

Linköping University Medical Dissertations No. 1192

**Self-assessed and direct measured physical workload
among dentists in public dental clinics in Sweden during a
period of rationalizations**

Dirk Jonker

National Centre for Work and Rehabilitation
Department of Medical and Health Sciences
Linköping University, Sweden



Linköping University
FACULTY OF HEALTH SCIENCES

Linköping 2010

Self-assessed and direct measured physical workload among dentists in public dental clinics
in Sweden, during a period of rationalizations

©Dirk Jonker, 2010

Published articles have been reprinted with the permission of the copyright holder.

ISBN: 978-91-7393-347-6

ISSN 0345-0082

Printed in Sweden by LiU-Tryck, Linköping, Sweden, 2010

CONTENTS

ABSTRACT	7
SAMMANFATTNING PÅ SVENSKA	8
LIST OF PAPERS	11
ABBREVIATIONS	12
INTRODUCTION	13
Scope of the thesis	13
Prevalence of work-related musculoskeletal disorders	14
Prevalence of musculoskeletal disorders in dentistry	14
Conceptual model under study	15
Risk factors for WMSD	17
Risk factors for WMSD among dentists	18
Ergonomic intervention research	18
<i>Ergonomic interventions in dentistry</i>	19
The production system, rationalization and ergonomic implications	20
<i>Production system</i>	20
<i>Rationalization</i>	21
<i>Ergonomic implications</i>	21
<i>Society level</i>	23
MAIN AIM	25
Specific aims:	25
MATERIAL AND METHODS	27
Study Designs	27
Subjects	27
Methods	28
Assessment of perceived workload and work demands	28
<i>Questionnaire</i>	28
Assessment of tasks and their time distribution	29
<i>Observations</i>	29
<i>Assessment of waste during clinical dental work</i>	29
Assessment of physical workload at job level	31
<i>Electromyography</i>	31

<i>Inclinometry</i>	32
Data analysis	34
RESULTS	35
Paper I	35
Paper II	35
<i>Self-reported perception of physical demands at work and workload</i>	35
<i>Inclinometry and perception of physical demands at work and perception of workload</i>	35
Paper III	36
<i>Task time distribution</i>	36
<i>Task-related mechanical exposures</i>	36
Paper IV	37
<i>Time distribution of work tasks</i>	37
<i>Changes in task-related mechanical exposure between 2003 and 2009</i>	37
<i>Changes in mechanical exposure of VAW and/ non-VAW</i>	38
<i>Changes in mechanical exposure during video recordings and four hours of registrations</i>	38
GENERAL DISCUSSION	39
Methodological issues	39
<i>Selection</i>	39
<i>Observation bias</i>	39
<i>Study design</i>	40
<i>Exposure assessment by questionnaire</i>	40
<i>Measurement equipment</i>	41
<i>Representativity</i>	41
<i>Observer reliability of video-based task analysis</i>	42
<i>Physical workload and exposure assessments</i>	42
<i>Risk parameters and time aspects</i>	44
<i>Operationalization of the concept of rationalization</i>	45
Discussion of results	46
<i>Physical workload exposure at job level</i>	46
<i>Consequences of physical exposure due to rationalizations</i>	48

<i>Towards 'Sustainability'?</i>	49
<i>Conceptual exposure - risk model</i>	51
<i>Recommendations for future rationalizations</i>	52
CONCLUSION	55
EXAMPLES OF FUTURE RESEARCH	56
ACKNOWLEDGEMENTS	57
REFERENCES	58

ABSTRACT

Much research has been done on interventions to reduce work-related musculoskeletal disorders (WMSDs) at the workplace. However, this problem is still a major concern in working life. The economic cost for WMSDs corresponds to between 0.5% and 2% of the gross national product in some European countries, and in 2007, 8.6% of workers in the EU had experienced work-related health problems during the previous 12 months. In Sweden, one in five of all employees have rated occurrence of WMSDs during the previous 12 months.

In spite of comprehensive ergonomic improvements of workplace and tool design in dentistry the prevalence of musculoskeletal disorders in neck, upper arms and back is reported to be between 64% and 93%.

The present thesis investigates if the perceived high exertion during work corresponds to actual physical exposures. Further, it is investigated if risk full physical exposures may be generated due to rationalisations. Specifically, changes in physical exposures are investigated prospectively during a period of rationalisations. Empirical data on production system performance, individual measured physical workload, and self-rated physical workload are provided.

High estimates of self-rated workload were found. These high scores for perceived workload were associated with high measured muscular workload in the upper trapezius muscles. Also, negative correlations were found between low angular velocities in the head, neck and upper extremities on the one hand, and estimates for perceived workload on the other. Both measured muscular workload and mechanical exposure among dentists indicate a higher risk of developing WMSDs than in occupational groups with more varied work content. Value-Adding Work (VAW) comprised about 57% of the total working time and compared to industrial work an increase with about 20 percent units is hypothesised. Furthermore, VAW compared to non-VAW (“waste”) implies more awkward postures and especially low angular velocities interpreted as constrained postures.

Consequently, when increasing the proportion of time spent in VAW due to rationalisations, work intensification is expected. However, at follow up, we did not find such work intensification.

Previous research indicates that rationalisation in working life may be a key factor in the development of WMSD. The present thesis suggests that ergonomics may then be considered proactively as part of the rationalisation process.

SAMMANFATTNING PÅ SVENSKA

Mycket forskning har gjorts på insatser för att minska arbetsrelaterade belastningsskador (WMSDs) på arbetsplatsen. Arbetsrelaterade belastningsskador är dock fortfarande ett stort problem i arbetslivet. Den ekonomiska kostnaden för arbetsrelaterade besvär motsvarar mellan 0,5% och 2% av bruttonationalprodukten i vissa europeiska länder, och år 2007 hade 8,6% av arbetstagarna i EU upplevt arbetsrelaterade hälsoproblem under de senaste 12 månaderna. I Sverige, år 2008, hade en av fem anställda antingen fysiska eller stressrelaterade WMSDs under de senaste 12 månaderna.

Trots omfattande ergonomiska förbättringar på arbetsplatsen och förbättrad verktygsdesign inom tandvården är förekomsten av muskuloskeletala besvär i nacke, överarmar och rygg mellan 64% och 93%. Främst tandläkare och tandhygienister drabbas.

Denna avhandling undersöker om det som uppfattas som hög ansträngning under arbetet motsvarar den faktiska fysiska exponeringen. Vidare har det undersökts om rationaliseringar genererar fysiska exponeringar som ökar risken för WMSD. Förändringar i fysiska exponeringar har undersökts prospektivt under en period av rationaliseringar. Empiriska data om produktionssystemet prestanda, individuell mätt fysisk belastning, och självskattad fysisk belastning har tagits fram.

Höga skattningar för självskattad arbetsbelastning hittades. Dessa höga skattningar för upplevd arbetsbelastning var förknippade med hög uppmätt muskulär arbetsbelastning i de övre trapezius musklerna. Även negativ korrelation hittades mellan låga vinkelhastigheter i huvudet, nacke och övre extremiteter, och självskattad arbetsbelastning. Både uppmätt muskulär arbetsbelastning och mekanisk exponering bland tandläkare innebär en högre risk för WMSDs än för yrkesgrupper med mer varierat arbetsinnehåll.

Femtiosju procent of den totala arbetstiden var värde skapande arbete (VAW), och i jämförelse med monterings industri kan en hypotetisk ökning med 20 procent enheter förväntas. Dessutom innebär VAW jämfört med icke-VAW (slöserier) mer obekväma arbetsställningar och i synnerhet låga vinkelhastigheter och tolkas som ogynnsamma arbetsställningar.

Följaktligen, större tids andel VAW på grund av rationaliseringar, kan leda till ökad arbetsintensitet. Dock, vid uppföljning under en 6 års period, hittades inte sådan arbetsintensifiering.

Tidigare forskning visar att rationaliseringar i arbetslivet kan vara en viktig faktor i utvecklingen av WMSD. Kunskap från denna avhandling kan användas på ett förebyggande sätt, så att berörda intressenter blir aktivt involverade i rationaliserings processen.

LIST OF PAPERS

This thesis is based on the following papers, which are included at the end and referred to in the text according to their Roman numerals:

- I. Rolander, B., Jonker, D., Karsznia, A. & Oberg, T., 2005. Evaluation of muscular activity, local muscular fatigue, and muscular rest patterns among dentists. *Acta Odontol Scand*, 63 (4), 189-95.
- II. Jonker, D., Rolander, B. & Balogh, I., 2009. Relation between perceived and measured workload obtained by long-term inclinometry among dentists. *Appl Ergon*, 40 (3), 309-15.
- III. Jonker, D., Rolander, B., Balogh, I., Sandsjo, L., Ekberg, K. & Winkel, J., Mechanical exposure among general practice dentists and possible implications of rationalization. (*Pending revision*)
- IV. Jonker, D., Rolander, B., Balogh, I., Sandsjo, L., Ekberg, K. & Winkel, J., Rationalization in public dental care - impact on clinical work tasks and biomechanical exposure for dentists - a prospective study. *In manuscript*

ABBREVIATIONS

ARV	Average Rectified Value
Hz	Hertz
HRM	Human Resource Management
MPF	Mean Power Frequency
MVC	Maximum Voluntary Contraction
NPM	New Public Management
sEMG	Surface Electromyography
VAW	Value-Adding Work
WMSD	Work-related MusculoSkeletal Disorder(s)

INTRODUCTION

Scope of the thesis

Much research has been done on interventions to reduce work-related musculoskeletal disorders (WMSDs) in the workplace. However, this problem is still a major concern in working life (Silverstein and Clark 2004, van Oostrom *et al.* 2009, Westgaard and Winkel 2010). There is, therefore, a need for effective preventive actions. In order to prevent WMSDs, it is first necessary to understand their causes.

The aim of the studies in this thesis is to analyse physical work-related risk sources of WMSDs. Dentistry was chosen as a case for the studies.

In dentistry, a high prevalence of musculoskeletal complaints has been found during recent decades (Kronlund 1981, Akesson *et al.* 1997, Leggat *et al.* 2007), despite improvements in ergonomics, such as workplace- and tool design (Winkel and Westgaard 1996, Dong *et al.* 2007). Hence, ergonomic intervention, with the aim of reducing WMSDs, does not seem to be effective so far. One possible explanation might be a lack of precise measurements in ergonomics and the limited involvement of ergonomics in work organizational factors, such as rationalizations (Bernard 1997, Hansson *et al.* 2001, Dul and Neumann 2009, Westgaard and Winkel 2010).

Specifically, work organizational changes in dentistry in order to increase efficiency may imply increased prevalence of musculoskeletal disorders. The implementation of new management strategies may have ergonomic implications leading to elimination of the effect of the ergonomic improvements.

The thesis adds empirical information on:

- Associations between measured physical workload in clinical dental work and perceived workload among dentists
- Associations between measured physical workload for dentists and aspects of rationalizations in dentistry

Prevalence of work-related musculoskeletal disorders

Occupational musculoskeletal disorders or WMSDs are a major problem in the industrialized world (Hagberg *et al.* 1995, NRC. 2001, da Costa and Vieira 2010).

According to the European Agency for Safety and Health at Work, the economic cost of WMSDs corresponds to between 0.5% and 2% of the gross national product in some European countries (Buckle and Devereux 2002).

According to European Labour Force statistics (2007), 8.6% of the workers in the EU had experienced work-related health problems in the previous 12 months. Bone joint or muscle problems and stress, anxiety or depression were most prevalent (2007).

The results of the 18th Survey on work-related disorders reveal that about one in five of all employees has suffered during the previous 12 months from either physical or strain related WMSD (Swedish Work Environment Authority, 2008).

There is, therefore, a need for effective preventive actions. In order to prevent WMSDs, it is first necessary to understand their causes.

Prevalence of musculoskeletal disorders in dentistry

Musculoskeletal disorders have become a significant issue for the profession of dentistry and dental hygiene. In general, the prevalence for dentists and dental hygienists is reported to be between 64% and 93% (Hayes *et al.* 2009). The most prevalent regions for complaints are the neck, upper arms and back region (Åkesson *et al.* 1999, Alexopoulos *et al.* 2004, Leggat *et al.* 2007, Hayes *et al.* 2009). In comparison, the point prevalence in the neck-shoulder region among adults in developed countries is about 12 to 34% (Walker-Bone *et al.* 2003).

Conceptual model under study

This thesis will discuss the case of dentists in the context of an “exposure-risk” model (Figure 1). This model describes the relationship between mechanical exposure and risk factors for WMSD and has been suggested by (Westgaard and Winkel 1997).

In this model the internal exposure (level 3) component is determined by moments and forces within the human body, and results in acute physiological responses such as perceived physical workload and fatigue (level 4). The internal exposure is determined by the external exposure (level 2); and the size of the external exposure is determined by the work tasks, the equipment used and the existing time pressure. At the company level, external exposure is determined by the production system consisting of work organization and technological rationalization strategy (level 1). Finally, Figure 1 illustrates that the production system and thereby working conditions are influenced by market conditions and legislative demands from society. In the exposure-response relationships of the model, psychosocial and individual factors may act as modifying factors (Lundberg *et al.* 1994, Westgaard 1999).

Thus, both technological and organizational factors will influence dentists’ work content and reflect critical issues in terms of ergonomic/musculoskeletal risk factors. However, in what way, and to what extent, the relations within the “exposure-risk” model would be influenced is unclear, as there is a lack of quantitative exposure information on each component in the exposure-effect/response model in general and especially in patient-focused care work (Bernard 1997, Hansson *et al.* 2001, Landsbergis 2003). Thus, more detailed quantitative information on the components of the exposure-risk model, taking into account data from both external and internal exposure, is expected to increased knowledge about the associations between the dental work environment and the risk of developing musculoskeletal problems.

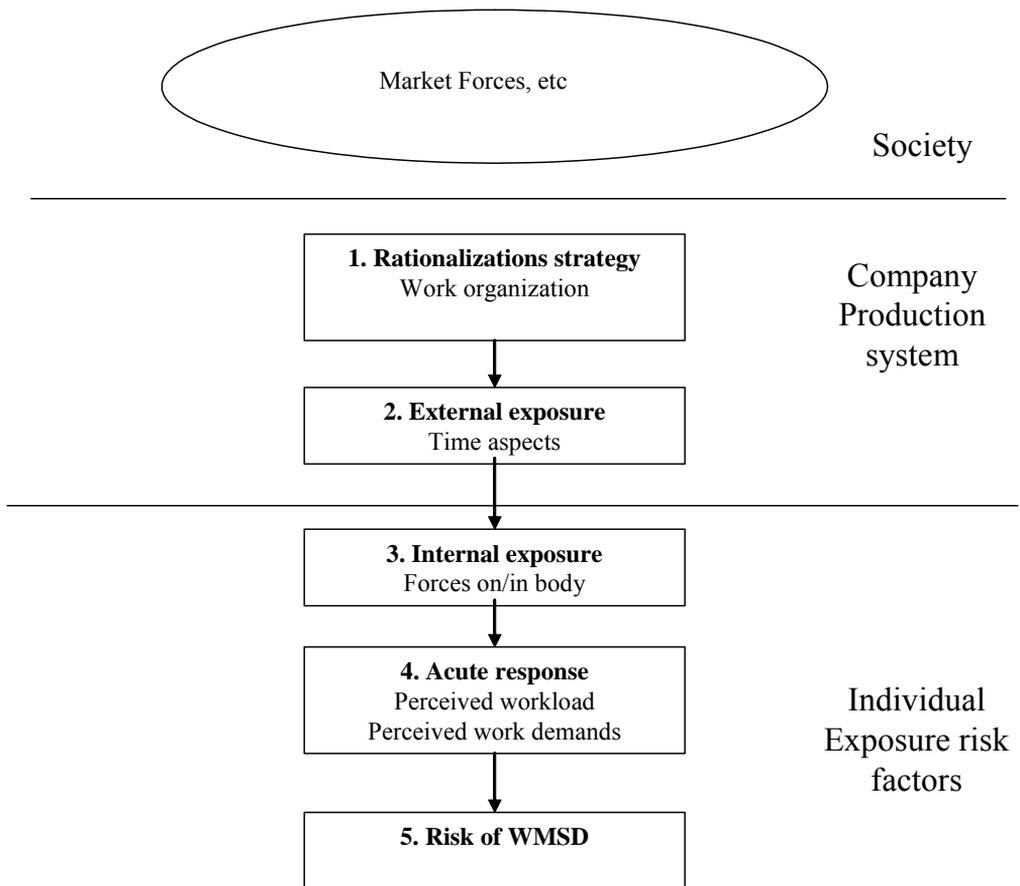


Figure 1. Model of structural levels influencing the development of work-related musculoskeletal disorders. Company's strategies on production system (levels 1 and 2) are influenced at society level. The internal exposure, at the individual level 3, is to a large extent determined by external exposure, level 2. This in turn influences individual acute physiological and psychological responses such as fatigue and discomfort, and finally risk of WMSD. (Adapted from Westgaard and Winkel, 1997; Winkel and Westgaard 2001).

Risk factors for WMSD

The term WMSD is used as descriptor for disorders and diseases of the musculoskeletal system with a proven or hypothetical work-related causal component (Hagberg *et al.* 1995). The World Health Organization has characterized work-related diseases as multifactorial to indicate that a number of risk factors (physical, work organizational, psychosocial, and individual) contribute to causing these diseases (WHO, 1985). Research on physical and psychosocial risk factors for musculoskeletal disorders has identified risk factors for the neck (Ariens *et al.* 2000), the neck and upper limbs (Bongers *et al.* 1993, Malchaire *et al.* 2001, Andersen *et al.* 2007) and the back (Hoogendoorn *et al.* 1999, Bakker *et al.* 2009). Risk factors for musculoskeletal disorders at an individual level are also well known from international reviews (Hagberg *et al.* 1995, Bernard 1997, Walker-Bone and Cooper 2005).

Physical risk factors have been briefly documented as forceful exertions, prolonged abnormal postures, awkward postures, static postures, repetition, vibration and cold.

Three main characteristics of physical workload have been suggested as key aspects of WMSD risk. These are load *amplitude* (level 3 in the model), for example the degree of arm elevation or neck flexion, forceful exertions, awkward postures and so on; and *repetitiveness* and *duration*, which are time aspects of workload (Winkel and Westgaard 1992, Winkel and Mathiassen 1994).

Time aspects (level 2 in the model) of physical workload have been studied less as risk factors than as exposure amplitudes (Wells *et al.* 2007). A possible explanation is that time-related variables are difficult to collect in epidemiological studies. While people report their tasks and activities reasonably well, the ability to estimate durations and time proportions is not as good (Wiktorin *et al.* 1993, Akesson *et al.* 2001, Unge *et al.* 2005). Assessing time aspects of exposure requires considerable resources and typically requires the use of direct measurements, for example by means of video recordings at the workplace in combination with measurements of muscular workload and work postures.

Time is a key issue in rationalization (levels 1 and 2 in the model). Most rationalizations generally aim to make more efficient use of time (Brödner and Forslin 2002). Rationalizations may influence both levels of loading and their time patterns. Changes in the time domain may cause the working day to become less porous, thereby reducing the chance of recovering physically and mentally. Time aspects of loading, such as variations across time, are supposed to be important for the risk of developing musculoskeletal disorders (Winkel and Westgaard 1992, Kilbom 1994a, Mathiassen 2006).

Risk factors for WMSD among dentists

Musculoskeletal disorders have been ascribed some specific risk factors in dentistry, such as highly demanding precision work, which is often performed with the arm abducted and unsupported (Green and Brown 1963, Yoser and Mito 2002, Yamalik 2007). Furthermore, dental work is often carried out with a forward flexed cervical spine also rotated and bent sideways. This implies a high static load in the neck and shoulder region.

The patient's mouth is a small surgical area where the dentist has to handle a variety of tools, and the high demands for good vision when carrying out the work tend to cause a forward bend and rotated positions of the body (Åkesson 2000).

Risk factors for WMSD in dentists are mainly investigated by means of questionnaires (Milerad and Ekenvall 1990, Rundcrantz *et al.* 1990, Lindfors *et al.* 2006). However, in a few studies of dentists, quantitative information regarding physical workload on the shoulders and arms has been assessed by means of observations and direct measurements, during specific or most common work tasks (Milerad *et al.* 1991, Åkesson *et al.* 1997, Finsen *et al.* 1998). Åkesson *et al.* (1997) studied movements and postures regarding dynamic components, such as angular velocities. Both Milerad *et al.* (1991) and Åkesson *et al.* (1997) assessed muscular activities by means of sEMG measurements during dental treatment by dentists at work. However, sEMG signs of fatigue, indicating acute response (level 4 in the model), were not evaluated (Westgaard and Winkel 1996, van der Beek and Frings-Dresen 1998). In addition, no field studies were found that investigate associations between measured internal workload exposure and acute response among dentists. Such associations are discussed in the conceptual exposure-risk model, in levels 3 and 4 respectively.

Ergonomic intervention research

The most common approach in intervention tends to concern the immediate physical workplace problems of a worker (individual level in the model) (Whysall *et al.* 2004, Westgaard and Winkel 2010). This approach may be sufficient as a “quick fix” of single details in the workplace. According to Kennedy *et al.* (2009) there is some evidence that individual-oriented interventions such as arm support, ergonomics training and workplace adjustments, new chairs and residual breaks help employees with upper extremity musculoskeletal disorders. It is also shown that intervention focusing on work style (body

posture) and workplace adjustment, combined with physical exercise, can reduce symptoms from the neck and upper limbs (Bernaards *et al.* 2006).

However, in a review study by van Oostrom *et al.* (2009), workplace interventions were not effective in reducing low back pain and upper extremity disorders. Hence, WMSDs still occur to a considerable extent, and the associated risk factors still remain.

It is suggested that the risk reduction depends on the fact that risks for WMSD exist in production system factors (levels 1 and 2 in the model) that are controlled by management level rather than by ergonomists (Westgaard and Winkel 2010).

In some cases, for example Volvo Car Corporation, a specific model has been developed to make ergonomic improvements, the main idea being that both production engineers and safety people work together. A standardized and participatory model of this kind, for measuring the level of risk and also for identifying solutions, provided a more effective ergonomic improvement process but demanded considerable resources and depended on support from management and unions, as well as a substantial training programme with regular use of the model (Tornstrom *et al.* 2008). An important aspect of intervention programmes is to engage stakeholders in the process (Franche *et al.* 2005, Tornstrom *et al.* 2008).

It is probably a more successful approach to introduce system thinking, which deals with how to integrate human factors into complex organizational development processes than parts or individuals (Neumann *et al.* 2009). Such an approach is rare among ergonomists, who generally prefer to target their efforts on the individual level of the exposure risk model (Whysall *et al.* 2004).

Ergonomic interventions in dentistry

In a recent review by Yamlik (2007), occupational risk factors and available recommendations for preventing WMSDs in dental practice are discussed. It was concluded that WMSDs are avoidable in dentistry; by paying attention to occupational and individual risk factors the risk can be reduced. The occupational risk factors referred to concerned education and training in performing high risk tasks, improvement of workstation design and training of the dental team in how to use equipment ergonomically. Rucker and Sunell (2002) recommended education/training and modification of behaviour for dentists. They argued that most of the high-risk ergonomic factors could be reduced, modified or eliminated by recognition of usage patterns associated with increased risks of experiencing musculoskeletal pain and discomfort. A daily self-care programme was also recommended.

Despite these interventions on the individual level, Lindfors *et al.* (2006) found that the physical load in dentistry was most strongly related to upper extremity disorders in female dental health workers. In addition, as shown in the previous section, the prevalence of WMSD among dentists is high. Thus, it seems that ergonomic interventions are primarily targeted at the individual level of the exposure-risk model. These kinds of interventions on the individual worker are usually not including exposures related to time aspects according the exposure-risk model.

The production system, rationalization and ergonomic implications

Production system

The term “production system” has been defined in many ways depending on the application. Wild (1995) defines a production system as an operating system that manufactures a product. Winkel and Westgaard (1996) divide a system into a technical and organizational subsystem. They propose that, in a production system the allocation of tasks between operators and the sequence that an individual follows should be considered as the organizational level in the rationalization process; and the allocation of functions between operators and machines should be seen as the technology level. Changes in production systems have major effects on biomechanical exposure and are possibly of much greater magnitude than many ergonomic interventions (Wells *et al.* 2007). Risk factors emerge from the interactions between the individual operator and organizational elements in the production system (Figure 1).

Operators’ physical workload profiles might be influenced primarily by the nature of the work itself (Marras *et al.* 1995, Allread *et al.* 2000, Hansson *et al.* 2010). Thus, design of production systems will imply several demands on the performance of the individual worker. In the following sections, rationalization strategies with implications for ergonomics in dentistry will be discussed.

Rationalization

Rationalization is defined, as “the methods of technique and organisation designed to secure the minimum of waste of either effort or material” (World Economic Conference in Geneva, 1927 cited by Westgaard and Winkel 2010). The main goal is to make work more effective. The types of waste have been the subject of elimination over time according to prevailing rationalizations.

Taylor (1911) created ‘scientific management’, where assembly work was divided into short tasks repeated many times by each worker. This approach has come to be referred to as Tayloristic job design, or more generally, “Taylorism”. This strategy was first used in line assembly in Ford car factories and formed a foundation for the modern assembly line (Björkman 1996). In the USA in the 1950s and 1960s, a number of scholars’ ideas and examples of how to create alternatives to Taylorism resulted in the so-called Human Relations Movement. They abandoned Taylorism and wanted to create a more enlarged and enriched job. This post-Tayloristic vision was replaced in the early 1990s. Since then, concepts such as Total Quality Management (TQM), Just In Time (JIT), New Public Management (NPM) and Human Resource Management (HRM) have been introduced both in industry and Swedish public healthcare services (Bjorkman 1996, Bejerot 1998, Almqvist 2006, Hasselbladh 2008).

Ergonomic implications

The rationalization strategy of “lean production” (Liker 2004) uses the terminology “value-adding” and “non-value-adding” (waste). “Value-adding” is defined as the portion of process time that employees spend on actions that create value as perceived by the customer (Keyte and Locher 2004). Thus, the common denominator for the management scholars referred to in the previous section, is to reduce waste. To design, order, and make a specific product or deliver a specific service, two categories of actions are involved: waste and its counterpart.

One major part of this thesis focus on ergonomic implications of this key issue of rationalization: increasing value-adding time at work and reducing non-value-adding time (waste).

Health consequences of lean-inspired management strategies are not well understood, although there are apparent links between these strategies and ergonomics. Björkman (1996) suggests that lean-inspired management strategies do not contribute to good ergonomic conditions. A possible explanation is that the work day has become less porous, i.e. increased work intensification due to a larger amount of value-adding time at work and reduction of rest

pauses. Lean practices have been associated with intensification of work pace, job strain and possibly with the increased occurrence of WMSD (Landsbergis *et al.* 1999, Kivimaki *et al.* 2001). However, there is limited available evidence that these trends in work organization increase occupation illness (Landsbergis 2003).

Nevertheless, in a review study Westgaard and Winkel (2010) found mostly negative effects of rationalizations for risk factors on occupational musculoskeletal and mental health. Modifiers to those risk factors, leading to positive effects of rationalizations, are good leadership, worker participation and dialogue between workers and management.

Only a few studies have been carried out that examined WMSD risk factors such as, force, postures and repetition and job rationalization at the same time, taking into account both the production system and individual level, as described in the model presented in Figure 1. Some studies indicate that reduced time for disturbances does not automatically result in higher risk of physical workload risk factors for WMSD (Christmansson *et al.* 2002, Womack *et al.* 2009). On the other hand, other studies indicate positive associations between rationalizations at work and increased risk of WMSD due to biomechanical exposure (Bao *et al.* 1996, Kazmierczak *et al.* 2005).

The introduction of NPM and HRM strategies in public dental care in Sweden has contributed to the development of more business-like dentistry exposed to market conditions according to lean-inspired and corresponding ideas (Bejerot *et al.* 1999, Almqvist 2006). Also, in studies in the Public Dental Service in Finland and the Dental Service in the UK, it was concluded that work organization efficiency must be enhanced in order to satisfy overall cost minimization (Widstrom *et al.* 2004, Cottingham and Toy 2009). It has been suggested that the high prevalence of WMSD in dentistry in Sweden is partly related to these rationalization strategies (Winkel and Westgaard 1996, Bejerot *et al.* 1999).

For example, in order to reduce mechanical exposure at the individual level, attempts were made to improve workplace- and tool design. During the 1960s in Sweden, patients were moved from a sitting to a lying posture during treatment, and all the tools were placed in ergonomically appropriate positions. The level (amplitude) of mechanical exposure was lowered; however, at the same time dentistry was rationalized.

This rationalization focused on improved performance by reducing time doing tasks considered as “waste” and by reallocating and reorganizing work tasks within the dentist’s work definition and between the personnel categories at the dental clinic. This process left one main task to the dentist: working with the patient. Concurrently, the ergonomics of the dental

clinic were improved in order to allow for improved productivity. However, these changes led to dentists working in an ergonomically ‘correct’ but constrained posture for most of their working hours. Consequently, the duration and frequency parameters of mechanical exposure were worsened at the same time, and the prevalence of dentists’ complaints remained at a high level (Kronlund 1981). Such a result is known as the “ergonomic pitfall” (Winkel and Westgaard 1996).

Society level

A Swedish government report presented in 2002 stated that dental teams have to achieve a more efficient mix of skills by further transferring some of dentists’ tasks to dental hygienists and dental nurses (SOU 2002:53). These recommendations issued at the national level were passed on to the regional level of the public dental care system to implement. Due partly to these recommendations, but also due to a poor financial situation and developments in information technology, the public dental care system of Jönköping County Council decided to implement a number of organizational and technical rationalizations during the period 2003-2008 (Munvädret 2003:9).

The following changes in work organization were implemented: tasks were delegated from dentists to lower-level professions with appropriate education; small clinics were merged with larger ones in the same region; financial feedback was given to each clinic on a monthly basis; in the annual salary revision over the period, salaries for dentists increased from below the national average to slightly above; an extra management level was implemented between top management and the directors of the clinics.

The technical changes comprised: introduction of an SMS reminder system to patients, with the aim of preventing loss of patients’ visits to the clinics; digital X-ray at the clinics; a new IT system to enable online communication between healthcare providers and insurance funds; a self-registration system for patients on arrival, for both receptionist and dental teams.

In accordance with the above reasoning, rationalization along these lines may increase the risk of WMSD problems among dentists. However, there has been no evaluation of quantitative relationships regarding how these changes in work organization in dentistry affect the risk of developing WMSD. This is essential for the description of exposure-effect/response relationships, showing the risk associated with different kinds of effects at the varying exposure levels. Knowledge of such relations is crucial for establishing exposure limits and preventive measures (Kilbom 1999).

Thus, there is a need to understand the relation between organizational system design and ergonomics in dentistry. In the long term, knowledge about these relations leads to more effective interventions, which aim to reduce the risk of WMSD at both the individual- and the production system level.

MAIN AIM

The general aim of this thesis is to study aspects of physical exposures among dentists in relation to risk for WMSD.

Empirical data on production system performance, individually measured physical workload, self-rated physical workload, as well as possible future consequences for mechanical exposure due to rationalization are provided by the appended four papers.

Specific aims:

To explore whether dentists show signs of high muscular workload/activity during clinical dental work (Paper I)

To explore if self-rated physical workload during dental work is reflected in measured postures and movements by dentists (Paper II)

To show how possible rationalizations in dental care may have consequences for biomechanical workload for dentists (Paper III)

To investigate if implemented rationalizations have led to increased risk of musculoskeletal disorders due to changes in biomechanical workload for dentists (Paper IV)

MATERIAL AND METHODS

Study Designs

In Papers I, II and III, cross-sectional study design was used. Paper IV is a prospective cohort study, with approximately six-year follow-up.

In Paper I, direct measurements at the ordinary workplace were used. In Paper II, both direct measurements and questionnaires were used at the ordinary workplace. Paper III and IV employ both observations and direct measurements at the ordinary workplace.

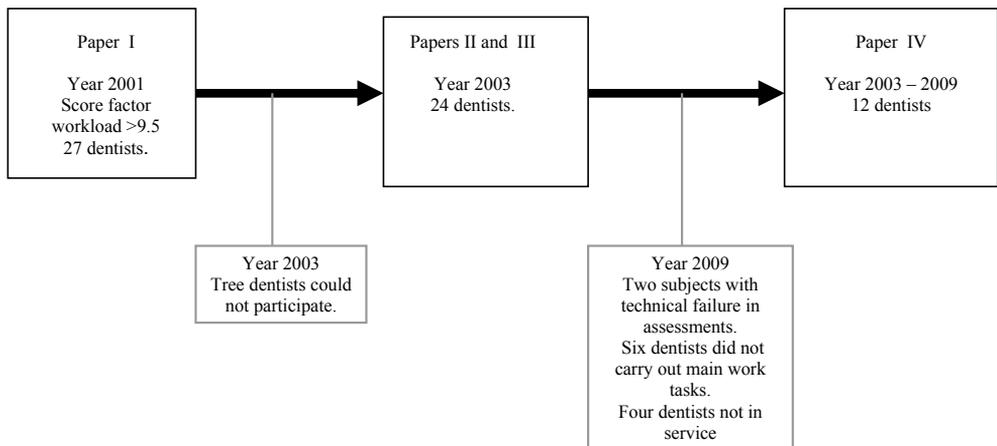


Fig. 2. Sample selection scheme of subjects in the thesis.

Subjects

The study base comprised 73 dentists with WMSD, participating in the Rolander and Bellner (2001) study (Rolander and Bellner 2001). Based on the outcome from a questionnaire, 27 dentists reporting high perceived workload were included in Paper I. Inclusion criteria were a score higher than 9.5 (bad conditions) on two factors: physical work demands and physical workload. The items on physical work conditions were calculated by a factor analysis in the Rolander and Bellner study (2001). All participants were employed at dental clinics in Jönköping County, Sweden. Their mean age was 48 (sd= 7.1, range=31-60) years and they had worked as dentists for an average of 19 (sd=8.5, range=2-35) years.

Fourteen dentists worked full-time (40 hours/week), and 13 worked part-time 30-39 hours a week. All but one were right-handed.

Two years later, 24 of the 27 in Paper I participated (14 female and 10 male) in Papers II and III. Their mean age was 51 (sd = 6.6, range: 39-62) years. They had worked as dentists for an average of 24 (sd = 7.2, range: 9-37) years. Their weekly working hours averaged 37 (sd = 3.7, range: 30-40). All were right-handed.

In Paper IV, 12 of the original 16 dentists who had performed all the observed main work tasks (See Table 2) in Paper III were followed up in 2009. The missing four dentists were not in service in 2009. The cohort constitutes 5 male and 7 female dentists. In 2003, they had a mean age of 51 (sd = 6.4 range: 39-59) years and had worked as dentists for an average of 22 (sd = 7.4 range: 9-34) years. All were right-handed.

Dropouts are shown in Fig. 2.

Methods

This section describes the overall methodological approach of the thesis. The methods used in the four appended papers are presented in Table 1.

Table 1. Methodological overview of the appended papers

Method	Information	Paper I	Paper II	Paper III	Paper IV
Self-report	Survey physical workload/demands		x		
Self-report	Work and break	x			
Observation	Work task time distribution		x		
Video recordings	Work task time distribution / waste analysis			x	x
Measurements	Inclinometry recording		x	x	x
Measurements	Surface electromyography (S-EMG)	x			

Assessment of perceived workload and work demands

Questionnaire

In Paper II a questionnaire was distributed on the web (Esmaker NX), immediately after the measured sequence of the working day. The questionnaire comprised two different groups of items: (1) demographic data (9 items); and (2) self-reported physical work conditions (9 items). The self-reported work conditions were estimated on a scale consisting of eleven squares, with extreme statements concerning the current condition at either end of the scale.

The lowest value, zero (“not at all”), indicated good work conditions and the highest value, ten (“greatly”), indicated bad conditions on a scale consisting of eleven squares.

The items used to quantify physical work conditions were determined by means of factor analysis in the previous study by Rolander and Bellner (2001). The two factors were: self-reported perception of physical demands at work (Factor 1) and self-reported perception of workload (Factor 2), consisting of four and three items respectively.

Assessment of tasks and their time distribution

Observations

The work tasks in Paper I were self-reported by the dentists. A simple task log was used which divided the working day into work and coffee breaks. The investigated working time started with the first patient in the morning and continued for about four hours.

In Paper II, the investigators employed a real-time synchronizing direct observation work task log on a computer. The investigated working time was about four hours. Ten different work tasks were identified: four in sitting positions and six while standing/walking. The observations concerned all tasks performed by the dentist. Coffee breaks were excluded.

Assessment of waste during clinical dental work

Video recordings

In Papers III and IV, dental work tasks were video-recorded using a digital camera (Canon MVX30i). The work tasks were evaluated during the first 45 minutes of the dentist’s working day by means of a video-based work activity analysis system (“Videolys” system; Chalmers University of Technology; Engström and Medbo, 1997) with a time resolution of 1 second. Initially, different work descriptions were derived and coded direct from the video recordings. The classification scheme was set up with the assistance of an experienced dentist and resulted in six main work tasks. Thereafter, the work was evaluated according to the so-called zero-based analysis (Engström and Medbo 1997). The activity analyses were used to estimate the “shop floor” work efficiency of dental work according to Value-Adding Work (VAW) and non-VAW (waste) (Keyte and Locher 2004). Descriptions of the results for the six main tasks are shown in Table 2.

Table 2. Description and classification of work tasks.

Classification	Work tasks	Description
VAW	Patient treatment	Principal activities during patient dental treatment, e.g. dental examination, dental filling therapy, tooth extraction, assessing X-ray pictures and reading patient's journal during dental treatment, reaching for tools and materials during dental patient treatment.
	Dental information	Dentist's information about treatment during the dental treatment. Conversation about dental treatment with patient or relatives to the patient during treatment.
Non-VAW	X-ray handling	Taking X-ray pictures, assessing and storing.
	Administration	Writing/reading and dictation to the patient file.
	Handling parts and materials	Adjusting patient and/or operator chair, handling of tools/materials, Hand hygiene. Transfers of the dentist in the dental practice. Walking to the next patient.
	Disturbances	Short spontaneous breaks during treatment lasting for more than one second. Social communication with patients or colleagues. Waiting.

In the present thesis, VAW was defined in accordance with (Neumann *et al.* 2006). This definition represents an engineering approach used in assembly work, including any assembly work and acquisition of components or tools that could be completed without the operators having to move from their assembly position. This approach influenced the current Papers III and IV, such that all intra-oral patient work and all treatment-related dialogue with a patient without leaving the “working position”, as defined by Rundcrantz *et al.* (1990), was considered as VAW. Consequently, all activities/tasks away from the patient were considered as non-VAW.

Periods of disturbances caused by the researchers were identified and excluded from further analyses. The video recording was stopped during scheduled breaks.

Assessment of physical workload at job level

In Papers I, II, III and IV, exposures at job level were assessed by technical measurements during four hours. Regular breaks and periods of disturbances caused by the investigators were excluded.

Electromyography

The muscle activity of the trapezius descendes was bilaterally registered with an sEMG recorder, the MyoGuard system (Biolin Medical, Göteborg, Sweden). This system is a portable unit for collection and real time analysis of myoelectric signals (Figure 3). A detailed description of the system has been presented by Sandsjö (2004).



Figure 3. The MyoGuard system. The figure shows electrode placement over the trapezius muscles and the datalogger unit on the right side of the hip.

Both the average rectified value (ARV) and mean power frequency (MPF) of the sEMG signal were analysed.

The Myoguard sEMG was calibrated before starting the measurement during work. During this process each subject was seated on an ordinary working chair with the lumbar spine resting against the back support. The subject performed three reference contractions, each lasting for 20s. The reference contraction was performed with both arms held at 90° abduction and in about 10° forward flexion from the frontal plane simultaneously, without any weight in the hands.

Normalization was performed by dividing all ARV values by the value obtained from the reference contraction and expressed as a percentage of this value, the reference voluntarily electrical activation (RVE). The frequency content of the signal was studied by calculating the frequency spectrum, with the MPF as an indicator of muscle fatigue (DeLuca 1984, Öberg *et al.* 1995). The MPF value was normalized in the same way as ARV, with all values expressed as percentages of the value obtained from the reference contraction.

The relative rest time analysis was based on individual registrations of trapezius activity during rest. Each reference contraction was followed by a registration with the muscle at rest. Three 20-second resting recordings were performed when each subject was sitting with their arms loosely placed on their lap and their shoulder muscles relaxed.

The rest threshold level is defined as the mean ARV value of the best, i. e. the lowest, of the attempted rest, to which 10% of the reference voluntary electrical activation (RVE) of reference contraction was added (Kadefors *et al.* 1996), resulting in a work/rest threshold of about 1.5-2% MVC. All ARV values below the rest threshold value are assumed to represent muscular rest. Accumulated muscular rest was calculated as the number of ARV-values below the rest threshold and presented as a percentage of the measured time.

Inclinometry

Inclinometry, based on triaxial accelerometers, was used to measure postures and movements for the head, back and upper arm (Hansson *et al.* 2006). Inclinometers were used to record the flexion/extension of the head and trunk and upper arms elevation relative to the line of gravity during the four hours of each dentist's regular work. A datalogger, with a sampling rate of 20Hz, was used for data acquisition (Logger Teknologi HB, Åkarp, Sweden). Analyses of the inclinometer data were performed with PC-based programs (Department of Occupational and Environmental Medicine, Lund University Hospital, Lund). Postures and angular velocities were calculated for each activity category obtained by synchronizing video and inclinometer recordings (Forsman *et al.* 2002).

One inclinometer was placed on the forehead, one on the upper back to the right of the cervical-thoracic spine at the level of C7 and Th1, and one on each upper arm (Figure 4).



Figure 4. Inclinometer datalogger and inclinometers attached on a dentist.

The reference position for the head and upper back (zero degrees flexion) was defined as the position obtained when the subject was standing, looking at a mark at eye level. The forward direction of the head and back was defined with the subject sitting, leaning straight forward, looking at the floor.

For the upper arms, 90° elevation was defined as the position obtained when subjects were standing with their arms elevated to 90° in the scapular plane. Zero degrees of elevation was recorded with the side of the body leaning against the backrest of a chair, the arm hanging perpendicular over the backrest of the chair with a dumbbell of 2 kg in the hand.

Data analysis

In general, descriptive statistics are presented as means (m), and 95 percent confidence interval (CI 95%) in Papers I-IV. The (CI 95%) dispersions for inclination data were adjusted according to the Bonferroni correction in Papers II and III. In order to estimate variation in velocities and postures, differences between 90th and 10th percentiles for inclinometry data were used (Paper III and IV).

For the inclinometry measurements, group means of the 50th percentile and group means of differences between 90th and 10th percentiles were used in order to estimate variation in velocities and postures (Mathiassen 2006).

In Paper I, differences in ARV%, accumulated muscular rest% and MPF% during work and coffee breaks were calculated using repeated measure ANOVA, with age and period of employment as covariates. Linear regression analysis was performed with time as an independent variable and ARV%, accumulated muscular rest% and MPF% as dependent variables. Results are presented in correlation coefficients (r) for the entire group and in slope coefficients (B) on an individual level.

Test of normality was performed with the Kolmogorov-Smirnov test in Papers I and IV.

In Paper II, Pearson correlations were used for associations between the self-assessment items in the two factors for perceived workload /demands and inclination data.

In Paper III, the ANOVA test for repeated measurements, adjusted for multiple comparisons by the Bonferroni method (Douglas and Altman 1999), was used in order to compare inclinometry data during the different VAW and non-VAW work tasks.

Paired t-tests were used for both comparing inclinometry data during the different work tasks in Paper II and in order to analyse changes during the same kind of VAW and non-VAW work tasks between year 2003 and 2009 (Paper IV). Paired t-tests were also used in order to detect differences in postures and movement velocities in both year 2003 and 2009, between 45 minutes of video recordings and the four hours of inclinometry recordings in Paper III and IV.

In order to analyse changes in time distribution during VAW and non-VAW tasks in follow-up Paper IV, the Wilcoxon signed ranked test for related samples was used.

Data were analysed with the statistical software SPSS for Windows.

Generally, significance was assumed at α level=0.05.

RESULTS

Paper I

The sEMG recordings showed that the group mean trapezius activity was 62% (CI 95%=55.8-68.8) /54% (CI95%=45.1-58.8) ARV in right/left side respectively. The accumulated muscular rest time was 34% (CI95%=26.5-41.1) / 31% (CI95%=24.0-38.0) of the total recorded time in the right / left side. Regression analysis between ARV% and time during work showed significant correlation coefficients (r), 0.53 (p<0.001) and -0.15 (p<0.05) for right and left sides respectively (**Paper I**, Figures 2 and 3).

When regression analysis was performed for each individual separately, there was some variation, with slope coefficients (B) from -0.05 to +0.2 on the right side and -0.12 to +0.12 on the left side. Eight of the dentists (27%) had negative slope coefficients (B) on the right side, and 16 (64%) on the left.

A visual comparison was obtained for all dentists with a positive slope on ARV% during work. They were compared with MPF% during work and none had a negative slope, indicating no typical signs of muscle fatigue.

Paper II

Self-reported perception of physical demands at work and workload

The reported mean score for the items in perceived physical work demands (Factor 1) and perceived physical workload (Factor 2) were $m=9.2-9.7$ and $m=8.8-9.5$ respectively.

Inclinometry and perception of physical demands at work and perception of workload

No significant correlation was found between perception of variables in physical demands at work (Factor 1), perception of workload (Factor 2), and inclination angles of the head, neck and upper arms.

Significant negative correlations ($r=-0.48$ to -0.66 $p<0.05$) were found between variables in the perception of workload (Factor 2) for the head, neck and upper arms movements and angular velocities in the 50th percentile (**Paper II**, Table3).

Paper III

Task time distribution

Dentists' VAW tasks comprised 57% of the total observed time (**Paper III**, Figure 1). The major part (87%) of the VAW consisted of "patient treatment". The tasks of "patient treatment", "handling parts and materials" and "disturbances" were carried out by all the dentists. "Dental information", "administration" and "X-ray handling" were carried out by 23, 20, and 19 dentists respectively.

Task-related mechanical exposures

Work postures

"Patient treatment task", constitute the major part of VAW and implied a significantly more flexed posture of the head compared with all other investigated work tasks. The median head flexion angle was 39.9°, compared with 19.5° during "administration" and "disturbances". For the back, "patient treatment" implied significantly more forward flexion than "handling parts and materials". With the exception of "administration" and "dental information", the range in position of the head, i.e. the difference between 10th and 90th percentiles, was significantly smaller in "patient treatment" compared with the other investigated work tasks (**Paper III**, Table 2).

The work postures of the right and left upper arms were in general not significantly influenced by any of the investigated work tasks.

Angular velocities

The "patient treatment" task implied generally lower medium movement velocities and smaller velocity ranges (90th – 10th percentiles) for the head and back compared with the other investigated work activities. The medium angular velocities and velocity ranges (90th -10th percentiles) of the upper arms were also generally lower and smaller during this activity. In particular, both medium movement velocities and velocity ranges (90th – 10th percentiles) of the right upper arm were lower and smaller compared with the "handling parts and materials" task. Furthermore, the medium movement velocities and velocity ranges (90th – 10th percentiles) of the left upper arm during "patient treatment" were significantly lower and smaller compared with the other investigated work tasks, with the exception of "administration" and "handling X-ray pictures". (**Paper III**, Table 3).

In summary, value-adding tasks (especially patient treatment) implied, to a greater extent than non-VAW tasks, mechanical exposures that are suspected to be associated with increased risk of WMSDs.

Paper IV

Time distribution of work tasks

The time consumption of the various work tasks was compared in year 2003 and 2009. VAW time as a proportion of total observed time tended to decrease on average from 57% at baseline in year 2003 to 45% in 2009 ($p=0.12$). Also the proportion of time spent on “patient treatment” tended to decrease on average from 47% in 2003 to 34% in 2009 and contributed solely to an overall reduction in the proportion of time spent on VAW in 2009 ($p=0.14$) (**Paper IV**, Table 1).

Changes in task-related mechanical exposure between 2003 and 2009

VAW Tasks

The median head inclination increased from 40° in 2003 to 46° in 2009, while performing “patient treatment” ($p=0.007$). The range of postures and movement velocities (90th – 10th percentiles) for the head were reduced by 10° and $5^\circ/s$ respectively in the follow-up year. The range in movement velocities (90th – 10th percentiles) for the right upper arm had also significantly decreased in 2009 by $11^\circ/s$. All these changes point towards more constrained work postures during patient treatment at follow-up (**Paper IV**, Tables 3 and 4).

Non-VAW tasks

During “X-ray handling”, the median elevation of the left upper arm was reduced from 35° in 2003 to 23° in 2009 ($p=0.02$), and the range of both right and left upper arm postures (90th – 10th percentiles) was also significantly reduced by 10° . Reduced median movement velocities for right (dominant) upper arm by $6^\circ/s$ ($p=0.08$) in combination with more narrow movement velocity ranges (90th – 10th percentiles) by $15^\circ/s$ ($p=0.01$) were found at follow-up.

During “administration”, median movement velocities and the range of movement velocities ($90^{\text{th}} - 10^{\text{th}}$) was in general reduced for all the investigated body parts in 2009 compared with 2003. Also a tendency towards a narrower posture range was found for back and upper

extremities in 2009 compared with 2003. Thus, both “X-ray handling” and “administration” were performed under more constrained conditions in the follow-up year.

In contrast, “handling parts and materials” implied more dynamic working conditions in 2009 compared with 2003 (**Paper IV**, Tables 3 and 4).

Changes in mechanical exposure of VAW and/ non-VAW.

No major changes in exposure occurred, except for an increase by 4° in head inclination during VAW, from 2003 to 2009. In both 2003 and 2009, VAW showed more forward flexed postures for the head and back compared with non-VAW. In addition, the figures for both the median movement velocities and movement velocity ranges were lower for head, back and upper arms during VAW, compared with non-VAW, both in 2003 and 2009 (**Paper IV**, Tables 3 and 4).

Changes in mechanical exposure during video recordings and four hours of registrations

With the exception of a reduced range of right upper arm postures (90th – 10th percentiles), from 33° in 2003 to 28° in 2009 during 45 minutes of video recordings and reduced medium movement velocities from 9.9°/s in 2003 to 8.9°/s in 2009 during four hours of inclinometry registrations, no significant changes were found in the follow-up year (**Paper IV**, Tables 3 and 4)

GENERAL DISCUSSION

Methodological issues

Selection

The 27 dentists studied were selected because they had reported WMSD, high perceived workload and high work demands in a previous study by Rolander and Bellner (2001). This might complicate generalization of the results. However, the investigated dentists in all the appended papers did not significantly differ from the remaining dentists included in the Rolander and Bellner (2001) study regarding perceived workload, work demands, length of employment and gender distribution.

Moreover, in cross-sectional studies, there is always a possibility of healthy worker selection, i.e., that subjects with WMSD are more liable than healthy ones to change jobs. Such a healthy selection phenomenon is partly supported by a five-year follow-up study among dentists in Sweden (Åkesson *et al.* 1999). However, less experienced dentists who had been employed for a shorter period of time were more likely to report WMSD (Chowanadisai *et al.* 2000, Leggat and Smith 2006). A possible explanation is that more experienced dentists have developed working techniques and coping strategies to help deal with WMSD. The dentists investigated in Paper I had on average been employed for 19 years, indicating an experienced group of dentists. Thus, it is not likely that the selection of the dentists in this thesis is a problem.

Observation bias

All the observations and technical measurements were performed at the workplace and the investigators were well aware of the working conditions. Therefore, there is a risk of observer bias.

In order to reduce observational bias, strict protocols were used. In Paper I a simple activity report was used by the dentists, dividing the observation into coffee breaks and dental work. In Paper II the investigators used a real time synchronizing log on a computer during a period of four hours, direct with the measurements of the work tasks. In Papers III and IV the work tasks were investigated by means of video recordings synchronized direct with the measurements at the workplace. Analysis of the video recordings allows high resolution (on second level) of the tasks during the work in terms of accuracy and applicability for time proportions. Furthermore, the combination of video recordings and synchronized direct

measurements enhanced the understanding of the mechanical exposures in an appropriate way (van der Beek and Frings-Dresen 1998).

Study design

The research designs in Papers I-III are cross-sectional. Such a design is appropriate for describing the status of phenomena or for describing relationships among phenomena at a fixed point in time. However, since the measurements were carried out during a period of time, on different subjects and on different weekdays, the results obtained achieve good validity.

The crossover design of Paper II is questionable when it comes to determining the direction of the associations between inclination data and perceived workload and work demands. However, in the proposed exposure-effect model by Westgaard and Winkel (1997), the internal exposure estimated by postures and movements precedes the acute response in terms of perceived workload and work demands. This suggests that the estimated postures and movements cause estimates of perceived workload.

In Paper IV the research design is prospective and appropriate for studying the dynamics of a variable or phenomenon over time. Furthermore, investigators may be in a position to impose numerous controls to rule out competing explanations for observed effects (Polit and Hungler 1995). However, due to the design used, the implemented "Rationalization" as reported in the introduction to this thesis could not identify the effects of the single rationalization measures.

Exposure assessment by questionnaire

In Paper II, a questionnaire was used in order to estimate acute response by means of the factors "perceived workload" and "work demands". Questions about the physical environment were answered on scales with eleven positions. The anchor points were labelled "Not at all" and "Greatly" respectively. The latter expression may have led to higher estimates and a smaller dispersion, compared with a more powerful expression such as "worst case". It is conceivable that the narrow dispersion and the small differences in the high estimates are of no clinical significance (Kirkwood and Jonatan 2003). The collected data are on an ordinal level and not equidistant, so there is a risk of bias in evaluating the size of perceived workload and work demands (Svensson 2000).

In a study of cleaners and office workers it was shown that subjects with complaints rate their exposure/load higher than those without. In fact, the subjects with complaints showed

lower direct exposure by means of direct measurements (Balogh *et al.* 2004). As all the dentists included suffer from some kind of WMSD, a slight overestimation of the perceived work estimates may be expected. However, when estimates of perceived workload for the 73 dentists with complaints were compared with those for dentists without complaints in the Rolander and Belner (2001) study, no differences were found.

Measurement equipment

The sEMG and inclinometry measure equipment used has a weight of approximately 2 kg and it is possible that dentists experience that it is heavy to carry around. Measurements would be biased if subjects changed their usual way of working during the measurement hours, e.g. by fewer pauses, or working in other postures. However, it seemed that the dentists more or less forgot the equipment and did not think about it during the measurements.

Representativity

An obvious pitfall would be, if exposures were not registered from representative work tasks, or if registrations were made on days that were either especially stressfully or calm. By measuring continuously during four hours, on varying days for different individuals, most of these problems have been avoided. However, the representativity of inclinometry measurements during the 45-min video recordings in both Paper III and Paper IV may be questioned. Postures and movement velocities were continuously recorded for each subject during four hours. Comparison between the mechanical exposures assessed during the video recordings and the four hours of continuous registration, showed only minor differences for the median head posture, range of head posture and range of head movements. In 2003 (**Paper III**, Table; 2 ;**Paper IV**, Tables 3 and 4) a more strenuous workload was found during the 45 minutes of video recording. This may suggest some overrepresentation of the work task “patient treatment” during the video recordings in 2003.

Concerning the 45 min of registration, it is reported that sample duration longer than 40 min is needed to reduce mechanical exposure bias to below 25% of true whole-day exposure when studying arm movements among house painters (Mathiassen and Svendsen 2009). However, the investigated exposure ranges among dentists are presumed to be smaller compared with the range of movements among housepainters. This suggests a small overall mechanical job exposure bias, strengthened by the minor differences between the four hours of registrations and the 45-min video registrations.

Observer reliability of video-based task analysis

In Papers III and IV a video analysing system was used to identify the tasks (“Videolys” system; Chalmers University of Technology; Engström and Medbo 1997). The method used for work task assessment has shown good reliability in studies of industrial work environments. In Paper III the reliability of work tasks analysis was assessed, as described by Kazmierczak *et al.* (2006). The time history agreement between two researchers who made independent analyses of 3h and 45 min of the video recordings was 82%. Kazmierczak *et al.* (2006) achieved 87% time history agreement between two independent observers, only slightly higher agreement than ours. This suggests that the assessment of dental healthcare work tasks in Papers III and IV has an acceptable reliability. Furthermore, since only one researcher analysed all the video recordings, no inter-individual observer bias was introduced in the comparisons between 2003 and 2009.

Physical workload and exposure assessments

Physical workload includes a multitude of dimensions. Our quantitative measurements included assessments of postures, movement and muscular load (Papers I-IV), which corresponds to previously identified risk factors, i.e. awkward postures (Åkesson *et al.* 1997, Finsen *et al.* 1998, Ariens *et al.* 2001) muscular load, fatigue and lack of relaxation (Veiersted and Westgaard 1993, Oberg *et al.* 1995, Hägg and Astrom 1997). As a simple measure of posture and movement variation, we calculated posture and movement range as the difference between the 10th and 90th percentiles (Mathiassen 2006). Hence relevant aspects were considered.

Concerning validity, with respect to risk estimation of WMSD, the task-based estimates are, in general, equivalent to, or less correct than, job exposure mean levels (Mathiassen *et al.* 2005). In our studies, physical workload was estimated both on task- and job exposure levels.

sEMG

In Paper I, sEMG was used to assess the physical workload in terms of internal exposure. The muscular activity in the descendents part on both sides of the trapezius was quantified. The recorded myoelectric activity was normalized towards a sub-maximal reference contraction; the arms from a defined postures without any weight in the hands given 100% Reference Voluntary Electrical Activation (RVE). Sub-maximal reference contraction was used instead of maximal performance test due to the fact that maximal efforts are heavily dependent on the participant’s motivation, especially among those who are afflicted with

shoulder problems. The reference postures used correspond to about 15% Maximally Voluntary Contraction (MVC) (Mathiassen *et al.* 1995).

The EMG amplitude (ARV%) can be used to obtain an estimate of the physical exposure during work, and a linear relationship between the EMG signal and exerted force up to about 30% MVC can be expected (Basmajian and DeLuca 1995). However, the validity of translations of EMG amplitude from the upper trapezius into exerted muscle force and movement was seriously questioned for tasks involving large or fast arm movements (Mathiassen *et al.* 1995).

On the other hand, fast upper arm movements probably occur infrequently in the case of dentists. This is confirmed by the low measured angular velocities in Papers II, III and IV. The sEMG activity levels are also influenced by several confounding factors such as perceived negative stress and wide inter-individual variation (Rissen *et al.* 2000, Nordander *et al.* 2004).

Mean power frequency analysis is used as an estimator for signs of muscular fatigue. A relation between lowered frequency spectrum of the sEMG and muscular fatigue during sustained contractions has been shown (DeLuca 1984). Further, a more than 8% reduction of MPF, compared with the initial reference contraction, can be indicative of muscular fatigue (Öberg *et al.* 1990). Yet, Minning *et al.* (2007) found that at a force amplitude level below 50-60% MVC, a decrease of the MPF is difficult to detect. In contrast, Hummel *et al.* (2005) found decreased MPF in the upper trapezius muscle at 30% MVC level during six minutes of sustained contraction. In our study, the actual measured ARV values (Paper I) corresponded to about 10-15% MVC. This probably explains why we found no decrease in the MPF values.

sEMG provides an opportunity to quantify the time proportions of muscular rest (Hagg and Astrom 1997, Nordander *et al.* 2000, Sandsjo *et al.* 2000). This aspect is most relevant to the risk of myalgia, due to an orderly recruitment of motor units, low threshold muscle fibres type I are vulnerable to muscle contractions of long duration, even at very low amplitudes; this is known as the “Cinderella hypothesis” (Henneman *et al.* 1965, Hägg 1991).

Also, it is possible that variation in muscular load levels will improve the occurrence of motor unit substitution (Thorn *et al.* 2002). Motor unit substitution and variability might be able to raise the threshold of recruitment for an exhausted motor unit – a factor that might protect for WMSD disorders during low static work (Westgaard and de Luca 1999, Madeleine 2010). However, with the single channel EMGs measurements used in Paper I it was not possible to estimate the occurrence of motor unit substitution variability (Madeleine 2010).

In Paper I we used time proportion of total muscle relaxation (accumulated muscle rest %) as an indicator of recovery time for the low-threshold motor units. We used a work/rest threshold of about 1.5-2.0% MVC. This is higher than in the studies by Hägg *et al.* (1997) and Hansson *et al.* (2000), as they used rest threshold value of about 0.5% MVC. This could imply that low muscular physical load is considered as muscular rest instead of low static load. This might explain the relative higher amount of accumulated muscular rest in Paper I.

Inclinometry

The inclinometry method used to estimate posture and movements has shown good precision and high reliability (Hansson *et al.* 2006). Rotation could not be measured with this method. However, concerning head inclination, it would be of interest to do this, as it could be observed in the video recordings that rotation is often combined with other movements such as flexion and bending of the neck to compensate for limited access to the mouth of the patient (Papers **II**, **III** and **IV**). Another limitation is that only posture and movements are estimated, while effects such as forces have not been considered.

Risk parameters and time aspects

Risk factors for WMSD with a special focus on time aspects are discussed in this thesis. Time aspects are crucial in relation to rationalizations. Physical workload, measured by postures and movements, with time aspects, were derived on both tasks and job levels in Papers III and IV. Time aspects of loading, such as variation over time, are suspected to be important for the risk of developing musculoskeletal disorders (Winkel and Westgaard 1992, Kilbom 1994b, Winkel and Mathiassen 1994).

Time patterns of physical workload can be expected to change in the future rationalization of dentistry. In Papers III and IV, detailed information on mechanical exposure has been evaluated by combining direct measurements and video-based observations of work task distribution according to previously described procedures. This allows us to consider aspects of exposures that are rarely considered in epidemiology and intervention studies. Furthermore, it allows us to consider the potential effects of rationalization, aiming at reducing the amount of waste/non-VAW. However, our assessment was confined to dentists, while the rationalizations aimed to reduce waste at system level. Thus, the complete result at the organizational level, seen as a reduction of waste, cannot be evaluated by the present study design, since changed distribution of work activities between occupational groups was not included in the study.

Operationalization of the concept of rationalization

Rationalization is defined, as “the methods of technique and organisation designed to secure the minimum of waste of either effort or material” (World Economic Conference in Geneva, 1927, cited in Westgaard and Winkel (2010). In industry, the recent focus in rationalization is concerned with maximizing the creation of value as perceived and paid for by the customer (Brödner and Forslin 2002, Keyte and Locher 2004).

The analysis system we used was developed for industrial purposes, and work tasks were classified according to an engineering and lean-production approach focusing on VAW vs. non-VAW (Liker 2004). The assessment of VAW performed in Papers III and IV implied that all activities which could be completed without the dentist having to move away from the patient have been considered as VAW (Neumann *et al.* 2006). Consequently, some typical work tasks usually carried out by a dentist, such as “assessing X-ray pictures while not in work position”, were not considered as VAW. Due to this methodical drawback the proportion of VAW may be slightly underestimated.

Furthermore, this approach can be discussed, mainly regarding the fact that the aim of industrial processes is to add value to a product, while healthcare provides a service to a patient. The industrial production perspective that is commonly used in healthcare services only refers to how to control costs and increase cost efficiency in terms of an economic discourse. The productivity is seen as the value from production in relation to used resources (Nordgren 2009). This concept does not consider the contribution of the patient in value creation, e.g. in terms of perceived quality of treatment (Grönroos and Ojasalo 2004).

However, the production approach used in Papers III and IV provides an interesting starting point to evaluate work tasks also in the healthcare sector. Further, with the introduction of new management styles such as NPM, HRM and lean-production ideas in the public sector, the patient is considered to be a customer; thus the perspective taken in this thesis was to discriminate between VAW and non-VAW (Bejerot *et al.* 1999, Nordgren 2004, Almqvist 2006, Cottingham and Toy 2009). Alternatively, in publicly funded healthcare, society could be considered the customer; however, that option was not chosen, as it would have included a broader analysis not confined to what is done in direct relation to the patient. It is evident that the current approach may be questioned but has a great deal to contribute, and that the concept applied in healthcare needs further elaboration in the future.

Discussion of results

Physical workload exposure at job level

Muscular load and risk assessment for WMSD

The mean ARV levels in the present study for both upper trapezius muscles were 54–62% of the calibration level. The corresponding load levels expressed in percent of MVC are about 5–9%. Åkesson *et al.* (1997) reported a median load of 8.4% of MVC in the upper trapezius muscles when performing dental work during dental treatment tasks, showing almost the same load values. This suggests small differences between the muscular load during patient treatment and the total muscular load at job level during four hours. This pattern was also confirmed by Finssen *et al.* (1998) investigating muscular load of dentists during the most common work tasks.

Hansson *et al.* (2010) showed that the muscular load in the 90th percentile of MVC is about 9%, for those working with varied office jobs known to have low risk of WMSD (Nordander *et al.* 2009). Our findings were almost the same for the investigated dentists in the 50th percentile, which is 7-9%. In general, high correlations can be found between EMG measurements in 50th and 90th percentiles in the upper trapezius (Hansson *et al.* 2010). This indicates a rather high muscular load and consequently increased risk of WMSD for dentists. In addition, on the right side there was an increase of the ARV during work, possibly caused by increased muscle fatigue (Stulen and De Luca 1978). This is contradicted by the absence of MPF changes in the present study. However, much higher ARV values are required for any reduction in the MPF (See the section on methodical considerations).

Accumulated rest % of total measured time was used as an indicator to evaluate the amount of recovery time for the low-threshold motor unit (Veiersted *et al.* 1990). Prolonged static contractions, with low accumulated muscular rest can result in an overload of type 1 muscle fibres and may be a primary risk factor for musculoskeletal disorders (Hägg 1991).

The accumulated rest was compared in studies using the Myoguard equipment and the same unloaded reference contraction. The result indicates that the accumulated muscle resting for a dentist is about 20% units lower than that of white-collar workers and approximately 10% units higher than that of female supermarket employees and female cashiers (Rissen *et al.* 2000, Sandsjö *et al.* 2000, Sandsjö 2004). (**Paper I**, Table 2). This low amount of muscular rest is associated with rather high prevalence of complaints from musculoskeletal system in jobs characterized as repetitive and constrained (Hagg and Astrom 1997, Nordander *et al.* 2009, Hansson *et al.* 2010). Consequently, an increased risk of WMSD may be expected due to sustained static muscular load in the trapezius muscles during dental work.

Thus, considering both the level of muscle activity and the occurrence of muscular rest in Paper I, the muscular workload in the upper trapezius for dentists indicates an increased risk of developing WMSDs.

Mechanical exposure and risk assessment for WMSD

Both head and upper arms were tilted forward or elevated more than about 27°-29° each, for half the observation time (**Papers II, III, and IV**). A forward head inclination of above 15°-20° during “an extended period”, may increase the risk of developing neck pain (Ohlsson *et al.* 1995, Bernard 1997, Ariens *et al.* 2001). In addition, the forward inclination of the back was about 16° or more during half the observation time (**Paper III**, Table 2 ; **Paper IV**; Table 3). Forward flexed back spine inclination in a sitting work posture produces higher muscular load in the neck than sitting with a slightly inclined backward or vertical back spine (Schuldt *et al.* 1986, Harms-Ringdahl and Schuldt 1988). It was shown that 79% of all the observed work tasks were performed in sitting positions (**Paper II**; Table 4). Thus, sitting work postures with flexed forward inclinations for both the back and the cervical spine were found during an extended time. It is possible that this may contribute to the risk of developing pain and WMSD in the neck regions.

Concerning the upper arms, Järvholm *et al.* (1991) showed that the intramuscular pressure in the supraspinatus muscle increases when the blood flow is impaired in unsupported arm positions exceeding 30° abduction and potentially increased risk of WMSD. The postures of the upper arms were only slightly (one to three degrees) below this value; consequently the risk of developing WMSD in the shoulder region due to impaired blood flow is not inconceivable.

The arm and head velocities (the 50th percentiles) in the present study are low compared with industrial assembly work (Christmansson *et al.* 2002, Balogh *et al.* 2006). The low velocity reflects the constrained postures typical for dentistry and thus seems to have a good “face validity”. In a study by Hansson *et al.* (2010), investigating measured postures and movements by inclinometers in different occupations, dentist work was classified as “repetitive non-industrial work”. Repetitive work showed elevated risk of developing WMSD compared with varied mobile work such as nursing and home-help work (Nordander *et al.* 2009).

Thus, the mechanical exposure figures, the risk level with regard to WMSD seems to be high compared to occupational groups with more varied work (Bernard 1997, NRC, 2001, da Costa and Viera 2010). Furthermore, the mechanical exposures were essentially unchanged for both

postures and velocities at job level during follow-up in Paper IV. Consequently no changes in risk of developing WMSD due to mechanical exposure could be expected (**Paper IV**, Tables 3 and 4).

Consequences of physical exposure due to rationalizations

Mechanical exposures and risk assessment during VAW

Generally, patient treatment comprises a major part of the VAW time: 87% in Paper III and 77% in Paper IV.

During patient treatment the head was held in a rather steep forward position, 40° to 46° (**Paper III** and **Paper IV**). This forward inclination of the head was significantly higher compared with other investigated work tasks. As stated in the previous section, forward head inclination above 15°-20° during “an extended period”, may increase the risk of developing neck pain (Ohlsson *et al.* 1995, Bernard 1997, Ariens *et al.* 2001). Furthermore, during the follow-up study an increase in forward flexion of the head was found, from 40° in 2003 to 46° in 2009 (**Paper IV**, Table 3). The effect of such an increase is not known in terms of increased risk. The angular velocities during patient treatment for the head, back and upper arms were significantly lower and the differences between the 90th and the 10th percentiles smaller, compared with other investigated work tasks, indicating far more constrained static working movements during the patient treatment task. This means that a major part of VAW is characterized by more constrained physical working conditions compared with the other work tasks investigated.

Comparing VAW with non-VAW with respect to mechanical exposure, more constrained working conditions were found during VAW (**Paper IV**, Tables 3 and 4).

Furthermore, the angular velocities for the head, back and upper arms during VAW in our study (**Paper III**, Table 4) are in general three to four times lower compared with VAW during industrial assembly work, assessed using similar analytical methods. The VAW during dental work implied higher figures for forward flexion of the head and back, compared with both material picking and car disassembly work. This indicates that mechanical exposure during dental VAW is more constrained than during industrial (dis)assembly work.

Mechanical exposure during non-VAW tasks

During “administration” work task, decreased movement velocities and more narrow posture range were found in the follow-up study. This may indicate a more constrained work posture, possibly due to more intensive VDU use during this task in the follow-up year.

Similar results were found by Arvidsson *et al.* (2006), when evaluating physical workload in connection with the computerization of air traffic control systems. In addition, the figures for median elevation postures for both years during administration tasks, for right and left upper arms, are about 29° and 25° respectively, and were considerably lower than for CAD operators. The CAD operators were shown to have a median elevation for right and left upper arms of about 43° and 39° respectively (Bystrom *et al.* 2002); however, they were working with their arms supported. During the video observations frequently unsupported arms were identified; a possible consequence of this which might be expected is raised sEMG activity in the trapezius muscles (Aaras *et al.* 1997, Karlqvist *et al.* 1998, Visser *et al.* 2000). In addition, the figures for angular velocities, both mean median and differences in 90th to 10th percentile ranges were also lower in the follow-up study (**Paper IV**, Table 4). Thus, administration tasks were performed under more constrained conditions at follow-up.

In contrast, the work task “handling parts and materials”, which comprised the major part of the non-VAW tasks (**Paper III**, Figure 1), implied in general the most dynamic working conditions compared with the other investigated work tasks. During this task all mean medium velocities were significantly higher and the range of velocities was wider, compared with both “patient treatment” and “administration” tasks (**Paper III**, Table 3). Furthermore, increased median movement velocities and wider movement ranges were found at follow-up compared with year 2003 (**Paper IV**, Table 4). The negative correlations found in Paper II, between increased median movement velocities and the items for perceived workload, confirm the more dynamic working conditions in the follow-up year for this work task.

Towards ‘Sustainability’?

The proportion of time spent on VAW was shown to be 59% of the total observed time in 2003 and 45% in 2009 (**Paper III**, Figure 1; **Paper IV**, Table 1). In studies of old-fashioned car disassembly, VAW comprised 30% (Kazmierczak *et al.* 2005); in modern industrialized work, such as motor and sewing machine assembly, it comprised about 70% (Bao *et al.* 1996, Neumann *et al.* 2006). Thus, the percentage of VAW in the present study is approximately 20-25 percentage units lower compared with industrial assembly work. In comparison with industrial work there may be potential for future rationalization. Furthermore, a major aim of rationalization is to reduce non-VAW (waste) and make more efficient use of time (Wild 1995, Brödner and Forslin 2002).

The introduction of NPM and HRM strategies in public dental care in Sweden have contributed to the development of more business-like dentistry exposed to market conditions (Winkel and Westgaard 1996, Bejerot *et al.* 1999, Almqvist 2006).

As shown in the previous sections and the results in Paper III, VAW implies more constrained mechanical exposures compared with non-VAW during dental work. When reducing non-VAW time, a particular important result in an ergonomic context may be reduced exposure porosity, i.e. a reduced occurrence of periods providing recovery (Winkel and Westgaard 2001, Wells *et al.* 2004). This may cause more constrained mechanical exposures, with a possible increased risk of developing WMSD.

However, Paper IV shows that the proportion of non-VAW time (waste) at the follow-up in 2009 was not reduced, but rather showed a trend towards an increase. Thus, no rationalization effect could be documented in terms of waste reduction for the dentists. Accordingly, the mechanical exposures, estimated as postures and movement velocities at job level, were essentially unchanged at follow-up. Thus, neither the amplitude (level 3 in the model) nor duration (level 2 in the model) aspects of workload were changed.

Furthermore, Rolander (Doctoral thesis, 2010) examined the same rationalizations among 65 dentists, concerning production performance and perceived workload. The dentists in our Paper IV were included in this group. He showed, at follow-up, that the dentists were producing more patient treatments and the estimates for perceived workload were lower. However, the estimates for perceived workload were still rather high.

This discrepancy between a tendency for decreased proportion of time spent on VAW on the one hand, and increased production on the other, seems contradictory. One possible explanation may be that some tasks have been allocated from dentists to other dental professions, allowing dentists to handle more patients. It is likely that changes in work organization in order to increase efficiency have taken place. A Government Official Report (SOU 2002:53) and (Abelsen and Olsen 2008) have shown that dental care teams can be more efficient in order to meet increased demands for dental care.

Furthermore, the method used to assess VAW in Paper IV was confined to dentists, while the rationalizations aimed to reduce waste at system level (dentistry). Thus, the complete result at system level, seen as a reduction of waste, cannot be properly evaluated by the study design in Paper IV.

Thus, our data suggest that the technical and organizational interventions introduced during the period 2003-2008, taken as a whole, have increased efficiency and, at least, not impaired

physical exposure; i.e., the interventions may have increased system sustainability, as defined by Docherty (2002), and Westgaard and Winkel (2010).

Conceptual exposure - risk model

In the previous sections connections were found between production system level and individual exposure risk factors.

At the individual level, Paper II showed negative significant correlations between variables in the perception of workload for the head, neck and upper arms and angular velocities in the 50th percentile. This clarified a relationship between internal exposure and acute response according to the exposure/risk model. A possible explanation is that low angular velocities are associated with fixed positions. The more precise the work is, the greater the need for stability. This is achieved by sustained contraction of the agonist and antagonist muscles around the joints of the arm. Self-rated perceived workload in the questionnaire may be interpreted as a subjective sensation. Subjective experience of sustained muscle contraction has been evaluated with psychophysical rating scales by Öberg *et al.* (1994) and Jorgensen *et al.* (1988). These studies showed a significant correlation between intermittent sustained muscle contractions in upper extremities and self-rated estimations on the Borg CR10 scale. This may be one explanation for the significant negative correlations between self-rated perceived workload and the measured angular velocities.

A similar result was found in the PEO study conducted on the same study group by Rolander *et al.* (2005), where it was shown that perceptions of uncomfortable working positions were negatively correlated with the frequency of a forward inclination of the neck >20 degrees, and positively correlated with the length of such sequences. These findings are in accordance with results in Paper II, implicating static work postures.

As reported by Madeleine (2010), a decreased amount of kinematical variability was found among meat-cutting workers with higher ratings for discomfort in the neck-shoulder region compared with those without discomfort. This confirms the connection between lowered dynamics in movements and perceived workload. In this study, decreased muscle motor unit variability was also associated with increased discomfort in the actual body region. Thus, increased discomfort/ perceived workload may reflect an important step towards WMSD.

In addition, in a study of cleaners with much higher upper arm velocities (172 deg/s) Laursen *et al.* (2003) found a positive correlation between angular velocity and the sEMG activity in the m. deltoideus. Further, in a study of 31 female cashiers, Rissén *et al.* (2000) showed a positive correlation between sEMG activities of the upper trapezius muscle and self-

rated perceived tension and exhaustion. However, the work tasks and joint movements of cleaners and cashiers are assumed to be much more dynamic than those of dentists. These findings support the presence of a U-shaped relationship between perceived workload and angular velocities in the neck and upper extremities. U-shaped relationship between exposure level and risk has previously been suggested by Winkel and Westgaard (1992).

Signs of sEMG fatigue was used as an indicator for acute response in the conceptual exposure/risk level model (Westgaard and Winkel 1996, van der Beek and Frings-Dresen 1998). However, the MPF analysis did not show any signs of muscular fatigue. Thus, any connection to acute response, due to a sufficient decrease of the MPF, according to the conceptual exposure/risk level is not found in Paper I.

Recommendations for future rationalizations

In this thesis we found that mechanical exposure during VAW is more risky than during non-VAW. We also found that the technical and organizational changes performed during follow-up did not reduce the proportion of time spent on non-VAW (waste), but rather showed a trend towards an increase. This is in contrast to the findings that rationalizations have mostly been associated with work intensification and increased risk factors in occupational health (Kivimaki *et al.* 2001, Westgaard and Winkel. 2010). In addition, some of the non-VAW work tasks, i.e. administration, showed more constrained biomechanical exposure during follow-up by the means of lower angular velocities.

Thus, it is not inconceivable that future rationalizations will lead to work intensification by means of increased proportion of time spent on VAW and more constrained biomechanical exposures also during non-VAW work tasks.

In the case of future rationalizations, it is important to create work tasks offering enriched mechanical exposure with more variation, in order to avoid an increased risk of WMSD among dentists, since it is generally believed that variation in mechanical exposure is beneficial to musculoskeletal health (Kilbom 1994b, Bongers 2001). A recommended way to achieve this is to integrate ergonomics with management strategies, as suggested by Dul and Neumann (2009). Further, several authors suggest that a greater reduction in the risk of developing WMSDs can be achieved if future work environmental interventions aim at the organization level (levels 1 and 2), not just at the workstation level (individual level) (Kleiner 2006, Imada and Carayon 2008).

For practitioners, the use of direct measurements in the field provides information about the ergonomic circumstances at the workplace. This information can be used to predict what might happen due to future changes in work organization. When integrating ergonomics into management teams, it is possible that this kind of information will be utilized more effectively, and more progress in reducing the risk of work-related musculoskeletal disorders can be expected.

CONCLUSION

To summarize the results of the four studies in this thesis, the high scores found for perceived workload were associated with high measured muscular workload in the upper trapezius muscles. Furthermore, mechanical exposure at job level seems to be higher than for occupational groups with more varied work. Also, negative correlations were found between low angular velocities in the head, neck and upper extremities, on the one hand, and estimates for perceived workload, on the other. VAW implies more awkward postures and especially lower angular velocities than non-VAW. Consequently, when increasing the proportion of time spent on VAW due to rationalizations (waste reduction), work intensification is expected. However, we found no such work intensification during a recent period of rationalisation.

EXAMPLES OF FUTURE RESEARCH

In this thesis we have found that non-VAW (waste) implies less risk due to mechanical exposures compared to VAW. A key issue in the future may be to investigate how to integrate this knowledge when developing a production system.

A key problem in the present thesis was to define VAW for dentist/dentistry. This issue needs further elaboration. The concept has previously been developed for industrial purpose and seems not to be optimal in healthcare service production.

Waste assessment in the present thesis was carried out at the individual level (job level). However, waste should be assessed at system level as well, as appears from the above discussion.

ACKNOWLEDGEMENTS

To my supervisors and co-authors:

Professor Kerstin Ekberg, for your commitment and confidence, and the ability to get the whole research team to work throughout this period. You were always a fixed “seamark”, during this long journey. Thanks for everything.

Professor Tommy Öberg, who with great enthusiasm got me to start this research project.

Professor Jörgen Winkel, the person who, under difficult circumstances, took over a substantial portion of the supervision after Professor Tommy Öberg. Thanks to your enthusiasm and knowledge, you create possibilities to establish contacts with other research networks. You always spurred me on to higher goals.

Dr Leif Sandsjö, the person who lent me Myoguarden once upon a time – about eleven years ago now. I still have it and have used it a bit more than I had imagined from the beginning. Thank you for the help.

Dr Istvan Balogh: For your assistance in finding a suitable supervising group. Thank you for all the work you did in connection with inclinometry data collection.

Bo Rolander for all our fruitful discussions over the speakerphone, all the pleasant trips and friendship, at times in difficult circumstances. We will invest in new projects in future time!

My research colleagues at the National Centre for Work and Rehabilitation, Department of Medical Health Sciences, Linköping University, Linköping, Sweden, for interesting seminars and rewarding comments.

My research colleagues at Occupational and Environmental Medicine, Lund University, where “Jönköpingspojarna” always felt welcome. Thanks for all the help with the inclinometry equipment.

To Philosophy Dr Alec Karznia for the assistance during the first and second Paper.

My colleagues at the Occupational Health Centre in Jönköping for your understanding and flexibility during this journey.

Dr Ulrika Öberg which has always supported and encouraged us.

All those who participated as subjects in the studies.

The study was financial supported by Futurum and “Land och Sjö-fonden”.

Last, but not least, sincere thanks to my family, Lia, Aard, Marjo and Emma, for their support and patience.

REFERENCES

- Aaras, A., Fostervold, K.I., Ro, O., Thoresen, M. & Larsen, S., 1997. Postural load during VDU work: A comparison between various work postures. *Ergonomics*, 40 (11), 1255-68.
- Abelsen, B. & Olsen, J.A., 2008. Task division between dentists and dental hygienists in Norway. *Community Dent Oral Epidemiol*, 36 (6), 558-66.
- Alexopoulos, E.C., Stathi, I.C. & Charizani, F., 2004. Prevalence of musculoskeletal disorders in dentists. *BMC Musculoskelet Disord*, 5, 16.
- Allread, W.G., Marras, W.S. & Burr, D.L., 2000. Measuring trunk motions in industry: Variability due to task factors, individual differences, and the amount of data collected. *Ergonomics*, 43 (6), 691-701.
- Almqvist, R., 2006. *New public management, - om konkurrensutsättning, kontrakt och kontroll* Malmö: Liber.
- Andersen, J.H., Haahr, J.P. & Frost, P., 2007. Risk factors for more severe regional musculoskeletal symptoms: A two-year prospective study of a general working population. *Arthritis Rheum*, 56 (4), 1355-64.
- Ariens, G.A., Bongers, P.M., Douwes, M., Miedema, M.C., Hoogendoorn, W.E., Van Der Wal, G., Bouter, L.M. & Van Mechelen, W., 2001. Are neck flexion, neck rotation, and sitting at work risk factors for neck pain? Results of a prospective cohort study. *Occup Environ Med*, 58 (3), 200-7.
- Ariens, G.A., Van Mechelen, W., Bongers, P.M., Bouter, L.M. & Van Der Wal, G., 2000. Physical risk factors for neck pain. *Scand J Work Environ Health*, 26 (1), 7-19.
- Arvidsson, I., Hansson, G.-Å., Mathiassen, S.E. & Skerfving, S., 2006. Changes in physical workload with implementation of mouse-based information technology in air traffic control. *International Journal of Industrial Ergonomics*, 36, 613-622.
- Bakker, E.W., Verhagen, A.P., Van Trijffel, E., Lucas, C. & Koes, B.W., 2009. Spinal mechanical load as a risk factor for low back pain: A systematic review of prospective cohort studies. *Spine (Phila Pa 1976)*, 34 (8), E281-93.
- Balogh, I., Ohlsson, K., Hansson, G.-Å., Engström, T. & Skerfving, S., 2006. Increasing the degree of automation in a production system: Consequences for the physical workload. *International Journal of Industrial Ergonomics*, 36, 353-365.
- Balogh, I., Orbaek, P., Ohlsson, K., Nordander, C., Unge, J., Winkel, J. & Hansson, G.A., 2004. Self-assessed and directly measured occupational physical activities--influence of musculoskeletal complaints, age and gender. *Appl Ergon*, 35 (1), 49-56.
- Bao, S., Mathiassen, S.E. & Winkel, J., 1996. Ergonomic effects of a management-based rationalization in assembly work - a case study. *Appl Ergon*, 27 (2), 89-99.
- Basmajian, J.V. & DeLuca, C.J., 1995. *Muscles alive. Their functions revealed by electromyography*. Baltimore: Williams and Wilkins.
- Bejerot, E., 1998. *Dentistry in Sweden. - healthy work or ruthless efficiency?* Doctoral Thesis p 26-27. Lund University.
- Bejerot, E., Soderfeldt, B., Aronsson, G., Harenstam, A. & Soderfeldt, M., 1999. Perceived control systems, work conditions, and efficiency among Swedish dentists: Interaction between two sides of human resource management. *Acta Odontol Scand*, 57 (1), 46-54.
- Bernaards, C.M., Ariens, G.A. & Hildebrandt, V.H., 2006. The (cost-)effectiveness of a lifestyle physical activity intervention in addition to a work style intervention on the recovery from neck and upper limb symptoms in computer workers. *BMC Musculoskelet Disord*, 7, 80.

- Bernard, B.P., 1997. Musculoskeletal disorders and workplace factors: A critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremity, and lower back. In Bernard, B.P. ed. Cincinnati: National Institute for Occupational Safety and Health (NIOSH), US Department of Health and Human Services, 97-141.
- Bjorkman, T., 1996. The rationalisation movement in perspective and some ergonomic implications. *Appl Ergon*, 27 (2), 111-7.
- Bongers, P.M., 2001. The cost of shoulder pain at work. *BMJ*, 322 (7278), 64-65.
- Bongers, P.M., De Winter, C.R., Kompier, M.A. & Hildebrandt, V.H., 1993. Psychosocial factors at work and musculoskeletal disease. *Scand J Work Environ Health*, 19 (5), 297-312.
- Brödner, P. & Forslin, J., 2002. O tempora, o mores! Work intensity - why again an issue? In Docherty, P. ed. *Creating sustainable work systems: Emerging perspectives and practice*. London: Taylor & Francis Books Ltd 26-48.
- Buckle, P.W. & Devereux, J.J., 2002. The nature of work-related neck and upper limb musculoskeletal disorders. *Appl Ergon*, 33 (3), 207-17.
- Bystrom, J.U., Hansson, G.A., Rylander, L., Ohlsson, K., Kallrot, G. & Skerfving, S., 2002. Physical workload on neck and upper limb using two CAD applications. *Appl Ergon*, 33 (1), 63-74.
- Chowanadisai, S., Kukiattrakoon, B., Yapong, B., Kedjarune, U. & Leggat, P.A., 2000. Occupational health problems of dentists in southern Thailand. *Int Dent J*, 50 (1), 36-40.
- Christmansson, M., Medbo, L., Hansson, G.-Å., Ohlsson, K., Unge Byström, J., Möller, T. & Forsman, M., 2002. A case study of a principally new way of materials kitting - an evaluation of time consumption and physical workload. *Int. J. Ind, Ergon*, 30, 49-65.
- Cottingham, J. & Toy, A., 2009. The industrialisation of the dental profession. *Br Dent J*, 206 (7), 347-50.
- Da Costa, B.R. & Vieira, E.R., 2010. Risk factors for work-related musculoskeletal disorders: A systematic review of recent longitudinal studies. *Am J Ind Med*, 53 (3), 285-323.
- Deluca, C.J., 1984. Myoelectric manifestations of localized muscle fatigue in humans cr. *Crit Rev Biomed Eng*, 11, 251-79.
- Docherty, P., Forslin, J. And Shani, A.B, 2002. *Creating sustainable work systems: Emerging perspectives and practice* London: Routledge.
- Dong, H., Loomer, P., Barr, A., Laroche, C., Young, E. & Rempel, D., 2007. The effect of tool handle shape on hand muscle load and pinch force in a simulated dental scaling task. *Appl Ergon*, 38 (5), 525-31.
- Douglas, G. & Altman, 1999. *Practical statistics for medical research*. New York: Chapman & Hall/CRC, 211.
- Dul, J. & Neumann, W.P., 2009. Ergonomics contributions to company strategies. *Appl Ergon*, 40 (4), 745-52.
- Engström, T. & Medbo, P., 1997. Data collection and analysis of manual work using video recording and personal computer techniques. *International Journal of Industrial Ergonomics*, 19, 291-298.
- European Labour Force Survey, 2007. *Statistics in focus 63/2009*.
- Finsen, L., Christensen, H. & Bakke, M., 1998. Musculoskeletal disorders among dentists and variation in dental work. *Appl Ergon*, 29 (2), 119-25.
- Forsman, M., Hansson, G.A., Medbo, L., Asterland, P. & Engstrom, T., 2002. A method for evaluation of manual work using synchronised video recordings and physiological measurements. *Appl Ergon*, 33 (6), 533-40.

- Franche, R.L., Baril, R., Shaw, W., Nicholas, M. & Loisel, P., 2005. Workplace-based return-to-work interventions: Optimizing the role of stakeholders in implementation and research. *J Occup Rehabil*, 15 (4), 525-42.
- Green, E.J. & Brown, M.E., 1963. An aid to the elimination of tension and fatigue: Body mechanics applied to the practice of dentistry. *J Am Dent Assoc*, 67, 679-97.
- Grönroos, C. & Ojasalo, P., 2004. Service productivity - towards a conceptualization of the transformation of economic results in service business. *Journal of Business Research*, 57, 414 - 423.
- Hagberg, M., Silverstein, B., Wells, R., Smith, M.J., Hendrick, H.W., Carayon, P. & Pirusse, M. eds. 1995. *Work related musculoskeletal disorders (wmsds): A reference book for prevention.*, London: Taylor & Francis.
- Hansson, G., Å., Balogh, I., Ohlsson, K., Granqvist, L., Nordander, C., Arvidsson, I., Åkesson, I., Unge, J., Rittner, R., Strömberg, U. & Skerfving, S., 2010. Physical workload in various types of work: Part 2. Neck, shoulder and upper arm. *International Journal of Industrial Ergonomics*, 40 (3), 267-281.
- Hansson, G.A., Arvidsson, I., Ohlsson, K., Nordander, C., Mathiassen, S.E., Skerfving, S. & Balogh, I., 2006. Precision of measurements of physical workload during standardised manual handling. Part ii: Inclinometry of head, upper back, neck and upper arms. *J Electromyogr Kinesiol*, 16 (2), 125-36.
- Hansson, G.A., Balogh, I., Bystrom, J.U., Ohlsson, K., Nordander, C., Asterland, P., Sjolander, S., Rylander, L., Winkel, J. & Skerfving, S., 2001. Questionnaire versus direct technical measurements in assessing postures and movements of the head, upper back, arms and hands. *Scand J Work Environ Health*, 27 (1), 30-40.
- Hansson, G.A., Balogh, I., Ohlsson, K., Palsson, B., Rylander, L. & Skerfving, S., 2000. Impact of physical exposure on neck and upper limb disorders in female workers. *Appl Ergon*, 31 (3), 301-10.
- Harms-Ringdahl, K. & Schuldt, K., 1988. Maximum neck extension strength and relative neck muscular load in different cervical spine positions. *Clinical Biomechanics*, 4, 17-24.
- Hasselbladh, H., 2008. *Bortom new public management. Institutionell transformation i svensk sjukvård.*, 1:1 ed. Halmstad: Academia Adacta.
- Hayes, M., Cockrell, D. & Smith, D.R., 2009. A systematic review of musculoskeletal disorders among dental professionals. *Int J Dent Hyg*, 7 (3), 159-65.
- Henneman, E., Somjen, G. & Carpenter, D.O., 1965. Excitability and inhibibility of motoneurons of different sizes. *J Neurophysiol*, 28 (3), 599-620.
- Hoogendoorn, W.E., Van Poppel, M.N., Bongers, P.M., Koes, B.W. & Bouter, L.M., 1999. Physical load during work and leisure time as risk factors for back pain. *Scand J Work Environ Health*, 25 (5), 387-403.
- Hummel, A., Laubli, T., Pozzo, M., Schenk, P., Spillmann, S. & Klipstein, A., 2005. Relationship between perceived exertion and mean power frequency of the EMG signal from the upper trapezius muscle during isometric shoulder elevation. *Eur J Appl Physiol*, 95 (4), 321-6.
- Hägg, G.M. ed. 1991. *Static workload and occupational myalgia - a new explanation model*, Amsterdam.: Elsevier Science.
- Hägg, G.M. & Åström, A., 1997. Load pattern and pressure pain threshold in the upper trapezius muscle and psychosocial factors in medical secretaries with and without shoulder/neck disorders. *Int Arch Occup Environ Health*, 69 (6), 423-32.
- Imada, A.S. & Carayon, P., 2008. Editors' comments on this special issue devoted to macroergonomics. *Appl Ergon*, 39 (4), 415-7.

- Järvholm, U., Palmerud, G., Karlsson, D., Herberts, P. & Kadefors, R., 1991. Intramuscular pressure and electromyography in four shoulder muscles. *J Orthop Res*, 9 (4), 609-19.
- Jørgensen, K., Fallentin, N., Krogh-Lund, C. & Jensen, B., 1988. Electromyography and fatigue during prolonged, low-level static contractions. *Eur J Appl Physiol Occup Physiol*, 57 (3), 316-21.
- Kadefors, R., Sandsjö, L. & Öberg, T., 1996. Evaluation of pause distribution patterns in the trapezius muscle. *The XI International Occupational Ergonomics and Safety Conference*. Zurich.
- Karlqvist, L.K., Bernmark, E., Ekenvall, L., Hagberg, M., Isaksson, A. & Rostö, T., 1998. Computer mouse position as a determinant of posture, muscular load and perceived exertion. *Scand J Work Environ Health*, 24 (1), 62-73.
- Kazmierczak, K., Mathiassen, S.E., Forsman, M. & Winkel, J., 2005. An integrated analysis of ergonomics and time consumption in Swedish 'craft-type' car disassembly. *Appl Ergon*, 36 (3), 263-73.
- Kazmierczak, K., Mathiassen, S.E., Neumann, P. & Winkel, J., 2006. Observer reliability of industrial activity analysis based on video recordings. *International Journal of Industrial Ergonomics*, 36, 275-282.
- Kennedy, C.A., Amick III, B.C., Dennerlein, J.T., Brewer, S., Catli, S., Williams, R., Serra, C., Gerr, F., Irvin, E., Mahood, Q., Franzblau, A., Van Eerd, D., Evanoff, B. & Rempel, D., 2009. Systematic review of the role of occupational health and safety interventions in the prevention of upper extremity musculoskeletal symptoms, signs, disorders, injuries, claims and lost time. *J Occup Rehabil*.
- Keyte, B. & Locher, D., 2004. *The complete lean enterprise. Value stream mapping for administrative and office processes*. New York. : Productivity Press.
- Kilbom, A., 1994a. Assessment of physical exposure in relation to work-related musculoskeletal disorders--what information can be obtained from systematic observations? *Scand J Work Environ Health*, 20 Spec No, 30-45.
- Kilbom, A., 1994b. Repetitive work of upper extremity: Part 2 - the scientific basis (knowledge base) for the guide *International Journal of Industrial Ergonomics*, 14, 59-86.
- Kilbom, A., 1999. Possibilities for regulatory actions in the prevention of musculoskeletal disorders. *Scand J Work Environ Health*, 25 Suppl 4, 5-12.
- Kirkwood, B.R. & Jonatan, A.C.S., 2003. *Essential medical statistics*, Second ed. Oxford.
- Kivimäki, M., Vahtera, J., Ferrie, J.E., Hemingway, H. & Pentti, J., 2001. Organisational downsizing and musculoskeletal problems in employees: A prospective study. *Occup Environ Med*, 58 (12), 811-7.
- Kleiner, B.M., 2006. Macroergonomics: Analysis and design of work systems. *Appl Ergon*, 37 (1), 81-9.
- Kronlund, J., 1981. Skapar forskare fler problem än de löser? In Bengtsson, G. & Sandsberg, Å. eds. *Forskning för förändring arbetslivscentrum*. Stockholm, 137-163 (in Swedish).
- Landsbergis, P.A., 2003. The changing organization of work and the safety and health of working people: A commentary. *J Occup Environ Med*, 45 (1), 61-72.
- Landsbergis, P.A., Cahill, J. & Schnall, P., 1999. The impact of lean production and related new systems of work organization on worker health. *J Occup Health Psychol*, 4 (2), 108-30.
- Laursen, B., Sogaard, K. & Sjøgaard, G., 2003. Biomechanical model predicting electromyographic activity in three shoulder muscles from 3D kinematics and external forces during cleaning work. *Clin Biomech (Bristol, Avon)*, 18 (4), 287 - 295.

- Leggat, P.A., Kedjarune, U. & Smith, D.R., 2007. Occupational health problems in modern dentistry: A review. *Ind Health*, 45 (5), 611-21.
- Leggat, P.A. & Smith, D.R., 2006. Musculoskeletal disorders self-reported by dentists in Queensland, Australia. *Aust Dent J*, 51 (4), 324-7.
- Liker, J., K., 2004. *The Toyota way - 14 management principles from the world's greatest manufacturer*. New York: McGraw-Hill.
- Lindfors, P., Von Thiele, U. & Lundberg, U., 2006. Work characteristics and upper extremity disorders in female dental health workers. *J Occup Health*, 48 (3), 192-7.
- Lundberg, U., Kadefors, R., Melin, B., Palmerud, G., Hassmen, P., Engstrom, M. & Dohns, I.E., 1994. Psychophysiological stress and EMG activity of the trapezius muscle. *Int J Behav Med*, 1 (4), 354-70.
- Madeleine, P., 2010. On functional motor adaptations: From the quantification of motor strategies to the prevention of musculoskeletal disorders in the neck-shoulder region. *Acta Physiol (Oxf)*, 199 Suppl 679, 1-46.
- Malchaire, J., Cock, N. & Vergracht, S., 2001. Review of the factors associated with musculoskeletal problems in epidemiological studies. *Int Arch Occup Environ Health*, 74 (2), 79-90.
- Marras, W.S., Lavender, S.A., Leurgans, S.E., Fathallah, F.A., Ferguson, S.A., Allread, W.G. & Rajulu, S.L., 1995. Biomechanical risk factors for occupationally related low back disorders. *Ergonomics*, 38 (2), 377-410.
- Mathiassen, S., E. & Svendsen, S., W., 2009. Systematic and random errors in postures percentiels assessed from limited exposure samples. *17th World Congress on Ergonomics, IEA 2009*. Beijing.
- Mathiassen, S.E., 2006. Diversity and variation in biomechanical exposure: What is it, and why would we like to know? *Appl Ergon*, 37 (4), 419-27.
- Mathiassen, S.E., Nordander, C., Svendsen, S.W., Wellman, H.M. & Dempsey, P.G., 2005. Task-based estimation of mechanical job exposure in occupational groups. *Scand J Work Environ Health*, 31 (2), 138-51.
- Mathiassen, S.E., Winkel, J. & Hägg, G.M., 1995. Normalization of surface EMG amplitude from the upper trapezius muscle in ergonomic studies - a review. *J Electromyogr Kinesiol*, 5, 197-226.
- Milerad, E. & Ekenvall, L., 1990. Symptoms of the neck and upper extremities in dentists. *Scand J Work Environ Health*, 16 (2), 129-34.
- Milerad, E., Ericson, M.O., Nisell, R. & Kilbom, A., 1991. An electromyographic study of dental work. *Ergonomics*, 34 (7), 953-62.
- Minning, S., Eliot, C.A., Uhl, T.L. & Malone, T.R., 2007. EMG analysis of shoulder muscle fatigue during resisted isometric shoulder elevation. *J Electromyogr Kinesiol*, 17 (2), 153-9.
- Munvädret, 2003:9. Jönköping County Council's newsletter for public dental care employees . In Swedish.
- National Research Council, 2001. *Musculoskeletal disorders and the workplace: Low back and upper extremities*. Washington, DC: National Academy Press.
- Neumann, W.P., Ekman, M. & Winkel, J., 2009. Integrating ergonomics into production system development--the Volvo powertrain case. *Appl Ergon*, 40 (3), 527-37.
- Neumann, W.P., Winkel, J., Medbo, L., Magneberg, R. & Mathiassen, S.E., 2006. Production system design elements influencing productivity and ergonomics - a case study of parallel and serial flow strategies. *International Journal of Operations & Production Management*, 26, 904-923.

- Nordander, C., Balogh, I., Mathiassen, S.E., Ohlsson, K., Unge, J., Skerfving, S. & Hansson, G.A., 2004. Precision of measurements of physical workload during standardised manual handling. Part i: Surface electromyography of m. Trapezius, m. Infraspinatus and the forearm extensors. *J Electromyogr Kinesiol*, 14 (4), 443-54.
- Nordander, C., Hansson, G.A., Rylander, L., Asterland, P., Bystrom, J.U., Ohlsson, K., Balogh, I. & Skerfving, S., 2000. Muscular rest and gap frequency as EMG measures of physical exposure: The impact of work tasks and individual related factors. *Ergonomics*, 43 (11), 1904-19.
- Nordander, C., Ohlsson, K., Akesson, I., Arvidsson, I., Balogh, I., Hansson, G.A., Stromberg, U., Rittner, R. & Skerfving, S., 2009. Risk of musculoskeletal disorders among females and males in repetitive/constrained work. *Ergonomics*, 52 (10), 1226-39.
- Nordgren, L., 2004. *Från patient till kund. Intåget av marknadstänkandet i sjukvården och förskutningen av patientens position.*, Third ed. Lund Lund Business Press.
- Nordgren, L., 2009. Value creation in health care services - developing service productivity. Experiences from Sweden. *International Journal of Public Sector Management*, 22, 114-127.
- Ohlsson, K., Attewell, R.G., Palsson, B., Karlsson, B., Balogh, I., Johnsson, B., Ahlm, A. & Skerfving, S., 1995. Repetitive industrial work and neck and upper limb disorders in females. *Am J Ind Med*, 27 (5), 731-47.
- Polit, D.F. & Hungler, B.P., 1995. *Nursing research, principles and methods.*, 5th ed. Philadelphia: J.B. Lippincott Company.
- Rissen, D., Melin, B., Sandsjö, L., Dohns, I. & Lundberg, U., 2000. Surface EMG and psychophysiological stress reactions in women during repetitive work. *Eur J Appl Physiol*, 83 (2-3), 215-22.
- Rolander, B., 2010. *Work conditions, musculoskeletal disorders and productivity of dentists in public dental care in Sweden. Are dentists working smarter instead of harder?* Doctoral thesis. Linköping University.
- Rolander, B. & Bellner, A.L., 2001. Experience of musculo-skeletal disorders, intensity of pain, and general conditions in work -- the case of employees in non-private dental clinics in a county in southern Sweden. *Work*, 17 (1), 65-73.
- Rolander, B., Karsznia, A., Jonker, D., Oberg, T. & Bellner, A.L., 2005. Perceived contra observed physical work load in Swedish dentists. *Work*, 25 (3), 253-62.
- Rucker, L.M. & Sunell, S., 2002. Ergonomic risk factors associated with clinical dentistry. *J Calif Dent Assoc*, 30 (2), 139-48.
- Rundercrantz, B.L., Johnsson, B. & Moritz, U., 1990. Cervical pain and discomfort among dentists. Epidemiological, clinical and therapeutic aspects. Part 1. A survey of pain and discomfort. *Swed Dent J*, 14 (2), 71-80.
- Sandsjö, L., Melin, B., Rissen, D., Dohns, I. & Lundberg, U., 2000. Trapezius muscle activity, neck and shoulder pain, and subjective experiences during monotonous work in women. *Eur J Appl Physiol*, 83 (2-3), 235-8.
- Sandsjö, L., 2004. *Ambulatory monitoring and analysis of surface electromyographic signals in ergonomic field studies (doctoral dissertation)*. Chalmers University of Technology.
- Schuldt, K., Ekholm, J., Harms-Ringdahl, K., Nemeth, G. & Arborelius, U.P., 1986. Effects of changes in sitting work posture on static neck and shoulder muscle activity. *Ergonomics*, 29 (12), 1525-37.
- Silverstein, B. & Clark, R., 2004. Interventions to reduce work-related musculoskeletal disorders. *J Electromyogr Kinesiol*, 14 (1), 135-52.
- SOU, 2002. Swedish national public investigations (53).

- Stulen, F.B. & De Luca, C.J., 1978. The relation between the myoelectric signal and physiological properties of constant-force isometric contractions. *Electroencephalogr Clin Neurophysiol*, 45 (6), 681-98.
- Swedish Work Environment Authority, 2008. *Work-related disorders.*, 2008:5.
- Svensson, E., 2000. Concordance between ratings using different scales for the same variable. *Stat Med*, 19 (24), 3483-96.
- Taylor, W.F., 1911. *The principles of scientific management*. New York.
- Thorn, S., Forsman, M., Zhang, Q. & Taoda, K., 2002. Low-threshold motor unit activity during a 1-h static contraction in the trapezius muscle. *International Journal of Industrial Ergonomics*, 30, 225-36.
- Tornstrom, L., Amprazis, J., Christmansson, M. & Eklund, J., 2008. A corporate workplace model for ergonomic assessments and improvements. *Appl Ergon*, 39 (2), 219-28.
- Unge, J., Hansson, G.A., Ohlsson, K., Nordander, C., Axmon, A., Winkel, J. & Skerfving, S., 2005. Validity of self-assessed reports of occurrence and duration of occupational tasks. *Ergonomics*, 48 (1), 12-24.
- Walker-Bone, K. & Cooper, C., 2005. Hard work never hurt anyone: Or did it? A review of occupational associations with soft tissue musculoskeletal disorders of the neck and upper limb. *Ann Rheum Dis*, 64 (10), 1391-6.
- Walker-Bone, K.E., Palmer, K.T., Reading, I. & Cooper, C., 2003. Soft-tissue rheumatic disorders of the neck and upper limb: Prevalence and risk factors. *Semin Arthritis Rheum*, 33 (3), 185-203.
- Van Der Beek, A.J. & Frings-Dresen, M.H., 1998. Assessment of mechanical exposure in ergonomic epidemiology. *Occup Environ Med*, 55 (5), 291-9.
- Van Oostrom, S.H., Driessen, M.T., De Vet, H.C., Franche, R.L., Schonstein, E., Loisel, P., Van Mechelen, W. & Anema, J.R., 2009. Workplace interventions for preventing work disability. *Cochrane Database Syst Rev*, (2), CD006955.
- Veiersted, K. B., Westgaard, R., H. & Andersen, P., 1990. Pattern of muscle activity during stereotyped work and its relation to muscle pain. *Int Arch Occup Environ Health*, 62, 31-41.
- Veiersted, K.B. & Westgaard, R.H., 1993. Development of trapezius myalgia among female workers performing light manual work. *Scand J Work Environ Health*, 19 (4), 277-83.
- Visser, B., De Korte, E., Van Der Kraan, I. & Kuijer, P., 2000. The effect of arm and wrist supports on the load of the upper extremity during vdu work. *Clin Biomech (Bristol, Avon)*, 15 Suppl 1, S34-8.
- Wells, R., Mathiassen, S.E., Medbo, L. & Winkel, J., 2007. Time--a key issue for musculoskeletal health and manufacturing. *Appl Ergon*, 38 (6), 733-44.
- Wells, R., Van Eerd, D. & Hagg, G., 2004. Mechanical exposure concepts using force as the agent. *Scand J Work Environ Health*, 30 (3), 179-90.
- Westgaard, R., H. & Winkel, J., 2010. Occupational musculoskeletal and mental health: Significance of rationalization and opportunities to create sustainable production systems - a systematic review. *Applied Ergonomics*.
- Westgaard, R.H., 1999. Effects of physical and mental stressors on muscle pain. *Scand J Work Environ Health*, 25 Suppl 4, 19-24.
- Westgaard, R.H. & De Luca, C.J., 1999. Motor unit substitution in long-duration contractions of the human trapezius muscle. *J Neurophysiol*, 82 (1), 501-4.
- Westgaard, R.H. & Winkel, J., 1996. Guidelines for occupational musculoskeletal load as a basis for intervention: A critical review. *Appl Ergon*, 27 (2), 79-88.
- Westgaard, R.H. & Winkel, J., 1997. Ergonomic intervention research for improved musculoskeletal health: A critical review. *International Journal of Industrial Ergonomics*, 20, 463-500.

- WHO, 1985. *Identification and control of work-related diseases*. World health organisation. *Technical report series 714*. Geneva.
- Whysall, Z.J., Haslam, R.A. & Haslam, C., 2004. Processes, barriers, and outcomes described by ergonomics consultants in preventing work-related musculoskeletal disorders. *Appl Ergon*, 35 (4), 343-51.
- Widstrom, E., Linna, M. & Niskanen, T., 2004. Productive efficiency and its determinants in the Finnish public dental service. *Community Dent Oral Epidemiol*, 32 (1), 31-40.
- Wiktorin, C., Karlqvist, L. & Winkel, J., 1993. Validity of self-reported exposures to work postures and manual materials handling. Stockholm MUSIC I study group. *Scand J Work Environ Health*, 19 (3), 208-14.
- Wild, R., 1995. *Production and operations management: Text and cases.*, 5th ed. London: Casell.
- Winkel, J. & Mathiassen, S.E., 1994. Assessment of physical work load in epidemiologic studies: Concepts, issues and operational considerations. *Ergonomics*, 37 (6), 979-88.
- Winkel, J. & Westgaard, R., 1992. Occupational and individual risk factors for shoulder-neck complaints: Part 2 - the scientific basis (literature review) for the guide. *Int J Ind Ergonomics*, 10 (85-104).
- Winkel, J. & Westgaard, R.H., 1996. A model for solving work related musculoskeletal problems in a profitable way. *Appl Ergon*, 27 (2), 71-7.
- Winkel, J. & Westgaard, R.H., 2001. Ergonomic intervention research for musculoskeletal health - some future trends. *33rd Nordic Ergonomics Society Conference*. Tampere: University of Tampere, 28-32.
- Womack, S.K., Armstrong, T.J. & Liker, J.K., 2009. Lean job design and musculoskeletal disorder risk: A two plant comparison. *Human Factors and Ergonomics in Manufacturing*, 19 (4), 279-293.
- Yamalik, N., 2007. Musculoskeletal disorders (msds) and dental practice part 2. Risk factors for dentistry, magnitude of the problem, prevention, and dental ergonomics. *Int Dent J*, 57 (1), 45-54.
- Yoser, A.J. & Mito, R.S., 2002. Injury prevention for the practice of dentistry. *J Calif Dent Assoc*, 30 (2), 170-6.
- Åkesson, I., 2000. *Occupational health risks in dentistry - musculoskeletal disorders and neuropathy in relation to exposure to physical workload, vibrations and mercury* Doctoral thesis. Lund University, Sweden.
- Åkesson, I., Balogh, I. & Skerfving, S., 2001. Self-reported and measured time of vibration exposure at ultrasonic scaling in dental hygienists. *Appl Ergon*, 32 (1), 47-51.
- Åkesson, I., Hansson, G.A., Balogh, I., Moritz, U. & Skerfving, S., 1997. Quantifying work load in neck, shoulders and wrists in female dentists. *Int Arch Occup Environ Health*, 69 (6), 461-74.
- Åkesson, I., Johnsson, B., Rylander, L., Moritz, U. & Skerfving, S., 1999. Musculoskeletal disorders among female dental personnel--clinical examination and a 5-year follow-up study of symptoms. *Int Arch Occup Environ Health*, 72 (6), 395-403.
- Öberg, T., Karsznia, A., Sandsjo, L. & Kadefors, R., 1995. Work load, fatigue, and pause patterns in clinical dental hygiene. *J Dent Hyg*, 69 (5), 223-9.
- Öberg, T., Sandsjo, L. & Kadefors, R., 1990. Electromyogram mean power frequency in non-fatigued trapezius muscle. *Eur J Appl Physiol Occup Physiol*, 61 (5-6), 362-9.
- Öberg, T., Sandsjo, L. & Kadefors, R., 1994. Subjective and objective evaluation of shoulder muscle fatigue. *Ergonomics*, 37 (8), 1323-33.