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Physical load in computer mouse work

Working technique, sex and stress aspects

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List of abbreviations

CI	Confidence interval
CWT	Color word test
DBP	Diastolic blood pressure
ECU	Extensor carpi ulnaris muscle
ED	Extensor digitorum muscle
EMG	Electromyography
FDI	First dorsal interossei muscle
HR	Heart rate
HRV	Heart rate variability
MPF	Mean power frequency
MVC	Maximal voluntary contraction
MVE	Maximal voluntary electrical activity
n	Number of subjects
ROM	Range of motion
RPE	Rating of perceived exertion
RVC	Reference voluntary contraction
RVE	Reference voluntary electrical activity
SBP	Systolic blood pressure
SD	Standard Deviation
VDU	Visual Display Unit

List of papers

This licentiate thesis is based on the following three publications, which will be referred to by their Roman numerals.

I Wahlström J, Svensson J, Hagberg M & Johnson PW (2000) Differences between work methods and gender in computer mouse use. *Scand J Work Environ Health*, 26(5), 390-397.

II Lindegård A, Wahlström J, Hagberg M, Hansson G-Å, Jonsson P & Wigaeus Tornqvist E The impact of working technique on physical loads - An exposure profile among newspaper editors. (submitted).

III Wahlström J, Hagberg M, Johnson PW, Rempel D & Svensson J Influence of time pressure and verbal provocation on physical load, physiological and psychological reactions during work with computer mouse. (submitted).

Contents

Introduction

During the last two decades the number of workers with Visual Display Units (VDUs) has increased. In 1999 approximately 60% of the Swedish work force used a VDU in their occupation (43), and these figures are believed to be increasing. Since the late 1980 the use of non-keyboard input devices has increased rapidly and today the market is filled with a large number of different non-keyboard input devices, but the most widely used is still the computer mouse.

Musculoskeletal symptoms among VDU operators in the Swedish work force are common (9), and the reported cases of musculoskeletal illness where work using computers was given as the reason for the morbidity increased by 20 % from 1992 to 1998 (56). Musculoskeletal symptoms of VDU operators are believed to have a multifactorial etiology. Non-neutral wrist, arm and neck postures, work station design, duration of computer work and psychological and social factors, such as time pressure and high perceived work load, are believed to interact in the development of these symptoms (5; 10; 41; 45). Several studies have suggested that an increased prevalence of upper extremity musculoskeletal symptoms may be associated with increased computer mouse use (12; 20; 29).

To understand the associations between physical and psychosocial load, and performance, comfort and musculoskeletal disorders better, there is still a need for more precise and quantative assessment of the exposure. There are in general three different ways of assessing the exposure: (1) subjective judgements, (2) systematic observations and (3) direct measurements. These three methods are generally in order of increasing precision (49; 52).

There is also a need to define terms and definitions. Physical load is here defined as factors relating to biomechanical forces generated in the body. In the literature, this has also been defined as ‘mechanical exposure’, to indicate that the full working environment is not considered (i.e. lighting, noise, thermal environment, work organisation, psychosocial factors etc.) (54). Psychosocial load is here defined as factors relating to the individual perception of: demands, decision latitude and social support. A mental stressor is considered equivalent to psychosocial exposure in the workplace. Stress is the nonspecific response to a stressor, and both physical and psychosocial load may act as stressors (Figure 1).

In a review of epidemiological findings on VDU work and musculoskeletal symptoms, Punnett & Bergqvist (41) stated that women appear to consistently report more neck and upper extremity symptoms than men. No definite explanations were found in the reviewed studies but differences in household work and childcare, work situation differences and constitutional differences were mentioned as possibilities. In a more recent review, Tittiranonda and colleagues (45) suggested that differences in anthropometrics might cause women to work in more extreme postures or at higher relative muscle forces than men.

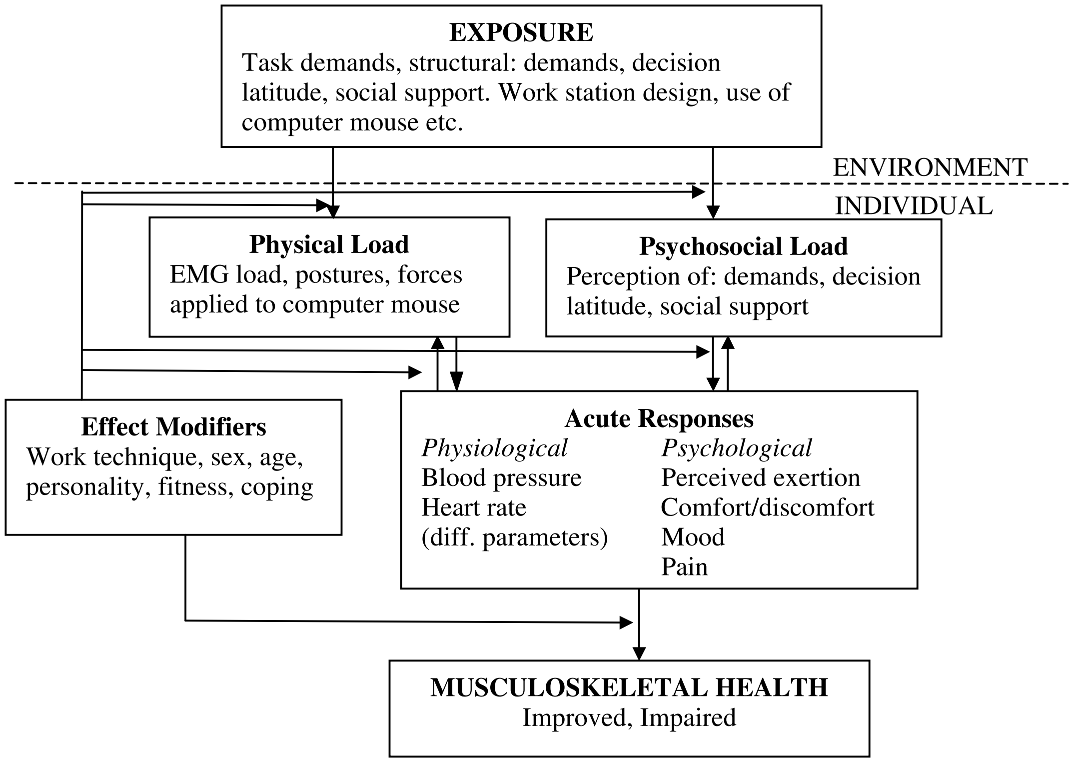

Figure 1. Model to indicate the relationship between exposure to VDU work and musculoskeletal health, modified from Westgaard & Winkel (54). Intermediate stages in this relationship are physical load (biomechanical forces) and psychosocial load to meet these demands, and short-term physiological and psychological responses. The acute responses listed in this model are only a subset of possible responses to physical and psychosocial load.

Differences in working technique when performing VDU work have not been well documented. However, inter-individual differences in working technique have been observed within other occupations (15; 44). There are two basic elements that characterise working technique: the method or systems of methods used to carry out a work task and the individual motor performance of the work task (33). Here the 'method' is defined as a way of operating the computer mouse or the keyboard, and the 'individual performance' is defined as individual differences in the performance (i.e. lifting of the shoulders, sitting in a tense position). Previous studies have shown that differences in mouse-location and work with or without forearm support affect the physical load in terms of muscle activity (1; 30).

Experimental studies have shown that mental stress can induce muscle activity (8; 35; 37; 46-48). Some of these experimental studies (8; 35; 37) have used the Stroop Color Word Test (CWT) as a stressor and the outcomes have been physical load (i.e. muscle activity of trapezius muscles) and acute physiological responses (i.e. heart rate and blood pressure). Other studies have used a complex two-choice reaction-time task (46-48) and focused on the muscle activity in the trapezius muscle but also measured muscle activity in other body regions. The CWT and the two-choice reaction-time task requires minimal physical activity during performance and are not easily transferred to real work situtions using a VDU or a computer mouse. It is hypothesised that other physical load factors than muscle activity (i.e. wrist movements and forces applied to the computer mouse) may be affected when working under stressful conditions.

Aim

The overall aim of this thesis was to evaluate how working technique, sex and stress influenced the physical load during computer mouse work. The specific research questions were:

Do different computer mouse operating methods or sex have an effect on physical load and acute psychological responses when using the computer mouse in a laboratory setting?
Do different working techniques or sex have an effect on physical load and acute psychological responses when working with a VDU in a field setting?
Do time pressure and verbal provocation (stress conditions) have any effect on physical load and acute physiological and psychological responses during computer mouse work?

Subjects and methods

Subjects

Studies I & III
Thirty subjects, 15 men and 15 women, volunteered to participate in the study. Subjects from various occupations were recruited from Sahlgrenska University Hospital, Göteborg, Sweden, and they participated in the experimental session during paid work time. The mean age was 34 (range 18-52) years for the men and 39 (range 22-60) years for the women. The mean height of the men was 181 (range 172-193) cm and for the women 167 (range 157-183) cm. Mean body mass index (BMI) of the men was 22.9 (range 19.9-27.2) and of the women 22.9 (range 19.0-28.3). The subjects were all experienced mouse users with a mean experience of 51 (range 6-144) months of mouse use at work or at home, and they all used their right hand to operate the computer mouse. Before the study, subjects were given written and verbal information explaining the experimental procedures. None of the subjects used medication for hypertension or any other cardiovascular disease and they were all free of upper extremity musculoskeletal disorders according to an interview.

The studies were approved by the ethical committee.

Study II
The study group consisted of all personnel in a newspaper editorial department who according to the supervisor had editing tasks as their main job task. Altogether 36 employees fulfilled the inclusion criteria. Two men and two women were excluded due to long-term sick-leave or temporary work at another newspaper. The mean age was 44 (range 26-57) years for the men and 42 (range 28-55) years for the women. The mean height of the men was 184 (range 175-192) cm and of the women 168 (range 154-175) cm. All the participants worked with the same editing program and had similar workplace design with easily adjustable chairs and working tables. The subjects were divided into subgroups according to sex (14 men, 18 women) and working technique.

The study was approved by the ethical committee.

Procedures

Studies I & III
An adjustable VDU work station was set up and the subjects adjusted the table and chair to fit their needs. A Macintosh computer with a 13-inch colour display and 101-key keyboard was used. Typically, subjects adjusted the chair so their legs were well supported with their feet resting flat on the floor; the table was adjusted so that the mouse and keyboard were approximately at elbow level and the monitor was at a fixed height above the work-surface.
In this experimental setting, the subjects performed text editing using a standardised text-editing task (Figure 2). The text-editing task consisted of eight paragraphs each containing five lines of 12-point Courier text. In each line, at a random location, one to four characters were highlighted using bold and coloured text. Subjects were instructed to highlight the coloured characters with the mouse and then delete the characters by hitting the delete key on the keyboard with the mouse-using hand.

TEXT-EDITING TASK

Lo**o**king back to all that has occurred to me since that
eventful day, I am scar**c**ely able to believe in the reality
of my adventures. They were truly so wonderf**u**l that even
now I am b**e**wildered when I think of them. My uncle was a
German, having married my mothers s**i**ster, an English woman.

Being very much attached to his fath**erl**ess nephew, he
i**nvi**ted me to study under him in his home in the
father**lan**d. This home was in a large town, and my uncle a
professor of philosophy, chemistry, geology, minera**log**y,
and many other o**log**ies. One day, after passing some hours

Figure 2. Standardised text-editing task that subjects performed (Studies I & III). In the original text the bold text was also highlighted using a coloured font.

Study I. Subjects were instructed by the same person to use three different methods to operate the mouse: 1) a wrist-based method (WB), where the forearm was fully supported on the desk and the mouse was moved by lifting and sweeping the mouse across the mouse-pad using the wrist; 2) an arm-based method (AB), where only the wrist was supported on the work-surface and the mouse was moved using movements initiated from the shoulder, and 3) their own method (Own). Before the study, in their own office, subjects were instructed on how to perform the different methods and asked to practice and familiarise themselves with using each method. On the day of the measurement, subjects practised at the experimental work-site to familiarise themselves with the equipment and to confirm that they performed the different computer mouse operating methods correctly. All subjects used their own method first and then the sequence with the WB and AB methods was arranged in a Latin square.

Study III. This experiment consisted of subjects working without and with time pressure and verbal provocation. In the control situation (same as when using their own method in Study I), subjects edited eight five-line paragraphs of 12-point Courier text (2 pages) with no time constraints imposed. Approximately 10 minutes later, in the stress situation, subjects were asked to perform the same task but do twice the amount of work (edit 4 pages). Here, subjects were asked to work as "fast as possible" and a time constraint of 40 seconds was imposed to complete each page of text editing. If the subjects could not complete the page of text, they were verbally prompted to use the "Page Down" key on the keyboard and continue with the text-editing task on the next page. Subjects were also verbally provoked every 15th second (e.g. "hurry up", "come on, you can do it faster" etc). The verbal provocation was given by the same test leader throughout the experiment. To assess the stability of the variables and the test/retest reliability, a subset of 15 subjects performed the control task a second time at the end of the experiment.

Study *II*

All measurements were made at the beginning of the work shift. First the subjects answered a questionnaire about VDU exposure (amount of computer/keyboard/mouse work etc), psychosocial load (job demands, decision latitude, social support etc) and about musculoskeletal and psychosomatic symptoms, and the duration of the symptoms. Before the measurements the subjects had been randomised into two groups. One group started with 10 minutes of standardised text editing (same task as in Studies I & III) at a separate work station. The other group started with 15 minutes of ordinary editing work. The two work tasks (ordinary work and standardised task) were performed approximately 15 minutes after one another, due to the time it took to move the equipment to the next work station.

Methods

Physical load

To assess the physical load (i.e. EMG, forces, postures) and acute responses to the physical load (i.e. ratings of perceived exertion and comfort) a variety of different measurement strategies was used (Figure 3a and 3b). EMG was used to assess muscle activity, an instrumented mouse to measure forces applied to the sides and button of the computer mouse, electrogoniometers to assess wrist postures and movements, and checklists to assess working methods and working technique. Subjects also rated perceived exertion (RPE) and comfort to assess the acute psychological responses to the physical load.

Figure 3a and 3b. Showing the position of the EMG electrodes, the electrogoniometer and the force-sensing mouse in the laboratory studies (Studies I & III).

Muscle activity

Studies I & III. Muscle activity from four separate muscles was recorded at 1 kHz using a commercial EMG system (ME 3000P, Mega Electronics Ltd, Koupio, Finland). The muscles examined were the right first interossei (FDI), the right extensor digitorum (ED) and the pars descendent of the right and left trapezius muscles. The electrodes for the FDI and ED were placed as recommended by Perotto et al. (40), and for the trapezius as recommended by Mathiassen et al. (39). Self-adhesive surface electrodes (M-00-S; Medicotest AS, Ølstykke, Denmark) were placed in pairs with a 35 mm inter-electrode distance. For the FDI muscle, the electrodes were modified (cut) resulting in an inter-electrode distance of 25 mm. Before attaching the electrodes, the skin was dry shaved and cleaned with alcohol. At the beginning of the recordings the subjects performed standardised maximal voluntary contractions (MVC) to obtain the maximal voluntary electrical activity (MVE) of the FDI and the ED. MVE in the FDI and the ED was set with maximum static contraction against manual resistance for a minimum of 3 seconds. Reference voluntary electrical activity (RVE) in the right and left trapezius muscles was set with the shoulders flexed 90°, thumbs up and a 1 kg dumbbell held in each hand for a minimum of 3 seconds (Figure 4). A 3-second sampling window was used to calculate the average electrical activity during the MVC and reference contractions. The raw data were recorded on-line using a

portable PC and monitored in real time for quality control. Full-wave rectifying and filtering of the EMG signal derived the muscular activity, using a time-constant of 100 ms. Data were analysed using the ME 3000P software version 1.5 (Mega Electronics Ltd, Koupio, Finland). The 50th percentile of the amplitude distribution was calculated for each subject and used to describe muscle activity.
Study II. The equipment, electrode placement and procedures for preparing the skin were the same as described above for Studies I & III. The muscles examined were the ED, extensor carpi ulnaris (ECU) and the upper trapezius muscle on the side operating the computer mouse (mouse trapezius), and the upper trapezius muscle on the side not operating the mouse (non-mouse trapezius). Self-adhesive surface electrodes (N-00-S, Medicotest A/S, Ølstykke, Denmark) were placed with a 20 mm inter-electrode distance. Each subject performed standardised MVC against manual resistance for 5 seconds to obtain the MVE of the ECU and the ED muscles. For the trapezius muscles, a reference voluntary contraction (RVC) was performed with a 1 kg dumbbell in each hand with the hands pronated and shoulders abducted 90° in the horizontal line for 15 seconds to obtain the RVE.

Data were analysed with the Megawin software version 1.21 (Mega Electronics Ltd, Koupio, Finland). Full-wave rectifying and filtering of the EMG signal derived the muscular activity, using a time-constant of 125 ms. MVE for ED and ECU was calculated using a 1-second moving average and the 1-second window with the highest average EMG-activity was used as the MVC. The RVE for the trapezius muscles was calculated using a 10-second moving average and the 10-second window with the highest average EMG-activity was used as the RVC. The 50th percentile of the amplitude distribution was calculated for each subject and used to describe the muscle activity. For analysing gap frequency and muscular rest of the trapezius muscles, a threshold level of twice the individual noise level (range 1.9-2.4 μV) was calculated for each subject. Muscular rest was defined as the summed duration of the gaps, relative to the total duration of the recording. The gap duration time was set to $\geq$ 125ms (18).

Figure 4. The posture used to assess the reference voluntary electrical activity (RVE) for the trapezius muscles in Studies I & III.

Forces applied to the computer mouse
To measure the forces applied to the sides and button, a force-sensing Apple ADBII mouse was used. The force-sensing mouse was fully operational and similar in weight, feel and appearance to an ordinary Apple ADBII mouse. The design and measurement accuracy of the force-sensing mouse has been validated, described, and discussed in detail elsewhere (23). A portable PC instrumented with a PCMCIA data acquisition card (National Instruments, DAQCard 700, Austin, Texas, USA) was used to collect and store the force data. The force signals from the mouse were amplified using a portable amplifier (Model 1210, FFA, Bromma, Sweden) and stored at 60 Hz on the hard disk of the computer. The force data were analysed using a program written in Labview 4.0 (National Instruments, Austin, Texas, USA). The program identified each time the mouse was used, called a grip episode, and kept track of idle periods, defined as any period the mouse was not used for one second or longer. For each grip episode, the program calculated the mean force, peak force and grip duration.

Maximum voluntary forces applied to the mouse
The maximum forces the subjects could apply to the sides and button of the mouse were measured after the experiment. The subjects were asked to apply MVC to the sides and button of an Apple ADBII mouse instrumented with load cells (Pinchmeter, Greenleaf Medical, Palo Alto, California, USA). The subjects were instructed to grip the mouse during the MVC the same way they gripped the mouse during the experiment. The MVC applied to the sides and button of the mouse was measured separately and the data were analysed using a program written in Labview 4.0 (National Instruments, Austin, Texas, USA). Using a 1-second moving average, the program identified the 1-second window with the highest average force and used that value as the MVC. The subjects applied three MVCs to the sides and the button of the mouse and the highest MVC applied to each location was chosen as the subject's MVC. If the difference between the highest and second highest MVC was greater than 10%, additional MVCs were collected to verify a maximum.

Wrist postures and movements
Studies I & III. A two-axis electrogoniometer (Model XM65, Penny & Giles Biometrics, Blackwood, Wales) and a data logger (Model DL 1001, Penny & Giles Biometrics, Blackwood, Wales) were used for recording flexion/extension and radial/ulnar deviation position and movements in the right wrist. The sampling frequency was 20 Hz. The reference (zero) position of the goniometer system was recorded when the subjects sat at the workstation with their arm fully pronated, resting in front of them with their hand pressed flat on the worksurface and in a neutral radial/ulnar position (13). The wrist position and movement data were calculated using an interactive data analysis program (Goniometer Analysis System, Version 1.0; Ergonomic and Research Consulting, Inc.; Seattle WA). The program calculated the mean position, mean velocity, mean power frequency of the power spectrum (MPF) and the range of motion (ROM) for both

flexion/extension and radial/ulnar deviation. MPF is defined as the center of gravity for the power spectrum (17), and the ROM was defined as the difference between the 95^{th} and the 5^{th} percentile of the wrist angles (17).

Study II. A glove, instrumented with two electrogoniometers, and a data logger (Greenleaf Medical, Palo Alto, CA, USA) were used to collect wrist positions and movements in the mouse-operating wrist with a sampling rate of 20 Hz. Calibration was done in four different wrist positions: 45° extension, 45° flexion, 25° ulnar deviation and 15° radial deviation using a calibration fixture (Greenleaf Medical, Palo Alto, CA, USA). The reference position (zero position) was recorded with the hand fully pronated and with the palm of the hand lying flat, in neutral radial/ulnar and flexion/extension positions, in the calibration fixture.

The data were transferred to the hard disc of a computer for subsequent analysis and then treated as described above in Studies I & III.

Checklists

Study I. To characterise subjects' own working methods with the computer mouse, three items from an ergonomic checklist were used: (1) how the forearm and/or wrist was supported (near the elbow at the proximal part of the forearm or distally at the wrist or hand), (2) whether the computer mouse was lifted from the surface and (3) the type of arm movements (whole arm or wrist and/or fingers). To characterise each subject's own method, video recordings were performed simultaneously from two different angles. Two of the researchers independently classified subjects, when using their own method, into one of three different groups (AB, WB or a hybrid (HB) method). If the results of these two persons differed, which occurred only 6 out of 30 times, a third researcher analysed the video recordings and made a final classification. To be categorised as a user of the AB method, subjects could not rest their forearm on the work-surface and had to use their whole arm to move the computer mouse. To be categorised as a user of the WB method, subjects supported their forearm on the work-surface and used wrist movements to repeatedly lift and move the computer mouse.

Study II. The working technique used during ordinary VDU work was observed and classified according to an observation protocol. The subjects' individual working technique was evaluated by an experienced ergonomist according to 9 items (Table 1), and the ergonomist was blinded to the measurement results. The items from the checklist was selected by an expert panel, consisting of six experienced practitioners and researchers in ergonomics. The same panel also developed the score range for each item. An overall working technique score (range 1-25) was then calculated and the higher the score the better the working technique. Before the data analysis, the subjects were divided into three subgroups: good working technique (5 men and 6 women), poor working technique (6 men and 5 women) and an intermediate working technique group (3 men and 7 women). In the analysis of the potential differences between good and poor working technique, the intermediate group was excluded.

Table 1. Items used for classification of working technique. The score range for each item is presented. The overall score ranged between 1 and 25.

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

Ratings of perceived exertion

Studies I & III. The subjects rated perceived exertion (RPE) before the experiment, after the use of each working method and the stress situation using a Borg scale (6) ranging from 6 to 20 which was modified to range between 0 and 14 (55). Subjects rated perceived exertion in five different body locations: neck/shoulder (scapular), right shoulder (upper arm), right forearm, right wrist and right hand/fingers. Before analysing the results, the different body locations were summed and divided into two different categories, proximal (neck/shoulder + shoulder) and distal (forearm + wrist + hand/fingers). The ratings of perceived exertion (difference between perceived exertion after the different registrations and before the experiment) were compared between working methods and between men and women.

Study II. The subjects rated their perceived exertion before and directly after the measurement. They rated perceived exertion in 11 different body locations: neck, shoulders, upper arms, forearms, wrists and hands/fingers on both the mouse-operating side and the non-mouse-operating side using the Borg CR-10 scale (6). Before analysing the results, the different body locations were summed and divided into four different categories, proximal (neck/shoulder + shoulder) on the mouse and the non-mouse-operating side, and distal (forearm + wrist + hand/fingers) on the mouse and the non-mouse-operating side. When analysing the results, the difference between before and after the measurement was used.

Ratings of comfort

After each setting in the laboratory and after the measurement in the field setting, subjects rated their overall comfort on a scale graded from – 4 (poor comfort) to + 4 (excellent comfort) (30).

Physiological and psychological reactions

In the third study (III), subjects were exposed to work under time pressure and verbal provocation. To assess the acute physiological and psychological reactions to these experimental conditions, a set of different measurements were made.

Blood pressure

Systolic and diastolic blood pressure (SBP, DBP) were registered with an ambulatory blood pressure monitor, CardioTens (Medikolt International AB, Skärholmen, Sweden). This equipment has been tested for validity and reliability (3), and the algorithm used in the apparatus was within the recommendations from the Association for the Advancement of Medical Instrumentation (AAMI). SBP and DBP were registered once during the control situation mid-way through the task. During the stress situation, SBP and DBP were measured approximately one minute after the start of the text-editing task.

Heart rate and heart rate variability

Heart rate variability (HRV) and heart rate were measured with the Polar Vantage NV™ heart rate monitor and data were analysed using the Precision Performance software version 2.0 (Polar Electro Oy, Professorintie 5, 90440 Kempele, Finland). The heart rate was registered "beat by beat" and then the data were filtered using an automatic procedure contained in the Polar software system. The low frequency domain (0.04-0.15 Hz) and the high frequency domain (0.15-0.40 Hz) of the HRV power spectrum were calculated using the Polar software system. The low frequency to high frequency ratio (LF/HF ratio) was calculated, together with the mean heart rate. The HF component of the power spectrum reflects parasympathetic activity and the LF component reflects sympathetic activity with vagal modulation and mental stress has been shown to lower HRV and give an increase in the LF/HF ratio (34).

Ratings of mood

To describe mood during work, a Swedish stress/energy questionnaire was used (31; 32). The checklist measures two factors, stress and energy, each comprising six items. Three adjectives within each factor are positively loaded and three are negatively loaded. The following items are included in the stress dimension: (positive) "rested", "relaxed" and "calm"; (negative) "tense", "stressed, and "pressured", and the following in the energy dimension: (positive) "active", "energetic" and "focused"; (negative) "dull", "ineffective" and "passive". The checklist uses a six-point scale (0-5) for each item, ranging from "not at all" to "very much". High values indicate a high stress and energy level, respectively. The means from the two different dimensions were calculated and the ratings were done immediately after each test.

Statistics

The descriptive data are presented as means with standard deviation (SD). In the experimental studies (I & III), the statistical analyses have been performed with parametric statistical methods, and in the field study non-parametric methods have been used.

In the first study (I), the comparisons between methods were made using Tukey adjusted t-tests (paired observations) and likewise adjusted 95% confidence intervals (95% CI) of the differences between means were calculated. Sex comparisons were made using t-tests (two independent groups) and were only performed on the data where subjects used their own method.

In the third study (III), comparisons between the stress and control situation were made using t-tests (paired observations) and 95% CI of the differences between means were calculated. Sex comparisons between the stress and control situation were made using t-tests (two independent groups) with the exception of the HR and LF/HF ratio, where the Wilcoxon rank sum test (non-parametric test for unpaired observations) was used due to drop-outs. In the comparisons of the two control situations, where there were only 15 subjects, the Wilcoxon rank sum test was used.

Due to technical problems in Studies I & III, the results from eight subjects were excluded from heart rate analysis. One female subject was excluded in the analysis of blood pressure, one male subject was excluded in the analysis of wrist postures and the result from another male subject was excluded in the analysis of muscle activity.

In the second study (II), all comparisons of independent groups were made with the Wilcoxon rank sum test, and the exact p-values are presented.

Due to technical problems, one female subject was excluded in the analysis of wrist postures and the result from a male subject was excluded in the analysis of muscle activity.

All statistical analyses were performed using the statistical software JMP, versions 3.2 and 4.0.2 (SAS institute Inc., Cary, NC, USA).

Results

Influence of sex and working method on physical load in an experimental setting

Sex comparisons

Women applied almost twice the force to the button of the mouse, when expressed as %MVC, compared to men (Table 2). No major differences were found when forces were expressed as Newtons. When operating the mouse, women had a greater ROM and tended to work with greater extension and greater ulnar deviation in the wrist compared to men (Table 2). The women also worked with higher muscle activity (%MVE) in the ED and tended to have higher muscle activity in the FDI compared to the men. The sex differences in the left and right trapezius muscles (%RVE) were small and no general trends could be observed.

Women tended to rate proximal perceived exertion higher than the men (mean difference = 0.8, 95 % CI = -1.6 ; 3.2) but the men tended to have higher ratings distally (mean difference = -1.3, 95 % CI = -3.9 ; 1.3). Women performed the task slightly faster (mean difference = -11 seconds, 95 % CI = -31 ; 8) and also produced slightly more errors (mean difference = 0.3, 95 % CI = -0.2 ; 0.8). No differences between the sexes were found in the comfort ratings. The mean (SD) maximum force men applied to the button and sides of the mouse were 60.4 N (14.9) and 98.6 N (22.2), respectively. The mean (SD) maximum force women applied to the button and sides of the mouse were 41.4 N (6.7) and 64.4 N (9.8), respectively.

Table 2. Mean values ± standard deviations (SD) of physical load for men and women, including mean differences and the 95% confidence intervals (95% CI) of the differences. (MVC = maximal voluntary contraction, p 0.50 = 50th percentile of the amplitude distribution, MVE = maximal voluntary electrical activity, RVE = reference voluntary electrical activity).

Physical Load	Sex		Difference		n
	Men	Women	Mean	95% CI	
Forces applied to mouse					30
Side Mean Force (%MVC)	0.82 ± 0.32	0.97 ± 0.40	-0.15	-0.42 ; 0.12	
Side Peak Force (%MVC)	1.44 ± 0.57	1.74 ± 0.80	-0.30	-0.82 ; 0.21	
Button Mean Force (%MVC)	1.20 ± 0.36	1.85 ± 0.63	-0.65	**-1.03 ; -0.26**	
Button Peak Force (%MVC)	2.92 ± 1.15	4.62 ± 1.76	-1.69	**-2.81 ; -0.58**	
Wrist flexion/extension					29
Mean position (°) [a]	25.9 ± 6.0	30.3 ± 5.7	-4.4	-8.9 ; 0.02	
Range of motion (°)	16.8 ± 3.8	21.7 ± 6.0	-4.9	**-8.8 ; -1.0**	
Mean velocity (°/s)	14.5 ± 2.6	14.8 ± 5.8	-0.3	-3.8 ; 3.1	
Mean power frequency (Hz)	0.76 ± 0.16	0.55 ± 0.16	0.21	**0.09 ; 0.33**	
Wrist radial/ulnar deviation					29
Mean position (°), [a]	7.2 ± 5.5	11.2 ± 7.8	-4.0	-9.2 ; 1.1	
Range of motion (°)	15.9 ± 6.3	21.8 ± 8.3	-5.9	**-11.5 ; -0.3**	
Mean velocity (°/s)	8.5 ± 2.9	11.2 ± 4.3	-2.6	-5.4 ; 0.2	
Mean power frequency (Hz)	0.39 ± 0.10	0.40 ± 0.13	0.01	-0.10 ; 0.08	
Muscle activity (p 0.50)					29
First Dorsal Interossei (%MVE)	7.6 ± 6.2	11.3 ± 8.5	-3.6	-9.3 ; 2.1	
Extensor Digitorum (%MVE)	7.6 ± 2.8	11.3 ± 4.2	-3.7	**-6.4 ; -0.9**	
Right Trapezius (%RVE)	30.9 ± 24.1	26.5 ± 15.5	4.5	-10.9 ; 19.8	
Left Trapezius (%RVE)	13.7 ± 15.0	15.8 ± 17.3	-2.1	-14.5 ; 10.3	

[a] Positive values denote extension and ulnar deviation.

Differences between mouse operating methods

When using the WB method, subjects applied higher mean and peak forces (%MVC) to the sides of the mouse compared to the other methods (Table 3).

Table 3. Mean differences and the 95% confidence intervals (95% CI) of the differences in physical load between mouse operating methods. (MVC = maximal voluntary contraction, p 0.50 = 50th percentile of the amplitude distribution, MVE = maximal voluntary electrical activity, RVE = reference voluntary electrical activity).

Physical Load	Comparison	Difference		n
		Mean	95% CI	
Forces applied to mouse				30
Side Mean Force (%MVC)	Own – wrist-based	-0.39	**-0.57 ; -0.22**	
	Own – arm-based	0.08	-0.09 ; 0.25	
	Wrist-based – arm-based	0.48	**0.31 ; 0.65**	
Side Peak Force (%MVC)	Own – wrist-based	-0.66	**-0.99 ; -0.33**	
	Own – arm-based	0.18	-0.15 ; 0.51	
	Wrist-based – arm-based	0.84	**0.51 ; 1.17**	
Button Mean Force (%MVC)	Own – wrist-based	0.23	**0.11 ; 0.35**	
	Own – arm-based	0.06	-0.06 ; 0.19	
	Wrist-based – arm-based	-0.17	**-0.29 ; -0.04**	
Button Peak Force (%MVC)	Own – wrist-based	0.06	-0.26 ; 0.38	
	Own – arm-based	-0.04	-0.28 ; 0.35	
	Wrist-based – arm-based	-0.10	-0.22 ; 0.41	

Wrist flexion/extension				29
Mean position (°)	Own – wrist-based	-0.9	-3.2 ; 1.4	
	Own – arm-based	-6.8	**-9.1 ; -4.5**	
	Wrist-based – arm-based	-5.9	**-8.2 ; -3.6**	
Range of motion (°)	Own – wrist-based	-1.6	-4.2 ; 0.9	
	Own – arm-based	-2.3	-4.9 ; 0.3	
	Wrist-based – arm-based	-0.6	-3.2 ; 1.9	
Mean velocity (°/s)	Own – wrist-based	-1.1	-2.4 ; 0.2	
	Own – arm-based	0.8	-0.5 ; 2.1	
	Wrist-based – arm-based	1.9	**0.6 ; 3.2**	
Mean power frequency (Hz)	Own – wrist-based	0.00	-0.10 ; 0.11	
	Own – arm-based	0.12	**0.01 ; 0.22**	
	Wrist-based – arm-based	0.11	**0.01 ; 0.22**	
Wrist radial/ulnar deviation				29
Mean position (°)	Own – wrist-based	0.4	-1.1 ; 1.9	
	Own – arm-based	0.1	-1.3 ; 1.6	
	Wrist-based – arm-based	-0.3	-1.7 ; 1.2	
Range of motion (°)	Own – wrist-based	-2.2	-5.1 ; 0.7	
	Own – arm-based	3.3	**0.4 ; 6.2**	
	Wrist-based – arm-based	5.5	**2.6 ; 8.4**	
Mean velocity (°/s)	Own – wrist-based	-1.2	-2.5 ; 0.2	
	Own – arm-based	1.4	**0.1 ; 2.8**	
	Wrist-based – arm-based	2.6	**1.3 ; 4.0**	
Mean power frequency (Hz)	Own – wrist-based	-0.02	-0.09 ; 0.05	
	Own – arm-based	-0.01	-0.08 ; 0.06	
	Wrist-based – arm-based	0.01	-0.06 ; 0.08	
Muscle activity (p 0.50)				29
First Dorsal Interossei (%MVE)	Own – wrist-based	0	-1.10 ; 1.10	
	Own – arm-based	-0.45	-1.55 ; 0.65	
	Wrist-based – arm-based	-0.45	-1.55 ; 0.65	
Extensor Digitorum (%MVE)	Own – wrist-based	-0.38	-1.25 ; 0.49	
	Own – arm-based	-0.55	-1.42 ; 0.32	
	Wrist-based – arm-based	-0.17	-1.04 ; 0.70	
Right Trapezius (%RVE)	Own – wrist-based	7.2	-2.4 ; 16.7	
	Own – arm-based	-23.8	**-33.3 ; -14.2**	
	Wrist-based – arm-based	-30.9	**-40.5 ; -21.4**	
Left Trapezius (%RVE)	Own – wrist-based	5.5	-1.2 ; 12.2	
	Own – arm-based	-7.3	**-14.0 ; -0.6**	
	Wrist-based – arm-based	-12.8	**-19.5 ;-6.1**	

Differences between methods were found in all goniometric variables and the most pronounced were the greater extension of the wrist when using the AB method, and higher velocities both in flexion/extension and radial/ulnar deviation movements when using the WB method. Muscle activity in the right and left trapezius muscles was dependent on working method. The highest muscle activity in the trapezius muscle was found when the subjects worked with the AB method and the lowest when working with the WB method. There were only small differences between methods in the FDI and the ED muscles.

Subjects rated their proximal perceived exertion higher after they had used the AB method compared to their own method (mean difference = 4.9, 95% CI = 3.1 ; 6.7), and compared to the WB method (mean difference = 4.0, 95% CI = 2.2 ; 5.7). Distal perceived exertion was rated highest after working with the WB method compared to their own (mean difference = 4.9, 95% CI = 2.4 ; 7.4), and compared to the AB method (mean difference = 2.0, 95% CI = -0.6 ; 4.5). Subjects rated their own method as most comfortable and the AB method as the least comfortable. When using the WB method, the duration to complete the task was longer compared to the subject's own method (mean difference = 37 seconds, 95% CI = 15 ; 58), and compared to the AB method (mean difference = 26 seconds, 95% CI = 5 ; 48).

Based on the video observations used to characterise each subject's own method, 9 subjects used an AB method, 7 used a WB method, and 14 subjects used a hybrid (HB) method (primarily a wrist-based method where the mouse was not lifted off the mouse pad).

Influence of sex and working technique on physical load in a field setting

The amount of time the subjects spent with VDU-work was 73% (range 30-100) for the men and 79% (range 33-100) for the women. During VDU work the men used the keyboard 43% (range 25-60) and the computer mouse/track-ball 54% (range 25-75) of the time. The women used the keyboard 44% (range 20-90) and the computer mouse/trackball 56% (range 10-80) of the time. An ordinary computer mouse was used by 28 of the 32 subjects, and the other four used a trackball.

Sex comparisons

Women worked with higher relative muscle activity in the ED muscle compared to men (Table 4). In the other muscles there were no great differences between the sexes, though the men had somewhat higher muscle activity (Table 4). No great differences were seen in gap frequency or muscular rest in the trapezius muscles between the sexes but the general pattern was that the women had somewhat more EMG gaps and had a larger proportion of muscular rest than the men.

Men tended to work with greater ulnar deviation than women, but in the other wrist positions and movement variables the differences were small (Table 4). There were small differences between the sexes in how proximal and distal perceived exertion changed from before to after ordinary VDU work. The rating of overall comfort showed that the perceived comfort was good or very good and there were only small differences between men and women.

Table 4. Mean values ± standard deviations (SD) of physical load for men (n=14) and women (n=17), including the mean differences and p-values of the Wilcoxon rank sum test. (p 0.50 = 50th percentile of the amplitude distribution, MVE = maximal voluntary electrical activity, RVE = reference voluntary electrical activity).

Physical Load	Sex		Differences	
	Men	Women	Mean	p-value
Muscle activity (p 0.50)				
Extensor Carpi Ulnaris (%MVE)	7.3 ± 3.2	6.9 ± 2.3	0.3	0.73
Extensor Digitorum (%MVE)	5.0 ± 2.4	6.2 ± 1.6	-1.2	**0.04**
Trapezius, mouse side (%RVE)	12.7 ± 10.2	9.4 ± 6.9	3.3	0.51
Trapezius, non-mouse side (%RVE)	10.2 ± 7.9	7.9 ± 8.9	2.3	0.25
Gap frequency (min^{-1})				
Trapezius, mouse side	9.9 ± 6.7	11.8 ± 6.0	-1.9	0.46
Trapezius, non-mouse side	15.6 ± 12.0	18.6 ± 10.4	-3.0	0.50
Muscular rest (% of time)				
Trapezius, mouse side	13.3 ± 14.4	17.2 ± 14.8	-3.9	0.22
Trapezius, non-mouse side	15.6 ± 12.1	19.7 ± 13.0	-4.1	0.37
Wrist flexion/extension				
Mean position (°) [a]	23.2 ± 7.6	21.9 ± 8.1	1.4	0.74
Range of motion (°)	26.2 ± 12.7	30.4 ± 9.7	-4.2	0.27
Mean velocity (°/s)	11.5 ± 5.9	11.8 ± 4.7	-0.4	0.71
Mean power frequency (Hz)	0.33 ± 0.14	0.28 ± 0.06	0.05	0.51
Wrist radial/ulnar deviation				
Mean position (°) [a]	14.2 ± 6.3	8.6 ± 8.8	3.5	0.06
Range of motion (°)	22.5 ± 7.0	23.2 ± 5.4	-0.8	0.43
Mean velocity (°/s)	7.6 ± 2.6	7.9 ± 2.9	-0.3	0.95
Mean power frequency (Hz)	0.24 ± 0.06	0.23 ± 0.06	0.01	0.92

[a] Positive values denote extension and ulnar deviation.

Differences between working techniques

In general, subjects classified as having a good working technique tended to have less muscle activity in all measured muscles compared to the subjects classified as having a poor working technique (Table 5). Subjects with a good working technique tended to have more EMG-gaps and more muscular rest in the trapezius muscle on the mouse-operating side than subjects with a poor working technique.

Subjects with a poor working technique tended to work with their wrist more extended and ulnar deviated than subjects with a good working technique. In the other goniometric variables, the differences were less.

Only small differences were present in ratings of perceived exertion and comfort between subjects with a good and a poor working technique.

Table 5. Mean values ± standard deviations (SD) of physical load for subjects with a good (n=11) and a poor (n=10) working technique, including the mean differences and p-values corresponding to the Wilcoxon rank sum test. (p 0.50 = 50th percentile of the amplitude distribution, MVE = maximal voluntary electrical activity, RVE = reference voluntary electrical activity).

Physical Load	Working technique		Differences	
	Good	Poor	Mean	p-value
Muscle activity (p 0.50)				
Extensor Carpi Ulnaris (%MVE)	5.9 ± 1.9	8.6 ± 3.2	-2.7	**0.03**
Extensor Digitorum (%MVE)	5.4 ± 1.6	6.1 ± 2.8	-0.7	0.34
Trapezius, mouse side (%RVE)	9.5 ± 8.2	15.2 ± 10.2	-5.7	0.24
Trapezius, non-mouse side (%RVE)	9.5 ± 10.2	12.2 ± 7.2	-2.7	0.20
Gap frequency (min^{-1})				
Trapezius, mouse side	11.5 ± 5.9	9.5 ± 7.5	2.0	0.53
Trapezius, non-mouse side	17.2 ± 11.9	14.4 ± 12.3	2.8	0.60
Muscular rest (% of time)				
Trapezius, mouse side	17.1 ± 14.0	11.6 ± 14.6	5.5	0.20
Trapezius, non-mouse side	17.1 ± 14.4	13.2 ± 9.6	3.9	0.65
Wrist flexion/extension				
Mean Position (°) [a]	20.3 ± 6.5	27.0 ± 7.9	-6.6	0.08
Range of motion (°)	26.7 ± 12.4	25.6 ± 10.0	1.1	0.89
Mean velocity (°/s)	11.8 ± 6.7	9.7 ± 3.5	2.1	0.55
Mean power frequency (Hz)	0.31 ± 0.15	0.31 ± 0.10	-0.000	0.62
Wrist radial/ulnar deviation				
Mean position (°) [a]	10.4 ± 8.1	15.6 ± 8.2	-5.2	0.17
Range of motion (°)	23.6 ± 7.4	21.3 ± 5.0	2.2	0.55
Mean velocity (°/s)	8.6 ± 3.7	6.8 ± 2.0	1.7	0.34
Mean power frequency (Hz)	0.23 ± 0.05	0.24 ± 0.07	-0.01	0.86

[a] Positive values denote extension and ulnar deviation.

Comparison of mouse-operating side and non-mouse-operating side

There was a tendency that the subjects worked with higher muscle activity in the trapezius muscle on the mouse-operating side compared with the non-mouse-operating side (mean difference: 1.9, p-value = 0.29). Subjects also tended to rate both proximal and distal perceived exertion higher on the mouse-operating side compared with the non-mouse-operating side (p = 0.11 and 0.20, respectively).

Physical load, physiological and psychological reactions during work under time pressure and verbal provocation

Physiological and psychological reactions

When the stress situation was compared with the control situation, HR, SBP, DBP and the LF/HF ratio increased (Figure 5). Subjects also rated the stress and the energy dimensions on the stress/energy scale higher during the stress situation compared with the control situation (Figure 5). Perceived exertion was rated higher both proximally (mean difference = 2.8, 95% CI = 1.5 ; 4.1) and distally (mean difference = 2.3, 95% CI = 0.7 ; 4.0) after the stress situation.

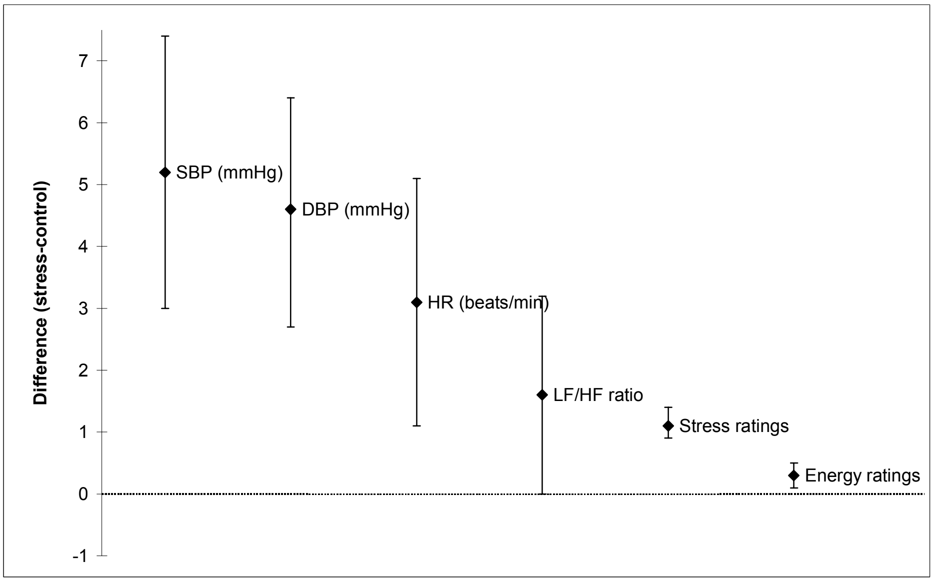

Figure 5. Mean differences in physiological and psychological reactions between stress and control conditions presented with the 95% confidence interval of the differences. (SBP=systolic blood pressure, n=29; DBP=diastolic blood pressure, n=29; HR=heart rate, n=22; LF/HF ratio, n=29; stress and energy ratings, n=30).

Physical load

Subjects applied more force to the sides and button of the mouse during the stress situation compared to the control situation (Table 6). The greatest differences were found in the peak forces applied to the sides and button of the mouse. MPF and the velocity of wrist flexion/extension and radial/ulnar deviation movements were greater during the stress situation compared to the control situation. The only variable that decreased was the ROM. Muscle activity increased in all four muscles during the stress condition (Table 6), with the greatest difference occurring in the right trapezius muscle. However, large inter-individual differences were seen in all measured muscles.

Table 6. Mean values ± standard deviations (SD) of physical load under control and stress conditions, including the mean differences and the 95% confidence intervals (95% CI) of the differences. (MVC = maximal voluntary contraction, p 0.50 = 50th percentile of the amplitude distribution, MVE = maximal voluntary electrical activity, RVE = reference voluntary electrical activity).

Physical Load	Condition		Difference		n
	Stress	Control	Mean	95% CL	
Forces applied to mouse					30
Side Mean Force (%MVC)	1.04 ± 0.47	0.89 ± 0.36	0.15	**0.05 ; 0.25**	
Side Peak Force (%MVC)	1.79 ± 0.92	1.59 ± 0.70	0.20	**-0.0 ; 0.41**	
Button Mean Force (%MVC)	1.64 ± 0.61	1.53 ± 0.60	0.11	**0.03 ; 0.20**	
Button Peak Force (%MVC)	4.59 ± 2.14	3.77 ± 1.69	0.82	**0.53 ; 1.10**	
Grip Duration (s)	2.4 ± 0.4	3.3 ± 0.4	-0.9	**-1.1 ; -0.7**	
Wrist flexion/extension					29
Mean position, (°) [a]	29.0 ± 6.4	28.2 ± 6.2	0.81	**0.1 ; 1.5**	
Range of motion, (°)	18.6 ± 6.0	19.4 ± 5.6	-0.7	-1.9 ; 0.4	
Mean velocity, (°/s)	19.2 ± 6.2	14.7 ± 4.5	4.5	**3.5 ; 5.6**	
Mean power frequency, (Hz)	0.88 ± 0.26	0.65 ± 0.19	0.23	**0.17 ; 0.29**	
Wrist radial/ulnar deviation					29
Mean position, (°) [a]	10.7 ± 7.2	9.3 ± 7.0	1.4	**0.3 ; 2.6**	
Range of motion, (°)	16.4 ± 6.5	19.0 ± 7.9	-2.6	**-4.1 ; -1.1**	
Mean velocity, (°/s)	12.0 ± 4.8	9.9 ± 3.9	2.1	**1.3 ; 2.9**	
Mean power frequency, (Hz)	0.53 ± 0.11	0.40 ± 0.12	0.13	**0.10 ; 0.17**	
Muscle activity (p 0.50)					29
First dorsal interossei (%MVE)	12.4 ± 9.5	9.5 ± 7.6	2.9	**1.8 ; 4.0**	
Extensor digitorum (%MVE)	11.5 ± 4.9	9.5 ± 4.0	2.0	**1.4 ; 2.7**	
Right trapezius (%RVE)	40.2 ± 30.9	28.6 ± 19.9	11.6	**3.9 ; 19.3**	
Left trapezius (%RVE)	19.5 ± 21.7	14.8 ± 16.0	4.7	-2.6 ; 12.0	

[a] Positive values denote extension and ulnar deviation.

Sex comparisons

There were no great differences between men and women in the effects of stress. Women had a greater increase in muscle activity in the FDI (mean difference = 2.3, 95% CI = 0.1 ; 4.4), but in the other measured muscles the differences between women and men were less. The men tended to have a greater increase than women in the forces applied to the button and sides of the computer mouse, with the greatest increase occurring in the mean forces applied to the button (mean difference = -0.1, 95% CI = -0.28 ; 0.06). Only small differences were found between men and women in ratings of perceived exertion and in wrist positions and movements.

There was a tendency for women to have a greater increase in the LF/HF ratio than men (mean difference = 2.3, p = 0.052). Only small differences between the sexes were found in HR, SBP, DBP and mood-ratings.

Stability and test/retest variability

Subjects worked faster during the second control registration and also had a shorter mouse grip duration (Table 7). No statistically significant differences in physiological reactions were found between the first and second control registration. The only physical load variable that differed statistically significantly between the first and second control registration was the mean velocity of the wrist in flexion/extension, as subjects worked with slightly higher velocities during the second control registration (Table 7). However, subjects tended to rate RPE higher and work with higher muscle activity and wrist velocities during the second control registration.

Table 7. Mean values ± standard deviations (SD), in physiological reactions, physical load, ratings of perceived exertion (RPE) and productivity between the first and second control registration, including the mean differences and p-values of the Wilcoxon rank sum test. (MVC = maximal voluntary contraction, p 0.50 = 50th percentile of the amplitude distribution, MVE = Maximal voluntary electrical activity, RVE = reference voluntary electrical activity).

Variable	Registration		Difference		
	Control 1	Control 2	Mean	p-value	n
Physiological reactions					
Systolic blood pressure (mmHg)	128.7 ± 11	127.3 ± 9.5	1.5	0.61	15
Diastolic blood pressure (mmHg)	82.0 ± 4.8	80.9 ± 5.5	1.1	0.31	15
Heart rate (beats/min)	77 ± 9.2	77 ± 8.8	0	0.73	13
LF/HF Ratio	1.88 ± 1.43	2.53 ± 2.05	-0.65	0.07	13
Forces applied to mouse					15
Side Mean Force (%MVC)	0.76 ± 0.32	0.74 ± 0.29	0.02	0.76	
Side Peak Force (%MVC)	1.34 ± 0.54	1.24 ± 0.44	0.10	0.42	
Button Mean Force (%MVC)	1.42 ± 0.55	1.40 ± 0.50	0.02	0.68	
Button Peak Force (%MVC)	3.46 ± 1.5	3.50 ± 1.3	-0.04	0.80	
Grip Duration (s)	3.1 ± 0.4	2.6 ± 0.3	0.51	**< 0.001**	
Wrist flexion/extension					14
Mean position, (°) [a]	27.4 ± 5.3	27.1 ± 5.7	0.3	0.63	
Range of motion, (°)	20.2 ± 6.9	21.3 ± 7.2	-1.2	0.28	
Mean velocity, (°/s)	16.5 ± 5.2	18.3 ± 6.7	-1.8	**0.02**	
Mean power frequency, (Hz)	0.72 ± 0.20	0.74 ± 0.16	-0.02	0.18	
Wrist radial/ulnar deviation					14
Mean position, (°) [a]	7.8 ± 7.4	6.9 ± 8.3	0.9	0.24	
Range of motion, (°)	17.9 ± 8.4	18.9 ± 8.9	-1.0	0.30	
Mean velocity, (°/s)	10.5 ± 4.4	11.3 ± 5.5	-0.8	0.09	
Mean power frequency, (Hz)	0.44 ± 0.12	0.41 ± 0.12	0.03	0.39	
Muscle activity (p 0.50)					15
First dorsal interossei (%MVE)	8.7 ± 8.3	10.3 ± 12.5	-1.6	0.26	
Extensor digitorum (%MVE)	7.8 ± 2.1	7.9 ± 2.3	-0.1	1.0	
Right trapezius (%RVE)	28.3 ± 22.9	31.8 ± 21.6	-3.5	0.32	
Left trapezius (%RVE)	10.9 ± 11.0	12.9 ± 10.6	-2.0	0.15	
Ratings of perceived exertion					15
Proximal (scale step)	-0.1 ± 3.1	0.5 ± 4.5	-0.7	0.46	
Distal (scale step)	2.6 ± 2.9	3.6 ± 3.1	-1.0	0.07	
Productivity					15
Duration of task (s)	181 ± 24	158 ± 17	22.9	**< 0.001**	
Number of errors	0.6 ± 0.6	1.0 ± 1.2	-0.4	0.17	

[a] Positive values denote extension and ulnar deviation.

Discussion

Differences between working techniques

Muscle activity

In the laboratory study (I), it was shown that different computer mouse operating methods affected the physical load and acute psychological responses to the load. The trapezius muscle was the most sensitive muscle for detecting differences in muscular load between methods. When looking for the extremes in the variables measured, the armbased method was distinguished from the other two methods, as subjects worked with higher muscle activity in the right trapezius muscle. The other muscles showed only small differences between methods, at least when looking at group mean levels of muscle activity. Previous studies have also shown that operating the computer mouse without support of the forearm results in increased trapezius muscle activity (1; 30). The field study (II) showed that subjects with a good working technique had less muscle activity in the extensor carpi ulnaris muscle than subjects with a poor working technique. The muscle activity in the extensor digitorum and the trapezius muscles showed similar results, although these results were not statistically significant. The general levels of muscle activity, both in the laboratory study (I) and in the field study (II), were low compared to results from other occupational groups with repetitive work tasks (18)(Table 3) but fairly consistent with results from other studies on computer mouse operators both in laboratory and in field settings (1; 2; 4; 11; 20; 27; 30; 36).

There was a general tendency that subjects classified as having a good working technique had more EMG-gaps and more muscular rest than subjects classified as having a poor working technique. Some studies have shown that having less EMG gaps may be associated with higher risk of developing musculoskeletal symptoms in the neck/shoulder region (19; 21; 51). However, other studies have not found any differences in the number of gaps between individuals with or without musculoskeletal symptoms from the neck/shoulder region (22; 50; 53). The link between muscle activity and musculoskeletal symptoms is unclear and several hypotheses have been proposed, for example: overload of type I muscle fibers or neuronal mechanisms including the gamma motor neuron (for an overview see Hagberg et al. (14)). It has also been discussed if the low levels of muscle activity recorded during light manual and/or VDU work are associated with increased risk of musculoskeletal symptoms, since the levels probably are hard to differentiate from levels during inactive living (53).

Forces applied to the computer mouse

The forces applied to the sides of the mouse were the most sensitive force-variables for detecting differences between working methods. In a study by Johnson et al (24), the forces applied to the sides of the mouse when performing a similar text-editing task were found to have a high correlation with regular work ($r = 0.89$). Whether these low forces applied to the sides and button of the mouse are associated with increased risk for developing musculoskeletal symptoms is unknown but the combination of high repetitiveness and long duration could be one plausible factor in the development of musculoskeletal symptoms.

Wrist positions and movements

Operating the computer mouse with different methods, or being classified as having a good or a poor working technique, affected the wrist position. In the first study (I) subjects extended their wrist more when using the armbased method, and subjects with a poor working technique tended to work with the wrist more extended and ulnar deviated (II). The difference in wrist posture was probably due to the fact that subjects with a poor working technique to a lesser degree than subjects with a good working technique supported their forearm. The same explanation is plausible when subjects used the armbased method (no forearm support allowed), which resulted in a more extended wrist.

The mean values of extension differed between the laboratory study (I) and the field study (II), ~28° and ~20°, respectively. This difference might be due to the fact that in the laboratory study (I) the keyboard and computer mouse were in fixed positions on the work table and subjects were not allowed to change this setting. In the field study (II), the keyboard and mouse were positioned by the subjects since the researchers did not change anything in the workplace design or settings before the measurements. Another explanation could be that two different devices were used to assess the wrist positions, and previous studies have reported differences in measurement accuracy between the two systems (25; 26). Electrogoniometers have been shown to be subject to position measurement errors (7; 17; 26). These errors often occur due to crosstalk, which could be described as a phenomenon where movement in one wrist plane (i.e. flexion/extension) cause a false signal in the other wrist plane (i.e. radial/ulnar deviation). Crosstalk could also be induced by forearm pronation/supination movements, but the results presented here would be less affected since the subjects did not change their pronation/supination angle when operating the keyboard or the computer mouse. Jonsson and co-workers (25) showed that the difference between the device used in laboratory studies (I, III) and in the field study (II) could be up to 5º for the wrist postures in attendance. An additional explanation is that it was the difference in calibration procedures of the goniometer systems that accounted for the difference. In the laboratory study (I) the hand was held flat (pressed) in a neutral radial/ulnar position on the work-surface, but in the field study (II) the calibration was made in a more anatomically neutral posture, using the calibration fixture, with the back of the hand aligned with the dorsum of the forearm. This small difference has been reported to give as large differences as 7° (26).

Only small differences were found in MPF between different working methods and techniques in the laboratory and field studies (I & II). However, there was a large discrepancy between the mean values, in flexion/extension movements between the laboratory study (0.68 Hz) and the field study (0.29 Hz). The difference in radial/ulnar deviation was less, 0.43 Hz and 0.24 Hz, respectively. In a previous study of computer mouse operators, the MPF ranged from 0.23-0.28 Hz in flexion/extension and 0.21-0.24 Hz in radial/ulnar deviation (28). The large difference between the laboratory study (I) and the field study (II) and the Karlqvist study (28) was probably due to the repetitive nature of the text-editing task. During the text-editing tasks subjects alternated between the using the mouse and the keyboard and the regular periodicity of movements most likely biased the MPF to higher values when compared to less periodic real work. Another explanation could be that the difference in the MPF values was due to equipment differences between the above-mentioned studies. However, that is most unlikely since the software used to analys the data in studies I & II was the same and has been compared with the analysis software used in the Karlqvist study (28), and the results did not show any differences (Jonsson P, Hansson G-Å & Johnson PW, unpublished results).

Ratings of perceived exertion
In the laboratory study (I), there were differences in RPE between the working methods, but in the field study (II) only minor differences were present between subjects with a good and a poor working technique. In the experimental setting (I), subjects performed movements (working methods) that they were not used to and that might be one explanation for the differences seen between methods. In the field study (II), the subjects used their normal working technique and maybe the data collection time was too short or the groups too small to distinguish between the two groups. It should also be noted that two different methods of assessing perceived exertion were used, the 0-14 scale and the CR-10 scale. However, the explanations given above are more likely to have caused the discrepancy between the studies.

Differences between the sexes

Muscle activity
Women worked with higher relative muscle activity in the extensor digitorum muscle, both in the laboratory study (I) and in the field study (II). This difference is probably due to strength differences between men and women. Thus, due to fixed forces required by the device or by the fixed device geometry, women have to use a higher proportion of their total capacity. Similar results have been reported by Karlqvist et al. (27; 30). In the other muscles examined, the differences between men and women were smaller and no consistent trends were seen.

Forces applied to the computer mouse
Women applied higher forces to the computer mouse when expressed as %MVC. Similar results have been reported by Johnson et al. (24). This may relate to the lower muscle strength among women and anthropometric differences, which influence biomechanical loads. Fixed button actuation forces in combination with strength differences is one probable explanation why women applied more relative

(%MVC) force than men. Another reason could be that women have smaller hands, which results in higher relative exertion levels to grip the mouse. One previous study has shown that prolonged mouse work could lead to fatigue of the forearm muscles (23). This implies that women with intense computer mouse work could be at higher risk of experiencing fatigue and discomfort in the forearm than men.

Wrist positions and movements
In the laboratory study (I) women worked with greater wrist extension, greater ulnar deviation, a greater ROM and had higher wrist velocities. The smaller stature of women and the fixed size of the devices used may explain part of this difference. The fixed size of the keyboard may have caused more outward rotation of the shoulder and ulnar deviation of the wrist and the fixed height of the mouse more wrist extension in women compared to men. In addition, the position of the keyboard and mouse was fixed on the desk. If the subjects had been allowed to change the position of the keyboard and mouse, the differences might have been smaller. That was indicated in the field study (II), where the subjects placed the keyboard and mouse where they found it most appropriate and in that study the general tendency was that men tended to work with their wrist more extended and more ulnar deviated than the women.

Physical load, physiological and psychological reactions during work under time pressure and verbal provocation

The intention of this study (III) was to put subjects in two different work situations and evaluate how the physical load and physiological and psychological reactions changed from relatively relaxed conditions to simulated stressful work conditions. The time pressure and verbal provocation (the stress situation) resulted in increased physiological and psychological reactions. These increases indicate that the time pressure and verbal provocation met the objectives of creating a stressful work situation.

The physical load increased in the stress situation compared to the control situation. As hypothesised, there was not only an increase in muscle activity but rather a more generalised increase which included higher forces applied to the computer mouse and more repetitive wrist movements.

Muscle activity increased in all the muscles during the stress situation. Based on decreases in the grip durations, part of the muscle activity increase in the FDI, ED and right trapezius muscles could be attributed to the fact that subjects worked faster in the stress situation. However, this productivity increase in the stress situation was relative to the first control registration. In the second control registration, performed on a subset of 15 subjects at the end of the experiment the work pace was faster than in the first control registration and more similar to the stress situation. Despite the performance similarities between the second control registration and stress situation, the magnitude of the differences between the first and second control registrations were much less than that observed between control and stress conditions. Therefore, this indicates that some of the increase in muscle activity was stress related. Muscle activity also tended to increase in the left trapezius, a muscle not actively used in the experiment. The observed increase in muscle activity in the left trapezius could be due to stress or contralateral co-activation. The most likely explanation in this study is that the increase in muscle activity in the left trapezius is due to a combination of these two factors. Previous studies have shown that both stress (8; 35; 37; 47) and contralateral co-activation (38; 42) can result in increased muscle activity in the trapezius muscles.

Birch and co-workers (4) have also investigated the effect of time pressure during simulated computer work and found that high time pressure combined with low precision and low mental demands resulted in higher EMG activity in the trapezius, infraspinatus, deltoid and extensor digitorum muscles, but high precision and high mental demands did not result in any change in muscle activity. Perhaps subjects worked faster with low precision and low mental demands and this increased the muscle activity, but with high precision and high mental demands, subjects had a slower overall work pace and this counterbalanced any increase in muscle activity. This indicates the importance of having some measure of productivity.

The forces applied to the button of the computer mouse increased 22% during stress conditions. This is not likely to be an effect of subjects' working faster during the stress situation since the forces were the same during the second control registration as in the first control registration, although subjects worked faster during the second control registration. This could imply that individuals with intense computer mouse work and adverse psychosocial working conditions (i.e. under stress, on time pressure) could be at higher risk of experiencing fatigue and discomfort in the forearm.

The MPF and velocities in the mouse-operating wrist increased in the stress situation. This is an expected result since subjects worked faster, though it might have some practical implications since MPF has been associated with a higher prevalence of musculoskeletal disorders in female industrial workers (16). In addition, ROM measures decreased in the stress situation, which indicates that the subjects worked in more constrained postures compared to the control situation.

Limitations

Study I

The subjects were instructed to use computer mouse operating methods that they did not use in their regular work. We tried to limit the effect of unfamiliar motion patterns with training sessions before the test. The data collection for each method was done during approximately 3-4 minutes, which may be a short time, but all the subjects were experienced computer mouse operators and should have had few if any, initial difficulties in performing the task. The task performed was text-editing and that limits the generalisability to other work tasks. However, it has been shown that the forces applied to the computer mouse during text-editing tasks have a high correlation with ordinary work task forces (24). Finally, only one type of mouse was tested in this study and it would be interesting to determine if the same trends occur with other mice.

Study II

The study group consisted of 32 newspaper editors and measurements were performed during ordinary editing work. The data collection time was extended to 15 minutes, compared with less than five minutes in the laboratory setting. Still, it could be argued that 15 minutes of work would not characterise the editors' total work time, but editing was the subjects' main job task and the editing was similar over the day and not believed to vary to a great extent between days or during the day. Future studies should investigate the variability between days and during the day to be able to optimise the data collection.

The choice of method of calculating a score from different items was due to the design of this study, where the aim was to compare an overall assessment of working technique with technical measurements of exposures/loads. A disadvantage of this method is that the impact of each item was not evaluated and two identical scores can have different profiles.

Study III

In this experimental study, time pressure and verbal provocation were used to provoke a stress reaction from the subjects. Whether the stressors used in this study are comparable with stressors that individuals are exposed to during daily work is uncertain, but the reactions to the stressors could reflect the reactions to different stressors during ordinary work. Since the order of the two different conditions was not randomised, the increases in physiological and psychological reactions and physical load during the stress situation could be an effect of subjects' working faster or an effect of time or learning. However, our results from the second control registration indicate that the increases in physiological and psychological reactions and physical load in the stress situation were likely to be stress-related. The observed results could also be an effect of time, but this is not very plausible since there were only small differences in physiological and psychological reactions and physical load between the 15 subjects who participated in the first and second control registrations. Most likely, there was a learning effect since the subjects performed the text-editing task faster during the second control registration (15% faster). This increase in speed/productivity in the second control registration may explain the general trend of the physical load factors being slightly higher compared to the first control condition. Finally, one potential limitation of this study was that the data collection for the two registrations was done during less than five minutes, which is a short time of exposure. Future studies should further investigate these effects and extend the data collection time.

Conclusions

The overall conclusions from this licenciate thesis can be summarised as follows:

- Different computer mouse operating methods affected the physical load; use of forearm support resulted in less muscle activity in the trapezius muscle and less extension of the wrist compared to not using forearm support.
- It was indicated that subjects classified as having a good working technique tended to work with less overall muscle activity, more EMG-gaps and muscular rest in the trapezius muscle on the mouse-operating side, and also tended to work with the wrist less extended and ulnar deviated than subjects with a poor working technique
- Women worked with higher relative muscle activity in the extensor digitorum muscle during computer mouse work
- Women applied more force, relative to their maximal capacity, to the button of the computer mouse
- Work under time pressure and verbal provocation (stress conditions) resulted in a higher overall physical load and increased physiological and psychological reactions compared to control conditions

Summary

Physical load in computer mouse work – working technique, sex and stress aspects. Arbete och Hälsa 2001:13

The overall aim of this licentiate thesis was to evaluate how working technique, sex and stress influenced the physical load during computer mouse work. The thesis is based upon three separate studies, two laboratory studies and a field study.

The specific aim of the first study was to investigate whether sex or different methods of operating the computer mouse have any effect on performance and physical load. Thirty experienced computer mouse users, 15 men and 15 women, participated in the study. The subjects performed a standardised text-editing task with three different computer mouse operating methods: a wrist-based method, an arm-based method and their own method. Sex comparisons were made when the subjects used their own method to operate the mouse. Electromyography, electrogoniometers and a force-sensing mouse were used to assess the physical load and ratings of perceived exertion and comfort to assess the acute responses to the physical load. The results showed that women worked with a higher physical load than the men in most of the measured variables and that the computer mouse operating method affected the physical load.

In the field study, 14 men and 18 women from a newspaper editorial department participated. The subjects performed 15 minutes of ordinary work and the physical load was assessed. Working technique was observed and classified according to an observation protocol and subjects were judged to have a good (n=11) or a poor (n=11) working technique. It was indicated that subjects classified as having a good working technique tended to work with less overall muscle activity, more EMG-gaps and muscular rest in the trapezius muscle on the mouse-operating side, and also tended to work with the wrist less extended and ulnar deviated than subjects with a poor working technique. No major differences were found between men and women, except that women worked with higher relative muscle activity in the extensor digitorum muscle.

The specific aim of the third study was to investigate whether time pressure and verbal provocation (stress conditions) had any effect on acute physiological and psychological reactions and physical load when operating a computer mouse. The study group was identical to that in the first study, as were the methods used to assess the physical load. The physiological reactions measured were: blood pressure, heart rate and heart rate variability. A stress/energy questionnaire was used to assess psychological reactions. The physical load and physiological and psychological reactions increased when operating the mouse under time pressure and verbal provocation (stress conditions) compared to control conditions.

Sammanfattning (Summary in Swedish)

Physical load in computer mouse work – work technique, sex and stress aspects. Arbete och Hälsa 2001:13

Den övergripande målsättningen med denna licentiatavhandling var att utvärdera hur arbetsteknik, kön och stress påverkade den fysiska belastningen vid arbete med datormus. Avhandlingen baseras på tre separata studier, två laborativa studier och en fältstudie.

Syftet med den första studien var att undersöka om kön och olika metoder för att styra datormusen påverkade fysisk belastning och prestation. Trettio erfarna datormusanvändare, 15 kvinnor och 15 män, deltog i studien. Deltagarna redigerade en standardiserad text-uppgift med tre olika arbetsmetoder: en handledsbaserad metod, en armbaserad metod och deras egen metod. Skillnader mellan män och kvinnor analyserades när deltagarna använde sin egen arbetsmetod för att styra datormusen. Elektromyografi (EMG), elektrogoniometrar och en instrumenterad datormus (vilken mätte hur stor kraft som applicerades på sidor och knapp) användes för att registrera fysisk belastning. Resultaten visade att kvinnor arbetade med större fysisk belastning i de flesta av mätvariablerna och att arbetsmetod påverkade den fysiska belastningen.

I fältstudien deltog 14 män och 18 kvinnor som alla arbetade på en redigeringsavdelning på en nyhetstidning. Under 15 minuters ordinarie arbete gjordes registreringar av den fysiska belastningen. Arbetsteknik observerades enligt en checklista och deltagarna klassifierades att ha god arbetsteknik (n=11) eller dålig arbetsteknik (n=11). Individer som klassades ha god arbetsteknik tenderade att arbeta med mindre muskelaktivitet i skuldra och underarm, fler EMG-gaps och större andel muskulär vila i skuldermuskulaturen på datormussidan. Individer med god arbetsteknik tenderade också att arbeta med mindre extension och mindre ulnardeviation i handleden än personer med dålig arbetsteknik. Inga större skillnader sågs mellan män och kvinnor i fysisk belastning, förutom att kvinnorna arbetade med högre relativ muskelaktivitet i underarmsmuskulaturen (m. extensor digitorum).

Det övergripande syftet med den tredje studien var att undersöka om tidspress och verbal provokation (stressförhållanden) hade någon effekt på akuta fysiologiska och psykologiska reaktioner samt fysisk belastning vid arbete med datormus. Studiegruppen och metoderna för att registrera fysisk belastning var identiska med den första studien. Blodtryck, hjärtfrekvens och hjärtfrekvensvariabilitet mättes för att karaktärisera de fysiologiska reaktionerna och stress/energiskalan användes för att mäta de psykologiska reaktionerna. Den fysiska belastningen och de fysiologiska och psykologiska reaktionerna ökade vid arbete under tidspress och verbal provokation (stressförhållanden) jämfört med en kontrollsituation.

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