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Working technique during computerwork

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

Agneta Lindegård Andersson

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1 Introduction

1.1 Computer work

The use of computer technology has affected working conditions immensely during the past few decades. The automation of industrial processes has created new working conditions in which computer technology is heavily involved. The computer has become an indispensable tool not only in office work, but also in most industrial processes. This has considerably increased the number of employees whose work requires the use of computers. A report on working conditions for the Swedish workforce concluded that, in 2005, 69% of all employees in Sweden used computer equipment of some kind every day (Statistics Sweden 2005). Between 1989 and 2005, the number of employees who reported spending at least 50% of their total working hours on computer work increased by approximately 250% for both men and women (Figure 1). Moreover, during the same period, the number of employees who reported spending most of their working time in front of a computer screen increased by approximately 100% for men and by 150% for women (Statistics Sweden 2005).

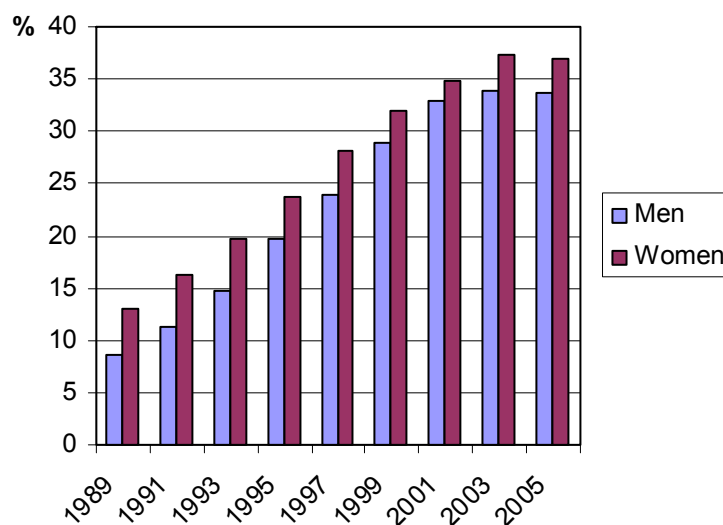


Figure 1. Percentages of the Swedish workforce who reported that computer use accounted for 50% or more of their total daily working hours in the years 1989-2005 (Statistics Sweden 2005).

The number of employees who reportedly used computers for 50% or more of their working hours in 2005 was approximately the same as in 2003. 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 spending nearly all their working hours using computers have also increased in the youngest age category, for both men and women. Approximately 25% of all computer users between 16 and 24 years of age (both men and women) are exposed to computer work for nearly all their working hours, compared to 10% of the men and 19% of the women in the oldest age group of 50-64 years (Statistics Sweden 2005). Among young people, the use of computers both during work and leisure has become part of a modern lifestyle. Computers are introduced to children at an early age, and consequently many young people have already been exposed to computer use long before they have entered the workforce, normally around 18-25 years of age.

The rapid development of information and communication technology (ICT), and computer technology in particular, is driven by market demands for new areas of usage. It is also fuelled by leading information technology companies competing to be the first to introduce new and better products. As a result, equipment is becoming increasingly portable and small, while each device is providing more functions. These trends, combined with a change in attitude towards the use of computers and other information and communication technologies, are likely to influence the incidence of musculoskeletal symptoms. The possibilities of “being reachable at all times” may be regarded as a double-edged sword, that may both have advantages and at the same time exacerbate the adverse health outcome related to increased biomechanical and psychological strain leading to musculoskeletal symptoms. In the long run this might reduce sustainable capacity to work. This scenario has been discussed in a qualitative study exploring attitudes towards ICT among young computer users in Sweden (Gustafsson et al., 2003).

1.2 Musculoskeletal symptoms in the general population

Musculoskeletal symptoms/disorders are major health problems that are prevalent in the general population of Sweden. Most of these conditions are not clinically well defined, and are collectively described as non-specific pain originating from parts of the body such as muscles, tendons, ligaments or nerves. Data on these conditions, published in 2005 indicated that 28% of the men and 44% of the women in the population reported that they had experienced pain in the neck and upper back area at least once a week during the preceding three months. Moreover, that 25% of the men and 37% of the women reported that they had experienced pain in the shoulder/arm region and furthermore that 13% of the men and 20% of the women reported that they had perceived pain in the wrist/hand region at least once a week during the preceding three months (Statistics Sweden, 2005). In addition, there was a slight increase in the occurrence of these

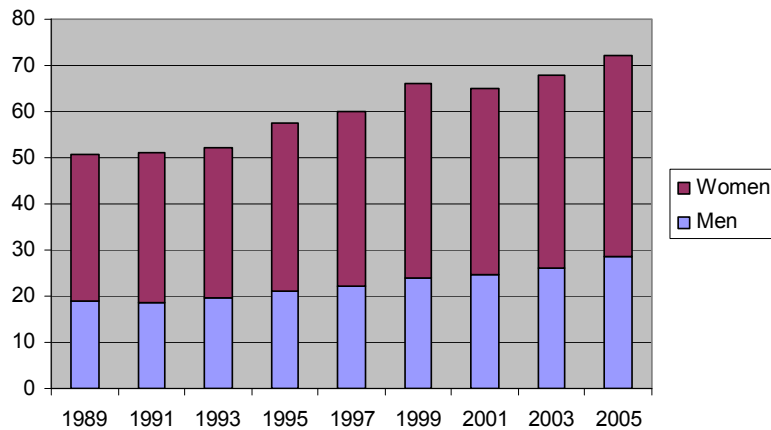


Figure 2. Prevalence (%) of neck and upper back symptoms in the Swedish workforce, 1989-2005. Based on reports of symptoms experienced at least once a week during the preceding three month (Statistics Sweden, 2005).

symptoms between 1989 and 2005, for both men and women (Figure 2). In general, musculoskeletal symptoms/disorders are more common among women, as demonstrated by the prevalence of neck/upper back pain/symptoms in both genders shown in figure 2.

1.3 Musculoskeletal symptoms among computer users

Exposure to computer work

Professional computer users of both genders who report that they spend most of their working hours in front of a computer have a slightly higher prevalence of symptoms of both the neck/upper back and shoulder/arm areas, than those who report spending approximately half their working hours in front of a computer (Figure 3; Statistics Sweden, 2005).

Multiple factors are thought to contribute to the development of musculoskeletal symptoms associated with computer work (Punnett and Bergqvist, 1997). Physical exposures, psychosocial exposures and individual factors, acting singly or in combination, are believed to play important roles in the development of neck and upper extremity symptoms associated with office and/or computer work.

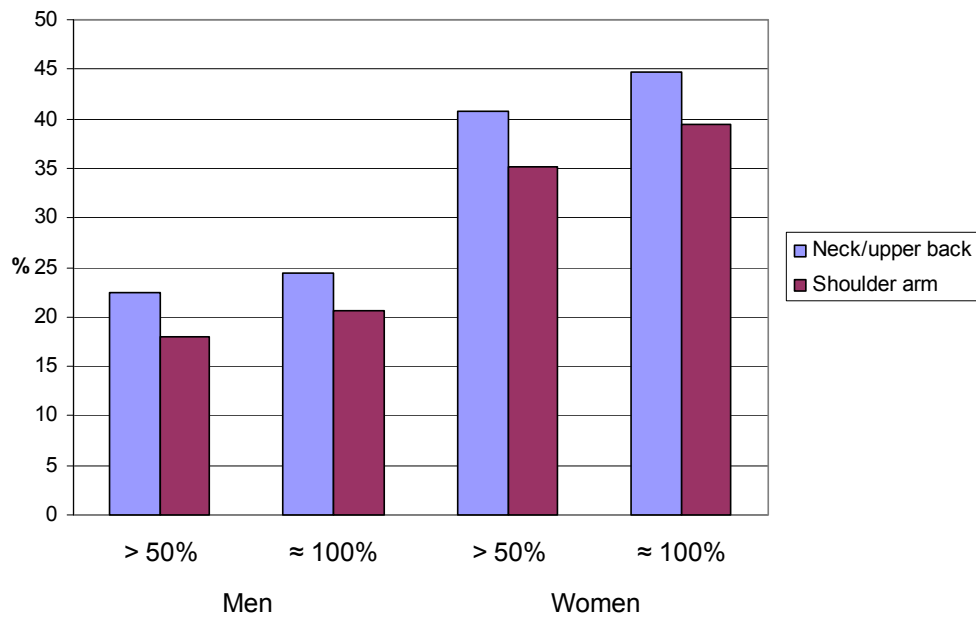


Figure 3. The prevalence (%) of neck/upper back and shoulder/arm symptoms among computer users, experienced at least once a week during the preceding three month (Statistics Sweden, 2005).

1.4 Physical exposures

Physical exposure can be defined as exposure related to biomechanical forces generated in the body. This has also been defined in the literature as “mechanical exposure”, to indicate that it excludes physical elements of the work environment (e.g. lighting, noise etc.) (Westgaard and Winkel, 1996). The term physical load is often used in connection with, or as a substitute for, the term physical exposure. The word “load” implies that these exposures are considered to be potentially harmful for muscles, joints, ligaments and generally for bone structures. It is well known among orthopedics that, up to a certain level, load on muscles, joints and bone structures can be beneficial for reconstruction of bone cartilage, prevention of osteoporosis and development of muscle strength.

This is based on the assumption that the structures involved (e.g. muscles) are provided with proper nutrients and a balance between activity and recovery. The U-shaped curve shown in figure 4 illustrates that, as for high loads, loads below a certain level may be risk factors for the development of musculoskeletal symptoms/disorders (Figure 4). The scientific literature has not yet reached a consensus regarding healthy or hazardous levels of physical load. Consequently, no recommendations have been made regarding healthy or unhealthy loads, except that intense or heavy loading of the lumbar spine should be avoided (Fallentin et al., 2001).

Various methods such as self-reports, observation assessments and technical measurements have been employed to quantify physical exposures related to computer work. In the studies on which this thesis is based, three different

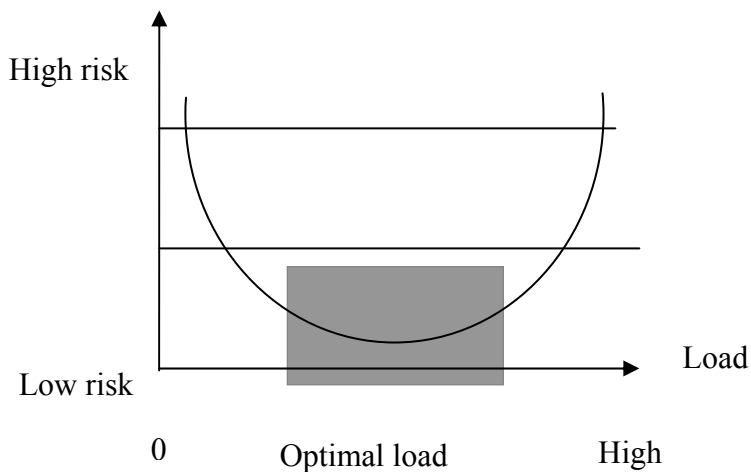


Figure 4. Relationship between levels of physical load and musculoskeletal symptoms.

methods of technical measurement were used to characterize physical exposure: electromyography (EMG) for measuring muscular activity, electrogoniometry for measuring wrist postures and movements, and an instrumented computer mouse for measuring the force applied to the computer mouse.

Muscle activity

When a skeletal muscle contracts an electronic signal is generated, which can be recorded and analyzed by an instrument called an electromyograph (EMG). This method of measuring muscular activity has been used for many years in ergonomic research. Several measures of muscular activity have been used in investigations of the occurrence of musculoskeletal symptoms/disorders (Hansson et al., 2000; Nordander et al., 2000; Veiersted and Westgaard, 1993). These include the amplitude distribution of muscular activity, and muscular rest characterized by gap frequency (times/min) and/or the total duration of gaps (percentage of total time). Some studies have found that a lack of muscular gaps may be a risk factor for neck and upper extremity symptoms/disorders (Hägg and Åström, 1997; Veiersted and Westgaard, 1993), but no evidence for such a relationship has been found in other studies (Vasseljen and Westgaard, 1995; Westgaard et al., 2001).

Several studies exploring the amplitude of muscle activity during computer work have found relatively low, but long-lasting muscle loads on the neck and upper extremities, corresponding to a mean activity level that is 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). Similar observations have been made in other studies on computer work (Hansson et al., 2000; Nordander et al., 2000; Wahlström et al., 2002).

Wrist positions and movements

Extreme positions of the wrist during intensive work performed with the hands have been considered potential risk factors for symptoms of the forearm, wrist and

hand (Malchaire et al., 1996; Viikari-Juntura and Silverstein, 1999). Previous studies in which the wrist positions of people performing computer tasks have shown that, when working with a standard keyboard and a traditional computer mouse, the mean extension of the wrist was approximately 20-25° (Arvidsson et al., 2006). They also found that wrist positions exceeding 30° occur for relatively short periods during the workday. Wrist posture also seems to affect the load on the forearm muscles during keyboard work, indicating that a wrist extension around 30° would require more than 25% of the maximum voluntary contraction (MVC) (Keir, 2002).

Wrist angles can be measured either with a manual goniometer or with an electrogoniometer. A study of computer users has found that postural measures over time were sufficiently constant to justify a single postural measurement in epidemiological studies, and that manual goniometry can be considered a valid method of measuring postures in computer users (Ortiz et al., 1997). In addition to measuring wrist positions and movements, electrogoniometry can be used to measure and characterize mean power frequency (MPF), which has been proposed as a measure of repetitive movement (Hansson et al., 1996; Malchaire et al., 1996; Viikari-Juntura and Silverstein, 1999). Electrogoniometry also provides the opportunity to collect data on the length of time that the wrist is placed at certain angles. This is valuable information since one of the potential risk factors for developing symptoms of the forearm and/or wrist is working in constrained and extreme postures for long periods of time (Bernard, 1997; Marcus et al., 2002; Sluiter et al., 2001; Viikari-Juntura and Silverstein, 1999).

Repetitive work has been associated with increased risks of developing wrist and forearm symptoms (Malchaire et al., 2001). It has been suggested that the risk increases with exposure to both extreme postures and repetitive movements (Bernard, 1997). Among computer users, the magnitude of exposure to repetitive computer work is likely to depend on the work task, and to vary substantially between different tasks. Since the health effects of repetitive work among computer users have not been sufficiently investigated, general conclusions cannot be drawn from the existing studies.

Force applied to the computer mouse

Another physical exposure to consider when investigating risk factors during computer work is the forces applied to the sides and button of the computer mouse. An earlier study has indicated that working with the computer mouse for long periods of time (i.e. 3-4 hours) can result in fatigue of the forearm muscles (Johnson, 1998). It has also been hypothesized that the force applied to the computer mouse may increase under the influence of stressful working conditions, and this hypothesis has been confirmed in studies investigating the effects of time pressure and verbal provocations on physiological and psychological reactions during computer work with a force-sensing mouse (Wahlstrom et al., 2002). It was further supported by the results of another study, which explored effects of

mental pressure on precision and on the force applied when working with the computer mouse (Visser et al., 2004).

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

Several cross-sectional studies have shown associations between physical exposures and neck/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). Conclusions regarding cause-effect relationships cannot be drawn from these studies, due to their cross-sectional design. However, recent longitudinal studies support some cross-sectional study findings regarding the impact of work postures (Gerr et al., 2002) and workplace layout (Juul-Kristensen et al., 2004; Korhonen et al., 2003).

In terms of exposure to physical risk factors, there are three fundamental dimensions to consider when evaluating potential risks: the duration, frequency and intensity of computer work. Computer work is characterized by low-intensity long-lasting exposure, and may be regarded as very light manual work compared to traditional industrial work. Industrial work usually involves well-known risk factors for the development of musculoskeletal symptoms/disorders, such as working with the arms above shoulder level and heavy lifting (Hagberg, 1996; Hagberg et al., 1995). Given the lack of “heavy physical exposure”, several hypotheses have been proposed for the etiology of neck and upper extremity symptoms/disorders associated with light manual work. One such hypothesis, the Cinderella hypothesis proposed by (Hägg, 1991), posits that overuse of type I muscle fibers during low intensity work without recovery may lead to selective motor unit fatigue, and ultimately to muscle fiber injuries. This theory is supported by studies on impaired blood microcirculation in specific muscle fibers (Larsson et al., 2004; Larsson et al., 1988). Moreover, recent experimental investigations of muscular activity during light manual work support the “Cinderella hypothesis”, and the established knowledge that stressful work conditions increase the risk of muscle overuse (Thorn et al., 2002; Thorn et al., 2006).

Several cross-sectional studies have shown associations between the duration of computer work and neck/upper extremity symptoms or disorders (Blatter, 2002; Cook et al., 2000; Jensen et al., 1998; Karlqvist et al., 2002), and several recent longitudinal studies have supported these cross-sectional findings (Gerr et al., 2002; Jensen, 2003; Juul-Kristensen et al., 2004; Wigaeus Tornqvist E, 2006). However, another longitudinal study concluded that the duration of computer use did not influence the prognosis of persistent pain in the arm or hand region of the subjects (Lassen et al., 2005). Moreover, it concluded that self-reported exposures associated with time spent using the mouse and the keyboard could predict pain or symptoms of the elbow/wrist/hand for low-level exposure, but could not predict clinical conditions verified through medical examinations (Lassen et al., 2004). The time spent on computer work without natural rest breaks have also been

studied and found to be associated with an increased risk of developing musculoskeletal symptoms of the neck and upper extremities (Punnett and Bergqvist, 1997). In accordance with the Cinderella hypothesis mentioned above, a long duration of computer use without breaks may pose even greater risks due to the lack of recovery. Previous studies have indicated that rest break patterns are associated with musculoskeletal symptoms in office workers tackling intensive computer tasks (Balci and Aghazadeh, 2003; McLean et al., 2001). Moreover, reduction in musculoskeletal symptoms has been observed following an intervention involving use of software to implement regular breaks during computer work (van den Heuvel et al., 2003)

Several cross-sectional studies have indicated that non-neutral working postures (e.g. extreme wrist positions) and workstation design (e.g. non-adjustable work chairs and/or working tables) are associated with neck and upper extremity symptoms (Bernard, 1997; Gerr et al., 2000; Punnett and Bergqvist, 1997; van den Heuvel et al., 2003). A recent longitudinal study has supported these findings, reporting associations between such symptoms and non-neutral working postures of the elbow and wrist (Gerr et al., 2002). However, another longitudinal study found that neck rotation and self-reported neck extension were the only risk factors for neck-shoulder symptoms (van den Heuvel et al., 2006). Nevertheless, a study evaluating the influence of neck flexion, neck rotation and sitting at work on the risk of developing neck pain in a heterogeneous group of workers including computer users, revealed that spending 95% of the working hours in a sitting position was a greater risk than neck posture (Ariens et al., 2001a). A study of factors that might predict the occurrence of neck and upper extremity symptoms in office workers found that a few variables related to ergonomics (screen height, pauses and reflexes in the screen) were predictive of such symptoms (Juhl-Kristensen et al., 2004). However, the evidence for a causal relationship between workstation design and neck and upper extremity symptoms/disorders remains insufficient.

Working with computers generally requires the use of both a keyboard and non-keyboard input devices. The computer mouse is by far the most common non-keyboard device. The introduction of alternative input devices has not been very successful, although some studies have indicated that the use of such alternatives may reduce the risk of upper extremity symptoms (Fernstrom and Ericson, 1997; Karlqvist et al., 1999). Moreover, variations in the design of the traditional computer mouse have been evaluated with respect to carpal tunnel syndrome, and no major differences have been found between different designs in terms of wrist positions or carpal tunnel pressure during computer work (Keir et al., 1999). However, an experimental study investigating differences in physical exposure, comfort and perceived exertion between two different computer mice found both muscle activity in the forearm muscles, and comfort ratings, to be lower when a computer mouse with a neutral hand position was used (Gustafsson and Hagberg, 2003). Regarding keyboards, previous cross-sectional studies have concluded that different types of keyboards (i.e. 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 published longitudinal study has confirmed these results. In addition, the study concluded that the relationship between keyboard design and upper extremity symptoms is supported by sufficient evidence to make recommendations for optimal keyboard design (Rempel et al 2006). Moreover, 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

In the past decade, there has been an increasing focus on work organization and psychosocial exposures in connection with musculoskeletal symptoms/disorders. A work organization or working system encompasses diverse features and components, from organizational structures and technology systems to work tasks (Hagberg et al., 1995). It is likely to have a substantial impact on physical exposures (e.g. duration and intensity of certain work tasks), psychosocial exposures (e.g. job demands and decision latitude), and psychological strain (e.g. emotional stress). For some factors, such as job demands, it may be difficult to separate the perception from objective measures of an “organizational demand” given that the perception is usually measured (i.e. self-rated demand).

For work organization and psychosocial exposures in general, earlier cross-sectional studies have shown that high demands and low control (inter alia) were risk factors for musculoskeletal symptoms, regardless of occupation involved (Bongers et al., 1993; Bongers et al., 2002; Devereux et al., 2002). An epidemiological review of longitudinal studies of work-related neck and upper extremity symptoms with respect to the impact of psychosocial factors supported these findings, although in most cases the relationship was neither very strong nor very specific (Bongers et al., 2006).

Questionnaires have most often been used to assess psychosocial exposure, although various other instruments have been developed 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 can lead to high levels of perceived stress. High demands and limited control at work, or a lack of social support, have been associated with perceived stress expressed as musculoskeletal symptoms and various psychological reactions (Aaras et al., 1998; Andersen et al., 2002; Ariens et al., 2001; Ariens et al., 2002; Birch et al., 2000; Bongers et al., 2002; Carayon et al., 1999; Wigaeus Tornqvist et al., 2001a). In a laboratory study by Wahlström and colleagues investigating the impact of perceived acute stress experienced during computer work on muscular activity, wrist movements and force applied to the computer mouse the results indicate that increases in muscle activity, rapid wrist movements and forces applied to the computer mouse

were associated with stressful working conditions relative to control conditions (Wahlström et al 2002). The results of similar studies, in which mental stress was induced amongst computer users in a laboratory setting, support these findings (Lundberg et al., 2001). A recent study investigating the possible effects of mental pressure and demands for precision on upper extremities found a considerable increase in the load as a result of mental pressure (Visser et al 2004). Another study, which investigated the effects of time pressure and precision demands on the oxygenation of two muscles, m. trapezius and m. extensor carpi radialis, found reductions in oxygenation of the latter during a mouse-operated computer task carried out under time pressure and high precision demands (Heiden et al., 2005).

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). A prospective study of forearm pain in computer users concluded that high demands and time pressure at work were risk factors for developing forearm pain, and found that women had a higher risk of developing such symptoms (Kryger et al., 2003). Another study has indicated that time pressure may have a negative impact on the prognosis of severe pain of the elbow-forearm and wrist-arm in computer users (Lassen et al., 2005). In addition, recently published data from a longitudinal study have shown that computer users who reported job strain were more prone to develop neck-shoulder symptoms compared to those who did not report these conditions (Hannan et al., 2005).

The risk of developing neck and upper extremity symptoms is probably related to various factors associated with a particular task as much as to the more physical dimensions of computer work. Such factors might include perceived stress caused by a “mismatch” between the employees’ competence level and the demands of their job. A study of potential risk factors for musculoskeletal symptoms and computer use has indicated that factors connected to the work task (e.g. stressful job situations, monotonous work tasks and low influence over the working situation) were more strongly associated with musculoskeletal outcome than working with a computer (Ekman and Hagberg, 2007). Moreover, the same study showed that 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 and psychosocial risk factors increases the risk of musculoskeletal symptoms developing (Punnett and Bergqvist, 1997; Wigaeus Tornqvist et al., 2001), compared with exposure to only one of these factors. The magnitude of the difference in risk has not, however, been fully investigated.

1.6 Individual factors

Many studies have shown that individual factors are related to musculoskeletal symptoms/disorders. Some of the more relevant and important individual factors to consider include sex, age, and individual characteristics such as vulnerability and working technique. In terms of gender, women appear to have a higher incidence of musculoskeletal symptoms regardless of occupation (Cassou et al., 2002; Cote et al., 2004; Ostergren et al., 2005). Age is another factor generally considered to influence the prevalence of musculoskeletal symptoms, which tends to be higher in older age groups. However, this trend is not clear with respect to computer work, and results from several studies have been inconclusive regarding the effects 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). There is insufficient knowledge regarding the impact of individual characteristics such as vulnerability, but several studies have observed that prior episodes of musculoskeletal pain/symptoms are strong predictors of recurrent pain/symptoms of 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

Two authors (Feuerstein, 1996; Kjellberg, 2003) have studied different aspects of working technique and their relationships 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 used, and the individual's motor performance in carrying out a given task (Kjellberg et al., 1998). Working technique refers to an individual's motor performance, e.g. the way in which a subject performs a computer work task. Earlier studies on working without supporting the forearms, a specific element of computer working technique, have shown a relationship with increased activity in the trapezius muscles (Aarås et al., 1997; Karlqvist et al., 1998). In a study of working methods among computer users, two different ways in which trained computer users perform work, using the computer mouse, was identified through observation assessments: the arm-based method and the wrist-based method (Wahlström et al 2000). The advantages of observations compared to, for instance, technical measurements include high capacity (e.g. one trained observer can often perform many assessments during a short period of time) and the fact that several relevant factors may be evaluated concurrently. In the ergonomics 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 encompasses many interacting factors, observation assessments can provide a cost-efficient way to evaluate exposure to hazardous conditions associated with working technique.

There is a lack of studies that have explored potential associations between working technique and physical and/or psychological strain. However, one study on different working methods and physical load found significantly lower levels

of muscle activity and less adverse working postures among subjects using a flexible working technique, i.e. one chosen by the subjects themselves, than others (Wahlstrom et al., 2000).

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

There is 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). Anthropometric measures such as differences in shoulder width and hand size have also been proposed 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 body regions was a predictor of persistent arm pain (Lassen et al., 2005). Moreover, constitutional or acquired 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 was identified as a possible risk factor for neck and upper extremity symptoms related to office and computer work (Feuerstein et al., 1997). Recent longitudinal studies have supported this finding by showing an increased risk of neck and upper extremity symptoms developing among subjects using an unfavorable work style (Feuerstein et al., 2004; Juul-Kristensen et al., 2004). Moreover, work style has shown to be related to an adverse health outcome with respect to frequency, intensity and duration of pain, functional limitations and upper extremity symptoms among symptomatic office/computer workers (Feuerstein, 1996; Haufler et al., 2000). Furthermore, that work style has a predictive value for the same variables (Nicholas, 2005).

Earlier studies have found relationships between single aspects of working technique, such as working with forearm support, and decreased physical load in terms of muscle activity of the trapezius muscles (Aarås et al., 1997; Karlqvist et al., 1998), and in a randomized controlled intervention study, the use of forearm support reduced upper extremity pain among computer users (Rempel et al., 2006). In accordance with these results, a large cohort study of computer workers in Denmark found that several dimensions of work style (such as low variation and high speed) were associated with symptoms in the neck and upper extremities (Juul-Kristensen and Jensen, 2005).

Psycho-biological factors such as discomfort, perceived exertion, perception of general muscle tension and their impact on the incidence of musculoskeletal symptoms/disorders have not been investigated in detail. However, some studies have shown an association between the perception of general muscular tension and symptoms in the neck and shoulder area (Holte et al., 2003; Westgaard and

De Luca, 2001). Another longitudinal study of 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 (Wahlstrom et al., 2004).

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

There is a lack of knowledge regarding 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 multifactorial. Several hypotheses have been proposed for the etiology of neck and upper extremity symptoms/disorders in relation to light manual work such as office tasks (Hägg, 1991; Johansson and Sojka, 1991; Knardahl, 2002). However, no consensus has emerged to this date regarding the mechanisms involved.

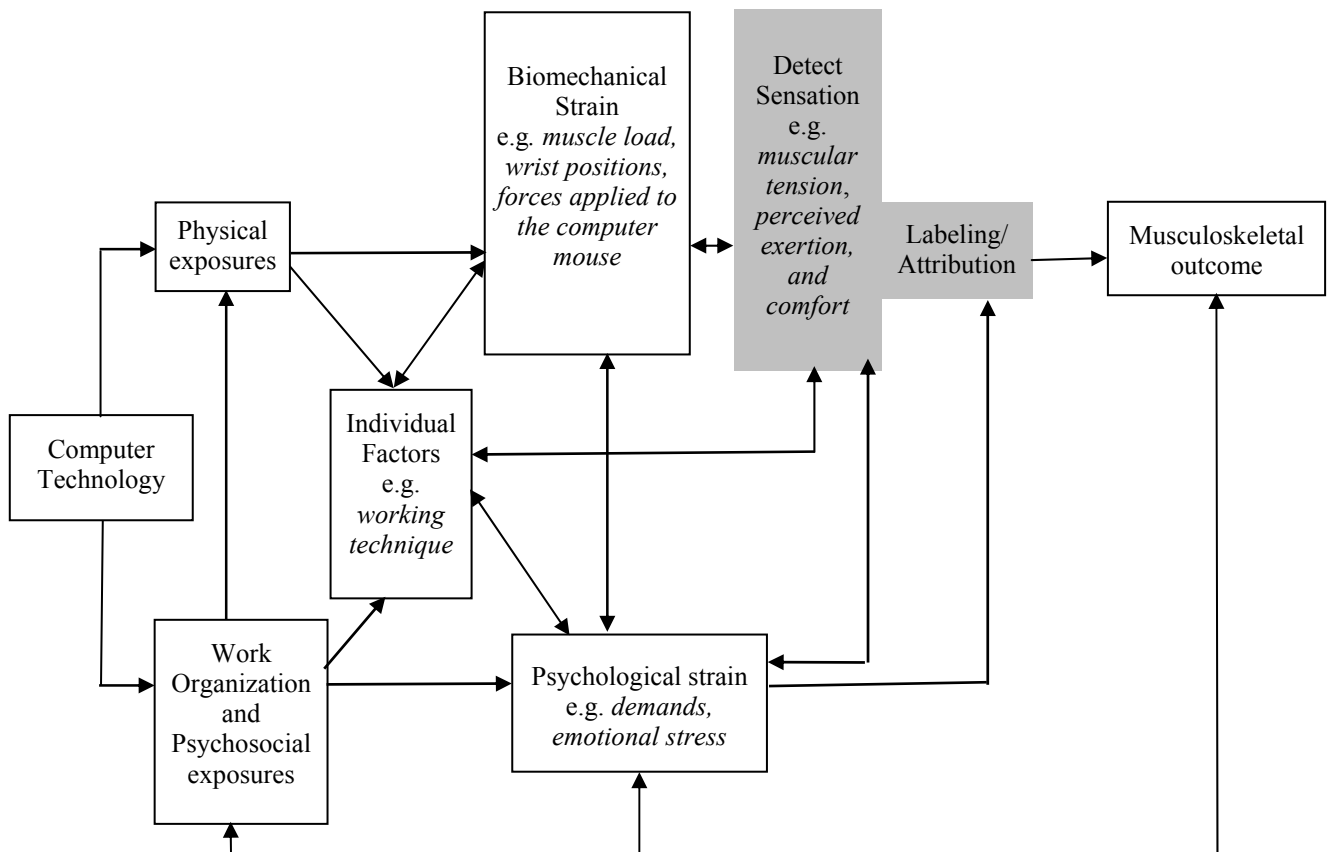


Figure 5. An ecological model of musculoskeletal disorders in computer work modified from Sauter & Swansson (Sauter and Swanson, 1996) and the Wahlström model (Wahlström, 2003). Items in italics are factors explored in this thesis.

Several models of the association between physical exposures, biomechanical strain, psychosocial exposures, psychological strain and individual factors have

also been presented, one of which is the ecological model of musculoskeletal disorders in office work proposed by Sauter and Swansson (Sauter and Swanson, 1996). A modified version of this model, with special reference to computer work, has been presented previously and was published in a doctoral thesis (Wahlström, 2003). The model presented in Figure 5 is an extended version of the Wahlström model, with entries in italics indicating the items explored in this thesis, which will be referred to as the Wahlström model throughout the thesis.

This model illustrates the complexity of the pathways and risk factors that lead to musculoskeletal symptoms/disorders. It suggests that musculoskeletal symptoms/disorders probably do not develop solely as a result of traditional physical risk factors that can be measured with technical measurements. The model also points out that the pathways leading to musculoskeletal outcome may be associated with differing perceptions. For instance, it has been suggested that perceived muscle tension is associated with neck and upper extremity symptoms/disorders (Wahlstrom et al., 2004). These perceived sensations may be regarded as responses to biomechanical strain (e.g. muscle load or extreme working postures) or to psychological strain (e.g. job demands and emotional stress) that modify the biomechanical strain of physical exposure and the psychosocial strain arising from factors such as work organization. Following the model, working technique as explored in this thesis could be considered an individual factor with possible connections to biomechanical strain (through increased physical loads), psychosocial strain (through perceptions of high demands and high emotional stress), and musculoskeletal outcome (through perceived exertion, comfort, muscle tension). According to the model, perceived sensations can be considered as mediators or early signs of musculoskeletal symptoms/disorders (Figure 5).

1.8 Aim of the thesis

The overall aims underlying this thesis were to evaluate whether working technique, perceived exertion and comfort during computer work were associated with biomechanical and psychosocial strain as well as with neck and upper extremity symptoms among computer users. The specific research questions addressed were:

1. Is working technique associated with muscle activity, wrist postures and forces applied to the computer mouse, respectively?
2. Is working technique associated with psychological demands, emotional stress and perceived muscle tension, respectively?
3. Is perceived comfort associated with expert's observations of work place layout and is perceived exertion associated with expert's observations of working postures?
4. Are working technique, perceived exertion and comfort, respectively, associated with the incidence of neck and upper extremity symptoms?

2. Subjects

2.1 Study designs

The studies included in this thesis represented several different designs. Studies I and II were cross-sectional studies evaluating possible associations between working technique, biomechanical strain, psychological strain and perceived muscle tension during computer work. Study III (and V) were methodological studies of possible associations between experts observations of working posture, and self-rated perceived exertion and experts observations of workplace layout, and self-rated perceived comfort. Study IV was a prospective longitudinal study of possible associations between working technique, perceived exertion and comfort, and the incidence of neck and upper extremity symptoms among computer users.

2.2 Subjects

Study I and II

The subjects in study I comprised all personnel in the editorial department of a daily newspaper who, according to the supervisor, had largely editing-based tasks. In total, 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 years (range 28-55) for the women. The estimated time spent on 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 the measurements were taken. All the participants worked with the same software program (Quark Xpress) and all had adjustable working chairs, as well as adjustable working tables.

The study group in study II included the 32 subjects from study 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 of the neck or upper extremities on the day the measurements were taken. All subjects had a modern workplace layout with easily adjustable chairs and working tables. The subjects in the editorial department all used the same software (Quark Xpress), while the subjects in the telecommunication company used various programs depending on the tasks they performed.

Study III, (V) and IV

Study population. The study population in studies III (V) and IV comprised 1529 computer users representing a variety of work settings from 44 different institutions, both private companies and public organizations. The subjects also represented various occupations such as call-center operators, engineers, receptionists, graphic designers and medical secretaries. A baseline questionnaire was completed by 1283 subjects (498 men and 785 women), and thus the response rate was 84%.

Study group. The study group in study III (and V) consisted of the 853 computer workers (382 men and 471 women) who, at baseline or at any of the follow-up sessions, had been free from musculoskeletal symptoms of the neck, shoulder and/or hand arm region in the preceding month. Being free from symptoms was defined as reporting less than 3 days of musculoskeletal symptoms during the previous month. The mean age was 42 years (range 20-65) for men and 44 years (range 21-65) for women. The mean duration of computer use was 83% (range 30-100) of the total working hours for the men, and was 78 % for the women (range 30-100). A computer mouse was used by 98% of the subjects while a trackball, joystick, touch pad or optical mouse was used by 2% of the subjects.

The study group in study IV consisted of the 853 computer users mentioned above. Data on the incidence of neck and upper extremity symptoms were collected using 10 monthly questionnaires during the observation period. The questions referred to the time period after the preceding questionnaire, usually corresponding to approximately one month, but longer in some cases due to vacations or absence for other reasons. When more than two follow-up questionnaires were missing, the subject was excluded from the study.

3. Methods

Various methods have been applied in the studies presented in this thesis. An overview of the key methods used is shown in table 1, and the main methods are listed in order of decreasing precision, and increasing versatility and capacity.

Table1. An overview of the methods used in the thesis.

	Study I	Study II	Study III(V)	Study(IV)
Technical measurements	x	x	x	x
<i>Electromyography (EMG)</i>	x	x		
<i>Electro goniometry</i>	x	x		
<i>Force sensing computer mouse</i>	x			
Expert observations	x	x	x	x
Questionnaires including selfratings		x	x	x

3.1 Technical measurements

Procedures

In studies I and II, the equipment used to measure muscular load and wrist positions or movements was attached to the subjects and calibrated in a room adjacent to the working area. After the calibration, the subjects were allowed to familiarize themselves with the equipment by carrying out their regular work tasks for some minutes before the actual measurements began. In both organizations, the workplace was equipped with 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 task for 15 minutes. When analyzing the data, measurements obtained in the first and last minutes of each 15-minute period were excluded, thus data collected over 13 minutes were used for each subject in both organizations. The aims and procedures of the study were presented at information meetings, and all subjects volunteered to participate in the study.

Muscular load

In order to characterize exposure to muscular load, the activities of four separate muscles (m. extensor digitorum, ED and m. carpi ulnaris (ECU) of the mouse-operating hand, and pars descendens of the right and left trapezius muscle) were recorded using bipolar surface EMG (ME 3000P4; Mega Electronics Ltd, Koupio, Finland). The raw data were monitored online for quality control and were stored on a personal computer (PC) with a sampling rate of 1000 Hz. The electrodes for the ED and ECU muscles were placed as recommended by (Perotto, 1994), and those for the trapezius muscles as recommended by (Mathiassen et al., 1995) (Figure 6). Self-adhesive surface electrodes (N-00-S, Medicotest A/S, Ølstykke, Denmark) were placed within a 20 mm inter-electrode distance. Before attaching the electrodes, the skin was dried, shaved, cleaned with alcohol, abraded with sandpaper and cleaned with water. Each subject performed standardized maximum voluntary contractions (MVCs) against manual resistance for 5 seconds, in order 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 seconds, to obtain the reference electrical activity (RVE).

The data were analyzed using Megavin software version 1.2 (Mega Electronics Ltd; Koupio, Finland). To characterize muscular activity, the raw EMG signals were 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 filter (3 dB). The MVEs for ED and ECU muscles were calculated using 1-second moving average windows, and in each case the 1-second window with the highest average EMG activity was used as the reference value. The RVEs for the trapezius muscles were calculated using 10-second moving averages, in each case

the 10-second window with the highest average EMG activity was chosen, and the mean of the three reference contractions was used as the reference value. The 10th percentile ($p=0.10$) and the 50th percentile ($p=0.50$) of the amplitude distribution were calculated for each subject, and were used to describe the muscular load. In order to analyze gap frequency and muscular rest for the trapezius muscles, a threshold of 2.5 % RVE was chosen. The RVE corresponds to a load of roughly 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 total 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 taken from the m. extensor carpi ulnaris (forearm muscle) was excluded since the main focus was to investigate the impact of psychosocial exposures on muscular load, and previous studies have shown that psychosocial load affects the central postural muscles more than the peripheral muscles such as those of the forearm (Toomingas et al., 1997). 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 during a light manual assembly task, (a work task comparable to computer work) has been investigated by Nordander and colleagues and a between days variability of 1.2% MVE and a between subject variability of 0.89% MVE for the 50th percentile of MVE normalized measurements was found for the right trapezius muscle (Nordander et al., 2004). In the forearm extensor muscles, the between day variability was 3.9 % MVE and the between subject variability was 3.1% MVE (Nordander et al., 2004). In addition, other studies have concluded that the magnitude of possible bias caused by measurement errors in epidemiological studies was acceptable (Netto, 2006; Nordander et al., 2004).



Figure 6. The position of the EMG electrodes.



Figure 7. The instrument 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) was 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, using a modified calibration fixture, at four different wrist positions: 45° extension, 45° flexion, 25° ulnar deviation and 15° radial deviation (Greenleaf Medical, Palo Alto, CA, USA). The reference (zero) position was recorded with the hand fully pronated and the palm lying flat, with the calibration fixture in neutral radial/ulnar and flexion/extension positions. The data were analyzed by commercially available software (GAS, Ergonomic & Research Consulting, Seattle, Wash., USA). The software program calculated the angular distribution, mean angular velocity and mean power frequency (MPF) of the power spectrum 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 ($p=0.10$), 50th ($p=0.50$) and 90th ($p=0.90$) percentiles of the registered angles in flexion/extension and radial/ulnar deviation were used to characterize wrist positions.

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

Forces applied to the computer mouse

A mouse instrument was used to measure the force applied to the sides and the button of the computer mouse (an Apple ADBII mouse developed at the University of California, San Francisco, CA, USA). The force-sensing computer mouse was installed at a separate workstation. The force was measured perpendicularly to the sides and the button of the mouse. The methodology for collecting data on the applied forces, the validity and accuracy of the equipment has 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 occasion when the mouse was used, for which the term grip episode was used. For each grip episode, the program calculated the mean force, peak force and the duration of the episode. In study I, the maximum forces were measured with an Apple ADBII mouse instrument using 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 the recording of the standardized task was completed. 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 using an observation protocol with three different parts, each investigating a different dimension of computer work: workplace layout, working technique, and working postures of the neck/shoulders and upper extremities (<http://www.amm.se/fhvmetodik>). The second part of the protocol was used to create the working technique score. The observation protocol was used together with a key explaining all variables and the different evaluation categories for each item included in the protocol. In study I and II the assessments were performed by three experienced ergonomists who were blinded to possible symptoms and results from the technical measurements. In study III (and V) the 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 on the evaluation of workplace layout and working postures using video recordings. They were trained until agreement in their judgments was obtained as determined by the principal investigator.

Development of the working technique scoring system

The working technique was characterized by an overall score for 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 expert panel. The selected items were weighted according to previously identified risk factors and the clinical experience of the expert panel. Therefore, variables believed to have a greater impact on biomechanical strain, perceived sensations and musculoskeletal outcomes had a higher range of possible scores than variables believed to have less impact on these variables. An overall working technique score (range 1-25) was calculated by summing the scores for the individual variables: the higher the score, the better the working technique.

Arm support on the input device-operating side was observed when evaluating both input device and keyboard work, since there were no differences in support for the left and right forearms when performing keyboard work. In study I and II, subjects with total scores of >15 were regarded as having a good working technique (n=11; 5 men, 6 women), subjects with total scores of 14-15 as having an intermediate working technique (n=10; 3 men 7 women), and subjects with total scores of <14 as having a poor working technique (n=11; 6 men, 5 women). In the subsequent analysis of differences between good and poor working techniques, the intermediate group was excluded. In study IV, the total possible score was 23 instead of 25 because the data were collected before the development of the working technique score, and one of the items was not included in the observation protocol. Subjects scoring ≥ 14 were regarded as

having a good working technique, those scoring 12-13 as having an acceptable working technique, and those scoring < 12 were as having a poor working technique.

In studies III and IV, informal tests conducted during training of the participating ergonomists showed there was fair-to-good inter-observer reliability after training regarding some of the items included in the checklist. In addition, during the training of the ergonomists, the checklist key was improved in order to facilitate reliable measurements. A recently published study on the reliability of the ergonomic checklist in a similar population of computer users has shown that the majority of variables included in the checklist have at least fair-to-good reliability (Norman et al., 2006).

Table 2. Variables used for classifying working technique. The score 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
	Not at all	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” in the logistic regression model as a proxy for working technique, since the hypothesis was that psychosocial strain may have a substantial impact on this variable. A general assumption among practitioners has been that psychosocial strain (e.g. job demands and emotional stress) often manifests itself physically as a tendency to “lift the shoulders” during stressful situations. Studies of psychosocial factors and musculoskeletal symptoms/disorders have indicated that mental stress is more often connected with musculoskeletal symptoms (non-specific muscle pain) in the central parts of the body than in the peripheral parts of the body, i.e. the arm or wrist/hand (Toomingas et al., 1997).

Working postures and work place layout

The ergonomic observations in study III (and V) regarding workplace layout were performed at the subject’s ordinary workstation while performing their most common computer task, and the results were immediately categorized and recorded in the protocol. 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 five items were used in the analysis; observations for the working table were excluded since there was no question corresponding to comfort with respect to the working table. Five-to-nine different variables were evaluated for each item, and there were 2-5 exposure categories for each variable. Observations from the four items included in the dimension workplace layout (chair, keyboard, screen and input device) then formed the basis for classification into three exposure groups: good, acceptable or poor workplace layout. These exposure classifications were made by an expert panel according to theoretical knowledge and empirical experience of known risk factors linked to workplace layout (Table 3).

The evaluation of working postures in study III (and V) was done using video recordings made at the subjects’ ordinary workstations while conducting their most common computer task. Different angles were used to obtain the optimal camera projections for making accurate assessments 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 for 2-3 minutes and the recordings were analyzed every 10th of a second by measuring the angles with a manual goniometer, in order to obtain a mode value. The observations were then divided into 2-5 categories for each body region, and were further classified into three exposure groups (high, medium and low) by the same expert panel, based on the considerations mentioned above (Table 3).

Table 3. Classification of workplace layout and working postures. All other combinations were considered to be 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 higher.	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 directly 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	Keyboard positioned directly 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 > 30 cm 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 of the neck and no protrusion of the head/neck and rotation of the neck $\leq 15^\circ$ and variation of the neck position 2-5 times/min or more or neck flexion 15-30° and variation of position 2-5 times/min or more and no rotation of the neck.	Neck extension $> 5^\circ$ or -5-15° flexion and the neck/head protruded. Neck position 15-30° flexion and variation of position < 2 times/min. Neck rotation $> 45^\circ$ or neck rotation 15-45° and variation in position < 2 times/min.
Working postures shoulder	Extension $< 15^\circ$ - $< 15^\circ$ flexion or shoulder 15-30° flexion and 0-30° abduction or abduction 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 $> 30^\circ$ and shoulder abduction $> 30^\circ$ or shoulder abduction between 15 and 30° and variation of position < 2 times/min. Outward rotation $> 30^\circ$ or outward rotation 15-30° and variation in position < 2 times/min
Working postures trunk	Extension $\leq 15^\circ$ - flexion $\leq 15^\circ$ or trunk extension $\geq 15^\circ$ and a variation of position > 5 times/min and a lateral flexion $< 5^\circ$.	Trunk flexion $> 15^\circ$ or trunk extension $> 15^\circ$ and in both cases variation of position < 2 times/min or lateral flexion $> 5^\circ$ or sitting with a tilted pelvis in $\geq 15^\circ$ extension and variation ≤ 1 time/min.
Working postures wrist/hand	Wrist extension $< 15^\circ$ - 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 $< 10^\circ$ and ulnar deviation $< 15^\circ$ and variation of position > 5 times/min	Extension of the wrist $> 30^\circ$ or extension 15-30° and variation of position < 2 times/min or radial deviation $> 10^\circ$ or ulnar deviation $> 30^\circ$.

3.3 Questionnaires and self-ratings

In addition, to questions about personal characteristics, data on exposures, occurrence of symptoms and psychological strain were collected using questionnaires in study II (job demands and emotional stress), and on perceived sensations in studies III and IV (perceived muscle tension, perceived exertion and comfort). In study IV data regarding days with symptoms experienced during the preceding month were also collected through questionnaires. These questions referred to working conditions during “normal” circumstances. The questionnaires used in studies III and IV were distributed and collected by ergonomists at occupational health care centers. In studies I and II, the questionnaire data were collected alongside the technical measurements taken by the investigators.

Psychological demands

Main components of the model suggested by Karasek and Teorell were used to assess psychological exposure in study II. A short Swedish version of the Job Content Questionnaire (Theorell et al., 1991) was used to assess psychological demands. Five questions (“Does your work require you to work fast”, “Does your work require you to work hard”, “Does your work demand a great effort”, “Do you have enough time to finish the work task”, “Are conflicting demands made at your work place”) were asked of subjects in the telecommunication company, and four of the questions (the question about working hard was excluded) of subjects 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 divided into two groups. 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.

The reliability of job demands as a variable included in the Job Content Questionnaire has been demonstrated in a previous study, where its internal consistency in a similar population (Swedish computer users) had a value of 0.7 (Cronbach’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 that measurements were taken. 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 levels for each adjective: very much, much, fairly, somewhat, almost not at all and not at all. For each subject, a median response was calculated. The variables were then divided into two groups; 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.

The reliability of the adjective checklist regarding internal consistency has been tested, and the estimated value for the stress dimension used in study II was 0.93 (Chronbach’s alpha) (Kjellberg and Wadman, 2002).

Perceived muscular tension

In study II, one of the questions included in the questionnaire was used to characterize muscle tension: “Have you, during the past month, experienced muscle tension (e.g. wrinkled your forehead, ground your teeth, and raised your shoulders)? 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 divide 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 only occasionally).

Comfort

In studies III (V) and IV, the subjects completed a questionnaire where they rated perceived comfort for 11 ergonomic items on a scale with nine response alternatives ranging from –4 (very, very poor) to +4 (very, very good). Four of the original 11 items on comfort were included in the analysis (comfort associated with working chair, computer screen, keyboard, input device). The excluded items referred to ergonomic factors such as light and noise, and were unrelated to the aims of the study. The items included were classified into three groups (good, acceptable and poor comfort), where negative values –4 to –1 were considered to indicate poor comfort, values of 0 to +2 acceptable comfort, and values of +3 to +4 good comfort.

We have not specifically tested the reliability of these items. However, Eklöf et al. (Eklöf et al., 2001) computed reliability to be satisfactory (approximately 0.90) in an index based on the comfort items in a sample of 400 Swedish computer users. Such a result would not have been likely if the items contributing to the score had poor reliability.

Perceived exertion

In studies III and IV, perceived exertion during computer work was rated on a modified Borg RPE-scale (Borg, 1990; Wigaeus Hjelm et al., 1995) in nine 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 these nine body regions (neck, shoulder, wrist, and low back), corresponding to the body regions in the observation protocol, were included in the analysis for study III.

In study IV, subjects rated perceived exertion in three of the nine original body regions (neck, shoulder and hand/arm). The ratings were classified into three groups – high, medium and low exertion. Ratings between 0 and 6 (0-fairly light) on the Borg scale represented low exertion, values between 7 and 10 (somewhat strenuous to strenuous) were considered as medium exertion, and values between 11-14 (very strenuous to very, very strenuous) as high exertion. In study IV, mean values for the perceived exertion were calculated for each of the three previously mentioned body regions. Subjects in study IV were classified into three groups, with values of 0–4 considered to represent low exertion, 5–7 medium exertion, and ≥ 8 high exertion.

4. Statistics

Study I

Study population subgroups were formed according to sex, ongoing symptoms (subjects with symptoms on the measurement day were defined as cases) and working technique. Prior to the analysis, it was decided that both computer mouse users (28 subjects) and trackball users (four subjects) would be included in the main group since the aim of the study was to evaluate the impact of different working techniques on physical load levels, rather than the differences between input devices. A trackball was used only when taking measurements at the subjects' ordinary workstations, and not during the experimental session when the force applied to input devices was measured. Descriptive data from measurements of muscular load (EMG) are presented as means with standard deviation (SD) values, and as medians with 25th and 75th percentiles. Goniometry data are presented as means and SD values. Data on the force applied to the mouse and manual goniometric measurements are presented as medians with 25th and 75th percentiles. Data from 13 minutes of ordinary computer work were used for the analysis of EMG and electrogoniometer measurements, as the first and last minutes were excluded. Similarly, for the 10-minute standard editing task data from the middle 8 minutes were used for analysis, as 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 with Fischer's exact two-tailed test for nominal data. The statistical significance level for the analyses was set to $p \leq 0.05$. 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 from the analysis of muscular load and one male subject from the analysis of wrist angles and positions.

Study II

The descriptive data are presented as median and range values, or mean and standard error of the mean (SEM) values. 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 gender (female =0 and male =1) influenced the physical load (i.e. muscle activity and 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 using the same explanatory variables as the multivariate linear regression models, described above. Age (continuous variable) and current musculoskeletal pain (no pain =0, pain =1) were controlled for in both the linear and logistic regression models. All statistical analyses were performed using the SAS statistical software, version 8.0 (SAS institute, Cary, N.C., USA). Statistical significance was assumed if $p \leq 0.05$. Due to technical problems, one woman and one man were excluded from the analysis of muscle activity, and the data for one woman were excluded from the analysis of wrist movements. Data were also missing for one woman in the ratings of emotional stress.

Study III (and V)

Statistical analyses were performed using the statistical software package SAS, version 8.0 (SAS institute Inc., Cary NC, USA (proc freq)). The data were analyzed 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 order consistency, 0 represents inconsistency and -1 represent inverse order consistency. The rank consistency can be good (high MA) even if a large degree of disagreement is present, provided that this disagreement is systematic (low PA, high MA). MA values were interpreted using the same reference values as for Kappa statistics. Values ≤ 0.20 were considered to represent no agreement 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 very good agreement.

Study IV

Symptoms were defined as reports of pain/aches in any of the body regions included in the questionnaire and of ≥ 3 days' duration during the preceding month. Symptoms experienced in various 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 person-time units corresponding to the period between the date of the questionnaire in which they were recorded as symptom-free for the first time, and the date of 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 of 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 on risk factors for musculoskeletal symptoms associated with 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 while operating the input device, lifting of the input device and range of movements while using the input device were the most important items differentiating a good working technique from a poor working technique (Study I) (Table 4).

Table 4. Scores for each item and 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 biomechanical strain

Muscular load

Results from Study I indicated that subjects who had a good working technique tended to have lower levels of muscular activity in all the muscles measured during the study. Significant differences were observed between subjects with good working technique compared with subjects with poor working technique in the activity of the trapezius muscle on the mouse-operating side, (10th percentile $p=0.02$, Figure 8), and of the forearm muscle ECU (extensor carpi ulnaris) (50th percentile $p=0.03$, Figure 9). Subjects with good working technique also tended to rest the mouse-operating trapezius muscle more 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 ($p=0.08$).

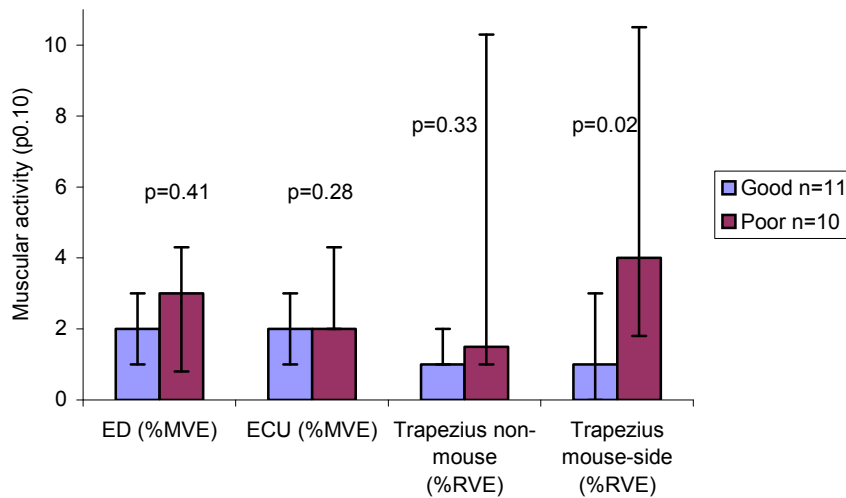


Figure 8. Muscular activity for the 10th percentile (median, 25th p and 75th percentile) showing that activity tended to be higher in all measured muscles except the ECU muscle for the poor working technique group compared with the good working technique group. There was a significant difference between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

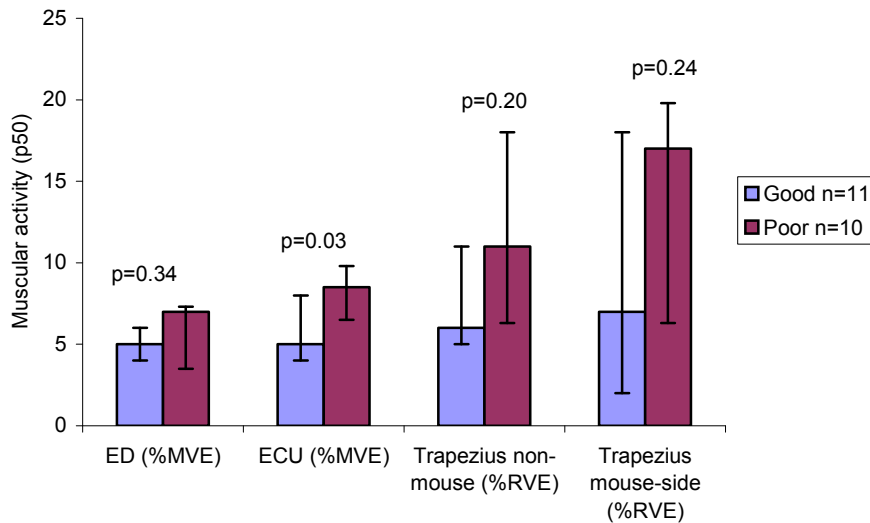


Figure 9. Muscular activity for the 50th percentile (medians, 25th p, 75th percentile) showing that activity tended to be higher in all measured muscles in the poor working technique group compared with the good working technique group, and there was with a significant difference between the groups for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

Wrist positions and movements

Subjects with good working technique worked with less extension of the wrist (10th percentile, $p=0.04$) than subjects with poor working technique (study I). Moreover, subjects with good working technique tended to work with less ulnar deviation than subjects with poor working technique, although these results were not statistically significant (Figure 10).

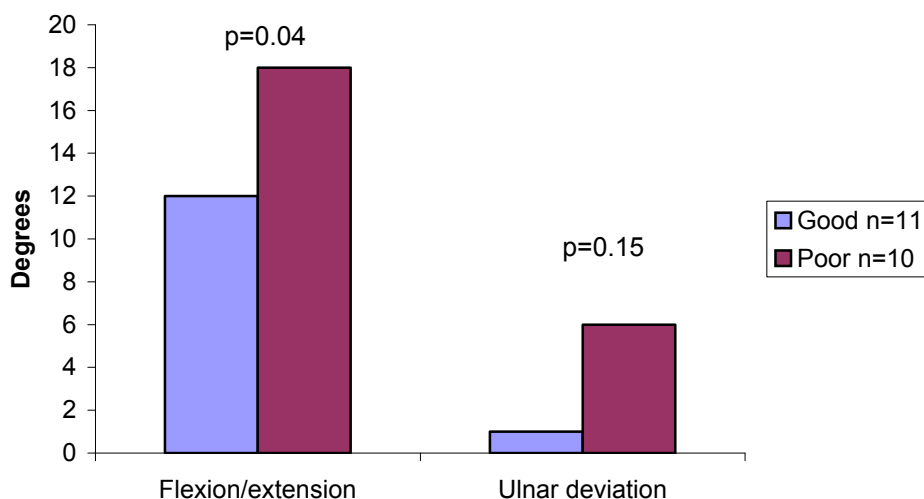


Figure 10. Wrist positions for the 10th percentile ($p_{0.10}$) in the two working technique groups.

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

Forces applied to the computer mouse

In study I, differences were found 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. No differences were detected for the force applied on the sides of the mouse. Moreover, no major differences of force applied on the button or the sides of the mouse were observed nor when comparing cases and symptom-free subjects neither when comparing subjects with good and poor working technique, respectively.

5.3 Working technique and psychological strain

In study II, higher muscle activity for the non-mouse operating m.trapezius muscle 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), after accounting 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. The percentages of variance explained (r^2) for the activity of the non mouse-operating trapezius muscle, and the trapezius muscle on the mouse-operating side were 29% and 13%, respectively. The inclusion of age and ongoing musculoskeletal pain did not change the results.

Table 5. Mean (SEM) of the variables used to characterize the physical load, grouped by the 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 subjects 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 (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) subjects 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)

After applying the scoring system for working technique, as described in Table 2, the results showed that subjects reporting high psychological demands and high muscular tension worked with poorer working technique than subjects with low demands and no perception of muscular tension ($p=0.03$ and $p=0.02$, Figures 11 and 12, respectively). There were no major differences in working technique scores between subjects with high and low perception of emotional stress.

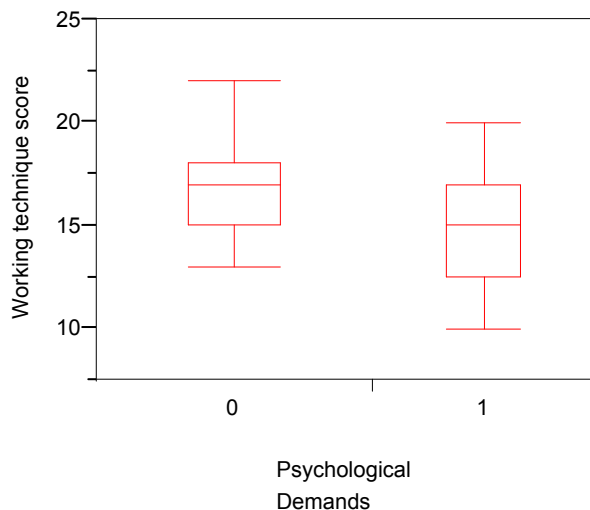


Figure 11. Working technique scores (high score=good working technique) for subjects with low and high psychological demands. The medians, 25th percentiles and 75th percentiles and inter the quartile range are presented.

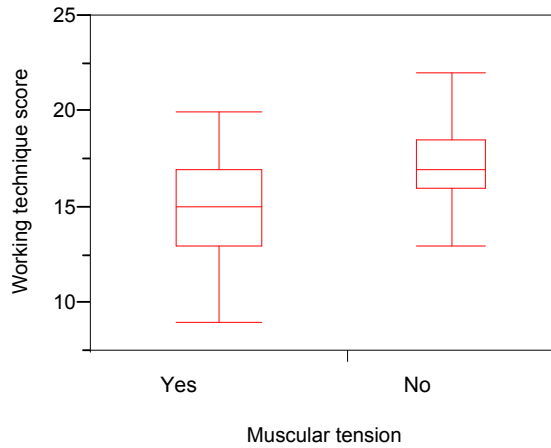


Figure 12. Working technique score (high scores=good working technique) for subjects who perceived muscle tension compared to those who did not. The medians, 25th percentile and 75th percentile and the inter quartile range are presented.

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

Results from study IV showed that working technique evaluated with the working technique score was not related to an increased risk of developing symptoms in any of the three body regions investigated in this study (neck/scapular area, shoulders, and hand/arm), for either men or women (Table 7 and 8).

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

Working technique	Tot=294	Men Symptom		
		Neck HR (95% CI)	Shoulder HR (95% CI)	Hand/arm HR (95% CI)
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. Hazard ratios, with 95% CI for women, for upper extremity symptoms in relation to observed working technique observed during computer work

Working technique	Tot 330	Women Symptoms		
		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)

In addition, using the proxy variable for working technique (lifted shoulders) in the analysis, as used previously in study II, did not increase the risk for the subjects who worked often with lifted shoulders compared to those who sometimes or never worked with lifted shoulders ($p=0.23$, 95%CI=0.84-1.86) for women; $p=0.22$, 95%CI=0.31-1.25 for men).

5.5 Perceived exertion and comfort

The results from study III showed that the agreement between computer users' ratings of perceived exertion in different body regions and the ergonomists' observations of working postures for the same body regions was good for all measured variables. The monotonic agreement (MA) between ratings and observations was 0.63 (0.61-0.64) for the neck, 0.63 (0.61-0.65) for the shoulder, 0.77 (0.75-0.79) for the wrist, and 0.72 (0.71-0.72) for the trunk. Moreover, the result from this study indicated a reasonably good agreement between computer users' ratings of comfort and the ergonomists' observations of the working chair (0:60, 0:59-0:61) and keyboard (0.58, 0.57-0.59). Furthermore, there was good agreement between computer users' ratings of comfort and the ergonomists' observations of the computer screen (0.72, 0.71-0.73) and input device (0.61, 0.60-0.62). Following correspondence prompted by the publication of study III, we re-examined the data and wrote a technical note (study V), in which the interpretation of the results was modified according to further knowledge of their statistical implications. A more strictly accurate interpretation of the results could be that, 'ratings of comfort and perceived exertion may serve as cost-efficient and user-friendly initial indicators, to identify workplaces with poor layout and poor possibilities for using optimal working postures', since there is fair-to-good agreement between self-reported poor comfort and self-rated high exertion. However, for 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, neck and upper extremity symptoms during computer work

The results from the univariate analysis conducted in study IV indicated that high perceived exertion of the neck, shoulders and arms/hands was associated with an increased risk of developing symptoms in these regions, for both men and women. 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). After accounting for previously identified risk factors in the multivariate analysis, perceived exertion remained significant in all three body regions, and the calculated hazard ratios did not change noticeably (changes between 0.3 and 0.5). Moreover, analysis of perceived exertion in relation to working technique found no association between poor working technique and high exertion. Subjects using a poor working technique were equally distributed between the low, medium and high exertion groups. Regarding perceived comfort, there was a tendency that the risk of developing neck and upper extremity symptoms tended to be higher among subjects who rated their comfort as medium to low, compared to those who gave a high comfort rating to their workplace layout. However, these results were not statistically significant.

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

Perceived Exertion	Men				Women			
	N	Neck	Symptom Shoulder	Hand/arm	N	Neck	Symptom Shoulder	Hand/arm
		HR (95% CI)	HR (95% CI)	HR (95% CI)		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 (0.80-1.68)	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 was on exploring the impact of working technique, perceived exertion and comfort during computer work on the onset of neck and upper extremity symptoms, as well as possible associations between working technique and biomechanical and psychosocial strain. In addition, the thesis explored the usability of a methodology based on subjective ratings, in relation to more costly methods of identifying working groups exposed to poor conditions related to workplace layout and working postures. The results and their implications are discussed in relation to the modified form of the Wahlström (2003) model of musculoskeletal symptoms/disorders previously presented in the first section of this thesis.

The results from studies I and II indicate an overall low level of muscular load, compared to results from earlier studies of other occupational groups performing repetitive work tasks, such as assembly line work (Balogh et al., 1999; Hansson et al., 2000). However, the results were consistent with previous studies on work using the computer mouse, both in the field and in experimental laboratory settings (Bystrom et al., 2002; Karlqvist et al., 1999; Karlqvist et al., 1998; Wahlstrom et al., 2000). Moreover, the results from study II showed that perceived emotional stress during the assessment period was associated with higher activity of the trapezius muscle on the side not operating the mouse. A previous study on supermarket cashiers found a correlation between muscular load during work and ratings of stress, where the correlation was stronger for the left compared to the right side (Rissén et al., 2000). A possible explanation for the finding of more pronounced differences for the non-active trapezius muscle could be that the active side is exposed to physical loads that can “mask” the effects of the psychosocial loads, in addition to being influenced by different kinds of stress.

6.1 Working technique and biomechanical strain

In study I, the working technique of the subjects was evaluated, scored and differences between groups with “good” and “poor” scores were analyzed. The results from study I indicated that subjects with a good working technique had lower levels of muscular load in the forearm muscles and the trapezius muscle on the mouse-operating side, compared to subjects with a poor working technique. On the other hand, the analysis of gaps and muscular rest showed no statistically significant differences between the working technique groups, although there was a tendency for subjects with good working technique to have more muscular rest ($p=0.09$). There were no major differences in gap frequency between the two working technique groups. Some previous studies that compared gap frequency between subjects with and without musculoskeletal symptoms have not found statistically significant differences between the groups (Vasseljen and Westgaard, 1995; Westgaard and De Luca, 2001). However, other studies have shown that a

lack of gaps could be a risk factor for neck and upper extremity disorders (Hägg and Åström, 1997; Veiersted and Westgaard, 1993). Muscular rest and gap frequencies have been previously explored in populations of cleaners and office workers by Nordander et al. (2000), who found that cleaners had a high risk of neck/shoulder pain, and much less muscular rest than office workers (median values of muscular rest time for the cleaners and office workers were 1.5% and 12%, respectively). In the same study, no significant differences were found with respect to gap frequency between the two occupational groups. Among the office workers, low values of muscular rest and high gap frequencies were recorded in subjects with a low subjective tendency to experience muscular tension. These findings, together with the results from our study, in which subjects with a poor working technique were found to have lower values of muscular rest than subjects with good working technique, imply that muscular rest could be a more suitable measure than gap frequencies in the context of computer work.

Exposure variance analysis (EVA) is another way to assess and characterize muscle activity. The main advantage of this method compared to alternatives such as gap frequency analysis, analysis of total rest time and analysis of the amplitude distribution of muscle activity, is that EVA enables structured quantification of variation patterns for variables, including recovery periods in muscular activity (Mathiassen and Winkel, 1991). EVA may be more suitable and could provide more information in cases where the measurement periods exceed 15 minutes, which was the timeframe for the EMG measurements in our study.

In our study we could not see any differences between the two working technique groups regarding forces applied to the computer mouse. Whether these forces are associated with increased risk of developing musculoskeletal symptoms is not known. However, it has been indicated that prolonged computer mouse work could lead to forearm muscle fatigue (Johnson, 1998).

Results from study I indicated that a good working technique was associated with less extension of the wrist. Previous studies on wrist position and finger movement have indicated that extreme wrist extension is associated with a risk of developing carpal tunnel syndrome, as well as forearm pain when carrying out repetitive tasks such as computer work (Cole et al., 2003; Keir and Wells, 2002). According to these results, it may be beneficial to focus on working technique training in ergonomic interventions related to 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 worked with lifted shoulders (poor working technique) more often than subjects who did not report these conditions. The reason for characterizing working technique with just one of the variables contributing to the overall score was that lifted shoulders was considered a priori

to be the most important contributor, since it reflects the subjects' reaction to mental load. 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 this is likely to 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 indicated that subjects reporting high psychological demands and perceived muscular tension used a poorer working technique compared to subjects with low demands and no perception of muscular tension. No major differences in working technique were observed between subjects with or without emotional stress.

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

The results from study I indicated that 28% of the subjects with a good working technique had ongoing symptoms of the neck and upper extremities, compared to 73% of the subjects with a poor working technique. One could argue that having symptoms might result in a change of working technique but, even so, it seems unlikely that subjects with symptoms would apply a poorer working technique, since that would probably increase the load and symptoms. Instead, the findings indicate that poor working technique contributes to the symptoms. A previous study on work style and symptoms among computer users has similar findings and concluded that an improved work style may be helpful in the management of neck and upper extremity symptoms or disorders (Feuerstein et al., 2004). The association between poor working technique and neck/upper extremity symptoms shown in study I was not supported by the findings of the longitudinal study IV, which found no statistically significant increases in the risk of developing neck and upper extremity symptoms for subjects with poor working technique. The most plausible explanation for the discrepancy is that the subjects in study I were a homogeneous group of workers performing identical tasks, while the subjects in study IV were employees carrying out various tasks in different organizations. It is likely that the task performed and the demands associated with it are more important, in terms of the musculoskeletal outcome, than the physical exposure connected to computer work. This hypothesis is supported by preliminary results of a study exploring neck and upper extremity symptoms associated with computer work in the Swedish workforce (Ekman and Hagberg, 2007). Moreover, one could argue that the lack of support for an association between working technique and symptoms in study IV may be due to the study having insufficient power. However, power calculations, performed in accordance with recommendations by Machin and colleagues (Machin D et al., 1997), indicated that the study had a power of approximately 70% to detect a 2-folded increased

risk with a significance level of $p \leq 0.05$ for neck symptoms. Regarding shoulder and arm/hand symptoms the power was lower but still acceptable.

Recent studies related to computer work have found that a poor work style can be associated with more symptoms of the neck and upper extremities, compared to a good work style (Feuerstein et al., 2004; Feuerstein et al., 2005; Juul-Kristensen and Jensen, 2005). One of the main reasons for this divergence may be the definition of working technique and the items used for classifying subjects 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 studies I II and IV and this thesis was based only on physical parameters that could be assessed by observations. As shown in this thesis, working technique may be influenced by psychosocial exposures such as job demands and emotional stress. The effects may be manifested either directly or through mediators such as perceived muscle tension or perceived exertion, which in turn lead to an increased risk of neck and upper extremity symptoms. Other studies have proposed that a lack of rest breaks, high personal work expectations and high work loads influence work style, leading to neck and upper extremity symptoms/disorders primarily through increased exposure to biomechanical strain (Feuerstein, 1996; Huang et al., 2003). In contrast to our results, which showed no distinct associations between working technique and the development of neck and upper extremity symptoms, a recent study has indicated that higher scores of a work style measure were independently associated with symptoms of 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 for identifying work places with poor layouts 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 has often been questioned, and results from earlier studies have been inconclusive. A study on 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 the validity of self-reported data depends on the questions asked (Leijon et al., 2002). Moreover, Leijon et al. (2002) found that specific questions regarding variables such as physical activity and sitting working postures had relatively high validity, while questions concerning bent/twisted work postures and repetitive movements had poor validity. Another study on possible bias from subjects rating both exposure and outcome (pain/symptoms) indicated no such risk concerning e.g. time, and weight (Toomingas et al., 1997a). The optimal method to use depends on the objectives of the study, and a recently published review showed that both observation assessments and self-reported data generally provide sufficient exactness to

establish priorities for intervention at the 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 that one of the sources of increased biomechanical strain during computer work could be sitting in awkward working postures for prolonged periods of time. However, in study IV poor working postures were observed as frequently in the group that reported low perceived exertion as in the group that reported high perceived exertion. This result is somewhat unexpected, and reveals that such multidimensional perceptions as exertion and comfort may mirror more complex pathways involved in biomechanical strain than traditionally identified exposures.

6.6 Perceived exertion, comfort and psychological strain

Both emotional stress and high job demands could contribute to psychological strains that affect perceptions of exertion and comfort. In study II it was observed that subjects who perceived stressful conditions worked more often with lifted shoulder than subjects who did not perceive such conditions. However, working with lifted shoulders and also a low overall score for working technique could be a response to poor work station layout as well as to emotional stress, but regardless of the true cause it will lead to increased exertion and poorer comfort than working with relaxed, lowered shoulders and/or using a more beneficial working technique. We did not explore possible interactions between psychological and biomechanical strain with respect to perceived exertion and comfort, but factors other than psychological and /or biomechanical strain emanating from psychosocial and /or physical exposures may (of course) influence perceived exertion and comfort.

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

Previous cross-sectional studies have indicated that discomfort and high perceived exertion may be associated with increased risks 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 confirmed these cross-sectional findings by showing that perceived exertion and, to a certain extent, perceived comfort during computer work are predictors for the development of neck and upper extremity symptoms. It is likely 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 may, to some extent, be unknown since, the mechanism(s) involved in the development of neck and upper extremity symptoms have not yet been fully elucidated. In our study we did not investigate the mechanisms involved in the associations between exertion, comfort and neck, shoulder and hand/arm symptoms, but we did ascertain that there were no clear associations between poor working postures and perceived high exertion.

Regarding muscle tension, a study recently published by Holte et al. (2003) 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 musculoskeletal symptoms/disorders. Results from study II showed that muscular tension is connected to working technique and a longitudinal study on computer users found increased risks of neck pain developing in 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

A major limitation of the studies is the relatively short periods in which technical measurements (EMG and Electrogoniometric) data were collected in studies I and II. 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 summed scores used to measure working technique in studies I, II and IV were based solely on variables related to physical attributes that could be observed. Another term describing different ways to perform a certain work task is work style. However, an important difference between our assessment of working technique and work style is that the latter is characterized not solely by physical attributes that can be observed, but also by variables that are closely associated with work organization and psychosocial exposure that the individuals can perceive. Factors found to be important for characterizing work-style apart from physical variables are individual factors like self-imposed work load and break patterns. Several recent studies on work style have confirmed that there 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 scores. 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 found that there was good to excellent inter- and intra- observer reliability for most of the items observed (Kjellberg et al., 2000).

The results presented in study IV are based on both self-ratings at baseline and self-reported symptoms during the follow up period, which could have been biased by either overestimations or underestimations of the risks. However, one study did not support this type of bias (dependant misclassification) when subjects rate both exposure and outcome (Toomingas et al., 1997). Since the exposure variables in study IV were assessed at baseline there is a risk that the ratings of exertion and comfort may have changed over time and such independent misclassification would result in an underestimation of the true risk estimates. Moreover, since multiple observers (32) were used in study IV there may have been significant variations between their observations, even though they were trained for a reasonably long period.

6.9 General considerations

Musculoskeletal symptoms/disorders are major causes of both sick leave and productivity losses 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). In contrast, in working situations where there are low levels of physical exposures and high levels of psychosocial exposures, e.g. many of the work tasks involved in computer work, there is still insufficient knowledge of factors associated with musculoskeletal symptoms/disorders. In addition, the clinical relevance and utility of the methods

used for identifying subjects at risk of developing musculoskeletal symptoms/disorders associated with these types of exposure have not yet been fully established. However, in recent years there have been great improvements in the scope 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, mainly because children are being introduced to computers at a very early age, the durations of potentially hazardous exposures are likely to be much longer than they are today. Studies focusing on methodologies with clinical and practical relevance are urgently required to facilitate the work of occupational health service centers by providing them with user-friendly, cost-efficient methods for preventing musculoskeletal symptoms/disorders. Valid, reliable and cost-efficient methods will be required to reduce costs associated with musculoskeletal symptoms/disorders due to sick leave, and reductions in productivity and work capacities among the working population, which lead to financial setbacks for individuals, companies/organizations and society.

7. Conclusions

General conclusions

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

Specific conclusions:

There was an association between working technique and muscle activity as well as between working technique and wrist positions. No association was found between working technique and force applied to the computer mouse (Study I).

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

An acceptable to good concordance was found between expert observations of workplace layout and self-ratings of perceived comfort. Furthermore, a good concordance was found between working postures and self-ratings of perceived exertion (Study III and V).

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

Future research

Future research activities will focus on further development of methods for exploring working technique and improving the working technique score by including psychological dimensions and break pattern variables. There is also a need to explore possible connections between physical activity and the development of musculoskeletal symptoms in order to create appropriate intervention strategies to prevent symptoms connected with computer work. Moreover, there is an urgent need to examine possible hazardous exposures associated not just with the use of computers, but with information and communication technology (ICT) in general, especially among young children and young adults.

Summary

Lindegård Andersson A (2007) *Working technique during computer work. Associations with biomechanical and psychosocial strain and neck and upper extremity symptoms. Arbeta och Hälsa* 2007;41:1

About 35 % of the working population in Sweden report that computer use accounts for 50% or more of their total working hours. Among employees who work with computers for more than half the working day approximately 40 % of the women and 25 % of the men experience symptoms in the neck and upper extremities at least once a week during the preceding 3 month. The overall aim of the studies underlying this thesis was to explore possible associations between working technique, perceived exertion, comfort, physical and psychosocial strains, and symptoms of the neck and upper extremities among computer users. Specific research questions addressed were:

- a) Whether working technique was associated with muscle activity, wrist positions and forces applied to the computer mouse, respectively?
- b) Whether working technique was associated with psychological demands, emotional stress and perceived muscle tension, respectively?
- c) Whether there were associations between self-rated perceived exertion and observations of working postures, and between self-rated comfort and observations of workplace layout.
- d) Whether working technique, perceived exertion and comfort, respectively, were 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 ($p=0.03$) and in the trapezius muscle ($p=0.02$) on the mouse operating side compared to subjects classified as having a poor working technique. Subjects who reported high levels of emotional stress worked more often with lifted shoulders compared to subjects who did not report stressful conditions. Subjects who reported high psychological demands and perceived muscular tension, respectively, used poorer working technique than subjects who did not perceive these conditions (demands, $p=0.03$, muscular tension, $p=0.02$). Moreover, the 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. 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, that high perceived exertion and low comfort were related to an increased incidence of neck, and

upper extremity symptoms while poor working technique was not associated with such a risk.

It is concluded that working technique is associated with both biomechanical strain (muscular load and wrist positions) and psychological strain (emotional stress and psychological demands), while no associations could be seen between working technique and the incidence of neck and upper extremity symptoms. Furthermore, high perceived exertion and low comfort are associated with the incidence of neck and upper extremity symptoms.

Sammanfattning

Lindgård Andersson A (2007) *Arbetsteknik och datorarbete. Samband med biomekaniska och psykologiska faktorer samt med symtom från nacke och övre extremiteter*. *Arbete och Hälsa* 2007;41:1

Nyligen publicerad statistik visar att 35 % av alla yrkesverksamma i Sverige använder datorn 50 % eller mer av den totala arbetstiden. 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 i samband med datorarbete. De specifika forskningsfrågorna var följande:

- a) Är arbetsteknik relaterad till muskel aktivitet, handledsvinklar 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 individers upplevda komfort och mellan expertobservationer av arbetsställningar och individers skattningar av upplevd ansträngning?
- 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 arbetsplatslayout 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 samband mellan utveckling av symtom och skattning av ansträngning

och komfort emedan detta samband inte kunde ses beträffande arbetsteknik och symptom.

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 symptom från nacke, och övre extremiteten. Vidare att hög ansträngning och låg komfort var relaterat till en ökad risk att drabbas av symptom från nacke, och övre extremiteten.

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