the frequency-weighted acceleration in the three directions as an average over an eight-hour working day.

In the standard (ISO 2001), a risk-prediction is also presented, including daily exposure time and number of years before the onset of vascular symptoms for 10% of an exposed population. No risk prediction has been established for neurological symptoms. However, some studies suggest an exposure-response relationship between exposure to HAV and neurological symptoms (Bovenzi 1998; Futatsuka 1996; Gemne et al. 1995; Jang et al. 2002; Pelmear et al. 1995).

An alternative approach to the assessment of vibration exposure is to measure the vibration power absorbed in the hand and arm. It has been suggested that this assessment gives more information about the risk of injuries compared to the conventional measurements (Burström 1990). The assumption is that the energy dissipated in the hand and the arm is causing the damage. Apart from the vibration level, frequency and direction, the amount of absorbed power is also related to grip force and body posture (Burström 1994).

A new directive from the European Parliament will be implemented in the member states of the EU within the year 2005 (European Parliament and the Council of the European Union 2002). It
proposes a vibration exposure limit value of 5 m/s\(^2\) and an action value of 2.5 m/s\(^2\) as an average over an eight-hour working day. The employers’ obligations include assessing the risks, reducing exposure, informing the workers, and performing health surveillance. Preventive measures are important in order to avoid personal suffering, medical costs, compensation costs and loss of work days.

**Consequences of HAV**

Apart from physical suffering, HAVS affects daily life and causes functional impairments and social consequences for the sufferer.

**Medical consequences**

The different symptoms of HAV may appear separately or combined (Lindsell and Griffin 1999; Pelmeir and Leong 2000; Strömberg et al. 1996). HAVS is to some extent reversible after discontinuation of the exposure. The recovery is dependent on the type and severity of symptoms (Pelmeir and Leong 2000), age (Bovenzi et al. 1998), exposure time (Bovenzi et al. 1998), and smoking habits (Cherniack et al. 2000). The diagnosis of HAVS is based on the history of vibration exposure, subjective symptoms and laboratory tests (Griffin and Bovenzi 2002; Nilsson 2002).

Attacks of finger blanching, also referred to as white fingers or secondary Raynaud’s phenomenon, are the most thoroughly investigated symptoms related to HAV (Palmer et al. 2001). The finger blanching attacks are caused by a spasm in the blood vessels and are triggered by exposure to cold or dampness. Cold intolerance is a vascular symptom that also may appear in persons exposed to HAV (Strömberg et al. 1996).

The neurological symptoms include intermittent tingling, numbness and paraesthesia (Griffin 1990). Neurological symptoms have recently received more attention, as they are more common than vascular symptoms (McGeoch and Gilmour 2000; Palmer et al. 2001; Strömberg et al. 1996). Neurological symptoms also have a shorter latency period than vascular symptoms (Pelmeir and Leong 2000) and recovery, if achieved, takes longer (Futatsuka et al. 1985; Pelmeir and Leong 2000). Neurological symptoms are often the reason why persons exposed to vibration seek medical care, change jobs or quit work altogether (Lundborg 1994).
Exposure to HAV, repetitive hand movements and forceful exertions have been cited as etiological factors for carpal tunnel syndrome, CTS (Viikari-Juntura and Silverstein 1999). CTS is a nerve entrapment neuropathy affecting the median nerve in the hand, where it causes tingling and pain. It is not known which of the mentioned factors is the most important (NIOSH 1997).

Exposure to HAV may also cause a decrease in muscle force (Färkkilä et al. 1986; Necking et al. 2002) and musculoskeletal disorders in wrists, arms and shoulders (Ariëns et al. 2000; Hagberg 2002; Kihlberg and Hagberg 1997; van der Windt et al. 2000). A relationship has been shown between rheumatoid arthritis and exposure to HAV in men (Reckner Olsson et al. 2004), and it was explained by the mechanical effects on the joints.

Symptoms similar to HAVS are also seen in the general population with no vibration exposure, e.g. white fingers and CTS, which both have a higher prevalence in women (Becker et al. 2002; Leppert et al. 1987; Mondelli et al. 2002; Palmer et al. 2000a; Silman et al. 1990).

Work with hand-held vibrating machines with a frequency lower than 150 Hz may exhibit a tonic vibration reflex leading to an involuntary muscle contraction (Radwin et al. 1987). This leads to a harder grip on the machine, which in turn may cause a higher transmission of vibrating power to the hand (Burström 1994) and increase the risk of disorders in upper extremities.

**Functional impairments**

The symptoms in vessels, nerves, muscles and joints can result in weakness, clumsiness, pain and loss of hand coordination (Futatsuka and Oka 2001; Haines et al. 2000; Åkesson et al. 1995). At work, this is manifested as difficulties in performing manual work and handling tools and machines (Lundborg 1994). The symptoms might cause problems for persons in certain occupations requiring high manipulative skills and the ability to perform fine precision movements, such as dentists and electricians. Outdoor work, e.g. on construction sites, might be impossible especially for persons suffering from white fingers (Pelmear and Taylor 1991). Decreased precision and weakness might also involve an accident risk (Lundström 1986). A proper hand function is also needed when
performing household chores and leisure activities. Everyday actions like buttoning and handling small objects cause problems for persons suffering from HAVS (Palmer et al. 2002; Toibana et al. 2002).

**Social consequences**

The medical consequences of HAVS have been thoroughly described, but the social consequences have seldom been studied, with the exception of a study by Haines, which showed that HAVS affects sleep and social life (Haines et al. 2000). Cederlund found a decrease in the quality of life, which included everyday activities, subjective well-being and symptoms of ill health among vibration-injured men (Cederlund et al. 1999). The everyday activities that were most difficult to perform were e.g. being outdoors in cold weather, working with vibrating machines, lifting and carrying objects, writing by hand and picking up small items.

**Gender analysis**

A theory developed by Connell (Connell 1987) was used as the theoretical basis for the gender analysis in this thesis. Gender division is based on two main principles – division of labour and male supremacy. These principles are obvious in most societies.

Sweden has a higher percentage of employed women than most other countries. Women constitute 48% of the paid workforce (European Foundation for the improvement of living and working conditions 2000). Although Sweden is considered to be a country with a strong women’s movement and an egalitarian culture, the labour market is very gender segregated (Gonäs and Spånt 1997). Women and men are unevenly distributed throughout different occupations and women are found in a smaller number of sectors compared to men (Östlin 1996). They are occupied in health care and the social sector, while men work in higher positions and earn more money. This division is one example of male supremacy (Connell 1987). Women are more likely to be assigned to or choose unskilled work and repetitive tasks (Fransson-Hall et al. 1995). They are recruited for job tasks such as assembling, sorting, cleaning and packing. Women and men have different work tasks even if they have the same job title (Messing et al. 1994; Nordander et al. 1999; Stellman 1994). Women also have less opportunity to
develop and to influence their work situation (Wright et al. 1994; Östlin 1996). They remain in the monotony of the assembly lines with an associated risk of occupational injuries, while men advance to more skilled jobs (Messing et al. 1998). Men are the norm against which women are measured (Connell 1987). Work places and equipment are designed for men, since the labour market historically has been a male arena. A woman working at a work station designed for a man will encounter problems, due to the biological differences between women and men in average height and muscle strength (Karlqvist 1997). Preventive action has mainly been taken in male-dominated occupations (Bäckström 1997).

Male supremacy is obvious as regards the legislation on HAV. The exposure limit values are based on research on men, and so is the frequency-weighting curve (ISO 2001), that specifies which frequencies that have a larger risk for injury (Miwa 1968). The risk-prediction is also based on studies on men.

Women exposed to HAV are investigated less often than exposed men (Bylund 1998). Few studies include women, and the risks have hardly ever been compared between women and men. A review on relevant literature on the subject showed that 90% comprised men only, 5% only concerned women, and the remaining 5% comprised both women and men (Bylund 1998). A comparison of risks had been made in half of the studies comprising both women and men. A summary of studies on HAV of recent date is presented in table 2. Studies on women are rare among those presented at the 10th International Conference on Hand-Arm Vibration in 2004 (HAV 10) and among studies published in scientific journals during the year 2004 (Table 2).

Table 2. Number of articles on HAV published in scientific journals during the year 2004 and at the Conference HAV 10 in Las Vegas, Nevada, June 2004.

<table>
<thead>
<tr>
<th></th>
<th>Women</th>
<th>Men</th>
<th>Women + men</th>
<th>Unknown</th>
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<tbody>
<tr>
<td>HAV 10</td>
<td>3</td>
<td>19</td>
<td>4</td>
<td>12</td>
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<tr>
<td>Journals 2004</td>
<td>6</td>
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In some of the few studies that have compared women and men, it has been shown that women have a shorter latency time to the development of symptoms (Urban and Lukás 2000) and a higher
prevalence of symptoms compared to men performing the same work (Dart 1946; Zetterberg and Öfverholm 1999). A study by Dimberg and Odén showed a higher prevalence of white fingers among female employees in an aircraft manufacturing company (Dimberg and Odén 1991), which was explained by their lower weight and height. Female dentists have a higher prevalence of hand and wrist symptoms compared to male dentists (Åkesson et al. 2000). Furthermore, a study by Neely and Burström showed that hand-arm vibration affects women and men differently, in that female subjects rate perceived intensity and discomfort higher than male subjects do (Neely et al. 2001).
The overall purpose of this thesis was to study physical, functional and social consequences of vibration injuries in women, together with factors that might affect the consequences and the risk of injury.

The specific objectives of the studies were:

- to study in which occupations vibration injuries occur (paper I).

- to investigate the latency time and the symptoms of vibration injuries in women (paper I).

- to achieve an understanding of how the everyday life of vibration-injured women is affected (paper III).

- to determine the absorption of vibration in female and male subjects (paper II).

- to study whether the handle size and the vibration level affect the performance of a precision task and ratings of difficulty and discomfort (paper IV).
MATERIAL AND METHODS

The thesis is based on one epidemiological study (paper I), two experimental studies (paper II and IV), and one qualitative study (paper III). A specification of the data collection methods and outcome variables in the different studies is shown in table 3.

Table 3. Data collection methods and outcome variables in papers I-IV.

<table>
<thead>
<tr>
<th>Paper</th>
<th>I</th>
<th>II</th>
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<th>IV</th>
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<tbody>
<tr>
<td>Questionnaire</td>
<td>■</td>
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<tr>
<td>Power absorption</td>
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<td></td>
<td></td>
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<tr>
<td>Anthropometric measures</td>
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<td>■</td>
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<tr>
<td>Maximal hand grip strength</td>
<td>■</td>
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<tr>
<td>Interview</td>
<td></td>
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<tr>
<td>Ratings (discomfort and difficulty)</td>
<td>■</td>
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<tr>
<td>Precision task on handle</td>
<td>■</td>
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<tr>
<td>Ranking of handles</td>
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**Paper I**

The purpose of the study was to gather basic information on women who have reported an occupational injury due to HAV, in particular concerning work-related conditions and consequences of the injury.

**Data collection methods**

**Questionnaire**

A questionnaire developed on the basis of earlier questionnaires on vibration-related diseases (Johansson and Hagberg 1990) was sent to women who had reported an injury related to HAV. The questionnaire consisted of questions on the development of symptoms, work tasks, current work situation, sick leave, vibration exposure and other occurring occupational factors. The questionnaire also included questions on the ability to perform
activities and duties, including not only those related to job tasks, household chores and leisure activities, but also minor actions such as handling small items.

**Vibration exposure**
The accumulated vibration exposure (mh/s²) for each woman was calculated as the product of the self-reported total hours of vibration exposure per day and week, and the vibration level of each machine type used. The accumulated vibration exposure was calculated on 200 working days a year. The information on the average vibration level was retrieved from a database containing measurement data (NIWL 2000).

**Subjects**
All occupational injuries in Sweden, including accidents, diseases and commuting accidents, must be reported to the Social Insurance Office. The reports are forwarded to the Swedish Board of Occupational Safety and Health, where the data is entered into the Swedish Work Injury System, ISA. Economical benefits may be payable by the Social Insurance Office if the disease is approved as an occupational injury. It is also possible to receive compensation from the labour market no-fault liability insurance, administered by AFA. The information on women who had reported a work-related disease and were coded as hand-arm vibration cases was retrieved from the databases at ISA and AFA.
The study was sent to 941 women, of which 342 did not answer or refused to participate in the study. Two-hundred and twenty-five did not consider HAV to be the cause of their injury. The final study population comprised 374 women from the whole of Sweden.

**Statistical methods**
The statistical analyses were performed with SPSS. Prevalence rates were given in percentage. Means were presented with 95% confidence intervals or SD. Student’s t-test was used to compare mean values of continuous variables. The Chi-square test was used to test for differences in categorical variables.
This experimental study was made in order to investigate if there is a gender difference in absorbed power during exposure to vibration at different levels and in different directions. In a laboratory setting, subjects were exposed to vibration from a handle.

**Data collection methods**

**Power absorption**
The assessment involves a measurement of the force and velocity of the vibrating handle. The absorbed power was directly calculated from these parameters and the absorbed power (P) is expressed in terms of transmitted force (F) in N and vibration velocity (v) in m/s; P = F x v (Nm/s or W). The total amount of absorbed power, i.e. vibration absorption per unit of time, was calculated for each 1/3-octave band in the frequency range of 4 to 800 Hz. The exposure was given in two vibration directions, X<sub>h</sub> and Z<sub>h</sub>, in accordance with ISO 5349 (ISO 2001), and at two frequency-weighted acceleration levels, namely 3 and 6 m/s<sup>2</sup>.

**Anthropometric measures**
The volumes of the subjects’ hands, forearms and arms were measured by submerging the hands and arms in a water container and measuring the displacement. The length and width of the hands and arms were measured with callipers.

**Maximal hand grip strength**
The maximal hand grip strength was measured with a hydraulic dynamometer (JAMAR 5030J1).

**Subjects**
Twelve female and twelve male subjects were recruited for this laboratory study. Most of them were students (ages 19-30, mean 23.8). The subjects were chosen in order to obtain uniform volumes and sizes of the hands and arms.

**Statistical methods**
Student’s t-test was used to compare mean values of continuous variables. Correlations between anthropometric values and absorbed power were evaluated by using the Pearson correlation coefficient. Analysis of covariance was used to adjust power absorption for anthropometrical measurements.


**Paper III**

The aim of the qualitative study was to gain an insight into the impact of the injury on the everyday life of vibration-injured women.

**Data collection method**

**Interview**

A qualitative research method has been used in this study, as it is a useful way of capturing a wide range of social effects (Mergler 1999). In-depth interviews were conducted and analysed following the steps laid out in Grounded Theory (Strauss and Corbin 1990). An interview guide was used (Kvale 1997) and the main topic of interest was the consequences of the injury. Another issue of interest was for example the present employment situation. The interviews lasted for 60-100 minutes and were tape recorded and transcribed verbatim. The transcribed interviews were coded line by line, and the codes were then linked to theoretical codes, depending on relationships and similarities in the data. The sampling and analysis were made concurrently. Properties of the categories were defined. The two authors performed the analysis of the data independently and the findings were discussed before being accepted. The findings were also discussed with other researchers with experience in this research field.

**Subjects**

Eight women were purposively sampled from the women in paper I according to the sampling strategy of maximum variation. The women had different symptoms, ages and occupations. They were metal workers, wood workers and dental personnel.

**Paper IV**

The aim of this experimental study was to control if gender, handle size, vibration level, maximum grip force and anthropometric measures have an impact on the performance of a task and on ratings of difficulty and discomfort.
**Data collection methods**

**Precision task**
In a laboratory setting, the subjects were exposed to vibrations in handles (100 Hz, 2.5 and 5 m/s²) with different diameters (30, 38 and 46 mm). They were instructed to hold the handle and follow as closely as possible a straight red target line on a computer screen by adjusting the grip force.

**Ratings of discomfort and difficulty**
Ratings of perceived difficulty and discomfort during exposure to HAV were made by using Borg’s category ratio scale, CR10 (Borg 1998). The ratings were made directly after each task.

**Maximal hand grip**
Hand grip strength was measured with a hydraulic dynamometer (JAMAR 5030J1).

**Anthropometric measures**
The measurement of the length and width of the hands and arms was made with callipers. The subjects’ weight was measured and information on the subjects’ height was collected from the subjects.

**Subjects**
20 female (age 22.4 (SD 1.9) years, range 20-28) and 20 male (age 22.3 (SD 1.1) years, range 20-23) students participated.

**Statistical methods**
The dependent variables were the average divergence from the line and average applied grip force on the handle, together with the ratings on difficulty and discomfort. Student’s t-test was used to compare mean values of continuous variables between female and male subjects. Data was also analyzed using ANOVA for repeated measures with the between-subject factors of sex, grip force, anthropological measures and maximal grip strength, and the within-subject factor of vibration level and handle size. The association between variables was assessed by linear regression.
RESULTS

Paper I

*A descriptive study of women injured by hand-arm vibration*

The women had reported an occupational injury and the prevalence of symptoms was high, as expected. Neurological symptoms were more common than vascular ones. At the time of reporting the injury, 91% suffered from numbness, 80% from pain in the fingers, and 54% from white fingers.

The women had been exposed to an average of 4.000 m/s$^2$ and half of the women were exposed to less than 1.600 m/s$^2$. The vascular symptoms were related to the accumulated vibration exposure.

Carpal tunnel release had been performed on 43% of the women. CTS was not related to the accumulated vibration exposure, but to body mass index. Smokers had a higher prevalence of most symptoms compared to non-smokers. Neurological symptoms developed after an average of seven years of exposure and vascular symptoms developed after nine years.

The women reported difficulties in performing various household chores, leisure activities and everyday tasks e.g. carrying grocery bags (83%), doing needlework (80%), and handling small objects (70%). Sleep interference was reported by two-thirds of the women and affected family relationships were reported by a third of the women.

At the time of the injury, the women were occupied as metal workers, dental personnel, wood product assemblers, drivers, and agricultural workers. The occupational group with the highest relative risk of vibration injuries was dental technicians.

Fifty per cent of the women had retrained or retired. Two-thirds of the women, mainly unskilled workers, had stopped using vibrating machines.
**Paper II**

*Power absorption in women and men exposed to hand-arm vibration*

Exposure to higher vibration levels resulted in a higher amount of absorbed power. The absorption was higher in the $Z_h$ direction than in $X_h$.

Male subjects had a significantly higher amount of absorbed power during exposure to 6 m/s$^2$ in $Z_h$ direction than had women. After adjustment for anthropometric measures, the male subjects still had a higher absorption, but it was not significant.

The correlation between arm volume and absorption of power was significant in the $Z_h$ direction (3 m/s$^2$).

Female and male subjects had different patterns concerning the correlation between the absorption of vibration and anthropometric measures.

The subjects’ grip force was not correlated to the absorbed power.

**Paper III**

*Experiences and consequences in women with hand-arm vibration injuries*

The in-depth interview study showed that the vibration injuries had affected all areas of the women’s everyday lives. Numbness, pain and reduced hand function caused difficulties in performing activities at work, household duties and leisure activities. The consequences were described as a loss at all levels - physical function, sensation, body image, independence, social life, and self-esteem.

The women described shortcomings in connection with household duties e.g. hanging up laundry, carrying grocery bags and cleaning. Everyday tasks like writing with a pen and carrying a child also caused problems. Outdoor activities like bicycling, driving a car and gardening increased the symptoms.

The women had given up most of their leisure activities in order to manage their jobs.
The women put the blame of the injury on their own deficiencies, and defended their employers. In contrast, they described negative encounters with medical professionals and insurance officials.

**Paper IV**

*Hand-arm vibration. Handle size and performance*

Male subjects achieved better results in all experiments with the vibrating handles. The performance did not differ much between the different handles and vibration levels.

No gender difference was shown in the ratings of difficulty and discomfort. The handle size affected the ratings of difficulty. Anthropometric measures and maximum grip strength had more influence on the female subjects’ results and ratings than on those of the male subjects.

Eight female and five male subjects did not realize that the vibration was presented from handles of different sizes.
DISCUSSION

Consequences

The consequences of vibration injuries were investigated in paper I and III. Apart from medical symptoms, various problems related to work, home maintenance and leisure time were reported.

Paper I showed that a high proportion of the women suffered from medical consequences, for example numbness, muscle weakness, pain and carpal tunnel syndrome, when they reported the injury. The women reported a major impact on their ability to perform household chores and leisure activities. Seventy per cent of the women reported problems handling small items, which is often mentioned by vibration-injured persons (Futatsuka and Oka 2001). Disrupted sleep and affected family relationships were also reported.

The vibration injuries had a considerable effect on the women’s work situation. From the total of 374 women, 1/5 had retired and as many had retrained due to the injury. Sixty per cent of the women had stopped working with vibrating tools, mainly those in blue-collar work. Among the eight women in the interview study (paper III), three had severe injuries and were no longer able to work. The interviewed women mentioned activities that they no longer were able to perform at work, but described even more activities related to household chores. This is in line with a study on work-related upper extremity cumulative trauma, which showed that the home life is more affected than the work life (Keogh et al. 2000).

The women had handed over most household activities to other family members, but they still had the main responsibility for planning and coordination. Due to this they experienced a loss of independence. The women expressed a bad conscience and a loss of their value as women and mothers due to this realignment of traditional family structures and home-related chores. They also expressed concern for their husbands’ double burden, e.g. responsibilities for home making in addition to paid employment. The women struggled to continue working and to keep up the feature of being a good mother and wife. Family is one of the
institutions that are relevant in the organisation of gender (Connell 1987) and home maintenance is one way of creating conventional femininity.

The consequences were expressed as a loss on all levels, which has been described earlier in association with chronic illness (Kelley 1998). Changes in the women’s life-style and restrictions in their social activities were described. Particularly those who no longer were in work expressed a loss of self-esteem and value. The decreased function or loss of function affected the women’s perception of themselves. The extensive consequences of occupational injuries have earlier been described and the literature review by Dembe depicts impacts on relationships as well as vocational function and general well-being (Dembe 2001).

The women had given up most leisure activities in order to be able to stay in work, which emphasizes that work plays a central role in their lives together with family-related issues. This is in line with a study by Christiansen, which showed that occupation is a central means through which people express their identities (Christiansen 1999).

Most of the mentioned consequences were related to the hands, and a proper hand function is a prerequisite for managing in most occupations. A study on assembly workers (Fransson-Hall et al. 1996) showed that the hand was held in a grip during 88% of the total working time. The women also expressed grief over the deteriorated appearance of the hands due to surgical scars and swelling. This underlines that a damaged appearance and a change in body image might affect the identity (Christiansen 1999), since the body is considered to be “the women’s most important capital” according to the ideas of Simone de Beauvoir (de Beauvoir 1949).

The women expressed negative experiences with the workers compensation system and medical care providers, which is reported in several other studies (Henriksson 1995; Reid et al. 1991).

**Affecting factors**

Different factors affect the risk of being injured and the consequences of the injury. Some of them are presented in the papers, but other factors that also have an impact are not studied, e.g. stress and the climate.
HAV exposure
The risk of developing HAVS is related to the magnitude, frequency and total duration of the vibration. The exposure-response relationship on vascular symptoms in the ISO 5349 (ISO 2001) is based on old studies on heavily exposed men (Bovenzi 1998). Paper I showed a high prevalence of symptoms among women, even though they had been exposed to a relatively low vibration. Half of the women had been exposed to an accumulated vibration of less than 1600 m/s². One reason for this might be that a third of the women in the study population were dental or medical personnel. They are exposed to high-frequency vibrations, (Rytkönen and Sorainen 2001; Åkesson et al. 1995), and the frequency-weighting (ISO 2001) discounts force contribution above 1500 Hz. Earlier studies have shown that the vibration level in dental equipment is clearly below the limit values (Rytkönen and Sorainen 2001). This might imply a low accumulated vibration exposure. However, there is an ongoing discussion whether frequency weighting underestimates the risk of HAVS in tools that vibrate at frequencies above 1500 Hz (Bovenzi 1998; Griffin 1997). The National Institute for Occupational Safety and Health, NIOSH, has concluded that frequency-unweighted measurement through 5,000 Hz is the appropriate means of assessing the health risk (NIOSH 1989). The frequency-weighting curve (ISO 2001) that specifies which frequencies carry a larger risk of injury is derived from subjective assessments of vibration comfort made by men (Miwa 1968). The pattern of power absorption differs between female and male subjects (paper II), which might indicate that the current frequency-weighting curve is not appropriate for women exposed to vibration. In addition, the power absorption differed significantly between the different vibration directions, which also provides a reason to discuss the relevance of the frequency-weighting curve.

Only the vascular symptoms were correlated to the exposure, and there is reason to believe that the symptoms are also related to other workplace factors (paper I).

Paper II showed that female subjects did not have a higher absorption of power. Women’s higher prevalence of HAVS and shorter latency time shown in some studies are probably not due to a difference in vibration absorption.
Other occupational factors

The women were exposed to several risk factors in their work (paper I and III). Apart from exposure to HAV, they were also exposed to repetitive hand motions, awkward positions, and heavy lifts. The women who were metal and wood workers used power grips and worked with large and heavy tools. It has earlier been demonstrated that male-oriented tool design and work settings cause injuries in women (Dutta et al. 1994; Morse and Hinds 1993).

Women in male-dominated occupations have more work-related disorders and sick leave compared to women in occupations dominated by women (Hensing and Alexanderson 2004) and to men in the same occupation (Alexanderson et al. 1994; de Zwart et al. 2001; Fransson-Hall et al. 1995; Islam et al. 2001). The higher prevalence of musculoskeletal disorders in the upper body among women is explained by their greater exposure to poor working conditions and repetitive work tasks (Nordander et al. 1999; Strazdins and Bammer 2004). Some researchers state that the prevalence of musculoskeletal disorders is equal in women and men under equal working conditions (McDiarmid et al. 2000).

The gendered division in paid work (Connell 1987) is shown in that women are given more repetitive work tasks and are exposed to poorer working conditions than men are. Adjustments out of concern for the women’s health were made for those in industrial jobs (paper III). They were assigned less heavy but repetitive work tasks, which were considered to be more suitable for women. By accepting these adjustments, the women themselves contributed to work segregation.

The effect of different handle sizes was investigated in paper IV. The performance did not differ much between the different handles. The subjects made every possible effort to achieve good results and several subjects did not even notice that the handles were of different sizes. Handle size, anthropometric measures and maximum grip strength had more influence on the female subjects’ results and ratings than on those of the male subjects. One conclusion is that everyone starting a new job should be given sufficient time to practice the work tasks, to obtain tools of the right size, and select the proper work surface level. Psychophysical ratings might be a way to attain better insight into the workers’ situation (Wos et al. 1988), e.g. when choosing between different machines or tools. Applying anthropometric data and taking into
account a wider range of physical characteristics will benefit both women and men in the workplace. The responsibility for a proper work environment lies with the employer, but occupational health personnel have a thorough knowledge of these issues and could be engaged in this work. New employees in general, and probably women in male-dominated areas in particular, might hesitate to ask for special arrangements to be made, such as being provided with smaller tools. Tool manufacturers state that it is often feasible to redesign tools to suit smaller hands, but it is impractical to provide different sizes of tools where work rotation is applied (personal communication Lars Skogsberg, Atlas Copco).

Other mentioned explanations to the women’s higher prevalence of work-related disorders are less stimulation, fewer development opportunities, and less influence (Roxburgh 1996; Wright et al. 1994). The dental personnel (paper III) reported more opportunities to influence their situation and make demands upon work situation than women in blue-collar work. It is known that white-collar workers have more influence on their working conditions (Östlin 1996). The subordination of women (Connell 1987) in the gender system is also evident in that the employers more often make arrangements for men who encounter problems in the workplace (Niedhammer et al. 2000).

**Biological factors**

Women’s gendered attitudes were made apparent when the women mentioned shortcomings in themselves as causes of the injury, e.g. body size, insufficient strength, “bad genes inherited from their mothers” and even pregnancy (paper III), even though they had reported the disorder as work-related. This was also shown in a study on women’s rehabilitation (Ahlgren and Hammarström 2000).

Biological differences, e.g. body size and physical capacity, have been mentioned as explanations for the higher risk of injuries in women (Kelsh and Sahl 1996). The risk differences are also explained by the workplace design in interaction with women’s physical characteristics, which make them more vulnerable (Headapohl 1993). The average woman is at a disadvantage compared to men in terms of strength and endurance. The differences in anthropometry, e.g. the smaller hands, constitute a risk factor for women entering non-traditional jobs, where they handle tools and machines designed for the male body. Papers II
and IV showed that women have a lower maximum grip force and smaller hands than men. This is in agreement with other studies that have shown that the average woman has 2/3 of the muscle strength of the average man (Harkonen et al. 1993; Headapohl 1993; Miller et al. 1993). Women’s lower handgrip strength means that they are forced to use a higher proportion of their maximal grip force when they use the same tools as men. Women also report a lower pain pressure threshold in the hands than men do, which might suggest that symptoms are noticed earlier than in men (Fransson-Hall and Kilbom 1993). This may explain why the latency time, i.e. the time from the initial vibration exposure to the onset of symptoms, was shorter for the women (paper I) compared to studies on men (McGeoch and Gilmour 2000; Necking et al. 2002; Urban and Lukás 2000).

Paper III showed that shorter persons had a tendency for higher energy absorption. Short women’s higher prevalence of symptoms is also described by Fransson-Hall (Fransson-Hall et al. 1995) and Wild (Wild et al. 1987).

**Personal characteristics**

Predisposing diseases are other factors of importance for developing a vibration injury. Forty-three per cent of the women had undergone carpal tunnel surgery (paper I). It is not known whether the CTS was related to work or to hormones or diseases. The higher prevalence of CTS and white fingers, which contraindicates vibration exposure, is higher among women in general (Becker et al. 2002; Tanaka et al. 1997).

Twenty-nine per cent of the women were smokers (paper I). Smokers had a higher prevalence of all symptoms. Some studies show that smokers more often suffer from vascular and neurological symptoms in the hands (Cherniack et al. 2000; Letz et al. 1992; Nathan et al. 1996; Tanaka et al. 1997; Zetterberg and Öfverholm 1999), while others show no association between symptoms and smoking (Leppert et al. 1987; McGeoch and Gilmour 2000).

The women described themselves as hard-working with a high level of working morale (paper III), which might have affected the risk of injury.
Double burden
Women’s higher prevalence of work-related disorders has also been explained by their double burden, i.e. their responsibilities for home making in addition to paid employment (Dahlberg et al. 2004). Although women today constitute half of the working population in Sweden, they still have the main responsibility for childcare and housekeeping (Werner et al. 2003). The women’s opportunities to recover physically after a working day are reduced by this division of domestic tasks (Strazdins and Bammer 2004). The women in paper III stated that help from other family members was crucial for their ability to stay in work. The women’s families had taken over most household activities, but the women still had the main responsibility for planning and coordination. This is in line with other studies showing that social support is regarded to be important for the ability to work (Dyck and Jongbloed 2000) and for the rehabilitation process (Östlund et al. 2001).

Family concerns were also mentioned in other contexts, for example when an opportunity to participate in a rehabilitation program or to retrain was given up if the family became affected. This has also been shown in studies on women’s rehabilitation (Ahlgren and Hammarström 2000) and women with chronic pain (Werner et al. 2003). These attitudes could be regarded as effects of a socially dominant image - “a real woman” should run her home - and the women strive to adjust to that.

Work injury
The women in papers I and III have reported the injury to the Social Insurance Office or AFA, but it is known that only a small proportion of all work-related disorders are reported (Statistics Sweden 2003a). A survey on work diseases showed that 3 % of the Swedish women (approximately 4,500) had symptoms from vibration exposure (Statistics Sweden 2003b) but only eight women reported an injury to the Social Insurance Office in 2003 (Statistics Sweden 2004). It is not plausible that only eight women suffer from symptoms serious enough to report. There are several possible explanations for these low numbers. The tendency to report occupational injuries is affected by the compensation regulation. It is also related to factors such as the type of injury, unionisation rates and activity (Morse et al. 2000). There is less available knowledge on women’s occupational health (Stellman 1999), which results in the
fact that women are not encouraged to report their injuries (Morse et al. 2000).

The reporting of the injury is also dependent on the economical benefits. Apart from economical reasons, it is also of importance to report occupational diseases in order to obtain official statistics. The statistics from ISA and AFA are used in policy making, when allocating resources for preventive actions and to identify risk groups in the work environment. The inconsiderable number of reported vibration injuries among women does not give the correct information, and consequently does not identify vibration as a risk factor for women. Paper I and III clearly show that vibration injuries seriously affect the women. It seems more appropriate that the mentioned survey on work diseases (Statistics Sweden 2003b) should be used for the above-mentioned purposes rather than the number of reported occupational injuries.

Insufficient knowledge about the obligation to report might also be an explanation for the low number of reported vibration injuries. The opinion of medical professionals is important. If they state that the disease might be related to work, the tendency to report is higher and the sufferer has a higher possibility of receiving workers’ compensation (Morse et al. 2000).

Thirty-two per cent of the women in paper I had been encouraged by union representatives to report the injury and 25% of the women were assisted by occupational health personnel (Bylund 2000). Only 8% stated that the employer had encouraged them to report the injury. Occupational health personnel have a good knowledge of the risks that can occur in the workplace (Vingård and Hagberg 2001). The reduction of the occupational health service in the 1990s was unfortunate in this respect. The primary health care also plays a vital role in identifying cases of occupational disease and general practitioners should be given sufficient knowledge about these issues.

The low number of reported vibration-injuries among women might also be related to the diagnosis. An early and correct diagnosis may prevent the progression of the injury (Dahlin and Lundborg 2001). Permanent changes may occur if the exposure is not decreased. A missed or an incorrect diagnosis might result in incorrect treatment. HAVS is often misdiagnosed as CTS (Miller et al. 1994). CTS can be cured by surgery, but carpal tunnel release is not always
successful in vibration-injured persons, and might lead to a loss of grip strength (Boström et al. 1994; Hagberg et al. 1991; Strömberg et al. 1999). Forty-three per cent of the women had undergone surgery (paper I), but CTS was not correlated with the accumulated vibration exposure.

Male supremacy (Connell 1987) is obvious in that disease manifestations have been identified through studies on men. This might have led to a miscategorisation and an underreporting of women’s work-related health. There is reason to believe that work-related CTS among women has been miscategorised and instead been related to their hormonal status. The women had experienced that health professionals had attributed their symptoms to hormonal and “female issues” and not to the work environment, while the women themselves considered the symptoms to be work-related (paper III). Clinical examinations of both female and male patients, who are suffering from e.g. neuropathy in the hands, should include questions on their work history and current situation concerning vibration exposure, as well as other occupational issues. Neuropathy in women should not directly be associated with hormonal factors. The doctors should be as detailed in asking for the work history when they examine women as they are when examining men, but there might be reason to pose different questions to women than to men.

Paper III showed that receiving a diagnosis of their invisible disease was important in order to avoid disbelief from others and to avoid being regarded as a fraud. A correct diagnosis is also the most important basis for the assessment of an occupational injury. Male supremacy (Connell 1987) is visible in that women’s work-related diseases are less often approved as occupational diseases (Lippel 2003). The reason for this is claimed to be that women have more musculoskeletal disorders, while men report accidents, which are easier to prove. However, this is not correct concerning the situation in Sweden, where the Swedish Social Insurance Office accepted 16% of women’s and 31% of men’s work related musculoskeletal diseases (1997-1999) (Swedish Work Environment Authority 2000).
Knowledge
A prerequisite for preventing, curing and reporting occupational diseases is sufficient prevailing knowledge. Research and knowledge on the risks of vibration exposure in women are sparse. One explanation for this poor interest is that men more often work in occupations where exposure to vibrations is present, but it must be acknowledged that women constitute a significant proportion of vibration-exposed persons. When searching for relevant scientific literature on injuries related to HAV in women, it was hard to draw conclusions about women’s risks, since the sex of the participants in the studies was not always specified. This has also been shown in literature studies on articles on occupational health (Ekervall et al. 1993; Niedhammer et al. 2000). It may be assumed that unspecified persons, subjects or patients are men. Women have also been deliberately excluded from studies on HAV (Pelme and Kusiak 1994).

The fact that women are investigated less is true not only in HAV research, but also in research on work-related health, which has mostly been performed on men (Niedhammer et al. 2000). Men’s work has been considered to be more dangerous and risky. Women’s work has been regarded as safe and the risks have been underestimated (Messing et al. 2003; Niedhammer et al. 2000). The research methods used in occupational health are developed for studying men’s working conditions and symptoms. These measures do not always suit women, whose working conditions and life situations are different. Studies including specific analyses of women tend to use weaker epidemiological methodologies (Niedhammer et al. 2000; Zahm et al. 1994).

The fact that women constitute half of the working force has not been recognised in society. Research, working conditions, medical treatment, to mention a few examples, are still based on the presupposition that the labour market is a male arena (Messing et al. 2003). This thesis suggests that gender-related issues influence women who use vibrating machines, concerning e.g. the risk of injury, work place design, diagnoses, and legislation.
Comments on methods

Register study
As already mentioned, the true incidence of vibration injuries in Sweden is unclear. Register data is still the best available source of information, despite the fact that it does not give the whole picture.

It is not indicated whether the women’s injuries have been approved as vibration injuries or occupational injuries at all. The injury was simply labelled as a hand-arm vibration case by the official who entered the data into the database.

Inclusion criteria
A high proportion of those who in some way answered the questionnaire did not consider HAV to be the cause of the injury (paper I). A third of those who in any way responded to the questionnaire stated in phone calls or letters that HAV was not the cause of the injury. The reason might be related to a lack of knowledge about the risks. The title of the questionnaire was “A study on vibration injuries in women” and the women might have considered e.g. ergonomic factors to be the cause of the symptoms rather than vibration injuries. An incorrect classification of the reported injury in the databases might also be a reason why so many women stated themselves that HAV was not the reason for their injury.

The study population in paper II can be discussed. The subjects were chosen in order to have uniform anthropometric measures. Even though we recruited female subjects who were taller and heavier than the male subjects, the male subjects still had larger volumes of the hands and arms. The energy absorption was consequently adjusted for differences in anthropometric measures in the analysis.

Self reported symptoms
No medical examinations were made on the women in paper I. The information on the symptoms was based on self-reports. Some questions concerned symptoms at the time when the injury was reported, which in certain cases took place several years earlier. This may have resulted in a recall bias. However, the reliability of self-reported information on symptoms in persons exposed to vibration is reported to be adequate (Ekenvall et al. 1989; Flodmark and Lundborg 1997).
The symptoms reported are not specific to HAVS, with the exception of white fingers. Work-related musculoskeletal disorders and HAVS have similar manifestations and cause similar symptoms. Consequently, the reported symptoms are not necessarily a result of vibration exposure alone.

**Vibration exposure**
The exposure was self-assessed, which may introduce a bias in the calculation of the accumulated vibration exposure. In self-assessment of earlier exposure, a recall bias may also present a problem. Self-reported vibration exposure is often over-estimated (Åkesson et al. 2001), which might lead to an under-estimation of the risk. Palmer and his co-workers compared self-assessed exposure with simultaneous observations and found that the workers over-estimated the exposure to HAV by on average 2.5 times (Palmer et al. 2000b).

The accumulated vibration exposure was roughly calculated on the average vibration level of the machine in question. Vibration levels differ from machine to machine depending on age and condition.
CONCLUSION

- The risk of vibration injuries in women is present in many occupations. Dental personnel is at the highest risk in relation to the number of people in each occupational group.

- The women who reported a vibration injury suffered from numbness, pain, muscular weakness and white fingers. Neurological symptoms were more common and developed after a shorter period of exposure compared to vascular symptoms.

- The vibration injuries caused extensive effects on the women’s everyday life, at work, at home and during leisure time.

- No difference was found between female and male subjects concerning the power absorption during vibration exposure.

- In the female subjects the handle size, anthropometric measures and maximum grip strength influenced the performance of the precision task and also the ratings of difficulty and discomfort.
A number of new research areas have been identified in this thesis. The research methods used in occupational health are developed for studying men’s working conditions and symptoms. There is a need for more varied methodological approaches. Qualitative approaches are to date seldom used in the field of occupational health and never used in research on vibrations issues. Quantitative and qualitative research methods are recommended to be used together as they complement each other in defining research questions and interventions (Mergler 1999).

There is a general need for research data on women. Knowledge on women’s conditions should be obtained by studying women. It is misleading to extrapolate from research results on men. In order to identify risk factors for both women and men, the effects of gender must be considered in research questions. Separate analyses must be performed and the patterns for men and women should be compared. When subjects are exposed to vibration in laboratory studies, they should include both women and men. Journal editors should require authors to state the sex of their study populations.

A better understanding of the factors involved in the under-reporting of occupational injuries is important for the estimation of the magnitude of the diseases. Studies are also needed to examine the disparities between women and men with respect to claim processing and vocational, functional and domestic impacts.

More studies are needed on the social consequences of vibration injuries. A qualitative study should be performed in order to investigate the consequences of HAV injuries in men. There is reason to believe that men would describe other consequences than those mentioned by the women in paper III.

Research is needed to find the most effective pedagogical method of spreading the information on risks and risk prevention to employers, and also to evaluate the outcome of these efforts. This is utterly important at present, since a new directive is currently being implemented.
Epidemiological studies should be performed on dental personnel, who are exposed not only to high-frequency vibration but also to awkward positions and repetitive hand movements. The prevalence of different symptoms and injuries should be studied in order to establish whether a new frequency-weighting approach is needed and whether the same patterns are found in women and men.
Exponering för hand-arm vibrationer, HAV, förekommer i många yrken, t.ex. hos metall- och träarbetare, byggnadsarbetare, elektriker, tandvårdspersonal och fotvårdsspecialister. De som hanterar vibrerande maskiner riskerar att drabbas av påverkan på kärl, nerver, muskler och leder i händer och armar.

De flesta som exponeras för HAV är män, men under de senaste decennierna har antalet exponerade kvinnor ökat och utgör en ansenlig andel i vissa yrkesgrupper. Forskning kring vibrationsskador hos kvinnor har gjorts i begränsad omfattning, men några studier antyder att kvinnor i större omfattning drabbas av vibrationsskador och utvecklar skada efter kortare exponeringstid. Avhandlingen syftar till att öka kunskapen om konsekvenserna av HAV för kvinnor samt de faktorer som har betydelse för konsekvenser och risker.

Delstudie I var en enkätstudie som riktade sig till kvinnor som anmält arbetsskada relaterad till HAV. Studiepopulationen omfattade 374 kvinnor som anmält skada under åren 1988-1997. Den yrkesgrupp som har största risken att drabbas av vibrationsskada relaterat till antalet verksamma i yrket var tandtekniker. Den totala vibrationsexponeringen var för de flesta av kvinnorna låg, men många besvärades av domningar och värk i armar och händer, svaghet samt vita fingrar. Kvinnornas besvär debuterade efter i genomsnitt 7 års exponering. Rökare hade mer symptom än icke-rökare. Många av kvinnorna hade fått försämrad förmåga att utföra vardagliga sysslor och fritidssysselsättning. Två tredjedelar av kvinnorna angav att de hade sömnproblem, och en tredjedel angav att skadan hade påverkat deras förhållande till familjen. Två tredjedelar av kvinnorna hade slutat att arbeta med vibrerande maskiner, och 40% hade pensionerats eller omskolat sig.

Syftet med studie II var att undersöka om det finns könsskillnader vad gäller upptaget av vibrationsenergi. Studien gjordes på 12 kvinnliga och 12 manliga försökspersoner som exponerades för vibrationer i ett handtag vid två nivåer och i två riktningar, $X_n$, och
SVENSK SAMMANFATTNING

Z_h. Den högre vibrationsnivån samt vibrationer i Z_h-riktningen orsakade högre energiupptag. Inga könsskillnader fanns, när justering gjorts för kroppsmätt. Studien antyder att en eventuell högre förekomst av vibrationsskador hos kvinnor inte beror på skillnader i upptag av vibrationer.


observerade inte förhållandena. Studien understryker betydelsen av att informera om riskerna med att använda maskiner och verktyg med felaktig eller opassande utformning. Det är också önskvärt att de som använder vibrerande maskiner ges möjlighet att välja bland olika storlekar eller utformning på maskinerna.
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