Health and safety management of hand-arm vibration

preconditions and outcomes

Fisk, Karin

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Abstract

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Exposure to hand-arm vibration from hand-held power tools can result in the development of vibration injuries over time. Being afflicted by these types of injuries may have far-reaching consequences for the individual, for industries and for society. Many are affected by these disorders and among Swedish men, vibration injury is the most common compensated work injury. The obligations and rights of employers and employees concerning exposure to vibration are legally regulated. However, deficiencies have been seen in employers' compliance with the vibration regulations. Several aspects and actors interact around this issue. Hence, a holistic and exploratory view is needed to determine the contributing aspects and actors that influence the preconditions for proactive health and safety management in order to reduce vibration exposure and injuries.

The conclusions of the two studies were that companies could improve their knowledge concerning vibration, their awareness of the risks involved, their communication between employees, and between employees and management. Leadership has an important role in ensuring that information is provided on how to avoid harmful exposures. The understanding and acceptance of new tools are central, and tool manufacturers have a central role in ensuring that a range of low-vibration tools is available. Change processes must be well-designed where employees are involved and participate in the change in working practices. Only then can acceptance be created for the impact of new tools on working methods and craftsmanship, and the implementation can result in changes in a workplace culture where low-vibration tools are considered a natural part of the job. The research highlights the importance of improving the proactive health and safety management regarding vibration, and of raising awareness about vibration exposure and injuries in companies.

Key words

vibration exposure, risk perception, holistic approach

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Sammanfattning

Det övergripande syftet med denna forskning har varit att få ökad kunskap och förståelse för de aspekter och aktörer som bidrar till bra förutsättningar och resultat för det förebyggande arbetsmiljöarbetet avseende vibrationsexponering. De främsta målen var 1) att undersöka snickares uppfattningar om det förebyggande arbetsmiljöarbetet på sina arbetsplatser, samt 2) att explorativt undersöka de aspekter och aktörer som kan påverka genomförandet av planerade förändringsprocesser i fyra branscher avseende lågvibrerande handhållna maskiner. Detta gjordes med hjälp av observationer i fält, genom ett frågeformulär och genom explorativa semi-strukturerade intervjuer.

Exponering för hand-arm vibrationer från handhållna maskiner kan leda till att vibrationsskador uppstår. Att drabbas av vibrationsskador kan få långtgående konsekvenser både för individen, men även inom branscher och för samhället i stort. Många drabbas av dessa skador - vibrationsskada är den vanligaste godkända arbetsskadan bland svenska män. Arbetsgivares och anställdas skyldigheter och rättigheter när det gäller exponering för vibrationer är lagstadgade. Brister i arbetsgivarnas efterlevnad av vibrationsföreskrifterna har dock setts. Flera aspekter och aktörer samverkar kring denna fråga och därför behövs ett holistiskt och explorativt synsätt för att definiera vilka bidragande aspekter och aktörer som påverkar förutsättningarna för ett förebyggande arbetsmiljöarbete för att minska vibrationsexponering och skador.

Slutsatser från studierna var att kunskap om vibrationer, medvetenhet om riskerna med vibrationer samt kommunikationen mellan anställda och mellan anställda och ledning kan förbättras i företagen. Ledarskapet har en viktig roll för att säkerställa att information ges om hur man undviker skadlig exponering. En förståelse och acceptans för nya maskiner är viktigt, och maskintillverkare har en central roll i att säkerställa att lågvibrerande maskiner finns att tillgå. Förändringsprocesser bör vara väl utformade, där medarbetarna är delaktiga och deltar i förändringen av hur arbetet utförs. Först då kan acceptans skapas för nya maskiners inverkan på arbetssätt och hantverk och implementeringen kan resultera i en förändrad arbetsplatskultur där lågvibrerande maskiner anses vara en naturlig del av arbetet. Denna forskning belyser vikten av att förbättra det förebyggande arbetsmiljöarbetet avseende vibrationer, och att öka medvetenheten om vibrationsexponering och skador hos företagen.

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List of appended papers

This thesis is based on the following publications, referred to by their Roman numerals:

I: **Hand-arm vibration: Swedish Carpenters' Perceptions of Health and Safety Management**
Fisk K., Nordander C., Ek Å.
Occupational Medicine, 2023;73(2):85-90

II: **Aspects Affecting the Health and Safety Management and the Implementation of Measures to Reduce Vibration Exposure in Industry**
Fisk K., Ek Å.
Submitted to an international scientific journal, 2023

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Contents

Introduction

This section introduces the background to the research presented in the licentiate thesis. The aim and objectives of the research are also presented, followed by the theoretical framework.

Background

Exposure to hand-arm vibration from hand-held power tools can lead to the development of neurological, vascular, and musculoskeletal disorders. Typical symptoms of the hand-arm vibration syndrome (HAVS) are numbness and tingling in the hands, and an increased cold sensibility. This can result in impaired hand function, dexterity, sensation, and strength. Some people also experience finger blanching or white fingers [1]. Suffering from a vibration injury can have far-reaching consequences for the individual. It may affect the ability to carry out one's work and consequently have other life-changing effects, such as being forced to leave your profession. This can also have a psychological impact on the individual, as it may affect the person's sense of self-worth [2], and workers with vibration injuries may experience a reduced quality of life [3]. Vibration injuries also entail the consideration of societal costs for those who are affected and need to be on sick-leave or redeployed [4]. The costs of vibration injuries, when skilled labour is lost, are also likely to be substantial for industries such as construction and manufacturing, where many workers are exposed to vibration.

Many are affected by these disorders. Vibration injury is the most common compensated work injury among Swedish men. Out of 2,143 men who received compensation for work-related injuries between 2016 and 2020, 34% received it for a vibration injury [5]. This does not appear to be a decreasing problem, as the number of reported injuries has remained constant over these years [6]. Vibration injuries also affect young people to a high degree; 45% of the compensated men were under the age of 46 [6]. Metalworkers, construction workers and carpenters were the professional groups with the highest proportion of employees exposed to vibration at least a quarter of their

workday [6]. High vibration exposures most often occur in construction, for masons, builders and carpenters [7]. In women, dental technicians are one of the highest risk groups for vibration injuries [8].

The health and safety management obligations, as well as the obligations and rights of employers and employees regarding exposure to vibration, are regulated by the European Union Vibration Directive 2002/44/EC [9] and the Swedish legislation that follows the Directive [10]. The responsibilities of the employer defined in the Directive are, among others, to perform risk assessments of vibration exposures and to inform and educate workers about the risks of vibration exposure and the results of the risk assessments. If there is a risk of injuries, workers shall be offered regular health surveillance. However, when they have carried out inspections, the Swedish Work Environment Authority have found deficiencies in employers' compliance with the vibration regulations [11]. The same deficiencies have been observed by occupational and environmental clinics and occupational health services in Sweden [12, 13].

In a multifaceted reality, however, it is not possible to single out a sole contributor to the vibration injury problem. Several aspects and actors influence and interact with the issue of vibration injuries. This affects the proactive health and safety management thereof. More knowledge about these influential aspects is needed to strengthen preventive work, in order to reduce vibration exposure and injuries. One needs to take a sociotechnical systems view, in which the individual is placed into technical and organizational context [14]. Thus, a holistic and exploratory view is important to determine the contributing aspects and actors that influence the preconditions for proactive health and safety management in order to reduce vibration exposure and injuries. Examples of this are the importance of considering the individual power tool user's attitudes and behaviours, along with the professional culture that prevails in a given professional group. The insight and awareness of vibration exposure risks within companies is also important to consider. An example of influencing actors are the tool manufacturers, who have an important role in making safe tools available. Technological development in both the construction and manufacturing industries is advancing rapidly, but in the field of hand-held power tools it has remained relatively still. The thesis research includes data collection from industrial workplaces where low-vibration hand-held power tools were to be introduced. Knowledge is needed of the aspects providing preconditions for implementing such change processes with positive outcome for vibration exposure, and to enable successful implementation of vibration reducing measures. There is an additional need for knowledge about the aspects that provide preconditions for companies to have well-functioning, systematic and proactive health and safety management regarding exposure to hand-arm vibration.

Aim and objectives

The overall aim of the research presented in this thesis was to gain increased knowledge and understanding of aspects and actors that contribute to the preconditions and outcomes for a proactive health and safety management regarding vibration exposure in a Swedish context. Different aspects were studied, as reported in Paper I at an individual level of those working with vibrating power tools, and in Paper II during the implementation of vibration reducing measures at workplaces.

Paper I

The objectives of the study presented in Paper I were to investigate carpenters -a large professional group in construction that have substantial vibration exposure - and their perceptions of the proactive health and safety management at their work sites. The objectives were also to see if the perceptions were influenced by age, company size, exposure, or symptoms in the carpenters' hands, and to see if they felt that they could influence their working conditions. Their perceptions of their working conditions, and how they can influence them, are important aspects for improvements.

Paper II

The objective of the research in Paper II was to carry out an exploratory investigation of aspects and actors that could influence the implementation of planned change processes in four industries regarding low-vibration hand-held power tools. The focus was on aspects and actors that affect health and safety management regarding vibration in order to gain knowledge of how to produce well-thought-out change processes.

Theoretical framework

This section presents the theoretical background related to the thesis research.

A systems perspective

Working environments, in which workers operate hand-held power tools and risk being afflicted by a vibration injury, are influenced and controlled by many people and organisations at different system levels and in different ways. Health and safety are the shared responsibility of everybody working in the system. In such a sociotechnical

system, where there is an interaction between man and technology, actors influence each other through feedback control functions.

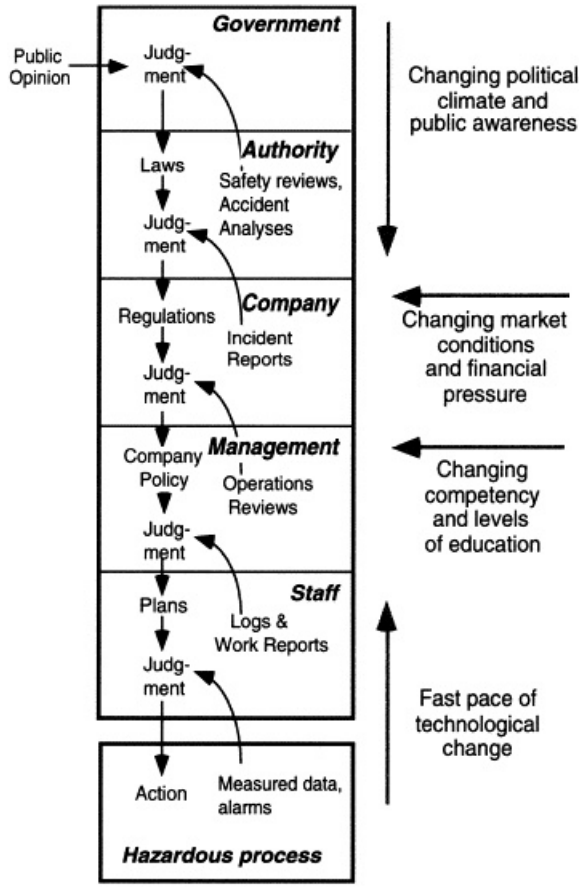

Figure 1: The Rasmussen risk management framework [14].

Rasmussen's risk management framework (Figure 1), illustrates the importance of having guidance with feedback between the various levels in society that are involved in risk management decision-making [14]. The government at the top of the framework is the national legislature. However, in the case of vibration, there is an additional legislative level above the national level: the European Union government. The national authorities draw up provisions based on legislation and are responsible for surveying the provisions at workplaces. Corporate management then applies the provisions in their health and safety policy. The operative management, in turn, is responsible for developing the policy into health and safety routines and plans. When it comes to vibration, this could be to introduce health surveillance and carry out risk assessments in the workplace. The staff are involved in putting the plans and routines into prac-

tice. It is vital that there is feedback between the different levels to ensure that the lower levels have sufficient knowledge, resources and motivation [14] for improving health and safety. This is appropriately done through the process of continuous improvements [15] and through learning for health and safety within the organisation [16]. Figure 1 also shows the severe environmental pressures in a dynamic, competitive society that many organisations are subject to. For example, in the construction industry, there may be increased demands to press deadlines in order to win tenders. This can negatively affect the work environment and the ability to work safely. A conflict of aims is created between production and health and safety.

Legislation regarding vibration

The European Union Vibration Directive 2002/44/EC regulates the obligations and rights of employers and employees in terms of exposure to vibrations [9]. The Swedish legislation, which followed the Directive, went into effect in 2005 with the Swedish Work Environment Authority's Statute Book, AFS 2005:15 [10]. The responsibilities of the employer defined in the Directive are, among others, to perform risk assessments to determine the level of vibration exposure and to inform and educate workers about the risks of vibration exposure and the results of the risk assessments. It is important for employees to know the level of exposure they have or may have in their work so that they can make active choices that keep exposure levels down when possible. It is also important that they have knowledge about the risk of being exposed to vibration and the injuries that may result from it, so that they can be alert to any signs of a vibration injury. There is a limit value of 5 m/s^2, 8h daily for vibration exposure that shall not be exceeded. There is also an action value of 2.5 m/s^2. If exceeded, measures shall be taken. For instance, the employer is obligated to establish an action plan to reduce vibration exposure. If the action value is exceeded, or if there is a risk of injuries, workers shall be offered regular health surveillance.

Of all the patients referred to Occupational and Environmental Medicine in Lund between 2012 and 2015, with a suspected vibration injury, and who had an ongoing exposure, 30% had an estimated exposure above the vibration limit value. 47% had an exposure above the action value [17]. A large proportion of the patients thus appear to be subject to a vibration exposure that is not permitted by law. When the Swedish Work Environment Authority carried out targeted inspections for vibrations, deficiencies in compliance with the vibration regulations were found in 70% of the 600 inspected employers [11]. Deficiencies included requirements for risk assessment and regular health surveillance. In an investigation carried out by Swedish Occupational and Environmental Medicine clinics [12], 246 patients examined for vibration injuries answered a survey on measures taken regarding vibrations at the workplace

before and after their visit to the clinic. Only 8% reported that they had received information about vibrations from their employer, and only 18% were offered regular health surveillance [12]. In another Swedish survey [13], sent to occupational health services and companies in one region, only 30% of the occupational health services responded that they were engaged by companies to do risk assessments and 45% were engaged to do health surveillance for vibration.

Measures to reduce vibration exposure

Vibration occurs when a body of mass oscillates back and forth around an equilibrium point. In a hand-held power tool, the source of vibration can be a piston hitting a chisel or an unbalanced rotating movement. The vibration gives rise to energy that is transferred through the tool and the tool handle and into the hand of the user. This gradually can lead to the occurrence of injuries.

The energy transfer model describes the order of introduction of preventive measures to reduce hand-arm vibration [18]. The model is based on the existence of an energy source, a target (for example a human) that can be damaged by the energy, and barriers that can prevent the energy from damaging the vulnerable target. From this model, Haddon developed ten strategies, divided into three parts, for accident prevention [18]. The first part of the strategies involve modification or prevention of the energy source. First thereafter, the preventive measures should focus on barriers between the hazard and the target, and at the very last, there are strategies to protect the target itself.

There are effective measures to reduce vibration levels and the effects of vibration. Following Haddon's strategies, the first measure or strategy that should be considered is to prevent energy build-up, which means to investigate whether hand-held vibration tools need to be used at all in the production process. The worker's safety and health should be taken into account already in the planning or design process before the start of a construction or manufacturing project [19], in order to reduce the need to use heavily vibrating tools. It may be possible to find alternative work methods, automation or the substitution of work processes [20].

The following of Haddon's strategies in the first part involve the modification and limitation of energy from the source. Alltough hand-held power tools have been used for more than a hundred years, small changes have been made in their fundamental design. Hence, there is a large potential to reduce vibration from hand-held power tools by redesign [21]. The selection of suitable equipment can also largely influence the vibration exposure [20], and manufacturers of hand-held tools are required to provide information on vibration emissions from the tools [22]. Using suitable tools

and equipment on the job site is important [23], since old or unsuitable tools can lead to more hazardous vibration exposures and vibration levels can vary considerably between different tools of the same type [24]. Wear in equipment should also be considered since it is associated with a risk for increased vibration levels [20]. It is important to have an effective machine maintenance programme, where existing equipment is regularly checked and maintained is important. The choice and the wear of consumables such as abrasive discs, chisels, or bits can affect the vibration levels. Strategies in the second part concerns barriers, which can be created to separate the source and the target by remote control of tools, for instance, or physical barriers such as vibration dampening handles. Strategies related to the vulnerable target in the last part can be protection from cold or health surveillance.

Proactive health and safety management regarding vibration need to be present in all three parts of Haddon's model; the reduction of energy (i.e., risk assessment and measures to reduce vibration exposure), but also having different types of barriers in place, or strategies aimed at the target. To avoid vibration injuries with great certainty, a series of different functions will be needed that protect against the occurrence of symptoms. A so-called defence-in-depth creates layers of protection, where if one function fails, another takes over. A defence-in-depth could be constructed by using Haddon's strategies together with other functions such as creating an understanding and awareness about vibration, having clear instructions on the use of tools for different work tasks, and having a purchasing policy and maintenance programme with the purpose of lowering vibration.

Systematic and proactive health and safety management

Occupational health and safety should be managed by a systematic assessment of risks and the implementation of measures to improve the work environment [25]. Systematic health and safety management shall be included as a natural part of day-to-day activities, and employees should be able to participate in health and safety management [25]. In the improvement of health and safety, as in any improvement work, it is important to tackle problems and system weaknesses systematically and carefully. Continuous improvements, that are based on regular company health and safety audits where identified risks and deficiencies are addressed consecutively, are important for achieving a good work environment [15, 26].

One systematic process for continuous improvement is the PDSA cycle, or the Deming cycle (Figure 2). This model integrates improvement with learning to gain valuable knowledge about working processes, for example [15]. PDSA is an abbreviation for the four phases included in the cycle: Plan-Do-Study-Act. In the first planning phase, when problems with health and safety arise, the essential cause needs to be determined

and any decisions for change needs to be based on facts. After collecting the available data, predictions about the improvement and plans for measures and actions to take will be made in this first phase. In the second phase, the plans are carried out and implemented in practice. It is important in the second phase that everyone involved in the implementation is fully aware of the problem and decided measures [27]. After implementation, in the study phase, the process needs to be re-examined to see if the introduced measures led to an improvement. In the final acting phase, lessons are learnt from the implemented measures and the implementation process. If the measures were successful, they should be retained. If not, the learning that was generated should be integrated through another lap in the cycle.

Figure 2: The Deming cycle, or the PDSA (PDCA) cycle [15].

In Sweden, only 60% of a sizable workforce that was studied considered that systematic health and safety management existed at the workplace [28]. It can be difficult, with limited resources, for organisations to integrate the continuous improvement process, and it is common that OHS measures are evaluated with less focus on continuous improvement[29].

Implementation and change processes

Implementation is about getting something; a way of working, a system or a technology; to go from being new and foreign to being an organisational routine and part of everyday work [30]. A successful implementation and normalisation of a new practice or measure is driven by four mechanisms, according to May and Finch [30]. 1) Coherence and context around a measure are important, so that ideas about the measure's use are given, and that it is perceived as meaningful. 2) Participation of all the involved actors is essential in the implementation of the measure, to have a collectively invested

commitment. 3) Collective actions, where efforts are invested in the implementation of measures. Here it is important to be aware of how the measure's properties may affect job allocation, skills or how well it can be integrated with existing practices, for instance. 4) Finally, appraisal of the measures will be made by its users, both formally and informally and both individually and within the group. It is important that the appraisals eventually are positively redefined to give an understanding of the measure and its function.

Well-designed change processes are important in all industries when health and safety measures are to be introduced and used. Van der Molen et al. found that the implementation of ergonomic measures in an organisation (where such measures may be technical, procedural, or organisational) involved seven levels of changing behaviour: 1) being aware of existing risks and their possible measures, 2) understanding the measures, 3) wanting to introduce the measures, 4) intending to buy/lease the measures, 5) having the ability to use the measures, 6) using the measures, and 7) continuing to use the measures [31]. Aspects affecting the implementation of health and safety measures can exist on all levels, and that is why it is important to adopt a holistic approach when identifying such aspects [29]. The implementation processes of health and safety measures should be viewed as a long-term commitment to workers' health and safety, and consequently, should be incorporated into a management framework [29].

Methodology

This section presents the research process, study setting, data material, and the different methods for data collection and the data analysis used.

The research process

Important incentives for me to conduct this research came from meeting patients afflicted by vibration injuries when they visited the Occupational and Environmental Medicine Clinic in Lund. I work there as an occupational hygienist and am well acquainted with vibration exposure measurements and assessments. In the meetings with patients, other questions also emerged regarding proactive health and safety management and why it was often incomplete at the patients' workplaces. When a research project regarding vibration injuries and exposure in carpenters was about to start, it was close at hand for me to also want to investigate proactive health and safety management at the carpenters' work sites.

An opportunity arose sometime later for me to participate in a development project of low-vibration power tools. There must be customer demand in order for these tools to start being manufactured and used, and thus lead to reduced vibration exposure at workplaces. There was hope in the development project that companies would want to start to buying these new low-vibrating tools, but there was an awareness that this would not happen overnight. It was clear that if such tools with heavily reduced vibration levels started to be used in companies, it would be a central part of the solution to the vibration injury problem. I thus considered it important to investigate what aspects would promote the demand and use of new low-vibration tools in companies.

Study settings and data material

The research presented in this thesis is the product of two larger research projects. The Paper I study on carpenters' perceptions of health and safety management was the product of a project investigating Swedish carpenters vibration exposure in relation to the Swedish vibration legislation, and whether the carpenters showed signs of vibration injuries compared to a control group of painters.

The Paper II study on aspects affecting the implementation of low-vibration hand-held power tools was the product of a project aimed at developing and testing prototypes of hand-held power tools with reduced vibration levels.

Carpenters and vibrating tools

Carpenters are the most common professional group referred to the Occupational and Environmental Medicine Clinic in Lund with the issue of vibration injury. Carpenters also have a complex work situation, that involves a variety of work tasks using a large number of different power tools. The types of tools used were noted in a review of the approved occupational injury cases with a diagnosis of vibration injury between 2014 and 2017. Construction workers were the work group that used the most tools. The four most common tools in construction work were the demolition hammer, reciprocating saw, impact drill, and driver (see Figure 3) [32]. The complexity and the extensive use of vibration tools make it not only difficult to assess carpenters' vibration exposure, it also makes it difficult for carpenters to avoid being exposed to vibration. This is why knowledge is needed about the carpenters' perceptions of proactive health and safety management.

(a) (b) (c) (d)

Figure 3: Carpenters using an impact drill (a), a reciprocating saw (b) and a driver (c), and tools collected in a wheel barrel to be used by a carpenter during a day (d).

In the Paper I study, two large and two medium-sized construction companies in southern Sweden took part, and 18 work sites from those companies were visited. All the carpenters that were working at the work sites during the study time were asked to participate. Participation was voluntary, but the companies were informed that it was desirable that all employees took part if possible. This was to avoid that only those who already had symptoms of vibration injury would participate.

Implementing low-vibration hand-held power tool prototypes in four vibration exposed industries

Different stakeholders involved in the issue of vibration injury were brought together in the project that was aimed at developing low-vibration power tools by newly developed techniques to reduce vibration in the handles of the tools. The stakeholders included tool users, tool manufacturers, social partners, authorities and researchers. A number of tool types were identified by the tool users and manufacturers at the beginning of the project that were considered would give rise to either high vibration exposure or a substantial risk of vibration injury. They were therefore suitable to be redesigned. The redesigned tool prototypes were then introduced and tested in industrial environments in different industries. Five of those organisations were included in the Paper II study: a quarry, a steelworks, two construction companies and one dental laboratory. The tools that were selected for redesign in these environments are shown in Figure 4: pneumatic rock drills at the quarry, rammers at the steel works, vibration plates at the construction companies and hand-pieces at the dental laboratory (i.e., small motor-driven units for grinding work). An equipment rental company that was connected to one of the construction companies was also included in the study with the aim of investigating its impact on the implementation of new tools at workplaces.

Operators or skilled workers in the industrial environment where the tool prototypes had been, or were to be introduced, took part in the study along with their management team.

(a) (b)

(c) (d)

Figure 4: The different tools for which low-vibration prototypes were developed within the four industries. The figure shows the rock drill (a), the rammer (b), a vibration plate (c) and a dental hand-piece (d).

Data collection

Data were collected through observations in the field, through a questionnaire and through semi-structured, exploratory interviews. The different methods for data collection are described in the following three subsections.

Field studies

Data were collected during visits in the field in both the Paper I and II studies. Field visits to the construction sites, a quarry, a steelwork and a dental laboratory made it possible to observe the work with the hand-held power tools and the environment in which the work was performed. This provided valuable information and understanding of the execution of work tasks, as well as the various situations and factors that may arise on the job when using the tools. Field study observations may well give more valid knowledge of people's behaviour and their interaction with their environ-

ment than interviewing subjects about their behaviour. Observation and field studies of actual behaviour, supplemented by interviews, may give more valid information about implicit or tacit understandings of things that are taken for granted in a group or a culture [33].

Questionnaire study

The carpenters in Paper I answered a questionnaire using a tablet computer while they were waiting to be medically examined. There were twelve questions about the carpenters' perception of health and safety work at the sites, especially regarding hand-arm vibration. The questions touched on different aspects of the proactive health and safety management work including: management's commitment to safety, employees' involvement in health and safety work, health and safety information and communication, improvement work, and risk perception. The items were answered using one of two five-point scales ("never, seldom, sometimes, often, always" or "not at all, barely, a little, much, very much"). The items were extracted from a questionnaire used in previous studies [34], where the relevant items were developed through literature reviews, for instance. Pilot studies and reliability analyses were conducted. The current questionnaire also included medical questions about, for instance, symptoms from the hands, other diseases, medication and tobacco use. Questions regarding the carpenters' vibration exposure dealt with both the current exposure and the type of tools used, as well as past exposure and employment.

Using questionnaires in research is often less costly and quicker than doing interviews. Using a questionnaire can also make respondents feel more comfortable answering certain types of questions, without the presence of an interviewer [35]. Difficulties that may arise using a questionnaire are often about formulating questions. The questions in the questionnaire must be easily understood and must lend themselves to appropriate and meaningful data analysis. In this case, there was also a time limit for the medical examination, and the carpenters needed to be able to answer the questionnaire fairly quickly. Another limitation of questionnaires is that they often generate low response rates [35]. However, this problem was overcome in this study by having the carpenters fill in the questionnaire while they sat to warm their hands before being examined. The carpenters were given instructions before filling in the questionnaire and they had access to research staff in case they had any questions.

Interview study

Interviews are a suitable data collection method for investigating people's understanding, experiences, or perspectives on the world in which they live and operate [33].

However, if the purpose of a study is to investigate opinions of larger groups, where larger samples of respondents are necessary, interviews may not be a relevant method. Qualitative interviews are usually more time-consuming to perform, analyse and report than questionnaires [33].

A semi-structured interview has predefined themes to be covered in the interview, and a list of questions to be asked. At the same time, there is openness to changes in the order or forms of the questions, and specific answers can be followed up by adding new questions [33]. Exploratory interviews, in contrast to those with hypothesis-testing purposes, are usually more open and less structured. In such interviews, a new issue or a complex problem is introduced in order to better describe or define it [33]. In this study, a total of 28 semi-structured and exploratory interviews were conducted in five of the participating companies. All but one was recorded with the permission of the interviewee. One person declined to be recorded, in this case careful notes were kept. At the dental engineering laboratory, a three-hour field visit through all the departments took place, led by a safety representative and the health and safety manager.

The interviews in Paper II were conducted with people on several organisational levels, such as operators or skilled workers, safety representatives, supervisors, health and safety managers, production managers, top management, as well as representatives of the purchasing organisations. This was performed to capture different views and perspectives from people in various functions in the studied organisations. A broad and exploratory stance was taken when investigating aspects that could impact tool implementation and the interviews included topics such as: vibration problem insight, risk awareness and work practice, knowledge of technical tool designs and supply of tools, change management work, attitudes towards and willingness to use tools, knowledge and information about vibrations, and experiences of low-vibrating tool prototypes. Interview questions were formulated taking thematic and dynamic dimensions into account so that the questions were relevant to the research topic, were easy to understand, and that nurtured a positive interaction in the interview situation [33]. Follow-up questions were asked when needed.

Data analysis

Statistical analysis

Statistical calculations of the results from the questionnaire were performed using IBM SPSS Statistics 24. The differences between various subgroups were tested with the Mann-Whitney U test. It is used as the parametric Student's t-Test for Indepen-

dent Samples to determine if there are statistically significant differences between two groups. However, the Mann–Whitney U-Test is used on non-parametric data, such as ordinal data, whereas the Student's t-Test is used with data associated with parametric distributions. The Mann-Whitney U test does not compare the means, but the two groups' median scores [36]. There were ordinal data from the questionnaire in this research.

Content analysis

The recorded interviews were transcribed verbatim and analysed using content analysis [37]. Content analysis is a method that helps you keep track of the aspects relating to the research topic. This method focuses on certain preselected key aspects, called dimensions or main categories, that together form the coding frame, or the structure of the material. In this way, the processing of a large amount of material will be simplified, and it will facilitate getting a better overview of the material. On the other hand, a coding frame acts as a filter through which the material is viewed and aspects that are not covered by the coding frame may be lost [37].

In the Paper II study, the main categories were based on the interview guide. Subcategories were then specified inductively from the material. For each main category, there will be a number of subcategories specifying the meaning in the material with respect to the main category [37]. Meaning-bearing units of coding relating to the main categories were identified from the transcript. The meaning-bearing units were then segmented, condensed and categorised into subcategories. The segmentation of interview transcripts involves decontextualisation to a certain part (i.e., the coding unit is removed from the context of the surrounding material). Therefore, in cases where the context was unclear, an explanatory text was linked to each coded unit. The material from each company was analysed separately, using the same coding frame. The results were then compared.

Summary of papers

Paper I
Hand–arm vibration: Swedish carpenters' perceptions of health and safety management

Paper I reports on an assessment study of carpenters' perceptions of the proactive health and safety management work at construction sites in Sweden. Workers in the construction industry are highly exposed to vibration from hand-held power tools, and carpenters make up the largest professional group in this industry. Employers in the construction industry often fail to comply with legislation regarding vibration exposure.

The objective of the research was to assess carpenters' perceptions of proactive health and safety management regarding hand-arm vibration at their work site. The objective was also to investigate whether the perceptions were influenced by age, size of the company, amount of daily hand–arm vibration exposure or the presence or absence of symptoms in their hands, and to investigate whether the carpenters felt that they can influence their working conditions.

194 carpenters from four construction companies and 18 construction sites answered a questionnaire on health and safety management, on symptoms indicating injury, and on the use of vibrating tools.

The results from the questionnaire showed that attitudes to health and safety management were generally positive. However, 36% of the carpenters reported that the health and safety regulations and routines did not function in practice, and 40% claimed that they did not receive the necessary information on the effects of vibration. Most respondents (74%) perceived a high risk of vibration injury in their work. Younger carpenters, carpenters employed at smaller companies, and carpenters with symptoms indicating injury or with higher vibration exposure reported more negative percep-

tions.

In general, the carpenters were positive to management's commitment to health and safety management. However, the results indicate deficiencies in the way in which this commitment is applied in practice at the workplace. This is because many employers did not comply with the existing vibration laws. The risk of incurring a vibration injury may have been overshadowed by other more prominent risks at the sites, and it is possible that this was reflected in the carpenters' answers. The results highlight the importance of raising awareness concerning vibration exposure and possible injuries and strengthening proactive health and safety programmes, especially in smaller companies.

Paper II
Aspects Affecting the Health and Safety Management and the Implementation of Measures to Reduce Vibration Exposure in Industry

The objective of this study was to exploratory investigate aspects that could affect the implementation and future use of low-vibration hand-held power tools in four types of industries: construction, quarrying, steelworks, and dental laboratories. A sociotechnical approach was employed, and the study included different persons involved in health and safety management of the organisations at various organisational levels.

Field visits including observations and interviews were conducted in six organisations within the four industries. A total of 28 semi-structured and exploratory interviews were conducted with persons on different organisational levels within the companies. The interviews included topics such as: vibration problem insight, risk awareness and work practice, knowledge of technical tool designs and supply of tools, change management work, attitudes to and willingness to use tools, knowledge and information about vibrations, and experiences of tool prototypes. Visits to workplaces also gave a general indication of vibration exposure, awareness, and knowledge of the risks associated with vibration exposure, as well as the level of acceptance of low-vibration tools throughout the organisations.

The results showed a need to increase knowledge and awareness of vibration exposure and risks in the organisations, as well as a need for increased communication between employers and employees on the topic. Aspects affecting implementation also included: overcoming a fear of changes in craftsmanship or conservatism around

certain brands in order to gain user acceptance of new tools; having a clear and consistent leadership for change with great commitment, and having manufacturers or rental companies ensure the availability of low-vibrating power tools. There needs to be a customer demand for low-vibrating tools development and supply. Implementation requires well-thought-out change processes with workers involved in the change, as well as continuos dialogue throughout the process.

Discussion

The aim of the two studies presented in this thesis was to gain knowledge and understanding of aspects and actors that contribute to preconditions and outcomes for proactive health and safety management regarding workers' vibration exposure. The studies can be seen as initial steps in investigating all the various aspects that can affect the health and safety management of hand-arm vibration. The results draw attention to some of the difficulties that exist in creating a healthy work environment. The methods used were a questionnaire to investigate carpenters' perceptions of health and safety management at their work sites, and semi-structured interviews to investigate aspects that can influence change processes. These methods were combined with observations in the field.

Methodological issues

A strength of the questionnaire study was the high number of carpenters who participated, and that all carpenters working at the participating work sites took part in the study. A limitation was that only large and medium-sized companies were involved; no smaller companies took part. Including smaller companies may have shown a greater difference in the results, since it is possible that the health and safety management of the large and medium-sized companies was somewhat better than average. The work sites were selected by contacts at the construction companies. It was difficult to know if their health and safety management differed from other work sites within these companies. The items regarding perceptions of health and safety management were part of a bigger questionnaire that limited the number of such items. Even though the items were included in a larger questionnaire that was entirely about hand-arm vibration, it is still questionable as to whether the carpenters were really thinking about health and safety management regarding vibration when answering the questions. They may have instead been thinking about general accident prevention, something that is often more focused on in construction. The possibil-

ity of recall bias should also be considered, for instance, carpenters who already have symptoms in their hands might be more likely to remember deficiencies in health and safety management. Interviewing the carpenters, or including free text responses in the questionnaire, could have enriched the study. Unfortunately, this was not possible due to practical reasons. However, observations in the field provided a broader insight into the carpenters' work.

Interviews were performed in four different industries. Had the interviews instead been limited to one industry, there may have been an opportunity to investigate aspects relating to that industry in depth. Instead, interviews were performed with a broad explorative perspective, with people working in different positions, and with the ability to compare different industries. This can, nevertheless, be seen as a strength of the study.

To obtain as good validity or trustworthiness as possible in qualitative research, several strategies can be adopted. Examples are accounting for the personal bias of the interviewer and the interviewee and having a consistent and meticulous decision trail in data analysis methods, with clarity in terms of thought processes and interpretations. Engaging other researchers or using different methods and perspectives can help validate the findings [38]. A structured method for data analysis was used in this research. The interview protocol was prepared in cooperation with other researchers involved in the R&D project. The first interviews were carried out by two researchers, who aimed to achieve consensus on how the questions were asked. The subcategories that were identified were reviewed by two researchers to ensure that the interview responses were interpreted in the same way. It is, of course, still possible that the influence of the researcher can give rise to bias; likewise, can preconceptions or ideas of both the interviewer and the interviewee give rise to bias. Field observations were also helpful in validating the findings from the interviews. The industries, companies and study participants that were included were largely based on practical considerations and on conditions within the larger project. If smaller companies had been included, it may have produced different results.

Discussion on the results

The results from the study of the carpenters (Paper I) showed that they were positive to the health and safety management at their workplace, despite their perceptions of the high risk of injury and lack of practical routines. In the implementation study (Paper II), companies with good intentions to reduce vibration injuries actively participated. Still, shortcomings regarding vibration knowledge or awareness were discovered within those companies. This shows the complexity of the problem, and that

positive attitudes and intentions regarding health and safety should be followed up by practical routines such as health surveillance, risk assessments and implementation of measures. Studies in the Swedish construction industry show that there is a strong focus on accident prevention, but considerably less on preventing long-term health risks [39]. The positive results in presented in Paper I indicate that the carpenters to some extent had accident prevention in mind when answering the questionnaire. The Paper II study also showed that the risk of vibration was overshadowed by other, more prominent, risks, such as extreme heat or dusty work in the steelworks, exposure to quartz dust at the quarry, or the risk of falling accidents at the construction site. In the professions investigated, hand-arm vibration is always present and thus can be difficult to avoid despite otherwise good health and safety measures. Thus, it may be that exposure to vibration is regarded as a natural part of their work, and that vibration may also be connected to experiences of craftsmanship or performance. In the Paper I study though, it was found that the occurrence of symptoms may result in workers being more alert to the fact that their work with vibrating power tools involves risks.

An important result from this research is that knowledge and awareness about vibration need to be improved in the participating companies. Information on vibration and the risks for employees should be provided more systematically. This includes giving ongoing information about the regulations that govern the use of vibrating tools, and who to turn to in the case of symptoms. A lack of information and worker training on how to perform work tasks in a safe and healthy manner when using vibration tools is likely to result in less knowledge among workers about exposure to vibration and the risk of injuries. Such minimal knowledge can also affect the workers' ability to influence their own exposure through informed choices, for example, about what tools to use for different work tasks. A study of construction workers found that the group who received more safety training had an increased perception of risk (in terms of how they rated the consequences of risks at work and of the likelihood of risks occurring) [40]. Lack of information may also be a barrier in the implementation of measures. This can be overcome by comprehensive training [29].

Many of the interviewees in the Paper II study were aware that measures such as work rotation alone were not enough to sufficiently reduce vibration exposure in the workplace; improved low-vibration tools were also required. However, concern was expressed in all the industries studied regarding the way in which new tools could change work performance and affect craftsmanship. For the implementations of measures to be fully accepted and utilized, they must be able to be integrated into current work practices and procedures [29]. This emphasizes the importance of the workers being able to recognize the functions of a tool in practice, and may be an important reason why skilled workers in construction tend to choose tools of the brand they are used to. If technical solutions are too complex or incompatible with the work task, or

if they can affect the quality of the work, the working practices or craftsmanship, this can lead to resistance to change among workers [29, 30]. The understanding, acceptance, and participation of those who are to use the tools are thus important. Time should be made available, for example, through a temporarily reduced production rate for workers to learn to use new tools,

Management needs to support and encourage employees to raise concerns about health and safety, and to ensure that employees are involved in changes to their working conditions [41]. The carpenters in the first study (Paper I) felt that they could influence their working conditions. However, carpenters with symptoms, higher exposure, or working in a smaller company were less positive. In the Paper II study, the employees in all industries, apart from the dental lab, felt that they could influence which tools were to be purchased. There was, however, a lack of information in all industries regarding the upcoming implementation of new tools. Open communication between employers and employees is vital, and the interaction and cooperation of employees are important in relation to health and safety [42, 43]. Meldrum, Hare, and Cameron [44] found that workers' engagement in health and safety management depends on the following: their own capabilities to engage, give feedback or share knowledge concerning their work; their perceptions or expectations of the organization or management; their attitudes and behaviours regarding risks and safety; and their actual involvement in risk assessments. In the implementation of health and safety measures, it is also important that those affected by the given measures are allowed to express their opinions and suggestions for improvements [29], such as in the purchase of new power tools. In the construction companies, however, there was a tendency to transfer responsibility in the decision-making chain, since management often complied completely with the skilled workers' wishes in choosing power tools. Management thus plays the important role of being clear and consistent about stating that the first priority is the health and safety of the staff, even if it means going against the wishes of the staff. This can be demonstrated by allocating time and resources to implement health and safety measures [29]. It is important to have committed and motivated management in order to achieve workplaces that are safe and healthy [19]. Management involvement is one of the most effective factors to facilitate safety [45]. Sawacha et al. investigated factors affecting safety performance on construction sites. They found that the management's talk about safety was the factor that mostly influenced safety performance [46]. It is thus important that management regularly talk to employees about working in a way that minimizes vibration exposure.

The participating companies in the studies were large or medium-sized. Health and safety work is more visible in larger companies because they have more resources available and have developed formal systems and appointed personnel to work with these issues. Nordlöf et al. state that certain underlying factors, such as structure, knowl-

edge, and the available recourses in a company change with the size of the company [47]. This can result in greater difficulties for smaller companies to maintain health and safety management efforts [47]. Even if the health and safety work is more formally well-organised in large companies, studies show that routines often fail in everyday work [48]. The carpenters working in medium-sized companies gave more negative responses. This may indicate that they do not perceive that they have the same management support as carpenters in larger companies.

In the Paper I study, younger carpenters were less positive about their health and safety management compared to older ones. It was pointed out in the interview study (Paper II) that it would be easier for younger workers learning the trade to accept new tools since they were not yet that accustomed to a certain way of working. Younger employees probably have, to a higher extent, received information on health and safety during their vocational training [49] and may therefore know more about risks in the work environment and the employer's obligations. Older workers, on the other hand, may have experienced much less focus on health and safety and consequently perceive the current practices more positively. Another factor contributing to the more negative perception of younger workers may be because they are less experienced employees and often perform more repetitive tasks that are ergonomically monotonous and that lead to higher vibration exposure [50].

In the interview study (Paper II), questions arose regarding the obligations of manufacturers to provide safe and ergonomic tools in industries. The EU Machine Directive states that manufacturers must ensure that equipment is designed such that risks due to vibration are reduced to the lowest possible level. Currently, however, there is no regulation preventing high levels of vibration in equipment [22]. It is important that tool manufacturers, despite this, take responsibility for their part in the development of low-vibration tools as they have a central role in ensuring that a range of low-vibration tools is available. Many of the tools used in the companies in this thesis research had very high vibration levels, and the limit value was exceeded. This indicates a clear need for a change to new tool technologies in order to reduce vibration exposure. Customer demand for low-vibration tools is needed, as this will drive the development and supply of such tools. Manufacturers are also obligated to provide easily understandable and relevant information on vibration levels [22]. These levels are used to a large extent when assessing the risks associated with vibration at workplaces. The interviewees expressed concern about the declared levels of vibration and questioned whether they could really trust these values. Using the declared vibration values in risk assessment may result in a systematic underestimation of the risk of vibration injuries [51].

The project reported in Paper II had participants from various societal levels such as tool users, tool manufacturers, and legislative authority. This helped to enhance the

dialogue between these actors and provided a better understanding of each other's needs and challenges concerning vibration exposure. More of these kinds of arenas are needed, where actors at different levels can exchange knowledge and continue to promote the development of better tools and measures to reduce vibration injuries. In this thesis, the different aspects addressed that provide preconditions for proactive health and safety management regarding vibration exposure, can together construct a defence-in-depth to protect against the occurrence of vibration injuries.

Conclusions

From the two studies presented in this thesis, the following overall conclusions affecting preconditions and outcomes for a proactive health and safety management regarding vibration can be drawn.

Knowledge concerning vibration and awareness of the risks involved could be improved in companies, and it is important that people working with hand-held power tools receive training. Knowledge could also be better disseminated in companies.

The communication between employees, and between employees and management, could be improved so that routine and risk information is available to the employees, and so that management has a good understanding of the working conditions and injury status of their workforce. An ongoing dialogue between employees and managers will be necessary to ensure the successful introduction and use of new tools.

Leadership has an important role. Clear and consistent directives from management are essential in ensuring that there are definitive instructions on how work should be performed, and which tools should be used, to avoid harmful exposures.

The understanding and acceptance of new tools are central. A change can affect the work and craftsmanship, and the understanding, acceptance, and participation of those who are to use the tools are thus important

Tool manufacturers have a central role in ensuring that a range of low-vibration tools is available. Customer demand for low-vibration tools is needed, as this will drive the development and supply of such tools.

Change processes should be well-designed so that knowledge and information on upcoming measures are provided and that the employees are involved and participate in the change in working practices. Only then can acceptance be created for the introduction of new tools and their impact on working methods and craftsmanship. Such a change may take time, but if implemented well, it can result in changes in a workplace culture where low-vibration tools are considered a natural part of the work.

The importance of improving proactive health and safety management regarding vibration has been highlighted, particularly in respect to practical routines and especially for smaller companies. The risk of vibration is often overshadowed by other, more prominent risks. This highlights the importance of raising awareness about vibration exposure, vibration injuries and the employer's legal obligations in companies.

Future Research

The findings so far demonstrate the complexity of addressing vibration exposure in workplaces. More research is required on how to achieve a well-functioning, proactive health and safety management of vibration exposure. An important part of health and safety management that focuses on vibration is risk assessments in workplaces. Risk assessments of vibration exposure is not an easy task, especially in the varying types of work one can find in construction. To assess the risk of vibration exposure and compare it with limit and action values, one needs information about the tool vibration, but also about the user time during the day. Today's measurement methods for evaluating vibration exposure at work are time consuming and require the involvement of a safety engineer or the equivalent. Traditionally, vibration levels are measured on different vibrating tools, while user times are subjectively assessed via interviews or surveys. Carrying out more objective measurements of usage time, such as through time studies, has so far been expensive and time consuming. Consequently, subjective methods have dominated, even though studies show that these methods lead to large overestimates of exposure times [52, 53]. In this licentiate research, a large proportion of the carpenters reported such extensive use of vibrating tools that their exposure was above the limit value. The use of hand-held tools is central to construction workers. Such tools are used in almost every work task. However, the use is often not continuous but consists of many intermittent steps, for example, drilling a hole, or screwing a screw. This type of use makes it particularly difficult to estimate usage times and to estimate actual exposure. This is why complete risk assessments are rarely carried out.

Several manufacturers of hand-held power tools are starting to develop various digital solutions to help customers manage their equipment. Through digital tracking of each tool's performance and runtime, employers get information about where the machines are and who uses them. This information can also be used to monitor vibration exposure. A digital system developed for tool management has been validated by the Occupational and Environmental Medicine Clinic to be able to provide accurate information on the usage time for power tools.

The plan for future research in the PhD studies is to evaluate carpenters' exposure to vibrating tools. This will be achieved through measurements of vibration levels on many tools, but also by evaluating different ways of measuring and estimating the exposure time (user estimation, observation, and measurements by digital system) and investigate how this affects the assessment of vibration exposure. Further studies will address the challenges in assessing vibration exposure, in terms of the measurement and interpretation of both vibration levels and user time.

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Scientific publications

Author contributions

Paper I: Hand-arm vibration: Swedish Carpenters' Perceptions of Health and Safety Management

Fisk and Ek formulated the objectives of the study. Fisk performed the data collection, as well as most of the data analysis. Fisk did the main writing, however Ek took part in reflecting on the results as well as in manuscript writing. Nordander commented on a later version of a manuscript

Paper II: Aspects Affecting the Health and Safety Management and the Implementation of Measures to Reduce Vibration Exposure in Industry

The study was conceived and designed by both authors. Fisk performed the majority of the data collection, and together with Ek most of the data analysis. Both authors took part in reflecting on the results and in writing the paper, however Fisk did the main writing.

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