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

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Inclinometry ........................................................................................................... 32

Data analysis ........................................................................................................ 34

RESULTS .................................................................................................................. 35

Paper I .................................................................................................................... 35

Self-reported perception of physical demands at work and workload ........ 35

Inclinometry and perception of physical demands at work and perception of
workload ................................................................................................................. 35

Paper II .................................................................................................................. 35

Paper III ............................................................................................................... 36

Task time distribution .......................................................................................... 36

Task-related mechanical exposures .................................................................... 36

Paper IV ............................................................................................................... 37

Time distribution of work tasks .......................................................................... 37

Changes in task-related mechanical exposure between 2003 and 2009 .... 37

Changes in mechanical exposure of VAW and/ non-VAW ......................... 38

Changes in mechanical exposure during video recordings and four hours of
registrations ............................................................................................................. 38

GENERAL DISCUSSION ....................................................................................... 39

Methodological issues ......................................................................................... 39

Selection ................................................................................................................ 39

Observation bias ................................................................................................. 39

Study design ......................................................................................................... 40

Exposure assessment by questionnaire ............................................................. 40

Measurement equipment ..................................................................................... 41

Representativity ................................................................................................... 41

Observer reliability of video-based task analysis .............................................. 42

Physical workload and exposure assessments ................................................. 42

Risk parameters and time aspects ...................................................................... 44

Operationalization of the concept of rationalization ......................................... 45

Discussion of results ............................................................................................ 46

Physical workload exposure at job level ............................................................ 46

Consequences of physical exposure due to rationalizations ......................... 48
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 upplevt 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 måttad 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.

Femtio procent av 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 obekväma 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:


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

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>ARV</td>
<td>Average Rectified Value</td>
</tr>
<tr>
<td>Hz</td>
<td>Hertz</td>
</tr>
<tr>
<td>HRM</td>
<td>Human Resource Management</td>
</tr>
<tr>
<td>MPF</td>
<td>Mean Power Frequency</td>
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<tr>
<td>MVC</td>
<td>Maximum Voluntary Contraction</td>
</tr>
<tr>
<td>NPM</td>
<td>New Public Management</td>
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<tr>
<td>sEMG</td>
<td>Surface Electromyography</td>
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<tr>
<td>VAW</td>
<td>Value-Adding Work</td>
</tr>
<tr>
<td>WMSD</td>
<td>Work-related MusculoSkeletal Disorder(s)</td>
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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 occupation 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 (Munvärdet 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.

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.

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

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

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 an 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.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Work tasks</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>VAW</td>
<td>Patient treatment</td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td>Dental information</td>
<td>Dentist’s information about treatment during the dental treatment. Conversation about dental treatment with patient or relatives to the patient during treatment.</td>
</tr>
<tr>
<td>Non-VAW</td>
<td>X-ray handling</td>
<td>Taking X-ray pictures, assessing and storing.</td>
</tr>
<tr>
<td></td>
<td>Administration</td>
<td>Writing/reading and dictation to the patient file.</td>
</tr>
<tr>
<td></td>
<td>Handling parts and materials</td>
<td>Adjusting patient and/or operator chair, handling of tools/materials, Hand hygiene.</td>
</tr>
<tr>
<td></td>
<td>Disturbances</td>
<td>Transfers of the dentist in the dental practice. Walking to the next patient. Short spontaneous breaks during treatment lasting for more than one second. Social communication with patients or colleagues. Waiting.</td>
</tr>
</tbody>
</table>

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 descendens 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).

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).
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 $\alpha$ 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°/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°/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 medium 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°/s (p= 0.08) in combination with more narrow movement velocity ranges (90th – 10th percentiles) by 15°/s (p=0.01) were found at follow-up.

During “administration”, median movement velocities and the range of movement velocities (90th – 10th) 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 Aström 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 1 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, Sandsjo 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
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 works 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 50\(^{th}\) 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 \textit{et al.} (1994) and Jorgensen \textit{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 \textit{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 \textit{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 \textit{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.
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