Musculoskeletal disorders in demanding computer work - with air traffic control as a model

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CONTENTS

LIST OF PAPERS

This thesis is based on the following four papers, referred to by their roman numerals:

I. Arvidsson I, Arvidsson M, Axmon A, Hansson G-Å, Johansson CR, Skerfving S. Musculoskeletal disorders among female and male air traffic controllers performing identical and demanding computer work. Ergonomics 2006;49:1052-1067.

II. Arvidsson I, Hansson G-Å, Mathiassen SE, Skerfving S. Changes in physical workload with implementation of mouse-based information technology in air traffic control. International Journal of Industrial Ergonomics 2006;36:613-622.

III. Arvidsson I, Hansson G-Å, Mathiassen SE, Skerfving S. Neck postures in air traffic controllers with and without neck/shoulder disorders. Applied Ergonomics 2008;39:255-260.

IV. Arvidsson I, Axmon A, Skerfving S. Musculoskeletal disorders in computer work – a 20 months follow-up after introduction of a mouse-based system. Submitted.

ABBREVIATIONS

ATCC	Air traffic control Centre
CI	95% confidence interval
COPSOQ	Copenhagen Psychosocial Questionnaire
EMG	Surface Electromyography
MSD	Musculoskeletal Disorders
MVC	Maximal Voluntary Contraction
MVE	Electrical activity at MVC
n	number of subjects
n.s.	non significant
OR	Odds ratio
POR	Prevalence Odds Ratio
r_S	Spearman´s rank correlation
SD	Standard deviation
VDU	Visual display unit
WRMSD	Work-related musculoskeletal disorders

INTRODUCTION

Computer work – use and risks

Computer work

Over the past 20 years, the information technology has changed dramatically. Computerized work tasks have increased continuously. Hence, computers have become necessary work tools in most occupations and are used by remarkably many operators, worldwide. In the Swedish workforce, 70% of the females and 68% of the men used computers in their daily work in 2005, compared to 36% and 41%, respectively, in 1991 (Statistics Sweden, 2005). Furthermore, computers are used for a multitude of purposes during leisure time, in all age groups.

The computer mouse is the most commonly used non-keyboard in-put device (Woods et al., 2003; Statistics Sweden, 2005). Although alternative methods (e.g. roller-mouse) are available at some work places, presumably, the use of computer mice will be common also in future computer systems.

Musculoskeletal disorders in computer work

Because of the widespread computer use, identification of health risk factors are of great importance. Traditionally, work-related musculoskeletal disorders (WRMSD) are considered to be associated with heavy loads. In computer work, the physical loads are low. Still, musculoskeletal disorders (MSD) in neck and upper limbs are frequently reported among computer operators (e.g. Gerr et al., 2002; Juul-Kristensen et al., 2004a; Wahlström, 2005). However, the relation between such low exposures and MSD is not clearly understood.

A number of different risk factors, associated with the physical exposures, have been proposed. Poor workstation design, including e.g. high placed computer screen or lack of arm support, have been found to increase the risk (Marcus et al., 2002; Korhonen et al., 2003; Jensen, 2003; Rempel et al., 2006). The role of non-keyboard in-put devices are important, because of their effects on the posture, movements and muscular load (Karlqvist et al., 1998 and 1999; Unge Byström et al., 2002). While some studies did not find any association between mouse use and musculoskeletal symptoms (Blatter and Bongers, 2002; Sillanpää et al., 2003), others indicated that pain in the neck, arms and hands was more associated to mouse use than to keyboard (Karlqvist et al., 2002; Kryger et al., 2003; Brandt et al., 2004). One reason may be that mouse use poses higher demand on eye-hand coordination, as compared to keyboard (Laursen et al., 2002), due to the need of combining precise hand and finger movements with a visual focus on the screen. This might, in turn, lead to more constrained postures. Further, very low levels of muscular rest for the forearm extensor muscles have been found during mouse operations (Unge Byström et al., 2002).

An important modifier of physical exposure in computer work may be time pressure and intensity of work operations (Birch et al., 2000; McLean and Urquhart, 2002).

Further, the modifying effect might differ according to computer-technology system and work-station design. How and to what extent work intensity influence the physical workload needs further penetration.

The scientific evidence of causal relationships between different aspects of computer work and disorders is not strong. Hence, in recent reviews (Frølund Thomsen, 2005; Veierstedt et al., 2006; Ijmker et al., 2007), only limited to moderate evidence was found for an association between the duration of mouse use and disorders in the hand-arm region. In neck and shoulders, the evidence was even weaker. This doubtfulness may be explained by the fact that only a few prospective studies have been conducted, and such are crucial for assessments of causal relationships. Further, there were vague/indistinct estimates of disorders (Hviid Andersen et al., 2004) and limitations in the exposure assessments. Hence, since computer work generally requires use of both keyboard and mouse, disengagement of those exposures was complicated. In addition, the assessment of duration was mainly based on self-reports (e.g. Funch Lassen et al., 2004; Jensen, 2003), which overestimate the time (Hviid Andersen et al., 2008).

Therefore, there is a need for prospective studies of the effect of computer and mouse work on disorders, with a good description of mouse use, objective assessments of the physical exposures and well-defined recordings of disorders.

Neck postures

A particular aspect of the physical exposure is the neck postures during computer work. According to a common clinical conception, prolonged computer work with an extended neck can lead to neck/shoulder disorders. Hence, self-reported neck extension has been identified as a risk factor for neck/shoulder symptoms among office workers (Chiu et al., 2002; van den Heuvel et al., 2006). In the literature, a similar "forward head posture" is described, and defined as a combination of "extension of the upper cervical spine and flexion of the lower cervical spine" (Szeto et al., 2002; McLean, 2005). However, using a two-dimensional video-based motion-analysis system, Szeto et al. (2002) showed only non-significant trends of increased forward head posture among female symptomatic office workers, compared to asymptomatic controls. Hence, more data and a more sensitive method may clarify whether there is any association between such neck postures and disorders among computer operators.

Gender aspects

Several studies among computer operators indicate that MSD are more common among women than in men (Ekman et al., 2000; Gerr et al., 2002; Brandt et al., 2004). The reasons are unclear. One explanation may be that the genders have different work tasks, and therefore different physical and mental demands (Blangsted et al. 2003). Accordingly, Karlqvist et al. (2002) found that women in computer work more often than men were exposed to harmful physical and psychological work conditions.

Hence, establishment of any gender difference in disorders among computer operators can only be made when females and males perform exactly the same computer work.

Another explanation to differences in disorder rates may be that women and men, despite the same work, have different physical exposures, e.g. due to different anthropometrics and/or working technique (Tittiranonda et al., 1999; Wahlström et al., 2000). Furthermore, there may be a gender difference in the perceptions of psychosocial factors (Muhonen and Torkelson, 2003), or in conditions outside work (Lundberg, 2002). Hence, it is of interest to study whether the physical workload and the perception of the psychosocial work environment differ between women and men in the same work.

Air traffic control

In epidemiological studies of computer work, problems in interpretation may occur due to heterogeneous occupational groups, including subjects with different work tasks, work-station designs, educational levels and socioeconomic status. Further, technology systems may change, and on an individual basis, during the studied period.

Air traffic controllers constitute a very homogenous occupational group, where all subjects have the same education, salary agreement and socioeconomic status. Their work is based almost entirely on information technology. In two Swedish radar-control centres, about 300 female and male controllers perform exactly the same work tasks in identical work stations.

The work is associated with a very high responsibility. Furthermore, there are high mental workloads in terms of perception, attention, information processing, problem solving and decision making (Arvidsson, 2006). Hence, it is a demanding computer work.

In March year 2005, a new computerized system for air traffic control was introduced, which resulted in a momentary and major change of work methods and work-station design for all the controllers at the same time. The old, “traditional” system contained a variety of work tools, including keyboard, trackball, paper strips and manual writing, while the new one was characterized by intensive mouse use. Hence, this almost “experimental field situation” offered an opportunity to study the effects on the physical exposure when the same work task was performed in two different information technology systems (“varied” and mouse-intensive), and the musculoskeletal health before and after the change. In addition, gender differences and psychosocial factors could be accurately assessed.

Methods for assessment of musculoskeletal risk in epidemiological studies

Physical exposure

Relevant aspects of physical exposures are postures, movements and muscular load, including the three dimensions level (amplitude), repetitiveness (frequency) and duration (Winkel & Mathiassen, 1994). In general, the physical workloads may be assessed by (1) job title, (2) self-reports by questionnaire, (3) systematic observations, and (4) technical measurements.

Assessment based on job title gives only crude information, since the same job title may include a variety of different work tasks (Nordander et al., 1999) and, therefore, quite different physical exposures. For instance, in computer work, the exposure may vary depending on different computer-technology systems. Further, none of the before-mentioned dimensions (level, frequency and duration) could be assessed accurately from title.

Self-reports based on questionnaires give opportunities to assess large populations and many aspects, at reasonable costs. Further, information about exposures may be obtained, without limitations to the time periods when observations or recordings are performed. Such methods have been widely used in epidemiological studies of risk factors, also in computer work (e.g. Jensen et al., 1998; Brandt et al., 2004). However, the validity of the information given in questionnaires is not obvious (Wiktorin et al., 1993; Hansson et al., 2001a), e.g. as regards the duration of mouse-work (Hviid Andersen et al., 2008).

Systematic observations give access to more detailed information than questionnaires. They may be well suited in tasks with a short cycle time, while in varied work with dynamic transitions, such methods are very time-consuming. In computer work, they may provide a cost-efficient way to evaluate different aspects of physical loads concurrently (Lindegård et al., 2003). However, observational methods involve a certain degree of subjective assessments on part of the observer, and, compared to technical measurements, such have a low validity (De Looze et al., 1994).

Technical measurements provide detailed information, with objective (i.e. independent of the examiner) and quantitative data on physical workloads. Hence, it is considered to be the most reliable method (Winkel and Mathiassen, 1994). Several important aspects of physical loads may be best quantified by such measurements, e.g. movement velocities, force (Spielholz et al., 2001) and postures. Further, due to the high precision in technical measurements, small, but biologically important, differences may be detected in work tasks with seemingly similar physical exposures, e.g. in mouse work as compared to keyboard. In addition, measures in, e.g., muscular rest may give important information related to the pathomechanisms. Interesting aspects are the objective assessments of mouse and keyboard use (frequency of key strokes and mouse-clicks, by computerized measurements; Hviid Andersen et al., 2008), and forces applied to the computer mouse (by a force-sensing mouse; Johnsson et al., 2000; Wahlström et al., 2002), although some aspects, e.g. the attention-related activity before and after a mouse-click (Søgarard et al., 2001), could not be measured.

A set of different methods for technical measurements of postures, movements and muscular load, have been developed/improved and validated by our research-group (Nordander et al., 2004; Hansson et al., 2006; Balogh et al., in press), and used in studies of many occupational groups.

Psychosocial work environment

During the last decades, there has been an increasing focus on the relation between psychosocial factors and MSD. Hence, high demands, low decision latitude, low social support and low job satisfaction are some of the areas that are considered to influence work-related disorders (e.g. Ariens et al., 2001; Johansson Hanse, 2002). Psychosocial factors seem to be more associated with disorders in neck/shoulders, than in the elbows/hands region (Hannan et al., 2005). Further, since physical and psychosocial factors are often associated (Hägg and Åström, 1997; Sjøgaard et al., 2000), in studies of relations between physical factors and disorders, psychosocial factors may be potential confounders.

In most studies, rather than the "objective" psychosocial work environment, the individuals' perception of psychosocial factors is assessed by questionnaire. Then, the demand-control model, developed by Karasek and Theorell (1990**),** is the one most commonly used. However, more detailed information is given by the recently developed Copenhagen Psychosocial Questionnaire (COPSOQ; Kristensen et al., 2005).

Musculoskeletal disorders

Assessment of MSD may be conducted in different ways. In large study groups, the most commonly used method is self-reports by questionnaires (Karlqvist et al., 2002; Jensen et al., 1998; Funch Lassen et al., 2004). The Nordic Questionnaire is widely used and validated (Kuorinka et al., 1987), and hence, comparisons between studies are possible. Therefore, this method is a valuable tool for screening of symptoms/complaints in different occupational groups, in order to identify risky work environments. However, questionnaires provide only limited information about the character of the complaints, although different scales have been used to identify the frequency (Holmström and Moritz, 1991) and intensity of pain, as well as the level of disability (Funch Lassen et al., 2004).

More information about the severity of musculoskeletal health problems is obtained by standardized physical examinations (Ohlsson et al., 1994a; Sluiter et al., 2001). Such also aim at limiting subjective character and to specificity as to affected tissues, which is of importance for the understanding of relations to physical exposures and of the underlying pathomechanism(s).

AIMS

To assess the objective physical exposure in operators performing demanding computer work, to compare the same work task in different information technology systems (one “varied”, i.e., with different input devices and one “mouse-intensive”) and to find out whether work intensity affected the exposure.

To describe any gender difference in the physical exposure.

To explore the occurrence of musculoskeletal disorders in neck, upper extremities and upper back among air traffic controllers.

To assess whether there is any difference in risk of disorders between women and men performing exactly the same computer work.

To develop a method to measure neck flexion/extension during work, and to compare recordings in operators with and without neck/shoulders/upper back disorders.

To evaluate the impact on musculoskeletal disorders in neck, upper extremities and upper back of a change of information technology systems, from a “varied” to a “mouse-intensive” one.

To assess the psychosocial work environment in air traffic control and to compare the different systems.

MATERIALS AND METHODS

Work tasks

Air traffic control

Two Air Traffic Control Centres (ATCC) in Malmö and Stockholm control the airspace over southern Sweden. The control centres consist of 45 identical work stations for radar control. The work is performed in day and night shifts. The controllers are scheduled to work in cycles of 1.5 h uninterrupted work "on-line", followed by a break of 45 min, in total ≥ 5 h computer work per day. In addition, the controllers use personal computers during their breaks for other occupational tasks, such as e-mail communication, on average 1 h (range 0.5-3) per day.

"Old", "varied" system of air traffic control

In the "old" system (**Papers I** and **II**), each air traffic controller was responsible for one sector of the air space, controlled from circular radar screens (diameter 500 mm, lower edge 80 mm over the desk top, not adjustable). Air-plane information was given on paper strips, which were kept in holders at the desk in front of the controllers. Changes in height, speed or course of the air crafts were noted manually on the strips. The desks height (735 mm) was not adjustable to fit different statures. Microphones and headsets were used, as well as keyboard and trackball. The positions for the keyboard and trackball were fixed and placed with a distance of 425 mm and 460 mm, respectively, from the edge of the desk. The height of the keyboard was approximately 20 mm. The controllers had a choice between different chairs, all adjustable.

"New", mouse-intensive system

In the "new" system (**Paper II**), each sector is controlled from two work stations, and the controllers work pair-wise. Each controller has a large, squared VDU screen (sized 505 x 505 mm), a regular computer screen (sized 320 mm x 400 mm), a keyboard (height 25 mm) and an ordinary computer mouse. The placements of keyboard and mouse are flexible and the chairs are adjustable, but the desks have a fixed height (735 mm). Most of the information is given on the large VDU screen. The work is characterised by very intensive mouse use; the keyboard is used only to a minor extent.

Below, the wording "varied system" is applied for the "old", "traditional" air traffic control system, which was used by the controllers at the baseline examinations. Accordingly, "mouse-intensive" system is applied as the term for the new air traffic control system, used at the follow-up examination.

Study designs

This thesis comprises two cross-sectional studies of the musculoskeletal health among air traffic controllers, performed before (**Paper I**) and after (**Paper IV**) a “natural” intervention (i.e., a change of computer system; **Figure 1**). Most of the controllers (n=148) were followed in a prospective design (**Paper IV**). In addition, the physical workload in a subgroup of controllers was measured technically (**Paper II**). Furthermore, a case-control study was performed, regarding neck postures among air traffic controllers with and without neck/shoulders/upper back disorders (**Paper III**).

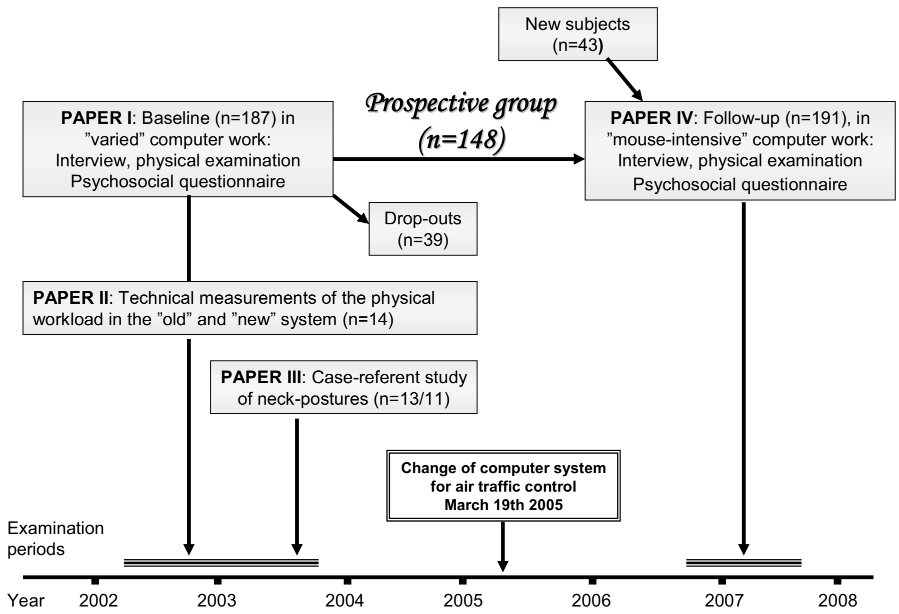


Figure 1. Study designs. The follow-up was carried out two years later than planned, due to an unexpected delay in the introduction of the new system.

Subjects

Paper I. The occurrence of musculoskeletal disorders was assessed in a study group of 187 air traffic controllers (**Figure 1**; 90 women and 97 men), including all presently employed certified controllers at the ATCC in Malmö (n=148), together with all ≥ 45 years in Stockholm (n=39; stratified sampling to enable efficient evaluation of age effects). Mean ages and times of employment were in the females 37 (range 24-55) years and 11 (range 0-29) years, respectively, and in the males 41 (range 26-58) years and 15 (0-34) years. The participation rate was 100%. At baseline, 128 subjects (68%) worked full time (30-40 h/week), and 59 subjects (32%) part time as controllers (20 h/week) and part time performing administrative work tasks.

Paper II. The physical workload was recorded in a sub-group of 14 right handed air traffic controllers, 7 women (mean age 43 years; height 172 cm; weight 74 kg) and 7 men (39 years; 181 cm; 86 kg), during air traffic control in the varied system (authentic) and in the mouse-intensive one (simulated; **Figure 1**). They were all experienced performers of both work tasks.

Paper III. Thirteen cases with neck/shoulders/upper back disorders (mean age 38, range 27-55 years) and 11 healthy referents (mean age 35, range 25-51 years) were selected from a study base consisting of all female controllers at the ATCC in Malmö (n=70; **Figure1**; **Figure 2**). The first step for selection of cases and referents was based on the interview and physical examination performed in **Paper I**. Then, the females identified as cases or referents participated in a second examination of neck/shoulders/upper back, after an average of 1.5 years (**Figure 2**). Subjects who did not fulfil the criteria for a case or a referent, respectively, were excluded.

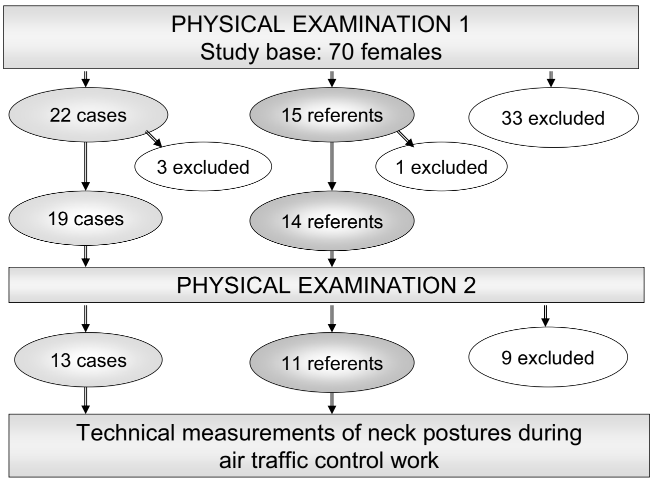


Figure 2. Recruitment scheme of cases and referents in **Paper III**.

Paper IV. The follow-up examination was made after an average of 4.5 (range 2.9-5.3) years (**Figure 1**), in 148 out of the 187 subjects (79%), 71 women (mean age 42, range 27-60 years) and 77 men (mean age 45, range 30-60 years). The controllers had worked in the mouse-intensive system for an average of 20 (range 3-27) months, preceded by 1.5-2 month's education in simulated air traffic control. Among the 39 drop-out subjects (20 men and 19 women), 36 have been reached for an interview. The proportion of full-time controllers was 78% and part-time administrative work 22%. In addition, 43 “new” subjects, 15 females (mean age 35, range 26-46 years) and 28 men (mean age 35, range 26-54 years), who started or re-started their work in the period between baseline and follow-up, were examined (**Figure 1).**

Methods

Physical workload

Measurements procedure
In **Paper II**, the physical workload, in terms of postures, movements and muscular load, was measured continuously during (1) authentic air traffic control in the varied system during a mean of 59 (range 56-65) min, followed by (2) breaks in 40 (range 30-49) min, and, finally, (3) simulated air traffic control in the mouse-intensive system during 51 (range 46-55) min.

Work intensity
The work intensity was determined by the air traffic situation, i.e. the number of aircrafts under control, which varied widely between different working periods (**Paper II**). In order to perform adequate comparisons between the systems, the number and flight routes of the aircrafts in the sector were registered during the work period in the varied system (the authentic situation), and then, for each controller, a specific simulation program was conducted, in order to copy the observed traffic situation into the simulated one. Further, after each working period, the operators rated their perception of the air traffic intensity, on a 100 mm Visual Analogue Scale. Then, analysis of associations between the physical exposure and objective, as well as perceived work intensity, were performed.

In **Paper III**, postures and movements of head, neck and upper back were recorded in the 13 cases and 11 referents, during an ordinary work period (mean 56, range 26-66 min) in authentic air traffic control in the varied system (**Figure 2**).

Inclinometry
Inclinometry, based on triaxial accelerometers, was used to measure the postures (flexion/extension and right/left lateral flexion angles, relative to the line of gravity) and movements for the head, upper back and upper arms (Hansson et al., 2001b and 2006; **Papers I**, **II** and **III**). One inclinometer was placed on the forehead, one on the upper back (C7/ThI) and one on each upper arm. Reference position for head, neck and upper back was recorded, when the subject was standing upright, looking at a mark in eye-level, which defined 0° of inclination. The reference position (0º elevation) for each upper arm was obtained with the subject seated, with the side of the body leaning towards the armrest of a chair and the arm hanging perpendicular over the armrest, with a 2 kg dumbbell in the hand. Memory cards and data loggers (Logger Teknologi HB, Åkarp, Sweden), with a sampling frequency of 20 Hz, were used to collect inclinometer and goniometer data (see below).

A method for assessment of flexion/extension and right/left lateral flexion angles for the neck was developed (Hansson et al., 2006). For each sample, the neck angles were calculated as the difference between the corresponding measures for the head and upper back (**Papers II** and **III**).

Since air traffic control is a sedentary work, the influence of a seated, as compared to a standing reference position was investigated, in the 24 women in **Paper III**. The original reference position for head, neck and upper back (described above) was compared to a reference recorded when the subjects were sitting upright on a stool, with the lower back/hips and shoulders leaned against a wall, looking at a mark in eye-level. In each subject, the recordings of standing and seated references were repeated three times, twice before and one time after the work period.

A seated reference compared to a standing reference, caused only minor differences in the mean of the three recordings of postures for the head, neck and upper back (-0.4°, 1.1° and -1.4°, respectively). Hence, the original standing reference position was used in the present studies.

Goniometry
Wrist positions and movements were recorded bilaterally (**Papers I** and **II**), for both the flexion/extension and the deviation angles, using biaxial flexible goniometers (XM75, Biometrics Ltd., Cwmfelinfach, Gwent, UK). For details see Hansson et al. (1996).

Electromyography
Bipolar surface electromyographic (EMG) registrations were recorded bilaterally for the trapezius muscles and the forearm extensors. The muscular activity was normalised to the EMG activity (MVE) recorded during maximal voluntary contractions. For details, see Nordander et al. (2004).

Variables
Data on postures (°) and movement velocities (°/s) were presented in terms of the 10^{th}, 50^{th} and 90^{th} percentiles of the cumulated distributions during the recorded periods. Further, for inclinometer and goniometer data, the posture ranges were presented as the 95^{th} – 5^{th} percentiles. For EMG data, percentiles were supplemented with the proportions of time at muscular "rest", i.e. an amplitude <0.5 %MVE (Nordander et al., 2004). In goniometry, the measure of low velocity (velocity <1°/s) was selected to characterize when the hand was held still.

Psychosocial work environment
The perception of the psychosocial work environment was assessed by Copenhagen Psychosocial Questionnaire (COPSOQ; Kristensen et al., 2005; **Paper I** and **IV**). The original method included 30 dimensions, from which 16 dimensions (in total 75 questions) were chosen in this study, to cover four psychosocial areas: (1) *demands,* including the dimensions quantitative, cognitive, emotional, emotion concealment and

sensorial demands, (2) *decision latitude,* including influence at work, freedom at work, predictability and role-clarity, (3) *support,* including social support, feedback at work, social relations and sense of community, and (4) s*tress,* including behavioural, somatic and cognitive stress.

The controllers were asked about their opinion about the new air traffic control system *per se* (usability), and about ergonomic factors at the new work stations (**Paper IV**). Assessment of perceived work intensity is described above.

Musculoskeletal disorders

Complaints
The subjects were asked about musculoskeletal complaints (Standardised Nordic Questionnaire, SNQ, Kuorinka et al. 1987) during the last 12 months and the last 7 days (**Papers I**, **III** and **IV**), as well as sick leave due to these complaints. Furthermore, they were asked whether the complaints were work-related, i.e. caused or associated with the work

Diagnoses
A standardised physical examination of the neck and upper limbs (Ohlsson et al., 1994a) was performed in all subjects, by the same physical therapist (**Papers I, III** and **IV)**. Diagnoses were made by the examiner, according to predefined criteria of findings. No diagnosis was available for upper back.

The same method has been used by other examiners in several other occupational groups (e.g. Ohlsson et al., 1994b; Åkesson et al., 1999; Nordander et al., submitted); which gives opportunities to compare the present results with the outcome in different occupations. The reliability of the method, in terms of inter-observer agreement (including the present examiner), has been evaluated, and has been found to be generally good (Nordander, 2004; Nordander et al., to be published).

Findings
The number of findings was calculated for each individual. In **Paper III**, the findings score was calculated in three levels of seriousness (none = 0 point; moderate =1 point; severe = 2 points), while in **Paper IV**, only two levels were used (none = 0 point; positive finding = 1 point).

Non-occupational factors

Data on non-occupational factors were collected: computer use during leisure time (no computer use; < 2 hours/week; 2-5 hours/week; > 5 hours/week), sport activities (<once/week; 1-2 times/week; > 2 times/week); number of children at home and smoking (yes/no).

Statistical methods

Generally, in *dichotomous variables,* comparing independent groups, e.g. gender differences in complaints and diagnoses, the prevalence odds ratio (POR) with 95% confidence interval (CI) was calculated, using logistic regression. In **Paper I**, the change-in-estimate method suggested by Greenland (1989) was used to determine which confounders should be included. In related samples, e.g. in comparisons within subjects between baseline and follow-up, McNemar´s test was used.

Ordinal data, obtained in, e.g., psychosocial scores or number of findings, were analyzed using Wilcoxon´s matched pairs signed rank test when in related samples, and Mann-Whitney´s test in independent groups. The same tests were used when analysing the *numerical data,* e.g. in physical exposures and age. Spearman´s rank correlation (r_S) was used for associations between ordinal and/or numerical outcomes. All tests were adjusted for ties.

To account for the increase in age in the prospective group followed from baseline to follow-up (mean 4.5 years; **Figure 1**; **Paper IV**), logistic regression was employed on all baseline outcome information [complaints (total and work-related) and diagnoses; n=187] to estimate the odds ratio (OR) associated with one year's increase in age. At follow-up (n=148), the probability for outcome was adjusted for the time between the examinations. The sum of the probabilities was interpreted as the expected number of outcomes, and was compared to the observed number, using a chi-square test. Similarly, the number of findings at baseline was related to age, using linear regression, expected values were calculated, and the differences between expected and observed were analyzed, using Wilcoxon´s matched pairs signed rank test.

In all tests, p=0.05 (two-sided) was used to denote "statistically significant".

RESULTS WITH COMMENTS

Physical exposure

Workload in air traffic control

In the v*aried system*, the work was generally characterized by low biomechanical loads (**Papers I** and **II; Figures 3-6** in **GENERAL DISCUSSION,** pages 39-40), with relatively low movement velocities and muscular activities. However, there were interruptions with dynamic movements and somewhat higher muscular peak loads. Median head and upper back postures were slightly flexed and the wrists were somewhat dorsi-flexed. The time proportions of rest in the forearm extensors and trapezius muscles were high.

The *mouse-intensive system* caused a major change of the physical exposures (**Paper II; Figures 3-6**). The movement velocities and the posture ranges (95^{th} – 5^{th} percentiles) for head, neck and upper arms were on average only half of the values as compared to the varied system, which indicates less posture variation. The head was held in a more upright position. However, the proportions of rest in the trapezius muscles were still very high.

In the right, mouse-operating arm, the proportion of time with muscular rest in the forearm extensors was much lower in the mouse-intensive system, as compared to the varied one (3.5 vs. 9% of time), and the muscular load was higher (e.g. 8.1 vs. 4.3 %MVE for the 50^{th} percentile; **Paper II**). Hence, the mouse-intensive system was associated with more constrained hand/forearm work.

Effect of work intensity

There were significant associations between perceived work intensity and physical exposures in both the varied and mouse-intensive system, but in opposite directions (**Paper II**). Generally, posture ranges and movement velocities increased at higher work intensity in the varied system, while they decreased in the mouse-intensive one. However, the EMG-recordings were not significantly associated with work intensity.

Gender

In the varied system, there were no major differences between female and male operators, while gender differences occurred in the mouse-intensive one (**Paper II**). Hence, the females leaned their back forward and extended the neck, while the males sat upright with the neck slightly flexed.

Neck postures in cases and referents

There was no significant difference in neck postures between cases of neck/shoulders/upper back disorders and healthy referents (**Paper III**). In both groups, the median neck position was extended, however, with large inter-individual differences [-10º (SD 8º) among the cases and -9º (SD 10º) among the referents; p=0.9]. Neither did the movement velocities differ significantly between the groups. Hence, the belief that neck-extension posture is associated with disorders in neck/shoulders/upper back was not supported by the present data.

Psychosocial work environment

Perceptive conditions in air traffic control

Generally, the perception of the psychosocial work environment was good (Arvidsson, 2006). The work was characterized by high demands, low decision latitude, high social support and low stress (**Papers I** and **IV**), as compared to a Danish referent population (Kristensen et al., 2005).

Some aspects changed from baseline (varied system) to follow-up (mouse-intensive system); the controllers reported significantly lower decision latitude and higher social support. The area demands did not change significantly, while the sub-dimensions “sensorial” and “quantitative” demands increased and “emotional demands” decreased (**Paper IV**). Furthermore, the area stress did not change, but the sub-dimension “somatic stress” increased. For the other sub-dimensions, there were no significant changes.

Gender

At baseline, the females reported lower decision latitude than the men (**Paper I**), particularly in the two sub-dimensions “influence at work” and “freedom at work”. This was also the case at follow-up [scores 36 (SD 11) *vs*. 40 (SD 12); p=0.02 and 22 (SD 18) *vs*. 27 (SD 17); p=0.04]. Further, females had higher scores in the sub-dimensions “somatic stress” and “cognitive stress” (both systems) and “social support” (only at baseline). No other psychosocial area or sub-dimension differed between the genders.

Associations with musculoskeletal findings

In the varied system, there were statistically significant associations between psychosocial scores (high demands, low decision latitude and high stress) and findings in *elbows/hands* (**Table 1**), although the correlations were fairly low. At follow-up, no such associations were present, despite the increase of findings in elbows/hands in the mouse-intensive system.

The stress-scores were associated with findings in *neck/shoulders/upper back*, in both the varied and the mouse-intensive system (**Table 1**). Further, associations were found for high demands in the varied system and low decision latitude in the mouse-intensive one.

Table 1. Associations (Spearman's rank correlation; r_S) between psychosocial scores and findings in elbows/hands and neck/shoulders/upper back in 137 air traffic controllers (66 females and 71 males). r_S and p-values are given only when statistically significant.

Body region / Psychosocial area		Varied All	Varied Females	Varied Males	Mouse-intensive All	Mouse-intensive Females	Mouse-intensive Males
Elbows/hands							
Demands	r_S	0.21	-	0.23	-	-	-
	p	0.01	n.s.	0.05	n.s.	n.s.	n.s.
Decision latitude	r_S	-0.18	-	-	-	-	-
	p	0.04	n.s.	n.s.	n.s.	n.s.	n.s.
Support	r_S	-	-	-	-	-0.27	-
	p	n.s.	n.s.	n.s.	n.s.	0.03	n.s.
Stress	r_S	0.17	0.25	-	-	0.32	-
	p	0.05	0.05	n.s.	n.s.	<0.01	n.s.
Neck/shoulders/upper back							
Demands	r_S	0.20	0.26	-	-	0.36	-
	p	0.02	0.03	n.s.	n.s.	<0.01	n.s.
Decision latitude	r_S	-	-	-	-0.18	-	-
	p	n.s.	n.s.	n.s.	0.04	n.s.	n.s.
Support	r_S	-	-	-	-	-0.29	-
	p	n.s.	n.s.	n.s.	n.s.	0.02	n.s.
Stress	r_S	0.32	0.44	-	0.24	0.39	-
	p	<0.001	<0.001	n.s.	<0.01	<0.01	n.s.

Gender

Associations between psychosocial factors and findings were more pronounced in females than in males (**Table 1**). In *men*, only high demands and findings in elbows/hands in the varied system were statistically significantly associated. In *females*, findings were associated to increased stress in all parameters, with the highest coefficient for neck/shoulders/upper back in the varied system ($r_S = 0.44$). Further, high demands were associated with findings in neck/shoulders/upper back (both systems) and there were negative correlations between support and findings in both elbows/hands and neck/shoulders/upper back (only in the mouse-intensive one).

Association between stress-score and time proportion of rest in m. trapezius

In the sub-group of controllers who participated in the technical measurements of the physical exposure (n=14), a tendency of a negative association between stress-score and proportion of rest in the right trapezius muscle was observed ($r_S = -0.51$; p=0.06). Hence, despite a very high average in muscular rest for m. trapezius, it seems like individuals with higher perceived stress had less muscular rest.

Musculoskeletal disorders

Below reported measures concerns the prospective group (n=148), except where noted.

Varied system (baseline)

The disorder rates in *elbows/hands* were low in the varied system, in all outcome measures (**Papers I** and **IV**), also as compared to diagnoses in other occupational groups examined by the same methods (**GENERAL DISCUSSION, Figure 7,** page 43). In *neck/shoulders/upper back*, the prevalences of diagnoses and complaints were considerably higher than in elbows/hands (**Papers I** and **IV**). The prevalence of at least one diagnosis was similar to operators in "Partly VDU work" (**Figure 8**, page 44), significantly higher than in "varied office work" among the females (20 vs. 6%; p=0.04), but not in the men (10% vs. 7%, p=0.23). The most common diagnosis was Tension neck syndrome.

Mouse-intensive system (follow-up)

The disorder rates in *elbows/hands* became consistently higher in the mouse-intensive system, as compared to the varied one (complaints 18 *vs.* 30%; p=0.05, diagnoses 3.4 *vs.* 10%; p=0.01 and findings per individual, medians 1 *vs.* 2; p<0.01; **Figure 7)**, even when taking into account the increase of age between the examinations (**Paper IV**). Further, the prevalences of work-related complaints increased (16 *vs*. 40%), and the differences in disorders between right and left arms (shoulder, elbow and hand combined) became more pronounced.

The disorder rates in *neck/shoulders/upper back* did not change in a consistent way (**Paper IV; Figure 8**). Neither complaints (7-days and work-related), nor diagnoses differed statistically significantly from the rates in the varied system (7-days 41 *vs*. 48%, work-related complaints 45 *vs*. 50%, and diagnoses 18 *vs*. 22%). Age-adjustments did not change the results. In findings, a statistically significant increase was found in the mouse-intensive system, but the significance declined after adjustments for the increase of age. However, in stratified analysis, the outcome measures differed between age-groups (reported below).

New subjects (n=43) compared to the original baseline group (n=187)

In *elbows/hands*, the 43 new subjects at follow-up had significantly higher prevalences of complaints and significantly more findings, compared to the original baseline group including 187 subjects, after adjusting for gender and age (**Paper IV**). For elbows/hands diagnoses, there were no significant differences. Disorders in *neck/shoulders/upper back* (complaints, diagnoses and findings) did not differ significantly between the groups.

Sick leave

Only 4% of the controllers reported that they had been on sick-leave due to MSD in neck and upper limbs, at both the varied (**Paper I**) and mouse-intensive system.

Individual factors

Age

The controllers were dichotomized into groups of "young" and "old", based on the median age at baseline (37 years). In the varied system, all disorders parameters increased by age, except for complaints in neck/shoulders/upper back (**Papers I** and **IV**). Further, in the mouse-intensive one, "old" subjects had more disorders in elbows/hands, in spite of a strong increase also among the "young" ones. However, in neck/shoulders/upper back, a different pattern was found: "young" subjects increased steeply, while the "old" tended to decrease in both diagnoses and findings.

Gender

In *elbows/hands*, there were no statistically significant gender differences in diagnoses and complaints, in neither system (**Table 2**). However, in *neck/shoulders/upper back,* the females had much higher disorder rates than the men in the varied system, and the gender differences became even more pronounced in the mouse-intensive one. The number of findings followed the same general pattern (data not shown).

Table 2. Prevalences of diagnoses and complaints in elbows/hands and neck/shoulders/upper back, in the varied (**Paper I**) and mouse-intensive system, in 70/71 female compared to 77 male air traffic controllers. POR = Prevalence odds ratio, adjusted for age; CI = 95% confidence interval.

Region Measure	System	Prevalence (%) Females	 Males	POR (CI)
Elbows/hands				
Complaints	Varied	18	18	1.3 (CI 0.5 – 3.2)
	Mouse	32	27	1.4 (CI 0.7 – 2.9)
Diagnoses	Varied	4.3	2.6	3.5 (CI 0.5 – 26)
	Mouse	11	9.1	1.5 (CI 0.5 – 4.5)
Neck/shoulder/upper back				
Complaints	Varied	52	31	2.6 (CI 1.3 – 5.1)
	Mouse	63	34	3.4 (CI 1.7 – 6.8)
Diagnoses	Varied	24	12	3.3 (CI 1.3 – 8.5)
	Mouse	34	12	3.7 (CI 1.6 – 8.7)

Stature

Low height was not statistically significantly associated with increase of disorders, neither among women, nor in men (**Paper I**) in neither system (e.g. association between height and findings in elbows/hands in the mouse-intensive system: females r_S 0.06; p=0.63; males r_S 0.08; p=0.51).

Visual conditions
The use of progressive lenses were more common in the mouse-intensive system than in the varied one (28 vs. 18 operators), most likely due to the increase in age. In the varied system, operators using progressive lenses at work were at higher risk for neck/shoulders/upper back diagnoses than those without progressive lenses (**Paper I**). However, after age-adjustments, the statistical significance disappeared. In the mouse-intensive system, there was no association between progressive lenses and disorders.

Associations between eye strain and findings in neck/shoulders/upper back were found in both the varied ($r_S = 0.22$; $p<0.01$) and mouse-intensive system ($r_S = 0.20$; p=0.02), but eye strain was not associated with findings in elbows/hands. Further, eye strain was more prevalent among the cases with neck/shoulder/upper back disorders, than in the referents (**Paper III**), but subjects with and without eye-strain did not differ in neck postures.

Other non-occupational factors
Computer use during leisure time increased significantly between the two examinations, while sport activities, number of children at home and smoking did not change (**Paper IV**). The same pattern was found in both genders.

Non-occupational factors were assessed in relation to disorders. At baseline, a negative correlation was found between sports activities and findings in neck/shoulders/upper back (r_S=-0.17; p=0.04). Further, at follow-up, findings in neck/shoulders/upper back displayed a negative association with computer use outside work (r_S=-0.18; p=0.03; **Paper IV**). Findings in elbows/hands were not statistically significantly associated to the non-occupational factors, in neither examination.

In comparisons between the genders, it was found that men used computers more frequently during spare-time, than the females (**Paper I**), in both examinations. The other non-occupational factors did not differ between the genders.

There was an association between the number of children and findings in neck/shoulders/upper back at both baseline and follow-up, but only in the men. At baseline only, there was an association between less frequent sports-activities and complaints in neck/shoulders/upper back among the men (**Paper I**), and in findings among the women (neck/shoulders/upper back r_S -0.25; p=0.03 and elbows/hands r_S -0.24; p=0.04). No other non-occupational measure was significantly associated with findings, neither among women nor men in neither system.

GENERAL DISCUSSION

Methodological issues

Selection

The air traffic control work is associated with a very high responsibility. The operators may possess specific mental qualities, including a high stress tolerance. Hence, through pre-educational tests, they were selected into the occupation. Furthermore, they have a high socioeconomic status. It is possible that these characteristics are associated with a low risk of MSD (Ariens et al., 2001a; Hannan et al., 2005).

In a cross-sectional study design, there is always a possibility of a healthy workers selection, i.e. that subjects with MSD are more liable than healthy ones to change jobs, or to receive a sick pensioning. However, most likely, this is not a problem among the air traffic controllers, since reported short-term sick-leave rates due to MSD were very low (4%) and none of them were on long-term sick-leave during any of the two examination periods (**Papers I** and **IV**). It could not be assessed whether someone had left her/his employment because of MSD prior the first study, but none had left during the 4.5 years between baseline and follow-up, because of that reason (see below).

Another possible source of bias is that invited subjects refrain to participate. However, the participation rate was 100% at baseline (**Paper I**), and at follow-up, only one subject declined participation in the physical examination (while she accepted the interview; **Paper IV**). Hence, this was not a problem.

In a prospective study design (**Paper IV**), the risk of a selection bias due to drop-outs in follow-up needs to be considered. Their fraction was fairly small (21%). In the 36 out of 39 drop-outs who were interviewed, the reason was not musculoskeletal problems. Neither did the disorders at baseline among the drop-outs differ from the study group.

Information / observations

Observer bias

The interviews and physical examinations (**Papers I** and **IV**), as well as the technical measurements (**Paper II**), were performed at the work place. Hence, the examiner was well aware of the working conditions. Therefore, there is a risk of an observer bias. However, strict protocols were followed in order to minimize such.

The gender of the individual could not be blinded to the examiner. Hence, observer bias must also be considered in relation to the assessment of gender differences in disorders (**Paper I**). However, it is unlikely that this explains a major part of the gender effects; in fact, the hypothesis was that the difference should be minor in the present work.

Reporting bias

There is a public concern that computer and mouse uses may have adverse effects on musculoskeletal health. Moreover, at follow-up, the air traffic controllers were aware of the physical exposure in the mouse-intensive system, due to information of our previous study (**Paper II**). This might – to some extent – have influenced the reporting of complaints at follow-up, but less likely the results of the physical examination.

Exposure time duration

Due to technical problems and air traffic safety reasons, the introduction of the new mouse-intensive air traffic control system was delayed for more than two years (**Paper IV**). The consequences were an extended period of work in the varied system and a somewhat shorter exposure time in the mouse-intensive one, than was expected in the original study plan. It might be argued that some of the disorders recorded at follow-up were caused by the extended work time in the varied system. However, the frequency of elbows/hands disorders was low in the first examination, despite 12 years (median) of work in the varied system, and most of the controllers reported that complaints had started only after the change of system. The exposure time in the mouse-intensive system (median 20 months) was long enough to induce elbows/hands disorders. In neck/shoulders/upper back there was no consistent change, maybe because the time was too short at the present exposure level (Ohlsson et al., 1989).

A common source of bias in prospective studies is an uncontrolled change of exposures, e.g. in information technology, a gradual change of work tasks and computer system. A major strength of this thesis (**Paper II**) is the momentary change of exposure, including all operators at the same time.

Physical exposure

For practical reasons, it was not possible to measure the physical exposure in all subjects (**Paper II**). The studied group included only those operators who worked as operative controller in the varied system and, at the same time, were experienced in the simulation of the mouse-intensive system before the change (the “test pilots”). However, there is no reason to believe that their physical exposure differed from the total group of air traffic controllers. Furthermore, the group included subjects with, as well as without, disorders.

Physical exposure, in terms of working technique, is influenced by two different elements (Kjellberg et al., 1998): the method of carrying out a work task (i.e. the two systems in this context) and the individual’s performance of a given task. While our main aim was to compare the physical workload in the two systems, there were only limited possibilities to assess differences in the individual’s motor performances, and within-subjects associations between physical workload and disorders.

The assessment of the physical workload was performed as paired measurements, the same day, in both systems (**Paper II**). The air traffic intensity was carefully considered, since the number of aircrafts in the authentic situation was counted and copied into the simulated one. As a consequence, the measurements in the varied and mouse-intensive system could not be performed in random order. However, the controllers had about 45 min break between the measurement periods, and we found no signs of muscular fatigue, in EMG.

The recordings were performed during a mean of 59 minutes in the varied system and 51 minutes in the mouse-intensive one. Those durations are fairly short. However, since the work intensity was carefully adjusted, they are sufficiently long to enable comparisons of the same individual in the two systems. Further, although the work intensity varied between the subjects, we believe that at a group level, the measurements were representative for the average daily exposure.

It is possible that the measuring equipment, with a total weight of approximately 3 kg, has influenced the muscular load, which, in turn, may affect working technique and motor performance. However, since the measurements were performed in an identical way in both systems (**Paper II**), this should not bias the comparisons between the systems.

We compared work in authentic air traffic control in the varied system with simulated control in the mouse-intensive one (**Paper II**). However, the simulation was performed under very realistic conditions and was of the kind that the controllers used for advanced training in preparation for the change of system. Neither the number of aircrafts, nor the perceived work intensity, differed significantly between the systems. The mental demands may be different in an authentic situation, but we believe that the simulated control was representative with respect to the physical workload.

In an epidemiological context, the daily use of computer and mouse are important measures for assessments of dose-response (Frølund Thomsen 2005; IJmker et al., 2007). The work organisation gives a very well-defined duration of the computer work (≥ 5 hours/day; **Paper IV**), due to the fact that all controllers had identical work tasks, a homogenous work exposure, and a strict schedule for work and breaks**.**

Physical workload includes a multitude of dimensions. Our quantitative measurements included assessments of postures, movement velocities and muscular load (**Paper II**), which corresponds to previously identified risk factors in computer work, i.e. awkward postures (Ariens et al., 2001b; Korhonen et al., 2003; van den Heuvel et al., 2006), lack of arm support (Rempel et al., 2006), muscular load and lack of relaxation (Veierstedt et al., 1993; Hägg and Åström, 1997; Sjögaard et al., 2000). Hence, relevant aspects were considered.

The present three methods for assessment of physical exposures are well documented, carefully validated and frequently used, (Hansson et al., 2001 and 2006; Nordander et al., 2004; Balogh et al., in press). The methods of *inclinometry* (Bernmark and Wiktorin, 2002) and *goniometry* have high qualities; the imprecision of the methods *per se* were small. However, there are some methodological problems: In inclinometry, rotation round the vertical axis could not be measured. As a consequence, head rotation could not be assessed and upper arm elevation was used as a measure for flexion and abduction, independent of direction. In goniometry, a well-known source of error is crosstalk due to pro/supination of the forearm and, at the same time, pronounced wrist flexion/extension (Hansson et al., 2004). However, this is not a major problem in the present study, since no substantial rotation of the goniometer end-blocks are present in computer work.

The *EMG* activities showed a high inter-individual difference (**Paper II**), which is in accordance with other studies of different subjects performing the same task (Balogh et al., 1999; Mathiassen et al., 2002; Unge Byström et al., 2002). This may partly be explained by inherent imprecision of the method (Nordander et al., 2004), but also by real differences between the individuals in adaptation to the workplaces (due to anthropometrics), or in working technique. Also, the between-subjects variability may be influenced by individual patterns of muscle activities (Thorn et al., 2002; Zennaro et al., 2003) and by different thickness and electrical properties of the tissues between the muscles and the electrodes (Mathiassen et al., 1995). However, since the activity is related to the maximal voluntary contractions (MVC), the latter aspect is compensated. Furthermore, psychosocial factors may affect the EMG (se below). This variability may explain why the EMG activity – in contrast to goniometer and inclinometer data - did not correlate significantly with the air traffic intensity. However, since the subjects were used as their own controls in the comparison of systems, the statistical effects of the between-subjects variability was reduced.

The muscular rest is relevant to the risk of myalgia. Based on physiological and empirical data, a threshold level of 0.5 %MVE was chosen for defining muscular rest in m. trapezius (Hansson et al., 2000). The same level was used for the forearm extensor muscles. However, due to a generally lower maximal force and MVE in the hands, compared to the shoulders, the threshold in absolute values (i.e. µV) becomes lower. Hence, the EMG recordings in the forearm extensors, compared to m. trapezius, may be more sensitive to noise. Furthermore, females have a lower maximal hand force than men, which may explain why females generally have lower proportions of rest. Numerically, such gender difference was present also among the air traffic controllers (**GENERAL DISCUSSION**; **Figure 4,** page 39).

The definition of neck postures is not self-evident. We defined the neck as the joint between the head and upper back (**Papers II** and **III**). Many controllers leaned their back forward and kept the head in a close to upright position (i.e. that the head was held extended relative to the back), resulting in an extension of the neck. However, in the study of Ariens et al. (2001b), “neck flexion” was based on observations of head inclinations, with no consideration of the upper back posture. Further, Psihogios et al. (2001) defined neck flexion based on the line through vertebrae C7 and the *Tragus.* Hence, these measures may not be comparable.

In the case-control study among female subjects with and without neck/shoulders/upper back disorders (**Paper III**), we did not find any significant difference in neck flexion/extension. Hence, the hypothesis of an association between disorders and a habitual neck extension during computer work could not be confirmed. However, the cases may have adjusted an earlier awkward habitual posture in response to their pain, which limits the possibility for making conclusions about a lack of causal relationship.

Psychosocial work environment

The COPSOC questionnaire (**Papers I** and **IV**) was selected because it had many dimensions which were well suited to reflect the work situation of the air controllers. It is more extensive – and thus demanding - than the now classical method by Karasek and Theorell (1990). However, the needed cooperation was no problem, since 94% of the controllers completed the form. It should be stressed, that COPSOC, like any similar questionnaire, reflects the subjective perceived psychosocial work environment, rather than the "objective" one. Hence, the controllers had varying perceptions of exactly the same work, though – of course - much more narrow than in a mixture of many work situations (Kristensen et al., 2005).

Musculoskeletal disorders

Subjective complaints were recorded by the Nordic Questionnaire (Kuorinka et al., 1987; **Papers I, III** and **IV**). At baseline (**Paper I**), we used the 12-months as well as the 7-days prevalence, while the 12-months prevalence was excluded at follow-up (**Paper IV),** in order to decrease the multiple inference.

However, complaints are not very informative. While some individuals suffer from severe illness due to MSD, which may imply sick pensioning and impairment of life quality, others may only perceive slight symptoms which are not interfering with their work or daily activities. Further, in the same individual, the intensity of the disorders may vary over time (Åkesson et al., 1999; Luime et al., 2005; Silverstein et al., 2006; **Paper III)**.

An advantage with a physical examination, compared to reported complaints, is a more objective assessment of disorders and the tissues involved. However, the findings in the physical examination include both symptoms (e.g. perceived pain from different body regions) and signs (e.g. decreased range of motion, muscle weakness and palpation tenderness). At baseline, 75% of the findings in neck/shoulders/upper back consisted of signs and the remaining 25% of symptoms. Corresponding distributions of signs and symptoms at follow-up were 77% and 23%, respectively. In elbows/hands, the share of signs was somewhat lower: 65% at baseline and 70% at follow-up. Similar patterns were present in both genders.

Further, despite the standardized method, the examinations include judgements by the examiner, e.g. for palpation tenderness. In our studies (**Papers I, III** and **IV**), all examinations were performed by the same examiner, which increases the chance of detecting a change between baseline and follow-up (**Paper IV**).

Several methods, with different diagnostic criteria, have been used for clinical examinations of neck and upper extremities (Ohlsson 1994a, Sluiter et al., 2001). In epidemiological studies, the criteria for diagnoses are of vital importance for the outcome; too strict ones may identify very few cases, which is a problem in the analysis of risk factors. The same problem may occur if the criteria are not strict enough, with a consequence of too many cases. Accordingly, since our former diagnostic criteria in elbows/hands, especially for nerve-entrapments, were found to be too strict (Nordander, 2004), they were revised in the follow-up (**Paper IV**) and, accordingly, baseline-data were recalculated to allow comparisons.

The diagnosis Tension neck syndrome, which is characterized of neck/shoulder myalgia and headache, was one of the most common diagnoses among the controllers (**Papers I** and **IV**). There is an ongoing debate about the diagnosis *per se*, and the pathomechanisms behind it (Palmer and Smedley, 2007; Sluiter et al., 2001). Also, the diagnosis is not listed in WHO International Classification of Diseases and Related Health Problems (Tenth Revision; ICD-10; WHO 1990). However, we used the diagnosis (**Papers I, III** and **IV**) because it constitutes a typical and severe condition, which has been found to force individuals, at least in some occupations, to change job or to sick pensioning. However, the affected subjects among the controllers seemed to be able to continue working, maybe due to low levels of physical exposure and extended time for recovery between the work periods.

The present method for physical examination was originally constructed for analysis of risk factors in industrial work tasks (Ohlsson et al., 1994a and 1994b), which were mainly characterized of repetitive, but dynamic arm and hand movements. In information technology, a “new” kind of exposure is prevalent: long-lasting low-levels muscular activity due to static and constrained work. Hence, in some aspects the diagnostic criteria may not be well suited for “non-specific diffuse forearm pain” (Harrington et al., 1998; Kryger et al., 2003).

The number of findings was used as an outcome measure, in order to increase sensitivity (**Papers III** and **IV**). These ordinal data also allowed more powerful analyses of correlations with the psychosocial scores and other potential confounders. However, the use of findings scores includes problems, i.e. the non-linearity in relation to severity of disorders. Hence, only non-parametric descriptives and statistical tests were used.

The reported disorder measures were grouped according to anatomical regions: neck, shoulders and upper back, and elbows and hands. These body regions were considered as natural unities, due to clinical experience of a close connection between the body regions in development of disorders.

Comparisons

It is not obvious how to select a meaningful referent groups for the present studies. A sufficiently large group of computer operators, not using a computer mouse, and with similar socioeconomic conditions, hardly exists. For the prospective study (**Paper IV**), a referent group of air traffic controllers who continued in the varied system would have been the optimal choice. However, all Swedish air traffic controllers changed system at the same moment. Thus, we choose to compare with subjects in many other types of work, examined by the same methods (reported below) and partly during the same time period. Then, we could assess whether the air traffic controllers changed their position in the pattern of many occupations.

Confounding

The prevalences of MSD increase with age in the general population (Bergman et al., 2001). Hence, a type of confounding may be that the controllers were on average 4.5 years older at follow-up, compared to baseline (**Paper IV**). Therefore, a statistical model was used to handle the increase of age. Due to a low turn-over among the controllers, age and time of employment were closely associated, and thus not analysed separately. Also, changes of computer use outside work, increased responsibility for children at home, smoking and sport activities were considered as potential confounders, i.e. they might have changed over time. These factors did not account for the increase of disorders, associated with the change of system. Confounders in the comparisons between the genders are discussed below, in “Gender aspects”.

Further, changes in psychosocial factors between baseline and follow-up may influence the disorders, and thus be considered as confounders of an association between the physical workload and MSD (**Paper IV**). Most likely, this was not the case, since the psychosocial area that was impaired between the examinations, (i.e. decision latitude) was not associated with findings in elbows/hands. There was a positive correlation between stress and findings for neck/shoulders/upper back, at both examinations. For this, however, the causality could not be assessed.

Statistics

The study group of air traffic controllers was very homogenous, but rather small. However, it was large enough to handle the major research questions, including the differences in disorders between women and men (**Paper I**) and between varied and mouse-intensive computer work at baseline and follow-up (**Paper IV**). Also, since the study group was extended with older subjects (controllers ≥45 years, by stratified sampling), it was also possible to assess age effects (**Papers I** and **IV**). In comparisons of the physical workload between the systems (**Paper II**), and neck-postures between cases and referents (**Paper III**), the statistical power was high enough to detect differences of biological interests. However, as to gender-differences in physical workload, the number of subjects was sufficient for a general description, while the chance of demonstrating statistically significant differences was limited.

The model used for prediction of age-effects in disorders between baseline and follow-up (**Paper IV**), did not change the crude results. We believe that the age-adjustment method was well suited for the whole group. However, gender-stratified analysis was not performed, since the predictions became unstable due to the limited group sizes and few cases at baseline.

Physical exposure in air traffic control

General aspects

Compared to a wide range of occupations in many branches (recorded by exactly the same methods), the air traffic control work was characterized by low biomechanical workloads (**Figures 3-6**; Hansson et al., submitted; Hansson et al., to be published).

The varied system included different in-put devices and manual writing, and accordingly, the measure of e.g. wrist-movement velocities (90^{th} percentile) was similar to “varied office work” and “partly VDU work” (**Figure 3**). The workload in the mouse-intensive system was, in many aspects, similar to that recorded in VDU and CAD work. Hence, the proportion of muscular rest in the forearm extensors was even lower in “CAD work” and “VDU work, mouse” than among the controllers (**Figure 4**), while the wrist velocities were at similarly low levels (**Figure 3**). This indicates that the physical exposure in the new system, with regards to forearms and hands, was similar to work performed in other mouse-intensive settings. An unexpected measure among the controllers was the extremely high proportions of rest in the trapezius muscles, as compared to the other occupational groups (**Figure 5**). This will be discussed in relation to pathomechanisms (see below). Of course, some measures differed widely between the groups (**Figures 3-6**), because of the quite different characteristics of work tasks (e.g. in meat cutting compared to computer work).

Differences between varied and mouse-intensive computer work

The physical load in hand/forearm was low in the varied system, as indicated by a high proportion of time with low velocities in the wrists (**Paper II**), combined with much rest in the extensor muscles (**Figure 4**). In the mouse-intensive system, the time with low velocity was equally high, but it was associated with a much higher muscular activity and a lower proportion of rest, indicating constrained hand/forearm work.

In the mouse-intensive system, the head was held in a more upright position (**Paper II; Figure 6**), with low movement velocities and very narrow posture ranges, which most likely are explained by the need of constant visual focus on the screen, during the mouse operations (Laursen et al., 2002). Generally, the movement velocities and the posture ranges for head, neck and upper arms were on average only half of the values, as compared to the varied system, which indicates less posture variation. However, the proportions of muscular rest for the trapezius muscles did not differ significantly between the systems (**Figure 5**).

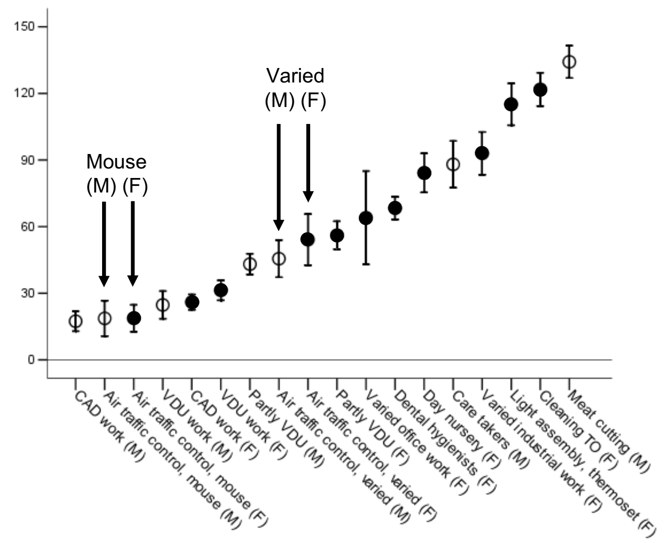


Figure 3. Wrist movement velocities (º/s; 90th percentile; right hand) in females (F; closed symbols) and males (M; open) in different occupational groups (Hansson et al., submitted).

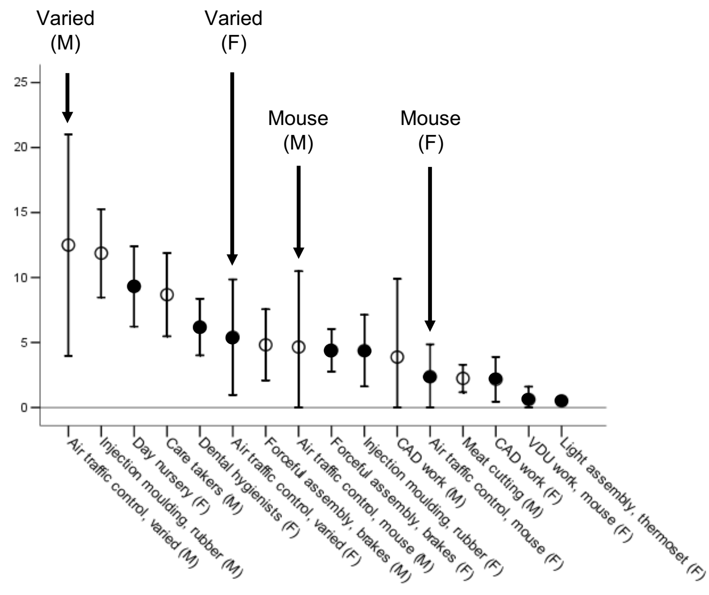


Figure 4. Proportions of muscular rest (<0.5 %MVE) in the right forearm extensors, in females (F; closed symbols) and males (M; open) in different occupational groups (data from Hansson et al., submitted). Arrows indicate air traffic controllers in varied and mouse-intensive work.

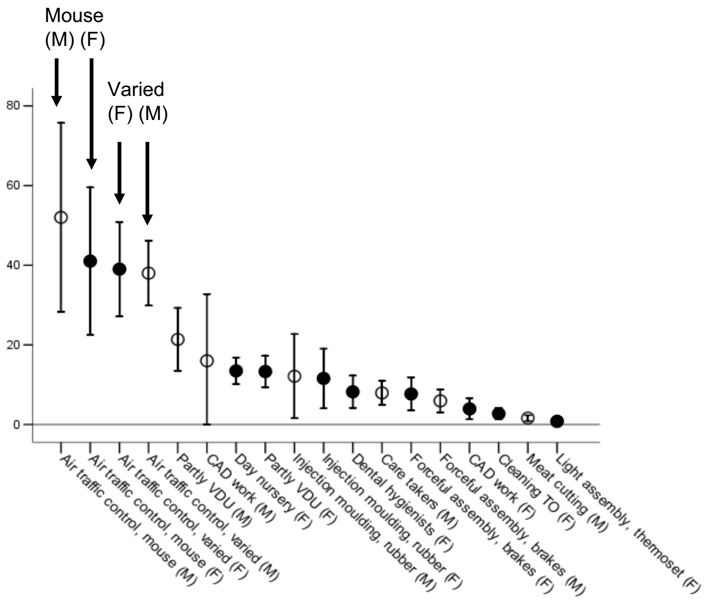


Figure 5. Proportions of muscular rest (<0.5% MVE) in the right trapezius muscle, in females (F; closed symbols) and males (M; open) in different occupation groups (data from Hansson et al., to be published).

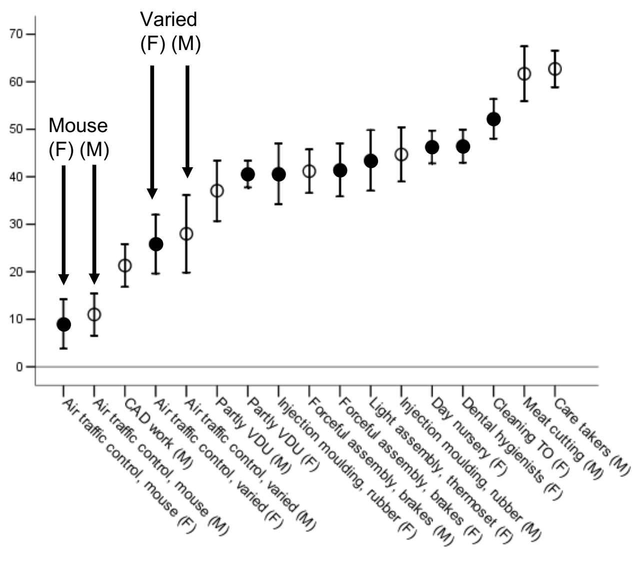


Figure 6. Head flexion (º; 90th percentile) in females (F; closed symbols) and males (M; open) in different occupational groups (data from Hansson et al., to be published). Arrows indicate air traffic controllers in varied and mouse-intensive work.

The work intensity, in terms of perceived air traffic intensity and number of aircrafts, was related to movement velocities, posture ranges and muscular load (**Paper II**). The outcome indicated that the characteristics of the "old" and "new" technology were amplified at high work intensity: In the varied system, the movements became wider and faster, while in the mouse-intensive system the work became even more constrained, probably caused by higher mental focus and concentration at high work intensity.

Psychosocial work environment

Air traffic control in general

There is a lack of control in the air traffic control work, as to the number, the density and the positions of the air crafts. Further, the work is associated with a high mental workload. Accordingly, the controller reported high demands and low decision latitude at both baseline and follow up, as compared to Danish reference population including many occupations (Kristensen et al., 2005; **Paper I** and **IV**). In individuals, this combination ("job-strain") is considered to be a risk factor for adverse health (Hannan et al., 2005). Despite this, the stress levels were low in the controllers (Kristensen et al., 2005). This may be explained by the presumed high stress-tolerance among the controllers, but also by the high perception of social support.

Comparisons between the systems

The mouse-intensive system was associated with even lower decision latitude than the varied one (**Paper IV**). The characteristics of the work tasks were similar in both systems, and hence, other explanations must be sought for. In the varied system, each aircraft was represented by a paper strip, kept at the desk in front of the controllers, while in the mouse-intensive system; all information was given by the computer. This may be perceived as less concrete information, and thus, less control. The increase of social support and the decrease of emotional demands are most likely explained by the fact that the controllers worked two-by-two in the mouse-intensive system, which facilitates communication. The total area of demands did not change, while the sub-dimension sensorial demands did. This may be related to the mouse operations, because of the need of precise hand and finger movements, in combination with a visual focus on the screen.

The area stress did not change between baseline and follow-up, while the sub-dimension "somatic stress" increased. This dimension includes questions about perceived somatic symptoms, e.g. pain in chest or stomach, palpitation of the heart, dizziness and muscular tension. The perception of muscular tension, as well as dizziness, may be explained by the constrained postures and fixed head position. It is also possible that the introduction of the new system was a cause of stress. However, at follow-up, the controllers had been working for an average of 20 months in the mouse-intensive system, and almost all were satisfied with the usability (**Paper IV**).

Although the somatic symptoms became more prevalent at follow-up, the scores were still low compared to the referents (Kristensen et al., 2005).

Psychosocial work environment and disorders

There were some statistically significant associations between psychosocial factors and musculoskeletal findings, at both baseline and follow-up (**RESULTS WITH COMMENTS**). However, in the psychosocial area that was negatively affected by the change of system (i.e. decision latitude), there was only a limited association with findings in neck/shoulders/upper back (**Paper IV**). The area support increased at follow-up, in both genders. Therefore, the negative association between support and findings in both neck/shoulders/upper back and elbows/hands, found among the females only, was not considered as a confounder of the relation between the physical workload and disorders. Hence, it seems unlikely that the incident disorders in elbows/hands were mediated through psychosocial factors.

Musculoskeletal disorders

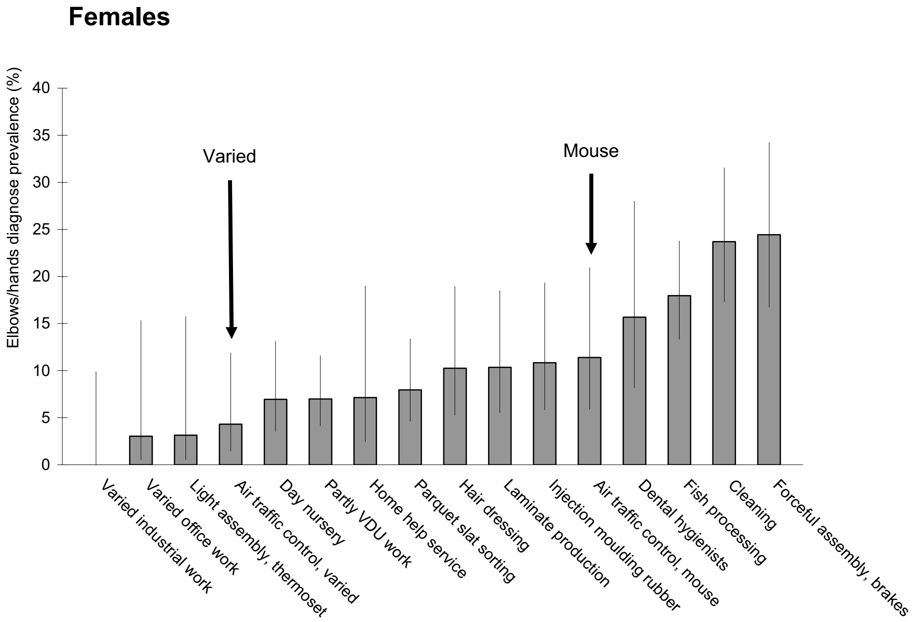
General aspects

In the varied system, the frequency of elbows/hands complaints the last 7 days were lower than in other computer operators (**Paper I**; Jensen et al., 1998; Cook et al., 2000), while in the mouse-intensive system (**Paper IV**), the complaints-rates were at similar levels. The prevalences of neck/shoulders/upper back complaints in the controllers were fairly high in both systems (**Papers I** and **IV**), similar to other operators performing computer and mouse work (Jensen et al., 1998; Cook et al., 2000).

Regarding diagnoses, comparisons are only meaningful for studies using the same diagnostic criteria. Hence, the controllers may be compared to 2.677 individuals in 24 different occupational groups, examined by the same methods (Nordander et al., submitted; **Figures 7-8**). These groups represent several branches, with a variety of work tasks and different socioeconomic status.

Differences between varied and mouse-intensive computer work

The prevalences of elbows/hands *diagnoses* were low in the varied system (**Paper I**), similar to groups with varied/mobile work, e.g. “varied office work” in females and “partly VDU-work” in males (Nordander et al., submitted). This was probably explained by the low biomechanical loads in forearm/hands. Hence, by the change to mouse-intensive work, the prevalence among the controllers, compared to the referents**,** was “transferred to the right” and became similar even to the occupational groups with repetitive/constrained work (**Figure 7)**.



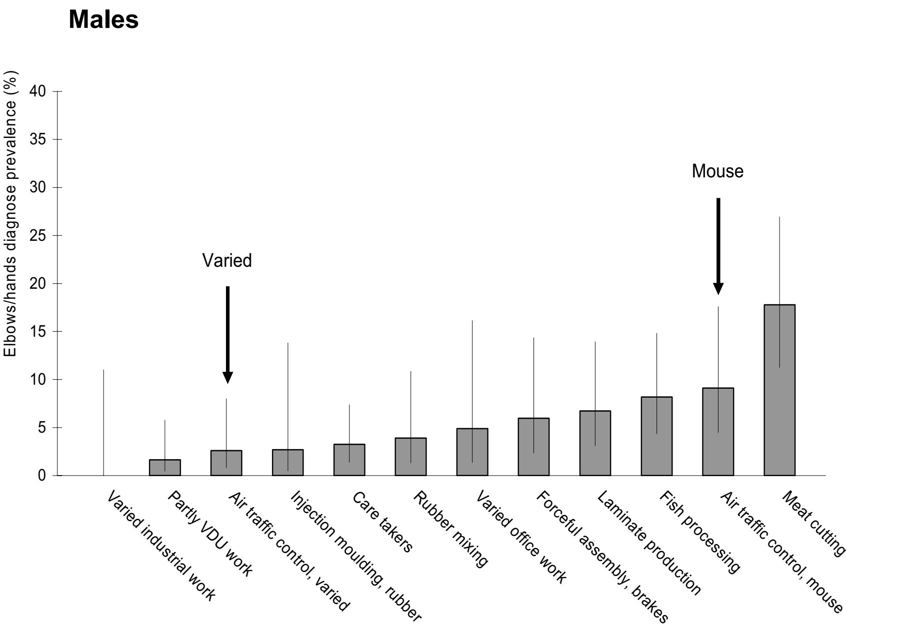
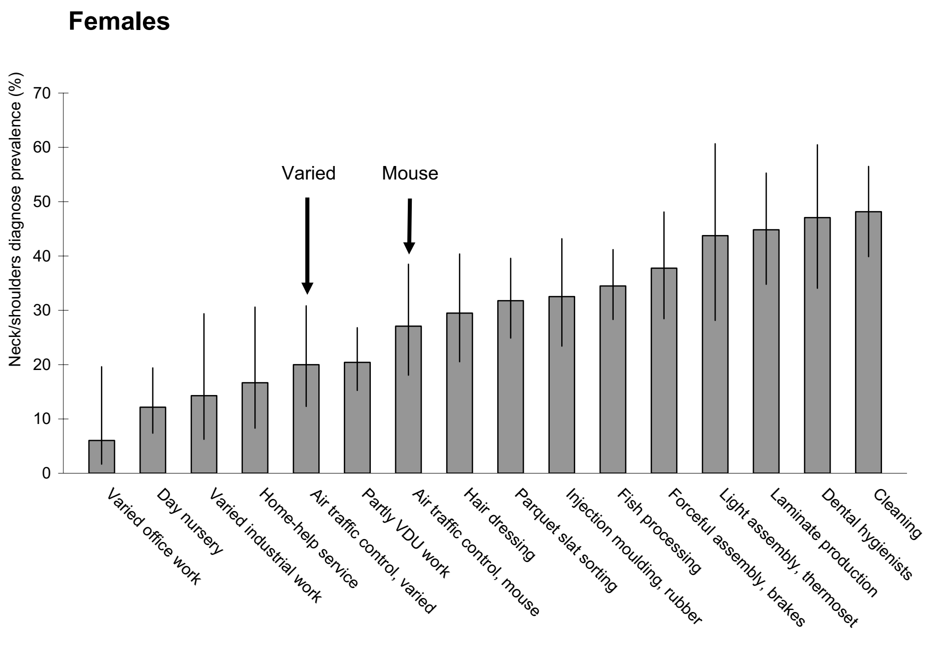


Figure 7. Prevalence of at least one elbows/hands diagnosis among females (above) and males in different occupational groups (Nordander et al., submitted; with additions). Arrows indicate the air traffic controllers in varied and mouse-operative work, respectively. Thin bars indicate 95% confidence interval.



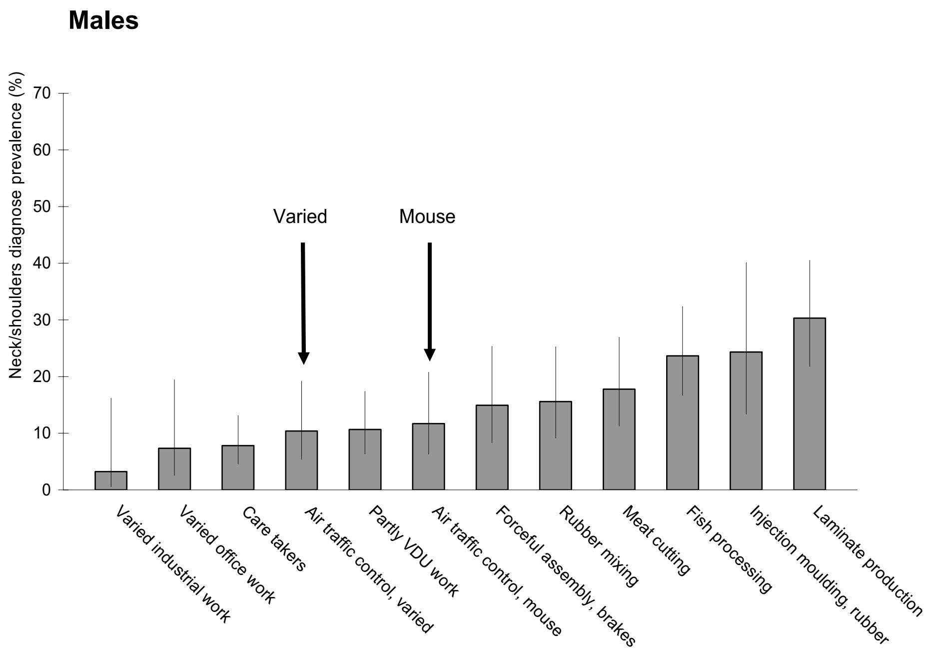


Figure 8. Prevalence of at least one neck/shoulder diagnoses in females (above) and males, in different occupational groups (Trapezius myalgia is not included; Nordander et al., submitted; with additions). Arrows indicate air traffic controllers in varied and mouse-operative work, respectively. Thin bars indicate 95% confidence interval.

A strong increase of specific findings (signs) in the right forearm was found in the mouse-intensive system (e.g. tenderness 5-8 cm distally of the lateral epicondyle, in 34% of the subjects at follow-up *vs*. 8% at baseline, and local tenderness at the edge of *m. pronator teres* in 15 vs. 5%, respectively), probably caused by the mouse operations. Those signs did not fulfil any elbows/hands diagnosis in all subjects, but they were counted in the measure of findings.

Disorders in neck/shoulders/upper back did not change significantly between baseline and follow-up (**Paper IV**). The prevalences of neck/shoulder diagnoses in the controllers were similar to those in "partly VDU-work". Compared to "varied office work", the females had a slightly higher risk, while the males did not differ. Of course, the rates were much lower than in groups with repetitive/constrained work (Nordander et al., submitted; **Figure 8**).

The lack of difference between the systems may be explained by the before mentioned equally high proportions of rest in the trapezius muscles (**Paper II).** Also, while the mouse-intensive system was associated with prolonged static postures, other adverse ergonomic factors were present in the varied one. According to the Statute Book of the Swedish National Board of Occupational Safety and Health; provision "Work with display screen equipment" (AFS 1998:5)**,** those work stations did not fulfil the requirements of a flexible arrangement of the keyboard and trackball. Further, the present placements were defined as "poor", according to the observation method used by Lindegård et al. (2003), implying increased risk of neck pain (Korhonen et al. 2003). Further, in neither system were the desk height and screen adjustable to fit different anthropometrics. This may contribute to explain the lack of difference.

Pathomechanistic aspects

In the present studies, mouse-intensive work was associated with low rest in the forearm extensor muscles (**Paper II**), which is in accordance with studies of mouse-intensive CAD work (Unge Byström et al., 2002).

The mechanism(s) behind the development of pain in muscles, or adjacent tissues, caused by work tasks with sustained activation and low force requirements, are not fully understood. There are, however, a number of hypotheses/theories, which are partly overlapping (Visser and van Dieën, 2006). The most commonly cited one may be the "Cinderella hypothesis" proposed by Hägg (1991), which postulates a recruitment pattern, where low-threshold motor-units (type-1 fibres) are activated first, and de-recruited last ("first up and last to bed"), and hence, always active during periods of sustained muscle contraction. During experimental computer-mouse operations (Forsman et al., 2002), some motor-units in the extensor digitorum communis muscle were found to be continuously active, while others were not, which supports this hypothesis. The lack of rest in those specific muscle fibres may result in overuse and damage. In addition, motor-units were found to be active even before and after a mouse-click, indicating an attention-related muscular activity (Søgaard et al., 2001; Finsen et al., 2001). Effects of the above mentioned mechanisms are, most likely, amplified in work tasks with a low degree of exposure variation (i.e. changes in exposure across time, as well as diversity in exposure levels; Mathiassen, 2006).

Another hypothesis concerns hampered blood flow and reduction of muscle fibre oxygenation (Visser and van Dieën, 2006). According to this, a lowered blood flow in the trapezius muscle was found among subjects with neck/shoulder disorders, compared to healthy referents (Larsson et al., 1998). Further, an increased number of fibres with disturbed metabolism ("moth-eaten fibres") were found in subjects with myalgia (Larsson et al., 2004).

Other proposed mechanisms relevant for work tasks with sustained muscular activation, are accumulation of calcium ions (Gissel et al., 2000) and intramuscular shear forces (Vøllestad and Røe, 2003).

The above-mentioned hypotheses seem to be well suited to explain the increase of elbows/hands disorders among the controllers in the mouse-intensive system (**Paper IV**). However, while there was a lack of rest in the forearm extensor muscle, the opposite was found for the trapezius muscles (**Paper II**). With respect to this, the prevalences of Tension neck syndrome and Trapezius myalgia (**Papers I** and **IV**) were surprisingly high. Similar paradoxical results were found in a study of Westgaard et al. (2001).

In experimental studies of the trapezius muscles during computer work, some motor units were found to be continuously active, in support of the Cinderella hypothesis (Thorn et al., 2002). However, the motor-unit recruitment patterns showed a large inter-individual variation. Despite the high average, such variation in rest-levels was found among also the controllers (**Paper II; Figure 5**). Hence, it is possible that in some of the present subjects, there was a selective recruitment of motor units, and that these were the ones that suffered from neck/shoulder disorders (**Papers I** and **IV**).

Also, due to the high mental demands in the air traffic control work, the muscular activity may be related to psychosocial factors (Lundberg 2002). It has been found that mental and physical load activate the same motor-units (Lundberg et al., 2002; Søgaard et al., 2001). Hence, in the recordings of muscular load in an admittedly small sub-group of controllers (n=14; **Paper II**), there was a tendency of an association between a low proportion of rest in the right trapezius muscle and a high stress score (**RESULTS WITH COMMENTS**). Further, association between stress and findings in neck/shoulders/upper back was present for the whole study group (**Paper IV**). This indicates that individuals react differently to similar objective work demands, and hence, on the individual level, there may be an association between stress, low rest in the trapezius muscles and disorders, as stated by Lundberg et al. (2002).

It is also possible that the disorders are related to pain-initiating mechanisms, which are associated with stress and not mediated through muscle activity (Westgaard et al., 2001). Hence, a hypothesis proposed by Knardahl (2002), postulates that pain-generating mechanism originates from blood vessel/nociceptor interactions in the connective tissue of the muscle, in work tasks with high cognitive demands and low muscular activity.

Disorders severity and sick leave

Among the controllers with complaints from neck/shoulders/upper back the last seven days at follow-up, 45% of the women and 36% of the men received at least one neck-shoulder diagnosis (**Paper IV**). Corresponding figures (mean values) in occupational groups with repetitive work tasks, examined by the same methods (Nordander et al., submitted), were 73% for women and 69% for men. This may reflect an occurrence of more serious disorders due to the work exposures in repetitive work, but also a higher liability to report neck/shoulder symptoms among the controllers, because of attitudes or cultural aspects. However, another pattern was found for elbows/hands: The quotients between diagnoses and complaints were generally lower, and the figures were similar in the controllers (36% in females and 34% in males); as compared to operators in repetitive work (27% and 37% respectively). This might indicate that the elbows/hands disorders among the controllers were relatively more severe, than the neck/shoulders/upper back ones.

Hence, the air traffic controllers may be considered as an affected occupational group, with respect to musculoskeletal disorders in elbows/hands. Although the severity of the disorders in neck/shoulders/upper back may vary, also symptoms and early signs are of importance in the preventive perspective. However, the sick-leave rates were low among the controllers, compared to many other groups. This may be explained by the fact that the controllers have long breaks between the work periods, and hence, an opportunity for recovery.

Individual factors

Age

The increase of disorders at higher age, found in the varied system, is in accordance with findings in the general population (Bergman et al., 2000). Unexpectedly, in the mouse-intensive system, the “young” controllers had higher prevalences of diagnoses in neck/shoulders/upper back, than the “old” ones. Hence, several “old” subjects, who received a diagnosis in the varied system, were recovered in the mouse-intensive one. This may be explained by chance, possibly by physical exercise (Ahlgren et al., 2001) or because experienced subjects with disorders adjust their work patterns. However, also in previous studies of computer operators, inconclusive effects of age on disorders have been reported (Karlqvist et al., 2002; Brandt et al., 2004; Funch Lassen et al., 2004**).**

Gender

In almost all studies of work-related musculoskeletal disorders, females were at higher risk than men (de Zwart et al., 2001; Treaster and Burr, 2004; Nordander, submitted).

This gender difference was also present in computer work (Ekman et al., 2000; Gerr et al., 2002; Funch Lassen et al., 2004; **Paper I**). Differences in disorders rates may be explained by diverse occupational exposures, due to different occupations or work tasks (Nordander et al., 1999). Further, if the same work tasks are present, females´ lower strength and anthropometrics may cause a relatively higher workload (Tittiranonda 1999; Nordander et al., in press).

However, female and male air traffic controllers do have identical working conditions. Further, the work is not force-demanding, which may reduce exposure differences caused by lower strength in women (Lundberg, 2002). Still, there was a substantial gender difference in neck/shoulder diagnoses: two-fold higher rates in the women at baseline (**Paper I**), with amplification at follow-up (almost three-fold; **RESULTS WITH COMMENTS**; **Paper IV**).

The most pronounced increase among the females in the mouse-intensive system was for diagnoses in the right shoulder (**Paper IV**). Hence, the prevalences of bicipital tendonitis (10%) and acromioclavicular syndrome (11%) became high, also as compared to the mean prevalences among females in repetitive/constrained work (6% and 7%, respectively; Nordander et al., submitted). In contrast, the shoulder diagnoses did not increase at all among the males at follow-up.

On the other hand, both genders increased in elbows/hands disorders in the mouse-intensive system, without significant gender-difference, neither at baseline, nor at follow-up (**RESULTS WITH COMMENTS**).

Maybe the differences in neck/shoulders/upper back disorders were influenced by the fact that men are taller than women, and that the workstations were not adjustable. However, there was no association between low height and disorders, neither among women, nor men**.** Further, the only substantial gender difference in physical workload was in upper back and neck postures in the mouse-intensive system (**Paper II**). While the men were sitting upright with slightly flexed neck, the females were leaning their back forward, with an extension of the neck. Further, neck extension was associated with a higher muscular load in the trapezius muscles. Therefore, neck extension was studied as a risk factor for neck/shoulders/upper back disorders in the case-referent study among females (**Paper III**). However, since there was no difference in neck-postures between cases and referents, our data do not support that the higher frequencies of disorders in females were explained by such postures.

The genders differed most in the diagnoses Tension neck syndrome, Trapezius myalgia and shoulder tendonitis (**Paper IV**), in which the diagnostic criteria included muscle tenderness. Hence, when the signs were preliminary grouped into categories (i.e. sum of findings for e.g. restricted mobility and palpation tenderness, respectively), the most pronounced difference between women and men was in palpation tenderness, while the mobility did not differ. Hence, one explanation of the higher frequencies of neck/shoulders/upper back disorders in women may be a higher susceptibility in the muscles, and a higher perception of pain (Chesterton et al., 2003).

However, the gender difference may also be explained by other factors. The females perceived lower decision latitude at both baseline (**Paper I**) and follow-up, but those scores were not significantly associated with findings. Further, the females reported higher stress than the men at follow-up (but not at baseline) and their stress scores were to a higher extent associated with musculoskeletal findings (**RESULTS WITH COMMENTS**). This is in accordance with the study of Östergren et al. (2005). In a conventional prospective study, the potential risk factors at baseline would have been used in analysis of outcome at follow-up. However, in the present study design, including an intervention, such analyses are precluded. Hence, due to the cross-sectional design at both baseline and follow-up, it is not clear whether the stress caused the disorders, or if the opposite scenario was present (Theorell and Hasselhorn, 2005). Nevertheless, psychosocial factors may have contributed to the higher disorder rates in neck/shoulders/upper back, among females.

Furthermore, differences in non-occupational factors (care of children, sports activities, computer use during leisure time and smoking) may be confounders of the gender comparisons. However, only computer use outside work differed between the genders (**RESULTS WITH COMMENTS**). Further, there was a positive association between number of children at home and findings in neck/shoulders/upper back, but only in the men. Thus, there might be a negative confounding, meaning that the sex difference was even greater.

Visual conditions

Visual discomfort has been associated with computer work (Punnett and Bergqvist, 1997; Aarås et al., 1998). Lighting conditions at the workplace, contrast in the screen and monitor placement are important factors (Aarås et al., 1998; Psihogios et al., 2001; Fostervold, 2003), as well as appropriate optometric corrections (Horgen et al., 2002). Hence, the use of progressive lenses among the controllers was associated with disorders in neck/shoulders/upper back at baseline (**Paper I**), but this was not confirmed at follow-up (**RESULTS WITH COMMENTS**). When the mouse-intensive system was introduced, the work place was investigated by an optician and the operators were offered an extra occupational optometric examination. This may have resulted in more adequate optical corrections, since a larger fraction of the controllers were satisfied with their progressive lenses at follow-up (82%) compared to baseline (72%).

The association between visual discomfort and disorders in neck/shoulders/upper back, observed in the controllers (**Paper III, RESULTS WITH COMMENTS**), is in accordance with other studies (Treaster et al., 2006; Helland et al., 2008). The mechanisms is not clear: Maybe subjects with a high susceptibility are at risk for both conditions, or maybe disorders cause a general muscle tension which also involves the eyes. Further, visual discomfort may affect the postures (Horgen et al., 2002), which, in turn, may lead to disorders. However, in the controllers, the neck postures did not differ between subjects with and without eye-strain (**Paper III**).

Practical implications

A new modern and technically very advanced computer system was introduced for air traffic control. However, as regards ergonomic factors at the work places, there were shortcomings, with an association between the physical workload and disorders. Further, disorders seem to be associated with stress.

There may be a causal pathway through bad physical exposures and pain to stress, which, in turn, may lead to risky misjudgements in the air traffic control work. Hence, besides suffering among individuals, work environment factors may be of importance for air traffic safety (Arvidsson, 2006).

Hence, preventive measures should be implemented. There is a need for more adequate workstations, with individually adjustable desk height (including possibilities to alter between seated and standing work) and flexible placements of screen and computer equipments. Further, the work place arrangements should facilitate arm rest, since such reduces the risk of neck-shoulder disorders (Rempel et al., 2006).

Further, the software should be improved to facilitate pathways through keyboard-commands, instead of mouse ones (short-commands), in order to minimize the number of mouse-clicks. In particular, double-clicks should be avoided (Søgaard et al., 2001). Also, alternative in-put devices, e.g. roller-mouse, should be available. In a future perspective, the air traffic control work may be well suited for use of speech recognition (Juhl Kristensen et al., 2004b), which may reduce adverse effects of mouse use. In addition, visual conditions should be optimized by adequate lightning and good contrast in the screens. These improvements may also reduce the sensorial demands.

The air traffic control work will always mean high mental demands, similar only to other occupational groups with a high responsibility. However, in some aspects the psychosocial conditions may be improved, particularly in the before mentioned dimension “sensorial demands”, as well as in the area decision latitude; “freedom at work” and “influence at work”.

The most preferable work condition includes a natural variety of tasks, and hence, a variation in the physical and mental loads (Mathiassen, 2006). Since the air traffic control work does not include such variation, their good breaks are needed. However, the operator should use the time off for physical activity and mental relaxation, rather than to continue with computer work during the breaks. Further, physical exercise may prevent disorders (Hildebrandt et al., 2000), as well as reduce pain in already affected subjects (Ahlgren et al., 2001).

The controllers are spending many hours with high mental focus on the screen, performing intensive mouse-operations. These conditions are prevalent in many computer operators. Hence, the advices of preventive measures are suitable also to other kinds of computer work, particularly in demanding applications, e.g. CAD-work (Unge Byström et al., 2002).

Generally, computer work is associated with a low level of physical activity. The present study shows that the frequency of movements in mouse-intensive work was even lower. In a public health context, physical inactivity is considered as a risk factor for many adverse health effects (Levine, 2004). Since the use of computers in working life, as well as during leisure time, can be predicted to increase immensely (also because children are being introduced to computers at early age) this source of physical inactivity will contribute to ill health.

CONCLUSIONS

In demanding computer work in air traffic control, a "varied system" with different input devices, was characterized by low physical workloads in neck and upper extremities, with high fractions of muscular rest and low movement velocities, as compared to manual work, but similar to, or higher than, other office/computer work. The controllers worked without extreme positions.

Female and male controllers perform exactly the same work. There were no major gender differences in physical workload. However, the female operators had higher prevalences of neck/shoulders/upper back disorders (complaints, as well as diagnoses and findings) than the males, especially for "Tension neck syndrome". In elbows/hands, there were no gender differences.

Compared to other office workers, the female controllers had a slightly higher risk of neck/shoulder diagnoses. As to elbows/hands diagnoses, neither gender differed. The prevalences were, as expected, much lower than in repetitive work.

There was no significant association between neck/shoulders/upper back disorders in women and flexion/extension of the neck.

Change to a mouse-intensive computer system caused major changes of the physical exposures, towards lower movement velocities and less varying postures, and lower muscular rest in the right forearm. These system differences were amplified at high work intensities. However, the proportion of muscular rest in the trapezius muscles was still very high.

In the mouse-intensive system, gender differences occurred: Females leaned their back forward and extended their neck, while males kept their back in an upright position, with slightly flexed neck.

Disorders in elbows/hands increased significantly after an average of 20 months of work in the mouse-intensive system, as compared to the varied one, while disorders in neck/shoulders/upper back did not change in a consistent way.

The perception of the psychosocial work environment was characterized by high demands (in particular cognitive and sensory), low decision latitude, high social support and low stress. The change of system meant an amplification of sensory demands and low decision latitude, while the support increased. However, the psychosocial factors did not explain the increase of elbows/hands disorders.

While air traffic control was studied, the conclusions, at least for physical workload and risk of disorders, are most likely applicable to similar technological developments in other settings.

ISSUES FOR FUTURE RESEARCH

To assess the physical, psychosocial and psychophysiological exposure, in operators performing simulated compared to authentic air traffic control.

To explore the association between muscular activity and rest patterns in the trapezius muscles, with work intensity and perceived stress during authentic work. Further, to evaluate the relationship between these factors and the occurrence of musculoskeletal disorders.

To further penetrate the different categories of findings; i.e. “objective” signs (palpation tenderness, joint mobility and specific tests), as well as reported symptoms (i.e. perceived pain and “neurological symptoms”) in the physical examination, and their relation to gender, age and pathomechanisms.

To evaluate the physical exposure and musculoskeletal health among the air traffic controllers, after interventions in work-place design (including in-put devices) and development of computer soft ware.

To establish dose-response relationships between objectively quantified physical exposure and musculoskeletal disorders (including categories of findings), in female and male subjects with various physical exposures, in different occupational groups.

SVENSK SAMMANFATTNING

Arbetsrelaterade muskuloskeletala sjukdomar är vanliga. Dessa innebär ett stort lidande för enskilda individer och enorma kostnader för samhället. Vår teoretiska utgångspunkt är att den fysiska arbetsbelastningen har en avgörande betydelse för uppkomst av muskuloskeletal sjukdom, modifierat av psykosociala faktorer.

Under de senaste decennierna har informationsteknologin förändrats dramatiskt. För de flesta yrkesverksamma är datorn nu ett nödvändigt arbetsredskap. Muskuloskeletala besvär/sjukdomar från nacke och övre extremiteter har rapporterats vid datorintensivt arbete. Arbetsplatsen utformning och valet av styrdon anses kunna påverka risken. Användning av datormus har ökat och kan utgöra en större risk för besvär/sjukdom, jämfört med tangentbord. Kunskaperna om kausala samband är dock bristfälliga.

Kvinnor har rapporterats vara mer drabbade än män, men det är oklart om det beror på skillnader i kön, arbetsuppgifter, fysisk belastning eller psykosociala faktorer.

Flygledning med radar baseras nästan helt på informationsteknologi. Flygledare utgör en unikt homogen yrkesgrupp, där alla har samma arbetsuppgifter, arbetsstationer, utbildning och status. Könsfördelningen är jämn. I mars 2005 genomfördes ett momentant skifte av datorteknik för flygledning, vilket innebar en stor förändring av arbetsmetoder och arbetsplatsutformning: Det ”gamla” systemet, med varierad belastning (tangentbord, rullboll pappersstrippar och manuellt skrivarbete), ersattes av ett mus-intensivt datorsystem.

Denna närmast ”experimentella situation”, gav möjlighet att studera skillnader i fysisk belastning när samma arbetsuppgift utförs med olika datorteknik (”varierat” och mus-intensivt), förekomst av muskuloskeletala besvär/sjukdomar vid krävande datorarbete, skillnader mellan kvinnor och män med exakt samma arbetsuppgifter, samt musarbetets betydelse för den muskuloskeletala hälsan. Vi har också studerat sambandet mellan besvär/sjukdom i nacke/skuldror/övre rygg och bakåtböjd arbetsställning för nacken.

Fysisk belastning registrerades genom tekniska mätningar av arbetsställningar, rörelser och muskelaktivitet hos 14 personer, under autentisk flygledning i det gamla, ”varierade” systemet och, samma dag, i simulering av det nya mus-intensiva. Flygtrafikintensiteten var lika i båda systemen.

Det ”varierade” systemet innebar låg fysisk belastning för nacke och övre extremiteter, med relativt låga rörelsehastigheter och hög andel muskulär vila, liknande ett varierat kontors- och datorarbete. Inga extrema positioner registrerades. Mätningarna visade inga större skillnader mellan könen.

Före systembytet kartlades muskuloskeletal hälsa i nacke och övre extremiteter med intervju och fysikaliska undersökningar, och psykosocial arbetsmiljö med enkät, hos 187 flygledare (90 kvinnor och 97 män). Flygledarna hade något högre prevalenser av besvär/sjukdom från nacke och skuldror/axlar, jämfört med grupper med annat kontorsarbete (undersökta med samma metoder), men betydligt lägre än i manuellt, repetitivt arbete. Förekomsten av besvär/sjukdom från underarm och hand var låg, jämfört med andra yrkesgrupper.

Trots samma arbete, hade kvinnorna betydligt mer besvär/sjukdom än män från nacke/axlar/övre rygg, men för armbåge/hand fanns ingen könsskillnad.

Samband mellan besvär/sjukdom i nacke/skuldror/övre rygg och datorarbete med bakåtböjd nacke, studerades genom tekniska mätningar av nackvinklar (efter utveckling av metod, baserad på inklinometri) under flygledning, hos en grupp kvinnor med besvär/sjukdom (n=13), jämfört med friska kontroller (n=11). Vi fann ingen skillnad i nackpositioner mellan grupperna.

Det mus-intensiva datorsystemet innebar lägre rörelsehastigheter och mindre variation av arbetsställningar än det ”varierade”, samt högre belastning och betydligt mindre vila för underarmens muskulatur. Skillnaderna mellan systemen accentuerades vid hög trafikintensitet. Andelen vila i kappmuskeln (m. *trapezius*) var hög även i det mus-intensiva systemet.

I genomsnitt tjugo månader efter systembytet undersöktes åter den muskuloskeletala hälsan, hos 148 av flygledarna (71 kvinnor och 77 män; 79%) med samma metoder. Resultaten visade en tydlig ökning av besvär/sjukdom i armbåge/hand, med likartat mönster hos båda könen. För nacke/axlar fanns inga konsistenta och signifikanta skillnader.

Den psykosociala arbetsmiljön karakteriserades av höga krav, låg kontroll, högt stöd och låg stress, men med stora individuella skillnader. Systembytet medförde ökade kognitiva och sensoriska krav, lägre kontroll, men ökat socialt stöd. Förändringarna i upplevd psykosocial arbetsmiljö var inte associerade med besvär/sjukdom i armbåge/hand.

Vi tror att resultaten är generaliserbara till liknande förändringar i annat datorarbete.

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