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Physical exposure, musculoskeletal
symptoms and attitudes
related to ICT use

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List of papers

This thesis is based on following publications, which will be referred to in the text by the Roman numerals I-IV:

- I. Gustafsson E., Dellve L., Edlund M., Hagberg M. The use of information technology among young adults – experience, attitudes and health beliefs. *Applied Ergonomics* 2003; 34, 565-570.
- II. Gustafsson E., Hagberg M. Computer mouse use in two different hand positions: exposure, comfort, exertion and productivity. *Applied Ergonomics* 2003; 34, 107-113.
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- IV. Gustafsson E., Johnson P.W., Lindegård A., Hagberg M. Texting on mobile phones – Are there differences in postures and working techniques between young adults with and without musculoskeletal symptoms?
Manuscript

List of abbreviations

APB	Abductor pollicis brevis muscle
APL	Abductor pollicis longus muscle
CI	Confidence interval
ECU	Extensor carpi ulnaris muscle
ED	Extensor digitorum muscle
EMG	Electromyography
FDI	First dorsal interossei muscle
ICT	Information and communication technology
IT	Information technology
LTRAP	Left trapezius muscle
Md	Median
MPF	Mean power frequency
MVC	Maximal voluntary contraction
MVE	Maximal voluntary electrical activity
RTRAP	Right trapezius muscle
RVE	Reference voluntary electrical activity
SE	Standard error
SMS	Short message service

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1. Introduction

1.1 Information and communication technology

The development of the information and communication technology (ICT) the last twenty years has meant a change of life style in work/school, at home and in leisure time for many of us. The access and exposure to different kinds of information and communication technologies such as computers and mobile phones has continued to increase over the last decade (Roberts, 2000; Bohler and Schuz, 2004; Schuz, 2005; Dimonte and Ricchiuto, 2006; Mezei et al., 2007; Nordicom, 2008). 87 % of the Swedish population (aged 9-79) had access to a personal computer in 2007 compared with approximately 10 % in 1987 (Nordicom, 2008). The number of persons (aged 16-74) who use computers every day has continued to increase, in just the past two years, computer use has increased from 79 % in 2006 to 87 % in 2008 (Statistics Sweden 2008). Ninety-six percent of the Swedish population (aged 9-79) has access to a mobile phone and 62 % use the mobile phone for sending text messages (SMS) an average day. Among those aged 15-29 the access of computers was 93 % and of mobile phones 100 % (Nordicom, 2008).

ICT technology is offering new ways of communicating and there is a concern that this widespread use of ICT could potentially have an adverse impact upon individual and social processes in everyday life. Today we have little knowledge of how this use of different kinds of ICT influences the users' behaviour, psychological well-being and health. Considering the widespread use of ICT it is of importance to identify the factors and conditions, related to this use, which influence our health.

ICT may have an impact on psychological health although causal mechanisms are unclear. In an explorative prospective cohort study of young adult ICT users was found that for women high combined use of computer and mobile phones was associated with increased risk of reporting prolonged stress and symptoms of depression. For men, the number of mobile phone calls and SMS messages per day were associated with sleep disturbances and SMS use was associated with symptoms of depression (Thomé et al., 2007).

1.2 Input devices

Human interaction with the computers started with the manual handling of punch-cards (key punch operators or accounting machine operators) which in the 1960's changed to inputting data via keyboards. The design of the keyboard evolved from the mechanical typewriter with the keys placed in straight parallel rows with the letters placed in a special order called the qwerty keyboard based on the order of the top left row of characters. Still most keyboards are manufactured with the

straight, parallel alignment of rows, and this design has been shown to lead to non neutral hand and forearm postures.

Since the late 1980's alternative keyboards have been introduced, with most of the keyboard designs split in the middle and/or tented. These keyboards attempt to straighten the wrist (i.e. decrease extension and ulnar deviation) and reduce forearm pronation (i.e. inward rotation of the hand towards the thumb) by another orientation of the keys. An alternative keyboard design (split keyboard) promotes a more neutral wrist position (decreased extension and ulnar deviation) and an increased perceived comfort (Tittiranonda et al., 1999; Zecevic et al., 2000). This design was suggested for the mechanical typewriters as early as 1926 by Klockenberg (Klockenberg, 1926) but his idea for a more natural and restful hand position during keying did not become popular back then. In 1960's and in 1970's these design concepts were again suggested for keyboards but were never manufactured (Kroemer, 1972; Nakaseko et al., 1985).

The first computer mouse was born at Stanford Research Institute in California, USA in 1964, but the mouse was not made for common use until twenty years later. Most mice used today still have the same shape and placement of the buttons as when the mouse was first designed. You hold them between the thumb and the little finger while the digit finger is used to press the button and with almost fully pronated (inward rotation towards the thumb) forearm/hand. In later years mice that are higher on the thumb side allowing a more neutral forearm/hand position has been introduced. There is also introduced a so called vertical mouse which is designed more like a joystick and allow a full neutral forearm/hand position during use of the mouse (Aaras and Ro, 1997).

Several other non-keyboard devices besides the mouse are available today in combination with the keyboard. One of the most common in Sweden is the roller mouse, actually a long stick, which is placed in front of the keyboard and the cursor is moved by rolling the stick with the fingers. Another is the trackball, a movable ball mounted in a fixed base placed on the table. The touchpad, usually seen on laptops, is a flat surface that can detect finger contact. The computer pen is held like a traditional pen and is moved over a graphics tablet similar to a touchpad. Touch screens, today often seen in mobile phones and iPods, are integrated into existing displays and can be used as a keyboard. In later years mobile phones have become more and more like small computers with a visual display, built-in functions and some with full-functioning, small qwerty keyboards.

1.3 Musculoskeletal symptoms/disorders

In general population

Upper extremity musculoskeletal symptoms/disorders are common in the general population and particularly in the working population causing suffering and loss of salary for the individual, loss of productivity and increased costs for the employers as well as for the society. 32-34 % of the Swedish working population

(16-64 years) in 2008 reported that they experience pain in neck and upper extremities every week (Statistics Sweden 2008). There are reported a difference between gender with women having higher prevalence of musculoskeletal symptoms/disorders in neck and upper extremities, compared to men (Strazdins and Bammer, 2004; Treaster and Burr, 2004; Roquelaure et al., 2006; Nordander et al., 2007), which is in agreement with reported results from the Swedish working population (women 38-42 %, men 26-27 %) (Statistics Sweden 2008).

Among computer users

Mostly reported musculoskeletal symptoms due to computer use are non specific musculoskeletal symptoms from neck/shoulder and upper extremities. Disorders associated with computer work are wrist tendonitis, and tenosynovitis, medial and lateral epicondylitis, De Quervain's tenosynovitis, and carpal tunnel syndrome (Village et al., 2005).

Despite the low physical loads associated with the use high prevalence of musculoskeletal symptoms/disorders in neck and upper extremities are reported among computer users (Ekman et al., 2000; Gerr et al., 2002; Brandt et al., 2004; Juul-Kristensen et al., 2004; Wahlstrom, 2005; Eltayeb et al., 2007). Computing related neck and upper extremity pain has been reported among college and graduate students during the last ten years (Katz et al., 2000; Schlossberg et al., 2004; Jenkins et al., 2007; Menendez et al., 2009).

In line with the findings in the general working population there are reported a difference between gender also among computer users with female having higher prevalence of musculoskeletal symptoms/disorders compared to men (Jensen et al., 1998; Gerr et al., 2002). It has also been reported that women apply a greater relative force and work with higher levels of muscle activity compared to men (Karlqvist et al., 1999; Wahlstrom et al., 2000).

Today computers and mobile phones are introduced to children at an early age both at home and in school which mean they will be exposed to possible risk factors at an earlier age and to a greater amount compared to the adult population of today. With growing concern how this early and intense exposure will influence the physical and psychological health of this generation and the incidence of musculoskeletal symptoms/disorders in their adult life.

Due to the widespread use of computers and mobile phones identification of risk factors for musculoskeletal disorders are of great importance.

The dramatically increased use of small keyboards (i.e. mobile phones, smart phones, Blackberrys; Netbooks etc) for texting and functions involving intensive key pressing with the thumbs especially among young people has raised the question how to ergonomically evaluate the physical exposures associated with this use and how to identify risk factors for mss/msd due to this use.

Associations with input device use

Already in the early 1910's a report about telegraphists' cramp was presented by the Departmental Committee of the General Post Office in London and problems were observed with any key arrangements: "any instrument which calls for repeated fine muscular movements of the same kind may involve a relative 'occupation spasm' or 'craft neurosis'" (Thompson and Sinclair, 1912; Kadefors and Läubli, 2002). In the 1960's "occupational cramp" was identified among telegraph operators in Australia though the conventional keyboards had replaced the Morse machines in the fifties. In England among key punch operators were observed musculoskeletal symptoms which were explained as local fatigue due to the repetitive movement of the upper limb and similar observations were made among accounting machine operators (Komoike and Horiguchi, 1971; Hunting et al., 1980; Maeda et al., 1980; Kadefors and Läubli, 2002).

Risk factors for developing neck and upper extremity musculoskeletal symptoms/disorders due to computer keyboard use have been fairly rigorously studied over the last fifteen years. Prolonged keyboard use, work in non neutral postures in the wrist and a lack of forearm support have been reported to be risk factors for the development of upper extremity musculoskeletal disorders (Aaras et al., 1998; Karlqvist et al., 1998; Blatter and Bongers, 2002; Karlqvist et al., 2002; Jensen, 2003; Kryger et al., 2003; Lassen et al., 2004).

In a review from 2006 of the literature on keyboard use and musculoskeletal outcomes among computer users (Gerr et al., 2006) was concluded several methodological limitations, including non-representative samples, imprecise or biased measures of exposure and health outcome, incomplete control of confounding. The most consistent finding was the association observed between hours keying and arm/hand outcomes. Placing the keyboard below the elbow, limiting head rotation, and resting the arms appears to result in reduced risk of neck/shoulder outcomes. Minimizing ulnar deviation and keyboard thickness appears to result in reduced risk of arm/hand outcomes.

An association between non-neutral postures of the wrist and elbow during computer work and neck and upper extremity musculoskeletal symptoms have been reported in a longitudinal study (Gerr et al., 2002) which supports the findings from several earlier cross-sectional studies (Bernard, 1997; Punnett and Bergqvist, 1997; Gerr et al., 2000).

A randomised controlled intervention study found that forearm support during computer use had a protected effect for neck/shoulder disorder and to reduce neck/shoulder and upper extremity pain (Rempel et al., 2006) which supported findings from a prospective epidemiological study which found arm support to be associated with a lower risk of neck/shoulder symptoms and disorders (Marcus et al., 2002) and earlier cross sectional studies (Hunting et al., 1981; Aaras et al., 1998; Aaras et al., 2001; Gerr et al., 2006). In a recently published experimental study the same pattern was found among children aged 12-14 years (Straker et al., 2008a). Forearm support has been shown to decrease muscle activity in neck and

shoulders during keyboard and mouse use in (Aaras and Ro, 1997; Aaras et al., 1998; Karlqvist et al., 1998; Woods et al., 2002; Cook et al., 2004).

Fast repetitive finger movements due to an activation of co-contraction in neck and upper limb muscles and a lack of variation in activation of motor-units is considered to be a risk factor for the development of musculoskeletal symptoms/disorders (Rissen et al., 2000; Sandsjo et al., 2000; Schnoz et al., 2000; Sjogaard et al., 2000). Unsufficient rest breaks from computer work has been reported as risk factor due to lack of motor-unit silence during work (Forsman et al., 1999; Kadefors et al., 1999; Birch et al., 2000; Jensen et al., 2000; Kitahara et al., 2000; Forsman et al., 2001; Sogaard et al., 2001; Forsman et al., 2002; Thorn et al., 2002).

Double clicking on the mouse button has been reported as a risk factor due to fast motor unit firing induces peak muscle load (Sjogaard et al., 2001; Sogaard et al., 2001). Low levels of muscular rest for the forearm extensor muscles have been found during mouse operations (Bystrom et al., 2002). Extreme wrist extension has been reported as a risk factor during intensive mouse use due to high pressure in the carpal tunnel (Keir et al., 1999). More extreme ulnar deviation of the wrist has been shown among computer mouse users compared to keyboard users (Karlqvist et al., 1994).

A moderate evidence for a positive association between the duration of mouse use and upper extremity symptoms/disorders has been concluded in recent years also with indications for a dose-response relationship (Jensen, 2003; Kryger et al., 2003; Village et al., 2005; Ijmker et al., 2007; Tornqvist et al., 2009).

In a repeated measures laboratory experiment (Dennerlein and Johnson, 2006) where 30 adult computer users completed five different computer tasks in order to determine differences in biomechanical risk factors across computer tasks were found that keyboard-intensive tasks were associated with less neutral wrist postures, larger wrist velocities and accelerations, and larger dynamic forearm muscle activity while mouse-intensive tasks were associated with less neutral shoulder postures and less variability in forearm muscle activity. A mixture of mouse and keyboard use was associated with higher shoulder muscle activity, larger range of motion and larger velocities and accelerations of the upper arm.

Some alternative pointing devices (e.g. trackball and a vertical mouse) have been shown to have a positive effect on musculoskeletal outcomes compared to a conventional mouse (Aarås et al., 1999; Rempel et al., 2006).

Excessive mobile phone use with active texting has in a case report been related to first CMCJ arthritis of the thumb (Ming et al., 2006) and in another report been related to a tender swelling in the dorsi-radial aspect of the mid-forearm (Menz, 2005).

In recent years reports of musculoskeletal symptoms from the hand and forearm after intensive use of smartphones or blackberrys have been presented on the net and these symptoms have been referred to as Blackberry thumb.

Repetitive pushing (e.g. during pipetting) and repetitive movements with the thumb (e.g. during piano playing and typing) have been reported as risk factors

for developing musculoskeletal disorders in the thumb and the extrinsic thumb musculature in the forearm (Fredriksson, 1995; Moore, 1997).

There is no study published that has evaluated the physical exposure during text entering on mobile phone.

The development of musculoskeletal symptoms/disorders

Today the relationship between the development of musculoskeletal symptoms/disorders and the low level exposure as in computer use is considered to be multifactorial though not still fully explained. Generally, physical factors, psychosocial factors and individual factors are considered to be present (Bongers et al., 2006).

Already 300 years ago Bernardino Ramazzini (Ramazzini, 1940 (First published 1713)) described the multifactorial background of musculoskeletal symptoms/disorders. In 1700 he wrote about the relationship between “word processing” and upper extremity disorders: *“The maladies that afflict the clerks arise from three causes: First, constant sitting, secondly the incessant movement of the hand and always in the same direction, thirdly the strain on the mind from the effort not to disfigure the books by errors. Constant writing considerably fatigues the hand and whole arm on account of the continual and almost tense tension of the muscles and tendons. I knew a man who was skilled in rapid writing and by perpetual writing, began first to complain of an excessive weariness of his whole right arm, which could be removed by no medicines, and which was at last succeeded by a perfect paralysis of the whole arm”*. Unfortunately his work was not further developed. Not until 250 years later Maeda described the multifactorial background of musculoskeletal disorders in light mechanical work (Maeda, 1977).

Physical risk factors

Physical factors causing musculoskeletal symptoms/disorders are supposed to exert their effects through physical (mechanical) forces arising in the body (i.e. the physical load). These forces may initiate or contribute to pathophysiological changes and are suggested to be expressed as biomechanical events occurring in the body. Acute responses e.g. perceived exertion and increased oxygen consumption are developed in the body as a consequence of this internal exposure. In the long run chronic effects such as musculoskeletal disorders or an improved oxygen transportation system may develop (Winkel and Mathiassen, 1994).

An ecological model of presumed pathways from exposure to light manual work, as computer work, to musculoskeletal outcomes were described by Sauter and Swanson in 1996 (Sauter and Swanson, 1996), later modified by Wahlstrom (Wahlstrom, 2005) and Lindegard (Lindegard, 2007). The model covers the physical ergonomic exposure as well as the psychosocial exposure and biomechanical as well as psychological mechanisms causing musculoskeletal outcomes.

Psychosocial risk factors

Psychosocial factors as high demands, low decision latitude, time pressure, mental stress, job dissatisfaction, high work load and lack of social support have been proposed as psychosocial risk factors alone or together with physical factors for the development of musculoskeletal symptoms. These psychosocial factors seem to be more associated with disorders in the neck/shoulders, than in the arm/hand (Ariens et al., 2001a; Ariens et al., 2001b; Andersen et al., 2002; Bongers et al., 2002; Johansson Hanse, 2002; Hannan et al., 2005; Tornqvist et al., 2009). Mental load, distress and/or time pressure have been shown to increase muscle activity (Lundberg et al., 1999; Rissen et al., 2000; Sandsjo et al., 2000; Sjogaard et al., 2000). Mental stress induced during computer use in laboratory settings has shown an association with increased physical load such as increased muscle activity, higher velocity in wrist movements, increased forces applied to the computer mouse (Lundberg et al., 2002; Wahlstrom et al., 2002; Visser et al., 2004). Furthermore, mental load has been shown to activate the same motor-units as computer operations do (Forsman et al., 1999; Kadefors et al., 1999; Birch et al., 2000; Jensen et al., 2000; Kitahara et al., 2000; Forsman et al., 2001; Sogaard et al., 2001; Forsman et al., 2002; Thorn et al., 2002).

An exposure to a combination of physical and psychosocial risk factors seems to increase the risk for developing musculoskeletal symptoms compared to only physical factors or only psychosocial factors (Punnett and Bergqvist, 1997; Wigaeus Tornqvist et al., 2001).

Individual risk factors

Several studies have shown an association between individual factors (e.g. age, gender, and anthropometry) and an increased risk for the development of musculoskeletal symptoms/disorders (Karlqvist et al., 1998; Cassou et al., 2002; Karlqvist et al., 2002; Cote et al., 2004; Ostergren et al., 2005; Oude Hengel et al., 2008; Tornqvist et al., 2009). One study has investigated the effect of varying thumb sizes in relation to the experience of using mobile phone for sending text messages. The results confirmed that varying thumb sizes affect users' text messaging satisfaction (Balakrishnan and Yeow, 2008). Another important individual factor to consider when estimating risk factor for the development of musculoskeletal symptoms/disorders is the individual performance technique or working technique.

Working technique

The concept of working technique is considered to consist of two basic elements (Kjellberg et al., 1998): the method used to carry out a task (e.g. sitting/standing, one/two hands grip, one/two thumbs key press) and the individual motor performance of the task (e.g. movement velocity, range of movements, pause pattern). The concept of work style is used similar to working technique but is more multidimensional including cognitive, behavioural and physiological stress

response to work (Feuerstein, 1996). A high-risk work style includes taking shorter or fewer breaks, working through pain, and making high demands on one's own performances (Feuerstein et al., 2005).

Working technique has been shown to affect physical loads. Use of forearm support during computer work has been shown to decrease the muscle activity in neck/shoulder (Aaras and Ro, 1997; Aaras et al., 1998; Karlqvist et al., 1998; Woods et al., 2002; Cook et al., 2004). Different working methods during computer mouse use such as forearm/shoulder movements compared to wrist movements have been shown to affect muscular loads (Wahlstrom et al., 2000). Computer users classified as having a good working technique have been shown to work with less muscular load in the forearm and in the trapezius muscle on the mouse operating side compare to those classified as having a poor working technique (Lindegard et al., 2003).

1.4 Exposure assessment

Physical exposure

Measurement of physical (mechanical) exposure can be obtained by subjective judgements (self reports or expert judgements), systematic observations (direct observations or video observations) and direct measurements (in real life or during simulations in the laboratory).

Direct methods of measurements have higher precision than the other methods and systematic observations give more detailed information than questionnaires. Important physical variables to measure in order to adequately assess the physical exposure are postures, movements, muscle activity and forces. The data of the physical exposure variable are suggested to include the three conceptual variables exposure level (amplitude), temporal pattern of exposure (repetitiveness or frequency) and exposure duration (Winkel and Mathiassen, 1994; Westgaard and Winkel, 1996; van der Beek and Frings-Dresen, 1998).

Postures and movements

In a systematic overview and evaluation of the methods used for quantifying mechanical exposures were concluded that self reported exposure data cannot validly replace observations or direct measurements in the assessment of the duration of exposure to working postures during a specific period and that trained observers are able to estimate body angles of subjects in a static posture to a high level of both accuracy and precision, but validity proved to be unsatisfactory for very dynamic tasks. For the assessment of movements were concluded that only by video observation in slow motion and by direct methods of measurement can one or more of the dimensions of exposure to movement be assessed accurately and observational methods are generally suitable to accurately assess variables about the working method (van der Beek and Frings-Dresen, 1998).

Direct measures of e.g. wrist or thumb positions can be performed by a manual or an electrogoniometer. Manual goniometry is considered to be a valid method

when measuring postures in computer users (Ortiz et al., 1997). For objective and quantitative measures of postures and movements, expressed in ° or °/s the use of an electrogoniometer is necessary. Furthermore, the electrogoniometry measure gives you data about the mean power frequency (MPF), which has been proposed as a measure of repetitive movements (Hansson et al., 1996; Viikari-Juntura and Silverstein, 1999), the velocity, and the pause pattern of the movements.

Muscle activity

The working muscle is producing electrical activity which can be measured by electromyography (EMG) either through intra-muscular or surface electrodes. This method of direct measurement is common in ergonomic research to assess muscle activity. In most studies the EMG data is normalized to a reference contraction due to the large inter-individual differences in the amplitude of the signal (Mathiassen et al., 1995).

Mechanical load has been supposed to be a risk factor for the development of musculoskeletal disorders, due to the intramuscular pressure, which impairs the blood flow and therefore affect the nutrition of the tissue (Jarvholm et al., 1991). Consequently load limits based on the 10th (static load), 50th (median load), and 90th (peak load) percentiles of the amplitude distribution were proposed to quantify the EMG data in relation to this risk (Jonsson, 1982).

However in activities like computer use, characterized by low levels of muscle activity, later studies have concluded that no safe lower limit of muscle activity exists (Westgaard and Winkel, 1996). Increased awareness of the need for load variation have occurred and measures of gap frequency (i.e. number of periods with muscle activity below predefined threshold level per time unit) and muscular rest (i.e. the total time with muscle activity below the predefined threshold level relative to the total duration of the recording time) can be used to assess the muscle activity pattern (Veiersted et al., 1993; Kadefors et al., 1999; Hansson et al., 2000; Forsman et al., 2001; Lundberg et al., 2002; Thorn et al., 2002).

Psychosocial exposures/conditions

The psychosocial exposure is usually assessed through self reports by questionnaires, diaries and interviews. Psychosocial conditions are complexed and difficult to capture while qualitative methods can be useful. Qualitative research aims at developing concepts that help us to understand social phenomena in interactions, emphasising the subject's own experience, views and deeper meanings (Denzin and Lincoln, 2000). One of the most used methods in qualitative research is the grounded theory method developed and presented by Anselm Strauss and Barney Glaser between 1920 and 1950 at the Chicago School of Sociology (Glaser and Strauss, 1969).

Grounded theory

The method studies basic social processes and the aim for the method is to generate theoretical frameworks which explain the collected data. The method is mostly inductive since the classic grounded theory method emphasizes the

development of theory from empirical data (Glaser and Strauss, 1969; Glaser, 1992) but also deductive since concept and theories are constantly changed and developed in constant comparison with the experiences from the empiricism.

A constructivist version of grounded theory has been developed by Kathy Charmaz (Charmaz, 2000), which assumes that multiple realities exist in contrast to the classical grounded theory which assumes a “one and only real reality”, an external reality that researchers can discover and record. She assumes that grounded theories are interpretative descriptions of the studied world rather than exact pictures of it. In contrast to Glaser and Strauss, who assumed an objective external reality with a neutral observer, a grounded theory separated from the observer, she means that construction of grounded theories is influenced by interactions between the people involved in the research process. The researcher is part of what he/she studies, not separated from it. A theory should emphasize understanding rather than explanation. According to Charmaz, the potential strength of grounded theory lies in its analytic power to theorize how meanings, actions, and social structures are constructed. The grounded theory methodology is offering tools for understanding subjects’ empirical worlds (Charmaz, 2000; 2006). The two main characteristics of grounded theory are the systematics in the methodology and the constant comparative method. Every part of the data, i.e. emerging codes, categories, properties, and dimensions are constantly compared with other parts of the data to explore variations, similarities and differences in the data (Hallberg, 2006).

1.5 Aims

The overall aim of this thesis was to obtain new ergonomic knowledge of the physical exposure associated with the use of information and communication technology with emphasis on small keyboards, computer mice and young adult ICT users.

Specific research questions were:

- What experiences, attitudes and health beliefs are expressed among young adults related to their ICT use?
- Are there any differences in physical exposure when working with a vertical computer mouse (neutral hand position) compared to a traditional flat computer mouse (pronated hand position)?
- Are there any differences in thumb movements and muscle activity (a) across various mobile phone tasks (b) between young adults with and without musculoskeletal symptoms in the upper extremities and (c) between gender?
- Are there any differences in postures and working techniques between young adults with and without musculoskeletal symptoms in the upper extremities when using a mobile phone for text entering? Are there differences in muscle activity and thumb movements between different postures and working techniques?

2. Materials and Methods

2.1 Study designs and study populations

This thesis comprises both quantitative and qualitative study designs. *Paper I* is an interview study with a qualitative approach, in which the analysis of data was performed with the grounded theory method (with a constructivist approach), in an attempt to understand experiences of, and attitudes and health beliefs to ICT (information and communication technology) among young ICT users. *Paper II* is a comparative experimental study which evaluated muscle activity, wrist positions/movements, perceived comfort, perceived exertion and productivity among experienced computer users while working with two different computer mice. *Paper III and IV* are lab-based experimental studies where subjects entered text messages on mobile phones. In these two studies, thumb movements (III,IV), muscle activity (III,IV), perceived exertion (IV), postures (IV) and working techniques (IV) were compared between young adults with and without neck and/or upper extremities musculoskeletal symptoms.

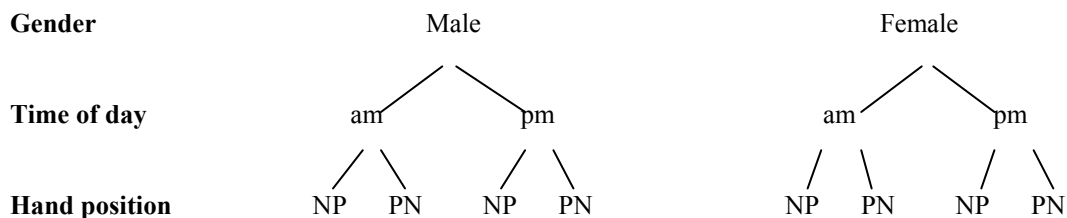
The study population in *Paper I* consisted of 25 young ICT users (18-24 years). They were recruited from different programs at the University of Gothenburg (medical, computer and engineering; 5 women, 4 men, median age 22 years) and upper secondary schools (construction and health care; 3 men, median age 19 years) in Gothenburg to represent different kinds of ICT usage as well as different lengths of study programmes (strategic sampling). An equal sex distribution was also a concern in the sampling. They participated voluntarily in the study by registering themselves in answer to a message on the notice board at their university/school. The interviews were carried out in 2001. During the week immediately prior to the interview, they all used the two major information technologies, personal computer and mobile telephone. The areas of use were mainly communication with friends or family members and seeking information.

The study population in *Paper II* consisted of 19 (10 female and 9 male) experienced computer mouse users recruited from the department of Occupational and Environmental Medicine (24-64 years). In this study a traditional flat computer mouse (pronated hand position) and a prototype vertical mouse (neutral hand position) were compared (Figure 1). At their own computer workstation, the subjects performed a standardised text editing task for 15 minutes with each mouse. All subject used their right hand to operate the computer mouse. Their hand sizes (hand width x hand length) varied between 7.5 x 16.5 cm and 10.5 x 21 cm (Md 9.0 and 18.5 cm respectively).



Figure 1. The traditional mouse with the pronated hand position to the left and the vertical mouse with the neutral hand position to the right. The main button of the vertical mouse is placed under the pad of the index (or middle) finger when gripping the mouse and you use the button by pushing it horizontally towards the mouse.

Working at their normal workspace subjects were instructed to select randomly located highlighted characters in paragraphs of text with each mouse and then delete the characters by hitting the delete key on the. The order between the two mice was balanced with respect to sex and the time of day the experiment took place (morning or afternoon). (Figure 2)



Figur 2. Order of the hand positions (i.e. the two mice) balanced with gender and time of day. am = morning; pm = afternoon, NP = neutral - pronated hand position; PN = pronated - neutral hand position.

The study population in *Paper III and IV* consisted of 56 ICT users (19-25 years) recruited from an ongoing cohort of 3000 young adults. Participants had been asked to fill out a web survey on their use of ICT and their musculoskeletal health. Potential study subjects were interviewed over the phone. To be included in this study, subjects had to report that they used their mobile phone daily to send SMS messages or play games. Questions were also asked to ascertain whether subjects were with or without musculoskeletal pain. Of the 56 subjects recruited,

15 subjects were healthy and 41 had neck and/or upper extremity musculoskeletal symptoms. The young adults without symptoms were those who reported no pain in the shoulder girdles/arms/wrists/hands or numbness/tingling in hand/fingers during the last 12 months in the web survey and reported to be pain-free at the time of interview. The young adults with symptoms were those who reported ongoing symptoms in the last seven days in the web survey and reported to be in pain at the time of interview. The young adults with symptoms were all clinical examined by physicians according to a prescribed medical protocol (Hagberg and Violante, 2007). The diagnoses of the young adults with symptoms were neck pain (cervicalgia, n=13), neck and arm pain (cervicobrachial syndrome, n=22) and arm-hand pain (brachialgia, n=6).

In *Paper III* the young adults performed four distinct tasks with the same “standard” mobile phone (Nokia model 3310, Eshoo, Finland, 113mm x 48mm x 22mm) and one task on their own personal mobile phone. The first task they performed was making a phone call with the “standard” mobile phone and then talking on the phone for four minutes (A). This task acted as a reference task since talking required gripping the phone (as during text entering) but not pressing the keys (the factor we wanted to study). Then, they performed three different SMS tasks with the standard phone: entering a 300 character standardized SMS message from a piece of paper while sitting (B), composing and entering their “own” 300 character SMS message while sitting (C) and composing and entering their “own” 300 character SMS message while standing (D). The experiment concluded with the young adults composing and entering their own 300 character SMS message on their own personal mobile phone while sitting (E). During the standardized SMS task (B) they were instructed to turn off and not use the automatic word completion function, which required that they had to text every character. During their “own” SMS tasks (C-E) they were instructed to write and use the functions they normally did when entering an ordinary SMS message. The order of the four SMS tasks (B-E) was randomised for each subject. The standardized SMS message task (B) was performed by all 56 subjects and 24 of the 56 subjects performed all tasks (A-E).

The young adults were instructed to sit and stand using the same positions and working techniques that matched how they used their mobile phones in real life. The chair used in sitting tasks had a backrest, and armrests and no wheels. A video documentation was made of the subjects’ posture during every task.

In *Paper IV* the young adults were instructed to compose and enter an own 300 character text message with the standard mobile phone while sitting.

2.2 Measuring methods

In *Paper I* the data were collected through individual thematised interviews. An interview guide with open questions was used, and the young adults were encouraged to talk in their own words about their experience of IT (information technology) use. The main questions were: Can you describe your use of

information technology (IT)?; What are your views about the use of IT?; Do you think the use of IT can influence health, positively and/or negatively? Probing questions such as “Can you tell us more about that?” and “Could you give an example?” were used to keep the conversation focused around their attitudes, coherence and health beliefs. The interviews lasted about 25-60 minutes and were tape-recorded and transcribed verbatim.

Registration of muscle activity

The muscle activity was registered by electromyography, EMG (Paper II: Muscle Tester ME3000P4, Paper III-IV: Muscle Tester ME 3000P8, Mega Electronics Ltd, Kuopio, Finland) using two 10 mm diameter disposable EMG electrodes (N-00-S; Medicotest A/S, Ballerup, Denmark) with a 20 mm inter-electrode spacing.

In *Paper II* the muscle activity in four muscles was registered: the right extensor digitorum (ED) and the right extensor carpi ulnaris (ECU) in the forearm, the right first dorsal interossei (FDI) in the hand and the pars descendent of the right trapezius muscle in the shoulder. The electrodes for the ED and the ECU were placed measured from the lateral epicondyle, on 1/3 of the distance between the epicondyle and the styloid process of radius (ED) and styloid process of ulna (ECU) respectively and for the FDI the electrodes were placed over the muscle belly in the web between the thumb and the index finger (Perotto, 1994). The electrodes for the trapezius were placed 20 mm lateral to the midpoint of the line between the seventh cervical vertebra and acromion (Mathiassen et al., 1995). (Figure 3)



Figure 3. The position of the EMG electrodes and the electrogoniometer in work with the vertical mouse in *Paper II*.

In *Paper III and IV* the muscular activity in six muscles in the right forearm/hand and both shoulders was registered: the right extensor digitorum (ED), the right first dorsal interossei (FDI), the right abductor pollicis longus (APL), the right abductor pollicis brevis (APB) and the pars descendens of the right (RTRAP) and left trapezius (LTRAP) muscle. The electrodes for the APB were placed over the muscle belly between the MCP and the CMC joints (Perotto, 1994). The APL electrodes were placed on the forearm proximal to the styloid process of radius where the working muscle was palpated. The other electrodes were placed as described for Paper II above. (Figure 4)



Figure 4. The position of the EMG electrodes during text entering on mobile phone in *Paper III and IV*.

The EMG signals were monitored in real-time for quality control and recorded on-line at 1000 Hz to the hard disc of a laptop computer. The EMG signal was bandpassed filtered between 8 - 500 Hz. In the data analysis, the EMG signal was rectified and averaged using a 125 ms moving window.

Standardized contractions were performed by the young adults in order to normalize muscle activity. For the ED, the ECU, FDI, APL and APB, maximal voluntary electrical activity (MVE) was obtained while the subject was asked to perform a 5 s maximum contraction against manual resistance. They performed these contractions while seated, with their forearm supported on a table surface individually adjusted to elbow height. For the trapezius muscles a submaximal reference voluntary electrical activity (RVE) was used for normalisation. The RVE was determined as the mean activity recorded while the subject was seated and abducting both arms to 90° (in the frontal plane) while holding a 1 kg dumbbell fully pronated in each hand for 15 s.

The EMG-data in Paper II were analysed in the ME3000P software version 1.5, in Paper II-IV in Labview (Version 6.1; National Instruments; Austin, TX,

USA) and the 10th (static level), 50th (median level) and 90th (peak level) percentile of the muscle activity for each subject were calculated.

Registration of wrist positions and movements

In *Paper II* a biaxial electrogoniometer and a data logger (Model X65 and DL1001, Biometrics; Gwent, UK) were used to register flexion/extension and radial/ulnar deviation of the right wrist (Figure 5). The goniometer was applied to the dorsal side of the wrist on the right hand according to the manual of the goniometer used.

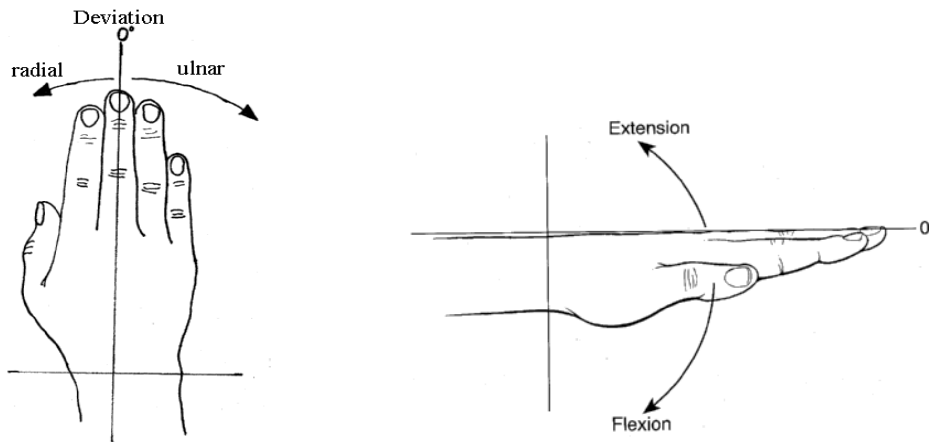


Figure 5. Radial/ulnar deviation and extension/flexion movements in the wrist. Modified after Greene & Heckman (Greene and Heckman, 1994).

The reference (zero) position of the wrist was recorded when the forearm fully pronated was held in a deviation and flexion/extension neutral position with the palm down on the desk (Greene and Heckman, 1994). The sampling rate was 20 Hz and the measuring data were transmitted after the measurement from the data logger to a PC, where they were analysed using a program written in Labview. The program calculated the 10th, 50th and 90th percentile of the wrist angle distribution, the mean velocity and the mean power frequency (MPF) for both flexion/extension and radial/ulnar deviation. A power spectrum was calculated using the Auto Power Spectrum virtual instrument (VI) in Labview. MPF was calculated on the portion of the power spectrum between 0 and 5 Hz with a low frequency cut-off of 0.033 Hz to eliminate the DC component of the spectrum (MPF calculated between 0.033 – 5 Hz). MPF is defined as the centre of gravity for the power spectrum and has been used as a measure of repetitiveness (Hansson et al., 1996).

Registration of thumb positions and movements

In Paper III-IV a biaxial electrogoniometer (Model SG 110, Biometrics; Gwent, UK) was used to measure adduction/abduction i.e. palmarabduction (Greene and Heckman, 1994)(Greene and Heckman, 1994) and flexion/extension of the thumb.

The endblocks of the goniometer were applied on the dorsal side of the proximal phalange on the right thumb and on the medial aspect of the radius just proximal to the wrist joint (Figure 6). Both goniometer endblocks were rigidly secured to the subject's wrist and thumb using double-sided tape. The thumb's general orientation was considered as the orientation of the proximal phalange. The electrogoniometer signals were monitored in real-time and recorded on-line at 1000 Hz at the same time as the EMG signals.

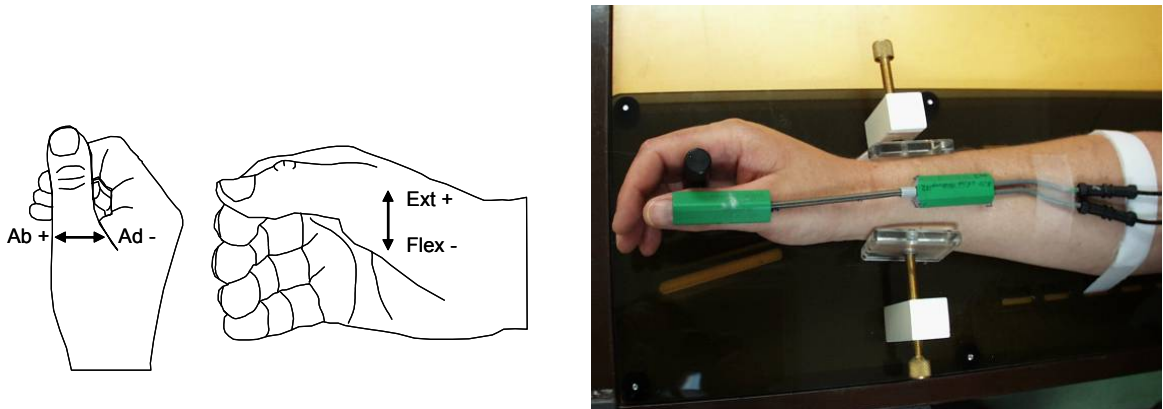


Figure 6. Definition of the neutral adduction/abduction (Ad/Ab) and flexion/extension (Flex/Ext) posture and sign conventions used to define thumb positions (left). Hand with electrogoniometer in the goniometer calibration fixture (right), thumb in neutral adduction/abduction and flexion/extension position.

The electrogoniometer data were analysed using a program written in Labview (Version 6.1; National Instruments; Austin, TX, USA). By taking every 50th sample, the program down sampled the data to 20 Hz. For each movement axis, the program calculated the 50th percentile thumb postures, the median thumb velocity, the mean power frequency (MPF) of the movements, the pause percentage – defined as the percentage of time thumb velocities were below 5°/s, the mean pause duration and the number of pauses per minute.

Registration of posture and working technique

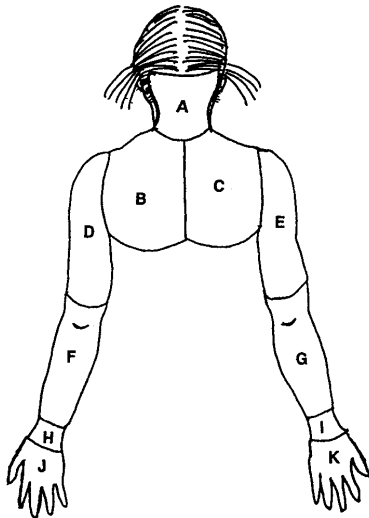
In *Paper IV* the young adult's individual posture and working technique during the task was registered using an observation protocol. The observational protocol noted whether the young adult sat with or without back support, with the head in a neutral or flexed position, with or without forearm support, used a one or two handed grip on the phone, used a one or two thumb text entering technique, entering text with medial side or pad/tip of the thumb and had high or moderate/low velocity in the thumb movements.

Neck flexion, shoulder abduction and shoulder flexion were measured with a manual goniometer during the first five minutes of the task. A video recording of the young adults' postures and movements was obtained during the performance of the task.

Perceived exertion

In *Paper II*, using a Borg CR-10 scale (Borg, 1990), each subject rated their perceived exertion in the neck, shoulders, arms, wrists and hands immediately before and after work with the traditional and the vertical mouse. The difference between the rated perceived exertion before and after work with each mouse was calculated for every rated body area.

In *Paper IV*, using a Borg CR-10 scale (Borg, 1990), the young adults rated their perceived exertion in neck and shoulder girdle, upper arm, forearm, hand and thumb immediately before and after completing a 300 character text message on a mobile phone.



0	Nothing at all
0,5	Extremely weak
1	Very weak
2	Weak
3	Moderate
4	Somewhat strong
5	Strong (heavy)
6	–
7	Very strong
8	–
9	–
10	Extremely strong (almost max)
	Maximal

Figure 7. Rated body areas (A-K) and Borg’s CR-10 scale.

Perceived comfort

In Paper II the subjects after work with each mouse, rated the perceived general comfort using a bipolar scale, ranging from –4, very poor comfort, to +4, excellent comfort (Karlqvist et al., 1995).

Productivity

In Paper II the number of pages edited within the specified time and the number of errors was calculated for each hand position.

In Paper IV the time to complete the 300 character text message was recorded for each subject.

2.3 Methods of analysis

Grounded theory

In *Paper I* the raw data in the transcribed interviews were analysed in a stepwise coding procedure. The first step was to transform the raw data into codes, which defined actions or events within them. A set of questions were asked e.g. What is actually happening here (in the data)? Systematic line-by-line coding was used, where each line of the interviews was examined and initial codes defined (Glaser, 1978; Charmaz, 2000). The codes were then grouped together into categories and subcategories by a constant comparison with raw data where the connections between a category and its subcategories were searched for. In the focused coding, concepts which reappeared frequently were examined and described in a more abstract core category. This core category is central to the data, can be related to all other categories and subcategories, and accounts for most of the variation in data.

Theoretical memos were used for the purpose of overview analysis of data. These theoretical memos were discussed in seminars, compared with raw data and further refined.

The analysis continued until theoretical saturation was achieved, i.e. until no new data occurred in the interviews.

Statistical methods

In *Paper II* the results of the group are presented as medians for each of the two mouse conditions as well as medians for the differences of all the subjects with 95% confidence intervals (CI) for median values (Altman, 1991). As the data were showed to be not normally distributed, the differences in the results between the two computer mice, offering a pronated and neutral hand position respectively, were compared by using the Wilcoxon signed rank test for repeated measurement. Differences between gender, order of the two hand positions and time of day were compared with the Wilcoxon rank sum test for group comparison. The tests of significance were two-tailed with a significance level of 0.05. The p-values were read from table B9 Wilcoxon one sample (or matched pairs) test and table B10 The Mann-Whitney test (Wilcoxon two sample test) in Altman (Altman, 1991).

In *Paper III* the muscle activity and thumb electrogoniometer data across the four tasks (A, C-E) are presented as group means \pm one standard error of the mean in the text, figures and tables (n=24). As these data was approximately normally distributed, repeated measures analysis of variance methods were used to compare the different tasks (Figure 2, Table 3), one model for each parameter. Fixed effects included in the model were task, gender, group and all interactions (Random Effects-Mixed Model in statistical program JMP). Where significant differences were found between tasks, a Tukey's HSD post-hoc analysis was used to identify tasks that were different from one another.

Group and gender differences in muscle activity and thumb goniometry measures when performing the standardized SMS task (B) were analysed with linear regression (n=56, Table 2 and 4). Determinants included in this model were group, gender and the interaction.

A power calculation showed that we had a power of 99 % to detect a difference of 5%RVE in median muscle activity and a difference of 5° in the median angle of the thumb movements between the groups assuming a standard error of 4. Significance was accepted when p-values were less than 0.05. The calculations were made in the statistical program JMP (version 5.0.1, SAS Institute Inc., NC, USA).

In *Paper IV* the differences in working techniques between those with symptoms and those without symptoms are presented as proportions and differences in proportions with 95%CI for the differences. The calculations were made in the statistical program CIA with a calculation method according to Wilson (Altman, 2000). The differences in muscle activity, thumb goniometer data and productivity between the groups working with different working techniques are presented as differences of group means with 95%CI. The changes between the rated perceived exertion before and after the performed task were calculated for each subject for every rated body area. The calculated changes were coded with +1 for positive value (increased exertion), with 0 for no change and with -1 for negative value (decreased exertion). The differences in changes in perceived exertion between groups were compared with the Wilcoxon's rank sum test (Mann Whitney U test). Statistical significance was set at p-values less than 0.05. These calculations were made in the statistical program JMP (version 5.0.1, SAS Institute Inc., NC, USA).

Power calculations showed that we had approximately 40 % power to detect a difference in posture and working techniques between the groups and a power of 99 % to detect a difference of 5%RVE in median muscle activity and a difference of 5° in the median angle of the thumb movements between the groups assuming a standard error of 4.

3. Results

In *Paper I* the focused coding generated one core category about the subjects' overall experience of, and attitudes to, information technology, *the two sides of being social, efficient and independent here and now*. Their private and social roles related to performance and experiences of time were important aspects. The core category included dimensions of almost unlimited perceived opportunities as well as risks.

Four descriptive categories were related to the core category. A feeling of *freedom* and *efficiency* on the positive side, related to perceived opportunities, and

a feeling of *restrictions on living space* and *intangibility* on the other side, related to perceived risks. (Figure 8)

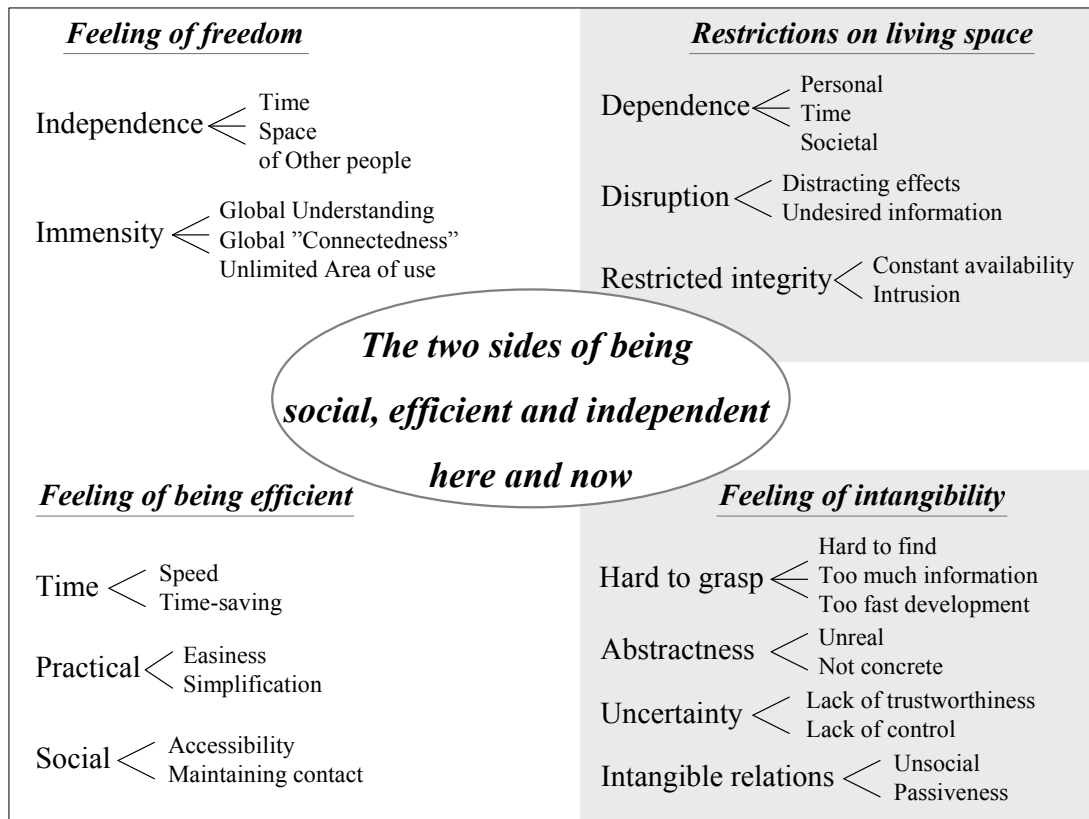


Figure 8. Model of young adults' experience of IT use. The core category and the four descriptive categories.

Differences in physical exposure between a neutral and a pronated hand position in computer mouse use

In *Paper II* there were some differences in physical exposure found between the traditional and the prototype vertical mouse. Work with the vertical mouse offering a neutral hand position showed a decrease in ulnar wrist deviation (though great inter individual differences), a decrease in mean velocity in the deviation movements and furthermore a decrease in the muscle activity in the extensor muscles (EDC, ECU) in the right forearm and in the first dorsal interossei muscle (FDI) in the hand compared to the pronated hand position with the traditional mouse. No differences in muscle activity levels for the right trapezius muscle were seen between the two hand positions in the group though there was a great interindividual variation. (Table 1 and 2)

Table 1. Wrist positions and movements in work with a pronated and a neutral hand position and the difference between the two hand positions (n=15). Md= Group median, 95%CI= 95% Confidence Interval. A positive value in wrist angles stands for extension and ulnar deviation. A negative value stands for flexion and radial deviation.

Wrist position and movement	Pronated		Neutral		Difference (Pronated-Neutral)		
	Md	95%CI	Md	95%CI	Md	95%CI	p-value
Flexion/extension							
10 th percentile (°)	14	4;22	11	-7;16	7	0;16	<0.01
50 th percentile (°)	23	14;32	18	2;31	5	-2;16	<0.1
90 th percentile (°)	31	16;36	23	14;32	5	-4;13	>0.2
MPF (Hz)	0.60	0.50;0.98	0.63	0.46;0.92	-0.09	-0.19;0.14	>0.2
Velocity (°/s)	12.7	9.9;15.8	14.8	11.6;18.6	-0.8	-6.8;1.6	>0.2
Deviation							
10 th percentile (°)	-2	-7;2	-7	-11;-4	5	0;13	<0.05
50 th percentile (°)	5	-2;7	-4	-9;0	7	2;14	<0.01
90 th percentile (°)	11	4;11	4	0;9	5	0;9	<0.02
MPF (Hz)	0.51	0.38;0.55	0.44	0.37;0.52	0.07	-0.08;0.17	>0.2
Velocity (°/s)	8.7	7.1;10.5	7.0	5.2;8.9	1.5	-0.1;3.6	<0.05

Table 2. Muscle activity in work with pronated and neutral hand position and the difference in muscular activity in work with the two positions (n=19). Md=Group median, 95%CI=95% Confidence Interval. %MVE (Maximal Voluntary Electrical Activity) and %RVE (Reference Voluntary Electrical Activity) are given.

Muscle activity	Pronated		Neutral		Difference (Pronated-Neutral)		
	Md	95%CI	Md	95%CI	Md	95%CI	p-value
M Extensor digitorum							
10 th percentile (%MVE)	5.0	3;6	3.0	2;4	2.0	1;3	<0.001
50 th percentile (%MVE)	8.0	6;9	5.0	3;7	3.0	2;5	<0.001
90 th percentile (%MVE)	13.0	8;16	11.0	6;12	3.0	2;6	<0.001
M Extensor carpi ulnaris							
10 th percentile (%MVE)	5.0	4;8	3.0	2;5	2.0	2;4	<0.001
50 th percentile (%MVE)	8.0	7;12	6.0	4;7	3.0	2;5	<0.001
90 th percentile (%MVE)	17.0	13;18	12.0	9;13	5.0	3;6	<0.001
M Interossei 1							
10 th percentile (%MVE)	2.0	1;4	1.0	0;2	1.0	0;1	<0.05
50 th percentile (%MVE)	6.5	5;10	2.0	1;4	5.0	3;7	<0.01
90 th percentile (%MVE)	11.5	8;16	4.0	2;7	7.5	4;13	<0.001
M Trapezius (pars descendens)							
10 th percentile (%RVE)	5.5	2;8	5.0	3;8	0	-2;1	>0.2
50 th percentile (%RVE)	12.0	8;16	11.0	7;18	0	-3;4	>0.2
90 th percentile (%RVE)	28.0	15;38	25.0	16;37	0	-9;4	>0.2

The perceived exertion was rated higher in right shoulder (CI -0.5;2, p<0.1) and wrist

(CI -1;2, $p < 0.05$) in work with the traditional mouse compared to the vertical mouse. In the other rated body areas no statistically significant differences in perceived exertion between the two hand positions were found. Three subjects rated work with the vertical mouse offering a neutral hand position to give better general comfort than the pronated position, while 19 subjects rated work with the vertical mouse less comfortable (Md -1 scale step, CI -2;-1, $p < 0.05$).

All subjects edited fewer pages (Md -2.5 pages, CI -3.25;-1.5, $p < 0.05$) when working with the vertical mouse compared to the traditional mouse. All subjects preferred to work with the traditional mouse compared with the vertical mouse used in the study, but both advantages and disadvantages with the vertical mouse were expressed. Experienced advantages with the vertical mouse among the users were above all the neutral hand position, a lower resistance of the mouse button and a comfortable grip. Experienced disadvantages were above all a lower precision, a bad hand size fit, and a difficulty in moving the mouse.

Muscle activity during mobile phone use

In *Paper III* compared to talking on the mobile phone which was the reference exposure, median muscle activity was higher in four of the six muscles when entering SMS messages into the mobile phone. The two exceptions were the FDI and RTRAP muscles. While seated the median muscle activity levels in the APB averaged 5.2 ± 0.6 %MVE, in the APL 8.0 ± 0.9 %MVE, in the FDI 5.2 ± 0.6 %MVE, in the ED 5.6 ± 0.6 %MVE, and in LTRAP and RTRAP $2.8 \pm 1.1\%$ and 4.3 ± 1.5 %RVE respectively.

When comparing muscle activity when the young adults entered SMS messages on their own and the standard phone while sitting, only small differences were observed in muscle activity. The only statistical differences were seen in the FDI muscle, the median ($p = 0.052$) and peak 90th ($p = 0.046$) percentile, with higher muscle activity when they used their own phone.

Thumb postures and movements during mobile phone use

In *Paper III* with respect to thumb position, entering an SMS message placed the thumb in abduction and flexion relative to adducted and extended thumb posture when talking. During SMS messaging, the MPF and thumb movement velocities were significantly higher compare to talking, with higher velocities in Ad/Ab compared to F/E. There was significantly less pause time, significantly fewer pauses and shorter mean pause durations during text entering compared to talking on the phone. When the young adults entered SMS messages with their own phone, the thumbs were less abducted ($p = 0.02$) compared with the standard phone.

Gender differences

In *Paper III* when entering the standardized SMS message, while seated, using the standard phone there were significant differences in muscle activity between gender in the extensor muscle ($p < 0.01$) and the abductor pollicis longus (the median percentile, $p = 0.02$) with females having higher muscle activity than males

(Table 3). There were also some gender differences in thumb movements with females working in larger abduction ($p=0.24$), moving the thumb with higher velocity ($p=0.20$ in flexion/extension) and taking fewer pauses ($p=0.13$ in flexion/extension) than males; however none of these differences were statistically significant (Table 4).

Differences between subjects with and without musculoskeletal symptoms

In *Paper III* there were significant differences in muscle activity in the abductor pollicis longus between the young adults with and without musculoskeletal symptoms (the 50th percentile, $p=0.04$) with higher muscle activity in the group without symptoms (Table 3). The trapezius muscle activity was consistently higher in the group with symptoms, though not statistically significant ($p=0.11-0.66$). The young adults with symptoms tended to move the thumb faster ($p=0.20$ in flexion/extension), and to take fewer pauses ($p=0.17-0.35$) than those without symptoms, though none of these differences were statistically significant (Table 4).

There were no statistical significant differences in muscle activity or thumb movements between the young adults with and without musculoskeletal symptoms based on the diagnosed symptoms (neck/arm pain, forearm/hand pain or both locations of pain). All three sub groups of diagnosis showed the same pattern as the whole group of young adults with symptoms compare to the healthy group.

No interactions between gender and groups in muscle activity and thumb movements were seen ($p=0.33-1.00$ and $p=0.09-0.94$ respectively).

Table 3. Gender and group differences in 10th, 50th and 90th percentile muscle activity levels while performing the standardized task. Group means and standards error are given. (APB= appollicis brevis; APL=appollicis longus; FDI=first dorsal interossei; ED=extensor digitorum; LTRAP=left trapezius; RTRAP=right trapezius; %MVE= % maximal voluntary electrical activity; %RVE= % reference voluntary electrical activity)

Muscle		Female n=30	Male n=25	Diff	Healthy n=15	w/Symptoms n=40	Diff
APB (%MVE)	p0.10	1.4 ± 0.2	1.3 ± 0.2	0.1	1.0 ±	1.5 ± 0.2	-0.5
	p0.50	5.3 ± 0.6	3.8 ± 0.6	1.5	0.2	4.8 ± 0.5	-0.6
	p0.90	16.2 ±	12.7 ±	3.5	4.2 ±	14.2 ± 1.3	1.7
		1.5	1.6		0.8		
					15.9 ±		
					2.2		
APL (%MVE)	p0.10	3.8 ± 0.3	2.8 ± 0.4	1.0	4.2 ±	3.1 ± 0.2	1.1
	p0.50	7.3 ± 0.6	5.2 ± 0.7	2.1	0.7	5.8 ± 0.7	1.9
	p0.90	12.9 ±	8.9 ± 1.2	4.0	7.7 ±	10.3 ± 0.8	3.0
		1.1			1.3		
					13.3 ±		
					2.2		
ED (%MVE)	p0.10	3.2 ± 0.3	2.0 ± 0.2	1.2	2.9 ±	2.5 ± 0.2	0.4
	p0.50	5.5 ± 0.4	3.5 ± 0.4	2.0	0.5	4.5 ± 0.4	0.5
	p0.90	9.2 ± 0.6	6.0 ± 0.5	3.2	5.0 ±	7.6 ± 0.5	0.4
					0.7		
					8.0 ±		
					1.0		
FDI (%MVE)	p0.10	2.1 ± 0.3	1.5 ± 0.2	0.6	1.7 ±	1.8 ± 0.3	-0.3
	p0.50	4.9 ± 0.6	3.4 ± 0.5	1.5	0.2	4.4 ± 0.6	-0.6
	p0.90	12.3 ±	9.2 ± 1.3	3.1	3.8 ±	11.2 ± 1.2	-0.9
		1.3			0.5		
					10.3 ±		
					1.3		
LTRAP (%RVE)	p0.10	2.0 ± 0.5	1.5 ± 0.6	0.5	0.8 ±	2.1 ± 0.5	-1.3
	p0.50	3.5 ± 0.8	2.8 ± 0.8	0.7	0.3	3.7 ± 0.7	-2.0
	p0.90	7.9 ± 1.1	6.1 ± 1.1	1.8	1.7 ±	7.9 ± 1.0	-2.9
					0.6		
					5.0 ±		
					1.0		
RTRAP (%RVE)	p0.10	2.2 ± 0.8	2.7 ± 1.1	-0.5	2.0 ±	2.6 ± 0.9	-0.62
	p0.50	3.8 ± 1.1	4.0 ± 1.4	-0.2	0.8	4.2 ± 1.1	-1.1
	p0.90	6.7 ± 1.4	6.7 ± 1.8	0	3.1 ±	7.4 ± 1.4	-3.0
					1.2		
					4.7 ±		
					1.6		

Table 4. Gender and group differences in thumb postures and movements while performing the standardized task. Group means and standards error are given. A positive value in median angle stands for abduction and extension while a negative value stands for adduction and flexion. (Ad/Ab=adduction/abduction; Flex/Ext=flexion/extension)

Parameter	Position	Female n=31	Male n=25	Diff	Healthy n=15	w/Symptoms n=41	Diff
Median angle (°)	Ad/Ab	18.2 ± 1.9	12.1 ± 2.8	6.1	13.0 ± 2.1	14.9 ± 2.2	-1.9
	Flex/Ext	-9.5 ± 2.4	-11.5 ± 1.8	-2.0	-13.2 ± 3.2	-9.4 ± 1.8	3.8
Median velocity (°/s)	Ad/Ab	6.6 ± 0.5	6.2 ± 0.5	0.4	6.2 ± 0.7	6.6 ± 0.4	-0.4
	Flex/Ext	6.3 ± 0.3	5.7 ± 0.3	0.6	5.2 ± 0.4	6.5 ± 0.3	-1.3
MPF (Hz)	Ad/Ab	0.35	0.31 ±	0.04	0.32 ±	0.34 ± 0.01	-
	Flex/Ext	±0.01	0.01	0.03	0.01	0.39 ± 0.01	0.02
		0.40	0.37 ±		0.38 ±		-
		±0.01	0.02		0.02		0.01
Pause %	Ad/Ab	0.19	0.18 ±	0.01	0.22 ±	0.19 ± 0.02	0.03
	Flex/Ext	±0.02	0.02	-	0.03	0.17 ± 0.01	0.04
		0.17	0.20 ±	0.03	0.21 ±		
		±0.01	0.02		0.02		
Pause duration (s)	Ad/Ab	1.05	1.06 ±	-	1.06 ±	1.05 ± 0.03	0.01
	Flex/Ext	±0.03	0.03	0.01	0.04	1.03 ± 0.03	0.04
		1.04	1.04 ±	0.00	1.07 ±		
		±0.03	0.04		0.03		
Pauses/Minute (n)	Ad/Ab	10.0 ± 0.8	10.0 ± 0.8	0.0	10.9 ± 1.2	10.0 ± 0.6	0.9
	Flex/Ext	9.4 ± 0.6	11.0 ± 0.8	-1.6	11.3 ± 0.8	8.8 ± 0.6	1.5

In *Paper IV* during the texting task it was more common in the group with musculoskeletal symptoms to sit with the head bent forward and to sit without forearm and back support compared to the group without symptoms. Also a higher proportion of young adults with musculoskeletal symptoms entered text with one rather than two thumbs though this difference was not significantly different from the group without symptoms. (Table 5)

Table 5. Differences in posture and working technique between young adults with and without musculoskeletal symptoms. Proportions and differences of proportions with 95%CI are given.

Posture	Proportions		Diff of prop	95%CI
	No symptoms (n=15)	Symptoms (n=41)		
Back support	13/15 (0.87)	18/41 (0.44)	0.43	0.14;0.60
Neck flexion (observed)	10/15 (0.67)	38/41 (0.93)	-0.26	-0.51;-0.04
Neck flexion $\geq 20^\circ$	12/15 (0.80)	36/41 (0.88)	-0.08	-0.34;0.11
Neck flexion $\geq 30^\circ$	7/15 (0.47)	26/41 (0.63)	-0.17	-0.42;0.11
Neck flexion $\geq 40^\circ$	1/15 (0.07)	17/41 (0.42)	-0.35	-0.51;-0.08
Forearm support	14/15 (0.93)	27/41 (0.66)	0.28	0.01;0.44
1-hand grip	7/15 (0.47)	14/41 (0.34)	0.13	-0,14;0,39
1-thumb key press	7/15 (0.47)	28/41 (0.68)	-0.22	-0,47;0,06
Key press with medial side of the thumb	9/15 (0.60)	28/41 (0.68)	-0.08	-0.35;0.17
Key press velocity (observed)	3/15 (0.20)	14/41 (0.34)	-0.14	-0.34;0.14

Muscle activity in work with different posture and working technique

In *Paper III* sitting and standing influenced trapezius muscle activity. When entering an SMS message while standing, the muscle activity in the trapezius muscles was significantly higher compared to performing the same task sitting. Whether the young adults were sitting or standing also affected thumb position, they worked with less thumb abduction ($p = 0.04$) when entering an SMS message while standing.

In *Paper IV* lower muscle activity in the left and right trapezius muscles was registered in the group who used forearm support during the given text task compared with/to those who did not used forearm support. Higher muscle activity was registered in the ED muscle in the group who used one hand grip compared to those who used two hands grip. The group who worked with observed high velocity had higher muscle activity levels in both the ED muscle and the APL muscle.

Thumb postures and movements in work with different posture and working technique

In *Paper IV*, the group who used a single hand, thumb key press technique had higher median velocity, lower pause % and lower number of pauses per minutes compared to those who used a two thumbs technique. Higher median velocity (though not significant) and higher MPF was registered for the group with high observed velocity compared to those with observed low/moderate velocity.

Productivity and perceived exertion in work with different posture and working technique

In *Paper IV*, the young adults who worked with observed high velocity showed higher productivity, (i.e. they took less time to perform the text task), than those who worked with observed moderate or low velocity (1.7 minutes difference, 95%CI 0.7;2.7).

No differences in productivity were seen between the young adults with musculoskeletal symptoms compared to those without symptoms. However, the subgroup diagnosed with hand/arm symptoms showed higher productivity, i.e. they needed shorter time to perform the task, compared to the group without symptoms (1.4 minutes difference, 95%CI 0.2;2.6).

The young adults who pressed the key with the medial side of the thumb rated higher perceived exertion in the forearm compared to those who used the pad or tip of the thumb (p-value 0.040). No significant differences in changes in rated perceived exertion before and after the text entering task were seen between the young adults with and without musculoskeletal symptoms (p-value 0.36-0.65). However, a higher proportion of the females rated higher perceived exertion in the hand after performing the task compared to the males (64 % and 33 % respectively, p-value 0.018).

4. Discussion

4.1 Experiences and attitudes related to IT/ICT use

The main findings in *Paper I* were the young adults' experience of being social, efficient and independent here and now; IT was described as a tool for being and acting in the present. However, they experienced an ambivalent relation to their own use and to IT use in general. While they perceived almost unlimited opportunities in connection with IT, they also had misgivings and perceived risks in relation to IT use. This experience of both opportunities and risks in IT use is supported by a Swedish study about the human being in the information society (Bradley, 2000), which concluded that the use of IT can lead to access and integration or isolation; to autonomy and self-determination or decreased levels of control; to balance or overload (or underload) in contacts and information.

Increased freedom and efficiency, if IT is used in the right way, can lead to increased quality of life, but there is also a risk of negative stress. The phenomenon called IT stress has been characterised as too much (or too little) workload, information, contacts with people and flexibility. "Internet stress" has later been described as related to information overload, contact overload, requirements of availability, difficulty in separating noise from essentials, a

changing level of expectations and a changed perception of time and space (Bradley, 2000). These are factors that were all experienced by the young adults in the present study.

The young adults experienced a risk of distanced relations in the use of IT. They expressed that people can hide behind the computer screen, avoid conflicts or avoid difficult meetings with others, experiences that could contribute to personal growth and development. The use of IT can give us more time for human contacts, but it has often produced the opposite effect and pointed out that children and young people may lose an important period in the development of their identity if they are exposed too early and too intensively to electronic communication without face-to-face meetings (Bradley, 2000).

Security, contacts and communication with other people were experienced by the young adults. These are factors that constitute the basic needs, which are required to achieve mental health. Social support, which can provide for security, social contacts, approval and belonging are considered to have a positive influence on the individual's health and well-being (House and Kahn, 1985; Johnson and Hall, 1988). A development towards an increased need for local affiliation to balance the increase in global contacts has been described (Bradley and Bradley, 2001), which can explain the perceived need among the young adults to always be accessible and always be able to reach others. A feeling of "connectedness" has been presented as an important protective factor when it comes to health risks for adolescents (Blum, 1998). It is important to be accepted, to belong and to identify oneself with the group. Too many contacts, however, as well as sound and visual impressions and too much information, are factors that lead to overstimulation, which can result in negative stress. Different kinds of experienced disruptions are also related to overstimulation. Increased levels of cognitive demands when using IT at work have been shown to influence the stress and health of employees (Carayon, 2001). The degree of stress depends on the individual's cognitive appraisal of the event, whether it is a threat, a challenge, harmful or is benign or irrelevant. Personal factors that affect cognitive appraisal are commitments; that is, what is important to people, and their beliefs (Folkman, 1997).

Some of the experienced feelings, such as increased dependence and a feeling of intangibility, are related to an experience of lack of control. Experiencing lack of control gives the individual a feeling of helplessness and is considered to influence his or her self-esteem and in the long run health (Seligman, 1975). Situational appraisals of control have an influence on emotion and the way we cope with a situation (Lazarus and Folkman, 1984).

The response to psychosocial exposure of IT/ICT use seems to a high degree be depending on individual factors/conditions like experiences and attitudes expressed in *Paper I*.

4.2 Physical exposure in work with a vertical compared to a traditional computer mouse

Muscular activity

In *Paper II* the muscle activity in the extensor muscles of the forearm decreased during work with the vertical mouse (neutral hand position), compared with the traditional mouse (pronated hand position). This result is in agreement with another study evaluating the muscle activity in work with a vertical mouse (Aaras and Ro, 1997) and can probably be explained by the fact that the neutral hand position is a more relaxing position for the muscles with the wrist in a rest position similar to the position when standing with the arm hanging relaxed beside the body. In work with the neutral hand position the hand and wrist was resting on the vertical mouse. Another explanation may be that the vertical mouse in *Paper II* like Aarås' vertical mouse was mainly moved by whole arm movements. The decrease in muscle activity in the FDI during work with the vertical mouse (neutral hand position) cannot entirely be explained by the hand position but is probably partly due to the fact that less force was needed to click the button of the vertical mouse and the different grip compared to the traditional mouse.

Wrist positions and movements

In *Paper II* the decrease in ulnar deviation in work with the vertical mouse (neutral hand position) could be expected since the ulnar side of the hand and wrist are resting on the mouse during the mouse operations. The trend indicating a decrease in wrist extension and frequency of deviation movements in work with the vertical mouse (neutral hand position) can also be explained by the design of the vertical mouse, which mostly required the subjects to use grosser arm movements rather than finer wrist movements. If we consider the effect of the goniometer measurement errors due to crosstalk and offset errors associated with supination/pronation (Jonsson and Johnson, 2001; Johnson et al., 2002) the "true" difference in wrist extension between the vertical and the traditional mouse would be larger and the wrist position in the deviation plane would be more neutral with the vertical mouse (neutral hand position).

Perceived exertion and comfort

There was a great variation in perceived exertion among the subjects during work with the two mice. This can probably be explained by differences in working technique between the subjects and the fact that some of them had difficulties moving the vertical mouse smoothly on the desk surface. The differences in perceived exertion in work with the two mice for each subject were small, except for the right shoulder and hand. This and the perceived lower general comfort can probably also be explained by the fact that some of the subjects had difficulties moving the vertical mouse smoothly. In work with the vertical mouse (neutral hand position), most of the subjects used a technique where they moved the input device with arm movements, in contrast to the traditional mouse (pronated hand

position), where they moved the input device with hand or finger movements. Arm movements involve larger muscles, with the end result being rougher and more coarsely. Whereas hand and finger movements involve smaller muscles resulting in more controlled, motor movements.

Productivity, preference and users comments

The lower productivity expressed by the number of pages edited during work with the vertical mouse (neutral hand position) in *Paper II* is supported by another study (Straker et al., 2000) which found a decrease in performance by 11 % even after 2 weeks of practice with a vertical mouse. In *Paper II* almost all subjects considered work with the vertical mouse (neutral hand position) to be more restful and convenient for the hand and the wrist but all subjects still preferred to work with the traditional mouse. Half of the subjects considered the vertical mouse to have less precision and to be more difficult to move than the traditional mouse used which can probably at least partly be explained by their familiarity with this mouse design but may also be explained by the design of the vertical mouse used in the study.

4.3 Physical exposure during text entering on a mobile phone

Muscle activity

In *Paper III and IV* the trapezius (below 5 %RVE, i.e. approximately 1 %MVE) and forearm (5-8 %MVE) muscle activity levels during text entering were relatively low compared with previous reported median muscle activity levels during common computer activities, including gripping, mouse clicking and/or key pressing, exposures associated with musculoskeletal symptoms (Aaras and Ro, 1997; Jensen et al., 1998; Laursen et al., 2001; Thorn et al., 2005; Thorn et al., 2007).

Compared to talking, muscle activity in *Paper III* was higher in four of the six muscles when entering SMS messages into the mobile phone. The two exceptions were the FDI muscle and the right trapezius muscle. The higher muscle activity in the FDI muscle during talking compared to entering an SMS message is likely due to the fact that the FDI muscle is involved in holding the phone in opposition with the thumb when the mobile phone is held up against the ear. When an SMS message is being entered, the phone can rest in the palm of the hand, and as a result, unlike when held against the ear, less grip force is needed to hold the phone since users do not have to counteract gravity in order to prevent the phone from slipping out of the hand. The higher muscle activity in the right trapezius muscle during talking is likely due to this muscle's role elevating the arm and stabilizing the shoulder girdle when holding the phone up against the ear.

When comparing muscle activity when the young adults entered SMS messages on their own and the standard phone while sitting, differences were only found in FDI muscle activity. When the young adults used their own phone, both

median and peak muscle activity was higher. This difference in FDI muscle activity may be due to the subjects' own phones being smaller in size relative to the standard phone.

Thumb postures and movements

In *Paper III and IV* text entering placed the thumb in an abducted and flexed posture. When the young adults entered SMS messages with their own versus the standard phone, their thumbs were less abducted ($p = 0.02$) when using their own phone, all other differences were not statistically significant. These differences in thumb posture may be due to phone size since the young adults' own phones were on average shorter, narrower and thinner than the standard phone.

Gender differences

In *Paper III* there were significant gender differences in muscular activity in the extensor digitorum and the abductor pollicis longus with females having higher muscle activity levels. Other studies have demonstrated that, during computer mouse use, females tend to have higher muscular activity levels than males (Karlqvist et al., 1999; Wahlstrom et al., 2000). These muscle activity differences were assumed to be related to differences in anthropometry and muscular strength. Furthermore females tended to work in greater thumb abduction, to move their thumbs with higher velocities and to have fewer pauses in the thumb movements compared to males. All factors may lead to the larger changes in rated perceived exertion in the hand for females compared to males found in *Paper IV*. The larger thumb abduction for the females in *Paper III* is probably due to smaller hand size resulting in larger thumb movements in order to reach the keys. This, perhaps together with the females having higher median velocity, less pause percentage and fewer pauses than males, could explain the higher muscle activity in the ED and the APL.

Differences between subjects with and without musculoskeletal symptoms

In *Paper III* there were significant differences in muscle activity in the abductor pollicis longus between the young adults with and without symptoms; however the young adults without symptoms tended to have higher levels of muscle activity. The trapezius muscle activity was consistently higher in the young adults with symptoms, though not statistically significant. The "vicious circle model" (Johansson and Sojka, 1991) suggests that muscle pain probably lead to increased muscle activity during muscle work. In accordance with this, one study has found higher electromyographic activity in the neck and shoulder muscles in subjects with neck and shoulder complaints (Madeleine et al., 2003). The lower muscle activity in the APL in the group with symptoms is a contradictory result but might be explained by the findings in a study where they found lower electromyographic activity in the extensor carpi ulnaris in high activity phases in low precision computer mouse work during experimental muscle pain (Birch et al., 2000).

In a study with female industrial workers with highly repetitive work tasks it was found that subjects with hand/wrist pain moved their wrists with lower

velocity compared with subjects without pain (Balogh et al., 1999). It would be reasonable to expect that due to pain the young adults with symptoms in *Paper III* should move the thumb slower. On the contrary, the young adults with symptoms tended to move their thumbs with higher speed compared to those without symptoms. The higher velocity may partially explain why they have developed symptoms/disorders. High movement velocity has been shown to be a risk factor for musculoskeletal disorders (Marras and Schoenmarklin, 1993) and fast thumb movements are considered to be a risk factor for developing De Quervain's disease (Moore, 1997). One study has shown that occupations involving repetitive thumb movements where there was a perception of not having enough rest breaks, there was an elevated risk for osteoarthritis of the thumb (Fontana et al., 2007). This finding is in accordance with a case report of CMCJ arthritis associated with excessive texting with a mobile phone (Ming et al., 2006).

Furthermore the young adults with symptoms tended to have fewer and shorter pauses compared to those without symptoms. Several studies have found that subjects with neck/shoulder complaints show less trapezius muscle rest than those without complaints (Veiersted et al., 1993; Hagg and Astrom, 1997; Sandsjo et al., 2000; Thorn et al., 2007). If one presumes that the pause pattern of the thumb movements are linked to the pauses of muscle activity in the thumb muscles, perhaps one can consider the pause pattern as a probable risk factor for musculoskeletal disorders in the hand and forearm. Although not significant, symptomatic young adults in *Paper III* were found to move their thumb faster and to take fewer and shorter pauses compared to those without symptoms. This is in accordance with earlier studies which have shown an association between high repetitiveness in wrist movements and musculoskeletal disorders in the neck/shoulder and the hand/arm area (Marras and Schoenmarklin, 1993; Ranney et al., 1995; Latko et al., 1999; Viikari-Juntura and Silverstein, 1999). There are also studies that have found associations between high velocities and repetitiveness in thumb movements and musculoskeletal symptoms/disorders in the thumb and forearm (Moore, 1997; Ming et al., 2006; Fontana et al., 2007).

Differences in productivity and perceived exertion between subjects with and without musculoskeletal symptoms

An association between self reported reduced productivity and musculoskeletal symptoms in the upper extremities were found in a prospective cohort study of 2914 young adults (Bostrom et al., 2008). In a cross-sectional designed study of 654 computer workers with neck/shoulder or hand/arm symptoms were self reported productivity loss involved in 26 % of all the cases and in 36 % of cases with both neck/shoulder and hand/arm symptoms (van den Heuvel et al., 2007). We found no significant differences in productivity between those with and without symptoms. However, on the contrary the subgroup diagnosed with hand/arm symptoms needed shorter time to perform the task, compared to the group without symptoms. The higher productivity in this group despite their symptoms may partially be explained by the short duration of the task. When they

are working for hours in school or work their symptoms may affect their performance more.

No differences in changes in rated perceived exertion before and after the text entering task were seen between the young adults with and without musculoskeletal symptoms.

Postures and working techniques

In *Paper III* sitting or standing while performing an SMS message influenced the muscle activity in the trapezius muscles. When entering an SMS message while standing, the muscle activity in the trapezius was significantly higher compared to performing the same task sitting. A study evaluated the muscle activity of computer workers during a whole working day (Mork and Westgaard, 2007) found that muscle activity in the trapezius was elevated in standing compared to sitting during computer work. However, while standing the subjects in their study were not doing the same task as in sitting position using the computer but talking to colleagues, handling print-outs etc. In the present study while sitting, the young adults were able to rest their arms on their thighs, the armrests or on the table in front of them, the higher trapezius muscle activity while standing was probably due to the young adults not being able to support their arms. Forearm support during keyboard and mouse use has been reported to decrease neck and shoulder muscle activity (Aaras et al., 1998; Aaras et al., 2001; Woods et al., 2002; Cook et al., 2004) and the results in this study indicate that having arm support, while text entering, may reduce trapezius muscle load. Whether the young adults were sitting or standing also affected the thumb position. They worked with less thumb abduction but larger flexion while standing. These postural differences are likely the result of the arms being unsupported allowing a greater flexibility in the wrist and hand when entering text while standing.

Working techniques and musculoskeletal symptoms/disorders

In *Paper IV* during the text entering task it was more common in the group with musculoskeletal symptoms to sit with the head bent forward and to sit without forearm and back support compared to the group without symptoms. Also a higher proportion of young adults with musculoskeletal symptoms entered text with one rather than two thumbs though this difference was not significantly different from the group without symptoms.

The high proportion of sitting with head bent forward in the group with musculoskeletal symptoms compared to those without symptoms is in agreement with earlier studies on different occupational groups. Two prospective cohort studies have shown an increased risk for neck or neck/shoulder pain or sick leave due to neck pain in work with neck flexion $\geq 20^\circ$ more than 40 % and two thirds of the working time respectively or $\geq 45^\circ$ more than 5 % of working time (Ariens et al., 2002; Andersen et al., 2003). In a case-control study with computer users a tendency for greater head-neck flexion was shown in the group with reported neck and shoulder discomfort compared to those without reported discomfort (Szeto et al., 2002; Szeto et al., 2005). A recently published study identified that neck

flexion greater than 20° during keyboard use can discriminate between individuals with and without musculoskeletal disorders of the upper extremity (Baker et al., 2008).

The lower proportion of forearm support use in the group with symptoms is in agreement with earlier studies of computer users. There has been shown an association between forearm support use and reduced risk of neck/shoulder symptoms or reduction of neck/shoulder pain among computer users (Aaras et al., 1998; Aaras et al., 2001; Marcus et al., 2002; Gerr et al., 2006; Rempel et al., 2006; Straker et al., 2008b).

Eighty-seven percent of the young adults without symptoms preferred to sit with back support compared to 44 % of those with symptoms. Back support may influence neck posture, promoting more neutral neck postures and thereby decreasing risk for neck/shoulder symptoms (Ariens et al., 2002; Andersen et al., 2003).

Entering text with one thumb rather than two was more common among those with symptoms though the difference was not significant. Since this one thumb technique resulted in higher velocities and less pause time compared to the use of both thumbs this technique may increase the risk for developing musculoskeletal symptoms.

Muscle activity and thumb postures and movements in work with different posture and working technique

In *Paper IV* the group who supported their forearms during the texting had significantly lower muscle activity in the trapezius muscles compared to those who did not support their forearms. Forearm support has been shown to decrease neck and shoulder muscle activity during keyboard and mouse use among computer users (Aaras and Ro, 1997; Aaras et al., 1998; Karlqvist et al., 1998; Woods et al., 2002; Cook et al., 2004) and furthermore, as mentioned above, to reduce the risk for neck/shoulder symptoms.

The group who used a one hand grip when performing the text entering on the mobile phone showed higher muscle activity in the ED muscle which could be expected since this muscle is active in gripping activities.

The group who entered text with one thumb had higher median velocity, lower pause percentage and lower number of pauses per minute in the thumb movements which was logical and could be expected since they used the same thumb for all key presses in contrast to those who alternated between both thumbs.

Those who used the medial side of the thumb when pressing the key pads rated higher exertion in the forearm and they had a tendency to higher muscle activity in the FDI muscle. These results may be explained by the awkward thumb posture associated with this technique which is likely to affect the FDI muscle.

The group who performed the texting task with high observed velocity had higher measured median velocity and higher MPF compared to the group with low or moderate observed velocity which gives a validation to the observed high velocity variable. This group also had higher productivity (i.e. they performed the

task in shorter time) and higher muscle activity in the ED and the APL. The higher muscle activity in the ED could be associated with the greater demands associated with stabilizing the phone during high velocity thumb movements. High thumb velocities have been shown to be associated with higher static load in the ED muscle (Jonsson et al. 2009, In manuscript).

4.4 A model of musculoskeletal outcomes in ICT use

The pathway from ICT use to the development of musculoskeletal symptoms/disorders may be explained as in the model in Figure 9 (items in italics have been studied in this thesis), modified from an ecological model of musculoskeletal disorders in VDT work (Sauter and Swanson, 1996). It can be hypothesized that ICT use implies both physical and psychosocial exposure to the user e.g. mouse design (*Paper II*), phone size (*Paper III-IV*), task (*Paper III*), demands of constant availability (*Paper I*), and control/lack of control (*Paper I*). These exposures are influenced (“filtered”, illustrated by the broken line) by individual factors e.g. gender and working technique before they cause biomechanical and/or psychological internal events in the body e.g. muscle activity (*Paper II-IV*) and feelings of independence/dependence (*Paper I*). These events can be detected by the individual as e.g. perceived exertion and comfort (*Paper II, IV*) and has been suggested (Wahlstrom, 2005) as early signs of musculoskeletal symptoms/disorders. Sauter and Swanson hypothesized in their original model that an individual’s reaction (labeling/attribution) on the detected sensation probably affects the musculoskeletal outcome.

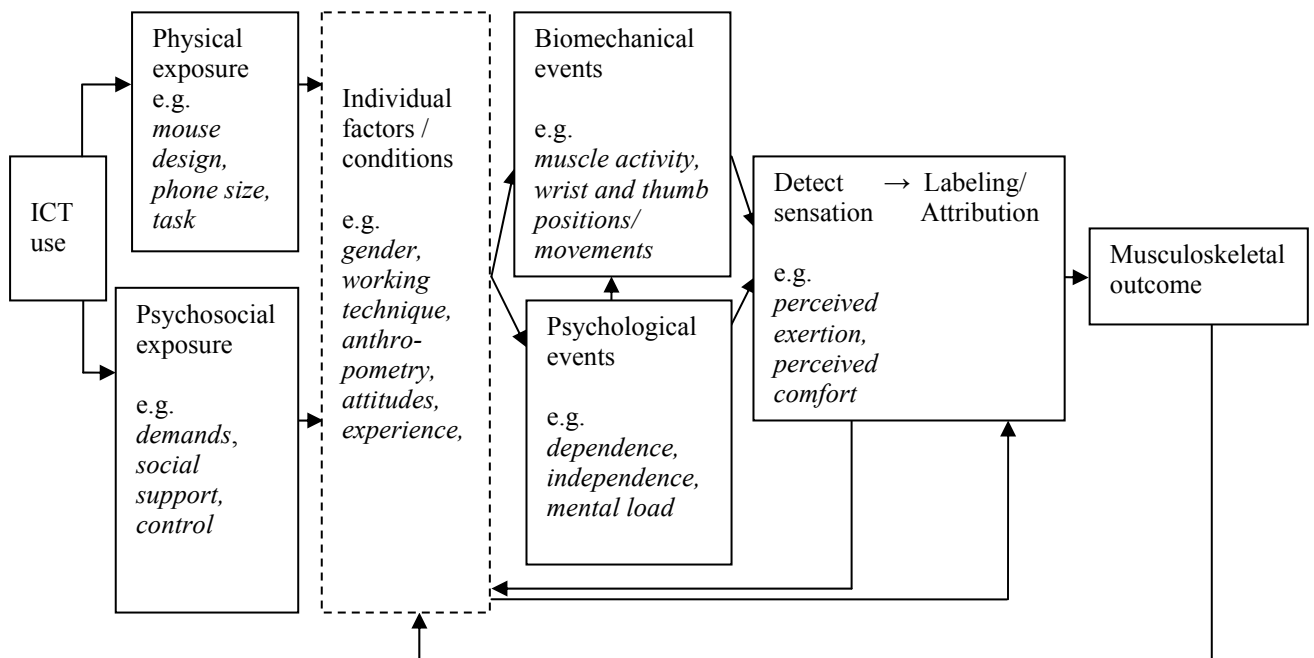


Figure 9. A model of musculoskeletal outcomes in ICT use. Modified from Sauter & Swanson (Sauter and Swanson, 1996).

Possible effects on musculoskeletal outcomes of expressed experiences and attitudes related to IT/ICT

The young adults in *Paper I* perceived both opportunities and risks in their use of IT. The perceived opportunities, with the feeling of freedom and the feeling of being efficient, may imply a positive psychosocial exposure and in many ways increase their quality of life, and their physical and mental health. The perceived risks associated with IT, with the feelings of restrictions of living space and the feeling of intangibility, may on the other hand imply a negative psychosocial exposure, which may lead to negative stress. Mental load in relation to computer use has been found to increase muscle activity (Lundberg et al., 1999; Rissen et al., 2000; Sandsjo et al., 2000; Sjogaard et al., 2000; Wahlstrom et al., 2002) and to be a risk factor for neck pain (Ariens et al., 2001b).

Possible effects on musculoskeletal outcomes with a neutral hand position in computer mouse use

In *Paper II* the mouse design influenced biomechanical events and perceived exertion and comfort. A decreased muscle activity in the extensor muscles in the forearm and in the first dorsal interossei muscle in the hand, and a decreased extension and deviation in the wrist were seen during work with the vertical mouse (neutral hand position).

High muscular load in the forearm muscles, like high repetitiveness in wrist movements and extreme postures in the wrist, has been associated with musculoskeletal disorders (Marras and Schoenmarklin, 1993; Ranney et al., 1995; Bernard, 1997; Viikari-Juntura and Silverstein, 1999). Low levels of muscular rest for the forearm extensor muscles have been found during traditional mouse operations (Bystrom et al., 2002). Extreme wrist extension has been reported as a risk factor during intensive traditional mouse use due to high pressure in the carpal tunnel (Keir et al., 1999) and minimizing ulnar deviation appear to reduce risk of arm/hand outcomes. According to this it is likely that a neutral hand position in work with a computer mouse can decrease the risk of musculoskeletal disorders in intensive computer mouse use. This is also in agreement with a longitudinal study (Aarås et al., 1999), which showed that work with the vertical mouse used significantly reduced the pain in the neck, shoulder, forearm and hand for VDU workers who experienced pain in these areas.

Possible musculoskeletal outcomes when text entering on a mobile phone

In *Paper III and IV* phone size and task affected the biomechanical events. When the young adults used their own phone, which was smaller, the median and peak muscle activity in the FDI was higher (*III*) and the thumb was less abducted (*IV*) compared with using the standard phone. When text entering, the muscle activity was higher in four of the six muscles compared to when talking.

In *Paper III and IV* the individual factors gender, working technique and probably anthropometry affected the biomechanical events. Females had higher muscle activity levels in the extensor muscles in the forearm and in the abductor pollicis longus compared to males (*III*). Furthermore, females tended to work in greater thumb abduction, to move their thumbs with higher velocities and to have fewer pauses in the thumb movements which could explain the higher muscle activity in the extensor muscle and the abductor pollicis longus (*III*). The differences in muscle activity and thumb abduction may be explained by differences in anthropometry between females and males. The higher muscle activity in the extensor muscle and the thumb abductor may have resulted in the found larger changes in rated perceived exertion (detect sensation) in the hand for females (*IV*). Sitting or standing affected the muscle activity in the trapezius and the thumb abduction (*III*). This higher muscle activity was probably caused by a lack of arm support in the standing position. In *Paper IV* forearm support affected muscle activity in the trapezius, one or two hands grip and the observed velocity in the thumb movements affected the muscle activity in the extensor muscle in the forearm, and one or two thumbs press technique affected the velocity and the pause pattern in the thumb movements.

In *Paper IV* the young adults with musculoskeletal symptoms had different working techniques than those without symptoms. It was more common in the group with symptoms to sit with the head bent forward, to sit without forearm support, to sit without back support, and to enter text with one rather than two thumbs compared to the group without symptoms.

In *Paper III* the young adults with musculoskeletal symptoms had different muscle activity levels in the trapezius and the abductor pollicis longus, and different velocity and pause pattern in the thumb movements compared to those without symptoms. These differences in biomechanical events could be explained by the differences found in working techniques (*IV*).

Due to the cross-sectional design of the study in *Paper II, III and IV* we can not draw any causal conclusions of associations between any exposure and musculoskeletal outcomes.

4.5 Methodological considerations

Most of the students interviewed in *Paper I* associated IT with computers and the Internet, but also with mobile phones. This has probably influenced the results. Most of what they expressed was related to these technologies, which is natural because it was these technologies they mainly used. The sample of subjects interviewed is not necessarily representative of young adults in general. The subjects were selected to represent different kinds and amounts of IT use. The age group was selected because of their entrance in working life would occur within a couple of years. We are all influenced by people in our surroundings, such as friends and family, teachers, the media etc. It is uncertain whether it really was their own experience the study group expressed, or whether their attitudes were influenced by the surrounding environment, but both are equally important from a health perspective. The subjects were instructed to speak freely about their own experience of IT use. The interviewers felt that the subjects talked freely about their experience and did not in any essential way adjust their narratives according to what they thought we wanted to hear.

The analysis continued until saturation was achieved. However, we adopt the constructivist's view of saturation, i.e. a more elastic concept related to time and context (Charmaz, 2000). A constant comparison between different aspects of the raw data was made in every step of the analysis, and discussed within the research group in order to achieve credibility. The theoretical model of young adults' experience of IT use can be considered to have reliability since similar relationships between phenomena frequently emerged from the data (Dellve et al., 2002).

In *Paper II* an electrogoniometer was used to measure wrist positions and movements. Forearm pronation/supination has been shown to affect wrist goniometer measurement accuracy (Hansson et al., 1996; Buchholtz and Wellman, 1997; Johnson et al., 2002). One study (Jonsson and Johnson, 2001; Johnson et al., 2002) has evaluated and compared the crosstalk and off-set error during use of two different electrogoniometer systems including the system used in the present study. The goniometers were calibrated with the subject's wrist in 90° pronation as in the present study. Their study showed that the measured

values differ from the true values. The true value can be calculated by adding the error shown in their study to the measured value. According to this, if we perform the calculation of the effect for one typical subject, represented by the group median values, for a representative wrist position (the 50th percentile of flexion/extension and deviation) the effect of the forearm supination/pronation in the present study would be in pronated hand position (90° pronation) +1° in flexion/extension and +4° in deviation. Hence, the true value for the 50th percentile should be 24° extension and 9° deviation. In neutral hand position (0° supination/0° pronation) the effect would be -9° in flexion/extension and +5° in deviation. Hence, the true value for the 50th percentile should be 9° extension and 1° deviation. If we consider this effect of forearm supination/pronation the difference in wrist extension will be larger and the wrist position in the deviation plane will be more neutral compared to the measured values presented in the present study in work with the neutral hand position compared to the pronated hand position.

Since the EMG analysis program only provided EMG results in integers units, there is an uncertainty in the size of the calculated differences of $\pm 1\%$ MVE/RVE. This might affect the results, especially where the differences are small, since only 19 subjects were studied.

Since the standardised task only consisted of text editing, the results of this study can only be assumed to be valid for this kind of computer work.

It is possible that the time of practice with the prototype mouse was too short for some of the subjects. A longer time of practice would perhaps have given other results, above all regarding productivity, perceived comfort and preference. However one study (Straker et al., 2000) has shown the same results with a vertical mouse even after two weeks of practice. It is also possible that 15 minutes of work with each mouse was too short. A longer time of measurement would perhaps have given other results, especially regarding perceived exertion.

We are fully aware of the difficulty in measuring thumb movements due to the complexity of its function with the principal motions flexion/extension, adduction/abduction and opposition.

In *Paper III and IV* the proximal phalange of the thumb was used to measure thumb position/orientation relative to the forearm. However, the thumb is composed of more than just the proximal phalange and articulates about multiple joints and bones. As a result, the electrogoniometer was measuring over three joints (the MCP-joint, the CMC-joint and the radiocarpal joint), so it was possible that the measured position/orientation at the proximal phalange could have contributions from more than one joint. However, it has been shown that electrogoniometers has validity for measuring simple thumb movements and that electrogoniometers can provide quantitative information on thumb movements during thumb intensive activities such as text entering on a mobile phone (Jonsson et al., 2007).

The measures of muscle activity in *Paper III and IV* do not cover all muscles in the neck/shoulder, forearm and thumb area that can be affected by different

postures and performance techniques. The results of differences in muscle activity are influenced by our choice of which muscles to measure. Since we used surface electrodes to register the muscle activity we were limited to superficial muscles. Choice of other muscles may have shown other differences in physical load due to different postures and performance technique.

The order between the different tasks in Paper III was randomised. At the end of the trial the subjects performed the standardised task once again. In order to evaluate the test-retest reliability of the muscle activity in the trapezius a matched-pairs analyse was conducted (using the matched pairs function in the analyse program JMP). The mean of the differences between the two measures was 0.6 %RVE with higher value for the second measure. In comparison with the level of the muscle activities in the trapezius muscle during the tasks this is a small difference and a difference of no clinical importance. The limits for the confidence interval for the mean difference were -1.85 to 3.07 %RVE, but even this difference is consider to be of no clinical importance.

5. Conclusions

General conclusions

Computer mouse design has an effect on the muscle activity in the forearm and hand, and on wrist posture and movements. The individual factors working technique and gender have an effect on muscle activity and thumb movements when entering text on a mobile phone. Furthermore, there were differences in working technique, muscle activity, and thumb movements between young adults with musculoskeletal symptoms and those without symptoms.

Specific conclusions:

The young adults experienced information and communication technology (ICT) as a tool for being and acting in the present, to be social, efficient and independent with almost unlimited opportunities but also risks. The believed physical health risks were related to long duration of use, uncomfortable/awkward work postures, and less physical activity. (*Paper I*)

Work with a vertical computer mouse (neutral hand position) decreased the muscle activity in the extensor muscles in the forearm and in the first dorsal interossei muscle in the hand, and the ulnar deviation in the wrist compared to a traditional mouse (pronated hand position). (*Paper II*)

Postures (sitting or standing) and the type of mobile phone task affect muscle activity and thumb positions during mobile phone use. The young adults with musculoskeletal symptoms had lower muscle activity levels in the abductor pollicis longus and tended to have higher velocity and to have fewer pauses in the thumb movements compared to those without symptoms. Females had higher muscle activity in the extensor muscle in the forearm and the abductor pollicis longus when text entering compared to males (*Paper III*)

It was more common in the group with musculoskeletal symptoms to sit with the head bent forward and to sit without forearm and back support compared to the group without symptoms. Furthermore, use of forearm support decreased the muscle activity in the trapezius muscles. (*Paper IV*)

Future research

Considering the widespread use of information and communication technology not only in the working population but especially among children and adolescents it is of great importance to continue to identify factors and conditions related to this use that can influence their future health. Further evaluation is needed to confirm whether some working techniques among ICT users are risk factors for developing musculoskeletal disorders. Today there are a lot of ergonomic guidelines aimed to prevent musculoskeletal disorders, however with rather weak scientific bases. Still, limits for safe exposure are missing. There is an urgent need of establishing safe exposure limits in ICT use in order to prevent musculoskeletal disorders.

Summary

Physical exposure, musculoskeletal symptoms and attitudes related to ICT use

High prevalence of musculoskeletal symptoms/disorders in neck and upper extremities are reported among computer users despite the low physical loads associated with this use.

Considering the widespread use of information and communication technology together with mobile phones becoming more and more like small computers with full-functioning, small keyboards, it is of importance to identify the factors and conditions related to this use, that influence our health.

The overall aim of this thesis was to obtain new ergonomic knowledge of the physical exposure associated with the use of information and communication technology with emphasis on small keyboards, computer mice and young adults.

Specific research questions were:

- What experiences, attitudes and health beliefs are expressed among young adults related to their ICT use?
- Are there any differences in physical exposure when working with a vertical computer mouse (neutral hand position) compared to a traditional flat computer mouse (pronated hand position)?
- Are there any differences in thumb movements and muscle activity (a) across various mobile phone tasks (b) between young adults with and without musculoskeletal symptoms in the upper extremities and (c) between gender?
- Are there any differences in postures and working techniques between young adults with and without musculoskeletal symptoms in the upper extremities when using a mobile phone for text entering? Are there differences in muscle activity and thumb movements between different postures and working techniques?

This thesis comprises both quantitative and qualitative study designs. *Paper I* is an interview study with young adult ICT users. A qualitative approach was used, in which the analysis of data was performed with the grounded theory method with a constructivist approach. *Paper II* is a comparative experimental study which evaluated muscle activity and wrist postures/movements, perceived comfort, perceived exertion and productivity among experienced computer users during work with a traditional (pronated hand position) and a vertical (neutral hand position) computer mouse. *Paper III and IV* are lab-based experimental studies with young adults with and without musculoskeletal symptoms from neck and/or upper extremities, in which thumb movements, muscle activity, perceived exertion, postures and working techniques when entering text on a mobile phone were evaluated.

In *Paper I* the main findings were the young adults' two-sided experience of information technology as a tool for being and acting in the present, to be social,

efficient and independent with almost unlimited opportunities but also risks. The believed physical health risks were related to long duration of use, uncomfortable/awkward work postures, and less physical activity. In *Paper II* it was showed that work with a vertical computer mouse (neutral hand position) decreased the muscle activity in the extensor muscles in the forearm and in the first dorsal interossei muscle in the hand, and the ulnar deviation in the wrist compared to a traditional mouse (pronated hand position). In *Paper III and IV*, when text entering on a mobile phone, higher muscle activity in the thumb, the extensor muscles in the forearm and the left trapezius muscle was found compared to talking on the phone. Standing increased the trapezius muscle activity compared to sitting. The young adults with musculoskeletal symptoms had lower muscle activity in the abductor pollicis longus and tended to have higher velocity and fewer pauses in the thumb movements compared to those without symptoms. Females had higher muscle activity in the first dorsal interossei and the abductor pollicis longus compared to males. It was more common in the group with symptoms to sit with the head bent forward, to sit without forearm and back support and to enter text with one thumb rather than two compared to those without symptoms. Use of forearm support decreased the muscle activity in the trapezius muscles. Use of one hand grip increased the muscle activity in the extensor muscles in the forearm. High observed velocity in the thumb movements was associated with higher productivity and increased muscle activity in the extensor muscles in the forearm compared to low or moderate velocity.

In conclusion, this thesis shows that computer mouse design has an effect on the muscle activity in the forearm and the hand, and on the wrist positions and movements. It also shows that the individual factors working technique and gender have an effect on muscle activity and thumb movements when text entering on a mobile phone. Furthermore, there were differences in working technique, muscle activity, and thumb movements between the young adults with musculoskeletal symptoms in the neck and upper extremities and those without.

Sammanfattning

Fysisk exponering, muskuloskeletala symtom och attityder relaterat till ICT användning

Muskuloskeletala symtom/besvär i nacke och övre extremiteterna rapporteras vara vanliga bland datoranvändare. Den utbredda användningen av informations- och kommunikationsteknologi (ICT) och utvecklingen av mobiltelefonerna till att alltmer likna små datorer med små tangentbord gör det viktigt att identifiera faktorer och förhållanden, relaterade till denna användning, som påverkar vår hälsa.

Det övergripande syftet med denna avhandling var att få ny ergonomisk kunskap om den fysiska exponeringen vid användning av informations- och kommunikationsteknologi, med särskild inriktning på små tangentbord, datormöss och unga vuxna ICT användare.

Specifika forskningsfrågor var:

- Vilka erfarenheter, attityder och upplevelser av hälsokonsekvenser relaterat till deras ICT användning uttrycks bland unga vuxna?
- Finns skillnader i fysisk exponering vid användning av en traditionell datormus (pronerad handställning) jämfört med en vertikal datormus (neutral handställning)?
- Finns skillnader i muskelaktivitet och tumrörelser (a) vid olika uppgifter på mobiltelefon? (b) mellan unga vuxna med och utan muskuloskeletala symtom i nacke och övre extremiteterna? och (c) mellan män och kvinnor?
- Finns skillnader i kroppsställningar och arbetsteknik hos unga vuxna med och utan symtom när man skriver textmeddelanden på mobiltelefon? Finns skillnader i muskelaktivitet och tumrörelser mellan olika kroppsställningar och arbetstekniker?

Denna avhandling innehåller både kvalitativ och kvantitativa studiedesigner. *Studie I* är en intervjustudie med unga vuxna ICT användare. En kvalitativ ansats användes och dataanalysen utfördes enligt grounded theory metoden med ett konstruktivistiskt synsätt. *Studie II* är en jämförande experimentell studie som utvärderade muskelaktivitet med emg (elektromyografi), handledsställningar/handledsrörelser med elektrogoniometri, upplevd ansträngning och komfort samt prestation hos vana datormusanvändare vid användning av en traditionell horisontell datormus som greppas med en pronerad (inåtroterad) handställning och en vertikal datormus som greppas med neutral handställning. *Studie III och IV* är experimentella studier, med unga vuxna med och utan muskuloskeletala symtom i nacke och övre extremiteterna, som utvärderade tumpositioner/tumrörelser med elektrogoniometri, muskelaktivitet med emg, upplevd ansträngning med skattningsskala, kroppsställningar och arbetsteknik med observationsprotokoll vid textinmatning (SMS) på mobiltelefon.

Studie I visade att de unga vuxna upplevde ICT som ett verktyg för att vara och agera i nätet, att vara sociala, effektiva och oberoende med nästan obegränsade möjligheter men också risker. De upplevda fysiska hälsoriskerna var relaterade till långvarig användning, obekväma/olämpliga arbetsställningar och minskad fysisk aktivitet. *Studie II* visade att arbete med den vertikala datormusen (neutral handställning) minskade muskelaktiviteten i underarmens extensormuskler och i första bakre interosseusmuskeln i handen samt ulnardeviationen i handleden jämfört med den traditionella musen (pronerad handställning). *Studie III och IV* visade att muskelaktiviteten var högre i tummen, i underarmens extensorer och i vänster trapeziusmuskel vid textinmatning (SMS) på mobiltelefon jämfört med samtal på telefonen. Stående textinmatning ökade muskelaktiviteten i trapeziusmusklerna. De unga vuxna med muskuloskeletala symtom hade lägre muskelaktivitet i tummens långa abduktormuskel (abductor pollicis longus) och tenderade att ha högre hastighet och färre pauser i sina tumrörelser jämfört med dem utan symtom. Kvinnor hade högre muskelaktivitet i handens första dorsala interosseimuskel och i tummens långa abduktormuskel jämfört med män. Det var mer vanligt i gruppen med symtom att sitta med huvudet böjt framåt, att sitta utan att avlasta underarmarna, att sitta utan ryggstöd och att skriva in text med en tumme hellre än två jämfört med dem utan symtom. Avlastning av underarmarna minskade muskelaktiviteten i trapeziusmusklerna. Användning av enhandsgrepp ökade muskelaktiviteten i underarmens extensormuskler. Hög observerad hastighet i tumrörelserna var associerad med högre muskelaktivitet i underarmens extensormuskler jämfört med låg eller måttlig hastighet.

Sammanfattningsvis visar denna avhandling att datormusdesign påverkar muskelaktiviteten i underarm och hand samt handledsställningen och handledsrörelserna. Den visar också att individfaktorerna arbetsteknik och kön påverkar muskelaktivitet och tumrörelser vid textinmatning (SMS) på mobiltelefon. Dessutom fanns skillnader i arbetsteknik, muskelaktivitet och tumrörelser mellan unga vuxna med muskuloskeletala symtom i nacke och övre extremiteter och de utan symtom.

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