Working technique during computer work

Associations with biomechanical and psychological strain and neck and upper extremity musculoskeletal symptoms

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April 2007

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Published and printed by
Intellecta DocuSys AB, Göteborg, Sweden, 2007

ISBN 978-91-628-7098-0

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“The great end of life is not knowledge but action!”
Thomas Henry Huxley (1825-1895)

List of papers

This thesis is based on the following five publications which will be referred to by their roman numerals

I Lindegård A, Wahlström J, Hagberg M, Hansson G-Å, Jonsson P, Wigaeus Tornqvist E. The impact of working technique on physical loads – an exposure profile among newspaper editors. *Ergonomics* 2003; 48:135-42.

II Wahlström J, Lindegård A, Ahlborg G Jr, Ekman A, Hagberg M. Perceived muscle tension, emotional stress, psychological demands and physical load during VDU work. *Int Arch Occup Environ Health* (2003) 76:584-590.

III Lindegård A, Karlberg C, Wigaeus Tornqvist E, Hagberg M, Toomingas A. Concordance between VDU-users' ratings of comfort and perceived exertion with experts' observations of workplace layout and working postures. *Appl Ergon.* 2005 May; 36(3):319-25.

IV Lindegård Andersson A, Wahlström J, Hagberg M, Toomingas A, Wigaeus Tornqvist E. The influence of working technique, comfort and perceived exertion on the incidence of upper extremity symptoms among VDU-users.
Submitted

V Lindegård Andersson A, Ekman A. Reply to short communication concerning ”Concordance between VDU-users` ratings of comfort and perceived exertion with experts` observations of workplace layout and working postures”. Technical note
Applied Ergonomics
In press

Contents

1 Introduction

1.1 Computer work

The use of computer technology has immensely affected working conditions during the last two decades. Automatization of industrial processes has generated a new kind of working situations where we more or less depend on computer technology. Computers have become an indispensable work tool, not only in office work, but in almost all industrial processes. This fact has considerably increased the numbers of employees who are depending on computers to be able to perform their daily work tasks. A report from 2005 covering statistical data concerning working conditions in the Swedish work force concluded that 69 % of the total number of employees in Sweden was using some kind of computer equipment every day (Statistics Sweden 2005). Between 1989 and 2005 the number of employees who reported that they spend at least 50 % of their total working hours with computer work increased with approximately 250 % for both men and women (Figure 1). Moreover, the number of workers who reported that they worked in front of the computer screen nearly all of their working time increased with approximately 100 % for men and 150 % for women during the same period (Statistics Sweden 2005).

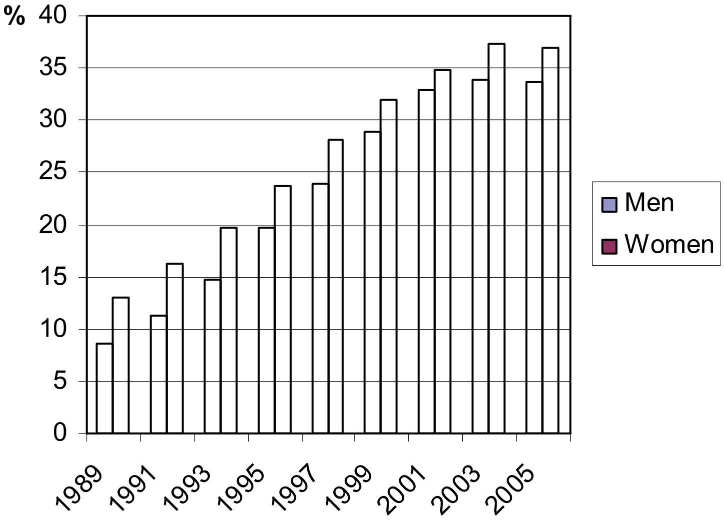

***Figure 1** Percent of the Swedish work force who reported daily computer use for 50% or more of their total working hours (Statistics Sweden 2005).*

Between 2003 and 2005 the amount of employees using computers for 50 % or more were approximately the same. However, there has been a shift in the population towards more computer work in the younger age groups i.e. young adults (16-24 years) and for those between 30-49 years compared with those in the older age group (50-64) (Statistics Sweden 2005). The numbers of computer users who report that they spend nearly all their working hours with computers have also increased in the youngest age category, both regarding men and women. Approximately 25 % of all computer users between 16-24 years (both men and women) are exposed to computer work nearly all their total working hours, compared to 10 % of the men and 19% of the women in the oldest age group 50-64 years (Statistics Sweden 2005) Among young people the use of computers both during work and leisure time has become part of a modern lifestyle. Computers are introduced to children at an early age. The consequence of this are that many young people have already been exposed to computer work for a long period of time before they enter into working life, normally at age 18-25.

The rapid progress of information and communication technology (ICT) in general, and computer technology in particular, is not only generated by a demand for new areas of usage from the market, but also from the "competition" among the leading information technology companies to be first with new and "better" products. The existing equipments become portable and smaller, and provided with more and more functions. It is possible that this development in combination with a change in attitude towards the use of computers and other sources of information and communication technology in a near future will have an impact on the occurrence of musculoskeletal symptoms, psychosocial stress, biomechanical strain and sustainable work ability among young adults. The possibilities of "being reached at any time and in any place" may in this context be a double-edged sword with respect to the above mentioned consequences (Gustafsson et al., 2003).

1.2 Musculoskeletal symptoms in the general population

Musculoskeletal symptoms/disorders are a major health problem with high prevalence in the general population in Sweden. Most of these conditions are not clinically well defined disorders and are to be characterized as unspecific pain emanating from e.g. muscles, tendons, ligament or nerves. Data from 2005 concerning these conditions showed that 28 % of the men and 44 % of the women reported pain in the neck and upper back area at least once a week during the last 3 months (Statistics Sweden, 2005). In addition, there has also been a slight increase of symptoms during the time period between 1989-2005 for both men and women (Figure 2). Moreover, 25 % of the men and 37% of the women reported pain/symptoms from the shoulder/arm region and 13 % of the men and 20 % of the women reported pain from the wrists/hands at least once a week during the preceding 3 month (Statistics, 2005). Musculoskeletal symptoms/disorders are in general more common among women than among men, as demonstrated by the prevalence of neck/upper back pain/symptoms for men and women , respectively shown in figure 2 (Figure 2).

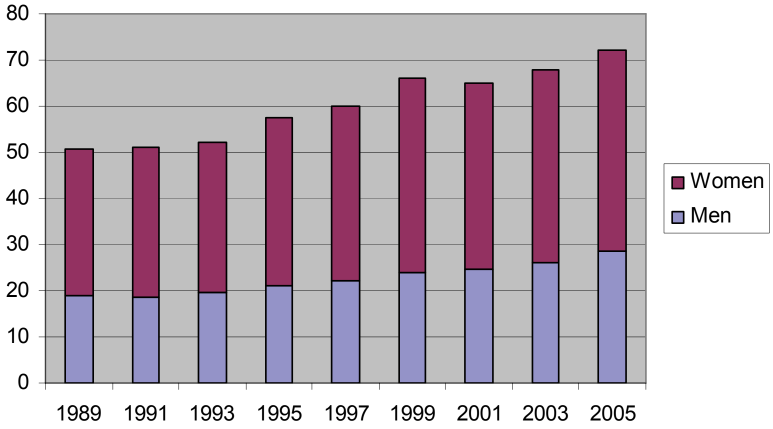

***Figure 2** The prevalence (%) of neck and upper back symptoms at least once a week during the last 3 month in the Swedish work force between the years 1989-2005 (Statistics Sweden, 2005).*

1.3 Musculoskeletal symptoms among computer users

Exposure to computer work

Musculoskeletal symptoms among professional computer users are common (Ekman et al., 2000). There is a slightly higher prevalence of symptoms from both the neck/upper back and shoulder/arm area among professional computer users who report that they spend almost all their working hours in front of the computer compared with those who report that they spend approximately half of their working hours in front of the computer, and the pattern are similar for both men and women (Figure 3) (Statistics Sweden, 2005).

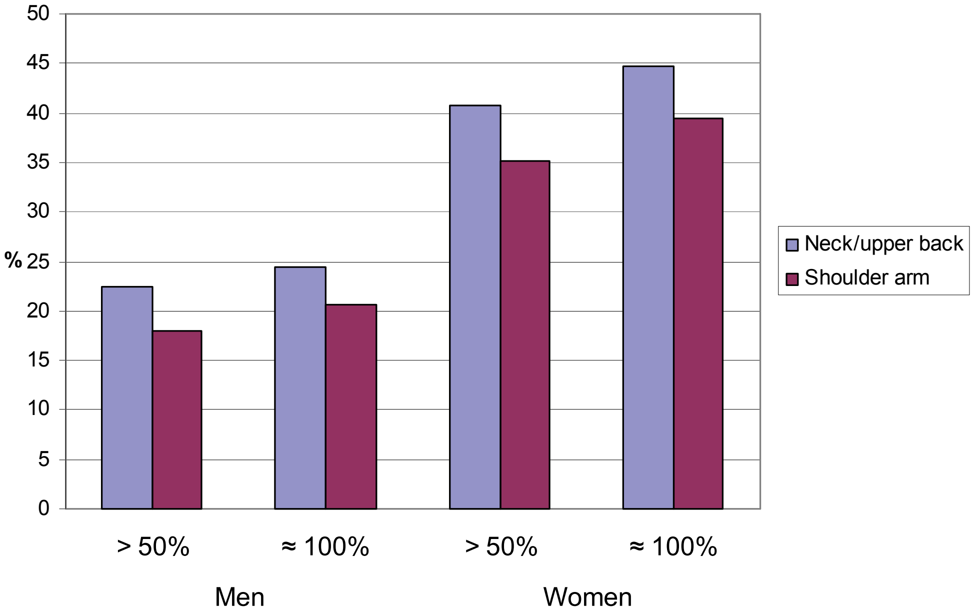

***Figure 3** The prevalence (%) of neck/upper back and shoulder/arm symptoms, at least once a week during the last 3 month, among computer users (Statistics Sweden, 2005).*

Musculoskeletal symptoms during computer work are believed to be multifactorial (Punnett and Bergqvist, 1997)and it is likely to believe that physical exposures, psychosocial exposures and individual factors, respectively, as well as these factors in combination are important for the development of neck and upper extremity symptoms in connection with office work in general and computer work in particular.

1.4 Physical exposures

Physical exposure could be defined as factors relating to biomechanical forces generated in the body. In the literature this has also been defined as “mechanical exposure”, to indicate that the entire work environment (e.g. lighting, noise) was not considered (Westgaard and Winkel, 1996). The term physical load is often used in connection with, or instead of the term physical exposure. The word “load” implicates that these exposures are to be considered as potentially harmful regarding e.g. structures like muscles, joints, ligaments and bone structures in general. According to orthopedic knowledge load up to a certain level on e.g. muscles, joints and bone structures are considered to be beneficial for the process of reconstruction of bone cartilage, prevention of osteoporosis, and for muscle strength. Given that the structures involved (e.g. muscles) are provided with proper nutrients and a balance between activity and recuperation. The u-shaped curved shown in figure 5 demonstrates that “load” below a certain level might be considered as a risk as well as high loads for the development of musculoskeletal symptoms/disorders (Figure 5). In the scientific literature there is so far no consensus regarding neither salutary levels of physical loads nor hazardous levels. Due to this fact no recommendations regarding neither “healthy” nor “unhealthy” physical loads have been proposed except for loads regarding hazardous intensity of heavy loading for the lumbar spine in connection with work related exposure (Fallentin et al., 2001).

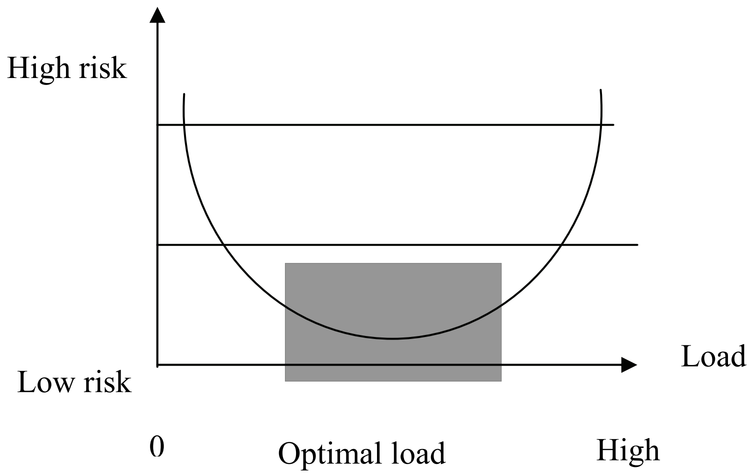

Figure 5 *Associations between levels of physical load and musculoskeletal symptoms.*

To quantify physical exposures relevant for computer work a variety of methods have been used e.g. self-reports, observation assessments and technical measurements. In the studies this thesis is based upon, 3 different methods of technical measurements characterizing physical exposure have been used: electromyography for measuring muscular activity, electrogoniometry for measuring wrist postures and movements and an instrumented computer mouse for measuring forces applied to the computer mouse.

Muscle activity

When a skeletal muscle contracts an electronic signal is generated through stimulation of muscle fibers leading to a contraction in the muscle. This signal can be recorded and analyzed: a process referred to as electromyography (EMG). This method of measuring muscular activity has been used for many years in ergonomic research. Measures of muscular activity, e.g. the amplitude distribution of the muscle activity, measures of muscular rest either characterized as gap frequency (1/min) or total duration of gaps (% of total time period) have been studied in relation to musculoskeletal symptoms/disorders (Hansson et al., 2000; Nordander et al., 2000a; Veiersted and Westgaard, 1993). Some of these studies have found that lack of muscular gaps may be a risk factor for neck and upper extremity symptoms/disorders (Hägg and Åström, 1997; Veiersted and Westgaard, 1993) while others have failed to show such a relationship (Vasseljen and Westgaard, 1995; Westgaard et al., 2001).

Studies exploring the amplitude of muscle activity during computer work have demonstrated that the relatively low but long lasting muscle load posed on the neck and upper extremities during computer work correspond to a mean activity of approximately 4% of the maximal voluntary electrical activity on the dominant side of the upper trapezius muscle (Jensen et al., 1998; Jensen et al., 1999). Other studies on computer work have reached similar results (Hansson et al., 2000; Nordander et al., 2000b; Wahlström et al., 2002).

Wrist positions and movements

Extreme positions of the wrist during hand-intensive work have been considered as a potential risk factor for symptoms from the forearm, wrist and hand (Malchaire et al., 1996; Viikari-Juntura and Silverstein, 1999). Previously conducted studies of wrist positions during computer work tasks have shown that the mean extension of the wrist when working with a standard keyboard and a traditional computer mouse is approximately between 20-25°, and that wrist positions exceeding 30° is present relatively short periods of the total working hours (Arvidsson et al., 2006). The wrist posture also seem to have an impact on the load on the forearm muscles during keyboard work indicating that a wrist extension around 30° will require the use of more than 25% of the MVC (maximum voluntary contraction) (Keir, 2002).

Wrist angles can be measured by using a manual goniometer or by using electrogoniometry. A study of computer users observed that the stability of postural measures over time was sufficient to justify a single postural measurement in epidemiologic studies and that manual goniometry may be considered a valid method to measure postures among computer users (Ortiz et al., 1997). Using electrogoniometry to measure wrist positions and movements provides in addition to measure wrist angles manually, a method to measure and characterize mean power frequency (MPF), which has been proposed in the literature as a measure of repetitiveness (Hansson et al., 1996; Malchaire et al., 1996; Viikari-Juntura and Silverstein, 1999). Electrogoniometry also provides the opportunity to collect data concerning the time frame in which the wrist has been in certain angle intervals. This information is valuable since one of the potential risk factors for developing symptoms from the forearm and/or wrist is recognized to be working in constrained and extreme postures over long periods of time (Bernard, 1997; Marcus et al., 2002; Sluiter et al., 2001; Viikari-Juntura and Silverstein, 1999).

Repetitive work in general has been associated with increased risk of developing wrist and forearm symptoms (Malchaire et al., 2001).With exposure to both extreme postures and repetitive movements, it has been suggested that the risk increases (Bernard, 1997). Among computer users the magnitude of the exposure to repetitive work in connection to computer use is likely to depend on the work task and is likely to vary at lot between different tasks. Since the effects of repetitiveness on health outcome among computer users have not been sufficiently investigated, no general conclusions can be drawn from the existing studies.

Forces applied to the computer mouse

Another physical exposure to consider when investigating relevant risk factors during computer work is the forces applied to the sides and button of the computer mouse. An earlier study has indicated that computer mouse work for a prolonged period of time (3-4 hours) result in muscle fatigue in the forearm muscles (Johnson, 1998). It has been hypothesized that forces applied to the computer mouse may increase under the influence of stressful working conditions. This hypothesis has been confirmed in studies investigating the effects of time pressure and verbal provocations on physiological and psychological reactions during computer mouse work using a force sensing mouse (Wahlstrom et al., 2002). In coherence another study exploring the effects of mental pressure on precision and forces applied to the computer mouse reached the same results (Visser et al., 2004).

Physical risk factors for neck and upper extremity symptoms during computer work

Several cross sectional studies have observed associations between physical exposures and neck and upper extremity symptoms during computer work (Bergqvist et al., 1995; Faucett and Rempel, 1994; Karlqvist et al., 2002; Punnett and Bergqvist, 1997; Tittiranonda et al., 1999). Due to the cross sectional design of these studies it has been impossible to draw conclusions regarding cause-effect relations ship. However, recent longitudinal studies support some of the cross sectional findings regarding the impact of work postures (Gerr et al., 2002), and work place layout (Juul-Kristensen et al., 2004; Korhonen et al., 2003). Regarding exposure to physical risk factors there are three fundamental dimensions to consider when evaluating the potential risk; duration, frequency and intensity. Computer work might be considered as very light manual work where the employees are exposed to low intensity, long lasting exposures compared to traditional industrial work where working with e.g. the arms above shoulder level, and heavy lifting are well known risk factors for the development of musculoskeletal symptoms/disorders (Hagberg, 1996; Hagberg et al., 1995). Due to the lack of “heavy physical exposure” different hypothesis have been proposed regarding the etiology of neck and upper extremity symptoms/disorders in connection to light manual work. One hypothesis addressing this issue is the Cinderella hypothesis proposed by Hägg in 1991 (Hägg, 1991)) where overuse of type I muscle fibres during low intensity work load without recovery, may lead to selective motor unit fatigue and in the end to muscle fibres injuries. This theory is supported by studies on impaired blood microcirculation through specific muscle fibres (Larsson et al., 2004; Larsson et al., 1988). Moreover, recent experimental studies investigating muscular activity in light manual work support the “Cinderella hypothesis” and add to the knowledge that stressful work situation increases the risk of muscle overuse in the same context (Thorn et al., 2002; Thorn et al., 2006).

Several cross sectional studies have shown associations between the duration of computer work time and neck and upper extremity symptoms/disorders (Blatter, 2002; Cook et al., 2000; Jensen et al., 1998; Karlqvist et al., 2002). Additionally, in concordance with the these results recent longitudinal studies have supported the cross sectional findings (Gerr et al., 2002; Jensen, 2003; Juul-Kristensen et al., 2004; Wigaeus Tornqvist E, 2006). However, another longitudinal study has concluded that duration of computer time did not influence the prognosis for persistent pain in the arm/hand region (Lassen et al., 2005). Moreover, that self-reported exposures concerning that mouse and keyboard time predicted elbow and wrist/hand pain/symptoms from low exposure levels, but mouse and keyboard time were not predictors of clinical conditions verified through medical examinations (Lassen et al., 2004). In addition time spent with computer work without natural rest breaks have also been studied and found to be associated with an increased risk of developing musculoskeletal symptom from the neck and upper extremities (Punnett and Bergqvist, 1997). In concordance with the above mentioned Cinderella hypothesis, long duration of computer work without breaks might impose an even greater risk due to lack of recovery time. Previous studies have indicated that rest break patterns were associated with musculoskeletal symptoms in office workers with intensive computer work tasks (Balci and Aghazadeh, 2003; McLean et al., 2001). Moreover, an intervention using software programs to implement regular breaks during computer work have shown a decrease of musculoskeletal symptoms after the intervention (van den Heuvel et al., 2003)

Non-neutral working postures (e.g. extreme wrist positions), and work station design e.g. non-adjustable work chairs and/or working tables have in cross sectional studies been identified as risk factors for neck and upper extremity symptoms (Bernard, 1997; Gerr et al., 2000; Punnett and Bergqvist, 1997; van den Heuvel et al., 2003). A recently conducted longitudinal study has supported these findings regarding non neutral working postures in the elbow and wrist (Gerr et al., 2002). However, another longitudinal study only identified neck rotation and self-reported neck extension as risk factors for neck-shoulder symptoms (van den Heuvel et al., 2006). However, a study evaluating the influence of neck flexion, neck rotation and sitting at work on the risk of developing neck pain in a heterogeneous work group including computer users, revealed that sitting 95% of the working hours was a greater risk than neck posture (Ariens et al., 2001a). A study of prognostic factors for musculoskeletal symptoms in office workers concluded that only a few ergonomic factors (screen height, pauses and reflexes in the screen) were prognostic factors for neck and upper extremity symptoms (Juul-Kristensen et al., 2004). However, the evidence for a causal relationship between work station design and neck and upper extremity symptoms/disorders are still insufficient.

Working with computers in most situations requires the use of both a keyboard and a non-keyboard input devices. The by far most common non-keyboards device is the computer mouse. The introduction of alternative input devices has not been very successful; though some studies have indicated that the use of alternatives might reduce the risk for upper extremity symptoms (Fernstrom and Ericson, 1997; Karlqvist et al., 1999). Moreover different designs of the traditional computer mouse have been evaluated in relation to carpal tunnel syndrome and the results showed no major differences between the different mouse designs regarding wrist positions or carpal tunnel pressure during computer work (Keir et al., 1999). However, an experimental study investigating the differences in physical exposure, comfort, and perceived exertion between two different computer mice indicated decreased muscle activity in the forearm muscles but at the same time lower ratings of comfort when using a computer mouse with a neutral hand position (Gustafsson and Hagberg, 2003).Regarding keyboards, previously conducted cross sectional studies have concluded that different kind of keyboards (e.i split keyboard, tilted keyboard) have an effect on working postures, productivity, comfort and usability (Marklin and Simoneau, 2004; Woods and Babski-Reeves, 2005; Zecevic et al., 2000). A recently presented longitudinal study confirmed these results and moreover concluded that there are enough evidence for a relationship between the keyboard design and upper extremity symptoms to be able to make recommendations concerning design of the keyboards (Rempel et al., 2007; Rempel et al., 2006). In addition, in a review Brewer and colleagues have concluded that there was a moderate evidence for an association between the use of alternative pointing devices in connection with computer work and a decrease in musculoskeletal or visual adverse health effects (Brewer et al., 2006).

1.5 Work organization and psychosocial exposures

During the last decade work organization and psychosocial exposures have gained focus in connection with musculoskeletal symptoms/disorders. The work organization or work system consists of different components from organizational structures and technology systems to work tasks (Hagberg et al., 1995). It is likely that work organization have an impact on both physical exposures in terms of e.g., duration and intensity of a certain work task, psychosocial exposures, e.g. job demands and decision latitude, and psychological strain, e.g. emotional stress. Regarding some factors, for instance job demands, it might be difficult to separate the "organizational demands" from the perception of a certain demand since we usually measure the perception, i.e. self-rated demands, and not objectively measured demands. Regarding work organization and psychosocial exposures, earlier cross sectional studies has shown that e.g. high demands as well as low control were risk factors for musculoskeletal symptoms (Bongers et al., 1993; Bongers et al., 2002; Devereux et al., 2002). Moreover, an epidemiological review of longitudinal studies of work related neck and upper extremity symptoms and the impact of psychosocial factors supported these findings, however in most cases the relationship were neither very strong nor very specific (Bongers et al., 2006).

The most common way of assessing psychosocial exposure has been through questionnaires. A variety of instruments have been elaborated over the years. One of the most widely used instrument has been the demand-control model developed and published by Karasek and Theorell (Karasek and Theorell, 1990)
Many studies have indicated that a variety of psychosocial factors, such as high job demands, weak job control and lack of social support, can lead to high perceived stress levels, manifested as both symptoms from the musculoskeletal system as well as different kinds of psychological reactions (Aaras et al., 1998; Andersen et al., 2002; Ariens et al., 2001b; Ariens et al., 2002; Birch et al., 2000; Bongers et al., 2002; Carayon et al., 1999; Wigaeus Tornqvist et al., 2001a).

Earlier research has shown that mental stress can increase muscle activity during simulated VDU-work (Lundberg et al., 2002). In a study of computer users it has been concluded that mental stress tends to increase the forces applied to the computer mouse and leads to more rapid wrist movements during computer work (Wahlstrom et al., 2002). In a recent study investigating the effects of mental pressure and precision on the load of the upper extremity showed that mental pressure increase the load on the upper extremity considerably (Visser et al., 2004). Another study on effects of time pressure and precision demands on the oxygenation of the m.trapezius and m extensor carpi radialis showed that the oxygenation decreased in the forearm muscle (m.extensor carpi radialis) during a mouse-operated computer task conducted under time pressure and high precision demands (Heiden et al., 2005). The impact of perceived acute stress during computer work on muscular activity, wrist movements and forces applied to the computer mouse as well as blood pressure and heart rate variability have been investigated in a laboratory study by Wahlström et al and the results indicated an association between stressful working situations and increased muscle activity, more rapid wrist movements, higher forces applied to the computer mouse compared to a control situation (Wahlstrom et al., 2002).

Similar studies regarding provoked mental stress in a laboratory setting conducted on computer users supported these findings (Lundberg et al., 2001).

Work organization and psychosocial risk factors for neck and upper extremity symptoms during computer work

Several cross-sectional studies have indicated that work organization and psychosocial exposures are associated with neck and upper extremity symptoms during computer work (Bongers et al., 1993; Karlqvist et al., 2002; Polanyi et al., 1997). In a prospective study on forearm pain on computer users it has been concluded that high demands and time pressure were risk factors for developing forearm pain and moreover that women had a higher risk of developing symptoms than men (Kryger et al., 2003). Another study has indicated that time pressure may have negative impact on the prognosis for severe elbow-forearm and wrist-arm pain among computer users (Lassen et al., 2005). Newly published data from a longitudinal study have showed that computer users who reported job strain were more prone to develop neck-shoulder symptoms than those who did not report these conditions (Hannan et al., 2005).

It is likely to believe that factors connected to the work task, including perceived stress, caused by for instance a "mismatch" between the competence level of the employees and the job demands, might be as important as the more physical dimensions of computer work for neck and upper extremity symptoms. In a study of potential risk factors for musculoskeletal symptoms and computer use, the results showed that factors connected to the work task like e.g. stressful job situations, monotonous work tasks and low influence over the working situation were in fact more strongly associated with musculoskeletal outcome than working with a computer (Ekman and Hagberg, 2007).Moreover, the same study showed the stressful work situations were more prevalent among computer users (32%) than among non-computer users (20%).

It has also been shown that a combination of both physical risk factors and psychosocial risk factors produces a higher risk of developing musculoskeletal symptoms (Punnett and Bergqvist, 1997; Wigaeus Tornqvist et al., 2001a) compared to being exposed to only one of these exposures. The magnitude of the increased risk however, has not been fully investigated.

1.6 Individual factors

Individual factors have in many studies shown to be related to musculoskeletal symptoms/disorders. Some of the relevant and important individual factors to consider are the influence of sex, age, and individual characteristics e.g. vulnerability, and working technique. Regarding sex and musculoskeletal symptoms women seem to have a higher incidence of symptoms regardless of occupation involved (Cassou et al., 2002; Cote et al., 2004; Ostergren et al., 2005).

Age is another factor that is generally considered to influence the prevalence of musculoskeletal symptoms leading to more symptoms in older age groups. However, in connection to computer work the same pattern is not as prominent and results from several studies have been inconclusive regarding the impact of age (Cassou et al., 2002; Cote et al., 2004; Karlqvist et al., 2002; Ostergren et al., 2005; Punnett and Bergqvist, 1997;

Wigaeus Tornqvist E, 2006). Knowledge regarding the impact of individual characteristics such as vulnerability is insufficient, but several studies have observed that prior episodes of musculoskeletal pain/symptoms are a strong predictor of recurrent pain/symptom in the neck and upper extremities (Juul-Kristensen et al., 2004; Luime et al., 2005; Miranda et al., 2001; Wigaeus Tornqvist et al., 2001b).

Working technique

A few authors (Feuerstein, 1996; Kjellberg, 2003) have studied different aspects of working technique and their relations to musculoskeletal symptoms/disorders. According to the latter study, there are two discriminating basic elements that characterize working technique: the method or system of methods, and the individual motor performance used to carry out a given task (Kjellberg et al., 1998). Working technique refers to the individual motor performance e.g. the way a subject perform a computer work task. Earlier studies of one specific element of working technique during computer work, working without supporting the forearms, has shown to be related to increased muscle activity in the trapezius muscles (Aarås et al., 1997; Karlqvist et al., 1998). Through clinical observations of computer users two different ways of performing computer mouse work commonly used among trained computer users has been identified, the arm-based method and the wrist-based method. Working technique can be measured in many different ways but the most commonly used method for assessing working technique is through observations. The advantages with observations compared to for instants technical measurements include high capacity e.g. one trained observer can often perform many assessments during a short period of time, and also the fact that several relevant factors may be evaluated at the same time. In the ergonomic field there is a need for more user-friendly, less expensive and less time consuming methods in general practice (Li and Buckle, 1999; Winkel and Mathiassen, 1994) and since working technique consists of many interacting factors, observation assessments, may provide a cost efficient, and less time consuming way of evaluating exposure to hazardous parameters connected to working technique.

There is a lack of studies exploring the potential associations between working technique and physical and psychological strain. However, one study concerning different work methods and physical load, showed that muscular load showed significantly decreased levels of muscle activity and more preferable working postures among subjects using a flexible (chosen by the subjects themselves) working technique (Wahlstrom et al., 2000).

Individual risk factors for neck and upper extremity symptoms during computer work

Regarding computer work there are substantial scientific evidence showing that musculoskeletal symptoms are more common among female compared with male computer users (Ekman et al., 2000; Jensen et al., 2002; Karlqvist et al., 2002; Korhonen et al., 2003) Possible explanations discussed in the previous literature are differences in occupational exposures and differences in exposures in leisure time between men and women (Ekman et al., 2000).Anthropometrical measures e.g differences in shoulder width and hand size have also been discussed as possible factors increasing the risk for women (Karlqvist et al., 1998; Tittiranonda et al., 1999). One study of risk factors among computer users indicated that pain in other regions was a predictor of persistent arm pain (Lassen et al., 2005). Moreover, constitutional or required vulnerability (biological or psychological) as well as socioeconomic factors may have an impact on the risk of developing musculoskeletal symptoms/disorders in connection with computer work (Cole and Rivilis, 2004).

In a cross sectional study work style has been identified as a possible risk factor for neck and upper extremity symptoms in connection with office and computer work (Feuerstein et al., 1997). Recent longitudinal studies have supported these findings by showing an increased risk for subjects applying an unfavorable work style to develop neck and upper extremity symptoms (Feuerstein et al., 2004b; Juul-Kristensen et al., 2004). Moreover, work style has shown to be related to frequency, intensity and duration of pain, and to functional limitations among office workers with upper extremity symptoms (Feuerstein, 1996; Haufler et al., 2000). Furthermore, a recently conducted study has indicated that work style has a predictive value for the same variables (functional limitations, upper extremity symptoms (Nicholas, 2005).

Single items connected to working technique e.g. working with forearm support has in earlier studies shown to be related to a decrease in physical load in terms of muscle activity in the trapezius muscles (Aarås et al., 1997; Karlqvist et al., 1998). In a randomized controlled intervention study the results showed that use of forearm support reduced upper extremity pain among computer users (Rempel et al., 2006). In concordance with these results a large cohort study of computer workers in Denmark has concluded that several dimensions connected to work style (variation and speed) were associated with fewer symptoms in the neck and upper extremities (Juul-Kristensen and Jensen, 2005).

The impact of psycho-biological factors such as perception of discomfort, exertion, and muscular tension on the incidence of musculoskeletal symptoms/disorders has not been investigated in detail, although there are some studies showing an association between perception of general muscular tension and symptoms from the neck and shoulder area (Holte et al., 2003; Westgaard and De Luca, 2001). Another longitudinal study on muscle tension in the neck and shoulder area and the incidence of neck symptoms showed that high perceived muscle tension was a risk factor for the development of neck symptoms among computer users (Wahlström et al., 2004).

1.7 An ecological model exploring associations between computer work and musculoskeletal symptoms

There is a lack of knowledge concerning the physiological and morphological mechanisms involved in the development of musculoskeletal disorders, but there is a consensus in the scientific literature that the etiology is likely to be multi- factorial. Different hypothesis have been proposed regarding the etiology of neck and upper extremity symptoms/disorders in connection to light manual work e.g. office work (Hägg, 1991; Johansson and Sojka, 1991; Knardahl, 2002). However, no consensuses regarding the involved mechanism have been reached so far. Several models explaining the associations between physical exposures, biomechanical strain, psychosocial exposures, psychological strain and individual factors have been presented and one is the ecological model of musculoskeletal disorders in office work proposed by Sauter and Swansson in1996 (Sauter and Swanson, 1996).
A modified version of this model with special reference to computer work has previously been presented and published in a doctorial thesis (Wahlström, 2003). The model presented

in Figure 5 is an extended version of the Wahlström model where the items explored in this here thesis are in italics and will henceforth be referred to as the Wahlström model.

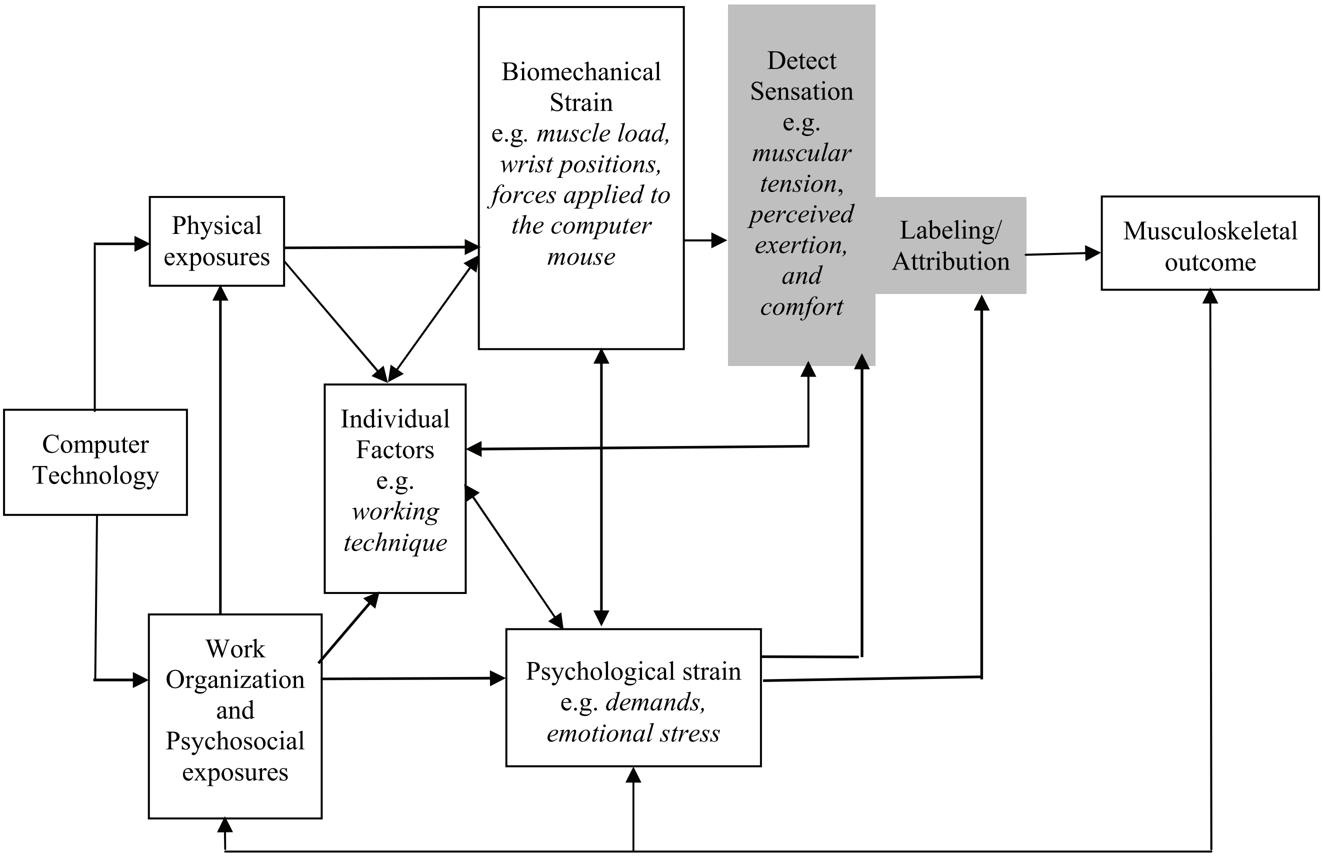

***Figure 5** An ecological model of musculoskeletal disorders in computer work-work modified from Sauter & Swansson (Sauter and Swanson, 1996) and from the Wahlström model (Wahlström, 2003). Items in italics are factors explored in this thesis.*

This model elucidates the complexity of the pathways regarding risk factors leading to musculoskeletal symptoms/disorders. The model reveals that it is likely to believe that musculoskeletal symptoms/disorders do not solely develop from traditional physical risk factors that ca be measured with e.g. technical measurements. The model also points out that the pathways leading to musculoskeletal outcome might take detours through different kind of perceptions. It has been indicated that, perceived muscle tension are associated with neck and upper extremity symptoms/disorders (Wahlstrom et al., 2004). These detecting sensation may be regarded as responses to biomechanical strain (e.g.muscle load, extreme working postures) or to psychological strain (e.g. job demands and emotional stress)and modify the biomechanical strain of physical exposure and the psychosocial strain e.g. arising from work organization factors. Working technique explored in this here thesis could be regarded, following the model, as an individual factor with possible connections to biomechanical strain, (through higher physical loads), psychosocial strain, (through perception of high demands and high emotional stress) and through perceived exertion, comfort, muscle tension to musculoskeletal outcome.

According to the model detecting sensations could be regarded as mediators of musculoskeletal symptoms/disorders (Figure 5).

1.8 Aim

The overall aim of this thesis was to evaluate if working technique, perceived exertion and perceived comfort were associated with physical and psychosocial strain as well as neck and upper extremity symptoms among computer users.

The specific research questions addressed were:

Is working technique associated with muscle activity, wrist postures and forces applied to the computer mouse?

Is working technique associated with psychological demands, emotional stress and perceived muscle tension during computer work?

Is perceived exertion and comfort, respectively, associated with expert's observations of work place layout and working postures during computer work?

Is working technique, perceived exertion and comfort, respectively, associated with the incidence of neck and upper extremity symptoms/disorders in connection with computer work?

2. Subjects

2.1 Study designs

The studies included in this thesis demonstrate several study designs. *Study I* and *Study II* are cross sectional studies, evaluating possible associations between working technique, biomechanical strain, psychological strain and perceived muscle tension, respectively during computer work. *Study III* is a methodological study investigating possible associations between expert observations of working posture and work place layout and self-ratings of perceived exertion and comfort. *Study IV* is a prospective longitudinal study investigating possible associations between working technique, perceived exertion and comfort, respectively, and the incidence of neck and upper extremity symptoms/disorders during computer work.

2.2 Subjects

Study I and II

The subjects in *study I* consisted of all personnel in the editorial department of a daily newspaper who according to the supervisor had largely editing-based work tasks. Altogether, 36 employees fulfilled the inclusion criteria. Two men and two women were excluded due to long-term sick leave, or temporary work at another newspaper. The results are thus based on 32 subjects: 14 men and 18 women. The mean age was 44 years (range 26-57) for the men and 42 (range 28-55) for the women. Estimated time spend with computer work was 83% (range 33-100) of the total working hours for the men, and 78% (range 30-100) for the women. There were 18 subjects (58%) who reported neck/shoulder and/or upper extremities symptoms on the day of the measurements. All the participants worked with the same software program (Quark express) and all of the subjects had adjustable working chairs as well as adjustable working tables.

The study group in *study II* included the 32 subjects from s*tudy I* and 25 subjects from the engineering department of a telecommunication company in total 57 office workers (28 women and 29 men). The mean age was 39 years (range: 26-57), and the median duration of daily VDU use was 70% of the total working hours for the men (range 44-80) and 75% (range 60-90) for the women. There were 25 subjects (44%) who reported pain in the neck or upper extremities on the day of the measurements. In both organizations the main procedures and aims of the project were presented at information meetings and then subjects volunteered to participate in the study. All the subjects had a modern workplace layout with easily adjustable chairs and working tables. In the editorial department the subjects all used the same software (Quark Xpress), while the subjects in the telecommunication company used a variety of software, depending on the actual task performed.

Study III, IV and V

Study population

The study population in *study III and IV* comprised 1529 computer users representing a variety of work organizations from 44 different companies/organizations both private companies and public organizations. The subjects also represent different occupations e.g. call-center operators, engineers, receptionists, graphic industry workers, medical secretaries. A baseline questionnaire was answered by 1283 subjects (498 men and 785 women). A response rate of 84% was thus obtained.

Study group

The study group in st*udy III* consisted of the 853 computer workers (382 men and 471 women) whom at baseline or at any of the follow up occasions were free from musculoskeletal symptoms in the neck, shoulder and/or hand arm region during the proceeding month. The definition of being free from symptoms was reporting less than 3 days of musculoskeletal symptoms during the last month. The mean age for the men was 42 years (range 20-65) and for the women 44 years (range 21-65). The mean duration of computer work was for the men 83% (range 30-100) of total working hours and 78% (range 30-100) for the women. A computer mouse was used to by (98%) while trackball, joystick, touch pad or optical mouse was used by 2% of the subjects.

The study group in *study IV* consisted of the above mentioned 853 computer users. Incidence data were collected during the observation period by 10 monthly questionnaires regarding the occurrence of neck and upper extremity symptoms. The questions referred to the time period since the preceding questionnaire was answered, usually approximately one month but could be longer due to vacation or other reasons for absence. When more than two follow-up questionnaires were missing, the subject was omitted from the study.

3 Methods

Different methods have been used in this thesis. An overview of the methods focused in the thesis is shown in table 1. The methods are listed in the order of decreasing precision and increasing versatility and capacity.

Table 1. *An overview of the methods used in the thesis.*

	Study I	Study II	Study III	Study IV
Technical measurements	x	x		
Electromyography (EMG)	x			
Electro goniometry	x			
Force sensing computer mouse	x			
Expert observations	x	x	x	x
Questionnaires including self-ratings		x	x	x

3.1 Technical measurements

Procedure

In *study I and II* equipment for measuring muscular load and wrist positions/movements was attached and calibrated in an adjacent room. After the calibration, the subjects were allowed to get used to the equipment by working with their regular work tasks for a couple minutes before the actual measurements began. In both organizations the workplaces had easily adjustable working chairs and working tables and the subjects were free to choose where to place the input device and the keyboard during the measurements. The subjects then performed their ordinary work task during 15 minutes. When analyzing data, measurements obtained in the first and last minutes of each 15-minute period were excluded, so data collected over 13 minutes was used for each subject in both organizations. The aims and procedures of the study were presented at information meetings, and all of the subjects volunteered to participate in the study.

Muscular load

For characterizing exposure to muscular load, the muscle activity from four separate muscles (m. extensor digitorum, m. carpi ulnaris of the mouse operating hand, and pars descendent of the right and left trapezius muscle) was recorded using bipolar surface EMG (ME 3000P4; Mega Electronics Ltd, Koupio, Finland). Raw data were monitored on-line for quality control and stored on a personal computer (PC) with a sampling rate of 1000 Hz. The electrodes for the ED and ECU were placed as recommended by Perotto (Perotto, 1994) and those for the trapezius muscles as recommended by Mathiassen (Mathiassen et al., 1995) (Figure 6). Self-adhesive surface electrodes (N-00-S, Medicotest A/S, Ølstykke, Denmark) were placed with a 20 mm inter-electrode distance. Before attaching the electrodes, the skin was dry shaved and cleaned with alcohol, abraded with sandpaper and cleaned with water. Each subject performed standardized maximum voluntary contractions against manual resistance for 5 s (MVCs) to obtain the maximal voluntary electrical activity (MVE) of the ECU and the ED muscles. For the trapezius muscles, a reference voluntary contraction (RVC) was performed with a 1 kg dumbbell in each hand with the hands pronated and arms abducted 90° in the horizontal line for 15 s to obtain the reference electrical activity (RVE).

Data were analyzed with Megavin software version 1.2 (Mega Electronics Ltd; Koupio, Finland). To characterize muscular activity, the raw EMG signal was full-wave rectified and filtered, using a time-constant of 125 ms, sampling with a 12-bit A/D converter (at 1000 Hz per channel) and a 8 Hz to 480 Hz band-pass filtered (3 dB). MVE for ED and ECU was calculated using a 1 s moving average window and then using the 1 s window with the highest average EMG activity as the reference value. The RVE for the trapezius muscles was calculated using a 10 s moving average the 10 s window with the highest average EMG-activity was chosen and the mean value of the three reference contractions was used as the reference value. The 10th percentile (p0.10) and the 50th percentile (p0.50) of the amplitude distribution were calculated for each subject and used to describe the muscular load. For analyzing gap frequency and muscular rest of the trapezius muscles, a threshold of 2.5 % RVE was chosen. The RVE corresponds roughly to a load of 15%-20% MVC (Hansson et al., 2000). Thus, the gap definition of 2.5% RVE corresponds to 0.4%-0. 5 % MVC. Muscular rest was defined as the summed duration of the gaps relative to the total duration of the recording. The gap duration time was set to 125 ms (Hansson et al., 2000).

In *study II* the measurement from m.extensor carpi ulnaris (forearm muscle) was excluded, since the main focus in *study II* was to investigate the impact of psychosocial exposures on muscular load, and previously conducted studies have shown that psychosocial loads affects the central postural muscles more than peripheral muscles e.g. forearm muscles (Toomingas et al., 1997b). Thus, we concluded that no additional information relevant to the aim of the study could be obtained by analyzing EMG signals from the forearm muscles.

Reliability of surface EMG-measurements regarding trapezius muscles during a light manual assembly task, (a work task comparable to computer work) showed 1.2 % MVE between days variability and 0.89 % MVE between subject variability for the 50th percentile of MVE normalized measurements ((Nordander et al., 2004). In the forearm extensor muscles, the between day variability was for the 50th percentile 3.9 % MVE and the between subject variability was 31.% MVE (Nordander et al., 2004). Moreover, studies have concluded that the magnitude of possible biases caused by measurement errors in epidemiological studies were acceptable (Netto, 2006; Nordander et al., 2004).

***Figure 6** The position of the EMG electrodes*

***Figure 7** The instrumented glove used to measure wrist positions and movements*

Wrist positions and movements

A glove, equipped with two electrogoniometers, and a data logger (Greenleaf Medical, Palo Alto, CA, USA) were used to collect information on wrist positions and movements of the mouse operating hand with a sampling rate of 20 Hz (Figure 7). The instrument was calibrated at four different wrist positions: 45° extension, 45° flexion, 25° ulnar deviation and 15° radial deviation, using a modified calibration fixture (Greenleaf Medical, Palo Alto, CA, USA). The reference (zero) position was recorded with the hand fully pronated and the palm of the hand lying flat, in neutral radial/ulnar and flexion/extension positions in the calibration fixture. The data were analyzed by commercially available software (GAS, Ergonomic & Research Consulting, Seattle, Wash., USA). The program calculated the angular distribution, mean angular velocity and mean power frequency of the power spectrum (MPF) for both flexion/extension and radial/ulnar deviation. MPF is defined as the center of gravity for the power spectrum and has been used as a generalized measure of repetitiveness (Hansson et al., 1996). The 10th (p0.10), 50th (p0.50) and 90th (p0.90) percentiles of the registered angles in flexion/extension and radial/ulnar deviation were used to characterize wrist positions.

Regarding the reliability of elbow and forearm posture measurements a previous study has found that reliable measurements could be obtained regardless of the level of experience of the investigators. It was further shown that both standard manual and computerized goniometers have high both intra and inter tester reliability (Armstrong et al., 1998).

Forces applied to the computer mouse

An instrumented mouse was used to measure the forces applied to the sides and the button of the computer mouse (Apple ADBII mouse elaborated at the University of California, San Francisco, CA, USA). The force sensing computer mouse was installed at a separate workstation. The forces were measured perpendicular to the sides and the button. The methodology for collecting the applied forces, validity and measurement accuracy of the equipment have been described in detail elsewhere (Johnson et al., 2000). The force data were analyzed using a program written in Labview 4.0 (National Instruments; Austin, TX, USA). The program identified each time the mouse was used, called a grip episode. For each grip episode, the program calculated the mean force, peak force and the duration of the grip episode. In *study I* the maximum forces were measured with an Apple ADBII mouse instrumented with load cells (Pinchmeter; Greenleaf Medical; Palo Alto, CA, USA). The subjects applied maximum voluntary contractions (MVCs) to the side and button of the mouse. The MVCs were measured after recording the standardized task. The subjects were asked to grip the mouse in the same way as during the standardized editing task and to apply three MVCs to the side and button of the mouse. The highest force applied to each location was chosen as the subject's MVC.

3.2 Observation assessments

Working technique

Working technique was assessed with an observation protocol consisting of three different parts investigating different dimensions of computer work; work place layout, working technique, and working postures of the neck/shoulders and upper extremities (http//www.amm.se/fhvmetodik/checklista.pdf).Part two in the protocol (working technique part) was used to create the working technique score. The observation protocol was used together with a key where all variables included in the protocol were explained. The assessments were performed by an experienced ergonomists who was "blind" regarding possible symptoms and results from the direct measurements.

Development of the working technique scoring system

The working technique was characterized with a score, comprising nine different variables (Table 2). The variables were selected, by an expert panel, in accordance with findings in previous scientific studies of working technique characteristics and musculoskeletal load, in combination with the empirical experience of the members of the expert panel group. The included items were weighted according to previous identified risk factors and clinical experience in the expert panel group. Thus variables believed to have a greater impact on the biomechanical strain, detect sensations and musculoskeletal outcomes had a higher range of possible scores compared with variables believed to have less impact. An overall working technique score (range 1-25) was calculated as the sum of the scores for the individual variables. The higher the score, the better the working technique.

The arm support was observed from the input device-operating side, both when evaluating input device work and keyboard work, since there were no differences in support for the left and right forearm when performing keyboard work. In *study I* subjects having total scores of >15 were classified as having a good working technique (n=11; 5 men, 6 women), subjects with total scores 14-15 as having an intermediate working technique (n=10; 3 men 7 women) and subject with total scores <14 as having a poor working technique (n=11; 6 men, 5 women). In the analysis of the differences between good and poor working techniques, the intermediate group was excluded. In *study IV* the total score possible to obtain was 23 instead of 25 since the data collection for this study was made before the development of the working technique score and one of the items were not included in the observation protocol. Subjects scoring ≥ 14 were classified as having a good working technique, those scoring 12-13 as having an acceptable working technique and subsequently those scoring < 12 were characterized as having a poor working technique.

In *study III* and *IV* informal tests during training of the participating ergonomists revealed a fair to good inter observer reliability after training for some of items included in the checklist. Additionally, during the process of training of the ergonomists the checklist key was improved in order to facilitate reliable measurements. A recently published study regarding reliability of the checklist have shown that the majority of variables in the ergonomic checklist could be classified as having fair to good or higher reliability (Norman et al., 2006).

***Table 2** Variables used for classification of working technique. The score range for each item is presented. The overall score ranged between 1 and 25 (the higher the score the better the working technique).*

Item	Categories	Score
Support of the arms during keyboard work (score 0-5).	Proximal part of the hand	1
	Wrist	1
	Distal part of the forearm	1
	Proximal part of the forearm	1
	Elbow	1
	No support at all	0
Support of the mouse-operating arm during input device work (score 0-5).	Proximal part of the hand	1
	Wrist	1
	Distal part of the forearm	1
	Proximal part of the forearm	1
	Elbow	1
	No support at all	0
Lifting of the computer mouse (score 0-3).	None	3
	Hardly ever	2
	Now and then	1
	Frequently	0
Range of movements during input device work (score 1-3).	Small	3
	Medium	2
	Large	1
Velocity of movements during input device work (score 0-1).	Normal	1
	Fast and/or jerky	0
Type of working method during input device work (score 0-2).	Wrist/Fingers	2
	Forearm	1
	Whole arm	0
Sitting in a tense position (score 0-2).	Not at all	2
	Yes, sometimes	1
	Yes, most of the time	0
Lifting the shoulders during keyboard work (score 0-2).	Not at all	2
	Yes, sometimes	1
	Yes, most of the time	0
Lifting the shoulders during input device work (score 0-2).	Not at all	2
	Yes, sometimes	1
	Yes, most of the time	0

In *study II* we used the variable “working with lifted shoulders” as a proxy for working technique in the logistic regression model, since the hypothesis was that psychosocial strain might have an especially large impact on this variable. A general assumption among practitioners has been that psychosocial strain (e.g. job demands and emotional stress) often manifest themselves physically as a tendency to “lift the shoulders” during stressful situations. Studies of psychosocial factors and musculoskeletal symptoms/disorders have indicated that mental stress more often was connected with musculoskeletal symptoms (unspecific muscle pain) in the central parts of the body than from the peripheral parts, i.e. the arm or wrist/hand (Toomingas et al., 1997b).

Working postures and work place layout

In *study III* and *V* assessments of workplace layout and working postures were conducted according to part one (work place layout) and part three (working postures) of the checklist for computer work. The assessments were performed by 32 experienced ergonomists employed by different organizations and companies, both private and public. All participating ergonomists attended a course in evaluation of workplace layout and working postures from video recordings according to the observation protocol. They were trained until agreement in the judgments was obtained as decided by the principal investigator. The ergonomic observations were then performed at the subject's ordinary workstation during their most common computer task, and the results were categorized and written down in the protocol immediately. Five items concerning workplace layout were observed, the working chair, the working table, the computer screen, the keyboard and the input device. Four of the original 5 items were used in the analysis; the observation of the working table was excluded since there was no corresponding question regarding comfort concerning the working table. For each item, 5-9 different variables were evaluated and for every variable there were 2-5 exposure categories. Observations from the 4 items included in the dimension work place layout (chair, keyboard, screen and input device) than formed the base for classification into 3 exposure groups, good, acceptable or poor work place layout. These exposure classifications were made by an expert panel group according to theoretical knowledge and empirical experience concerning known risk factors linked to work place layout (Table 3).

The evaluation of working postures in *study III and V* was made from video recordings taken at the subjects ordinary work stations, during their most common computer task. Different angles were used to get the optimal camera projections in order to make accurate evaluations of the joint angles. The subjects were filmed from the side when evaluating neck flexion-extension, shoulder joint flexion-extension, trunk flexion-extension and wrist/hand flexion-extension, from behind when evaluating neck rotation, trunk lateral flexion and shoulder abduction and from behind and at an angle (45°) from above when evaluating shoulder joint rotation and wrist/hand deviation. The subjects were videotaped 2-3 minutes and the recordings were analyzed every 10th second by measuring the angles with a manual goniometer in order to obtain a mode value. The observations were than divided into 2-5 categories for each body region and further classified into 3 exposure groups (high, medium and low) by the same expert panel build on the same considerations as mentioned above (Table 3).

Table 3 *Classification of workplace layout and working postures. All other combinations were considered as acceptable work place layout.*

	Good	Poor
Working chair	Medium sitting height easily adjustable (feet and thighs supported). “Rocking” function. Narrow backrest. Adjustable or removable armrests. Backrest shoulder height or more.	No support or little support of feet and thighs **or** Non-adjustable sitting height.
Computer screen	Screen ≥ 17 inches. Screen position on the working table ≥ 50 cm from the operator. Screen position right in front of or not more than 10 cm deviation to either side. Position in height low or medium (neck position neutral or 0-20°). Possibilities of adjusting screen angle. No reflections from the window or light sources in the screen.	Screen ≤ 14 inches **or** screen position in depth < 50 cm from the operator **or** screen position > 10 cm deviation to either side **or** a high screen position in relation to the operator’s eyes (neck extension) **or** reflections from windows or light sources in the screen.
Keyboard	Position of the keyboard right in front of the operator. Distance from the shoulder (acromion) to the edge of the working table not more than 30 cm. Keyboard placed on the same working surface as the screen. Elbow angle 70-90°.	Keyboard placed on an extension table **and** no armrests or non-adjustable armrests on the working chair **or** keyboard on the same working surface as the screen and the keyboard placed < 15 cm from the edge of the working table **or** keyboard position more than 10 cm deviation to either side.
Input device	Input device on the same working surface as the keyboard. Position in depth, 15-35 cm from the edge of the working table and not more than 15 cm distance between the edge of the working table and the operator (acromion) and position of the input device in height lower than elbow height. Input device not more than 40 cm from the centre of the trunk of the operator in either lateral direction.	Input device on a separate extension table **or** on the same working surface as the keyboard but placed < 15 cm from the edge of the working table. Input device > 35 cm from the edge of the working table and > 30cm or <10 cm from the operator (acromion) **or** placing of the input device more than > 5 cm above elbow level **or**. position laterally > 40 cm from the centre of the trunk of the operator.
Working postures neck	-5-15° flexion in the neck and no protrusion of the head/neck and rotation of the neck ≤ 15°and variation of the neck position 2-5/times/min or more **or** neck flexion 15-30° and variation of position 2-5times/min or more and no rotation of the neck.	Neck extension > 5° **or** –5-15° flexion and the neck/head protruded. Neck position 15-30° flexion and variation of position <2 times/min. Neck rotation > 45° **or** neck rotation 15-45° and variation in position < 2 times/min.
Working postures shoulder	Extension < 15°- < 15° flexion **or** shoulder 15-30° flexion and 0-30° abduction **or a**bduction 15-30° and a variation of position 2-5 times/min.	Flexion 15-30°or more and variation in position <1 time/min **or** flexion > 30° and shoulder abduction > 30° **or** shoulder abduction between 15 and 30 ° and variation of position <2 times/min. Outward rotation >30° or outward rotation 15-30°and variation in position < 2 times/min
Working postures trunk	Extension ≤ 15°- flexion ≤ 15° **or** trunk extension ≥ 15° and a variation of position > 5 times/min and a lateral flexion < 5°.	Trunk flexion > 15° **or** trunk extension > 15° and in both cases variation of position < 2times/min **or** lateral flexion > 5° **or** sitting with a tilted pelvis in ≥ 15°extension and variation ≤ 1 time/min.
Working postures wrist/hand	Wrist extension < 15°-15°in flexion **or** extension of the wrist 15-30° and variation of position > 2 times/min and deviation of the wrist between radial deviation < 10° and ulnar deviation <15° and variation of position > 5 times/min	Extension of the wrist > 30° **or** extension 15-30° and variation of position < 2times/min **or** radial deviation > 10° **or** ulnar deviation >30°.

3.3 Questionnaires and self-ratings

Beside questions regarding personal data, exposures and occurrence of symptoms, data concerning psychological strain in *study II* (job demands and emotional stress) and detect sensations in *study III and IV* (perceived muscle tension, perceived exertion and comfort) were collected from questionnaires. The questions regarding exposures and symptoms *study IV* referred in to the working conditions during “normal” circumstances. Data regarding days with symptom during the preceding month were also collected through questionnaires in *study IV*. The questionnaires were distributed and collected by ergonomists at occupational health care centers in *study III and IV* and in *study II* the questionnaire data were collected in connection with the technical measurements performed by the investigators.

Psychological demands

In study II central components from the model suggested by Karasek and Teorell were used to assess psychological exposure. A short Swedish version of the Job Content Questionnaire (Theorell et al., 1991) was used to assess psychological demands. Five questions (Does your work demand that you work fast, Does your work demand that you work hard, Does your work demand a great effort, Do you have enough time to finish the work task, Does it exist conflicting demands at your work place) were asked in the telecommunication company, and four of the questions (excluding the question about working hard) in the editorial department of the newspaper, with specific reference to psychological demands during the preceding month. The response scale comprised four categories for each question: often, sometimes, seldom or never. For each subject, a median response (often, sometimes, seldom or never) was calculated. The group was then dichotomized. Subjects with a median response of “often” or “sometimes” were classified as having high psychological demands and subjects with a median response of “seldom” or “never” were classified as having low psychological demands.

Reliability of the job demand dimension included in the Job Content Questionnaire has in a previously conducted study in a similar population (Swedish computer users) showed an internal consistency of 0.7 (Chronbach´s alpha) (Eklöf, 2001).

Emotional stress

An adjective checklist (Kjellberg and Iwanowski, 1989; Kjellberg et al., 2000a) was used in *study II* to assess emotional stress during the day of the measurements. The stress dimension comprises six items, three positively loaded, and three negatively loaded. The responses for the positively loaded items were inverted before a median response was calculated. The following positively loaded items were included in the stress dimension: “rested”, “relaxed” and “calm”. The negatively loaded items were “tense”, “stressed” and “pressured”. The response scale comprised six categories for each adjective: very much, much, fairly, somewhat, almost not or not at all. For each subject a median response was calculated. The variables were than dichotomized; subjects with a median response of "fairly" to "very much" were classified as having high emotional stress, and subjects with a median response of "somewhat" to "not at all" were classified as having low emotional stress.

Reliability for the adjective checklist have been tested and the estimated value was 0.93 (Chronbach´s alpha) for the stress dimension used in *study II* (Kjellberg and Wadman, 2002).

Perceived muscular tension

In *study II* one of the questions from the questionnaire, "Have you during the past month experienced muscle tension (i.e. wrinkled your forehead, ground your teeth, raised your shoulder?), was used to characterize muscle tension. The response scale comprised four categories: never, a few times, a few times per week, one or several times per day. The data were used to split the subjects into two groups: a high-tension group (experiencing tension a few times per week or once to several times per day) and a low-tension group (experiencing tension never or a few times).

Comfort

In *study III and study IV* subjects answered a questionnaire where they rated perceived comfort for 11 ergonomic items on a comfort rating scale with 9 response alternatives ranging from –4 (very, very poor) to + 4 (very, very good). Four of the original 11 items concerning comfort from the questionnaire were included in the analysis (comfort concerning working chair, computer screen, keyboard, input device). The excluded items referred to ergonomic factors like light, and noise and were not relevant for the aim of the study. The included items were classified into three groups, good, acceptable and poor comfort where negative values –4 to –1 were considered as poor comfort, 0 to +2 were considered as acceptable comfort, and +3 to +4 were considered as good comfort. We have not specifically tested the reliability of the used items. However, Eklöf et al (Eklöf, 2001) computed reliability to be satisfactory (approximately 0.90) in a sample of 400 Swedish computer users. Such a result would not have been likely if the items making up the score would have had poor reliability.

Perceived exertion

In *study III and IV* perceived exertion during computer work were rated on a modified Borg RPE-scale (Borg, 1990; Wigaeus Hjelm et al., 1995) in 9 different body regions (eyes, neck, shoulders, thoracic part of the back, upper arm, elbow/ forearm, wrist, hand and fingers and the low back). Four of the original 9 body regions (neck, shoulder, wrist, and low back) corresponding to the same body regions in the observation protocol were included in the analysis in *study III* while in *study IV* subjects rated perceived exertion 3 of the original 9 body regions (neck, shoulder and hand/arm). The ratings were classified into three groups, high, medium and low exertion. Ratings from between 0-6 (0-fairly light) on the Borg scale were considered as low exertion, values between 7-10 (somewhat strenuous to strenuous) were considered as medium exertion and values between 11-14 (very strenuous to very, very strenuous) were considered as high exertion. In *study IV* mean values for the perceived exertion were calculated for the 3 previously mentioned body regions, respectively. Subjects in *study IV* were classified into three groups, with 0–4 considered to be low exertion, 5–7 to be medium exertion, and ≥8 to be high exertion.

4 Data and statistics

Study I

Study population subgroups were formed according to sex, ongoing symptoms (cases in this study were subjects with symptoms on the measurement day) and working technique. Before analysis it was decided to include both computer mouse users (28 subjects) and trackball users (four subjects) in the main group since the aim of the study was to evaluate the impact of different working techniques on the level of physical loads and not the difference between different kinds of input devices. In any case, a trackball was not used during the experimental session in which the forces applied to the input device were measured, only during the measurements performed at the subjects' ordinary workstations. The statistical significance level was set to p=0.05. Descriptive data from measurements of muscular load (EMG) are presented as means with standard deviation (SD), and as medians with 25th and 75th percentiles. Goniometry data are presented as means and SD. Mouse forces and manual goniometry data are presented as medians with 25th percentile and 75th percentile. Data from 13 min of ordinary computer work were used for analysis of EMG and electrogoniometer measurements. The first and last minutes of the EMG and electrogoniometer measurements were excluded. For the 10 min standard editing task, data from the middle 8 min were used for analysis. The first and last minutes were excluded. All comparisons of independent groups were made with Wilcoxon's Rank Sum Test Mann –Whitney U-test for ordinal data and Fischer's exact two-tailed test for nominal data. All statistical analyses were performed using the statistical software JMP version 4.0.2. (SAS institute Inc., Cary, NC, USA). Due to technical problems one female subject was excluded in the analysis of muscular load and one male subject in the analysis of wrist angles and positions.

Study II

The descriptive data are presented as medians and range or as means and standard error of the mean (SEM). We used a multivariate linear regression model to analyze how perceived muscular tension (low tension =0, high tension =1), emotional stress (low stress =0, high stress =1), psychological demands (low demands =0, high demands =1), organization (the editorial department = 0 and the telecommunication company =1) and sex (female =0 and male =1) influenced the physical load (i.e. muscle activity, wrist movements). The explanatory variables to be included in the model were decided a priori. The binary dependent variable, working technique, was analyzed with a logistic regression model with the same explanatory variables as described for the multivariate linear regression models. Age (continuous) and present musculoskeletal pain (no pain =0, pain =1) were controlled for in both the linear and logistic regression models. All statistical analyses were performed with the SAS statistical software, version 8.0 (SAS institute, Cary, N.C., USA). Statistical significance was assumed for P £ 0.05. Due to technical problems, one woman and one man were excluded in the analysis of muscle activity, and the result from one woman was excluded in the analysis of wrist movements. Data were also missing for one woman in the ratings of emotional stress.

Study III and study V

The statistical analysis was performed using the statistical software package SAS, version 8.0 (SAS institute Inc., Cary NC, USA (proc freq)). The data was analysed using a method developed for analyzing paired categorical data based on ranks (Svensson, 1993). The percentage of agreement (PA), the monotonic agreement (MA) and the 95% confidence interval (CI) for MA were used (Svensson, 1993). The MA measure can attain values between -1 and 1, where 1 represents total order of consistency, 0 represents total inconsistency and -1 represent inverse order consistency. The rank consistency can be good (high MA) even if we have large disagreement as long as this disagreement is systematic (low PA, high MA). For interpretation of the MA values the same reference values as for Kappa statistics was used. Values o0.20 were considered to represent no or very weak agreement, values between 0.21 and 0.4 weak agreement, values between 0.41 and 0.60 reasonably good agreement, values between 0.61 and 0.80 good agreement and values between 0.81 and 1.00 were considered to represent very good agreement.

Study IV

Symptoms were defined as reports of pain/aches in any of the body regions asked about, lasting ≥3 days, during the preceding month. Symptoms in the different body regions were compiled into three outcome categories. A case was defined as a subject who was classified as symptom free in all body regions at baseline or during a minimum of one follow-up period, and who later reported symptoms. Cases contributed with person-time corresponding to the period between the dates of the questionnaire when they were symptom free for the first time and the questionnaire in which they were classified as cases in the relevant body region for the first time.

Univariate hazard ratios (HR) with 95% confidence intervals (95% CI) for symptoms in the neck, shoulders, and arms/hands were calculated with Cox proportional hazard models using JMP version 5.0.1 and Proc Phreg (SAS v.9.0). All statistical analyses were performed separately for men and women. Variables were entered in a multivariate model together with variables that were found to be significantly associated with the relevant outcome in an earlier study concerning risk factors for musculoskeletal symptoms and computer work (Karlqvist et al., 2002).

5 Results

The results will be presented according to the previously proposed model for possible pathways between computer work, individual factors (working technique) biomechanical strain, psychological strain, detect sensations and musculoskeletal outcome.

5.1 Working technique

Forearm support, when operating the input device, lifting of the input device and range of movements with the input device were the most important items differentiating a good working technique from a poor working technique *(Study I)(*Table 4).

Table 4 *Score for each item for the two working technique groups. Median values and range (in brackets) are presented for each group.*

Observed item	Good Working technique (n=11)	Poor Working technique (n=10)
Support of the arms during keyboard work (score 0-5)	0 (0-3)	0 (0)
Support of the mouse-operating arm during input device work (score 0-5)	**3 (2-5)**	**1 (0-3)**
Lifting of the computer mouse (score 0-3)	**3 (2-3)**	**2 (0-3)**
Range of movements during input device work (score 1-3)	**3 (2-3)**	**2 (2-3)**
Velocity of movements during input device work (score 0-1)	1 (1-2)	1 (0-1)
Type of working technique during input device work (score 0-2)	2 (1-2)	2 (0-2)
Sitting in a tense position (score 0-2)	2 (0-2)	2 (0-2)
Lifting of the shoulders during keyboard work (score 0-2)	2 (1-2)	2 (1-2)
Lifting of the shoulders during input device work (score 0-2)	2 (1-2)	2 (1-2)

5.2 Working technique and physical strain

Muscular load

Results from S*tudy I* indicted that subjects judged to have a good working technique tended to have lower levels of muscular activity in all measured muscles, with significant differences between them and subjects with poor working technique for the trapezius muscle on the mouse operating side (p0.10=0.02) (Figure 8), and for the forearm muscle ECU (extensor carpi ulnaris) (p0.50=0.03) (Figure 9). Moreover, subjects with good working technique also tended to have more muscular rest in the mouse operating trapezius muscle than subjects who used a poor working technique, although these results were not statistically significant (p=0.09). The results also indicated that subjects who used a good working technique tended to report fewer symptoms from the neck/shoulder and upper limb than subjects using a poor working technique(p=0.08).

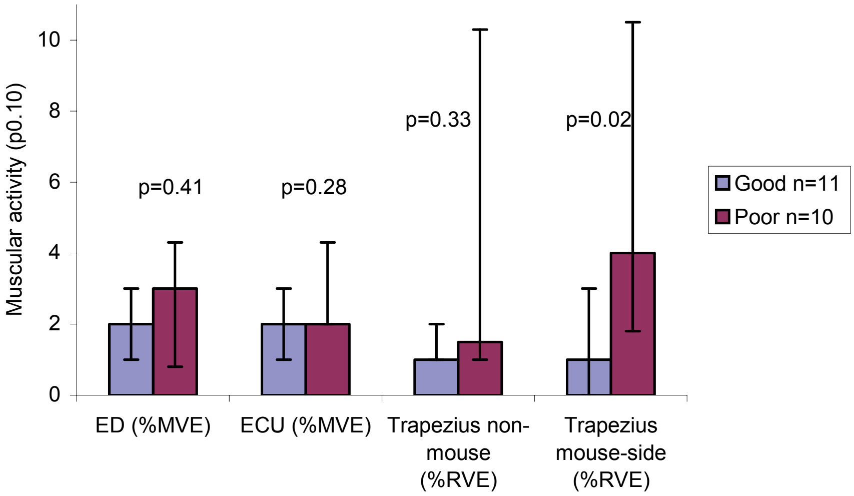

Figure 8 *Muscular activity for the 10th percentile (medians, 25th p and 75th p showing that activity tended to be higher in all measured muscles except ECU in the poor working technique group compared with the good working technique group and there was a significant difference between the groups for the trapezius muscle on the mouse operating side (p=0.02).*

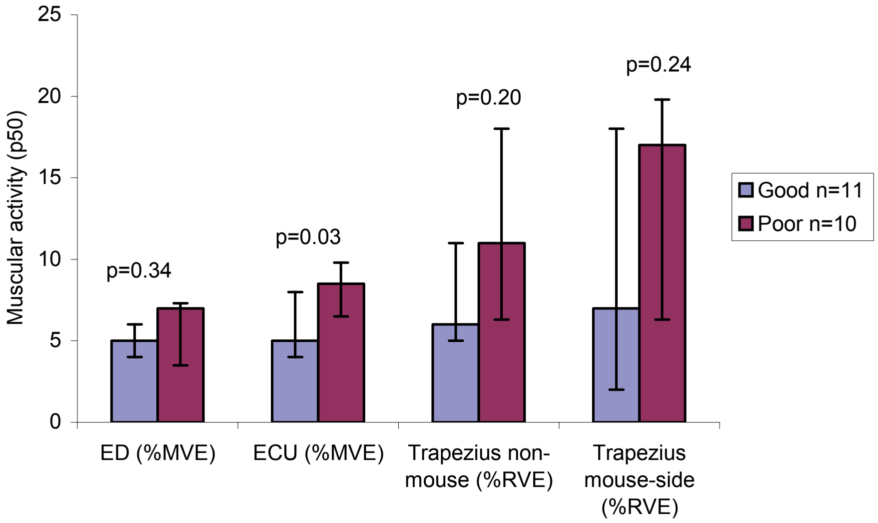

Figure 9 *Muscular activity for the 50th percentile (medians, 25th p, 75th p) showing that activity tended to be higher in all measured muscles in the poor working technique group compared with the good working technique group, and there was with a significant difference between the groups for the forearm muscle ECU (p=0.03).*

Wrist positions and movements

Regarding wrist positions and movements, subjects with good working technique worked with less extension in the wrist (p0.10, p=0.04) than subjects with poor working technique *(study I)*. Moreover, subjects with good working technique had a tendency to work with less ulnar deviation than subjects with poor working technique, although these results were not statistically significant (Figure 10).

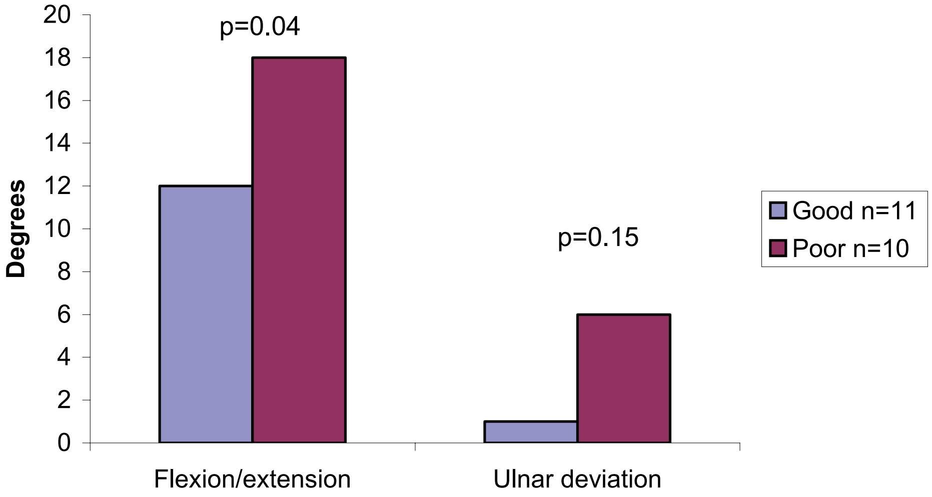

Figure 10 *Wrist positions for the 10th percentile (p0.10) in the two working technique groups.*

In *study II* we analyzed repetitive movements in the wrist in relation to muscular tension, emotional stress and psychological demands and found no associations between repetitive movements (characterized by mean power frequency) and perceived muscular tension, emotional stress or psychological demands.

Forces applied to the computer mouse

In *study I* there were differences present between men and women showing that the women applied higher mean (p=0.006) and peak forces (p=0.02) expressed as % MVC when operating the button of the mouse than the men did. No differences were present regarding side forces on the mouse. Moreover no major differences were observed in the comparison between cases and symptom free subjects for neither button forces nor side forces.

5.3 Working technique and psychological strain

In *study II* a higher muscle activity in the non-mouse operating m.trapezius was associated with both high emotional stress and high perception of muscle tension (8%RVE p=0.006) and (5% RVE p=0.05, respectively), when we controlled for all explanatory variables in the multivariate model. Subjects who reported high perceived muscle tension, also had higher muscle activity in the trapezius muscle on the mouse operating side (P=0.05) Descriptive data are presented in table 5 (Table 5). The explained variance (r_2) in the models was 0.29 for the non mouse-operating trapezius muscle, and 0.13 for the trapezius muscle on the mouse-operating side. The inclusion of age and ongoing musculoskeletal pain did not change the results.

Table 5 *Mean (SEM) of the different variables used to characterise the physical load grouped by the different explanatory variables used in the linear regression models.*

Response	**Explanatory variables**									
	Muscular tension		Emotional stress		Psychological demands		Organisation		Sex	
	No (n=26)	Yes (n=31)	Low (=45)	High (n=1)	Low (n=2)	High (n=34)	1 (n=32)	2 (n=2)	Men (n=29)	Women (n=28)
Muscle activity (%RVE), Trapezius mouse-side	6.8 (1.6)	12.1 (1.4)	9.2 (1.2)	12.2 (3.1)	8.9 (1.7)	10.3 (1.4)	10.9 (1.5)	8.1 (1.5)	9.5 (1.7)	9.9 (1.4)
Muscle rest (% time), Trapezius mouse-side	20.6 (3.4)	13.6 (3.0)	16.3 (2.5)	18.1 (6.0)	17.0 (3.7)	16.7 (2.9)	16.0 (3.1)	17.8 (3.5)	17.3 (3.2)	16.3 (3.3)
Muscle activity (%RVE) Trapezius, Non-mouse side	5.2 (1.0)	11.3 (1.9)	6.6 (0.9)	16.3 (4.3)	6.1 (1.3)	10.2 (1.8)	9.0 (1.5)	7.9 (2.0)	8.4 (1.5)	8.6 (1.9)
Muscular rest (% time) Trapezius non-mouse side	22.1 (3.4)	13.6 (2.7)	19.4 (2.5)	9.3 (3.8)	21.8 (3.9)	14.4 (2.4)	16.5 (3.0)	18.8 (3.2)	18.4 (3.3)	16.6 (2.9)
Muscle activity (%MVE), Extensor digitorum	6.0 (0.42)	5.9 (0.38)	6.0 (0.32)	5.5 (0.61)	5.8 (0.32)	6.0 (0.42)	5.7 (0.37)	6.3 (0.42)	5.5 (0.44)	6.4 (0.33)

Moreover, results from *study II* showed that *s*ubjects reporting high psychological demands and high emotional stress, worked with lifted shoulders more often than subjects reporting low psychological demands and low perceived emotional stress, respectively (Table 6).

***Table 6** Relative frequencies (%), (absolute numbers in brackets) of subjects who worked with lifted shoulders amongst (a) subjects who perceived muscle tension, emotional stress and psychological demands, respectively, and (b) who did not.*

Response	Explanatory variables					
	Muscular tension		Emotional stress		Psychological demands	
	No (n=26)	Yes (n=31)	Low (n=45)	High (n=11)	Low (n=23)	High (n=34)
Lifted shoulders						
No (n=40)	69 (18)	71 (22)	78 (35)	45 (5)	78 (18)	65 (22)
Yes (n=17)	31 (8)	29 (9)	22 (10)	55 (6)	22 (5)	35 (12)

When applying the scoring system for working technique, described in Table 1, in the analyzes the results showed that subjects reporting high psychological demands and high muscular tension worked with poorer working technique than did subjects with low demands and no perception of muscular tension, respectively (p=0.03 and p=0.02) (Figure 11 and Figure12). There were no major differences in working technique scores between subjects with high and low perception of emotional stress.

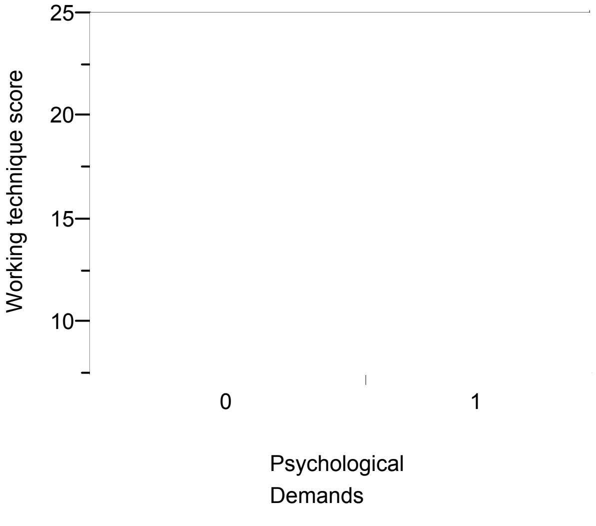

***Figure 11** Working technique scores (high score=good working technique) for subjects with low and high psychological demands. The median, 25th p and 75th p and inter quartile range are presented.*

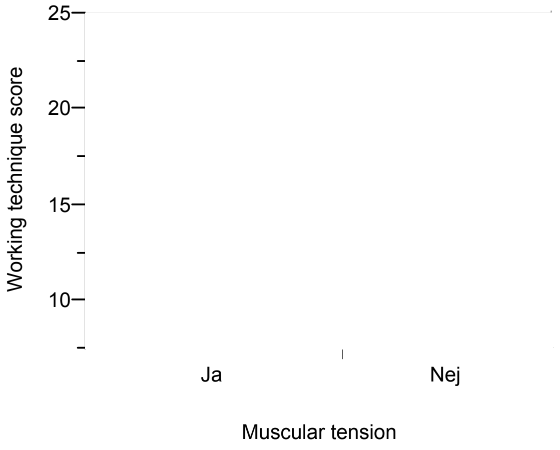

Figure. 12 *Working technique score (high scores=good working technique) for subjects who perceived muscle tension compared to those who did not. The median, 25thp and 75th p and inter quartile range are presented.*

5.4 Working technique and neck and upper extremity symptoms during computer work

Results from *study IV* showed that working technique evaluated according to the working technique score was not connected to an increased risk of developing symptoms in any of the 3 body regions in this study (neck/scapular area, shoulders, and hand/arm) neither for men nor for women (Table 7).

Table 7 *Risk ratios with 95% CI for men, for upper extremity symptoms in relation to observed working technique during VDU work.*

		Men		
		Symptom		
		Neck HR *(95% CI)*	**Shoulder** HR *(95% CI)*	**Hand/arm** HR *(95% CI)*
Working technique	**Tot=294**			
Good	n=64	1.0	1.0	1.0
Acceptable	n=174	0.8 *(0.49-1.40)*	1.0 *(0.45-2.27)*	1.0 *(0.56-1.2)*
Poor	n=56	0.6 *(0.30-1.31)*	1.0 *(0.36-2.76)*	1.4 *(0.53-2.46)*

Table 8 *Risk ratios with 95% CI for women, for upper extremity symptoms in relation to observed working technique during VDU work.*

		Women		
		Symptoms		
Working technique	**Tot 330**	**Neck** HR *(95% CI)*	**Shoulder** HR *(95% CI)*	**Arm/hand** HR *(95% CI)*
Good	n=54	1.0	1.0	1.0
Acceptable	n=199	1.0 *(0.64-1.60)*	1.4 *(0.71-2.78)*	1.4 *(0.78-2.68)*
Poor	n=77	1.1 *(0.65-1.82*	1.0 *(0.44-2.21)*	1.0 *(0.47-2.08)*

Moreover using the proxy variable for working technique previously used in *study II* (lifted shoulders) in the analyzes showed no increased risk in the group that worked often with lifted shoulders compared to those who sometimes or never work with lifted shoulders p=0.23, 95%CI (0.84-1.86) for women and p=0.22, 95%CI (0.31-1.25) for men.

5.5 Perceived exertion and comfort

Results from *study III* showed that the agreement between Computer users ratings of perceived exertion in different body regions and the ergonomists´ observation of working postures for the same body regions was good for all measured variables. Monotonic agreement (MA) between ratings and observations was for the neck 0.63 (0.61; 0.64), shoulder 0.63 (0.61; 0.65), wrist 0.77 (0.75; 0.79) and trunk 0.72 (0.71; 0.72). Moreover, that the result from this study showed that there was a reasonably good agreement between computer workers users' ratings of comfort and the ergonomists' observations of the working chair 0:60 (0:59; 0:61) and the keyboard, 0.58 (0.57-0.59).Furthermore that there was good agreement between VDU-users' ratings of comfort and the ergonomists' observations concerning the computer screen 0.72 (0.71-0.73) and the input device 0.61(0.60-0.62). Due to the scientific correspondence arising from the publication of *study III* we looked into the data one more time and wrote a technical note *study V* where the interpretation of the results were modified according to immersed knowledge about how to correctly interpret the outcome of the statistical method used. A more strict interpretation of the results might be that 'ratings of comfort and perceived exertion might serve as a cost-efficient and user-friendly initial survey-method to identify workplaces with poor workplace layout and poor possibilities to use optimal working postures' since there is fair to good agreement between self reported poor comfort and self-rated high exertion while regarding the group with ratings of good comfort and low exertion one would still have to use more time consuming and costly observation methods.

5.6 Perceived exertion and comfort and neck and upper extremity symptoms during computer work

The results from the univariate analysis in *study IV* showed that high perceived exertion in the neck, shoulders, and arms/hands was associated in both men and women with an increased risk of developing symptoms in the same regions. Moreover, there seemed to be a dose-response relationship between the level of perceived exertion and the risk of developing symptoms in all three regions, and in both sexes (Table 9). When controlling for previously identified risk factors in the multivariate analysis, perceived exertion stayed significant in all three body regions and the calculated hazard ratios did not change noticeably (changes of RR between 0.3–0.5). Moreover when analyzing perceived exertion in relation to working technique, in order to clarify if there were associations between poor working technique and high exertion, no such relationship was found. Subjects observed with using a poor working technique were equally distributed between the low, medium and high exertions groups. Regarding perceived comfort there was a tendency towards an increased risk of developing neck and upper extremity symptoms for subjects rating medium to low comfort compared to those who rated high comfort regarding their work place layout. However, these results were not statistically significant.

Table 9 *Risk ratios with 95% CI (in italics) for men and women for symptoms in different body regions in relation to perceived exertion during VDU work.*

	Men				**Women**			
		Symptom				**Symptom**		
Perceived		**Neck**	**Shoulder**	**Hand/arm**		**Neck**	**Shoulder**	**Hand/arm**
Exertion	N	HR *(95% CI)*	HR *(95% CI)*	HR *(95% CI)*	N	HR *(95% CI)*	HR *(95% CI)*	HR *(95% CI)*
Neck	**Tot=381**				**Tot=470**			
Low	233	1.0	1.0	1.0	246	1.0	1.0	1.0
Medium	124	1.5 *(0.96-2.23)*	**2.3** *(1.31-4.05)*	1.6 *(0.98-2.54)*	124	**1.5** *(1.08-2.05)*	1.4 *(0.90-2.14)*	1.1 *(0.73-1.55)*
High	24	**2.7** *(1.50-4.91)*	2.2 *(0.84-5.83)*	**3.1** *(1.64-6.04)*	24	**2.0** *(1.39-2.86)*	**2.1** *(1.32-3.43)*	1.5 *(0.96-2.28)*
Shoulder	**Tot=382**				**Tot=470**			
Low	276	1.0	1.0	1.0	333	1.0	1.0	1.0
Medium	90	1.4 *(0.88-2.12)*	**2.7** *(1.55-4.76)*	**1.8** *(1.10-2.83)*	107	**1.5** *(1.05-2.0)*	1.36 *(0.86-2.13)*	1.4 *(0.97-2.06)*
High	16	**2.4** *(1.19-4.80)*	**3.3** *(1.27-8.63)*	2.2 *(0.94-5.15)*	30	**2.0** *(1.24-3.14)*	**3.6** *(2.16-5.93)*	**1.8** *(1.01-3.10)*
Hand/arm	**Tot=382**				**Tot=469**			
Low	297	1.0	1.0	1.0	385	1.0	1.0	1.0
Medium	79	1.1 *(0.71-1.79)*	**2.0** *(1.12-3.52)*	**2.3** *(1.36-3.98)*	74	1.2 *(080-1.68)*	**1.7** *(1.10-2.73)*	**1.6** *(1.06-2.36)*
High	6	1.9 *(0.61-6.11)*	2.9 *(0.70-12.12)*	**2.9** *(0.90-9.15)*	10	1.5 *(0.67-3.41)*	**3.6** *(1.66-7.80)*	**2.6** *(1.23-5.68)*

6. Discussion

The emphasis of this thesis has been to explore the impact of working technique, perceived exertion and comfort during computer work on the onset of neck and upper extremity symptoms and moreover to explore possible associations between working technique and physical and psychosocial exposures. Furthermore to explore the usability of methods based on subjective ratings in relation to more costly methods for detecting work groups exposed to poor conditions concerning work place layout and working postures. The results from this thesis and the implications of the results will be discussed in relation to the proposed model of musculoskeletal symptoms/disorders modified from the Sauter and Swanson model (Sauter and Swanson, 1996) previously presented in the first section of this here thesis.

The results from *study I* and *study II* showed low levels of muscular load in general compared with results from earlier studies of other occupational groups performing repetitive work tasks e.g. material handling work (Balogh et al., 1999; Hansson et al., 2000). However, the results were consistent with previous studies on computer mouse work both in field studies and in experimental laboratory settings (Bystrom et al., 2002; Karlqvist et al., 1999; Karlqvist et al., 1998; Wahlstrom et al., 2000). Moreover results from *study II* showed that perceived emotional stress during the measurements was associated with higher muscle activity in the trapezius muscle on the non-mouse-operating side. A previous study on cashiers in a supermarket has found a correlation between muscular load during work and ratings of stress together with a stronger correlation for the left side than for the right side (Rissén et al., 2000). A possible explanation for the findings that the differences were more pronounced for the non-active trapezius muscle could be that the active side, besides being influenced by different kinds of stress, is also exposed to physical loads that might "mask" the effects of the psychosocial loads.

6.1 Working technique and biomechanical stain

In *study 1* the working technique was measured using the working technique score and differences between groups were analyzed with respect to this characterization. The results from *study I* showed that subjects judged to have a good working technique had lower levels of muscular load in the forearm muscles and in the trapezius muscle on the mouse-operating side than subjects with a poor working technique. The analysis of gaps and muscular rest, on the other hand showed no statistically significant differences between subjects with good working technique compared to subjects with poor working technique, although there was a tendency for the former to have more muscular rest (p=0.09). Regarding gap frequency, there were no major differences between the two working technique groups. Some studies have found no statistical differences in gaps between subjects with and without symptoms (Vasseljen and Westgaard, 1995; Westgaard and De Luca, 2001), while others have shown that lack of gaps may be a risk factor for neck and upper extremity disorders (Hägg and Åström, 1997; Veiersted and Westgaard, 1993). Muscular rest and gap frequencies have previously been explored among cleaners and office workers (Nordander et al., 2000a). The cleaners in the study by Nordander and co-workers had a high risk of neck/shoulder pain, and much less muscular rest than office workers (median value of muscular rest time for the cleaners and office workers were 1.5% and 12%, respectively). In the same study there were no significant differences in gap frequency between the two occupational groups. Among the office workers, low values of muscular rest and high gap frequencies were registered in subjects with a low subjective tendency to experience muscular tension. These findings, together with the results from our study, where subjects with a poor working technique were found to have lower values of muscular rest than subjects with good working technique implies that muscular rest could be a more suitable measure to use than gap frequencies regarding computer work. Additionally, During low force muscle contractions performed for a long time period, e.g. during computer work, lack of periods with exposure to more “heavy” physical load under a limited time period might be one plausible risk factor to consider when investigating cause-effect relation ship between physical load and neck and upper extremity symptoms/disorders. Another way to describe and characterize muscle activity has been through the so called exposure variance analysis (EVA). The main advantage with this method compared to gap frequency analysis, analysis of total rest time and analysis of the amplitude distribution of the muscle activity is that EVA-analyzes offers the opportunity to quantify the patterns of variation including recovery periods in muscular activity in a structured way (Mathiassen and Winkel, 1991). The EVA analyzes is probably more suitable and could provide more information when the measurement period are of longer duration than 15 minutes which was the time frame for the EMG measurements in our study.

Results from *study I* showed that a good working technique compared to poor was associated with less extension in the wrist. Previously conducted studies on wrist positions and finger movements have indicated that extreme wrist extension is associated with a risk of developing carpal tunnel syndrome, as well as forearm pain during repetitive work (e.g. computer work) (Cole et al., 2003; Keir and Wells, 2002). According to these results it may be relevant to focus on working technique training in ergonomic interventions concerning office work in general and computer work in particular.

6.2 Working technique and psychological strain

In *study II,* the data were analyzed using a proxy for working technique (lifted shoulders) and the results suggested that both emotional stress and psychological demands may be associated with working technique. Subjects who reported high psychological demands and emotional stress more often worked with lifted shoulders (poor working technique) than subjects who did not report these conditions. The reason for choosing just one of the variables contributing to the working technique score to characterize working technique in *study II,* was that we considered *a priori* lifted shoulders to be the most important factor in the score reflecting the reactions to mental loads. This decision was based on clinical experience and clinical findings in patients suffering from stress-related disorders. Musculoskeletal pain is commonly localized in the trapezius muscles of subjects reporting high levels of work-related stress, and it seems likely that this could be related to habitually lifting the shoulders. Studies have previously found an association between upper limb disorders and psychosocial factors (Andersen et al., 2002; Ariens et al., 2002; Bongers et al., 2002; Buckle, 1997; Devereux et al., 2002).

When using the score for working technique, instead of a single-item characteristic, the results showed that subjects reporting high psychological demands and perceived muscular tension used a poorer working technique than did subjects with low demands and no perception of muscular tension, respectively. No major differences were seen in working technique among subjects with emotional stress compared to subjects without emotional stress.

6.3 Working technique and neck and upper extremity symptoms during computer work

The results from *study I* showed that 28% of the subjects with a good working technique had ongoing symptoms from the neck and upper extremities while 73% of the subjects with a poor working technique had ongoing symptoms. One could argue that having symptoms might result in a change of working technique, but even so, it seems unlikely to believe that subjects with symptoms would apply a poorer working technique, since that would probably increase the load and symptoms. The findings rather indicate that poor current working technique contribute to the symptoms. A previous study concerning work style and symptoms among computer users have reached the same result and conclude that an improved work style may be helpful in the management of neck and upper extremity symptoms and disorders (Feuerstein et al., 2004a). The indicated association between poor working technique and neck and upper extremity symptoms in *study I* could not be supported in the longitudinal *study IV* where the results showed no statistically significant increased risk of developing neck and upper extremity symptoms for subjects with poor working technique. The lack of support for an association between working technique and symptoms in *study IV* however, could not solely be due to insufficient power of the study, since the power calculations performed in accordance with recommendation by Machin et al (Machin D et al., 1997) revealed more than 90% power for the study. The most plausible explanation could be that the subjects in *study I* consisted of a homogeneous group of workers performing identical work tasks while the subjects in *study IV* consisted of workers with various work tasks working in different organisations. It is likely to believe that the work task performed, and the demands connected to the work task are more important for the musculoskeletal outcome than the physical exposure connected to computer work. Recent preliminary results from a study exploring neck and upper extremity symptoms and computer work in the Swedish work force have supported this (Ekman and Hagberg, 2007). However, some recent studies of a work style and symptoms from the neck and upper extremity in connection to computer work have showed that a poor work style was associated with more symptoms from the neck and upper extremities compared to a good work style (Feuerstein et al., 2004a; Feuerstein et al., 2005; Juul-Kristensen and Jensen, 2005). One of the main reasons for this divergence might be due to the definition of working technique and hence to the items included for the classification into different exposure groups. The concept of work style includes physical, individual and psychosocial parameters while the working technique score used to characterize working technique in *study I and IV* in this thesis was based only on physical parameters. As shown in this thesis working technique could be influenced by psychosocial exposures like, job demands and emotional stress and either directly or through mediators like perceived muscle tension or perceived exertion lead to an increased risk of neck and upper extremity symptoms. In other studies it has been proposed that lack of rest breaks, high personal work expectations and high work load are factors influencing work style leading to neck and upper extremity symptoms/disorders primarily through increased exposure to biomechanical strain (Feuerstein, 1996; Huang et al., 2003). In contradiction to our results where we could se no distinct associations between working technique and the development of neck and upper extremity symptoms a recent study has indicated that higher scores on a work style measure were independently associated with symptoms from the musculoskeletal system (Nicholas, 2005).

6.4 Perceived exertion and comfort

The results from *study III* suggest that self rating of perceived exertion and comfort may be used as a cost efficient and user friendly survey method in order to identify work places with poor work place layout and non optimal working postures. This conclusion is applicable under the postulation that in a group that rate good comfort and low exertion it is necessary to combine self ratings with other methods e.g. observations. The validity of self reported data ratings and observations are often been questioned and results from earlier studies have been inconclusive. A study investigating work posture of the neck and upper extremities concluded that questionnaire assessed exposure data had low validity (Hansson et al., 2001) while others have concluded that validity of self reported data were depending on the questions asked (Leijon et al., 2002). Moreover, specific questions regarding e.g. physical activity and sitting working postures had good validity while questions concerning bent/twisted work postures and repetitive movements had poor validity (Leijon et al., 2002). Another study on possible bias from subjects rating both exposure and outcome (pain/symptoms) indicated no such risk concerning e.g. time, weight and physical exposure (Toomingas et al., 1997a). The choice of method is depending on the objectives of the study and a recently published review showed that both observation assessments and self reported data in general provided enough exactness to establish priorities for intervention on occupational safety and health practitioners level (David, 2005).

In connection with computer work ratings of perceived exertion, and perceived comfort have been frequently used in exposure assessment studies (Holte et al., 2003; Karlqvist et al., 1998; Tam and Yeung, 2006; Wahlstrom et al., 2004). In most studies self-ratings are used in connection with either observations or technical measurements in order to confirm that the objective findings correspond to the subjective perception. So far there had been few studies investigating the predictive value of self-ratings with respect to musculoskeletal symptoms.

6.5 Perceived exertion, comfort and biomechanical strain

According to the model it is reasonable to believe that biomechanical strain caused by an imposed physical workload will result in increased perceived exertion. It is likely, the one of the conceivable sources of increased biomechanical strain could be awkward working postures for a prolonged period of time during computer work. However, the results from *study IV* showed that observed poor working postures were as common in the group that rated high perceived exertion as in the group rating low perceived exertion. This result is somewhat unexpected, and reveals that such multidimensional perceptions as exertion and comfort may mirror more complex pathways to biomechanical strain than traditionally identified exposures.

6.6 Perceive exertion, comfort and psychological strain

Regarding possible pathways between perceived exertion and psychological strain it is believable that both emotional stress and high job demands might affect these perceptions. In *study II* it was observed that subjects who perceived stress full conditions worked more often with lifted shoulder than did subjects who did not perceive these conditions. Working with lifted shoulder could be a response to poor work station layout as well as to emotional stress and will regardless of "the true reason" consequently lead to an increased exertion and a poorer comfort compared with working with relaxed and lowered shoulders. We did not explore possible interactions between psychological and biomechanical strain with respect to perceived exertion and comfort, but it may be hypothesized there might be other sources influencing perceived exertion and comfort then psychological and /or biomechanical strain emanating from physical and /or psychosocial exposures.

6.7 Perceived exertion and comfort and neck and upper extremity symptoms during computer work

Cross sectional studies have previously indicated that discomfort and high perceived exertion might be associated with an increased risk for musculoskeletal neck and upper extremity symptoms/disorders (Hsu and Wang, 2003; Karlqvist et al., 2002; Liao and Drury, 2000; Ortiz-Hernandez et al., 2003). Results from *study IV* have confirmed these cross-sectional findings by showing that perceived exertion and also to a certain extend perceived comfort are good predictors for the development of neck and upper extremity symptoms in connection with computer work. It is likely to believe that exertion and comfort are mediators of either biomechanical strain and /or psychological strain according to the model previously presented in this thesis. The underlying exposures leading to the perception of exertion and comfort could to some extent be unknown since, the "true" mechanism or mechanisms for the development of neck and upper extremity symptoms are still not fully explained. In our study we did not explain or speculate concerning the source causing the association between exertion and comfort and neck, shoulder and hand/arm symptom, but we could ascertain that there were no clear associations between poor working postures and perceived high exertion.

Regarding muscle tension, a recently published study by Holte et al has confirmed the association between muscle activity in the trapezius muscle and hourly tension in an intra-subject comparison of low-tension and high-tension periods during a working day and that perceived general muscle tension may be involved in the development of musculosceletal symptoms/disorders (Holte et al., 2003).Results from *study II* showed that muscular tension is connected to working technique and a longitudinal study on computer users has shown an increased risk of developing neck pain for subjects who perceived high muscular tension (Wahlstrom et al., 2004). When considering these results, muscular tension may also be seen as a mediator of both biomechanical and psychological strain with possible connections to both known and unknown exposures in the same way as perceived exertion and comfort.

6.8 Methodological limitations

One major consideration is the relatively short duration of data collection time concerning the technical measurements (EMG and Electrogoniometry) in *study I and II*. However, variation over time for computer users concerning muscle activity and working postures are not believed to vary a lot. A study on computer users and working postures concluded that the stability of postural measures over time was sufficient to justify a single postural measurement in epidemiologic studies. Moreover, that manual goniometry could provide useful and sufficient information about upper extremity posture among computer users for use in epidemiologic studies (Ortiz et al., 1997). Still, it could be questioned how well these measures could reflect the mean daily exposure, since the within-day as well as the between-day variation is unknown. It is plausible to believe that the exposure for e.g. the newspaper editors increased as they get closer to the appointed deadline.

The sum score measuring working technique used in *study I, II and IV* measures only variables concerning physical exposures. Another term describing different ways to perform a certain work task is work style. One important difference between working technique and work style is that work style is characterized not only by physical exposures but also contains variables closely connected to work organization and psychosocial exposures. Factors found to be important for characterizing work-style apart from physical variables are individual factors like self imposed work load and break patterns. Studies on work style have confirmed that thei is an association between work style and musculoskeletal symptoms among computer users (Feuerstein et al., 2004b; Juul-Kristensen and Jensen, 2005). In the light of this new knowledge it would have been beneficial to include some of the work style dimensions in the working technique score. Concerning the working technique score we do not know enough about the reliability of the score. However, a study of working technique using a similar working technique score concerning lifting and patient transfer tasks has indicated good to excellent inter and intra observer reliability for most of the items observed (Kjellberg et al., 2000b).

Regarding *study IV* the results are based on both self-ratings at baseline and self-reported symptoms during the follow up period, which could have been biased by either an overestimation or an underestimation of the risk estimates. However, it has been shown that there is no support for the idea of bias to the relative risk estimates when subjects rate both exposure and outcome (Toomingas et al., 1997a). Since the exposure variables in *study IV* were assessed at baseline there might have been a risk that the ratings of exertion and comfort changed over time during the follow up period. Moreover, due to the amount of observers (32) used in *study IV* there might have been inter-individual reliability problem among the observers even though they were trained during a reasonably long period, there is a potential risk that the evaluation might differ between the observers.

6.9 General discussion

Musculoskeletal symptoms/disorders are a major course for both sick leave and productivity loss in all kinds of working situations. Regarding work tasks involving heavy physical loads like carrying or lifting heavy burdens, working in awkward positions with vibrating tools, or other work tasks with a combination of several risk factors e.g. vibrations, force and extreme joint angles a relationship between these exposures and musculoskeletal symptoms and disorders have already been established by several studies (Bernard, 1997; Hagberg et al., 2006; Hagberg et al., 2001; Hagberg et al., 1995). Regarding working situations characterized by low levels of physical exposures and high levels of psychosocial exposures exemplified by for instants many of the work tasks included in computer work the associations with musculoskeletal symptoms/disorders have so far not been sufficiently established. Nor has the clinical relevance or the usability of the used methods for identifying subjects at risk of developing musculoskeletal symptoms/disorders in connection with the above mentioned type of exposures. However, in recent years there have been great improvements regarding the possibilities to evaluate the influence of both physical and psychosocial exposures on the incidence of musculoskeletal symptoms due to the increased number of high quality longitudinal studies. Since exposures connected to computer use are expected to increase immensely primarily due to fact that computers are introduced to children at a very early age and as a consequence the duration of the exposures for possible hazardous exposures are much longer than what they are today. Future studies focusing on methodology with clinical and practical relevance in order to facilitate the work for the occupational health service centers by providing them with user friendly and cost efficient methods for prevention of musculoskeletal symptoms/disorders is urgent. Valid, reliable, and cost efficient methods will be required in order to reduce costs for musculoskeletal symptoms/disorders with regards to sick leave, low productivity and sustained work ability among the working population leading to financial setbacks for individuals , companies/organizations and society.

7 Conclusions

General conclusion

Working technique was associated with both increased biomechanical and psychological strain during computer work. High perceived exertion and poor comfort during computer work was associated with an increased risk of developing neck and upper extremity symptoms.

Specific conclusions:

There was an association between working technique muscle activity, wrist positions and forces applied to the computer mouse, respectively (*Study I).*

There was an association between muscular tension, emotional stress and muscular activity. Moreover, there was an association between working technique, emotional stress and perceived muscular tension, respectively *(Study II)*.

A concordance was found between expert observations of workplace layout and working postures and self-ratings of perceived comfort and exertion *(Study III and V).*

High perceived exertion was strongly related to an increased risk of developing neck and upper extremity symptoms, while poor working technique was not in associated with such a risk. *(Study IV).*

Future research

Future research activities will focus on further development of methods for exploring working technique and to improve the working technique score by including psychological dimensions and break patterns in the score. There is also a need to explore possible connections between physical activity and the development of musculoskeletal symptoms in order to be able to create intervention strategies for prevention of symptoms in connection with computer work. Moreover, an urgent research field is to look at different possible hazardous exposures in connection to the use of not only computers but to information and communication technology in general (ICT) especially among young children and young adults.

Summary

Working technique, during computer work

Associations with biomechanical and psychosocial strain and neck and upper extremity symptoms

About 35 % of the working population in Sweden report that they use computer for more than 50% of their total working hours. Regarding musculoskeletal symptoms it is known that women suffer more from these conditions than men in general. Among employees who work with computers more than half the working day approximately 40 % of the women and 25 % of the men report that they suffer from symptoms in the neck and upper extremities. The overall aim of the thesis was to explore possible associations between working technique, perceived exertion and comfort and physical and psychosocial strain as well as neck and upper extremity symptoms among computer users. Specific research questions addressed were;

a) If working technique was associated with muscle activity, wrist positions and forces applied to the computer mouse.
b) If working technique was associated with psychological demands, emotional stress and perceived muscle tension.
c) If there is an association between perceived exertion and comfort and observations of workplace layout and working postures.
d) If working technique perceived exertion and comfort was associated with neck and upper extremity symptoms/disorders.

Results showed that that subjects classified as having a good working technique worked with less muscular load in the forearm and in the trapezius muscle on the mouse operating side compared to subjects classified as having a poor working technique. Subjects who perceived muscular tension at least a few times per week during the proceeding month worked with higher muscle activity than subjects who did not perceive this condition. High emotional stress was associated with higher muscle activity in the trapezius muscle on the side not operating the computer mouse. Subjects who reported high levels of emotional stress worked more often with lifted shoulders compared to subjects who did not report stressful conditions. Moreover, that concordance between ratings of comfort and observations of workplace layout was reasonably good concerning the working chair and the keyboard and good regarding the computer screen and the input device. Regarding the concordance between ratings of perceived exertion and observations of working postures the results indicated good agreement for all measured body locations. This applies to the group that rated poor comfort and high exertion. Regarding the group with good comfort and low exertion ratings must be supplemented with observation assessment. Furthermore, there was a strong association between the development of neck, shoulder, and arm/hand symptoms and perceived exertion but no such relationship could be seen regarding working technique.

It is concluded that working technique is associate with both biomechanical and psychological strain, while no associations could be seen between working technique and an increased risk of developing neck and upper extremity symptoms. Furthermore, perceived exertion is a good predictor of neck and upper extremity symptoms.

Sammanfattning

Working technique, during computer work

Associations with biomechanical and psychosocial strain and neck and upper extremity symptoms

Nyligen publicerad statistik visar att 35 % av alla yrkesverksamma i Sverige använder datorn 50 % eller mer av den totala arbetstiden. När det gäller symtom från muskler och leder är det sedan tidigare känt att kvinnor drabbas oftare än män av dessa symtom generellt sett. Bland arbetstagare som uppgav att de arbetade 50 % eller mer vid datorn uppgav ca 40 % av kvinnorna och 25 % av männen att de hade symtom från nacke, axlar, armar eller händer mer än 1 gång under den senaste 3 månadersperioden. Det övergripande målet med denna avhandling var att studera möjliga associationer mellan arbetsteknik, upplevd ansträngning, upplevd komfort och fysiska och psykosociala faktorer samt symtom från nacke, axlar, arm/hand. De specifika forskningsfrågorna var följande:

a) Är arbetsteknik relaterad till muskel aktivitet, handledsvinklar och handledsrörelser samt till kraft applicerad på datormusen?
b) Är arbetsteknik relaterad till psykologiska krav, stress och upplevd muskelspänning?
c) Finns det ett samband mellan expertobservationer av arbetsplatsdesign och arbetsställningar och individers skattningar av upplevd ansträngning och komfort?
d) Är arbetsteknik, upplevd ansträngning eller komfort relaterat till en ökad risk att drabbas av symtom från nacke, axlar arm/hand?

Resultaten visade att personer som bedömdes ha en god arbetsteknik arbetade med mindre muskulär belastning än personer som bedömts ha en dålig arbetsteknik i underarm och skuldra. Vidare, att personer som upplevde muskulär spänning åtminstone ett par gånger i veckan arbetade med högre muskulär aktivitet i skuldermuskulaturen på bägge sidor jämfört med personer som inte upplevde muskulär spänning. Personer som upplevde emotionell stress arbetade med högre muskelaktivitet i skuldermuskulaturen än personer som inte upplevde sig som stressade. Dessutom fanns en tendens till att personer som upplevde antingen muskulär spänning eller emotionell stress oftare arbetade med uppdragna axlar jämfört med personer som inte upplevde dessa förhållanden. Samstämmigheten vad beträffar expert observationer av arbetsplats layout och arbetsställningar och självskattningar av upplevd komfort och ansträngning var för arbetsstol och tangent bord godtagbar. När det gäller bildskärm och styrdon (datormus) var samstämmigheten god. Detta gäller den grupp som skattade dålig komfort eller hög ansträngning. I gruppen som skattade god komfort eller låg ansträngning bör skattningarna kompletteras med expert observationer. Slutligen, det fanns ett starkt samband mellan utveckling av symtom och skattning av ansträngning emedan detta samband inte kunde ses beträffande arbetsteknik.

Sammanfattningsvis visar avhandlingen att arbetsteknik har samband med såväl fysisk som psykisk belastning samt att inget samband kunde ses mellan arbetsteknik och ökad risk att drabbas av symtom från nacke, axlar och /eller hand/arm. Vidare att ansträngning på ett tillförlitligt sätt kan förutsäga risken att drabbas av symptom från nacke, axlar och /eller hand/arm.

Acknowledgements

I would like to express my deep gratitude to everybody who has contributed to the work presented here and especially to:

Ewa Wigaeus Tornqvist National Institute For Working Life --my main supervisor, and also my very good friend for supporting me with both stimulating discussions and necessary remarks when ever needed during our ”endless” days of intellectual struggle.

Mats Hagberg Department of Occupational and Environmental Medicine–my assistant supervisor for good intellectual discussions and for valuable scientific advice.

Jens Wahlström Department of Occupational and Environmental Medicine Umeå– my second assistant supervisor my co-writer, former co-worker, and room-mate for 5 years, without whom the data collection and analyzing of results wouldn’t have been such a thrill!

Christina Ahlstrand ,Ewa Gustafsson and Maria Boström –co-workers at the Department of Occupational and Environmental Medicine, for invaluable help with the data collection, and for always keeping things I tend to “forget” in mind and for being such good friends.

Anna Ekman and Rebecka Vilhelmsson- for invaluable help with data- files, statistics and other ”problems” but most of all for good mental support when things were not going ”my way”.

My co-authors- Gert-Åke Hansson, Per Jonsson, Gunnar Ahlborg , Allan Toomingas, for valuable contributions and comments regarding the articles.

Mats Eklöf - my mentor and “informel” supervisor, for his never ending patience with my enthusiasm for discussions concerning all kind of problems and interesting aspects of life covering almost everything from statistics to politics.

Lotta Dellve, Sara Thomée, Ulrika Wedberg and Katrin Skagert for sharing valuable time outside work providing me with new skills such as singing, pilates training , and computer games.

All the members of my research group, the ”soup club” , and all other colleagues at Occupational and Environmental Medicine for turning every working day into a memorable moment!

My co-workers at the Institute for Stressmedicin for great support and for providing me with new challenges that kept me occupied all the time!

All patients in the Tuesday “stick-walking groups” for providing me with new brain cells through regular physical activity.

All the employees at all the different companies and organizations who willingly offered their valuable time to participate in the studies.

All the colleges around the country who participated in the data collection with great enthusiasm.

Helena, Emilia and Magnus—my children for letting me share their dreams and problems and for “learning” me to stay focused on the important things in life like magazines, boys, music and parties!

Christer--my beloved husband for giving me endless love, freedom and support whenever needed. But most of all for being a ”solid rock” to lean against during both good and bad times.

Financial support from the Swedish Council for Working Life, Social Research and AFA Insurance (AFA Försäkring) is acknowledged.

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