# Risk factors for arm-wrist-hand and neck-shoulder symptoms among office workers

*A longitudinal perspective*

The study presented in this thesis was performed at the Institute for Research in Extramural Medicine (EMGO Institute) of the VU University Medical Center, Amsterdam, The Netherlands. This was done in close collaboration with TNO Quality of Life, Hoofddorp, The Netherlands. The EMGO Institute participates in The Netherlands school of Primary Care Research (CaRe), which was re-acknowledged in 2000 by the Royal Netherlands Academy of Arts and Sciences (KNAW).

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# Risk factors for arm-wrist-hand and neck-shoulder symptoms among office workers
# A longitudinal perspective

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de Vrije Universiteit Amsterdam,
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# Contents

# 1

# General introduction

*Objectives & practical relevance*

The main objective of this thesis is to investigate the dose-response relationship between the duration of computer use at work and the onset of arm-wrist-hand and neck-shoulder symptoms among a cohort of office workers in the Netherlands. In addition, the relative contribution of risk factors related to work exposure, leisure time exposure and individual characteristics for the onset of arm-wrist-hand and neck-shoulder symptoms are determined. With this information rational decisions can be made concerning the development of primary preventive interventions.

A number of reasons justify this research endeavor. Firstly, nowadays office work and computer use are almost synonyms. In 2004, 3.3 million workers reported to frequently use a computer at work (1). This means that this research project focuses on roughly half of the working population in the Netherlands. Secondly, almost one out of three workers experienced regular or prolonged symptoms in the arm-wrist-hand or neck-shoulder region in the past 12 months (2). Thirdly, these symptoms are associated with reduced well-being (3), reduced productivity (4) and medical consumption (5). These symptoms thus impact individuals, companies, and societies.

*Terminology*

In the literature, self-reported pain or discomfort in the back, neck, shoulder or arm region are often addressed with terms such as musculoskeletal disorders (MSDs), upper extremity disorders (UEDs), or cumulative trauma disorders (CTDs). In this thesis, the terms “arm-wrist-hand symptoms” and “neck-shoulder symptoms” are used to reflect the subjective experience of pain or discomfort in the arm-wrist-hand and neck-shoulder region.

## A historical perspective on arm-wrist-hand and neck-shoulder symptoms among office workers

*Writer's and telegraphists' cramp*

The first case reports of arm-wrist-hand and neck-shoulder symptoms among office workers can be found in the works of the Italian physician Bernardo Ramazzini in the beginning of the 18th Century. He proposed that a triad of static working postures, repetitive movements with low variation in execution, and stressful working conditions (i.e. high responsibility and need to work fast and accurately) was the main cause of hand-arm symptoms among office workers ("clerks"). The mechanism underlying the symptoms was supposed to be a continuous strain on muscles and tendons (due to writing tasks) leading to intense fatigue of the hand and the whole arm (Ramazzini, 1713, cited in 6).

During the 19th century, medical reports began to document office workers who reported disabling pain, paralysis, and muscular spasms in the hands and wrists. Experts pointed to specific manual actions as the primary cause for the symptoms, since an office clerk could spend 10 to 12 hours on manual writing tasks on a typical day. Prolonged writing forced constant contraction of the affected muscles in grasping the pen. The continuation of activity without the ability to pause or recover would lead to a condition that was termed "localized chronic fatigue" (Thackrah, 1832, cited in 7). The clinical description of the symptoms revealed a mainly gradual onset over time in most cases, and intensification of symptoms with continued writing activities. Many physicians were perplexed by the broad range of reported symptoms and the gradual disease onset, which was contrary to that observed in infectious diseases or acute injuries that progressed more rapidly and unambiguously from an identifiable cause to a specific effect (7).

Although many of the reported symptoms in the hand-wrist region were called writer's cramp or scrivener's palsy, many physicians struggled to find an appropriate nomenclature. One of the reasons was that upon physical examination muscle or nerve dysfunction was rarely identified among patients (Poore, 1873, cited in 6). In addition, professional authors seemed seldom afflicted, whereas they were supposed to write as long as office workers (Dana, 1894; Gowers, 1888; Hamilton, 1881, cited in 7). An explanation for these conflicting observations was the hypothesis that poor psychosocial and physical working conditions contributed to the symptoms (Poore, 1897, cited in 6).

During the 19th century white collar workers holding other jobs also started to report arm-wrist-hand and neck-shoulder symptoms. Among them were telegraphists in Great Britain and the United States. Medical researchers attributed the symptoms to factors such as prolonged keying (i.e. a typical telegraphist made approximately 30,000-40,000 finger contractions per day [Fulton, 1884, cited in 7], physical characteristics of the Morse key, lack of workspace, improper adjustment of spring resistance and poor training and supervision (7). A study among 8153 operators revealed that 64% of the workers experienced some physical difficulty from keying. Approximately 9% of the workers were diagnosed with the label “telegraphists’ cramp” based on clinical criteria (Great Britain and Ireland Post Office, 1911, cited in 6). Factors such as age, job tenure, working hours, duration of sitting, and desk arrangement were not found to be associated with arm-wrist-hand and neck-shoulder symptoms.

Ergonomic solutions were offered by experts in order to prevent the onset of symptoms. Specially designed pens, and even typewriters were advised to prevent writer’s cramp. For the prevention of telegraphists’ cramp, job rotation (between sending and receiving functions), arm rests, redesign of telegraph keys, and the use of typewriters were offered as interventions.

At the beginning of the 20th century the reported symptoms were more and more attributed to predisposing psychological factors by medical specialists. Office workers were perceived as having a low risk for medically diagnosed disorders when compared to factory workers who were thought to have much higher physical demands (6).

After the First World War there was a decline in reports on hand-arm symptoms. At the end of the 19th and the start of the 20th century new machines such as the typewriter and the telephone were introduced, and more young (single) women started to work in offices. Three reasons, among others, might have contributed to the low number of reported symptoms in this period. Firstly, young women generally had short job tenures, since they typically worked 15 to 20 months before they got married and retired. Therefore, the cumulative exposure to repetitive and manually intensive tasks was limited. Secondly, the use of the typewriter was seen as less demanding than the work performed by writers and telegraphists in the 19th century. Thirdly, low job security and gender discrimination might have played a role in the lack of attention to prevalent symptoms and problems among women in office jobs (7).

*“Computer cramp”*

With the introduction of the computer and related technologies in the offices during the 1960s and 1970s, renewed attention for arm-wrist-hand and neck-shoulder symptoms among office workers was present. The first reports of computer-related arm-wrist-hand and neck-shoulder symptoms can be found among keyboard operators in Japan during the late 1950s and 1960s (8). The causative factors triggering the symptoms were thought to be excessive workload including both localized muscle loading and mental strain, and insufficient recovery from daily fatigue (9). “Keypunchers” were obliged to operate machines for as long as the working hours of other office workers, although their work rate was considerably faster. The number of strokes per day for an individual keypuncher amounted often more than 80,000 strokes per day. The disease aroused large social concern, and a name for the disease was born: “keypuncher disease” (8).

In Australia an epidemic of “repetitive strain injuries” took place among female office workers after the introduction of computers in the workplace (10, 11). Repetitive Strain Injury (RSI) was given official medical status in Australia based on the assumption that repetitive tasks involving the arms and hands and/or fixed working postures for extended periods could lead to overuse of soft tissues (i.e. an unspecified injury) and resulting arm-wrist-hand and neck-shoulder symptoms.

The lack of objective medical findings (i.e. muscle or nerve damage) among patients fuelled the medical debate about the origin of the arm-wrist-hand and neck-shoulder symptoms (12). One group believed in the medical explanation: overuse of soft tissues due to repetitive hand-arm tasks and / or fixed working postures. Another group had a different view: mental factors including mental disorders, and social factors including the fear of losing one's job due to the introduction of computers, mass hysteria due to media attention and union activism, labeling of symptoms as injury by the government, and a liberal compensation system.

The polarization of views regarding the onset of the epidemic also accounts for the offered explanations for the decline of the epidemic after the mid 1980s. Ergonomic interventions including improved workstations and added rest breaks were introduced widely, and some believed these interventions contributed to the decline. However, no interventions studies were performed in order to verify this explanation. Another explanation for the decline of both reported symptoms and compensation claims was a heightened societal skepticism about the symptoms based on a widely covered court decision not to compensate an RSI case anymore (13).

The United States experienced their own "epidemic" of Cumulative Trauma Disorders (CTDs). The term Cumulative Trauma Disorder reflects regional pain syndromes resulting from an assumed accumulation of repeated small strains and traumas over time (7). The incidence of compensation claims due to CTDs has quickly risen to 439,000 new cases in 1996, representing 64% of all reported occupational illnesses. Some authorities pointed to the introduction of computers and related technologies as a primary cause of the CTD epidemic. The introduction of computers was believed to contribute to less varied work tasks, a higher work pace, less spontaneous work breaks, resulting in a continuous strain on the worker (Mogensen, 1996, cited in 7). Although the first concerns related to the use of computers concentrated on radiation and resulting reproductive and eye disorders, arm-wrist-hand and neck-shoulder symptoms were also addressed. The National Institute of Safety and Health (NIOSH) conducted a number of studies among newspaper employees in the 1970s and 1980s.

Arm-wrist-hand and neck-shoulder symptoms including numbness in hands and loss of strength in the arms and high levels of workplace stress were frequently reported.

Some concluding remarks can be made on the history of arm-wrist-hand and neck-shoulder symptoms among office workers. Firstly, throughout history arm-wrist-hand and neck-shoulder symptoms have been reported among workers performing hand-arm activities requiring repetitive low force application for prolonged periods. Secondly, medical specialists have struggled to find a specific pathophysiologic cause for the reported symptoms among patients. As a result, a polarized discussion developed between those who believed that static working postures and prolonged repetitive low-force hand-arm activity at work (e.g. computer use) caused the symptoms and those who did not. However, the debates on the origin of arm-wrist-hand and neck-shoulder symptoms in office workers and the relative contribution of different factors were hardly ever backed up by sound scientific studies (12). In essence, this discussion still exists up to this date (14 - 18).

*Epidemiological studies on risk factors for arm-wrist-hand and neck-shoulder symptoms among office workers*

During the 1980s and 1990s a large number of cross-sectional epidemiological studies was performed among office workers worldwide. Punnett and Bergqvist summarized the results of all cross-sectional studies in a review (19). Their conclusions were that there was reasonable convincing evidence that the duration of computer use per se (i.e. keyboard use at that time) was causally related to hand-arm symptoms and disorders, mediated by repetitive motion of the fingers and sustained muscle loading of the forearm and wrist. In general, the odds of having symptoms compared to the odds of not having symptoms was 2 for more than 4 hours per day of self-reported keyboard use compared to less than 4 hours per day of self-reported keyboard use at work. For neck-shoulder symptoms and disorders the association with keyboard use was less clear, and it was hypothesized that mechanical factors (i.e. repetitive motion and sustained muscle activation) and organizational factors, such as task fragmentation, contributed together to the onset of neck-shoulder symptoms and disorders. In addition, high general work demands and postural stress resulting from poor workstation layout were thought to contribute to the onset of symptoms and disorders. One of their recommendations was to perform high-quality prospective cohort studies with measurement of all potential contributing factors (both work exposure and individual characteristics) in order to get more insight in causes and effects. At the start of this PhD project in 2002, two cohort studies among office workers could be identified (20 - 22).

*Study questions*

In line with the recommendations by Punnett and Bergqvist (19), two main study questions are answered in this thesis:

1. Does a long duration of computer use at work predict arm-wrist-hand symptoms and / or neck-shoulder symptoms among office workers?
2. What is the relative contribution of work exposure, leisure time exposure and individual characteristics in the onset of arm-wrist-hand and neck-shoulder symptoms among office workers?

In addition, two additional study questions are answered:

1. What is the reliability and validity of the self-reported duration of computer use at work?
2. What is the reliability and validity of self-reported correlates of work postures during computer use among office workers?

*Theoretical model*

In essence, there are three groups of risk factors based on epidemiological studies (21 - 24) and pathophysiological theory (25): physical factors (e.g. computer use and work posture), psychosocial factors (e.g. effort, reward, decision authority, task variety, mental demands), and individual characteristics (e.g. gender, age, previous symptoms). Moreover, physical and psychosocial factors can be encountered during work and leisure time.

One of the prevailing theories to explain pain causation among office workers is the Cinderella theory, proposed by Goran Hägg (25). In this theory, low-force demands during computer use and other demands during work, such as emotional and mental demands, lead to continuous activity of small muscle fibers, which are presumed to be active all the time, just like Cinderella. This continuous activity of small muscle fibers is believed to cause, over time, tissue damage, the stimulation of peripheral nociceptors and the experience of discomfort and pain (25).
It should be noted that effect modification and effect mediation is not studied in this thesis. Moreover, psychosocial factors resulting from leisure time (e.g. stressful life events) were not examined as risk factor, due to a restriction of items in the final questionnaire. This also applied to coping with physical and psychosocial factors at work, and catastrophizing. The specific hypotheses for the prospective cohort study can be found in Chapter 5.

*Outline of this thesis*

In Chapter 2 a systematic review of longitudinal studies on the association between the duration of computer use at work and the onset of arm-wrist-hand and neck-shoulder symptoms is described. This study sets the stage for Chapter 6 in which the relation between the registered duration of computer use at work and the onset of arm-wrist hand and neck-shoulder symptoms is examined in a longitudinal study.
In Chapters 3 and 4 the reliability and validity of self-reports on correlates of work posture during computer use and the duration of computer use at work is examined. These studies provide information on consequences of using self-reports in large-scale epidemiological studies.
In Chapter 5 the design of a prospective cohort study, the PROMO study, is described. PROMO stands for "Prospective Research on Musculoskeletal disorders among Office workers". The core study questions of this thesis will be answered in Chapters 6 and 7 based on the data collected in the PROMO study. In Chapter 6, the relation between the registered duration of

computer use at work and the onset of arm-wrist hand and neck-shoulder symptoms is examined in a longitudinal study.
The relative contribution of work exposure, leisure time exposure and individual characteristics in the onset of arm-wrist-hand and neck-shoulder symptoms is examined in Chapter 7. In Chapter 8, the results obtained in the studies described in Chapters 2 to 7 are critically discussed. Furthermore, in Chapter 8 recommendations for further research and practical implications are presented. This thesis ends with a summary in English and Dutch.

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# 2

## Should office workers spend fewer hours at their computer? A systematic review of the literature

IJmker S, Huysmans MA, Blatter BM, van der Beek AJ, van Mechelen W, Bongers PM. Should office workers spend fewer hours at their computer? A systematic review of the literature. Occup Environ Med. 2007;64(4):211-22.

## Abstract

Worldwide, millions of office workers use a computer. Reports of adverse health effects due to computer use have received considerable media attention. This systematic review summarises the evidence for a relation between the duration of work time spent using the computer and the incidence of hand-arm and neck-shoulder symptoms and disorders. Several databases were systematically searched up to 6 November 2005. Two reviewers independently selected articles that presented a risk estimate for the duration of computer use, included an outcome measure related to hand-arm or neck-shoulder symptoms or disorders, and had a longitudinal study design. The strength of the evidence was based on methodological quality and consistency of the results. Nine relevant articles were identified, of which six were rated as high quality. Moderate evidence was concluded for a positive association between the duration of mouse use and hand-arm symptoms. For this association, indications for a dose-response relationship were found. Risk estimates were in general stronger for the hand-arm region than for the neck-shoulder region, and stronger for mouse use than for total computer use and keyboard use. A pathophysiological model focusing on the overuse of muscles during computer use supports these differences. Future studies are needed to improve our understanding of safe levels of computer use by measuring the duration of computer use in a more objective way, differentiating between total computer use, mouse use and keyboard use, attaining sufficient exposure contrast, and collecting data on disability caused by symptoms.

## Introduction

The large-scale introduction of computers in the workplace has led to hundreds of millions of computer users worldwide. (1, 2) In many countries the widespread use of computers has led to considerable media attention concerning potential adverse health effects.

In the scientific literature, the rise and fall of an epidemic of “repetitive strain injuries” (i.e. workers reporting and claiming compensation for disorders of hand, arm, shoulder or neck) in Australia during the 1980s has been fuelling the debate whether computer use at work is a potential occupational hazard. (3) Proponents stated that repetitive movements and static load due to constrained working postures caused the “injuries”. Critics focused on the absence of objective clinical signs among patients and the role of a liberal compensation system, offering large sums of money to workers who felt unable to work due to hand, arm, shoulder or neck symptoms. (4) Some authors argued that lost lawsuits of workers against their employers were a main contributing factor to the decline of the epidemic. (5) In 1988, Bammer and Martin (4) concluded that the debate was characterized by a lack of empirical evidence to support many of the assertions made by both the proponents and the critics of the work-relatedness of repetitive strain injuries.

In this review, we will focus on the empirical evidence available for an association between the duration of work time spent using the computer (referred to as “duration of computer use”) and hand, arm, shoulder or neck symptoms and disorders. Previous reviews suggest that an association between the duration of computer use and disorders of hand, arm, shoulder or neck is present. In addition, computer use might be more strongly related to disorders of the hand and arm, than to disorders of the neck and shoulders. (6 - 9) However, the limitation of these reviews is that they are mainly based on cross-sectional studies. (6 - 8) Cross-sectional studies cannot disentangle causes and effects and are therefore considered to be inferior to longitudinal studies. (10) The recent narrative review by Wahlström (9) includes only part of the available longitudinal studies.

In order to get a more conclusive insight in the relationship between the duration of computer use and the incidence of hand-arm and neck-shoulder symptoms and disorders, a systematic review of longitudinal studies was performed. Since information on potential dose-response relationships is lacking, specific attention will be paid to this issue.

## Methods

*Search strategy*

Publications were retrieved by a computerized search of the following databases: MEDLINE (from 1950 to November 2005), NIOSHTIC 2, CISDOC, HSELINE, MHIDAS, OSHLINE (all from 1985 to April 2005) and PSYCINFO (from 1967 to April 2005). The databases were searched for published articles up to 6 November 2005. The keywords included: retrospective, prospective, longitudinal, follow-up, computer, keyboard, mouse, office, display, VDU, VDT, terminal, neck, shoulder, elbow, wrist, hand, upper extremity, upper limb, musculoskeletal, pain, physical symptom, physical health. After inclusion of the articles based on the selection criteria, references were checked for additional articles. Finally, personal databases of the authors were searched for relevant articles.

*Selection criteria*

Two reviewers (SIJ and MAH) independently selected relevant articles from the articles retrieved with the search strategy. The articles were selected based on the abstracts. If abstracts provided insufficient information, the full text of the articles was used. The selection criteria were: 1) the study population included computer workers, 2) the outcome included one or more syndromes, signs or symptoms related to pain or discomfort in hand, arm, shoulder or neck, 3) a risk estimate of the association between the duration of computer use, mouse use, or keyboard use and a relevant outcome measure (see 2) was presented, 4) the study had a longitudinal design (i.e. at least one follow-up measurement after baseline), and 5) the study was a full text, peer-reviewed article, written in English, Dutch or German. Experimental studies, letters and abstracts were excluded.

Table 1 Quality assessment list for prospective cohort studies.

| | |
|---|---|
| **Study design** | |
| 1. Was the participation rate at baseline at least 80% OR, if participation rate was < 80%, not selective regarding exposure (i.e. duration of computer use) and potential confounders (i.e. at least for gender and age)? | |
| 2. Was the response at follow-up at least 80% OR, if the response was < 80%, not selective regarding exposure (i.e. duration of computer use), potential effect modifiers (i.e. at least gender and age) and outcome (i.e. hand, arm, shoulder and neck symptoms or disorders)? | |
| **Exposure assessment** | |
| 3. Were the data on duration of computer use collected using standardised methods of acceptable quality? * | |
| 4. Were the data on ergonomic factors collected using standardised methods of acceptable quality? * | |
| 5. Were the data on psychosocial factors collected using standardised methods of acceptable quality? † | |
| 6. Were data on physical factors during leisure time collected and used in the analysis? | |
| 7. Were data on exposure change regarding the duration of computer use during the follow-up period (for example due to job change) collected and used in the analysis? | |
| **Outcome assessment** | |
| 8. Were the data on outcome collected using standardised methods of acceptable quality? ‡ | |
| **Data analysis** | |
| 9. Was the statistical method used appropriate for the outcome studied and was a measure of association presented, including confidence intervals or p-value? | |
| 10. Was the statistical analysis tested for confounding by gender and age? | |
| 11. Was the number of subjects in the multivariate analysis at least 10 times the number of independent variables? | |

* ICC > 0.60 or Kappa > 0.40 for test-retest reliability or interobserver reliability. Additionally for self-reports: ICC > 0.60 or Kappa > 0.40 or r > 0.75 for agreement with observation or direct measurement.
† ICC > 0.60 or Kappa > 0.40 for test-retest reliability. Additionally for self-reports, in the case of using scales: Cronbachs alpha > 0.70 for the majority of scales used.
‡ ICC > 0.60 or Kappa > 0.40 or r > 0.75 for test-retest reliability or interobserver reliability, or if (modified) Nordic questionnaire was used. (15 - 17)

*Quality assessment*

The articles that met the selection criteria were evaluated for methodological quality. We used a quality assessment list for prospective cohort studies, based on previous systematic reviews of risk factors for musculoskeletal disorders. (11 - 14) The full list of items is presented in table 1.

Two reviewers (SIJ and MAH) independently assessed the quality of the studies. All items were scored as positive, negative or unclear (i.e. meaning that insufficient information was available). For each item, the scoring of the two reviewers was compared. In case of disagreement, consensus was reached during a meeting. If agreement could not be reached, a third reviewer (AvdB) decided in the matter. Subsequently, the first author of the included articles was contacted to provide an opportunity to discuss the quality assessment of their article(s). Methodological quality assessment was based on the percentage of positive items over the total number of items. A high quality study was defined as scoring positive on more than 50% of the items, which is in concordance with previously published systematic reviews. (11 - 14)

*Data extraction*

Details on study population, exposure assessment, outcome assessment and data analysis were extracted from all articles. To examine the agreement between the two reviewers for the selection of articles and for the methodological quality assessment, Cohen's Kappa coefficients were calculated.

To evaluate the associations between the duration of computer use and hand, arm, shoulder and neck disorders, we decided to stratify according to the measure of computer use that was reported (total computer use, mouse use or keyboard use) and according to the location of the symptoms or disorders (i.e. neck-shoulder or hand-arm). Elbow symptoms were classified as hand-arm symptoms.

An association was scored as positive if the risk estimate (Odds Ratio, Rate Ratio or Hazard Ratio) was statistically significant, or if at least one of the presented exposure categories showed a point estimate larger than 2.0 (or smaller than 0.5).

*Levels of evidence*

In order to summarize the results of the studies, we used levels of evidence. Strong evidence was defined as consistent results for all tested associations, including at least two high quality studies. We anticipated that one article could present multiple associations for different case definitions and that multiple articles could present associations for the same cohort of workers. Therefore, multiple positive associations from the same cohort of workers were counted as one study.

The criterion of consistent results was met if at least 75% of all tested associations for the risk factor was positive (i.e. provided a statistically significant risk estimate, or a risk estimate larger than 2.0 or smaller than 0.5).

Moderate evidence was defined as consistent results for all tested associations (with a minimum of three associations tested) or consistent results for at least two high quality studies, irrespective of the findings from medium quality studies for that association. Insufficient evidence was defined as inconsistent results for all tested associations, including the situation in which less than three associations were evaluated.

*Dose-response analysis*

The dose-response relationship was evaluated if at least moderate evidence was available for an increased risk of developing hand-arm or neck-shoulder symptoms or disorders. We assessed dose-response qualitatively by plotting the point estimates against the exposure categories. Therefore, we extracted the point estimates for all reported exposure categories. We used the middle value of the lower and upper limit to reflect the average duration of computer use for that exposure category. If there was no upper limit for the highest exposure category, we conservatively used the lower limit to reflect the duration of computer use. Some studies presented exposure categories as a percentage of working time. Based on the distribution of working hours at baseline, we estimated the average number of working hours for the whole population and multiplied this average with the percentage of computer use to calculate the average duration of computer use for each exposure category. A general increase of risk (i.e. higher point estimates) over increasing duration categories for most studies was considered as evidence for a dose-response relationship.

## Results

*Search results*

The search strategy resulted in 277 hits. Applying the selection criteria resulted in nine articles. We excluded the longitudinal study by Lindstrom and co-workers (18), because cross-sectional analyses were performed. The two reviewers initially disagreed on the selection of one article, resulting in a kappa of 0.94. The references of the included articles provided one other article. (19) The final set of articles was based on five cohorts of workers: 1) the BIT-study (20, 21), 2) the NUDATA study (22 - 25), 3) Bergqvist et al. (19) 4) Marcus et al. (26), and 5) Korhonen et al. (27) See table 2 for the characteristics and results of the included articles.

Table 2 Characteristics and results of the included articles.

| **Cohort**<br>**First author**<br>**Quality score** | **Study population** | **Assessment duration of computer use** | **Case definition(s)** | **Results** | **Results continued** |
|---|---|---|---|---|---|
| **BIT**<br>**Jensen [20]**<br>42% | Employees from Danish companies and institutions. Selected companies provided employees with different types of computer work (data entry, word processing, graphic work, etc.).<br>Analyses were restricted to subjects working full time (32 - 41 hours-week, who had not changed jobs during follow-up.<br>N = 203 – 916 | Self-report<br>“How much of your work time do you work with your computer (including overtime and working at home)”<br>Response categories: Seldom; 25%; 50%; 75%; 100% | Self-reported symptoms for more than 7 days within the last year of the follow-up period.<br><br>Body regions studied: neck and hand-wrist | *Neck*<br>Total computer use:<br>- 0-25% of work time OR 1<br>- 50% of work time OR 1.5 (0.7-3.1)<br>- 75% of work time OR 1.3 (0.6-2.7)<br>- 100% of work time OR 1.6 (0.8-3.3)<br>Mouse use:<br>- Seldom OR 1.3 (0.4-4.3)<br>- 25% of work time OR 1<br>- 50-100% of work time OR 1.7 (0.5-5.7) | *Hand-wrist*<br>Total computer use:<br>- 0-25% of work time OR 1.5 (0.7-2.4)<br>- 50% of work time OR 1<br>- 75% of work time OR 2.0 (1.1-3.9)<br>- 100% of work time OR 2.3 (1.2-4.3)<br>Mouse use:<br>- Seldom OR 4.0 (1.1-14.4)<br>- 25% of work time OR 1<br>***- 50-100% of work time OR 4.0 (1.0-15.5)*** |
| **BIT**<br>**Juul-Kristensen [21]**<br>42% | See Jensen<br>Analyses restricted to workers who held the same job during follow-up.<br>N = 2002 | See Jensen | **Duration outcome**<br>Self-reported symptoms < 8 days in the past 12 months at baseline and >7 days during follow-up<br>**Intensity outcome**<br>Self-reported symptom intensity < 4 (scale 0-9) during last 3 months at baseline and >= 4 during last 3 months at | *Shoulder duration outcome*<br>Total computer use:<br>- 0–25% of work time OR 1<br>- 50% of work time OR 1.23 (0.63-2.40)<br>- 75% of work time OR 1.00 (0.51-1.94)<br>- Almost all work time OR 0.69 (0.34-1.39)<br>*Shoulder intensity outcome*<br>Total computer use: | *Elbow duration outcome*<br>Total computer use:<br>- 50% of work time OR 1.11 (0.51-2.40)<br>- 75% of work time OR 0.95 (0.43-2.10)<br>- Almost all work time OR 1.08 (0.48-2.39)<br>*Elbow intensity outcome*<br>Total computer use:<br>- 50% of work time OR 1.12 |

| | | | | | |
|---|---|---|---|---|---|
| | | | baseline + nonsymptomatic at both sides (left and right) and nonsymptomatic in nearby body regions<br><br>Body regions studied: elbow and shoulder | - 0-25% of work time OR 1<br>- 50% of work time OR 1.07 (0.60-1.90)<br>- 75% of work time OR 0.95 (0.53-1.70)<br>- Almost all work time OR 0.78 (0.43-1.43) | (0.58-2.18)<br>- 75% of work time OR 0.90 (0.47-1.74)<br>***- Almost all work time OR 1.08 (0.48-2.39)*** |
| NUDATA Andersen [22] **50%** | Employees from the Danish Association of Professional Technicians, i.e. technical assistants (draughtsmen) and machine technicians from 3527 public and private companies. Job tasks included technical drawing tasks, administrative and graphical tasks.<br>N = 5658 | Self-report<br>Participants estimated their average hours per week doing specified work tasks during the past four weeks (separately for tasks using the computer and tasks not using the computer). Questions for keyboard use and mouse use separately. Computer use (=mouse use + keyboard use) not used in the analysis due to high correlation with mouse use. | **Possible Carpal Tunnel Syndrome (CTS):**<br>Self-reported tingling or numbness in the right hand at least once a week within the last 3 months, with no or minor tingling/numbness at baseline.<br><br>Body regions studied: wrist (possible CTS) | Wrist (possible CTS)<br>Mouse use:<br>- 0 - < 2.5 hrs/wk OR 1<br>- 2.5 - < 5 hrs/wk OR 0.7 (0.3-1.9)<br>- 5 - < 10 hrs/wk OR 1.9 (0.9-4.0)<br>- 10 - < 15 hrs/wk OR 1.6 (0.8-3.3)<br>- 15 - < 20 hrs/wk OR 2.0 (0.9-4.2)<br>- 20 - < 25 hrs/wk OR 2.6 (1.2–5.5)<br>- 25 - < 30 hrs/wk OR 3.2 (1.3-7.9)<br>Keyboard use:<br>- 0 - < 2.5 hrs/wk OR 1<br>- 2.5 - < 5 hrs/wk OR 0.9 (0.4-1.8)<br>- 5 - < 10 hrs/wk OR 0.8 (0.4-1.5)<br>- 10 - < 15 hrs/wk OR 1.2 (0.6-2.5)<br>- 15 - < 20 hrs/wk OR 0.8 (0.4-1.5)<br>- >= 20 hrs/wk OR 1.4 (0.5–4.3) | |

| Cohort<br>First author<br>Quality score | Study population | Assessment duration of computer use | Case definition(s) | Results | Results continued |
|---|---|---|---|---|---|
| **NUDATA**<br>**Kryger [23]**<br>42% | See Andersen | Self-report<br>See Andersen | At least moderate to severe self-reported pain in the forearm within the past 7 days combined with quite a lot pain/discomfort during the past 12 months and at baseline none or less than moderate pain in the forearm in the past 7 days combined with less than "some" pain/tenderness during the past 12 months<br><br>Body regions studied: forearm | *Forearm*<br>Mouse use:<br>- 0-9 hrs/wk OR 1<br>- 10-19 hrs/wk OR 2.2 (1.0-4.7)<br>- 20-29 hrs/wk OR 2.6 (1.0-6.6)<br>- >= 30 hrs/wk OR 8.4 (2.5-29)<br>Keyboard use:<br>- 0-4 hrs/wk OR 1<br>- 5-9 hrs/wk OR 1.2 (0.5-2.9)<br>- 10-14 hrs/wk OR 1.3 (0.5-3.4)<br>- >= 15 hrs/wk OR 2.6 (0.9-7.3) | |
| **NUDATA**<br>**Brandt [24]**<br>42% | See Andersen | Self-report<br>See Andersen | Self-reported pain in the last 7 days of at least moderate degree and pain during the last 12 months of follow-up that bothered at least quite a lot and no complaints in the region during the 12 months prior to the baseline examination and less than moderate pain in the regional area during the last 7 days at baseline<br><br>Body regions studied: neck and shoulder | *Neck*<br>Mouse use:<br>- 0-9 hrs/wk OR 1<br>- 10-19 hrs/wk OR 1.1 (0.6-1.9)<br>- 20-29 hrs/wk OR 0.9 (0.4-1.9)<br>- >= 30 hrs/wk OR 2.4 (0.8-6.8)<br>Keyboard use:<br>- 0-4 hrs/wk OR 1<br>- 5-9 hrs/wk OR 1.1 (0.5-2.2)<br>- 10-14 hrs/wk OR 1.0 (0.4-2.2)<br>- >= 15 hrs/wk OR 1.8 (0.8-3.9) | *Shoulder*<br>Mouse use:<br>- 0-9 hrs/wk OR 1<br>- 10-19 hrs/wk OR 1.2 (0.7-2.1)<br>- 20-29 hrs/wk OR 1.9 (1.0-3.5)<br>- >= 30 hrs/wk OR 3.3 (1.2-8.9)<br>Keyboard use:<br>- 0-4 hrs/wk OR 1<br>- 5-9 hrs/wk OR 1.3 (0.7-2.6)<br>- 10-14 hrs/wk OR 1.6 (0.8-3.3)<br>***- >= 15 hrs/wk OR 2.2 (1.0-4.9)*** |

| | | | | | |
|---|---|---|---|---|---|
| **NUDATA**<br>**Lassen [25]**<br>42% | See Andersen | Self-report<br>See Andersen | *Case*<br>Any self-reported pain or discomfort during the past 12 months, but not at baseline<br>*Severe case*<br>Self-reported pain or discomfort lasting for > 30 days and causing at least "quite a lot of trouble" during the past 12 months at follow-up, but not at baseline<br><br>Body region studied: elbow and hand-wrist | *Elbow case*<br>Mouse use:<br>- < 2.5 hrs/wk OR 1<br>- 20 - < 25 hrs/wk OR 3.21 (2.03-5.17)<br>- 25 - < 30 hrs/wk OR 4.83 (2.79-8.40)<br>- >= 30 hrs/wk OR 4.74 (2.51-8.95)<br>Keyboard use:<br>- 0 - < 2.5 hrs/wk OR 1<br>- 2.5 - < 5 hrs/wk OR 1.04 (0.65-1.69)<br>- 5 - < 10 hrs/wk OR 1.47 (0.98-2.26)<br>- 10 - < 15 hrs/wk OR 1.33 (0.85-2.11)<br>- 15 - < 20 hrs/wk OR 1.29 (0.78-2.17)<br>***- >= 20 hrs/wk OR 1.98 (0.96-3.95)*** | *Hand-wrist case*<br>Mouse use:<br>- < 2.5 hours/week OR 1<br>- 2.5 - < 5 hrs/wk OR 1.57 (0.99-2.51)<br>- 5 - < 10 hrs/wk OR 2.16 (1.46-3.22)<br>- 10 - < 15 hrs/wk OR 2.05 (1.37-3.07)<br>- 15 - < 20 hrs/wk OR 2.46 (1.65-3.72)<br>- 20 - < 25 hrs/wk OR 2.07 (1.32-3.26)<br>- 25 - < 30 hrs/wk OR 3.16 (1.82-5.46)<br>- >= 30 hrs/wk OR 3.05 (1.63-5.67)<br>Keyboard use:<br>- Increase of 10 hrs/wk OR 1.29 (1.06-1.57)<br>- 0 - < 2.5 hrs/wk OR 1<br>- 2.5 - < 5 hrs/wk OR 0.63 (0.41-0.98)<br>- 5 - < 10 hrs/wk OR 0.73 (0.50-1.07) |

| Cohort<br>First author<br>Quality score | Study population | Assessment duration of computer use | Case definition(s) | Results | Results continued |
|---|---|---|---|---|---|
| **NUDATA**<br>**Lassen [25]**<br>Continued | | | | *Hand-wrist case*<br>Keyboard use (continued):<br>- 10 - < 15 hrs/week OR 0.80 (0.53-1.20)<br>- 15 - < 20 hrs/week OR 0.87 (0.55-1.38)<br>***- >= 20 hrs/week OR 1.04 (0.51 –2.04)***<br>*Severe elbow case*<br>Mouse use:<br>- < 2.5 hrs/wk OR 1<br>- 2.5 - < 5 hrs/wk OR 1.16 (0.34-3.54)<br>- 5 - < 10 hrs/wk OR 1.42 (0.58-3.64)<br>- 10 - < 15 hrs/wk OR 2.14 (0.93-5.32)<br>- 15 - < 20 hrs/wk OR 1.45 (0.59-3.78)<br>- 20 to < 25 hrs/wk OR 2.88 (1.18-7.54)<br>- 25 to < 30 hrs/wk OR 4.16 (1.45-12.13)<br>- >= 30 hrs/wk OR 6.91 (2.21-22.53)<br>Keyboard use:<br>- < 2.5 hrs/wk OR 1<br>- 2.5 - < 5 hrs/wk OR 1.09 (0.44-3.00)<br>- 5- < 10 hrs/wk OR 1.58 (0.71-4.03)<br>- 10 to < 15 hrs/wk OR 2.49 (1.08-6.53)<br>- 15 to < 20 hrs/wk OR 2.86 (1.08-8.12)<br>- >= 20 hrs/wk OR 3.79 (0.91-14.11) | *Severe hand-wrist case*<br>Mouse use:<br>- < 2.5 hrs/week OR 1<br>- 2.5 - < 5 hrs/wk OR 0.73 (0.23-2.01)<br>- 5 - < 10 hrs/wk OR 1.55 (0.74-3.34)<br>- 10 - < 15 hrs/wk OR 1.40 (0.68-3.01)<br>- 15 - < 20 hrs/wk OR 1.68 (0.82-3.58)<br>- 20 to < 25 hrs/wk OR 4.21 (2.12-8.85)<br>- 25 to < 30 hrs/wk OR 4.81 (2.18-10.99)<br>***- >= 30 hrs/wk OR 2.30 (0.83-6.26)***<br>Keyboard use:<br>- < 2.5 hrs/wk OR 1<br>- 2.5 - < 5 hrs/wk OR 1.14 (0.58-2.38)<br>- 5- < 10 hrs/wk OR 0.99 (0.54-1.95)<br>- 10 to < 15 hrs/wk OR 1.46 (0.76-2.98)<br>- 15 to < 20 hrs/wk OR 1.89 (0.90-4.10)<br>- >= 20 hrs/wk OR 1.60 (0.43-4.94) |

| | | | | |
|---|---|---|---|---|
| **Bergqvist et al. Bergqvist [19]**<br>42% | Employees working for seven companies in Stockholm, Sweden: travel agencies, a newspaper production company, postal office, and an insurance company. Included employees worked at least 75% of a full time contract.<br>N = 341 | Self-report<br>"How many hours per week did you work at the Visual Display Terminal?" Responses were categorized into three categories: no or occasional; < 30 hours/week; > 30 hours/week | Current self-reported pain or discomforts. Symptoms that occurred only occasionally and were of insignificant intensity were not taken into account.<br><br>Body regions studied: neck-shoulder; hand-wrist | *Neck-shoulder*<br>Total computer use:<br>- > 30 hrs/wk versus no or occasional total computer use<br>RR 1.25 (0.76-2.05) [univariate analysis]<br>*Hand-wrist*<br>Total computer use<br>- > 30 hrs/wk versus no or occasional total computer use<br>RR 3.75 (0.89-15.81) [univariate analysis] |

| Cohort<br>First author<br>Quality score | Study population | Assessment duration of computer use | Case definition(s) | Results | Results continued |
|---|---|---|---|---|---|
| **Marcus et al.**<br>**Marcus [26]**<br>75% | Newly hired workers who 1) anticipated using a computer for at least 15 hrs/wk, and 2) anticipated using a computer keyboard for at least as many hrs/wk as in their previous job. Job sectors included insurance, finance, food production, health care, and education.<br>N = 436 – 520 | Self-report, daily diary on hours spent keying | **Musculoskeletal symptoms**<br>Self-reported discomfort in weekly diary which was present at least one day during previous week and pain score (VAS) > 6 or using medication for control of the discomfort.<br>**Musculoskeletal disorders**<br>Positive if case definition for musculoskeletal symptoms was met and physical examination was positive.<br><br>Body regions studied: hand-arm, neck-shoulder | Neck-shoulder symptoms<br>Total computer use:<br>- Increase of 1 hr/wk HR 1.01 (0.99-1.03)<br>- 35 hrs/wk versus 15 hrs/wk HR 1.22 (0.82 - 1.81)<br>*Neck-shoulder disorders*<br>Total computer use:<br>- Increase of 1 hr/wk HR 1.01 (0.99-1.04)<br>- 35 hrs/wk versus 15 hrs/wk HR 1.22 (0.82 - 2.19) | Hand-arm symptoms<br>Total computer use:<br>- Increase of 1 hr/wk HR 1.04 (1.02-1.06)<br>- 35 hrs/wk versus 15 hrs/wk HR 2.19 (1.49 - 3.20)<br>Hand-arm disorders<br>Total computer use:<br>- Increase of 1 hr/wk HR 1.04 (1.02-1.06)<br>**- 35 hrs/wk versus 15 hrs/wk HR 2.19 (1.49 - 3.20)** |
| Korhonen et al<br>Korhonen [27]<br>50% | Full time working employees from three municipal administrative units.<br>N = 138 | Estimate how many percent of your working time during the preceding month you have used for each task of the following tasks (VDU work includes using keyboard or other input or control device, including short thinking periods and checking the results on the screen).<br>Response categories: < 50%, > 50% of work time | Local or radiating self-reported neck pain at follow-up for at least 8 days during the last 12 months AND experiencing local or radiating neck pain < 8 days at baseline.<br><br>Body regions studied: neck | *Neck*<br>Total computer use:<br>- < 50% of work time OR 1<br>- >= 50% of work time OR 1.0 (0.6-2.9)<br>[univariate analysis] | |

Table 3 Results of the methodological quality assessment.

| Cohort<br>First author | Study design | | Exposure and outcome assessment | | | | | | Data analysis | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1. Participation rate | 2. Response at follow- up | 3. Duration computer use | 4. Ergonomic factors | 5. Psychosocial factors | 6. Physical factors leisure time | 7. Exposure change | 8. Outcome | 9. Statistical model | 10. Confounding | 11. Statistical power | Score * (%) |
| **BIT** | | | | | | | | | | | | |
| **-** Jensen (20) | ? † | ? | ? | ? | ? | - | + | + | + | + | + | **45** |
| **-** Juul-Kristensen (21) | ? | ? | ? | ? | ? | - | + | + | + | + | + | **45** |
| **NUDATA** | | | | | | | | | | | | |
| **-** Andersen (22) | ? | + | ? | ? | ? | + | + | + | + | + | + | **64** |
| - Kryger (23) | ? | + | ? | ? | ? | + | ? | + | + | + | + | **55** |
| - Brandt (24) | ? | + | ? | ? | ? | + | ? | + | + | + | + | **55** |
| - Lassen (25) | ? | + | ? | ? | ? | + | ? | + | + | + | + | **55** |
| **Bergqvist et al.** | | | | | | | | | | | | |
| - Bergqvist (19) | + | + | ? | ? | ? | ? | + | ? | + | - | + | **45** |
| **Marcus et al.** | | | | | | | | | | | | |
| - Marcus (26) | + | + | ? | + | ? | + | + | ? | + | + | + | **73** |
| **Korhonen et al.** | | | | | | | | | | | | |
| - Korhonen (27) | + | ? | ? | ? | ? | + | ? | + | + | + | + | **55** |
| **Positive (%)** | **33** | **67** | **0** | **11** | **0** | **67** | **56** | **78** | **100** | **89** | **100** | |

* the percentage of positive items over the total number of items

† + = positive, - = negative and ? = unclear (insufficient information available)

*Methodological quality assessment*

Methodological quality assessment of the articles is presented in table 3. The kappa coefficient for the agreement between the ratings of the individual items (positive versus negative or unclear) of the two reviewers was 0.91 (disagreement on 5 out of 108 scored items). One item needed a decision of the third reviewer (AvdB); agreement on the other items was reached during the consensus meeting. Eight out of nine corresponding authors replied to our invitation to discuss the quality assessment. Based on the information, five unclear scores were replaced by positive scores. Six studies had a quality score exceeding 50%, which we considered as the cut off point for high quality. (22 - 27)

*Levels of evidence*

Figures 1 and 2 present point estimates and 95% confidence intervals, derived from the original articles, for the associations between the duration of total computer use, mouse use and keyboard use and hand-arm and neck-shoulder symptoms and disorders, respectively. We excluded one of the associations studied by Bergqvist et al (19), because the case-definition involved anatomical locations from both the hand-arm and the neck-shoulder region. Risk estimates were in general larger for mouse use than for total computer use and keyboard use. For neck-shoulder symptoms and disorders, fewer associations were positive than for hand-arm symptoms and disorders.

For hand-arm symptoms and disorders, moderate evidence was concluded for the association with duration of mouse use, since all studies showed a positive association, including three high quality studies based on the NUDATA cohort. (22, 23, 25) However, these were counted as one study. For the duration of total computer use and the duration of keyboard use insufficient evidence was concluded, since inconsistent results were found. For the duration of total computer use, associations from three cohorts were available. Only the NUDATA cohort investigated the duration of keyboard use.

For neck-shoulder symptoms and disorders, insufficient evidence was concluded for the duration of mouse use and the duration of keyboard use, since inconsistent results were found. For both mouse and keyboard use only the NUDATA cohort investigated the association with neck-shoulder symptoms and disorders. For the duration of total computer use, all tested associations failed to show a positive association. Four cohorts investigated total computer use, including two high quality studies. (26, 27)

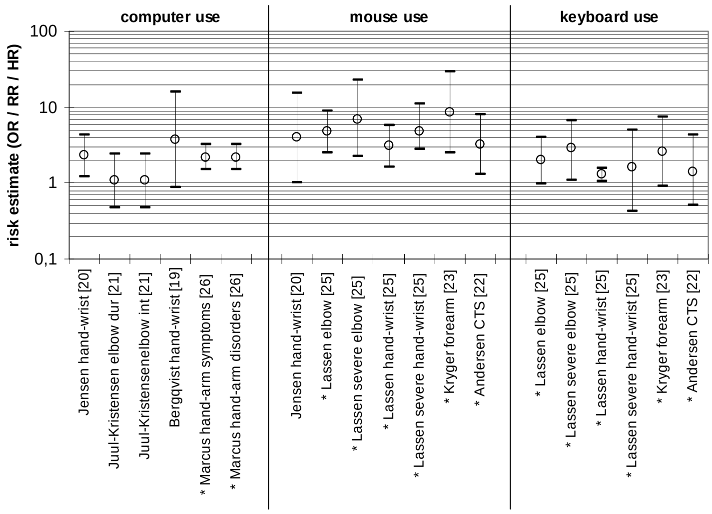


Figure 1 Risk estimates for the association between duration of computer use and hand-arm symptoms and disorders. See the italic numbers in the results columns of table 2 for exact values. (* = High quality study)

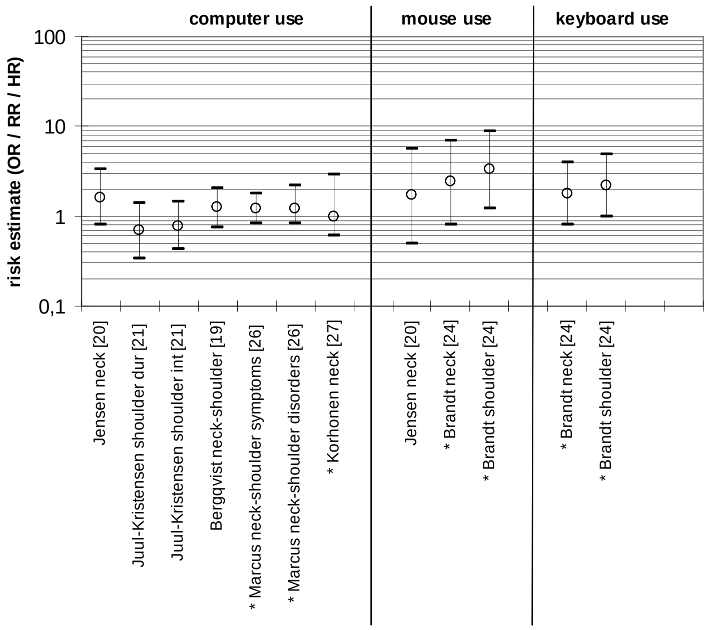


Figure 2 Risk estimates for the association between duration of computer use and neck-shoulder symptoms and disorders. See the italic numbers in the results columns of table 2 for exact values. (* = High quality study)

*Dose-response analysis*

Following the criteria set beforehand, we analyzed the relationship between the duration of mouse use and the incidence of hand-arm symptoms. In general, an increase in risk over duration categories can be observed from figure 3. However, the association between mouse use and hand-wrist symptoms reported by Jensen (20) and the association between mouse use and “severe” hand wrist pain found by Lassen and co-workers (25) did not show a clear increasing risk over duration categories (see figure 3). Jensen (20) reported an increased risk (OR 4.0) at a rather short duration of mouse use (i.e. approximately 4.5 hours per week), as well as an increased risk (OR 4.0) at a long duration of mouse use (i.e. approximately 27 hours per week). Lassen and co-workers (25) presented a drop in risk from 4.8 to 2.3 for their highest exposure category (i.e. > 30 hours per week).

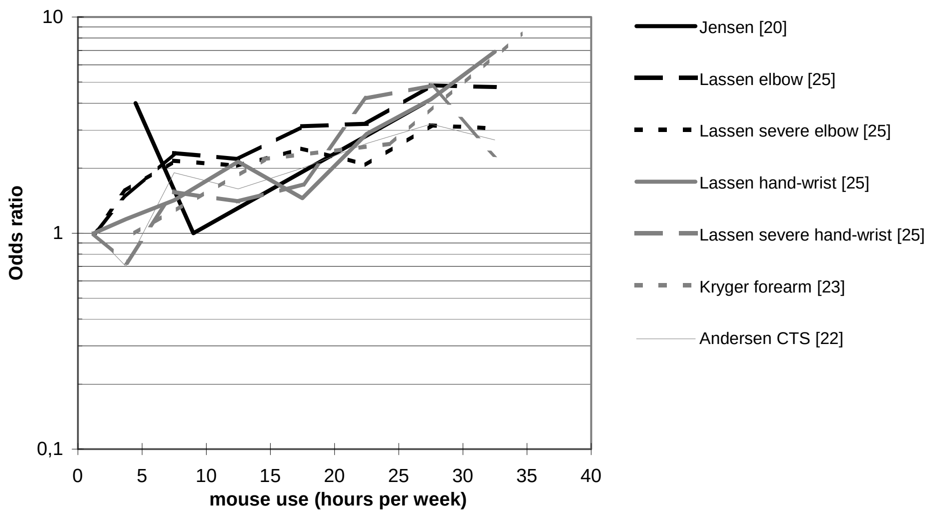


Figure 3 Odds ratios for the association between the duration of mouse use and hand-arm symptoms.

## Discussion

The results of this review of longitudinal studies confirm the finding of previous reviews. The duration of computer use was more consistently associated with hand-arm than with neck-shoulder symptoms and disorders. (6, 9) In addition, our review adds to the existing literature the observation that the duration of mouse use was more strongly and more consistently associated with the incidence of hand-arm symptoms than the duration of total computer use and keyboard use.

*Methodological considerations*

The studies included in this review all have substantial methodological quality, since they were based on longitudinal study designs and all but one scored positive on the quality items concerning statistical analysis. Still, the design of future studies might be improved by taking into account a number of methodological limitations that are present in the published studies.

First, all studies used self-report measurements to assess the duration of computer use. No study reported data on the test-retest reliability of these self-reports. Low test-retest reliability might be related to a poor validity of exposure measures. Moreover, several studies have shown that self-report measurements, on average, strongly overestimate the duration of computer use, resulting in misclassification. (28, 29) Assuming that this misclassification is nondifferential, this would lead to an underestimation of the true exposure-response relationship. (30) A recent development is the use of computer software to objectively measure the duration of computer use. Such software showed good agreement with observation, (31) and has already been used in an epidemiological study. (29)

Second, most studies in this review solely measured the duration of total computer use. General measures of the duration of computer use might not be able to detect the variability in the duration of mouse and keyboard use. This might explain the stronger risk estimates for the duration of mouse use in comparison with those for the duration of total computer use. However,

within the NUDATA cohort total computer use was not analyzed since it was highly related to mouse use. (22)
Third, all included articles had study populations consisting solely of computer users. This might have led to a limited exposure contrast (i.e. only the contrast present within the group of computer users) and a limited power to explain the contributing factors to the incidence of hand, arm, shoulder and neck symptoms among computer users. (6)
Fourth, most case definitions were based on arbitrary cut off points, based on the number of days on which pain or discomfort was experienced. In the NUDATA study (24, 25) very few participants met the criteria for a clinical diagnosis during follow-up (i.e. less than 2% incidence for both neck-shoulder and hand-arm disorders). In addition, self-reports showed very mild disability. In contrast to the NUDATA study, the study by Marcus and co-workers (32) showed a high incidence of clinical diagnoses (i.e. 35% incidence of neck-shoulder disorders and 21% incidence of hand-wrist disorders). One of the explanations for this difference between studies might be that the population studied by Marcus and co-workers consisted of newly hired workers. Newly hired workers might be more prone to health complaints, because they are not experienced with the physical and psychosocial exposures they have to deal with in the new job. The difference might also be attributed to selection effects within the NUDATA cohort: workers who are susceptible to or have suffered from hand, arm, shoulder or neck symptoms and disorders might have migrated to jobs with lower durations of exposure or might have left the workforce. Kryger and co-workers (23) indicated that the criteria used to establish a clinical diagnosis might be different between the NUDATA study and the one reported by Marcus and co-workers. In addition, it should be noted that physical examination might not have sufficient interobserver reliability (33) and that information on validity is largely unknown. (34)
Based on the limitations of physical examinations on the one hand, and the identical risk estimates for self-reported symptoms and clinically diagnosed disorders in the study by Gerr and co-workers (26) on the other hand, self-

reports of the degree of disability caused by symptoms might be preferred to grade the severity of symptoms in future epidemiological studies.
In order to estimate safe levels of the duration of computer use more precisely, more high quality studies are needed. These studies should focus on measuring the duration of computer use in a more objective way, differentiating between total computer use, mouse use and keyboard use, attaining sufficient exposure contrast, and collecting data on disability caused by symptoms.

*Sensitivity analysis*
The levels of evidence proposed in this review might have been influenced by arbitrary decisions concerning the criteria used in the methodological quality assessment. The methodological quality score ranged between 45 and 73%, with seven out of nine studies scoring between 45 and 55%. Based on this distribution, our a priori cut-off point of > 50% might have influenced the levels of evidence and potentially the results of this review. Shifting the cut-off point from > 50% to > 40%, would have only changed the level of evidence for the combination mouse use and hand-arm symptoms and disorders. Strong evidence, instead of moderate evidence, would have been concluded. In contrast, shifting the cut-off point to > 60%, would not have influenced our levels of evidence at all.
Variation of exposure contrasts between studies might also have influenced the levels of evidence via the consistency of results. Studies analyzing a limited exposure contrasts are less likely to find a positive association than studies analyzing large exposure contrasts. Large variations in exposure contrast between studies were only available for the associations between the duration of total computer use and both hand-arm and neck-shoulder symptoms and disorders. However, variation in exposure contrast was not likely to influence the levels of evidence for these associations. For the association between the duration of mouse use and neck-shoulder symptoms, a higher exposure contrast in the study by Jensen (20) might have lead to a positive association. In that case moderate evidence instead of insufficient evidence would have been concluded.

*Dose-response analysis*

In general, the dose-response analysis for hand-arm symptoms showed an increase in point estimates over an increasing duration of mouse use. Jensen and co-workers (20) presented an increased risk at a rather low duration of mouse use and again at a high duration of mouse use. It is possible that residual confounding was present in their study, because subjects who had a low exposure to mouse use might have had a high exposure to keyboard use, leading to a long duration of total computer use and thus an increased risk.

Lassen and co-workers (25) showed a decreased risk for developing severe hand-wrist pain at their highest exposure category (i.e. > 30 hours per week). A possible explanation is a saturation of biological pathways, or the presence of less susceptible workers at the highest exposure category due to selection in the past. (35)

To be able to explore a dose-response relationship we assumed that the relation between the point estimates of increasing exposure categories was linear. In addition, we had to estimate the average exposure within an exposure category. Both these factors might have biased our findings. However, these assumptions did not influence our general conclusion that the risk of developing hand-arm symptoms is higher at longer self-reported durations of mouse use.

*Biological plausibility*

The studies in this review that investigated the effects of the same exposure contrast on both the hand-arm and the neck-shoulder region, generally showed stronger risk estimates for the hand-arm region than for the neck-shoulder region. Studies on muscle activity during computer use are in line with these findings, since they indicate a higher loading of the hand-arm region (extensors of the wrist) compared to the neck-shoulder region (trapezius muscle). (36, 37, 38) In addition, Laursen and co-workers (39) found fewer EMG gaps in the extensor muscles of the wrist compared to the trapezius muscle during computer use, potentially indicating longer periods of continuous activation of local muscle fibers belonging to the same motor unit. The findings from both lines of research are supported by a hypothesis, which attributes a central role to the overuse of muscles and the physiological consequences of this overuse in the pathophysiological mechanism underlying hand, arm, shoulder and neck symptoms and disorders. (40)

Stronger risk estimates were found for mouse use than for keyboard use and total computer use. This difference can also be interpreted using the muscle overuse mechanism described above. Less variation in working postures during mouse use has been observed in comparison to keyboard work, (36, 41) potentially leading to a longer duration of continuous muscle loading. (42)

Based on the above, it seems that evidence for a pathophysiological mechanism is available. However, caution is needed. The central role of muscles in the pathophysiological mechanism has been criticized. (43) In addition, it should be borne in mind that the evidence found in this review for and against associations, was based on a limited number of studies. In addition, data for the effects of mouse and keyboard use are for the larger part derived from the NUDATA cohort. The possibility that a long duration of keyboard use can be a risk factor for developing hand, arm, shoulder or neck symptoms and disorders cannot be excluded, since only a limited range of exposures to keyboard use was available in the NUDATA cohort.

*Limitations of this review*

The conclusions of this review are based on a rather low number of cohort studies. Therefore, it is possible that the conclusions might change when new studies will become available in the future.

A second limitation is that we compared studies with different case definitions. This might have influenced the results. Future research might indicate whether the associations between the duration of computer use and hand-arm or neck-shoulder symptoms are sensitive to these differences in case definition.

In addition, our review focused on only one contributing factor to the incidence of hand-arm and neck-shoulder symptoms and disorders among computer users (i.e. duration of computer use). This does not represent the general concept of a multifactorial origin of musculoskeletal disorders. (6) (9) Moreover, it might be possible that other factors related to computer use (such as working postures or mental demands) act as effect modifiers of the association between the duration of computer use and hand-arm and neck-shoulder symptoms. A combination of, for example, high mental demands and long duration of computer use might lead to a higher incidence than a long duration of computer use per se. This might explain the observed variation between study populations of the effect of a longer daily duration of computer use.

*Conclusion*

This review showed moderate evidence for an association between the duration of mouse use and the incidence of hand-arm symptoms. Indications for a dose-response were found. In addition, the neck-shoulder region seemed less susceptible to exposure to computer use than the hand-arm region. Both findings are supported by a pathophysiological mechanism based on the overuse of muscles during computer use. The low number of high quality studies prevents drawing a firm conclusion. More research is needed to confirm our findings.

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# 3

# Test-retest reliability and concurrent validity of a web-based questionnaire measuring workstation and individual correlates of work postures during computer work

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**Abstract**

Introduction: “Ergonomic” questionnaires are widely used in epidemiological field studies to study the association between workstation characteristics, work posture and the onset of arm-wrist-hand and neck-shoulder disorders among office workers. Findings have been inconsistent regarding the putative adverse effect of work postures. Underestimation of the true association might be present in studies due to misclassification of subjects to risk (i.e. exposed to non-neutral working postures) and no-risk categories (i.e. not exposed to non-neutral working postures) based on questionnaire responses. The objectives of this study were to estimate the amount of misclassification resulting from the use of questionnaires.
Methods: Test-retest reliability and concurrent validity was assessed of a newly developed questionnaire, which collects data on workstation characteristics and on individual characteristics during computer work (i.e. work postures, movements and habits). Pictures were added where possible to provide visual guidance. The study population consisted of 84 office workers of a research department. They filled out the questionnaire on the internet twice, with an in-between period of two weeks. For a subgroup of workers (n=38) additional on-site observations and multiple manual goniometer measurements were performed.
Results: Percentage agreement ranged between 71% and 100% for the test-retest analysis, between 46% and 100% for the agreement between questionnaire and on-site observation, and between 26% and 71% for agreement between questionnaire and manual goniometer measurements. For 9 out of 12 tested items the percentage agreement between questionnaire and manual goniometer measurements was below 50%.
Conclusions: The questionnaire can be used to collect data on workstation characteristics, and some individual characteristics during computer work (i.e. work movements and habits), but does not seem to be useful to collect data on work postures during computer work in epidemiological field studies among office workers.

## Introduction

According to a review by Gerr and co-workers, previous epidemiological studies have provided inconsistent results regarding the role of work posture in the occurrence of hand, arm, shoulder and neck symptoms among office workers (1). Also, longitudinal studies published after this review have yielded negative findings (i.e. absence of association) or inconsistent findings regarding the risk of non-neutral work postures and workstation characteristics for the occurrence of hand, arm, shoulder and neck symptoms (2 - 8). One of the reasons for the lack of consistent positive findings might include differences in test-retest reliability and/or concurrent validity of the used measurement instruments to collect data on work postures during computer work. Insufficient test-retest reliability or concurrent validity of a measurement instrument is likely to lead to non-differential misclassification of subjects to risk (exposed) categories and reference (non-exposed) categories in an epidemiological study. As a result, underestimation of the true association between work postures and hand, arm, shoulder and neck symptoms might occur (9, 10). It is difficult to investigate this possibility, since data on the test-retest reliability and validity of questionnaires used in office populations is very scarce (11, 12). The use of questionnaires has the advantage of collecting data in a large group of workers against reasonable costs. In addition, information on a great variety of factors over a long period of time can be gathered. However, concerns regarding the validity of questionnaires to measure work postures have also been stated (13). The alternatives for questionnaires to validly measure work postures include on-site observations and direct measurements. These types of measurements are supposed to be more reliable and valid, but are more costly and less feasible when used in large groups of workers. Therefore, the search for useful questionnaires is still on.

Heinrich and co-workers (14) determined the agreement between a questionnaire measuring work postures and on-site observations of work postures by a trained observer in a population of computer workers. They

concluded that the questionnaire was not valid to assess work postures (i.e. the agreement between questionnaire and observation was low). One of their recommendations was to add pictures to the questionnaire. Based on this recommendation, we constructed a new questionnaire with pictures added to the items, which focuses on work postures during computer work. In addition, we developed questions that could be filled out easily by computer workers. These questions merely focus on workstation characteristics, since the computer workers themselves can observe these easily while working with the computer.
The objectives of this study were to estimate the amount of misclassification resulting from the use of a newly developed questionnaire to classify the exposure to non-neutral work postures during computer work. Therefore, test-retest reliability and concurrent validity with on-site observations and manual goniometer measurement were evaluated.

## Methods

*Design*

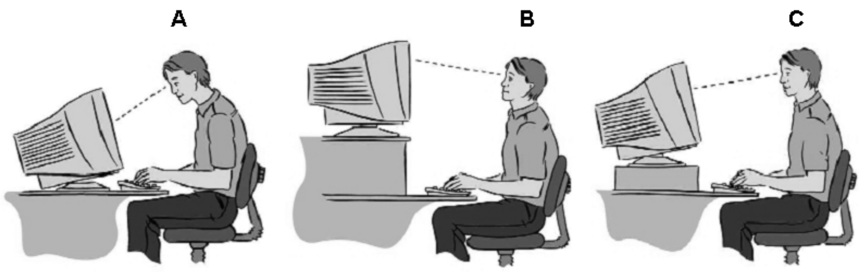
Employees of a research department of a university medical centre in the Netherlands were invited by e-mail to fill out a web-based questionnaire twice, with an in-between period of two weeks. In addition, a team of researchers walked around the department and asked individual employees to join the study. Subjects who joined the study were asked whether they approved additional measurements: observation of the same items as in the questionnaire and measurements of work postures with a manual goniometer. These measurements took place after the first questionnaire had been filled out. No exclusion criteria were applied. Participants signed informed consent sheets.

*Questionnaire*

The questionnaire contained 13 items on workstation characteristics and 12 items on individual characteristics during computer work (i.e. work postures, movements and habits). See Table 2 for more details. Pictures were added where possible to provide visual guidance. An example is presented in Figure 1. In total, 16 items were supported with a picture. The participants were invited by e-mail to fill out the web-based questionnaire. The e-mail contained a link that guided participants to the webpage with the questionnaire.

*Observation*

Two observers performed the observations. Each observer measured half of the subgroup of workers, who approved these additional measurements. The observer used a checklist containing exactly the same items and response categories as the questionnaire. The observer asked the employee to adopt his or her usual work posture and to try to ignore the observer. After the observation, the observer measured the distance from table edge to the keyboard edge with a tape measure.




Please indicate your monitor height. Please remain seated as usual. Do not sit upright if you usually do not sit upright.

A. Lower than eye height

B. Higher than eye height

C. At eye height or a little lower

Figure 1 Example of a questionnaire item with added picture.

*Manual goniometer measurements*

We decided to conduct manual goniometer measurements in accordance with measures made within a longitudinal study among computer users (15). In addition, data were available that supported the reliability of this method among computer workers (16).

Seven postural angles were measured six times using a manual goniometer. Participants were measured twice, once in the morning and once in the afternoon, on three different days. Both raters in this study were Health Sciences students who were trained to measure postural angles with a manual goniometer during four training sessions. Before, during and after the measurements, their inter-rater reliability was evaluated.

Measurement methods were based on those applied by Ortiz and co-workers (16). Postural angles of the wrist (radial and ulnar deviation, extension and flexion), elbow (flexion), shoulder (abduction and flexion) and head (tilt) were measured. Measurements were performed with inexpensive, commercially available manual goniometers (Bodybow-Holland, The Netherlands). Table 1 illustrates the protocol for arm and pivot placement of the goniometer. A 30-centimetre goniometer was used for measurements of elbow, shoulder and head tilt angle, and a 15-centimetre goniometer was used for measurements of wrist angles. In order to allow measurements relative to the true vertical, the 30-centimetre goniometer was modified by adding a carpenter’s level to one of its arms.

The angles were measured only at the side of the body where the mouse was placed. This choice was based on the results of Gerr and co-workers (17), who showed minor differences between measurements at the left and the right side of the body.

Each participant was approached unexpectedly while he or she used the computer. If a participant was not using the computer, the rater would return later to this participant to perform the measurements. Computer use included looking at the computer screen and using keyboard and mouse. The rater asked the participant to freeze until all angles were measured. The rater registered the measured angles and the type of input device use (mouse use or keyboard use). Measurements took 5 minutes at maximum, on each of the six occasions.

Table 1 Placement of goniometer pivot and arms for each postural measurement (16).

| **Postural angle (measured in degrees)** |
|---|
| Wrist ulnar/radial deviation |
| - pivot placed on midpoint between ulnar and radial styloid processes |
| - first arm placed at the midline of dorsal aspect of the forearm |
| - second arm aligned with the midline of the long finger metacarpophalangeal joint. |
| Wrist flexion/extension |
| - pivot placed on the radial styloid process |
| - first arm aligned with the radius |
| - second arm aligned with the midline of the index finger metacarpophalangeal joint |
| Elbow flexion |
| - pivot placed on lateral epicondyle of the humerus |
| - first arm aligned with the acromion process of the shoulder |
| - second arm aligned with the ulnar styloid process |
| Shoulder flexion/extension |
| - pivot placed on lateral aspect of acromion process of the shoulder |
| - first arm aligned vertically (carpenter's level for reference) |
| - second arm aligned with the lateral epicondyle of the humerus |
| Shoulder abduction/adduction |
| - pivot placed on posterior aspect of acromion process of the shoulder |
| - first arm aligned vertically (carpenter's level for reference) |
| - second arm aligned with posterior midline of upper arm |
| Head tilt |
| - pivot placed on the tragion |
| - first arm aligned vertically (carpenter's level for reference) |
| - second arm aligned with the infraorbitale of the eye |

*Statistical analysis*

Our main goal was to evaluate the amount of misclassification of subjects to risk (exposed) and reference (non-exposed) categories based on questionnaire data when compared with more precise and more accurate data collection methods (i.e. on-site observations and manual goniometer measurements). The response categories of all questionnaire items were dichotomized a priori into a risk category (non-neutral work posture) and a no-risk category (neutral work posture) in order to minimize exposure misclassification. The definition of these categories can be found in Table 2.

Limited test-retest reliability can be an independent source of exposure misclassification and was evaluated at first. Secondly, the agreement between the questionnaire data and the on-site observations was evaluated. On-site observations of elbow, forearm and wrist support during keyboard and mouse use were not performed, because the items were too difficult to observe. Finally, questionnaire data was compared with the manual goniometer measurements. For each subject we calculated the mean angle, based on the available measurements for that subject. In addition, some questionnaire items referred to a specific type of input device use: keyboard use or mouse use. If the input device use, displayed by a subject during a measurement occasion, did not correspond to the type of input device use of the questionnaire item, the recorded postural angle was excluded from the calculation of the mean postural angles for that subject. We selected questionnaire items with response categories that theoretically could separate neutral and non-neutral work postures (see Appendix 1). Table 2 shows corresponding questionnaire items and measured postural angles.

Two types of analysis were performed with the manual goniometer data. For the dichotomized questionnaire items, we calculated the mean angles measured with the manual goniometer and standard deviations. No statistical tests were performed, because small groups were expected. The main emphasis was to evaluate whether the expected direction of the differences, as described in the appendix, could be verified. In addition, the mean measured postural angles were dichotomized in a neutral and a non-neutral category (see Table 2) and compared with the dichotomized questionnaire data.

Table 2 Categorization of corresponding questionnaire response categories and manual goniometer measurements.

| Questionnaire | No Risk (Neutral) | Risk (Non-neutral) | Postural angle | Non-neutral category (degrees) |
|---|---|---|---|---|
| **Workstation characteristics** | | | | |
| Distance keyboard to table edge | Less than 10 centimetres | At least 10 centimetres | Shoulder flexion | > 25 [a] |
| Keyboard tilt | Keyboard pins not folded out (no tilt) | Keyboard pins folded out (tilt) | Wrist extension | > 15 [b] |
| Keyboard type | Split or compact keyboard | Normal, laptop, other | Wrist deviation | > 10 (ulnar) [b]; < -5 (radial) [b,c] |
| Keyboard height | At or slightly below elbow height | Above or below elbow height | Elbow flexion | < 121 [c] |
| Mouse type | Trackball | All other types | Wrist deviation | > 10 [b] |
| Monitor location | In line with keyboard | To the left or the right of the keyboard | - [d] | |
| Chair height | Knees at hip height | Knees lower or higher than hip height | - [d] | |
| Mouse characteristics: | | | | |
| - Ball | - No Ball | - Ball | [d] | |
| - Light | - Light | - No light | [d] | |
| - Wireless | - Wireless | - Not wireless | [d] | |
| - Scroll wheel | - No scroll wheel | - Scroll wheel | [d] | |
| Monitor height | Lower or at eye height | Higher than eye height | Head tilt | > 3 [c] |
| Mouse location | Directly aside the keyboard or in front of the keyboard | Not directly aside the keyboard, other location | Shoulder abduction | > 15 [a] |

| | | | | |
|---|---|---|---|---|
| **Individual characteristics** | | | | |
| Mouse handedness | Left | Right and variation between hands | Shoulder abduction | > 15 [b] |
| Use of document holder | Use of a document holder (when working with documents while using the computer) | No use of a document holder (when working with documents while using the computer) | Head tilt | > 3 [c] |
| Touch-typing | Looking at the monitor and or document while typing | Looking at hands or alternating between monitor / document and screen ("hunt and peck") while typing | Head tilt | > 3 [c] |
| Number of fingers used for typing | Ten | One to nine | Head tilt | > 3 [c] |
| Mouse movement | From the whole arm | From the wrist only | Wrist deviation | > 10 (ulnar) [b]; < -5 (radial) [b,c] |
| Neck rotation | No | Yes | | |
| Sitting posture | Straight back | Flexed back | - [d] | |
| Forward chin movement while looking at the monitor | Regularly | Infrequent or never | - [d] | |
| Support of elbow during keyboard use | Yes | No | - [d] | |
| Support of wrist or forearm during keyboard use | Yes | No | - [d] | |
| Support of elbow during mouse use | Yes | No | - [d] | |
| Support of wrist or forearm during mouse use | Yes | No | - [d] | |

[a] Gerr et al. (17)
[b] Juul-Kristensen et al. (20)
[c] Marcus et al. (15)
[d] no concurrent measurement available

In all analyses percentages of agreement were calculated. Low overall percentage agreement could be due to lack of agreement on the presence of non-neutral work posture, the absence of non-neutral work postures or both. Since neither the first nor the second questionnaire could be considered the “gold standard”, we calculated positive agreement, i.e. percentage of “average” agreement for identifying the non-neutral work posture and negative agreement, i.e. percentage of “average” agreement for identifying the neutral work posture, to provide more insight into the drivers of the overall percentage agreement (18). Sensitivity and specificity statistics were added instead of positive and negative agreement if the questionnaire data was compared with the on-site observations and the manual goniometer measurements, because on site-observations and manual goniometer measurements were assumed to be “gold standards”. Sensitivity reflects the percentage of workers correctly classified to the risk category (i.e. non-neutral work posture) based on the questionnaire data. Specificity reflects the percentage of workers correctly classified to the no-risk category (i.e. neutral work posture) based on the questionnaire data. Calculation of two-by-two tables, means and standard deviations was performed in SPSS (version 12.0). Percentage agreement, sensitivity and specificity statistics were calculated using a web-based application (http://faculty.vassar.edu/lowry/clin1.html). Finally, 95% Confidence intervals were calculated using the Wilson score method with continuity correction (19).

## Results

In total, 84 employees participated in the study. The participation rate was approximately 50%. All filled out the first questionnaire and 81 employees (96%) also filled out the second questionnaire. The average time between the questionnaires was 16 days (standard deviation: 5 days). In total, 70% of the study population was female and the mean age was 39 years (standard deviation: 10 years). In the three months preceding the questionnaire, 26% of the study population reported to experience regular

or long-lasting hand, arm, shoulder or neck symptoms. Self-reported duration of computer use at work (i.e. keyboard use, mouse use, or reading from the screen) ranged from 1 to 2 hours per day to more than 8 hours per day, with 43% of the participants reporting 6 to 8 hours of computer use per day. Other work tasks besides tasks requiring computer use included attending meetings, phoning and giving presentations.
In total, 38 participants (45% of the study population) approved additional observations and measurements. These participants were representative for the study population, regarding the mean time between the questionnaires, gender, age, history of symptoms, and self-reported duration of computer use at work. The original two-by-two tables, based upon which statistics were calculated, are presented in Appendix 2.

*Test-retest reliability*
The results of the analyses to evaluate test-retest reliability, agreement between questionnaire and observations, and agreement between questionnaire and manual goniometer measurement, are presented in Table 3. Percentage agreement ranged from 71-100%. The five items with the lowest percentage of agreement scored below 80% agreement: keyboard height, sitting posture, neck rotation, elbow support during keyboard use and elbow support during mouse use. For keyboard height elbow support during keyboard use and elbow support during mouse use, the proportions of specific agreement showed that agreement on the presence of risk (non-neutral work posture) were lower than agreement on absence of risk (neutral work posture). The corresponding percentages were 54% and 86% for keyboard height, 60% and 79% for elbow support during keyboard use, and 70% and 85% for elbow support during mouse use.

Table 3 Percentages agreement, positive agreement and negative agreement for the test-retest analysis.

| | Percentage agreement (95%CI) | Positive agreement [a] (95%CI) | Negative agreement [b] (95%CI) |
|---|---|---|---|
| **Workstation characteristics** | | | |
| Distance keyboard to table edge | 86 (77-93) | 56 (26-80) | 92 (81-96) |
| Keyboard tilt | 90 (81-95) | 91 (78-97) | 89 (72-96) |
| Keyboard type | 100 (94-100) | 100 (94-100) | 100 (40-100) |
| Keyboard height | 79 (68-90) | 54 (29-75) | 86 (74-93) |
| Mouse type | 96 (89-99) | 98 (90-100) | 40 (2-87) |
| Monitor location | 98 (91-100) | 88 (47-99) | 99 (92-100) |
| Chair height | 100 (94-100) | 100 (31-100) | 100 (94-100) |
| Mouse characteristics: | | | |
| - Ball | 98 (91-100) | 98 (90-99) | 94 (69-100) |
| - Light | 99 (92-100) | 99 (91-100) | 96 (64-100) |
| - Wireless | 100 (94-100) | 100 (94-100) | 100 (40-100) |
| - Scroll wheel | 95 (87-98) | 97 (89-100) | 78 (40-96) |
| Monitor height | 88 (78-94) | 71 (44-89) | 92 (82-97) |
| Mouse location | 83 (72-90) | 84 (70-92) | 74 (55-87) |
| **Individual characteristics** | | | |
| Mouse handedness | 100 (94-100) | 100 (56-100) | 100 (94-100) |
| Use of document holder | 95 (87-98) | 97 (90-100) | 50 (9-91) |
| Touch-typing | 96 (89-99) | 97 (85-99) | 95 (78-99) |
| Number of fingers used for typing | 99 (92-100) | 99 (88-100) | 98 (81-100) |
| Mouse movement | 88 (78-94) | 92 (82-97) | 71 (44-89) |
| Forward chin movement while looking at the monitor | 81 (71-89) | 88 (76-94) | 62 (36-80) |
| Neck rotation | 71 (30-95) | 75 (22-99) | 67 (13-98) |
| Sitting posture | 79 (68-90) | 78 (61-87) | 80 (63-89) |
| Support of elbow during keyboard use | 73 (62-82) | 61 (41-78) | 79 (66-89) |
| Support of wrist or forearm during keyboard use | 88 (78-94) | 44 (15-77) | 93 (84-97) |
| Support of elbow during mouse use | 79 (68-87) | 70 (49-84) | 84 (70-91) |
| Support of wrist or forearm during mouse use | 95 (87-98) | 60 (17-93) | 97 (90-100) |

[a] agreement on the presence of risk (non-neutral work posture)

[b] agreement on the absence of risk (neutral work posture)

*Agreement between questionnaire items and on-site observations*
Percentage agreement ranged between 46% and 100%. The five items with the lowest percentage of agreement scored below 70% agreement: keyboard height, mouse location, mouse movement (i.e. moving the mouse by moving the wrist only compared to moving the whole arm), sitting posture, and neck rotation. All items but mouse location had low sensitivity compared to specificity: 20% versus 70% for keyboard height, 50% versus 100% for mouse movement, 40% versus 53% for sitting posture, and 50% versus 100% for neck rotation. Mouse location had low specificity compared to sensitivity (48% versus 80%).

*Agreement between questionnaire items and measurements of postural angles with the manual goniometer*
All questionnaire items had percentages agreement lower than 80%, when compared with the manual goniometer measurements (see Table 4). Percentage agreement ranged between 29% (keyboard type) and 71% (distance keyboard to table edge). Nine out of 12 items scored lower than 50% agreement. Four of these items had substantially higher sensitivity than specificity: 90% versus 0% for keyboard type, 100 versus 12% mouse type, 100% versus 0% use of document holder, and 77% versus 28% mouse movement. One item had substantially higher specificity than sensitivity: keyboard height (100% specificity versus 31% sensitivity).

Table 4 Percentages agreement, sensitivity and specifity for the agreement between questionnaire and observations and manual goniometer measurements.

| Questionnaire 1 | Agreement with observations | | | Agreement with manual goniometer measureements | | |
|---|---|---|---|---|---|---|
| | Percentage Agreement (95%CI) | Sensitivity [%] (95%CI) | Specificity [%] (95%CI) | Percentage Agreement (95%CI) | Sensitivity [%] (95%CI) | Specificity [%] (95%CI) |
| **Workstation characteristics** | | | | | | |
| Distance keyboard to table edge | 88 (72-96) | 57 (20-88) | 96 (79-100) | 71 (52-85) | 0 (0-60) | 81 (61-93) |
| Keyboard tilt | 97 (85-100) | 95 (72-100) | 100 (79-100) | 45 (28-64) | 46 (28-66) | 33 (2-87) |
| Keyboard type | 100 (89-100) | 100 (88-100) | 100 (5-100) | 29 (15-48) | 90 (54-99) | 0 (0-19) |
| Keyboard height | 63 (46-78) | 20 (1-70) | 70 (51-84) | 35 (20-55) | 31 (16-51) | 100 (20-100) |
| Mouse type | 92 (78-98) | 92 (78-98) | nc [a] | 42 (27-59) | 100 (72-100) | 12 (3-32) |
| Monitor location | 100 (89-100) | 100 (46-100) | 100 (87-100) | - [b] | - [b] | - [b] |
| Chair height | 92 (78-98) | 50 (3-97) | 94 (80-99) | - [b] | - [b] | - [b] |
| Mouse characteristics: | | | | | | |
| - Ball | 100 (88-100) | 100 (31-100) | 100 (88-100) | - [b] | - [b] | - [b] |
| - Light | 100 (88-100) | 100 (88-100) | 100 (31-100) | - [b] | - [b] | - [b] |
| - Wireless | 100 (88-100) | 100 (88-100) | 100 (5-100) | - [b] | - [b] | - [b] |
| - Scroll wheel | 95 (80-99) | 95 (80-99) | nc [a] | - [b] | - [b] | - [b] |
| Monitor height | 79 (62-90) | 60 (17-93) | 82 (64-92) | 61 (43-76) | 31 (12-59) | 82 (59-94) |
| Mouse location | 61 (43-76) | 79 (49-94) | 50 (30-70) | 58 (41-73) | 63 (44-79) | 38 (10-74) |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Individual characteristics** | | | | | | |
| Mouse handedness | 100 (89-100) | 100 (40-100) | 100 (87-100) | 26 (14-43) | 10 (3-28) | 88 (59-94) |
| Use of document holder | 97 (85-100) | 100 (88-100) | 0 (0-95) | 42 (27-59) | 100 (76-100) | 0 (0-18) |
| Touch-typing | 89 (70-97) | 90 (68-98) | 83 (36-99) | 29 (15-48) | 46 (20-74) | 17 (4-42) |
| Number of fingers used for typing | 85 (65-95) | 86 (63-69) | 83 (36-99) | 32 (17-51) | 46 (20-74) | 22 (7-48) |
| Mouse movement | 55 (37-71) | 75 (51-90) | 23 (6-54) | 45 (29-62) | 77 (46-94) | 28 (13-50) |
| Forward chin movement while looking at the monitor | 31 (17-49) | 46 (22-73) | 20 (7-44) | - [b] | - [b] | - [b] |
| Neck rotation | 60 (17-93) | 50 (9-91) | 100 (5-100) | - [b] | - [b] | - [b] |
| Sitting posture | - [b] | - [b] | - [b] | - [b] | - [b] | - [b] |
| Support of elbow during keyboard use | - [b] | - [b] | - [b] | - [b] | - [b] | - [b] |
| Support of wrist or forearm during keyboard use | - [b] | - [b] | - [b] | - [b] | - [b] | - [b] |
| Support of elbow during mouse use | - [b] | - [b] | - [b] | - [b] | - [b] | - [b] |
| Support of wrist or forearm during mouse use | - [b] | - [b] | - [b] | - [b] | - [b] | - [b] |

[a] specificity could not be calculated, because the neutral category was not observed during observations

[b] no comparable measurement available

Table 5 Mean postural angles and standard deviation measured with the manual goniometer for dichotomized questionnaire items.

| Questionnaire item | Postural angle | No Risk (Neutral) Mean (sd) [degrees] | Risk (Non-neutral) Mean (sd) [degrees] | Direction of mean difference as expected? [d] |
|---|---|---|---|---|
| **Workstation characteristics** | | | | |
| Distance keyboard to table edge | Shoulder flexion | 13 (13) | 15 (10) | + |
| Keyboard tilt | Wrist extension | 30 (9) | 26 (9) | - |
| Keyboard type | Wrist deviation | 8 (-) [b] | 20 (14) | + |
| Keyboard height | Elbow flexion | 99 (11) | 99 (13) | - |
| Mouse type | Wrist ulnar deviation | -5 (-) [b] | 7 (7) | + |
| Monitor location | [a] | [a] | [a] | |
| Chair height | [a] | [a] | [a] | |
| Mouse characteristics: | | | | |
| - Ball | [a] | [a] | [a] | |
| - Light | [a] | [a] | [a] | |
| - Wireless | [a] | [a] | [a] | |
| - Scroll wheel | [a] | [a] | [a] | |
| Monitor height | Head tilt | 0 (9) | 3 (6) | + |
| Mouse location | Shoulder abduction | 31 (20) | 24 (9) | - |

| | | | | |
|---|---|---|---|---|
| **Individual characteristics** | | | | |
| Mouse handedness | Shoulder abduction | 27 (15) | 25 (13) | + |
| Use of document holder | Head tilt | - [c] | 1 (8) | ? |
| Touch-typing | Head tilt | 3 (6) | -4 (11) | + |
| Number of fingers used for typing | Head tilt | 3 (6) | -5 (11) | + |
| Mouse movement | Wrist ulnar deviation | 6 (6) | 7 (7) | + |
| Sitting posture | [a] | [a] | [a] | |
| Neck rotation | [a] | [a] | [a] | |
| Forward chin movement while looking at the monitor | [a] | [a] | [a] | |
| Support of elbow during keyboard use | [a] | [a] | [a] | |
| Support of wrist or forearm during keyboard use | [a] | [a] | [a] | |
| Support of elbow during mouse use | [a] | [a] | [a] | |
| Support of wrist or forearm during mouse use | [a] | [a] | [a] | |

[a] no concurrent measurement available,

[b] mean for one subject

[c] situation not observed

[d] see also appendix; + = yes, - = no, ? = unclear

In Table 5 the mean postural angles are presented for the dichotomized questionnaire responses. For the questionnaire items keyboard tilt, keyboard height and mouse location there was no difference in mean angle or the difference was not in concordance with the expected direction (see Appendix 1). The item on document holder use could not be evaluated, because the use of a document holder was not observed. All other items showed an expected direction in difference of the mean angle. However, standard deviations were large; indicating that the average work posture varied considerably between participants who were classified into the same risk category based on the questionnaire data.
Inter-rater reliability of the manual goniometer measurements was assessed before, during and after the study. The overall percentages agreement and 95% confidence intervals were: head tilt: 100% (70-100); wrist ulnar deviation: 67% (35-89); wrist extension 58% (29-84); shoulder abduction: 83% (51-97); shoulder flexion: 100% (70-100); elbow flexion: 100% (70-100).

**Discussion**

The results indicate that most questionnaire items can be measured with limited amount of resulting misclassification (i.e. < 20% misclassification). However, agreement of questionnaire items with work posture was lower, and resulted in more misclassification (i.e. 29% to 74% misclassification). Our results are in line with the literature. Karlqvist and co-workers (21) reported good test-retest reliability and agreement with direct measurements for self-reported keyboard location, but not for the questionnaire item on elbow height relative to keyboard height, which is consistent with our findings. Similar to our study, Karlqvist and co-workers reported low sensitivity compared to specificity for self-reported keyboard location and self-reported keyboard height. However, they found good agreement between self-reported mouse location and objective measurements, whereas we found limited agreement. This difference can be ascribed to a substantial lower specificity in our study (i.e. 50% versus

87%). The difference in specificity might be related to slight differences between studies in response type (i.e. participants in the Karlqvist et al. study had to put a cross on a pre-printed work desk and in our study they had to choose between different situations (with added pictures).
Compared with the results of Heinrich and co-workers (14), who used comparable questions without pictures, our questionnaire items seems to have higher agreement with on-site observations for the items monitor height (which was combined with neck rotation in one question) and monitor location. The differences seem to be attributable to a higher sensitivity of the questionnaire items in the current study (i.e. 60% / 50% versus 13% for monitor height / neck rotation, and 43% versus 100% for monitor location). However, in line with the findings of Heinrich and co-workers, self-reported chair height had limited sensitivity in the current study (i.e. 50% in both studies). This suggests that some questionnaire items with added pictures are more accurate than items without pictures. However, all our items still lacked sufficient agreement with measurement of postural angles, as has been shown previously by others among a population of industrial workers (22). Finally, the low agreement between workstation characteristics and work postures measured with a manual goniometer are in line with the results of Gerr and co-workers (17).
The strength of our study is the simultaneous evaluation of test-retest reliability and concurrent validity of the questionnaire. In addition, we evaluated a web-based questionnaire. To our knowledge this has not been done before for an instrument that collects data on work postures during computer work. We have not investigated whether paper and pencil questionnaires yield the same responses as web-based questionnaires. However, results from other research areas suggest that there are no relevant differences between paper and pencil and web-based questionnaires (23). The potential advantage of using a web-based questionnaire could be that employees fill out the questions when they are actually using the computer, providing an opportunity of self-observation. In addition, adding pictures to questionnaires might decrease differences between participants in the interpretation of questions and response

categories. We also obtained remarks from participants who indicated that the pictures provided positive mental variation in the process of filling out a long questionnaire.

Limitations in this study may have contributed to a low agreement between questionnaire items and observations and manual goniometer measurements. Firstly, subjects might have changed their work posture or workstation characteristics between filling out the first questionnaire and the on-site observations or manual goniometer measurements. However, excluding subjects who reported to have changed their work posture or workstation characteristics in the period between filling out the questionnaires (n=14) did not substantially improve agreement for all but one item. The percentage agreement between the self-reported distance between keyboard and table edge and the shoulder flexion angle (manual goniometer measurement) increased from 71% to 78%. Secondly, the contrast of exposure between workers in this study population might have been low when evaluated in the light of the variability in exposure over time of individual workers. The lack of contrast would make it difficult to achieve reasonable agreement between measurement instruments. Indications for this possibility were found in the post-hoc analysis of variance of the manual goniometer data. At maximum, the between-subject variation was two times higher than the within-subject variation. This finding is in contrast with the finding of Ortiz and co-workers who found that the between-subject variation was at least 7 times the within-subject variation when the same manual goniometer measurements were applied to a group of office workers (16). They concluded that one measurement with the manual goniometer would be sufficient to ensure sufficient exposure contrast between workers in epidemiological field studies. One reason for the difference in findings might be differences in computer tasks that were performed in the studies. In the study of Ortiz et al. subjects performed a ‘fairly stationary VDU keyboard task’. In the present study, however, most subjects performed variable computer tasks, using a broad variety of software programs, which might have increased within-subject variation.

Thirdly, the (test-retest) reliability and the (concurrent) validity of the criterion standard (in this study: on-site observation and manual goniometer measurement) might be limited. The raters in this study were students who were trained in measuring postural angles for this study. For wrist ulnar deviation and wrist extension the percentage agreement between the raters was less than 80% (67 and 58%, respectively). As a consequence of this limited inter-rater reliability, the agreement of the questionnaire items with manual goniometer measurements for the items mouse movement and mouse type might have been underestimated. However, the mean postural angles for wrist ulnar deviation and wrist extension were comparable to the angles measured with a manual goniometer in previous studies (16, 17). Another study reported comparable mean angles for wrist extension, but larger mean angles for wrist ulnar deviation among office workers (24). For the observations we did not gather data on interrater reliability. Post-hoc analysis revealed that the agreement between the questionnaire item on monitor height and on-site observation of the same item might have been somewhat underestimated. The agreement between questionnaire and observation exceeded 80% for one observer and was slightly lower than 80% for the other observer. Fourthly, the questionnaire asked for work postures that were usually adopted, while the observations concerned only one measurement in time and could thus have recorded unusual work postures. For manual goniometer measurements, this issue might be less of a problem, because multiple measurements were averaged. Finally, the study sample was small: in total 36 persons were measured. However, our results are in line with previous studies (see above), which in general give some credibility to our results.

Future studies might improve self-reports on work postures by developing new questionnaires and/or other response categories. However, we think that limited progress regarding reliability and validity can be made when the focus is solely on developing better questionnaires. Our study suggests that the exposure contrast in work postures during computer work (indicated by the between worker variation related to the within worker variation) is very limited among office workers. In order to be able to pick up differences in work postures during computer work, measurements with a higher precision should be used, for example electrogoniometers, which can capture work postures continuously. This is in line with recommendations made by others (13). Preferably, measurements should already be collected during the study design phase of an epidemiological study, since they can provide valuable information for decisions regarding resource allocation and measurement strategy (9, 25). However, at this moment large resources must be spent in terms of equipment, competence and time if these types of measurements are incorporated in large field studies. Finally, it is necessary to take into account work postures during work task not involving computer work, since these tasks may contribute to the total exposure to (non-neutral) work postures of office workers.

*Conclusions*

The questionnaire can be used to collect data on workstation characteristics, and some individual characteristics during computer work (i.e. work movements and habits), but does not seem to be useful to collect data on work postures during computer work in epidemiological field studies among office workers.

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Appendix 1 assumptions regarding the relationship between response categories of the questionnaire items and postural angles measured with the manual goniometer.

| **Questionnaire item** | |
|---|---|
| **Workstation characteristics** | |
| Distance keyboard to table edge | Positioning the keyboard further away from the table edge might increase shoulder flexion angle |
| Keyboard tilt | Tilting the keyboard (i.e. folding pins out) might increase wrist extension |
| Keyboard type | Split and compact keyboards have been developed to decrease ulnar deviation of the wrist during keyboard use. The use of split and compact keyboards might therefore decrease ulnar deviation of the wrist during keyboard use. |
| Keyboard height | A higher keyboard height might decrease the shoulder flexion angle |
| Mouse type | The trackball mouse has been developed to decrease ulnar deviation of the wrist during mouse use. The use of a trackball mouse might therefore decrease ulnar deviation of the wrist during mouse use |
| Mouse handedness | Most computer users have a numerical keypad positioned at the far right of the keyboard. Using the right hand to use the mouse might lead to more shoulder abduction than using the left hand exclusively. |
| Monitor location | [a] |
| Chair height | [a] |
| Mouse characteristics: | |
| - Ball | [a] |
| - Light | [a] |
| - Wireless | [a] |
| - Scroll wheel | [a] |
| Use of document holder | Use of document holder might decrease head tilt angle |
| Monitor height | Placement of the monitor higher than eye height might increase head tilt angle (towards more “extension”) |
| Touch-typing | Touch-typing might increase head tilt angle (towards less “flexion”) |
| Number of fingers used for typing | If a subject uses more finger during typing, the head tilt might increase (towards less “flexion”) |
| Mouse location | Mouse placement further away from the keyboard in lateral direction, might increase abduction of the shoulder |

| | |
|---|---|
| **Work postures** | |
| Mouse movement | Moving the mouse with the wrist only, might increase ulnar deviation of the wrist compared to moving the mouse with the whole arm |
| Neck rotation | [a] |
| Sitting posture | [a] |
| Forward chin movement while looking at the monitor | [a] |
| Support of elbow during keyboard use | [a] |
| Support of wrist or forearm during keyboard use | [a] |
| Support of elbow during mouse use | [a] |
| Support of wrist or forearm during mouse use | [a] |

[a] no concurrent measurement available

Appendix 2 two-by-two tables.

| Questionnaire 1 | | Questionnaire 2 | | Observation | | Manual Goniometer measurement | |
|---|---|---|---|---|---|---|---|
| | Category | Non-neutral | Neutral | Non-neutral | Neutral | Neutral | Non-neutral |
| **Workstation characteristics** | | | | | | | |
| Distance keyboard to table edge | Non-neutral | 7 | 6 | 4 | 1 | 5 | 0 |
| | Neutral | 5 | 63 | 3 | 26 | 22 | 4 |
| Keyboard tilt | Non-neutral | 42 | 3 | 18 | 0 | 2 | 13 |
| | Neutral | 5 | 31 | 1 | 19 | 1 | 15 |
| Keyboard type | Non-neutral | 77 | 0 | 37 | 0 | 21 | 9 |
| | Neutral | 0 | 4 | 0 | 1 | 0 | 1 |
| Keyboard height | Non-neutral | 10 | 13 | 1 | 10 | 0 | 9 |
| | Neutral | 4 | 54 | 4 | 23 | 2 | 20 |
| Mouse type | Non-neutral | 77 | 0 | 35 | 0 | 22 | 13 |
| | Neutral | 3 | 1 | 3 | 0 | 3 | 0 |
| Monitor location | Non-neutral | 7 | 0 | 5 | 0 | - [a] | - [a] |
| | Neutral | 2 | 72 | 0 | 33 | - [a] | - [a] |
| Chair height | Non-neutral | 3 | 0 | 1 | 2 | - [a] | - [a] |
| | Neutral | 0 | 78 | 1 | 34 | - [a] | - [a] |
| Monitor height | Non-neutral | 12 | 7 | 3 | 6 | 4 | 5 |
| | Neutral | 3 | 59 | 2 | 27 | 18 | 11 |
| Mouse location | Non-neutral | 42 | 9 | 11 | 12 | 5 | 19 |
| | Neutral | 7 | 23 | 3 | 12 | 3 | 11 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Individual characteristics** | | | | | | | |
| Mouse handedness | Non-neutral | 7 | 0 | 4 | 0 | 1 | 3 |
| | Neutral | 0 | 74 | 0 | 34 | 7 | 27 |
| Use of document holder | Non-neutral | 75 | 4 | 37 | 1 | 22 | 16 |
| | Neutral | 0 | 2 | 0 | 0 | 0 | 0 |
| Touch-typing | Non-neutral | 48 | 2 | 19 | 1 | 15 | 6 |
| | Neutral | 1 | 30 | 2 | 5 | 3 | 7 |
| Number of fingers used for typing | Non-neutral | 50 | 0 | 18 | 1 | 14 | 6 |
| | Neutral | 1 | 30 | 3 | 5 | 4 | 7 |
| Mouse movement | Non-neutral | 59 | 3 | 15 | 10 | 18 | 10 |
| | Neutral | 7 | 12 | 5 | 3 | 7 | 3 |
| Forward chin movement while looking at the monitor | Non-neutral | 54 | 7 | 7 | 16 | -[a] | -[a] |
| | Neutral | 8 | 12 | 8 | 4 | -[a] | -[a] |
| Neck rotation | Non-neutral | 3 | 1 | 2 | 0 | -[a] | -[a] |
| | Neutral | 1 | 2 | 2 | 1 | -[a] | -[a] |
| Sitting posture | Non-neutral | 31 | 11 | -[a] | -[a] | -[a] | -[a] |
| | Neutral | 6 | 33 | -[a] | -[a] | -[a] | -[a] |
| Support of elbow during keyboard use | Non-neutral | 17 | 13 | -[a] | -[a] | -[a] | -[a] |
| | Neutral | 9 | 42 | -[a] | -[a] | -[a] | -[a] |
| Support of wrist or forearm during keyboard use | Non-neutral | 4 | 8 | -[a] | -[a] | -[a] | -[a] |
| | Neutral | 2 | 67 | -[a] | -[a] | -[a] | -[a] |
| Support of elbow during mouse use | Non-neutral | 20 | 11 | -[a] | -[a] | -[a] | -[a] |
| | Neutral | 6 | 44 | -[a] | -[a] | -[a] | -[a] |
| Support of wrist or forearm during mouse use | Non-neutral | 3 | 3 | -[a] | -[a] | -[a] | -[a] |
| | Neutral | 1 | 74 | -[a] | -[a] | -[a] | -[a] |

[a] no concurrent measurement available

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# 4

# Test-retest reliability and validity of self-reported duration of computer use at work

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## Abstract

Objectives: The aims of this study were to evaluate the test-retest reliability and the validity of self-reported duration of computer use at work.
Methods: We studied test-retest reliability among 81 employees of a research department of a university medical centre. They filled out a web-based questionnaire twice with an in-between period of 14 days. Validity was studied among a group of 572 office workers who participated in an epidemiological field study. A software program recorded the duration of computer use at work during the 3 months preceding the questionnaire.
Results: Percentages of agreement for test-retest reliability were 75% (95% CI: 64% - 84%) for total computer use and 67% (95% CI: 55% - 77%) for mouse use. Percentages of agreement between self-report and registration were 18% (95% CI: 15% - 21%) for total computer use and 16% (95% CI: 13% - 19%) for mouse use. Misclassification was mainly non-differential in nature, since all evaluated subgroups showed at least 75% of misclassification.
Conclusions: The use of self-reports lead to misclassification of exposure to computer use for more than 80% of all subjects. This misclassification is predominantly non-differential in nature, and can only partly be explained by limited test-retest reliability.

## Introduction

Most longitudinal studies that address the association between the duration of computer use at work and the onset of arm-wrist-hand and neck-shoulder symptoms and disorders have used questionnaires to measure the duration of computer use at work. However, insufficient information is available regarding the reliability and validity of the questionnaires used in these studies (1). This lack of information might hamper the determination of a potential threshold dose (i.e. number of hours of computer use at work) that might be relevant in the prevention of musculoskeletal symptoms and disorders at work (2).

Previous studies have shown that computer workers generally overestimate their duration of computer use at work (2 - 5). In epidemiological studies, the overestimation by individual participants leads to misclassification of exposure (i.e. too high exposure values are assigned to participants). Depending on the nature of the misclassification, the strength of the association can be underestimated (most likely in the case of non-differential misclassification) or either underestimated or overestimated (in the case of differential misclassification).

The literature on this topic suggests that differential misclassification is likely. Faucett and Rempel (3) reported more overestimation among younger workers and workers with less psychological work load. Heinrich and co-workers (4) reported less overestimation among workers who worked fewer hours with the computer (according to their questionnaire). Homan and Armstrong (2) reported less overestimation among workers with longer durations of computer use (according to work sampling) than among those with shorter durations of computer use. In addition, managers seem to overestimate the duration to a lesser extent than non-managers (6). Misclassification was not related to symptom status in most studies that investigated the issue (4, 7). However, small sample sizes might have obscured actual differences. A recent large-scale study showed that prevalent arm symptoms can influence self-reported duration of computer use (8).

This study aims to explore two aspects related to misclassification of the duration of computer use at work obtained by self-reports: 1) test-retest reliability, and 2) validity. In addition, this study evaluated the relative importance of differential and non-differential misclassification. Limited test-retest reliability of questionnaires might contribute to misclassification. Secondly, limited validity between self-report and objective registration might contribute to misclassification. All studies to date have used continuous self-report estimates of the duration of computer use at work (i.e. the number of hours or percentage of time). In general, self-reports lack measurement precision (9), which challenges the collection of continuous self-report data. Therefore, we constructed a self-report measurement with a categorical response scale. Possibly, using a categorical instead of a continuous measurement scale reduces misclassification.

The first study question addresses the degree of test-retest reliability of a self-report measurement of the duration of computer use at work. The second study question focuses on the agreement between the self-reported duration of computer use at work and the registered duration of computer use at work.

## Methods

*Study population and design*

We used two different study populations to answer the study questions. To answer the first study question (on the test-retest reliability of the questionnaire), we included a group of employees of a research department of a university medical centre in the Netherlands. Participants filled out a web-based questionnaire twice with an in-between period of two weeks. To answer the second study question (on the validity of the questionnaire), we included a group of office workers who had filled out the 1-year follow-up questionnaire of the PROMO study (see for more details 10), and for whom software registration of the duration of computer use at work was available for the three months preceding the 1-year follow-up questionnaire of the PROMO study. Table 1 presents the characteristics of the two study populations. In the test-retest reliability study, 84 participants filled out the first questionnaire and 81 participants filled out both questionnaires. In the validity study, 572 participants filled out the questionnaire.

Table 1 Characteristics of the study populations for the evaluation of test-retest reliability (N = 81) and validity (N = 572).

| | | Test-retest | | Validity | |
|---|---|---|---|---|---|
| | | n | (%) | n | (%) |
| Gender | Male | 26 | 32 | 356 | 52 |
| | Female | 55 | 68 | 326 | 48 |
| Age (y) | < 30 | 27 | 33 | 71 | 12 |
| | 30 - 39 | 25 | 31 | 183 | 32 |
| | 40 - 49 | 16 | 20 | 189 | 33 |
| | > = 50 | 13 | 16 | 124 | 22 |
| | Missing | 0 | 0 | 5 | 1 |
| Self-reported total computer use at work (h / d) | 0 - < 2 | 3 | 4 | 2 | 1 |
| | 2 - < 4 | 12 | 15 | 70 | 12 |
| | 4 - < 6 | 30 | 37 | 254 | 44 |
| | 6 - < 8 | 35 | 43 | 240 | 42 |
| | > = 8 | 1 | 1 | 6 | 1 |
| Self-reported mouse use at work (h / d) | 0 - < 2 | 13 | 16 | 61 | 11 |
| | 2 - < 4 | 26 | 32 | 147 | 25 |
| | 4 - < 6 | 33 | 41 | 229 | 40 |
| | 6 - < 8 | 8 | 10 | 132 | 23 |
| | > = 8 | 1 | 1 | 3 | 1 |
| Arm-wrist-hand symptoms * | No | 74 | 91 | 478 | 84 |
| | Yes | 7 | 9 | 94 | 16 |
| Neck-shoulder symptoms * | No | 71 | 88 | 414 | 72 |
| | Yes | 10 | 12 | 158 | 28 |

Abbreviations: y = years, h / d = hours per day

* regular or long-lasting symptoms in the previous three months

*Measurements*

The questionnaire included a question on the duration of computer use at work: “How many hours per day do you use your computer during your work at the office (including reading from the screen)?” The question had seven response categories: never, 0-1, 1-2, 2-4, 4-6, 6-8, >8 hours/day). The same question was used for the duration of mouse use: “How many hours per day do you use your mouse during your work at the office?”. The participants were invited by e-mail to fill out the web-based questionnaire.

The e-mail contained a hyperlink that directed participants to the web page with the questionnaire.

Data on the registered duration of computer use at work were collected with the software program WorkPace version 3.0 (Niche Software Ltd/ErgoDirect). The program was installed on the personal computers and data were periodically sent to a central folder on the computer network. Data were stored for each individual as cumulative totals for each calendar day. The program estimated the duration of computer use based on the duration of the time interval between two consecutive active events (i.e. keying, mouse clicking or mouse movements). If a participant hit a key, moved or clicked the mouse within 30 seconds of previously hitting a key, or moving or clicking the mouse, then this "inter-events period" (in seconds) was stored as a usage period of total computer use. If the threshold time of 30 seconds was exceeded, then the elapsed time period between two usage periods was stored as a break from total computer use. This threshold value for total computer use reflects using keyboard or mouse, reading from the screen, or performing combinations of these activities. The threshold time for mouse use, which reflects clicking or moving the mouse (and not reading from the screen), was 5 seconds. Previous research has shown good agreement between the WorkPace estimate and systematic observation for the duration of total computer use (i.e. using keyboard or mouse, reading from the screen, or performing combinations of these activities). The average duration of total computer use based on WorkPace estimates was within 10% of the average duration of total computer use based on systematic observation (6, 11).

The mean daily duration of registered total computer use and mouse use was calculated by dividing the cumulative duration of registration during three months by the number of days for which the software program recorded activity (i.e. at least 1 second of use). Data from participants who worked at least two days per week on another location of their organization where no recordings could be made and data from participants who shared a computer account with a colleague were excluded from the analyses. In addition, data were excluded if the number of recorded days was less than 70% of the number of actual working days.

*Statistical analysis*

We calculated percentages of agreement, percentages of misclassification (i.e. 1 minus percentage agreement), and subdivisions of percentage misclassification (i.e. difference of 1 and > = 2 categories) to evaluate test-rest reliability of the self-report measure.

We performed four analyses to answer the second study question concerning validity. At first, we recoded both self-reported and registered data into the same categories (i.e. 0 to <2, 2 to <4, 4 to <6, 6 to <8, and 8 or more hours per day). Then we calculated, for computer use and mouse use separately, percentages of agreement, percentages of misclassification (i.e. 1 minus percentage agreement), and subdivisions of percentage misclassification (i.e. difference of 1 and > = 2 categories, underestimation and overestimation). Secondly, we dichotomized the self-reported and registered data with cut-off values of 2, 4 and 6 hours per day, and calculated percentage agreement, sensitivity and specificity. Thirdly, we performed separate analyses for subgroups of participants to investigate potential effect modification (i.e. differential misclassification of exposure). Based on previous findings in the literature (2 - 4, 6 - 8), we defined subgroups based on symptom status (i.e. the presence of regular or long-lasting arm-wrist-hand or neck-shoulder symptoms in the previous three months), self-reported computer use at work (cut off: 4 hours per day), gender, age, cognitive demands, decision authority, task variation, effort, reward and variation in registered computer use (cut-off: median). In addition, we calculated the difference between the self-reported duration of computer use and the registered duration of computer use for each participant, by using the middle score of the self-report categories as the estimate of self-reported duration of computer use. We used this data to plot the difference between the self-reported duration of computer use and the registered duration of computer use against the registered duration of computer use.

We used SPSS (version 12.0) for data transformation. Summary statistics and 95% confidence intervals were calculated using web-based applications (http://faculty.vassar.edu/lowry/kappa.html and http://faculty.vassar.edu/lowry/clin1.html).

## Results

*Test-retest reliability*

Tables 2 and 3 show the results for the test-retest analysis of self-reported computer use at work. The percentages agreement were 75% and 67% for total computer use and mouse use, respectively. The percentage misclassification was mainly restricted to neighboring categories, i.e. a difference of 1 category between the two questionnaires (22% for total computer use and 33% for mouse use).

Table 2 Results for the test-retest analysis of self-reported total computer use at work: cross table displaying frequencies and summary statistics (N=81).

| | Questionnaire 2 (h / d) | | | | |
|---|---|---|---|---|---|
| **Questionnaire 1 (h / d)** | **0 - < 2** | **2 - < 4** | **4 - < 6** | **6 - < 8** | **> = 8** |
| 0 - < 2 | 0 | 1 | 2 | 0 | 0 |
| 2 - < 4 | 1 | 8 | 3 | 0 | 0 |
| 4 - < 6 | 0 | 4 | 25 | 1 | 0 |
| 6 - < 8 | 0 | 0 | 8 | 27 | 0 |
| > = 8 | 0 | 0 | 0 | 0 | 1 |

Abbreviations: h / d = hours per day; CI = confidence interval
Percentage agreement = 75 (95% CI: 64 – 84)
Percentage misclassification = 25 (95% CI: 16 – 36)
Percentage misclassification for 1 category difference = 22 (95% CI: 14 – 33)
Percentage misclassification for > = 2 categories difference = 3 (95% CI: 0 – 10)

Table 3 Results for the test-retest analysis of self-reported mouse use at work: cross table displaying frequencies and summary statistics (N=81).

| | Questionnaire 2 (h / d) | | | | |
|---|---|---|---|---|---|
| **Questionnaire 1 (h / d)** | **0 - < 2** | **2 - < 4** | **4 - < 6** | **6 - < 8** | **> = 8** |
| 0 - < 2 | 10 | 3 | 0 | 0 | 0 |
| 2 - < 4 | 2 | 15 | 9 | 0 | 0 |
| 4 - < 6 | 0 | 3 | 23 | 7 | 0 |
| 6 - < 8 | 0 | 0 | 3 | 5 | 0 |
| > = 8 | 0 | 0 | 0 | 0 | 1 |

Abbreviations: h / d = hours per day; CI = confidence interval
Percentage agreement = 67 (95% CI: 55 – 77)
Percentage misclassification = 33 (95% CI: 23 – 45)
Percentage misclassification for 1 category difference = 33 (95% CI: 23 – 45)
Percentage misclassification for > = 2 categories difference = 0

*Validity*

Table 4 and 5 show the agreement between self-reported and registered computer use at work. The percentages agreement were 18% and 16% for total computer use and mouse use, respectively. Almost all misclassification was due to overestimation by self-report. For total computer use at work, 51% of all subjects overestimated their computer use by 1 category, and 30% by at least 2 categories (i.e. at least 2 hours per day). For mouse use at work, 35% of all subjects overestimated their mouse use by 1 category, and 48% by at least 2 categories (i.e. at least 2 hours per day).

Table 4 Agreement between self-reported and registered total computer use at work: cross table displaying frequencies and summary statistics (N=572).

| | Registration (h / d) | | | | |
|---|---|---|---|---|---|
| **Self-report (h / d)** | **0 - < 2** | **2 - < 4** | **4 - < 6** | **6 - < 8** | **> = 8** |
| 0 - < 2 | 2 | 0 | 0 | 0 | 0 |
| 2 - < 4 | 16 | 51 | 3 | 0 | 0 |
| 4 - < 6 | 22 | 185 | 47 | 0 | 0 |
| 6 - < 8 | 9 | 138 | 92 | 1 | 0 |
| > = 8 | 0 | 4 | 2 | 0 | 0 |

Abbreviations: h / d = hours per day; CI = confidence interval
Percentage agreement = 18 (95% CI: 15 – 21)
Percentage misclassification = 82 (95% CI: 74 – 85)
Percentage misclassification for 1 category underestimation by self-report = 1 (95% CI: 0 – 2)
Percentage misclassification for 1 category overestimation by self-report = 51 (95% CI: 47 – 55)
Percentage misclassification for > = 2 categories overestimation by self-report = 30 (95% CI: 27 – 35)

Table 5 Agreement between self-reported and registered mouse use at work: cross table displaying frequencies and summary statistics (N=572).

| | Registration (h / d) | | | | |
|---|---|---|---|---|---|
| **Self-report (h / d)** | **0 - < 2** | **2 - < 4** | **4 - < 6** | **6 - < 8** | **> = 8** |
| 0 - < 2 | 55 | 6 | 0 | 0 | 0 |
| 2 - < 4 | 111 | 36 | 0 | 0 | 0 |
| 4 - < 6 | 141 | 88 | 0 | 0 | 0 |
| 6 - < 8 | 60 | 71 | 1 | 0 | 0 |
| > = 8 | 2 | 1 | 0 | 0 | 0 |

Abbreviations: h / d = hours per day; CI = confidence interval
Percentage agreement = 16 (95% CI: 13 – 19)
Percentage misclassification = 84 (95% CI: 81 – 87)
Percentage misclassification for 1 category underestimation by self-report = 1 (95% CI: 0 – 2)
Percentage misclassification for 1 category overestimation by self-report = 35 (95% CI: 31 – 39)
Percentage misclassification for > = 2 categories overestimation by self-report = 48 (95% CI: 44 – 52)

The dichotomized data showed higher percentages of agreement. For total computer use, the highest percent agreement was present at the cut-off of 2 hours per day (92%), and for mouse use at the cut-off of 6 hours per day (76%). See Table 6. In general, sensitivity values were low due to overestimation by self-report.

Table 6 Agreement between self-reported and registered computer use at work for dichotomized data: summary statistics (N=572).

| | **Percentage agreement (95% CI)** | **Sensitivity (95% CI)** | **Specificity (95% CI)** |
|---|---|---|---|
| Total computer use at work | | | |
| Cut-off: 2 h / d | 92 (89 – 94) | 92 (89 – 94) | 100 (19 – 100) |
| Cut-off: 4 h / d | 37 (33 – 41) | 28 (25 – 33) | 96 (87 – 99) |
| Cut-off: 6 h / d | 57 (53 – 61) | 0 ( 0 – 3) | 100 (99 – 100) |
| Mouse use at work | | | |
| Cut-off: 2 h / d | 44 (40 – 48) | 39 (34 – 43) | 90 (79 – 96) |
| Cut-off: 4 h / d | 37 (33 – 41) | 0 (0 – 2) | 100 (97 – 100) |
| Cut-off: 6 h / d | 76 (73 – 80) | 0 (0 – 3) | 100 (98 – 100) |

Abbreviations: h / d = hours per day; CI = confidence interval

Managers and subjects who reported low task variation, arm-wrist-hand symptoms, or less than four hours per day of computer use at work showed higher agreement than non-managers and subjects who reported high task variation, no arm-wrist-hand symptoms or at least four hours per day duration of computer use at work (data not shown). However, agreement between self-reported and registered data was low for all subgroups. The percentages of agreement were below 25%, i.e. percentages of misclassification were at least 75% for all subgroups (data not shown). Figure 1 shows that the difference between self-reported and registered duration of computer use at work decreased over increasing durations of registered computer use at work.

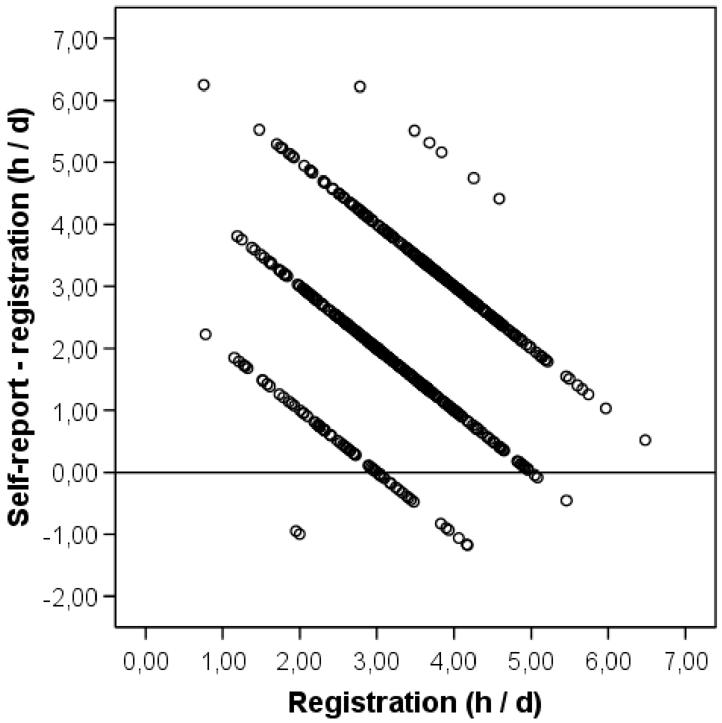


Figure 1 Scatter plot of differences between self-reported and registered total computer use at work (Y-axis) and registered total computer use at work (X-axis) [N=572].

**Discussion**

In this study we investigated the test-retest reliability and the validity of self-reported duration of computer use at work. Imperfect test-retest reliability introduced misclassification of exposure for 25% (total computer use) to 33% (mouse use) of all subjects. Misclassification in the test-retest analysis was restricted to one category (i.e. a difference up to 2 hours). The validity study showed that the use of self-reports leads to misclassification of 82% (total computer use) to 84% (mouse use) of all subjects. This misclassification was a result of overestimation by self-report in almost all cases. 30% (for total computer use) to 48% (for mouse use) of all subjects overestimated their computer use more than 2 hours per day.

Misclassification was mainly non-differential in nature, since in all evaluated subgroups at least 75% of misclassification was present.
Our results of the test-retest reliability study are in line with the results of Karlqvist (12), who found correlations of 0.92 and 0.75 for the estimated percent of total work time spent on VDU work and mouse use during VDU work. Self-reports seem to be prone to a limited amount of random measurement error, which can express itself by misclassification if categorical data are used, as in the current study.
Our results also seem to be in line with other studies that compared self-reported data on the duration of computer use at work and objective measurements. All published studies found that workers generally overestimated their duration of computer use at work in comparison with objective measurements (2 - 5). The amount of overestimation between previous studies and the current study are difficult to compare due to the use of continuous data in previous studies versus categorical data in the current study, and variation between studies in the time window over which comparisons have been made. Contrary to what was expected, the use of categorical data did not seem to improve agreement between self-report and objective measurement to a large extent, since 30% (total computer use) to 48% (mouse use) of all subjects overestimated their computer use for more than 2 hours per day in this study.
As already mentioned in the introduction, Heinrich and co-workers (4) reported less overestimation among workers who worked fewer hours with the computer (according to their questionnaire). Homan and Armstrong (2) reported less overestimation among workers with longer durations of computer use (according to work sampling) than among workers with shorter durations of computer use. These observations seem to be in contradiction. However, our data showed that both phenomena could be present at the same time (see Figure 1). It should be noted that an artificial “ceiling effect” might be present: workers cannot report longer durations of computer use than the number of hours they work. Despite the aforementioned trend, the differences in agreement between workers who had a long duration of computer use versus those who had a short duration

of computer use were small. For both groups the percentage of agreement was less than 25%. In general, non-differential misclassification seems to play a larger role than differential misclassification for all variables evaluated in this study.

The strengths of this study are the large sample size compared to most published studies, the extended time period over which objective data was collected, and the evaluation of both test-retest reliability and validity in one paper. Moreover, we used a "gold standard" with known measurement characteristics (6, 11).

A number of factors related to the design of this study might have biased our findings. At first, in the validity study we compared the self-reports to the average daily duration of computer use, based on software registration from the preceding three months before the questionnaire. It is possible that participants rated their computer use over a shorter recall period. However, the estimates of the daily duration of computer use were similar for the preceding week and the preceding month, making it unlikely that the time period over which the daily duration of computer use was calculated, biased our findings to a significant extent. Secondly, it is still unclear how participants interpreted "computer use at work". It is possible that participants interpreted this as including sitting at the desk. However, the Spearman correlation between the self-reported duration of sitting at the desk and the self-reported duration of computer use has been reported to be 0.30 (13). It follows that this explanation covers only a small part of the overestimation by self-report.

Another factor that might be responsible for the overestimation by self-report is inaccuracy of the software program. However, previous studies in populations with various job functions have shown that the average duration of registration was within 10% of the observed duration of computer use (6, 11). It follows that the inaccuracy of the software program might explain part of the overestimation of 1 category by self-report (i.e. 0 – 2 hours per day, observed for 35 – 51% of all subjects, see Tables 2 and 3). However, we think that it is unlikely that the overestimation of at least 2 categories can be explained by limitations of the software program (i.e.

overestimation of at least 2 hours per day, observed for 30% to 48% of all subjects, see Tables 4 and 5).

Dichotomization of self-reported data improved agreement with registration. However, the relatively high percentages agreement for the 2-hour and 6-hour cut-off for total computer use (i.e. 92% and 57%, respectively) and the 6-hour cut-off for mouse use (i.e. 76%) are biased due to skewed distributions. Only 2 subjects reported less than 2 hours of total computer use, and 1 subject had a registration for more than 6 hours of total computer use. No subjects had a registration for more than 4 hours per day of mouse use. It follows that only the 4-hour cut-off for total computer use and the 2-hour cut-off for mouse use could be used in epidemiological studies to study associations between self-reported computer use at work and the onset of arm-wrist-hand and neck-shoulder symptoms and disorders. Misclassification for these cut-offs was still present in the majority of subjects (i.e. 63% for total computer use and 56% for mouse use).

In several reviews it has been reported that an increasing duration of computer use at work is associated with an increased risk of musculoskeletal symptoms and disorders (1, 7). Most studies draw their conclusions based on self-reported duration of computer use at work. Given the results of the present study, it is likely that the use of self-reports leads to non-differential misclassification, and consequently underestimation of the strength of the association. In addition, the increased risk may be present at a lower duration of computer use at work. Future studies should increase our knowledge on the association between the duration of computer use at work and the onset of arm-wrist-hand and neck-shoulder symptoms and disorders by including more precise measurements of the duration of computer use at work. One possibility is to use event-driven diaries in which workers can record the actual tasks and time period spent on each task throughout the day (14). This approach obviously requires more time and effort on the part of the worker and may not be feasible in large-scale epidemiological field studies with repetitive measurements of the duration of computer use. The most promising

approach, however, would be to use software or other objective measurements to register the duration of computer use at work. It should be noted that objective measurements might need considerable resources to ensure reliable registration throughout a longer time period.
In conclusion, the use of self-reports leads to misclassification of exposure to computer use for more than 80% of all subjects. This misclassification is predominantly non-differential in nature, and can only partly be explained by limited test-retest reliability.

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# 5

# Prospective research on musuloskeletal disorders in office workers (PROMO): Study protocol

IJmker S, Blatter BM, van der Beek AJ, van Mechelen W, Bongers PM. Prospective research on musculoskeletal disorders in office workers (PROMO): study protocol. BMC Musculoskelet Disord. 2006;7:55.

[redacted]

## Abstract

Background: This article describes the background and study design of the PROMO study (Prospective Research on Musculoskeletal disorders in Office workers). Few longitudinal studies have been performed to investigate the risk factors responsible for the incidence of hand, arm, shoulder and neck symptoms among office workers, given the observation that a large group of office workers might be at risk worldwide. Therefore, the PROMO study was designed. The main aim is to quantify the contribution of exposure to occupational computer use to the incidence of hand, arm, shoulder and neck symptoms. The results of this study might lead to more effective and / or cost-efficient preventive interventions among office workers.
Methods / Design: A prospective cohort study is conducted, with a follow-up of 24 months. In total, 1821 participants filled out the first questionnaire (response rate of 74%). Data on exposure and outcome is collected using web-based self-reports. Outcome assessment takes place every three months during the follow-up period. Data on computer use are collected at baseline and continuously during follow-up using a software program.
Discussion: The advantages of the PROMO study include the long follow-up period, the repeated measurement of both exposure and outcome, and the objective measurement of the duration of computer use. In the PROMO study, hypotheses stemming from lab-based and field-based research will be investigated.


## Background

Occupational computer use has become very common in the last decades. In 2003, the United States entailed over 77 million persons who used a computer at work (1). In the European Union, over 88 million persons used a computer at work in 2002 (2). Moreover, over 50 million European workers reported to use the computer at least half of their work time (3).

Recent large-scale surveys show one-year prevalences of hand, arm, shoulder and neck symptoms ranging from 24 to 44% among office workers (4 - 6). The one-year incidence has been estimated to be 5 to 34%, depending on case definition and study population (4 - 8). It should be noted that in most studies, both the prevalence and incidence of symptoms are higher in the neck-shoulder region than in the hand-arm region.
Given the large source population and the possible high incidence, a large number of office workers may be at risk for developing hand, arm, shoulder or neck symptoms. In addition, the costs related to hand, arm, shoulder, and neck symptoms (i.e. due to reduced productivity, sick leave, work disability, and medical consumption) are considerable. Blatter et al. (10) estimated the total costs at 2.1 billion euros per year for the Netherlands. Therefore, office workers, employers, and governments might benefit from improvements in the primary prevention of hand, arm, shoulder and neck symptoms.
The available epidemiological evidence suggests that hand, arm, shoulder and neck symptoms are associated with the duration of computer use and, in fact, increase steadily with each hour of computer use per day (11). In addition, recent longitudinal studies suggest a dose-response relationship between the duration of mouse use and the incidence of hand-arm symptoms (4, 6, 7, 12). It should be noted that previous studies relied on self-reports for the measurement of the duration of computer use. However, the use of self-reports may lead to overestimation of the duration of computer use, which might result in misclassification (13 - 16). Misclassification might bias the risk estimate and hamper the correct classification of office workers at risk for prevention purposes.
Despite the available evidence, controversy exists in the scientific and public media on the explanation of the current prevalence and incidence of hand, arm, shoulder and neck symptoms among office workers. The contribution of occupational mechanical exposure (i.e. duration of computer use, working postures, and computer design) to the incidence of hand, arm, shoulder and neck symptoms has received ample attention.

Advocates of the work-relatedness of hand, arm, shoulder and neck symptoms propose that occupational mechanical exposures contribute to a large extent to the incidence of musculoskeletal disorders. The symptoms are explained by local muscle, tendon or nerve injury, caused by overload of the musculoskeletal system (17 - 19). In contrast, critics have contradicted consistent signs of muscle, tendon and nerve injury among patients reporting hand, arm, shoulder and neck symptoms (20). In addition, the contribution of occupational mechanical exposure to the incidence of hand, arm, shoulder and neck symptoms has been criticized (21 - 23). Alternative explanations for the incidence of hand, arm, shoulder and neck symptoms include, among others, poor lifestyle habits, poor psychosocial work context and sociological factors, including increased public awareness and a broad definition of work incapacity by the compensation system.

The main reason for designing the PROMO study (Prospective Research On Musculoskeletal disorders among Office workers) is that few longitudinal studies have been performed among office workers, and that no longitudinal study on risk factors has measured computer use objectively. The main study objective is to quantify the contribution of exposure to occupational computer use to the incidence of hand, arm, shoulder and neck symptoms among office workers. In the PROMO study, the term occupational computer use includes reading from the computer screen and the use of input devices: mouse use (i.e. clicking and moving the mouse) and keyboard use.

Exposure to occupational computer use can be defined in different ways. Most studies have operationalized exposure to computer use as the average (or cumulative) duration of computer use (or its constituents: mouse and keyboard use) over a certain time period. Other operationalizations include the cumulative number of keystrokes or mouse clicks, variation in computers use between days or weeks, and distribution of usage periods (i.e. number of breaks taken within a certain time period). In this study, exposure to computer use will be measured objectively with a

software program, which is installed on the individual workstation. In addition, self-reports will be collected.
The second study objective is to quantify the relative contribution of various occupational and non-occupational risk factors. Information on the population attributable fraction of risk factors and on the identification of subgroups with high risk will contribute to the discussion on the potential of preventive interventions among office workers and possibly to the design of preventive interventions among office workers.

In summary, the PROMO study addresses the following research questions:

A. What is the relation between the exposure to occupational computer use and the incidence of hand-arm and neck-shoulder symptoms?
B. What is the relative contribution of occupational mechanical exposure, occupational psychosocial exposure, leisure time exposure and individual factors to the incidence of hand-arm and neck-shoulder symptoms among office workers?

*Hypotheses*
With respect to research question A, we expect that hand-arm symptoms are more strongly related to the duration of computer use than neck-shoulder symptoms. Previous studies showed the strongest and most consistent associations for computer use with the incidence of hand-arm symptoms (4, 6, 7, 13). In addition, based on the same studies, we expect to find indications for a dose-response relationship between the duration of mouse use and the incidence of hand-arm symptoms.
By answering research question B, we will investigate the contribution of occupational computer use to the incidence of hand, arm, shoulder and neck symptoms, compared to the contribution of various other occupational and non-occupational risk factors. Firstly, we expect occupational computer use to be the strongest risk factor. Previous longitudinal studies, which included individual factors as well as estimates of occupational mechanical and psychosocial exposure, and leisure time exposure, have found the

most consistent and strongest associations between the duration of mouse use and the incidence of hand-arm symptoms (4, 6, 7, 13). In addition, we expect computer use to be more strongly associated with hand-arm and neck-shoulder symptoms than ergonomic factors (i.e. working posture and workstation characteristics) (24). If ergonomic factors have a causal contribution, one would expect that the association with hand-arm and or neck-shoulder symptoms would become stronger when exposed to longer durations of computer use. Besides occupational mouse use, we expect occupational psychosocial exposure to be an independent risk factor for neck-shoulder symptoms (25).

Secondly, we expect that low levels of leisure time physical activity contribute modestly, at most, to the incidence of hand-arm and neck-shoulder symptoms. Previous longitudinal studies among office workers failed to show an association between low levels of leisure time physical activity and hand-arm and neck-shoulder symptoms (6, 7, 9, 13). Workers exposed to high mental stress during work time and to low physical activity during leisure time were found to have an increased risk in one study (8). However, confidence intervals were wide in this study. It should be noted that most studies among office workers have included only crude measures of leisure time exposure. In a longitudinal study among manual workers and office workers, a protective effect of sports activities on the incidence of hand, arm, shoulder and neck symptoms was reported (9). However, specific leisure time activities might increase the risk of symptoms. Miranda and co-workers (27) reported an increased risk of incident shoulder symptoms when playing volleyball frequently. Thirdly, both female gender and previous symptoms have been reported frequently as risk factors among office workers in the published literature (female gender: 6 - 9, 13, 28; previous symptoms: 4, 5, 28). We will explore whether these individual factors act as effect modifiers in the associations between occupational and / or leisure time exposure, and hand-arm and neck-shoulder symptoms. In addition, we aim to explore the role of the personality trait overcommitment in the incidence of hand-arm and neck-shoulder symptoms. A longitudinal and a cross-sectional study showed indications of an increased risk of hand-arm and neck-shoulder symptoms among overcommited workers (29, 30)

## Methods/Design

*Study design*

A prospective cohort study is conducted, with a follow-up of 24 months. Assessment of the health outcome (symptoms and disability due to symptoms) takes place at baseline and every 3 months during follow-up. Exposure data on computer use are collected continuously during the study period, while additional exposure data and information on individual characteristics are gathered at baseline and after one year of follow-up. Participation is voluntarily and participants signed informed consent. The study design was approved by the Medical Ethics Committee of the VU University Medical Center (VUmc).

*Recruitment of the study population*

Companies with a source population of at least 500 office workers were invited to participate in the study. The study population was recruited from five different employers in the Netherlands: a brewery, a financial consultancy firm, a university, a transportation company, and an insurance company. A department within a company was included if the department had a computer network from which the software for recording the duration of computer use could be installed on individual workstations, and if at least three quarters of the employees fulfilled the inclusion criteria (see table 1).

Table 1 Inclusion criteria.

| | |
|---|---|
| 1. | The job function of the workers is “office worker”. Main tasks are computer use, participation in meetings, giving presentations, reading and phoning. |
| 2. | Workers have an individual e-mail address at work |

Employees within included departments were informed about the study via distributed flyers. In addition, all these employees received an e-mail with information on study objectives and required effort for participation. As incentive for participation, workers were offered the choice between two options. Firstly, the donation of a small sum of money (20 eurocents) to a charity organization (i.e. Medecins Sans Frontieres) for each questionnaire they would fill out. Secondly, joining a lottery for a weekend holiday to a European capital. The latter option was only possible if they would fill out all the questionnaires during follow-up. Finally, a team of researchers visited the worksites and asked individual employees to participate in the study. At the same time, memo blocks were handed out as incentive. In total, 2461 out of 9161 (27%) approached employees signed informed consent. Out of these 2461 participants, 1821 (74%) filled out the first questionnaire.

*Data collection procedure*

Data on exposure and outcome is collected using web-based self-reports. Participants receive an e-mail containing a link to a questionnaire. By request, they can fill out a hard copy of the questionnaire. In case of non-response, participants receive a maximum of two reminders by e-mail. In addition, data on computer use is collected objectively with a software program. Participants who leave their job during follow-up, receive a paper questionnaire to their home address in order to check symptom status and the possible contribution of symptom status to turnover. This information will be used to check if a healthy worker (selection) effect has occurred: symptomatic workers might leave the study more frequently than healthy workers, leading to biased associations.

*Assessment of exposure to computer use*

Data on computer use are collected at baseline and continuously during follow-up using the software program WorkPace version 3.0 (Niche Software Ltd / ErgoDirect). The program has been installed from the central network on the individual computer of the participants. The program records computer use from the moment the participant has logged in to the network. Data storage takes place on the individual computer. Periodically (i.e. after being logged in to the network for 6 hours, or during log-off) the individual data file is sent to a dedicated and secured folder on the central network. Recording is continued if a person logs in to the network on another computer. Registration of keystrokes, mouse clicks and mouse movements are stored as cumulative totals per day. Thus, separate estimates for the duration of total computer use (including reading from the screen, mouse and keyboard use), mouse use and keyboard can be retrieved. Based on the duration of the time interval between two consecutive active events (i.e. keying, mouse clicking or mouse movements), the duration of keyboard, mouse, and total computer use, as well as the duration of breaks are calculated. If a participant hits a key, moves or clicks a mouse within 30 seconds of previously hitting a key, moving or clicking the mouse, this “inter-events period” (in seconds) is stored as a usage period of total computer use. If the threshold time of 30 seconds is exceeded, the elapsed time period between two usage periods is stored as a break from total computer use. The threshold time for mouse use is 5 seconds and for keyboard use it is 2.5 seconds. Cumulative totals for several usage and break periods are stored for every day separately. Previous research has shown good agreement between the WorkPace estimate and systematic observation for the duration of total computer use. On group level, the average duration of total computer use estimated with WorkPace is within 10% of the average duration of total computer use estimated with systematic observation (15, 31)

*Assessment of other occupational exposures*

Self-reported data on duration of computer and mouse use, historical computer use, precision demands, use of break and exercise software, workstation characteristics and working postures while using keyboard and mouse are gathered at baseline and after one year of follow-up. Clarifying illustrations have been added to the questions on working postures for optimal validity. This questionnaire also contains questions on job tenure,

job contract characteristics (e.g. working hours and working days), overtime work and work continuation during formal (lunch) breaks.
Occupational psychosocial stressors and perceived stress are measured using a translated version of the Effort-Reward Imbalance questionnaire (32) and the need for recovery scale from the Questionnaire on Perception and Judgment of Work (33, 34). In addition, the subscale decision authority from the Job Content Questionnaire is used (35). Mental load is assessed by a subscale of the Questionnaire on Perception and Judgment of Work (33). Job satisfaction is measured using a single item of the Questionnaire Work and Health (36). In addition to baseline and one-year follow-up measurements, information on job satisfaction and rapid increases of general workload is collected every 3 months.

*Assessment of leisure time exposures*
At baseline and after one year of follow-up, physical activity during leisure time is assessed by two questions. The first question focuses on the average number of days per week in the last 3 months with moderate intensity physical activity (i.e. causing increased breathing frequency) lasting at least 30 minutes in total per day. This is done to check whether physical activity public health recommendations are met (37, 38). The second question focuses on the average number of days per week in the last 3 months with high intensity physical activity (i.e. causing sweating), and lasting at least 20 minutes in total per day (40, 41). Activities during leisure time involving forceful or repetitive arm or hand movements (e.g. participation in strength training of the upper extremities and racket sports, and playing music instruments) and duration of total computer use during leisure time are assessed separately with a self-administered questionnaire.

*Assessment of individual characteristics*
At baseline and after one year of follow-up, the personality trait overcommitment is measured within the Effort-Reward Imbalance questionnaire (32). General health, age, gender, education, hand

dominance (i.e. preferred hand for handwriting), body height and body weight are assessed with a self-administered questionnaire.

*Assessment of health outcomes*

Every three months, data concerning symptoms (pain or discomfort) in the lower back, neck, shoulder, arm or hand during the past 3 months are gathered by means of a validated, modified version (41) of the Nordic Questionnaire (42). Localization (anatomical region and side [left and or right]), duration and frequency of episodes of symptoms are recorded. The intensity of symptoms is measured using Von Korff scales (43). Limitations in work or leisure time activities due to symptoms are measured using a Dutch translation of the scales that were used in the EPI-mouse study (44). Data on the work-relatedness of symptoms and the presence of systematic disease or other causes of symptoms (e.g. traffic accident, burns, and rheumatic disease) are also gathered. Sick leave due to symptoms is measured by two questions that have shown adequate agreement with company records in back pain research: 97% specificity and 88% sensitivity (45). In addition, long-term sick leave (i.e. longer than 6 weeks) is registered by the participating organizations or their occupational health service. Data on duration (days), frequency, level (full or partial sick leave) and diagnostic code are gathered. Participants who consult the occupational physician (OP) because of prolonged sick leave (i.e. 3 to 6 weeks) are diagnosed according to the Dutch guideline for the management of arm, neck and shoulder symptoms by occupational physicians (46). All OPs connected to the participating organizations received training on diagnosing and coding hand, arm, shoulder and neck symptoms to reduce inter-observer variation in diagnosis and coding.

## Statistical analysis

*Case definition*

Subjects who report one or more symptoms in the hand-arm region and / or the neck-shoulder region during baseline or follow-up will only be labeled a case if they restrict their activities at home or at work during leisure time and/or used self-medication and/or visited a medical professional because of their symptoms. This definition is in concordance with the definition of the Health Council of the Netherlands, which states that hand, arm, shoulder and neck symptoms lead to limitations in daily functioning or to participation problems (47).

*Episodes*

Workers with and without symptoms at baseline will be followed during follow-up. In this study, data analysis is guided by the notion that hand, arm, shoulder and neck symptoms might be episodic and are recurrent in nature: symptoms are present at a certain time point, symptoms are absent for a certain time period afterwards and then may come back again. The implication for data analysis is that one subject may have more than one episode of hand, arm, shoulder or neck symptoms during the two years of follow-up. A separate episode in this study is defined by the presence of symptoms during a recall period of 3 months followed and preceded by a recall period of 3 months without symptoms. The transition from a symptom free period to an episode of symptoms will be modeled as the outcome variable. Time lags will be defined in order to ensure that exposure precedes the health outcome.

*Statistical models*

Relative risks and confidence intervals will be estimated using Poisson regression with robust error variance (48). We will use both the general linear model (i.e. “basic regression”) and its extension: Generalized Estimation Equations (GEE) (i.e. “basic regression for repeated measures”). In addition, we aim to contrast the findings of the above-mentioned analyses with models that can take into account random factors, and measurement errors: generalized linear latent and mixed models (49). These models have great flexibility by combining the advantages of hierarchical regression models (i.e. analyzing clustered data [e.g. repeated measures of the same subject]) and structural equation models (i.e. taking into account measurement errors). Finally, adjusted population attributable risks will be calculated, using adjusted relative risks and adjusted estimates of risk factor prevalence (50).

*Statistical power*

In a symptom free heterogeneous population of workers, the one-year incidence of neck-shoulder and hand-arm symptoms is expected to be 7.5% and 12.5%, respectively (4, 6, 7, 9, 13). Consequently, the two-year incidence is expected to be 15% for hand-arm, and 25% for neck-shoulder symptoms. Further calculation will be made for hand-arm symptoms, because of the lower incidence of these symptoms in the working population. It is well known that hand-arm symptoms are prevalent in the general population, including people not or little exposed to computer use. Therefore, a two-year incidence for hand-arm symptoms of 10% among low exposed subjects and 20% among high exposed subjects seems reasonable. This difference in incidence between low exposed and high exposed subjects can be detected in logistic regression with a sample of 429 subjects (51). To calculate sample size, we made the following assumptions: incidence at the mean for all factors in the model = 0.15, odds ratio determinant = 2.0, odds ratio confounder = 1.6, agreement between measured exposure and true score (validity) = 0.70, correlation between confounder and exposure (multicollinearity) = 0.30, statistical power = 0.80 and alpha = 0.05. In addition, to be able to study potential effect modification by individual factors we need to at least double the sample size (860 subjects). We assume that about 20% loss to follow-up may occur per year (40% for 2 years), resulting in a recruitment of 1433 subjects at baseline.

In addition to the sample size calculation above, repeated outcome assessment might decrease the required sample size, since we expect that neck-shoulder and hand-arm symptoms are episodic in nature (52). The required sample size is proportional to the number of outcome measurements and the intra class correlation (ICC) between (binary) outcome measurements (53). Based on our one-year follow-up data we calculated ICC for nine repeated measurements [see for formula: 54, p.224]. We used the procedure xtlogit in the Stata software, version 7, to estimate between subject variance on five repeated measures. As a result, the required sample size for hand-arm symptoms decreased from 429 subjects to 204 subjects. From this, it follows that the actual sample size of the PROMO study should be sufficient for adequate statistical power, taking potential effect modification into account.

## Discussion

*Methodological considerations*

The advantages of the PROMO study in comparison with studies published so far include the long follow-up duration (two years), the repeated measurements of both exposure and outcome, and the objective measurement of the duration of computer use. These features of our study will enhance the accuracy of risk estimates. In addition, the frequent exposure and outcome assessment will provide more insight in the time window(s) of relevant exposure effects. This issue has been identified as an important topic, but has up to now not received appropriate attention (55, 56).

At the same time, observational studies, including the PROMO study, are threatened by several sources of bias. Selection bias might be present, since only one out of four workers, who were invited for the study, participated. Selection bias might hamper generalizability of study findings to target populations. The generalizability of our findings is dependent on the distributions of effect modifiers in the target population, compared to our study population. An adjusted risk estimate in the absence of effect

modification is highly generalizable, since it is by definition independent of the distribution of confounders in a target population. In the literature, few effect modifiers have been identified among office workers, making selection bias unlikely, at this moment.
Internal validity is threatened, as in most observational cohort studies, by (residual) confounding. In order to ensure that participants could fill out the baseline questionnaire within 30 minutes, we decided to restrict the item pool to the most relevant variables based on the available evidence (11, 24, 57, 58). We cannot be certain that we did not miss relevant variables. In addition, except for the duration of computer use, all other exposures are measured by self-report. It is known that self-reported exposure estimates have more measurement error than “objective” estimates (55). In general, this will lead to an underestimation of the true risk. However, if more than one risk factor in a multivariate analysis is measured with error, as is the case in this study, both underestimation and overestimation may occur (59). It follows that our analysis on the contribution of various risk factors might be constrained by differences in measurement accuracy.

*Interpretation of epidemiological findings*

It has been suggested that information on physiological mechanisms is necessary to interpret epidemiological findings, since epidemiological data will always be compatible with a wide variety of underlying causal mechanisms (60). The integration of epidemiological and physiological data might enhance the identification of causal risk factors. However, a wide range of mechanisms has been proposed to explain hand, arm, shoulder and neck symptoms among office workers, making it difficult to identify the mechanism(s) at stake. Both peripheral tissue injury and reorganization of the central nervous system have been put forward as potential mechanisms (61). A substantial part of pathophysiological research has focused on sustained low intensity muscle activity, leading to muscle disorders and consecutive symptoms. Although supportive evidence for this mechanism is available (62), it has been criticized as well (63). Since empirical tests of different theories are not available, the specific physiologic mechanism(s) underlying hand, arm, shoulder and neck symptoms cannot be identified yet. A possibility for further investigation is to concurrently test the predictions of different theories in epidemiological studies. According to Barr and co-workers (61), a high repetition of movements is the main risk factor. According to Visser and co-workers (62), continuous low intensity muscle contraction (caused by occupational mechanical exposure and dependent on different situational and individual factors) is the risk factor of main interest. Knardahl (63) proposes mental demands (i.e. information processing demands) during computer use, as the most important risk factor. To concurrently test these theories, the amount of unique variation in the health outcome explained by the different constructs and the amount explained by shared variance could be investigated (64). Therefore, subgroups of workers should be defined, in which an increased risk is expected based on the constructs used in the theories. Moreover, the extent of improvement in the prediction of the health outcome by adding a construct from an alternative theory should be investigated. This improvement in prediction could be operationalized as the improvement in explained variance or the presentation of extra relevant attributable fractions for the added construct.  We will use this approach in the PROMO study.

Indirect evidence of causality might also be attained from the results of primary preventive interventions. However, only a small number of such studies has been published so far (65 - 67), making inferences based on this kind of evidence premature.

To increase our understanding of the etiology of hand, arm, shoulder and neck symptoms among office workers, the best way forward might be to combine multidisciplinary research efforts of observational and (lab- and field-based) experimental research. Hypotheses stemming from different research traditions should be tested (concurrently) under different situations, to make inferences about specificity and generalizability. It follows that the evidence from different levels of inference (e.g. genetics, physiology, biomechanics, individual behavior and culture) should be integrated to optimally serve the goals of public and occupational health

(68). For a start, in the PROMO study both lab-based researchers and field-based researchers will collaborate. Moreover, a range of different hypotheses will be used to interpret the collected data.

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# 6

## Revisiting an ongoing discussion: is the duration of computer use at work a risk factor for the onset of arm-wrist-hand and neck-shoulder symptoms?

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## Abstract

Introduction: The goal of this study was to examine the association between the duration of computer use at work and the onset of arm-wrist-hand and neck-shoulder symptoms.
Methods: A prospective cohort study among 1951 office workers was performed with a follow-up period of 2 years. Outcome was assessed every three months by questionnaire. Objective estimates of the duration of computer use at work were obtained by software registration. Subjective estimates of the duration of computer use at work and other self-reported covariates were obtained by questionnaire at baseline and after one year of follow-up. Relative Risks were estimated with Generalized Estimation Equations. Cases were identified based on the transition within 3 months of no, irregular or “minor” symptoms to regular or prolonged symptoms accompanied with a pain intensity exceeding 6 on a Von Korff scale 20 for worst symptoms or medication use to control symptoms.
Results: Self-reported exposure data were positively associated with the onset of both neck-shoulder and arm-wrist-hand symptoms. Registered exposure data were not associated with the outcomes.
Conclusion: The findings of the current prospective cohort study challenge the existence of a causal link between the duration of computer use at work and the onset of arm-wrist-hand and neck-shoulder symptoms, based on the absence of an association between the registered duration of computer use at work and the onset of arm-wrist-hand and neck-shoulder symptoms. The positive association between the self-reported duration of computer use at work and the onset of arm-wrist-hand and neck-shoulder symptoms could not be explained satisfactory.

## Introduction

The question whether a long duration of computer use at work challenges musculoskeletal health has been under debate for a considerable time. (1 - 4) The internal load during computer use can be characterized as sustained muscle activation due to prolonged exposure to low force, high repetition hand-arm activity and static working postures. Animal studies have provided evidence that sustained muscle activation and exposure to low force, high repetition hand-arm activity can lead to tissue damage and inflammation (5, 6, 7), which may be primary causes for the onset of musculoskeletal disorders and symptom experience among computer users. (8) Critics of this overuse hypothesis have attested that internal loads encountered during work activities are within physiological limits and may actually be necessary for normal functioning of the musculoskeletal system. (3, 9)

However, the overuse hypothesis is supported by evidence from epidemiological studies. In prospective cohort studies a dose-response relationship was found between the self-reported duration of mouse use at work and hand-arm symptoms. (10) Two recent prospective cohort studies, which used software registration to assess the duration of computer use at work, confirmed the positive association between the duration of computer use at work and the onset of arm-wrist-hand and neck-shoulder symptoms. (11, 12) Surprisingly, the strength of associations in studies with registered exposure data were in general weaker than previously reported with self-reported exposure data. (10) It was expected that registered exposure data would lead to stronger associations than self-reported exposure data, due to less non-differential misclassification of exposure. (10) In addition, a long duration of mouse use at work was only associated with acute symptoms, and not with prolonged symptoms. (11) This finding challenges the relevance of the association between the registered duration of computer use at work and acute musculoskeletal symptoms.

Although the debate on the potential effect of the duration of computer use at work on the onset of arm-wrist-hand and neck-shoulder symptoms has been ongoing for decades, this is only the third study that allows inference on the true effect of the duration of computer use on the onset of arm-wrist-hand and neck-shoulder symptoms, based on objectively measured data of the duration of computer use. In addition, to date, no study has used the same case definition to examine the associations between the self-reported and the registered duration of computer use at work and the onset of arm-wrist-hand and neck-shoulder symptoms. Therefore, the current study examines the association between the duration of computer use at work and the onset of arm-wrist-hand and neck-shoulder symptoms, by using both registered and self-reported exposure data.

## Methods

Data from a prospective cohort study among 1951 office workers with a follow-up duration of two years were used. Outcome was assessed every three months by means of a questionnaire. Risk factors were assessed with a questionnaire at baseline and after one year of follow-up. For a subgroup of workers, continuous registration of the duration of computer use at work was available. The Medical Ethics Committee of the VU University Medical Centre (VUmc) approved the study design and subjects signed informed consents before study participation. Additional information on the prospective cohort study can be found elsewhere. (13)

*Subjects*

Subjects were recruited from five organizations, which included public and private organizations. Preventive interventions were common, such as the use of break and reminder software, the use of ergonomic workstations, and ergonomic education. During the two-year follow-up, reorganizations took place in three out of five organizations. The main work tasks of the participants were computer-related tasks, attending meetings, making phone calls, and giving presentations.

*Assessment of the duration of computer use at work*

The duration of computer use at work was measured by software registration (Wellnomics WorkPace version 3.0, Wellnomics Ltd/ErgoDirect) and by questionnaire. From the software registrations we calculated the average weekly duration of computer use at work for each 3-month period during follow-up by dividing the cumulative time of usage in a three-month

period by the number of weeks in that period. The same was done for keyboard use and mouse use separately.
Data were excluded from the analysis from participants who worked at least two days per week at another location of their organization where no recordings could be made and data from participants who shared a computer account with a colleague. In addition, data were excluded if the number of recorded days was less than 70% of the number of actual working days in a three-month period.
For the missing data we imputed data (last observation carried forward), based on the finding that the between subject variation in duration of computer use was five times higher than the within subject variation for successive three-month periods. In addition, univariate associations with the outcome variables were similar for original data and original plus imputed data.
The baseline questionnaire and the questionnaire after one-year follow-up contained items on the duration of computer use at work. The exact wording was: "How many hours per day do you use your computer during your work at the office (including reading from the screen)?" The question had seven response categories: never, 0-1, 1-2, 2-4, 4-6, 6-8, >8 hours per day). A similar question was used for the duration of mouse use.

*Assessment of potential effect modifiers and confounders*
A priori we selected potential effect modifiers and confounders (see Appendix 1) based on previously reported risk factors (13) and on a pathophysiological hypothesis, in which continuous muscle activation plays an important role in the onset of arm-wrist-hand and neck-shoulder symptoms. (8, 14, 15, 16, 17)

*Identification of cases*
Symptoms in the arm-wrist-hand region and neck-shoulder region were assessed separately. This choice was based on previous work that suggested that the effect of computer use on these two body regions is different. (10, 18) Following Marcus et al. (19), cases were identified based

on the transition within 3 months of no, irregular or “minor” symptoms to regular or prolonged symptoms accompanied with a pain intensity exceeding 6 on a Von Korff scale (20) for worst symptoms or medication use to control symptoms. In a previous study among computer users this self-reported case definition was associated with the same risk factors as a case definition based on physical examination. (19)

*Statistical analysis*

Generalized Estimating Equations (GEE, STATA 7.0, College Station, TX) were used to estimate Rate Ratios (RRs) (21) for becoming a case. Separate analyses were performed for the neck-shoulder and the arm-wrist-hand region, and for self-reported and registered duration of computer use. Numerical variables were divided into quartiles. The variables for the registered duration of computer use at work were divided into tertiles, because of the lower number of available observations. Adjacent categories were collapsed if RRs in univariate analysis were similar for a given outcome. We strived to use the lowest number of categories to realistically model the relationship between the variable and the outcome. Variables measured at baseline and at one year-follow-up were treated as constants for each three-month period during the following year of follow-up. Covariates measured at baseline only, were treated as constants for all three-month periods during follow-up.

Univariate analyses were performed separately for each potential effect modifier / confounder. If the P-value of the Wald test was lower than or equal to 0.20, the variable was retained for further analysis. The remaining variables were then screened for multicollinearity. If the correlation between two variables exceeded 0.50, the variable with the strongest association with the outcome was retained. Subsequently, we explored effect modification with the remaining variables. Effect modification was assumed to be present if the P-value of the Wald test of the interaction term was lower than or equal to 0.05 in a model, which included the main effects. Finally, a full model with all the remaining potential confounders was tested.

If the P-value of the Wald test exceeded 0.10, the potential confounder was excluded from the final model in order to increase precision. (22)

## Results

*Subjects*

Baseline characteristics for subjects who responded to all follow-up questionnaires and for subjects who had missing responses during follow-up are presented in Table 1. Compared to subjects with no missing data during follow-up, subjects with missing data reported less often 6 to 8 hours per day of mouse use at work (i.e. 9% less often among subjects with 5 to 8 missing responses), less often historical exposure to daily computer use at work for at least 10 years (i.e. 15% less often among subjects with 5 - 8 missing responses), and were more often female (i.e. 9% to 11% more often for subjects with 1 to 4, and 5 to 8 missing responses).

*Incidence*

The 3-month incidence for neck-shoulder cases varied between 3.9% and 8.8%, and for arm-wrist-hand cases between 2.8% and 4.6% during the respective follow-up periods (Table 2). One out of every 4 participants (23%) became a single neck-shoulder case and one out of every 6 participants (17%) became a single arm-wrist-hand case during the two years of follow-up. The incidence of multiple cases (“recurrent cases”) was 8.8% of all participants for the neck-shoulder region and 5.7% for the arm-wrist-hand region. Co-morbidity of new symptoms in both neck-shoulder and arm-wrist-hand region was present in 10% of all cases. The largest part of the cohort did not meet the case definition at baseline and during follow-up: 62% of all participants for the neck-shoulder region and 72% of all participants for the arm-wrist-hand region.

Table 1 Comparison of baseline characteristics according to the number of missing follow-up responses. *

| | **Number of missing follow-up responses** | | |
|---|---|---|---|
| | 0 (n=1013) | 1 - 4 (n=523) | 5 - 8 (n=415) |
| Symptom status | | | |
| Prevalent NS symptoms | 154 (15) | 92 (18) | 89 (21) |
| Prevalent AWH symptoms | 101 (10) | 61 (12) | 57 (14) |
| Self-reported duration of total computer use at work, h / d | | | |
| 0 - < 2 | 19 (1.9) | 10 (1.9) | 5 (1.2) |
| 2 - < 4 | 128 (13) | 65 (12) | 49 (12) |
| 4 - < 6 | 428 (42) | 194 (37) | 157 (38) |
| 6 - < 8 | 419 (41) | 237 (45) | 199 (48) |
| > = 8 | 18 (1.8) | 17 (3.3) | 5 (1.2) |
| Self-reported duration of mouse use at work, h / d | | | |
| 0 - < 2 | 132 (13) | 58 (11) | 39 (9.4) |
| 2 - < 4 | 281 (28) | 142 (27) | 102 (25) |
| 4 - < 6 | 374 (37) | 186 (36) | 149 (36) |
| 6 - < 8 | 216 (21) | 130 (25) | 123 (30) |
| > = 8 | 8 (0.8) | 7 (1.3) | 2 (0.5) |
| Registered duration of total computer use at work, at 1-year follow-up, mean (SD), h / w | 12.4 (4.5) † | 11.5 (4.7) ‡ | 11.4 (4.7) ‡ |
| Registered duration of mouse use at work, at 1-year follow-up, mean (SD), h / w | 6.6 (3.1) † | 6.1 (3.2) § | 6.2 (3.1) ‡ |
| Registered duration of keyboard use at work, at 1-year follow-up, mean (SD), h / w | 3.0 (1.5) † | 2.7 (1.4) § | 2.7 (1.5) ‡ |
| Self-reported historical exposure to daily computer use, y | | | |
| 0 - < 2 | 53 (5.2) | 30 (5.7) | 41 (10) |
| 2 - < 5 | 164 (16) | 106 (20) | 97 (23) |
| 5 - < 10 | 285 (28) | 152 (29) | 134 (32) |
| > = 10 | 511 (50) | 235 (45) | 143 (35) |
| Self-reported increase in daily computer use during past year, yes | 192 (19) | 116 (22) | 104 (25) |
| Age, mean (SD), y | 41 (9.6) | 40 (9.8) | 38 (9.6) |
| Sex, female | 440 (43) | 271 (52) | 223 (54) |
| Number of working days, mean (SD), d / w | 4.5 (0.7) | 4.4 (0.8) | 4.4 (0.8) |
| Job contract, mean (SD), h / w | 34 (7.3) | 34 (6.7) | 33 (8.2) |
| Overwork, mean (SD), h / w | 4.6 (10) | 5.1 (12) | 5.1 (11) |

Abbreviations: NS = neck-shoulder, AWH = arm-wrist-hand, h / d = hours per day, SD = standard deviation, h / w = hours per week, y = years, d / w = days per week

* Data are expressed as absolute numbers (%) unless otherwise noted

† n = 453, ‡ n = 107, § n = 196

Table 2 Cases during follow-up. *

| Body region | Follow-up instance | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 3-month (n=1781†) | 6-month (n=1779‡) | 9-month (n=1761‡) | 12-month (n=1528‡) | 15-month (n=1436‡) | 18-month (n=1426‡) | 21-month (n=1411‡) | 24-month (n=1352‡) |
| **1** | 90 (5.1) | 124 (7.0) | 82 (4.7) | 135 (8.8) | 78 (5.4) | 82 (5.8) | 55 (3.9) | 60 (4.4) |
| **2** | 54 (3.0) | 68 (3.8) | 78 (4.4) | 67 (4.4) | 57 (4.0) | 65 (4.6) | 58 (4.1) | 38 (2.8) |

Body region 1 = Neck-shoulder
Body region 2 = Arm-wrist-hand
* Data are expressed as absolute numbers (% of total at particular follow-up instance).
Case definition: transition within three months of no, irregular or “minor” symptoms to regular or prolonged symptoms accompanied with pain intensity exceeding 6 on a Von Korff scale or medication use to control pain.
† subjects who responded at baseline and at 3-month follow-up
‡ subjects who responded at baseline, at the particular follow-up instance, and at the preceding follow-up instance

*Associations between the duration of computer use at work and case status*
Subjects who reported to use the computer at work for 4 to 6 hours per day were almost twice more likely than subjects reporting less than 4 hours per day to become an arm-wrist-hand case during follow-up (RR 1.9, 95% confidence interval (CI) 1.1-3.1; See Table 3). The risk of becoming an arm-wrist-hand case did not increase further for subjects reporting at least 6 hours computer use per day (RR 2.0, 95% CI 1.2-3.2). For the duration of self-reported mouse use, a moderate association was found with arm-wrist-hand symptoms (RR 1.4, 95% CI 0.9-2.1 for at least 4 hours per day versus 0 to 2 hours per day). For the neck-shoulder region, we found no association between the self-reported duration of total computer use at work and case status during follow-up. Subjects who reported at least 4 hours per day of mouse use at work, however, had a moderately increased risk of developing neck-shoulder symptoms (RR 1.5, 95% CI 1.1-2.0).
The registered duration of total computer use, mouse use and keyboard use at work was neither associated with the onset of arm-wrist-hand symptoms, nor with the onset of neck-shoulder symptoms.
Precision demands at work and duration of computer use during leisure

time modified the association between the self-reported duration of computer use at work and the onset of arm-wrist-hand symptoms. Higher exposure levels of the effect modifier in combination with a longer self-reported duration of computer use at work resulted in a weaker association with arm-wrist-hand symptoms as compared to the association with self-reported duration of computer use alone (data not presented). For all other evaluated associations, no effect modifiers were identified.

Table 3 Univariate and multivariate associations between self-reported and registered duration of computer use at work and arm-wrist-hand and neck-shoulder cases.

| | Arm-wrist-hand | | Neck-shoulder | |
|---|---|---|---|---|
| **Exposure variable** | Univariate RR (95% CI) | Multivariate * RR (95% CI) | Univariate RR (95% CI) | Multivariate † RR (95% CI) |
| Self-reported duration of total computer use at work, h / d | | | | |
| 0 - < 4 | 1 | 1 | 1 | 1 |
| 4 - < 6 | 1.4 (0.9-2.2) | 1.9 (1.1-3.1) | 1.3 (0.9-1.7) | 1.1 (0.8-1.5) |
| > = 6 | 2.0 (1.3-3.0) | 2.0 (1.2-3.2) | 1.7 (1.3-2.3) | 1.2 (0.9-1.6) |
| Self-reported duration of mouse use at work, h / d | | | | |
| 0 - < 2 | 1 | 1 | 1 | 1 |
| 2 - < 4 | 0.9 (0.6-1.4) | 1.1 (0.7-1.7) | 1.0 (0.7-1.4) | 1.1 (0.8-1.5) |
| > = 4 | 1.5 (1.0-2.2) | 1.4 (0.9-2.1) | 1.6 (1.2-2.2) | 1.5 (1.1-2.0) |
| Registered duration of total computer use at work, h / w | | | | |
| 1 - < 9 | 1 | 1 | 1 | 1 |
| 9 - < 14 | 1.0 (0.7-1.3) | 0.9 (0.5-1.4) | 0.9 (0.7-1.1) | 1.3 (0.9-1.8) |
| 14 – 35 | 1.0 (0.7-1.3) | 0.8 (0.5-1.2) | 0.9 (0.7-1.2) | 1.0 (0.7-1.4) |
| Registered duration of mouse use at work, h / w | | | | |
| 0 - < 4 | 1 | 1 | 1 | 1 |
| 4 - < 7 | 1.0 (0.7-1.4) | 0.8 (0.5-1.4) | 1.0 (0.8-1.3) | 0.9 (0.7-1.4) |
| 7 – 21 | 1.0 (0.8-1.4) | 0.9 (0.6-1.4) | 0.9 (0.7-1.2) | 0.8 (0.6-1.2) |
| Registered duration of keyboard use at work, h / w | | | | |
| 0 - < 2 | 1 | 1 | 1 | 1 |
| 2 - 3 | 1.1 (0.8-1.5) | 1.0 (0.7-1.5) | 1.0 (0.7-1.2) | 1.2 (0.8-1.6) |
| 3 - 13 | 0.8 (0.6-1.2) | 0.8 (0.5-1.2) | 0.8 (0.6-1.1) | 1.0 (0.7-1.4) |

Abbreviation: RR, rate ratio; 95% CI, 95% confidence interval

[*] *Self-reported duration of total computer use at work* (10.310 observations): adjusted for squeezing with hands at work, using computer and telephone at the same time at work, duration of computer use during leisure time, reward, task variety, gender, age, education; overcommitment, body mass index, disabling arm-wrist-hand symptoms in past year, disabling neck-shoulder symptoms in past year;

*Self-reported duration of mouse use at work* (10.307 observations): adjusted for squeezing with hands at work, using computer and telephone at the same time at work, duration of computer use during leisure time, reward, task variety, gender, age, education; overcommitment, body mass index, disabling arm-wrist-hand symptoms in past year, disabling neck-shoulder symptoms in past year;

*Registered duration of total computer use at work* (3953 observations), *registered duration of mouse use at work* (3953 observations), and *registered duration of keyboard use at work* (3951 observations): adjusted for reward, task variety, managerial job, mouse handedness, age, education, overcommitment, disabling arm-wrist-hand symptoms in past year, disabling neck-shoulder symptoms in past year;.

[†] *Self-reported duration of total computer use at work* (10.959 observations): adjusted for work continuation during formal breaks, repetitive tasks at work excluding computer use, using computer and telephone at the same time at work, decision authority, task variety, arm support during keyboard use, age, gender, education level, work disability due to arm-wrist-hand or neck-shoulder symptoms among acquaintances, disabling neck-shoulder symptoms in past year;

*Self-reported duration of mouse use at work* (10.987 observations): adjusted for work continuation during formal breaks, repetitive tasks at work excluding computer use, using computer and telephone at the same time at work, decision authority, age, gender, work disability due to arm-wrist-hand or neck-shoulder symptoms among acquaintances, disabling neck-shoulder symptoms in past year;

*Registered duration of total computer use at work* (4138 observations), *registered duration of mouse use at work* (4138 observations), and *registered duration of keyboard use at work* (4132 observations): adjusted for squeezing with hands at work, effort, decision authority, task variety, mental demands, arm support during keyboard use, age, gender, work disability due to arm-wrist-hand or neck-shoulder symptoms among acquaintances, disabling neck-shoulder symptoms in past year.

## Discussion

Previous studies have shown that office workers overestimate their duration of computer use at work, as compared to the registered duration of computer use at work. This leads to a high degree of non-differential misclassification of self-reported exposure data as compared to registered exposure data. (18, 23) Based on these findings, the expectation was that registered data would show stronger associations with the onset of symptoms than self-reported exposure data. (10) However, registered data on the duration of computer use at work did not show an association with case status during follow-up, whilst self-reported exposure data yielded positive associations with the onset of both arm-wrist-hand and neck-shoulder symptoms.

Two previous studies have investigated the relationship between the registered duration of computer use at work and the onset of arm-wrist-hand and neck-shoulder symptoms. (11, 12) In contrast to our findings, both studies found a statistically significant, positive association between the registered duration of computer use at work and the onset of arm-wrist-hand and neck-shoulder symptoms. This difference in findings between the current and previous studies might in part be explained by the time window between measurement of exposure and outcome. In the current study it was 3 months, and in the previous studies it was 1 week (11) and 1 day. (12) In addition, case definitions were different between studies. In the current study, subjects needed to report regular or prolonged symptoms of sufficient intensity in the past three months, whereas in the previous studies subjects had to report symptoms of sufficient intensity on one day. (11, 12) However, Andersen and co-workers (11) failed to find an association with prolonged symptoms, which compares to the findings in the current study. Taken together, the results of the currently available studies suggest that the registered duration of computer use at work is associated with a moderately increased risk of acute musculoskeletal symptoms. However, no association seems to be present with regular or prolonged symptoms.

One of the explanations for the discrepancy in findings between self-reported and registered exposure data may be selection bias. Due to missing data, the number of available observations for the analyses with registered exposure data was far lower than for the analyses with self-reported data. However, the identified associations between the self-reported duration of computer use at work and the onset of arm-wrist-hand and neck-shoulder symptoms were identical when selecting the subgroup of observations for which registered exposure data were available.

A second explanation for not finding an association with the registered duration of computer use at work may be self-regulation (i.e. workers who experience symptoms lower their exposure to computer use and remain healthy). (24) During the follow-up period no indications of such self-regulation took place, since case status during the first year of follow-up was not related to a decrease in the registered and self-reported duration of computer use at work during follow-up. This finding has also been reported previously. (11)

A third explanation might be that that differential misclassification of exposure due to symptom status has led to spurious associations between the self-reported duration of computer use at work and the onset of arm-wrist-hand and neck-shoulder symptoms. However, previous studies have shown that misclassification of computer use duration is largely independent of symptom status. (18, 25) It should also be noted that post-hoc analysis showed no association between the degree of overestimation by self-report as compared with registration, and the onset of arm-wrist-hand and neck-shoulder symptoms.

A third explanation may be that self-reported and registered duration of computer use at work do not measure the same construct. The correlation between self-reported and registered data in this study was 0.2 at maximum. In other studies, correlations between 0.36 and 0.61 have been reported. (23, 26) Therefore, it may be that self-reports measure a different construct than software registrations. Routinely collected data in occupational epidemiology, such as physical, psychosocial, and individual factors, together with registered computer use data explained at maximum 38% of the variance in the self-reported duration of computer use at work. (23) This limited explained variance could be related to limited precision of self-reports and/or unmeasured determinants of the self-reported duration of computer use at work.

Finally, the lack of an association with the registered data may reflect that the overuse hypothesis has shortcomings. Although animal studies have shown that prolonged exposure to low force, high repetition hand-arm activity can lead to muscle damage and inflammation, positive training effects (i.e. increased force production) of the same type of exposure have also been reported. (27) Moreover, muscle damage and/or inflammation might neither be a necessary nor a sufficient cause for triggering symptom experience. (28 - 30)

In conclusion, the findings of the current prospective cohort study challenge the existence of a causal link between the duration of computer use at work and the onset of arm-wrist-hand and neck-shoulder symptoms, based on the absence of an association between the registered duration of computer use at work and the onset of arm-wrist-hand and neck-shoulder symptoms. The positive association between the self-reported duration of computer use at work and the onset of arm-wrist-hand and neck-shoulder symptoms could not be explained satisfactory.

Appendix 1 Overview of potential confounders and potential effect modifiers.

| **Potential confounders** | **Potential effect modifiers** |
|---|---|
| Using computer and telephone at the same time at work | Using computer and telephone at the same time at work |
| Duration of computer use during leisure time | Duration of computer use during leisure time |
| Use of break and reminder software | Use of break and reminder software |
| Work continuation during formal breaks | Work continuation during formal breaks |
| Cognitive demands [*] | Cognitive demands [a] |
| Effort [†] | Effort [b] |
| Precision demands during mouse use | Precision demands during mouse use |
| Arm support during keyboard use | Arm support during keyboard use |
| Arm support during mouse use | Arm support during mouse use |
| Touch typing skill | Touch typing skill |
| Monitor height | Monitor height |
| Mouse location | Mouse location |
| Lack of space on desk for proper mouse use | Lack of space on desk for proper mouse use |
| Mouse functioning | Mouse functioning |
| Distance table edge to keyboard < 10cm | |
| Repetitive tasks at work excluding computer use | |
| Working with hands above shoulder height | |
| Pushing or pulling | |
| Manual materials handling | |
| Symptoms in the neck-shoulder region in the past year causing disability or medical consumption | |

| |
|---|
| Symptoms in the arm-wrist-hand region in the past year causing disability or medical consumption |
| General discomfort while working at desk |
| Number of years of daily computer use at work |
| Increase in duration of computer use in the past year |
| Moderate intensity physical activity |
| High intensity physical activity |
| Strength training of upper body |
| Playing golf |
| Playing sports involving upper extremities (e.g. racket sports, volleyball) |
| Hand intensive activities during leisure time |
| Reward [‡] |
| Overcommitment [§] |
| Decision authority [||] |
| Task variation [¶] |
| Gender |
| Age |
| Education level |
| Body Mass Index |
| Work disability due to neck-shoulder or arm-wrist hand symptoms among acquaintances |

[*] Cronbachs alpha = 0.73 (baseline); 0.76 (after one year of follow-up)
[†] Cronbachs alpha = 0.69 (baseline); 0.59 (after one year of follow-up)
[‡] Cronbachs alpha = 0.81 (baseline); 0.62 (after one year of follow-up)
[§] Cronbachs alpha = 0.74 (baseline); 0.78 (after one year of follow-up)
[||] Cronbachs alpha = 0.74 (baseline); 0.71 (after one year of follow-up)
[¶] Cronbachs alpha = 0.84 (baseline); 0.84 (after one year of follow-up)

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# 7

# The relative contribution of work exposure, leisure time exposure and individual characteristics in the onset of arm-wrist-hand and neck-shoulder symptoms among office workers

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**Abstract**

Introduction: The objectives of this study were to identify risk factors for the onset of arm-wrist-hand and neck-shoulder symptoms among office workers and to estimate the relative contribution of these risk factors by calculating Population Attributable Fractions (PAFs).
Methods: Data from a prospective cohort study among 1951 office workers with a follow-up duration of two years were used. Data on self-reported risk factors were collected at baseline and after one year of follow-up. For a subgroup of workers, continuous registration of the duration of computer use at work was available. Outcome was assessed every three months by means of a questionnaire. Population Attributable Fractions (PAFs) for individual risk factors were estimated based on Rate Ratios (RRs) obtained from Poisson regression using Generalized Estimation Equations (GEE).
Results: Among factors that increased the risk of the onset of arm-wrist-hand symptoms, the highest PAF values were found for > = 4 hours per day of self-reported computer use at work (PAF 0.46, 95% CI 0.11 - 0.68) and previous disabling arm-wrist-hand symptoms (PAF 0.33, 95% CI 0.26 – 0.41). Never squeezing firmly with hands, often / always using computer and phone at the same time, moderate to low reward, low task variation, at least 4 hours per day of self-reported computer use during leisure time, female gender, higher age, higher education level, moderate to high levels of overcommitment, BMI > 24 kg / m$^2$ and previous disabling neck-shoulder symptoms also increased the risk of the onset of arm-wrist-hand symptoms. Among factors that increased the risk of the onset of neck-shoulder symptoms, the highest PAF values were found for previous disabling neck-shoulder symptoms (PAF 0.45, 95% CI 0.39 – 0.51), and arm support during keyboard use (PAF 0.38, 95% CI 0.12 - 0.56). At least 4 hours per day of self-reported mouse use, often / always performing repetitive movements with hands (excluding computer use), sometimes / often / always using computer and telephone at the same time, low task variation, female gender, medium age, work continuation during formal breaks, and

having an acquaintance experiencing disabling symptoms also increased the risk of the onset of neck-shoulder symptoms.

The registered duration of computer use at work, monitor height, mouse and keyboard location, precision demands during mouse use, cognitive demands, and general physical activity during leisure time were, among other factors, not associated with the onset of arm-wrist-hand nor with the onset of neck-shoulder symptoms.

Conclusion: Previous disabling symptoms were identified as the most important risk factor for the onset of arm-wrist-hand and neck-shoulder symptoms among office workers. Preventive interventions should be aimed at modifying multiple modifiable risk factors at the same time in order to be effective.

## Introduction

Prevention of pain and discomfort among office workers might be worthwhile for society, companies and individuals. Cumulative 1-year incidences of 10% or more for various regional arm-wrist-hand and neck-shoulder symptoms have been reported among office workers (1 - 7), and symptoms may lead to restriction of work activities. As a result, both financial (8, 9) and emotional consequences (10) are prevalent. Due to the large source population, a high absolute number of office workers will experience arm-wrist-hand and neck-shoulder symptoms and related consequences.

Arm-wrist-hand and neck-shoulder symptoms are supposed to have a multifactorial origin: physical and psychosocial factors at work, physical factors during leisure time and individual factors are all likely to play a role (11 - 13). Despite the seemingly low physical demands during office work, it has been suggested that small muscle fibers might still be overloaded, which may result in the onset of arm-wrist-hand and neck-shoulder symptoms (14, 15).

In laboratory studies, the amount of muscle loading has been associated with a range of factors: lack of arm support (16, 17), low monitor placement

(18, 19), location of the mouse to the side or to the front of the operator (20, 21), location of the keyboard close to the table edge (22), high precision demands (23, 24), type of input device [i.e. mouse use versus keyboard use] (25, 26), high cognitive demands (27, 28); high emotional demands [e.g. time pressure and verbal provocation] (24, 29), female gender (30), personality traits (31, 32), and previous symptoms (33). Moreover, a long duration of computer use per se is a likely contributor to increased muscular loading (34, 35).

Since few longitudinal field studies have been performed among office workers (36), the knowledge base of risk factors for the onset of arm-wrist-hand and neck-shoulder symptoms among office workers relies mainly on laboratory studies and cross-sectional field studies (e.g. 37, 38). The current study aims at expanding the knowledge base of risk factors among office workers by investigating risk factors for the onset of arm-wrist-hand and neck-shoulder symptoms in a longitudinal study. In addition, the impact of the risk factors will be determined. No study up to date has estimated the impact of risk factors among office workers. Impact can be evaluated by means of Population Attributable Fractions (PAFs), which take into account risk factor prevalences and strength of associations. This information is important to support decision-making regarding the most effective preventive interventions.

## Methods

Data from a prospective cohort study among 1951 office workers with a follow-up duration of two years were used. Outcome was assessed by questionnaires every three months. Risk factors were assessed at baseline and after one year of follow-up. For a subgroup of workers, objective registration of the duration of computer use at work was available. The Medical Ethics Committee of the VU University Medical Centre (VUmc) approved the study design and subjects signed informed consents before study participation. Additional information on the prospective cohort study can be found elsewhere (13).

*Subjects*

Subjects were recruited from five organizations, which included public and private organizations. The main work tasks of the participants were computer-related tasks, attending meetings, making phone calls, and giving presentations. Preventive interventions within the organizations were common, such as the use of break and reminder software, use of ergonomic workstations, and ergonomic education. During the 2-year follow-up period, reorganizations within three out of five organizations took place.

*Assessment of potential risk factors*

Almost all potential risk factors were assessed by a web-based questionnaire. Participants could ask for a paper and pencil version, but only a minority requested this (i.e. less than 2% of all participants). A list of potential risk factors can be found in Tables 2 and 4 (identified risk factors) and Appendices A and B (risk factors not included in final models).

In addition to self-reported data, continuous registrations of the duration of computer use at work were collected by means of a software program (Wellnomics WorkPace version 3.0, obtained from ErgoDirect BV). In previous validation studies, estimates of the mean duration of computer use by the software program were within 10% of those obtained by video observations (39, 40). We calculated the average weekly duration of computer use at work by dividing the cumulative time of usage per week by the number of weeks in the 3-month period.

*Assessment of outcome*

Outcome was assessed every three months during the 2-year follow-up by means of a modified version of the Nordic Questionnaire (41, 42). In addition, data on symptom severity were collected on an 11-point Von Korff scale ranging from 0 (“no symptoms”) to 10 (“worst imaginable symptoms”) (43). A single question collected data on use of pain medication as a consequence of symptoms (yes / no). Data on symptoms, pain intensity and use of pain medication were collected separately for the neck-shoulder region and the arm-wrist-hand region. Cases were defined based on the reporting of regular or prolonged symptoms in the past three months, plus a symptom intensity level of at least 6 on a Von Korff scale or usage of pain medication, preceded by three months of no / minor symptoms (i.e. no regular / prolonged symptoms in past three months, or symptom intensity less than 6 and no pain medication use).

*Statistical analysis*

Cases during a 3-month period (t) were predicted by exposure to risk factors during the three months preceding this period (t-1). A maximum of eight possible transitions for becoming a case could be tested in this way for each subject. Rate Ratios (RRs) for the transition of no / minor symptoms to symptoms during a 3-month period were obtained from Poisson regression using Generalized Estimating Equations (GEE, STATA 7.0, College Station, TX; 44).

Numerical variables were divided into quartiles. The variables for the registered duration of computer use at work were divided into tertiles, because of less available observations. Adjacent categories were collapsed if RRs in univariate analysis were similar for a given outcome. We strived to use the lowest number of categories to realistically model the relationship between the variable and the outcome. Variables measured at baseline and at one-year follow-up were treated as constants for each 3-month period during the following year of follow-up. Variables measured at baseline only, were treated as constants for all 3-month periods during follow-up. The registered duration of computer use was treated as a time-dependent factor, and could thus vary over each 3-month period.

Separate analyses were performed for the arm-wrist-hand and the neck-shoulder region, because previous reviews indicated different effects of exposure to computer use on the two body regions (36, 45).

For each outcome, the final risk factors were identified in three steps. Firstly, we performed univariate analyses for each risk factor separately. If the P-value of the Wald test was lower or equal to 0.20, the variable was retained for further analysis.

Secondly, the remaining risk factors were screened for multicollinearity. If the correlation between two variables exceeded 0.50, the variable with the stronger association with the outcome was retained. A high correlation between the subscales effort and reward on the one hand, and the Effort Reward Imbalance (ERI) ratio on the other hand was identified. We decided to use the subscales effort and reward in further analysis for interpretation reasons.
Thirdly, a full model with all the remaining variables was tested. If the P-value of the Wald test exceeded 0.10, the potential risk factor was excluded from the final model in order to increase precision (46).
The proportions explained variance of the final models were estimated using multilevel logistic regression (47, p.225). Population Attributable Fractions (PAF) and 95% confidence intervals were calculated for each identified risk factor with a formula suited for adjusted RRs (48, 49).
Finally, we performed analyses in which the number of potentially modifiable risk factors was the determinant. Non-modifiable risk factors were included in the models as covariates.

## Results

*Study population*

The participation rate (i.e. subjects who agreed to participate in the study compared to all subjects who were approached) varied between 10% and 33% for the five participating organizations. Overall participation rate was 27%. For one of the organizations, which made up 46% of the baseline cohort, company records were available to compare participants and non-participants, see Table 1. Non-participants used the computer less than participants (11.0 hours per week versus 11.8 – 12.4 hours per week). Participants with missing data (i.e. at least one complete outcome assessment) during follow-up had a shorter mean job tenure than participants without missing data during follow-up (9.9 years versus 12.5 years), reported more often > = 6 hours per day of computer use at work (49% versus 43%), were younger (39 years versus 41 years), were more often female (53% versus 43%) and reported more often neck-shoulder symptoms at baseline (17% versus 13%). For other evaluated variables no large differences were present between participants and non-participants, nor between participants with and without missing data during follow-up.

Table 1 Baseline characteristics of participants and non-participants.

| **Risk factors** | **Participants No missing data during follow-up** | | **Participants Missing data during follow-up** * | | **Non-participants** | |
|---|---|---|---|---|---|---|
| **Work exposures** | **n** | **% / mean (sd)** | **n** | **% / mean (sd)** | **n** | **% / mean (sd)** |
| Mean company tenure (y) | 1010 | 12.5 (10.6) | 937 | 9.9 (9.8) | 2926 | 10.9 (9.9) |
| Mean job contract (h / w) | 1010 | 34.5 (7.3) | 937 | 33.9 (7.3) | 2926 | 34.3 (6.7) |
| Mean registered duration of computer use at work (h / w) | 272 | 12.4 (4.0) | 189 | 11.8 (4.4) | 1017 | 11.0 (5.6) |
| Self-reported duration of computer use at work ( h / d) | | | | | | |
| 0 - < 4 hrs / day | 147 | 15 | 129 | 14 | - † | - † |
| 4 - < 6 hrs / day | 428 | 42 | 351 | 37 | | |
| > = 6 hrs / day | 437 | 43 | 458 | 49 | | |
| **Individual characteristics** | | | | | | |
| Age | 1006 | 41.4 (9.6) | 915 | 38.9 (9.8) | 2926 | 39.6 (9.3) |
| Female gender | 1013 | 43.4 | 938 | 52.7 | 2926 | 44.5 |
| Prevalent neck-shoulder symptoms in past three months | 1013 | 12.8 | 938 | 17.2 | - † | - † |
| Prevalent arm-wrist-hand symptoms in past three months | 1013 | 9.7 | 938 | 11.4 | - † | - † |
| Disability due to neck-shoulder symptoms in past year | 1013 | 26.1 | 938 | 26.3 | - † | - † |
| Disability due to arm-wrist-hand symptoms in past year | 1013 | 18.8 | 938 | 21.2 | - † | - † |

Abbreviations: n = number of subjects, sd = standard deviation, y = years, h / w = hours per week, h / d = hours per day

* at least one complete outcome assessment missing during follow-up

† no data available

*Incidence*

The 3-month cumulative incidence varied between 3.9% and 8.8% for neck-shoulder symptoms during the follow-up periods (mean 5.7%), and varied between 2.8% and 4.6% for arm-wrist-hand symptoms (mean 3.7%). Recurrent symptoms (i.e. multiple episodes) made up 28% of all neck-shoulder symptoms and 25% of all arm-wrist-hand symptoms during follow-up.

*Risk factors for the onset of arm-wrist-hand symptoms*

The registered duration of computer use at work, monitor height, mouse and keyboard location, arm support during keyboard and mouse use, precision demands, cognitive demands, effort, decision authority, and general physical activity during leisure time were, among other factors, not identified as risk factors for the onset of arm-wrist-hand symptom (see Appendix A).

An increased risk for the onset of arm-wrist-hand symptoms was found for at least 4 hours per day of self-reported computer use at work, never squeezing firmly with hands at work, often / always using computer and telephone at the same time, moderate to low reward, low task variation, at least 4 hours per day of self-reported computer use during leisure time, female gender, higher age (49 – 68 years), moderate to high levels of overcommitment, BMI exceeding 24 kg / $m^2$, and having had disabling symptoms in arm-wrist-hand or neck-shoulder region in the past year (see Table 2). The strength of associations was in general low, with the exceptions of disabling arm-wrist hand symptoms in the past year (RR 3.9, 95% CI 3.0 – 5.1), and at least 4 hours per day of self-reported computer use at work (RR 2.0, 95% CI 1.2 – 3.2).

Table 2 Rate Ratios (RRs) and Population Attributable Fractions(PAFs) for risk factors associated with arm-wrist-hand symptoms

| **Risk factor** | **Univariate** | | **Multivariate** * | | **Multivariate, final model** † | | |
|---|---|---|---|---|---|---|---|
| | EO | RR (95% CI) | EO | RR (95% CI) | EO | RR (95% CI) | PAF (95% CI) |
| Self-reported duration of computer use at work (h / d) | | | | | | | |
| < 4 | 1657 | 1 | 1335 | 1 | 1404 | 1 | |
| >= 4 | 10221 | 1.7 (1.1-2.6) | 8655 | 1.8 (1.1-3.0) | 8906 | 2.0 (1.2-3.2) | 0.46 (0.11-0.68) |
| Firmly squeezing with hands | | | | | | | |
| Sometimes / Often / always | 746 | 1 | 604 | 1 | 623 | 1 | |
| Never | 10932 | 0.8 (0.5-1.1) | 9386 | 1.6 (1.0-2.5) | 9687 | 1.4(0.9-2.1) | 0.25 (0.00-0.52) ‡ |
| Computer and phone use at the same time | | | | | | | |
| Never / sometimes | 8775 | 1 | 7449 | 1 | 7750 | 1 | |
| Often / always | 3103 | 1.8 (1.4-2.2) | 2541 | 1.3 (1.1-1.6) | 2560 | 1.4 (1.1-1.7) | 0.09 (0.02-0.17) |
| Reward (range 0 – 20) | | | | | | | |
| 16 – 20 | 9000 | 1 | 7616 | 1 | 7849 | 1 | |
| 0 – 16 | 2876 | 1.8 (1.4-2.2) | 2374 | 1.4 (1.1-1.8) | 2461 | 1.4 (1.2-1.8) | 0.11 (0.03-0.19) |
| Task variation (range 0 – 12) | | | | | | | |
| 9 – 12 | 5305 | 1 | 4521 | 1 | 4663 | 1 | |
| 0 – 8 | 6573 | 1.9 (1.5-2.4) | 5469 | 1.5 (1.1-1.9) | 5647 | 1.5 (1.2-1.8) | 0.22 (0.07-0.35) |
| Self-reported duration of computer use during leisure time (h / d) | | | | | | | |
| < 4 | 11855 | 1 | 9524 | 1 | 9815 | 1 | |
| > = 4 | 612 | 1.6 (1.1-2.3) | 466 | 1.7 (1.1-2.4) | 495 | 1.6 (1.1-2.3) | 0.03 (0.00-0.06) |
| Gender | | | | | | | |
| Male | 6300 | 1 | 5517 | 1 | 5650 | 1 | |
| Female | 5386 | 1.8 (1.5-2.3) | 4473 | 1.4 (1.1-1.8) | 4660 | 1.4 (1.1-1.7) | 0.17 (0.05-0.28) |
| Age (y) | | | | | | | |
| 21-48 | 5427 | 1 | 4635 | 1 | 4766 | 1 | |
| 49-68 | 6171 | 1.2 (1.0-1.5) | 5355 | 1.3 (1.0-1.6) | 5544 | 1.3 (1.0-1.6) | 0.12 (0.00-0.25) ‡ |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Education | | | | | | | |
| Primary / secondary education | 9115 | 1 | 7818 | 1 | 2195 | 1 | |
| High school / university | 2533 | 1.4 (1.1-1.7) | 2172 | 0.8 (0.6-1.0) | 8115 | 0.9 (0.7-1.1) | 0.11 (0.00-0.30) ‡ |
| Overcommitment (range 0 - 20) | | | | | | | |
| 0 - 9 | 4428 | 1 | 3838 | 1 | 3968 | 1 | |
| 10 - 16 | 6911 | 1.7 (1.4-2.2) | 6152 | 1.5 (1.1-1.9) | 6342 | 1.5 (1.2-1.9) | 0.24 (0.09-0.38) |
| BMI (kg / $m^2$ ) | | | | | | | |
| 16 – 24 | 5451 | 1 | 4953 | 1 | 5187 | 1 | |
| 24 – 44 | 5473 | 1.2 (0.9-1.4) | 5037 | 1.2 (1.0-1.5) | 5123 | 1.2 (1.0-1.5) | 0.09 (0.00-0.21) |
| Disabling arm-wrist-hand symptoms within past year | | | | | | | |
| No | 10061 | 1 | 8240 | 1 | 8497 | 1 | |
| Yes | 2167 | 6.2 (5.1-7.6) | 1750 | 3.8 (2.9-5.0) | 1813 | 3.9 (3.0-5.1) | 0.33 (0.26-0.41) |
| Disabling neck-shoulder symptoms within past year | | | | | | | |
| No | 9114 | 1 | 7421 | 1 | 7656 | 1 | |
| Yes | 3114 | 3.2 (2.6-3.9) | 2569 | 1.4 (1.1-1.8) | 2654 | 1.4 (1.1-1.9) | 0.14 (0.02-0.26) |

Abbreviations: EO = Exposed Observations RR = Rate Ratio, PAF = Population Attributable Fraction, CI = Confidence Interval, h / d = hours per day, y = years;

BMI = Body Mass Index;

N = 10.310 observations (1720 subjects, 6 responses per subject on average);

Proportion explained variance = 0.24

* Adjusted for all risk factors in Table 2 and Appendix A

† Adjusted for all risk factors in Table 2

‡ 95% CI restricted to (0.00-1.00)

The highest PAF values for independent risk factors were found for at least 4 hours per day of self-reported computer use at work (PAF 0.46, 95% CI 0.11-0.68), having had disabling arm-wrist-hand symptoms in the past year (PAF 0.33, 95% CI 0.26 – 0.41), never squeezing firmly with hands (PAF 0.25, 95% CI 0.00 – 0.52), moderate to high levels of overcommitment (PAF 0.24, 95% CI 0.09 – 0.38), and low task variation (PAF 0.22, 95% CI 0.07 – 0.35).

An average subject was exposed to 3.1 (sd 1.3) potentially modifiable risk factors (see Table 3). Compared to 0 or 1 potentially modifiable risk factors, the RR increased from 2.2 (95% CI 1.2 - 4.2) for 2 potentially modifiable risk factors to 6.0 (95% CI 3.2 - 11.3) for 5 to 7 potentially modifiable risk factors.

Table 3 Rate Ratios (RRs) for the number of potentially modifiable risk factors associated with the onset of arm-wrist-hand symptoms.

| **Risk Factor** | | **EO** | **RR (95% CI)** |
|---|---|---|---|
| Number of potentially modifiable risk factors * | 0 / 1 | 1066 | 1 |
| | 2 | 2548 | 2.2 (1.2-4.2) |
| | 3 | 2951 | 3.2 (1.7-6.0) |
| | 4 | 2397 | 5.0 (2.7-9.4) |
| | 5 / 6 / 7 | 1348 | 6.0 (3.2-11.3) |

Abbreviations: EO = Exposed Observations RR = Rate Ratio, PAF = Population Attributable Fraction, CI = Confidence Interval

* >= 4 h / d of self-reported computer use at work, never squeezing firmly with hands, often / always using computer and telephone at the same time, moderate to low reward, low task variation, >= 4 h / d of self-reported computer use during leisure time, moderate to high levels of overcommitment

*Risk factors for the onset of neck-shoulder symptoms*

The registered duration of computer use at work, monitor height, mouse and keyboard location, precision demands, cognitive demands, effort, reward, decision authority, overcommitment, self-reported duration of computer use during leisure time, and general physical activity during leisure time were, among other factors, not identified as risk factors for the onset of neck-shoulder symptom (see Appendix B).

Table 4 Rate Ratios (RRs) and Population Attributable Fractions (PAFs) for risk factors associated with neck-shoulder symptoms.

| **Risk factor** | **Univariate** | | **Multivariate** [*] | | **Multivariate, final model** [†] | | |
|---|---|---|---|---|---|---|---|
| | EO | RR (95% CI) | EO | RR (95% CI) | EO | RR (95% CI) | PAF (95% CI) |
| Self-reported mouse use at work (h / d) | | | | | | | |
| < 4 hrs / day | 4730 | 1 | 3993 | 1 | 4394 | 1 | |
| >= 4 hrs / day | 7146 | 1.7 (1.4-2.0) | 5999 | 1.4 (1.2-1.7) | 6596 | 1.4 (1.1-1.6) | 0.19 (0.06-0.31) |
| Repetitive movements with hands (excl. computer use) | | | | | | | |
| Never / sometimes | 10762 | 1 | 9466 | 1 | 10374 | 1 | |
| Often / always | 634 | 2.0 (1.5-2.7) | 526 | 1.4 (1.0-1.8) | 616 | 1.5 (1.1-1.9) | 0.03 (0.00-0.06) |
| Computer and phone use at the same time | | | | | | | |
| Never | 2099 | 1 | 1730 | 1 | 1904 | 1 | |
| Sometimes / Often / always | 9780 | 1.4 (1.1-1.8) | 8262 | 1.3 (1.0-1.7) | 9086 | 1.3 (1.0-1.7) | 0.18 (0.00-0.36) [‡] |
| Arm support during keyboard use (most of the time) | | | | | | | |
| No | 1169 | 1 | 986 | 1 | 1066 | 1 | |
| Yes | 10713 | 1.6 (1.2-2.3) | 9006 | 1.7 (1.2-2.4) | 9924 | 1.7 (1.2-2.3) | 0.38 (0.12-0.56) |
| Task variation (range 0 – 12) | | | | | | | |
| 9 – 12 | 5305 | 1 | 4523 | 1 | 6050 | 1 | |
| 0 – 8 | 6574 | 1.6 (1.3-1.9) | 5469 | 1.2 (1.0-1.5) | 4940 | 1.3 (1.1 – 1.6) | 0.15 (0.03-0.26) |
| Gender | | | | | | | |
| Male | 6301 | 1 | 5519 | 1 | 5991 | 1 | |
| Female | 5386 | 1.8 (1.5-2.2) | 4473 | 1.4 (1.2-1.7) | 4999 | 1.4 (1.2-1.7) | 0.17 (0.08-0.26) |
| Age (y) | | | | | | | |
| 21-39 & 49-68 | 8368 | 1 | 7160 | 1 | 7929 | 1 | |
| 40-48 | 3231 | 1.3 (1.1-1.6) | 2832 | 1.3 (1.0-1.5) | 3061 | 1.2 (1.0-1.5) | 0.06 (0.00-0.12) |
| Work continuation during formal breaks | | | | | | | |
| No | 7529 | 1 | 6248 | 1 | 6908 | 1 | |
| Yes | 4350 | 1.2 (1.0-1.4) | 3744 | 1.2 (1.0-1.4) | 4082 | 1.2 (1.0-1.4) | 0.06 (0.00-0.13) [‡] |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Acquaintance experiencing disabling symptoms | | | | | | | |
| No | 6580 | 1 | 5552 | 1 | 6110 | 1 | |
| Yes | 5294 | 1.2 (1.0-1.5) | 4440 | 1.2 (1.0-1.4) | 4880 | 1.2 (1.0-1.4) | 0.07 (0.00-0.15) ‡ |
| Disabling neck-shoulder symptoms within past year | | | | | | | |
| No | 9115 | 1 | 7423 | 1 | 8172 | 1 | |
| Yes | 3114 | 5.8 (4.9-6.8) | 2569 | 4.5 (3.7-5.6) | 2818 | 5.3 (4.4-6.3) | 0.44 (0.39-0.51) |

Abbreviations: EO = Exposed Observations, RR = Rate Ratio, PAF = Population Attributable Fraction, CI= Confidence Interval, h / d = hours per day, excl. = excluding, y = years;

N = 10.990 observations (1783 subjects, 6 responses per subject on average);

Proportion explained variance = 0.18

* Adjusted for all risk factors in Table 4 and Appendix B

† Adjusted for all risk factors in Table 4

‡ 95% CI restricted to (0.00-1.00)

An increased risk for the onset of neck-shoulder symptoms was found for at least 4 hours per day of self-reported mouse use at work, often / always performing repetitive hand movements (excluding computer use), sometimes / often / always using computer and telephone at the same time, arm support during keyboard use, low task variation, female gender, medium age (i.e. 40 – 48 years), work continuation during formal breaks, having an acquaintance experiencing disabling symptoms, and having had disabling neck-shoulder symptoms in the past year (see Table 4). The strength of associations was low, with the exception of disabling neck-shoulder symptoms in the past year (RR 5.3, 95% CI 4.4 – 6.3).
The highest PAF values for independent risk factors were found for disabling neck-shoulder symptoms in the past year (PAF 0.44, 95% CI 0.39 – 0.51), and arm support during keyboard use (PAF 0.38, 95% CI 0.12-0.56).
On average, subjects were exposed to 3.3 (sd 1.1) potentially modifiable risk factors (see Table 5). Compared to 0 or 1 potentially modifiable risk factors, the RR increased from 1.3 (95% CI 0.7 - 2.5) for 2 potentially modifiable risk factors to 3.3 (95% CI 1.8 - 6.3) for 5 or 6 potentially modifiable risk factors.

Table 5 Rate Ratios (RRs) for the number of potentially modifiable risk factors associated with the onset of neck-shoulder symptoms.

| **Risk Factor** | | **EO** | **RR (95% CI)** |
|---|---|---|---|
| Number of potentially modifiable risk factors * | 0 / 1 | 492 | 1 |
| | 2 | 1874 | 1.3 (0.7-2.5) |
| | 3 | 3670 | 2.5 (1.4-4.6) |
| | 4 | 3651 | 3.1 (1.7-5.7) |
| | 5 / 6 | 1303 | 3.3 (1.8-6.3) |

Abbreviations: EO = Exposed Observations RR = Rate Ratio, PAF = Population Attributable Fraction, CI = Confidence Interval
* >= 4 h / d of self-reported mouse use at work, sometimes / often / always using computer and telephone at the same time, often / always repetitive hand movements (excluding computer use), arm support during keyboard use, low task variation, work continuation during formal breaks

*Explained variance*

The proportions of explained variance for the fitted models for independent risk factors were estimated at 0.24 (arm-wrist-hand symptoms) and 0.18 (neck-shoulder symptoms).

## Discussion

The objectives of this study were to identify risk factors for the onset of arm-wrist-hand and neck-shoulder symptoms among office workers and to estimate the relative contribution of these risk factors by calculating PAFs.
Having had previous symptoms was the most important risk factor for future symptoms, as has been documented previously among office workers (1, 3, 6), and also among other populations for low back and neck-shoulder symptoms (e.g. 50, 51). However, the (pathophysiological) mechanism(s) is largely unknown and merits further investigation. Potentially, increased tissue vulnerability, sensitization of the pain system in general, or sustained exposure after the initial symptom period could be involved. Also a general individual vulnerability independent of previous symptoms could play a role (52, 53).

In line with previous studies, we found a relation between the self-reported duration of mouse use at work and the onset of arm-wrist-hand and neck-shoulder symptoms (45). However, this study did not confirm the weak association between the registered duration of computer use and symptom onset, as reported in two previous longitudinal studies (54, 55). These findings together are still premature, but do not strengthen the hypothesis that the duration of computer use at work is an important risk factor for the onset of arm-wrist-hand and neck-shoulder symptoms among office workers.

Contrary to expectations, cognitive demands, precision demands during mouse use and workstation layout were not associated with the onset of neck-shoulder and arm-wrist-hand symptoms. In a previous cohort study among office workers, cognitive demands also failed to show an association with the onset of arm-wrist-hand and neck-shoulder symptoms

(3, 6). To our knowledge the effect of precision demands have not been studied before in a prospective cohort study. In line with the current study, most longitudinal studies have failed to show an association between mouse location, keyboard location, and monitor height on the one hand and the onset of arm-wrist-hand and neck-shoulder symptoms on the other hand (2 – 7 , 56 - 58). This lack of findings might be related to the absence of a strong association between workstation layout and work posture in field studies (59, 60).
A relatively new finding is the association between simultaneous computer and telephone use and both neck-shoulder and arm-wrist-hand symptoms. This association has only been suggested previously in a cross-sectional study (61). It should be noted that only 20% of the high-risk group used a headset.
Contrary to expectation (16), arm support during keyboard use was associated with an increased risk of symptoms in this study. It has been suggested that arm-support can lower muscle activity, but cannot prevent that sustained muscle activity remains present (17). In addition, previous studies have shown inconsistent findings for arm support during computer use (2, 3, 5 - 7). Therefore, arm support does not seem to be a recommended intervention for the prevention of symptoms.
Psychosocial factors at work have been documented to be independent risk factors for arm-wrist-hand and neck-shoulder symptoms (62). However, the reported associations have neither been strong nor consistent (62). The results of the current study and other studies among office workers fit into this picture. Low decision authority and high effort were not related with health outcome in the current study, and the strength of identified associations for low task variation, low reward, and modest to high overcommitment was weak (RRs between 1.3 and 1.5 ). Among other cohorts of office workers weak associations have been found with corresponding risk factors (3 – 5, 7, 57, 63). An underlying reason for inconsistent findings among cohorts might be that the tested constructs were not exactly the same due to the use of different questionnaires (e.g. 64).

The duration of computer use during leisure time contributed marginally to the onset of arm-wrist-hand symptoms. Physical exposures during leisure time that target the upper extremity and general physical activity during leisure time failed to show an association with symptom onset in both outcome regions, as has been reported previously among office workers (2, 5, 7, 57). The findings suggest that physical exposure during leisure time is of minor to no importance in the etiology of arm-wrist-hand and neck-shoulder symptoms among office workers.

Female gender was found to be an independent risk factor for both outcomes in this study, as has been consistently reported in the literature (1, 2, 4, 5, 7, 57). Age above 40 years was associated with an increased risk for the onset of arm-wrist-hand symptoms, which has been reported by some studies (7, 57), but not by others (1, 3, 6). A medium age (i.e. 40 - 48 years) showed a slightly increased risk of the onset of neck-shoulder symptoms, whereas in previous studies most often no association was found (3, 5, 6).

Taken together, the lack of expected findings in the current study, especially for the objectively registered duration of computer use at work, cognitive demands, precision demands during mouse use, and mouse location, challenge the plausibility of muscle overload as an important pathophysiological mechanism for the onset of arm-wrist-hand and neck-shoulder symptoms among office workers.

Preventive interventions could be aimed at promoting to not use arm support during keyboard use since a PAF of 0.38 was found. However, inconsistent findings in other studies for the effect or arm support during computer use questions whether a true causal association has been identified.

In this study a range of rather weak potentially modifiable risk factors has been identified (i.e. RRs of 1.2 to 1.7). Moreover, subjects had on average 3 of these potentially modifiable risk factors, and a strong association between the number of potentially modifiable risk factors and the onset of arm-wrist-hand and neck-shoulder symptoms was found. This could indicate that a single risk factor is not sufficient to cause the onset of

symptoms, but that a number of risk factors need to be present in order to cause the onset of symptoms (65). Therefore, the focus of preventive interventions should be laid on changing several of these risk factors at the same time. In order to increase efficiency, a screening questionnaire could be used to select workers with present risk factors (66). The following risk factors have the highest priority for preventive interventions (in order of importance): low task variation, using computer and telephone at the same time, moderate to low reward, moderate to high level of overcommitment, work continuation during formal breaks, often / always performing repetitive hand movements (excluding computer use), at least 4 hours per day of self-reported computer use during leisure time, and BMI exceeding 24 kg / $m^2$.
The strengths of this study include the broad range of risk factors included in the exposure assessment, the prospective design, and the calculation of PAFs. PAFs were not calculated in previous studies among office workers. Still, a number of limitations in this study might have biased the results. Firstly, in this study exposures were assessed with differing levels of precision and accuracy. This could have resulted in a lower probability of identifying risk factors. Secondly, selection of relatively healthy workers in this study might have biased associations towards the null. Three quarters of the population had more than 5 years experience with daily computer use at work (data not presented), and the mean company tenure was more than 10 years. Thirdly, a low exposure contrast might have biased association towards the null. Being an office worker might be related to a baseline risk, which increases only slightly dependent on several risk factors. For practical purposes, however, it can be argued that the magnitude of contrast observed in this study might well represent the practical maximum of change in exposure that can be realized in preventive interventions. Finally, the PAFs could have been overestimated due to the assumption that all identified risk factors are causal risk factors (48). More research is needed to verify that the identified risk factors are causal risk factors. Especially intervention studies can provide this information by investigating whether an actual lowering in exposure predicts a lowering in symptom incidence.

In conclusion, previous disabling symptoms were identified as the most important risk factor for the onset of arm-wrist-hand and neck-shoulder symptoms among office workers. Preventive interventions should be aimed at modifying multiple modifiable risk factors at the same time in order to be effective.

Appendix A Variables that were not included in the final model for the onset of arm-wrist-hand symptoms.

| **Risk factor** | **Univariate association** | | **Multivariate association*** | |
|---|---|---|---|---|
| | EO | RR (95% CI) | EO | RR (95% CI) |
| Registered duration of total computer use at work, h / w | | | | |
| 1 - < 9 | 999 | 1 | 999 | 1 |
| 9 - < 14 | 1730 | 0.8 (0.5-1.2) | 1730 | 0.9 (0.5-1.4) |
| 14 – 35 | 2085 | 0.7 (0.5-1.1) | 2085 | 0.9 (0.5-1.4) |
| Self-reported increase in total computer use at work in past year | | | | |
| No | 10056 | 1 | 8467 | 1 |
| Yes | 1825 | 1.3 (1.0-1.7) | 1523 | 1.0 (0.8-1.3) |
| Historical exposure to daily computer use, y | | | | |
| 0 - < 2 | 640 | 1 | - † | |
| > = 2 | 11046 | 1.1 (0.6-1.8) | | |
| High precision demands during mouse use, h / d | | | | |
| 0 | 8435 | 1 | 7149 | 1 |
| > = 0 | 3440 | 1.5 (1.2-1.9) | 2841 | 0.9 (0.7-1.3) |
| Repetitive movements with hands (excl. computer use) | | | | |
| Never | 9446 | 1 | 8310 | 1 |
| Sometimes/ often / always | 1949 | 1.7 (1.3-2.2) | 1680 | 1.1 (0.9-1.5) |
| Carrying loads > 5 kg | | | | |
| Never | 9459 | 1 | 8026 | 1 |
| Sometimes / frequent / very frequent | 2219 | 1.4 (1.1-1.8) | 1964 | 1.2 (0.9-1.5) |
| Pushing or Pulling | | | | |
| Never | 11343 | 1 | - † | |
| Sometimes / frequent / very frequent | 335 | 0.7 (0.4-1.5) | | |
| Using vibrating hand tools | | | | |
| Never | 10879 | 1 | - † | |
| Sometimes / frequent / very frequent | 156 | 1.7 (0.7-3.8) | | |
| Working with hands above shoulder height | | | | |
| Never | 10072 | 1 | 8679 | 1 |
| Sometimes / frequent / very frequent | 1606 | 1.5 (1.1-2.0) | 1311 | 0.9 (0.7-1.3) |

| | | | | |
|---|---|---|---|---|
| Job function | | | | |
| Non-management | 9772 | 1 | 8037 | 1 |
| Management | 2106 | 0.7 (0.5-0.9) | 1953 | 1.0 (0.8-1.4) |
| Job contract, h / w | | | | |
| < 25 | 1667 | 1 | 1346 | 1 |
| 25 - < 33 | 2237 | 0.8 (0.6-1.2) | 1891 | 1.0 (0.7-1.4) |
| 33 – 40 | 7963 | 0.8 (0.6-1.0) | 6753 | 1.0 (0.7-1.3) |
| Use of break and reminder software | | | | |
| Yes | 5735 | 1 | 4810 | 1 |
| No | 6146 | 0.8 (0.7-1.0) | 5180 | 1.0 (0.8-1.2) |
| Working comfortably while working at desk (most of the time) | | | | |
| No | 10937 | 1 | 9172 | 1 |
| Yes | 942 | 1.6 (1.1-2.1) | 818 | 1.2 (0.9-1.7) |
| Monitor height | | | | |
| At or little below eye height | 9539 | 1 | - † | |
| Higher than eye height | 740 | 0.8 (0.5-1.3) | | |
| Lower than eye height | 1600 | 0.9 (0.7-1.2) | | |
| Mouse location (most of the time) | | | | |
| Directly besides keyboard / between keyboard and table edge | 4268 | 1 | - † | |
| Further away from keyboard | 7611 | 1.0 (0.8-1.2) | | |
| Inability to move mouse freely due to space restrictions (most of the time) | | | | |
| No | 7915 | 1 | 6635 | 1 |
| Yes | 3963 | 1.4 (1.2-1.8) | 3355 | 1.2 (0.9-1.5) |
| Mouse functioning (most of the time) | | | | |
| Not proper | 6429 | 1 | 5261 | 1 |
| Proper | 5441 | 1.6 (1.3-1.9) | 4729 | 1.1 (0.9-1.4) |
| Arm support during keyboard use (most of the time) | | | | |
| No | 10786 | 1 | 9004 | 1 |
| Yes | 1095 | 0.8 (0.5-1.1) | 986 | 0.8 (0.5-1.1) |
| Mouse handedness | | | | |
| Right / Alternating left and right | 10972 | 1 | 9141 | 1 |
| Left | 907 | 1.3 (0.9-1.9) | 849 | 1.3 (0.9-1.9) |
| Arm support during mouse use (most of the time) | | | | |
| Yes | 11700 | 1 | - ‡ | |
| No | 178 | 0.3 (0.1-1.1) | | |
| Touch typing skill | | | | |
| Touch typing (not looking at keyboard during typing) | 4502 | 1 | - † | |
| Hunt and Peck (looking at keyboard during typing) | 7379 | 1.0 (0.8-1.3) | | |

| | | | | |
|---|---|---|---|---|
| Self-reported distance keyboard to table edge > 10 | | | | |
| cm (most of the time) | 2501 | 1 | 2090 | 1 |
| No | 9380 | 0.9 (0.7-1.1) | 7900 | 0.9 (0.7-1.2) |
| Yes | | | | |
| Effort | | | | |
| 0 – 3 | 3785 | 1 | 2957 | 1 |
| 4 - 8 | 6355 | 1.3 (1.0-1.6) | 5470 | 1.1 (0.8-1.4) |
| 9 -20 | 1730 | 1.6 (1.2-2.2) | 1563 | 1.0 (0.7-1.4) |
| Decision authority | | | | |
| 0 - 3 | 8817 | 1 | 7510 | 1 |
| 4 – 9 | 3059 | 1.5 (1.2-1.8) | 2480 | 0.9 (0.7-1.2) |
| Cognitive demands | | | | |
| 0 - 13 | 6335 | 1 | 5450 | 1 |
| 14 - 15 | 2912 | 1.4 (1.1-1.8) | 2416 | 0.9 (0.7-1.2) |
| 16 – 20 | 2596 | 1.7 (1.3-2.1) | 2124 | 1.0 (0.8-1.4) |
| Moderate intensity physical activity during leisure | | | | |
| time | 2290 | 1 | - [†] | |
| < 2 times per week | 9483 | 1.1 (0.9-1.5) | | |
| > = 2 times per week | | | | |
| High intensity physical activity during leisure time | | | | |
| 0 – 3 times per month | 2877 | 1 | - [†] | |
| > = 1 time per week | 11307 | 1.0 (0.8-1.3) | | |
| Strength training of upper body | | | | |
| Never - < 1 time per week | 9148 | 1 | - [†] | |
| > = 1 time per week | 2722 | 1.1 (0.9-1.4) | | |
| Playing golf | | | | |
| Never - < 1 time per week | 11503 | 1 | 9669 | 1 |
| > = 1 time per week | 367 | 0.4 (0.2-1.0) | 321 | 0.6 (0.2-1.5) |
| Playing sports involving upper extremity (excluding golf) | | | | |
| Never - < 1 time per week | 8741 | 1 | 7341 | 1 |
| > = 1 time per week | 3129 | 0.8 (0.6-1.0) | 2649 | 1.0 (0.8-1.3) |
| Hand intensive activities during leisure time | | | | |
| Never - < 1 time per week | 7717 | 1 | - [†] | |
| > = 1 time per week | 4153 | 1.1 (0.9-1.3) | | |
| Work continuation during formal breaks | | | | |
| No | 7529 | 1 | - [†] | |
| Yes | 4349 | 1.2 (0.9-1.4) | | |
| Acquaintance experiencing disabling symptoms | | | | |
| No | 6580 | 1 | - [†] | |
| Yes | 5293 | 1.1 (0.9-1.4) | | |
| General health | | | | |
| Good | 9122 | 1 | 7330 | 1 |
| Fair / moderate / bad | 2759 | 1.8 (1.5-2.3) | 2660 | 1.1 (0.9-1.4) |

Abbreviations: EO = Exposed Observations RR = Rate Ratio, PAF = Population Attributable Fraction, CI = Confidence Interval

* Adjusted for all risk factors in Appendix B and Table 4

† No univariate association, p-value of Wald test > 0.200

‡ Not included in multivariate models, because inclusion of this variable resulted in inability of the multivariate model to converge

## Appendix B Variables that were not included in the final model for the onset of neck-shoulder symptoms.

| **Risk Factor** | **Univariate association** | | **Multivariate association *** | |
|---|---|---|---|---|
| | EO | RR (95% CI) | EO | RR (95% CI) |
| Registered duration of total computer use at work, h / w | | | | |
| 1 - < 9 | 999 | 1 | - † | |
| 9 - < 14 | 1730 | 1.2 (0.8-1.7) | | |
| 14 – 35 | 2085 | 1.0 (0.7-1.4) | | |
| Self-reported increase in total computer use at work in past year | | | | |
| No | 10057 | 1 | 8469 | 1 |
| Yes | 1825 | 1.3 (1.0-1.6) | 1523 | 1.0 (0.8-1.3) |
| Historical exposure to daily computer use, y | | | | |
| 0 - < 2 | 640 | 1 | - † | |
| > = 2 | 11047 | 0.9 (0.6-1.3) | | |
| High precision demands during mouse use, h / d | | | | |
| 0 - < 4 | 11351 | 1 | 9611 | 1 |
| > = 4 | 525 | 1.6 (1.1-2.2) | 381 | 0.9 (0.6-1.4) |
| Firmly squeezing with hands | | | | |
| Never / Sometimes | 11579 | 1 | 9915 | 1 |
| Frequent / Very frequent | 100 | 1.7 (0.9-3.2) | 77 | 1.2 (0.6-2.3) |
| Carrying loads > 5 kg | | | | |
| Never | 9224 | 1 | 8028 | 1 |
| Sometimes / Frequent / Very frequent | 2455 | 1.2 (1.0-1.5) | 1964 | 1.1 (0.9-1.3) |
| Pushing or Pulling | | | | |
| Never | 11344 | 1 | - † | |
| Sometimes / Frequent / Very frequent | 335 | 0.8 (0.5-1.4) | | |
| Using vibrating hand tools | | | | |
| Never | 10880 | 1 | - † | |
| Sometimes / Frequent / Very frequent | 156 | 0.9 (0.4-1.8) | | |
| Working with hands above shoulder height | | | | |
| Never | 10073 | 1 | 8681 | 1 |
| Sometimes / Frequent / Very frequent | 1606 | 1.3 (1.0-1.6) | 1311 | 0.9 (0.7-1.2) |

| | | | | |
|---|---|---|---|---|
| Job function | | | | |
| Non-management | 9650 | 1 | 8039 | 1 |
| Management | 2229 | 0.7 (0.6-0.9) | 1953 | 0.9 (0.7-1.1) |
| Job contract, h / w | | | | |
| < 25 | 1667 | 1 | 1346 | 1 |
| 25 - < 33 | 2237 | 0.8 (0.6-1.1) | 1893 | 0.9 (0.7-1.3) |
| 33 - 40 | 7964 | 0.7 (0.6-0.9) | 6753 | 1.0 (0.7-1.3) |
| Use of break and reminder software | | | | |
| Yes | 5736 | 1 | 4812 | 1 |
| No | 6146 | 0.8 (0.7-1.0) | 5180 | 0.9 (0.7-1.1) |
| Working comfortably while working at desk (most of the time) | | | | |
| No | 942 | 1 | 818 | 1 |
| Yes | 10938 | 0.5 (0.4-0.7) | 9174 | 0.9 (0.7-1.2) |
| Monitor height | | | | |
| At or little below eye height / Higher than eye height | 11440 | 1 | 9349 | 1 |
| Lower than eye height | 740 | 0.7 (0.5-1.1) | 643 | 0.9 (0.6-1.4) |
| Mouse location (most of the time) | | | | |
| Directly besides keyboard / between keyboard and table edge | 4268 | 1 | - † | |
| Further away from keyboard | 7612 | 1.0 (0.8-1.2) | | |
| Inability to move mouse freely due to space restrictions (most of the time) | | | | |
| No | 7916 | 1 | 6637 | 1 |
| Yes | 3963 | 1.3 (1.1-1.6) | 4731 | 1.1 (0.9-1.3) |
| Mouse functioning (most of the time) | | | | |
| Not proper | 6430 | 1 | 5261 | 1 |
| Proper | 5441 | 1.3 (1.1-1.5) | 4731 | 1.1 (0.9-1.3) |
| Mouse handedness | | | | |
| Left | 1020 | 1 | - † | |
| Right | 10310 | 0.9 (0.7-1.2) | | |
| Alternating left and right | 550 | 1.2 (0.7-2.0) | | |
| Arm support during mouse use (most of the time) | | | | |
| Yes | 11700 | 1 | - † | |
| No | 179 | 0.9 (0.4-1.9) | | |
| Touch typing skill | | | | |
| Touch typing (not looking at keyboard during typing) | 4503 | 1 | - † | |
| Hunt and Peck (looking at keyboard during typing) | 7379 | 0.9 (0.8-1.1) | | |
| Self-reported distance keyboard to table edge > 10 cm (most of the time) | | | | |
| No | 2502 | 1 | - † | |
| Yes | 9380 | 1.1 (0.9-1.3) | | |

| | | | | |
|---|---|---|---|---|
| Effort | | | | |
| 0 - 3 | 3785 | 1 | 2957 | 1 |
| 4 - 20 | 8086 | 1.3 (1.1-1.6) | 7035 | 1.1 (0.9-1.4) |
| Reward | | | | |
| 0 - 16 | 2876 | 1 | 2374 | 1 |
| 17 - 19 | 6062 | 0.8 (0.7-1.0) | 5068 | 1.0 (0.8-1.3) |
| 20 | 2938 | 0.5 (0.4-0.7) | 2550 | 0.9 (0.7-1.2) |
| Decision authority | | | | |
| 0 - 5 | 3039 | 1 | 2480 | 1 |
| 6 – 9 | 8817 | 0.7 (0.6-0.8) | 7512 | 1.0 (0.8-1.2) |
| Cognitive demands | | | | |
| 0 - 11 | 3190 | 1 | 2755 | 1 |
| 12 - 13 | 3145 | 1.2 (0.9-1.5) | 2697 | 1.0 (0.8-1.3) |
| 14 - 20 | 5509 | 1.6 (1.3-2.0) | 4540 | 1.1 (0.9-1.4) |
| Self-reported duration of total computer use during leisure time, h / d | | | | |
| 0 | 2460 | 1 | 1927 | 1 |
| > 0 | 10008 | 0.7 (0.5-0.8) | 8065 | 0.9 (0.7-1.1) |
| Moderate intensity physical activity during leisure time, d / w | | | | |
| 0 | 589 | 1 | - † | |
| > = 1 | 11185 | 0.9 (0.6-1.3) | | |
| High intensity physical activity during leisure time | | | | |
| < 1 time per month | 2372 | 1 | - † | |
| > = 1 - 3 times per month | 9494 | 1.0 (0.8-1.2) | | |
| Strength training of upper body | | | | |
| Never - < 1 time per week | 9149 | 1 | - † | |
| > = 1 time per week | 2722 | 1.0 (0.8-1.3) | | |
| Playing golf | | | | |
| Never - < 1 time per week | 11504 | 1 | - † | |
| > = 1 time per week | 367 | 0.7 (0.4-1.3) | | |
| Playing sports involving upper extremity (excluding golf) | | | | |
| Never - < 1 time per week | 8742 | 1 | 7341 | 1 |
| > = 1 time per week | 3129 | 0.9 (0.7-1.0) | 2651 | 1.0 (0.8-1.2) |
| Hand intensive activities during leisure time | | | | |
| Never - < 1 time per week | 7717 | 1 | - † | |
| > = 1 time per week | 4151 | 1.0 (0.8-1.2) | | |
| Education level | | | | |
| Primary / secundary education | 9116 | 1 | 7820 | 1 |
| High school / university | 2533 | 1.2 (1.0-1.5) | 2172 | 0.9 (0.7-1.1) |
| Overcommitment | | | | |
| 0 - 9 | 9149 | 1 | 8008 | 1 |
| 10 - 16 | 2191 | 1.8 (1.5-2.1) | 1984 | 1.2 (0.9-1.4) |

| | | | | |
|---|---|---|---|---|
| Body Mass Index | | | | |
| 17 - < 24 | 5451 | 1 | - † | |
| 24 - 44 | 5474 | 1.0 (0.8-1.2) | | |
| General health | | | | |
| Good | 8682 | 1 | 7330 | 1 |
| Fair | 2783 | 1.8 (1.5-2.1) | 2321 | 1.1 (0.9-1.4) |
| Moderate / bad | 417 | 2.5 (1.8-3.5) | 341 | 1.0 (0.7-1.6) |
| Disabling arm-wrist-hand symptoms in the past year | | | | |
| No | 10062 | 1 | 8242 | 1 |
| Yes | 2167 | 3.0 (2.5-3.6) | 1750 | 1.1 (0.9-1.3) |

Abbreviations: EO = Exposed Observations RR = Rate Ratio, PAF = Population Attributable Fraction, CI = Confidence Interval

* Adjusted for all risk factors in Appendix A and Table 2

† No univariate association, p-value of Wald test > 0.200

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# 8

# General discussion

[redacted]

## Introduction

The primary aim of this thesis was to determine the relationship between the duration of computer use at work and the onset of arm-wrist-hand and neck-shoulder symptoms among office workers. An additional aim was to determine the relative contribution of risk factors related to work exposure, leisure time exposure and individual characteristics, to the onset of arm-wrist-hand and neck-shoulder symptoms among office workers. In the following paragraphs a summary of the main findings is presented, followed by a discussion of the results, the strengths and weaknesses of the performed studies and some theoretical conclusions. This chapter concludes with a number of recommendations for further research and with practical implications of the findings.

## Summary of main findings

*First main study question*

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**Does a long duration of computer use at work predict arm-wrist-hand symptoms and / or neck-shoulder symptoms among office workers?**
No. The registered duration of computer use at work did not predict arm-wrist-hand, nor neck-shoulder symptoms in the performed cohort study. The available evidence from three prospective cohort studies suggests that the registered duration of mouse use is weakly associated with acute symptoms but not with longer lasting symptoms. Due to a low number of available prospective cohort studies, future prospective cohort studies with registered exposure data have to be awaited before a final conclusion can be drawn.

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In Chapter 2 a systematic review of longitudinal studies is presented in which the association between the duration of computer use at work and the onset of arm-wrist-hand and neck-shoulder symptoms among office work was evaluated. Evidence for an increased risk of a long duration of computer use at work on the onset of arm-wrist-hand and neck-shoulder symptoms among office workers was only found for the duration of mouse use at work and arm-wrist-hand symptoms. Indications for a dose-response relationship were found. Based on the limited number of high quality studies that were performed, moderate evidence instead of strong evidence was concluded for this association. Total computer use (i.e. using mouse and keyboard and reading from the screen) and keyboard use at work were less consistently and less strongly associated with arm-wrist-hand and neck-shoulder symptoms than mouse use at work. In addition, associations tended to be stronger for the arm-wrist-hand region than for the neck-shoulder region. These empirical findings are in line with a pathophysiological model in which sustained muscle activation plays an important role. The main limitation of the studies included in the systematic review was the reliance on self-reported duration of computer use instead of objective measurements. In theory, the use of self-reports can lead to underestimation of the strength of the association in case of non-differential misclassification. However, in the case of differential misclassification also overestimation can occur.

In Chapter 6 the association between the duration of computer use at work and the onset of arm-wrist-hand and neck-shoulder symptoms among office workers was evaluated within a prospective cohort study. One of the main features of this study was that objective data on the duration of computer use at work had been collected by means of software registrations. Contrary to the expectation that registered exposure data would show stronger associations with musculoskeletal symptoms than self-reported exposure data, no association was found between the registered duration of computer use at work and arm-wrist-hand symptoms, nor between the registered duration of computer use at work and neck-shoulder symptoms. Positive associations were only found with the self-reported duration of computer use at work. Between the publication of the systematic review and the analysis of the prospective cohort study described in this thesis, two longitudinal studies were published that also evaluated the association between the registered duration of computer use at work and the onset of arm-wrist-hand and neck-shoulder symptoms (1, 2). These two studies found a positive association, although the strength of the association was weaker than found in studies that used the self-reported duration of computer use at work. In addition, the registered duration of mouse use at work was associated with acute / short-lasting symptoms and not with chronic symptoms, whereas the duration of keyboard use was not related to symptoms at all (1).

By adding the results of the prospective cohort study on the self-reported duration of computer use at work to the results of the studies included in the review, the following picture emerges: the self-reported duration of mouse use at work is consistently associated with both arm-wrist-hand and neck-shoulder symptoms among office workers (i.e. a positive association found in >= 75% of all studies in which the association has been tested). For the registered duration of computer use, only three studies are available and the results are in part contradicting. Thus, too few longitudinal studies are available to draw a firm conclusion at this point in time.

Although the results of the systematic review showed consistent associations and a supporting pathophysiological model was identified in line with the empirical findings, weak / absent associations between the registered duration of computer use at work and the onset of arm-wrist-hand and neck-shoulder symptoms in the available prospective cohort studies challenge the existence of a causal relation between the duration of computer use at work and the onset of arm-wrist-hand and neck-shoulder symptoms among office workers.

*Possible explanations for the findings on the first main study question*

The finding that the registered duration of computer use at work was not a risk factor for the onset of arm-wrist-hand and neck-shoulder symptoms, whereas the self-reported duration of computer use at work was identified as a risk factor, was unexpected.

The absence of an association with the registered duration of computer use at work could, amongst other explanations, be explained by (combinations of) healthy worker selection bias, self-regulation of exposure, lack of exposure contrast, and the use of crude exposure estimates. Selection of workers might have taken place before the start of the cohort study, since the majority of the cohort already had extensive experience with daily computer use at work and had long company tenures. Workers who were not able to cope with long durations of computer use at work during the beginning of their career might have switched jobs. Healthy worker selection bias might have been present to a limited extent during the study too, since participants with symptoms at baseline had more missing data during follow-up. In addition, participants who experienced symptoms or had experienced symptoms in the past year might have lowered their exposure levels to computer use. This self-regulation of exposure might then, in theory, explain the absence of an association. However, no indications were found for self-regulation during the study, since symptoms did not predict a decline in registered and self-reported duration of computer use at work. Another possibility for the lack of association between the registered duration of computer use at work and the onset of arm-wrist-hand and neck-shoulder symptoms is a potential lack of exposure contrast. By including only office workers into the cohort, a relatively homogeneous group might have been selected. Most workers were at least moderately exposed to computer use at work, and only few had extreme exposure levels.

A final explanation for the failure to find an association between the registered duration of computer use at work and the onset of arm-wrist-hand and neck-shoulder symptoms is the use of crude exposure estimates. In the performed cohort study the mean weekly durations of computer use were used as exposure estimates. It is possible that relevant information concerning, for example, peak exposures and long periods of use without breaks is lost by these estimates. However, preliminary analyses show that most variables based on the software are highly correlated to the mean weekly duration of use during a 3-month period.

From this discussion it can be concluded that no convincing explanation is available for the absence of an association between the registered duration of computer use at work and the onset of arm-wrist-hand and neck-shoulder symptoms in this data set, while it is present in reality. This indicates that the association may be absent in reality.

Besides explaining that the registered duration of computer use was not associated with musculoskeletal symptoms, the observed association between the self-reported duration of computer use and the onset of arm-wrist-hand and neck-shoulder symptoms should also be explained. An explanation could be that subjects attributed their symptoms to computer use. Participants who experienced symptoms in the past are at high risk for developing symptoms in the future. These participants might have attributed their previous symptoms to computer use and thereby overestimate their daily duration of computer use more than other participants, who did not have previous symptoms. However, overestimation was comparable in subgroups based on symptom status in the past year. Moreover, at one-year follow-up all subjects in the cohort were asked whether, in general, they attributed arm-wrist-hand or neck-shoulder symptoms to a long duration of computer use at work without breaks. However, attribution of symptoms to a long duration of computer use at work did not explain the overestimation of computer use by self-report. This was also true for the presence of current symptoms. Based on these data it was expected that differential misclassification of exposure due to attribution of symptoms was unlikely. This expectation was confirmed in a post-hoc analysis of the cohort data. In univariate analyses no association was found between the amount of overestimation of daily duration of computer use at work and arm-wrist-hand or neck-shoulder symptoms.

*Second main study question*

**What is the relative contribution of risk factors related to work exposure, leisure time exposure and individual characteristics in the onset of arm-wrist-hand and neck-shoulder symptoms among office workers?**

Previous symptoms are the main risk factor for the onset of arm-wrist-hand and neck-shoulder symptoms among office workers. A number of individual characteristics, and physical and psychosocial risk factors related to work exposure, all modestly contribute to the onset of symptoms. Leisure time exposures contributed marginally to symptom onset.

In Chapter 7 risk factors related to physical work exposures, psychosocial work exposures, physical leisure time exposures and individual characteristics were evaluated and the impact of identified risk factors on population level was estimated. Most hypotheses for this study were described in Chapter 5.

An increased risk for the onset of arm-wrist-hand symptoms was found for at least 4 hours per day of self-reported computer use at work, never squeezing firmly with hands at work, often / always using computer and telephone at the same time, moderate to low reward, low task variation, at least 4 hours per day of self-reported computer use during leisure time, female gender, higher age (i.e. 49 – 68 years), moderate to high levels of overcommitment, BMI exceeding 24 kg / $m^2$, and having had disabling symptoms in the arm-wrist-hand or neck-shoulder region in the past year. The strength of these associations was also low in general, with the exceptions of disabling arm-wrist hand symptoms in the past year (RR 3.9, 95% CI 3.0 – 5.1), and at least 4 hours per day of self-reported computer use at work (RR 2.0, 95% CI 1.2 – 3.2).

The registered duration of computer use at work, monitor height, mouse and keyboard location, arm support during keyboard and mouse use, precision demands, cognitive demands, effort, decision authority, and general physical activity during leisure time were, among other factors, not identified as risk factors for the onset of arm-wrist-hand symptoms.

An increased risk for the onset of neck-shoulder symptoms was found for at least 4 hours per day of self-reported mouse use at work, often / always performing repetitive hand movements (excluding computer use), sometimes / often / always using computer and telephone at the same time, arm support during keyboard use, low task variation, female gender, medium age (i.e. 40 – 48 years), work continuation during formal breaks, having an acquaintance experiencing disabling symptoms, and having had disabling neck-shoulder symptoms in the past year. The strength of these associations was low, with the exception of disabling neck-shoulder symptoms in the past year (RR 5.3, 95% CI 4.4 – 6.3).

The registered duration of computer use at work, monitor height, mouse and keyboard location, precision demands, cognitive demands, effort, reward, decision authority, overcommitment, self-reported duration of computer use during leisure time, and general physical activity during leisure time were, among other factors, not identified as risk factors for the onset of neck-shoulder symptoms.

Contrary to expectations, almost the same set of risk factors was identified for the onset arm-wrist-hand as for the onset of neck-shoulder symptoms. A long self-reported duration of mouse / computer use at work, computer and phone use at the same time, low task variation, female gender, medium to high age, and previous disabling symptoms in the past year were identified for both outcomes.

Previous symptoms had a large impact on population level (PAF 0.44, 95% CI 0.39 – 0.51, for neck-shoulder symptoms; PAF 0.33, 95% CI 0.26 – 0.41, for arm-wrist-hand symptoms). In addition, arm support during keyboard use had a considerable impact on neck-shoulder symptoms (PAF 0.38, 95% CI 0.12-0.56), and at least 4 hours per day of self-reported computer use at work on arm-wrist-hand symptoms (PAF 0.46, 95% CI 0.11-0.68). These PAF values indicate that if all office workers would not support their arms during keyboard use, 38% of all future episodes of neck-shoulder symptoms could be prevented. In addition, 46% of all future episodes of arm-wrist-hand symptoms could be prevented if all office workers would have less than 4 hours of (self-reported) computer use per day. However, the assumption underlying these calculations is that the risk factors are causal risk factors. For self-reported computer use at work, causality can be challenged due to the fact that the registered duration of computer use at work was not associated with the onset of symptoms and no convincing methodological explanation could be given for the absence of an association. For arm support during keyboard use, inconsistent results have been reported in other longitudinal studies. Therefore, it remains to be seen whether arm support during keyboard use is a causal risk factor.

In addition to arm support during keyboard use and self-reported computer use at work, a range of other potentially modifiable risk factors was identified. These risk factors had in general a weak association with the onset of musculoskeletal symptoms (i.e. RRs of 1.2 to 1.7). Moreover, subjects had on average 3 of these potentially modifiable risk factors, and a strong association between the number of potentially modifiable risk factors and the onset of arm-wrist-hand and neck-shoulder symptoms was found. This could indicate that a single risk factor is not sufficient to cause the onset of symptoms, but that a number of risk factors need to be present in order to cause the onset of symptoms (3). It follows that preventive interventions focusing on one risk factor or on a group of related risk factors are not likely to be effective. Preventive interventions focusing on a range of risk factors at the same time seem to be needed in order to be effective (by modifying risk factors). It remains to be seen whether this type of preventive interventions is feasible.

*First additional study question*

**What is the reliability and validity of self-reported duration of computer use at work?**

Imperfect test-retest reliability resulted in at least 25% of misclassification of exposure, and the overall agreement between self-report and software registration showed more than 80% of misclassification of exposure when using self-report.

Before the start of the current prospective cohort study it was already known that self-reported duration of computer use at work showed only moderate agreement with objective duration of computer use at work (4, 5). However, objective measurements are expensive. If the validity of self-reports could be improved, large prospective cohort studies (and companies) could use self-reports as a surrogate measure. Most previous validity studies had used continuous measurement scales for the self-reported duration of computer use at work (percentage of work time, minutes or hours per day). In the reliability and validity study described in Chapter 4, predefined categories were used, since it is known that self-report is low in precision. Software registrations were used as a "gold" standard. Imperfect test-retest reliability of these self-reports resulted in at least 25% of misclassification of exposure. Moreover, using self-reports resulted in more than 80% of misclassification, if compared to the gold standard. Approximately a third of all subjects overestimated their daily computer use by more than 2 hours. No clear indications of differential misclassification by symptom status, registered duration of computer use at work, individual characteristics, job title or psychosocial factors at work could be identified, since misclassification in all subgroups was comparable (i.e. at least 75%). The explanation that subjects (mis)interpreted the duration of computer use at work as the time spent sitting behind the desk, was also refuted.

Based on these results, it was expected that the use of self-reports in prospective cohort studies would mainly lead to non-differential misclassification of exposure and would bias the risk estimate towards the null. Therefore, we expected that the registered duration of computer use at would be more strongly associated with the onset of musculoskeletal symptoms than self-reported data. However, this expectation was not verified in the prospective cohort study, since registered duration was not related to the onset of symptoms, whereas self-reported duration was (Chapter 6). Therefore, it is possible that differential misclassification is present when using self-report. This differential misclassification is not likely related to a single factor but possibly to the additional effect of a number of factors.

*Second additional study question*

**What is the reliability and validity of self-reported correlates of work postures during computer use among office workers?**

Most self-reported variables related to work posture had acceptable test-retest reliability (percentage agreement ranged between 71% and 100%). However, low to moderate agreement was found between self-reported variables and objective measurements of work posture during computer use. The percentage agreement were below 50% for most items.

During the preparation and initial data gathering phase of the prospective cohort study described in this thesis, a number of prospective cohort studies was published that failed to find consistent (and expected) associations between work posture or work station characteristics (e.g. monitor height, keyboard and mouse location) and the onset of arm-wrist-hand and neck-shoulder symptoms. This may have been caused by non-differential misclassification of exposure due to poor measurement. In the current prospective cohort study a questionnaire was used in which pictures were added to the questions to clarify the items. Participants could compare their own posture to the pictures, since web-based questionnaires were used. It was expected that this new feature would increase validity (and thus decrease misclassification of exposure). The results of the reliability and validity study were presented in Chapter 3. It appeared that most self-reported variables related to work posture had acceptable test-retest reliability over a period of two weeks (the percentages agreement for the comparison between the two time points ranged between 71% and 100%). However, self-reports showed low to moderate agreement with observed work postures. The percentages agreement ranged between 26% and 71% for agreement between questionnaire and manual goniometer measurements. For 9 out of 12 tested items the percentage agreement was below 50%.

The use of self-reports on work posture during computer use might thus explain the lack of association between work posture or workstation characteristics and the onset of arm-wrist-hand and neck-shoulder symptoms among office workers. In addition, the lack of association between workstation characteristics and manual goniometer measurements of postures questions whether workstation characteristics are related to work postures. This might also question whether preventive efforts focused on changing workstation characteristics can be effective to prevent arm-wrist-hand and neck-shoulder symptoms in the current study population, since it seems unlikely that work postures will be affected to a large extent by these workstation changes. In the prospective cohort study indeed no association was found between monitor height, keyboard or mouse location and the onset of arm-wrist-hand and neck-shoulder symptoms among office workers.

**Strengths and weaknesses of the performed studies**

Methodological strengths and weaknesses have to be taken into consideration in the interpretation of the study results. Firstly, the methodological quality of the current prospective cohort study will be rated using the quality list used in Chapter 2. Secondly, some general methodological issues concerning exposure assessment, outcome assessment, recruitment of study population, and statistical analysis are raised.

*Methodological quality assessment of the prospective cohort study according to IJmker and co-workers (6)*

In Table 1 the results for the methodological quality are summarized. The argumentation for the applied scores can be found in Table 2.

The cut-off value for a high quality study in the systematic review of Chapter 2 was 50%. It follows from Table 1 that our prospective cohort study should be rated as high quality for the determinants self-reported duration of computer use at work and registered duration of computer use at work. However, the cut-off value for high quality in the systematic review was arbitrary. A study rated as high quality might still be biased to a considerable extent. Although methodological shortcomings are frequently addressed, the amount of resulting bias for any specific methodological shortcoming or a group of methodological shortcomings is largely unknown. Interestingly, it is frequently observed that authors bring up methodological shortcomings if their hypothesis is not verified, without taking into account that the results might be a 'true result' (8).

Table 1 Summary of the methodological quality assessment.

| **Cohort first author** | **Study design** | | **Exposure and outcome assessment** | | | | | | **Data analysis** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1. Participation rate | 2. Response at follow- up | 3. Duration computer use | 4. Ergonomic factors | 5. Psychosocial factors | 6. Physical factors leisure time | 7. Exposure change | 8. Outcome | 9. Statistical model | 10. Confounding | 11. Statistical power | Score * (%) |
| **Promo** | | | | | | | | | | | | |
| - IJmker (self-report) | - † | - | - | - | ? | + | + | + | + | + | + | **55** |
| - IJmker (registered) | - | - | + | - | ? | + | + | + | + | + | + | **64** |

* the percentage of positive items over the total number of Items

† + = positive, - = negative and ? = unclear (insufficient information available)

Table 2 Argumentation for the methodological quality scores in Table 1.

| |
|---|
| Study design |
| **1. Was the participation rate at baseline at least 80% OR, if participation rate was < 80%, not selective regarding exposure (i.e. duration of computer use) and potential confounders (i.e. at least for gender and age)?** The participation rate was well below 80% (i.e. 27%). Gender and age were similar for participants and non-participants. However, the mean registered duration of computer use at work was 1.4 hours per week lower among non-participants, and the standard deviation was higher among non-participants. The lower variation of the duration of computer use among participants could have resulted in inability to detect an association between the registered duration computer use at work and the onset of arm-wrist-hand and neck-shoulder symptoms. |
| **2. Was the response at follow-up at least 80% OR, if the response was < 80%, not selective regarding exposure (i.e. duration of computer use), potential effect modifiers (i.e. at least gender and age) and outcome (i.e. hand, arm, shoulder and neck symptoms or disorders)?** This prospective cohort study had 8 follow-up measurements. 1010 Participants had complete data and 937 participants had missing data on at least one of the follow-up measurements (i.e. non-response). Participants with missing data were more often females, were younger and had more often symptoms at baseline. It follows that selection bias might have biased the findings of the current prospective cohort study to some extent. |
| Exposure assessment |
| **3. Were the data on the duration of computer use collected using standardised methods of acceptable quality?** * Self-report has low agreement with software registration: the percentage agreement is less than 20% (see Chapter 4). However, the mean registered duration of computer use is within 10% of the mean observed duration of computer use at work using video observation within previous studies (4, 5). Thus, software registration, as used in the current prospective cohort study, is a valid method to assess the duration of computer use at work. |
| **4. Were the data on ergonomic factors collected using standardised methods of acceptable quality?** * The percentage agreement with objective measurements of most ergonomic factors was below 50%. See Chapter 3 of this thesis. |
| **5. Were the data on psychosocial factors collected using standardised methods of acceptable quality?** † Internal consistency of used scales was sufficient at baseline. At one-year follow-up some scales had lower internal consistency than at baseline. Still, the majority of scales had Cronbachs alpha values exceeding 0.70. No studies were located that evaluated the test-retest reliability of the used measurement scales among office workers. |
| **6. Were data on physical factors during leisure time collected and used in the analysis?** |

| |
|---|
| Data on sports and other leisure time activities involving hand-arm activity were collected and used in the analysis. |
| **7. Were data on exposure change regarding the duration of computer use during the follow-up period (for example due to job change) collected and used in the analysis?**<br>Both self-reported and registered data were assessed at least two times during follow-up. The statistical analyses took into account exposure change during follow-up. |
| Outcome assessment |
| **8. Were the data on outcome collected using standardised methods of acceptable quality?** ‡<br>A modified version of the Nordic Questionnaire formed the basis for outcome assessment. |
| Data analysis |
| **9. Was the statistical method used appropriate for the outcome studied and was a measure of association presented, including confidence intervals or p-value?**<br>Poisson regression was used, which is appropriate for binary outcomes (7). In addition, risk estimates and 95% confidence intervals were presented. |
| **10. Was the statistical analysis tested for confounding by gender and age?**<br>Analyses were adjusted for gender and age. |
| **11. Was the number of subjects in the multivariate analysis at least 10 times the number of independent variables?**<br>Yes. The number of independent variables in the multivariate models was at maximum 50, and the minimum number of subjects was 868. |

* ICC > 0.60 or Kappa > 0.40 for test-retest reliability or interobserver reliability. Additionally for self-reports: ICC > 0.60 or Kappa > 0.40 or r > 0.75 for agreement with observation or direct measurement.
† ICC > 0.60 or Kappa > 0.40 for test-retest reliability. Additionally for self-reports, in the case of using scales: Cronbachs alpha > 0.70 for the majority of scales used.
‡ ICC > 0.60 or Kappa > 0.40 or r > 0.75 for test-retest reliability or interobserver reliability, or if (modified) Nordic questionnaire was used.

*Exposure assessment*

The studies performed in Chapters 3 and 4 indicate that the use of self-report leads to considerable non-differential misclassification of exposure (i.e. measurement error). The general opinion is that non-differential misclassification leads to underestimated associations (i.e. bias towards the null) (9). However, this situation might not be true if the included confounders in the final multivariate model are measured with error (10). Therefore, it is possible that associations in this study could also be overestimated. In the performed prospective cohort study overestimation due to poorly measured confounders is not likely, since multivariate associations were not stronger than univariate associations.

Part of the measurement error encountered in Chapters 3 and 4 might be related to asking single questions instead of multiple questions related to the same construct that is being measured (11). Factor analysis has been performed for the self-reported variables related to work posture during computer use in order to search for underlying constructs. However, the associations between individual items were too low to combine questions into scales. The same was true for physical factors during leisure time. It follows that only single question factors were entered into the analysis. As a result, it might have been more difficult to find associations for these single item factors.

A data-driven approach was followed in order to determine cut-off values for several risk factors. By doing so the likelihood of finding increased risks is high, but the interpretation of findings can be hampered. A priori cut points with biological meaning are not present, since most studies use different questionnaires and categorization schemes to assess similar or related risk factors. This was also true in the current study.

*Outcome assessment*

Self-reported outcomes were used in this study. Furthermore, symptoms in the neck and shoulder region, and those in the arm, wrist and hand region were lumped. It is possible that self-reported outcomes lead to misclassification, due to the fact that subjects vary in their experience and threshold for pain and discomfort, and also in their reporting of pain and discomfort. However, symptom reports with sufficiently high thresholds in case definition, like ours, have shown strong associations with physical examinations (12). In addition, associations were similar when using self-reports with high case thresholds and when using physical examinations (13, 14). Another issue related to self-reported outcomes is common method bias. This bias results from using exposure and disease status from the same source (i.e. self-report) and might result in spurious associations

(15). However, this type of bias has not been supported by findings in musculoskeletal research (16), and the likelihood of bias is lower in prospective studies than in cross-sectional studies (17). Therefore, common method bias is not likely to have influenced the results described in this thesis to a great extent.

In Chapters 2 and 5 a case definition based on symptoms plus related disability (e.g. restriction of work activities, sick leave, or medical consumption) was described. The idea behind this case definition was to ensure that minor symptoms were excluded from case definition in order to reduce potential misclassification. However, this case definition was modified during the preparation of Chapters 6 and 7, due to the possibility that different sets of risk factors might contribute to symptoms on the one hand, and to disability if symptoms are present on the other hand (17). When using a case definition based on symptoms plus disability, potential predictors of onset, prognostic factors or a mix of both are identified. Because the focus of this thesis is on predictors of onset, we decided to modify our case definition. The used case definition based on symptoms, plus pain intensity >=6 or use of pain medication, might still suffer to some extent from this bias. The use of pain medication might be influenced by different risk factors than those that influence symptoms. However, on average, the difference of the 3-month cumulative incidence between symptoms, plus pain intensity >=6 or pain medication, and symptom plus pain intensity >=6 was only 0.2% for arm-wrist-hand-symptoms and 0.5% for neck-shoulder symptoms.

In this thesis arm, wrist and hand symptoms on the one and neck and shoulder symptoms on the other hand, were lumped into two categories. It has been argued that lumping should be avoided, because it can attenuate risk estimates (18, 19). It is thus possible that associations for specific body regions were underestimated. In the current cohort study we decided to lump outcome measures based on the assumption that sustained muscle activation plays an important role. Muscles such as the trapezius cover both the neck and shoulder region with their origo and insertion, and forearm muscles cover elbow, wrist and hand.  Our finding that risk factors

were similar for neck-shoulder and arm-wrist-hand symptoms seem to support our lumping of body regions among office workers.
In addition to lumping body regions in the case definitions, specific and non-specific symptoms (based on clinical findings) were lumped as well. Most symptoms among office workers lack physical findings during physical examination (20 - 23), and it remains unclear whether risk factors for specific symptoms are different from those for non-specific symptoms.

*Recruitment of study population*

Office workers were recruited at the workplace. It follows that workers on sick leave due to symptoms could not be enrolled. Possibly this has contributed to a less vulnerable cohort of workers, which might have attenuated risk estimates.
In addition, the study was introduced among companies and office workers as a study on the relationship between the duration of computer use at work and the onset of arm-wrist-hand and neck-shoulder symptoms. As a result, a selection of workers who use the computer slightly longer per day and who experience more often prevalent symptoms were enrolled when compared to the target population of office workers.
The above stated limitations might also be interpreted as an advantage, since if a preventive intervention would take place it would be likely that the same population that participated in the epidemiological study would participate in the intervention. In that respect, selection bias in this study might have contributed to a higher level of external validity.

*Statistical analysis of the cohort study*

The performed analyses were merely confined to additive effect modification (i.e. determination of independent risk factors). It is possible that multiplicative effect modification (also known as “interaction”) or mediation is present between risk factors. If present, this could lead to more refined determination of office workers at increased risk of developing arm-wrist-hand and neck-shoulder symptoms.

In the available prospective studies among computer users different time lags have been used. The studies in this thesis had a time window of 3 months. Two other published studies used shorter time windows of 1 day (2) and 1 week (1). It is unknown at present whether different time windows lead to different study results.

The explained variances of the final multivariate models were 18% and 24%. In musculoskeletal research, similar figures have been reported for binary outcomes (e.g. 24: 15%). These values may be underestimated due to the fact that an estimation procedure is used for binary outcomes (i.e. in the case of using logistic regression). If linear regression is used, explained variances are usually higher (25). For example a study by Bot and co-workers showed an explained variance of 47% (26).

Despite the likely underestimation of the explained variance due to the use of binary outcomes, it follows that a large part of the variance in the outcome measure was not explained by the included risk factors. It is possible that unmeasured confounders form part of the unexplained variance. However, measurement error of risk factors and outcomes also contribute to unexplained variance (11).

**Theoretical conclusions**

In the General Introduction, a theoretical model was presented in which three groups of risk factors determine the onset of musculoskeletal symptoms among office workers: physical factors, psychosocial factors and individual factors. Moreover, physical and psychosocial factors could be encountered during work and leisure time. In addition, it was proposed that sustained muscle activation could be an important pathophysiological link between risk factors and symptom onset among office workers.

The results of this thesis challenge the proposed model and proposed pathophysiological mechanism in several ways. Firstly, leisure time factors do not seem to be meaningfully related to the onset of musculoskeletal symptom among office workers and could thus be omitted from the model. Secondly, the strength of associations found in the performed cohort study was low, except for having had previous symptoms. The results of the cohort study suggest that multiple risk factors need to be present in order to cause symptom onset. Thirdly, the proposed pathophysiological link was not supported by empirical findings in the prospective cohort study. The lack of expected findings in the current study, especially for the registered duration of computer use at work, cognitive demands, precision demands during mouse use, and mouse location, challenge the plausibility of sustained muscle activation as an important pathophysiological mechanism for the onset of arm-wrist-hand and neck-shoulder symptoms among office workers. In addition, previous epidemiological studies using sustained muscle activation or muscle fatigue as a predictor, have failed to show a clear association with the onset of symptoms (27, 28).

One of the limitations of the Cinderella theory and also of other pathophysiological theories explaining symptom onset among workers with light physical demands, is the focus on local tissue injury or local physiological changes (e.g. 29 - 33). These local events might not have a direct connection with symptom experience, since symptom experience is not a local physiological event, but a perception involving higher central-nervous-system mechanisms (34, 35). Although these higher-central-nervous-system mechanisms are not well understood, some theories propose that local physiological events are not necessary nor sufficient for symptom onset (36 - 39), or even are a consequence instead of a cause of symptom onset (37). Moreover, it has been suggested that normal physiological sensations can be interpreted as symptoms due to a lowering of the perception threshold due to sensitization of the nervous system (40). The most important factor determining whether sensitization takes place is individual coping skills based on previous learning in dealing with physical and psychosocial factors in daily life. This theory might explain why factors like previous musculoskeletal symptoms (e.g. this thesis), psychological distress and depression have been found as risk factors for the onset of arm-wrist-hand and neck-shoulder symptoms (41), since these factors inherently implicate poor coping.

Contrary to a rational approach to explain the onset of symptoms, it has also been argued that the onset of symptoms has no explainable cause and that the experience of symptoms is simply a “predicament of life” (42, 43).

When looking back at the history of musculoskeletal symptoms among office workers (see General Introduction), it is remarkable that in essence the same pathophysiological theories and risk factors are used in research as already described in the 19th century. Still, we only know a small part of why a large group of workers experiences symptoms, and why an individual worker experiences an episode of symptoms and another worker does not. In order to understand more, it may be time to incorporate theories on the perception of symptoms in addition to biomedical theories focusing on local physiology only.

**Recommendations for further research**

From the findings in this thesis, some recommendations for further research can be derived.

1. More prospective cohort studies with objective data on the duration of computer use at work are needed in order to determine the consistency of results among different cohorts of office workers.
2. More refined exposure estimates of computer use at work should be developed. These exposure estimates should be tested in prospective cohort studies in order to confirm or falsify the findings of this thesis.
3. All factors (i.e. determinants, confounders and effect modifiers) included in statistical models on musculoskeletal symptoms among office workers should be measured with higher precision and accuracy. Moreover, to improve precision and accuracy multiple measures of the constructs might be needed.
4. The role of work postures in the onset of musculoskeletal symptoms among office workers should be further investigated. This factor was not measured well in the current study. In future prospective cohort

studies work postures should be validly measured with direct measurements in order to investigate whether duration, frequency and / or intensity of exposure to work postures contribute to symptom onset. Up to this time point, only one study has done so (44).

5. More research should be dedicated to understanding why previous experience of musculoskeletal symptoms is the best predictor for musculoskeletal symptoms in the future. This association is consistently reported in the literature, but the underlying (pathophysiological) mechanism is still largely unknown.
6. The effect of the time window between exposure and musculoskeletal outcomes should be further explored. If different time windows lead to different amounts of explained variance and / or variations in the strength of associations, this might have important implications for pathophysiological theory (45).
7. Future epidemiologic studies should explicitly aim at explaining more variance, since explained variance is one of the useful indicators of progress in musculoskeletal research. The added value of “new” risk factors, such as biological, social or genetic risk factors, should be evaluated by means of explained variance. In order to arrive at higher explained variances, pathophysiological theories based on symptom perception should be used besides theories focussing on local physiology.
8. The feasibility and (cost-)effectiveness of interventions to prevent arm-wrist-hand and neck-shoulder symptoms among office workers should be investigated. In these interventions multiple risk factors should be targeted at the same time.
9. Laboratory and field researchers focussing on musculoskeletal symptoms should collaborate more. Theories from both disciplines should be tested in both field and laboratory studies. In this way a more systematic approach of gaining knowledge about the onset of musculoskeletal symptoms can be achieved.

## Practical implications

The results of this thesis lead to the following practical implications for the prevention of arm-wrist-hand and neck-shoulder symptoms among office workers. These practical implications are aimed at professionals in the field of occupational health, who implement preventive interventions in daily practice.

1. A long duration of computer use at work has been described as an important risk factor for the onset of arm-wrist-hand and neck-shoulder symptoms among office workers. The current thesis challenges this idea. Firstly, the duration of mouse use seems to be more important than the duration of computer use at work in general, and the duration of keyboard use. A long duration of mouse use at work should still be treated as a risk factor, given the limited body of evidence that is available at this moment. However, preventive interventions focussing only on lowering the duration of mouse use will likely not be effective, since a long duration of registered mouse use does not seem to be a sufficient cause by itself for the onset of arm-wrist-hand and neck-shoulders symptoms among office workers.
2. A range of rather weak risk factors has been identified in this thesis. The focus of preventive interventions should be laid on changing several of these risk factors at the same time. In order to increase efficiency, a screening questionnaire could be used to tailor interventions to individual risk factor profiles.
3. By far the most import risk factor for the onset of arm-wrist-hand and neck-shoulder symptoms among office workers is previous symptoms. Office workers who have had previous symptoms are a high-risk group and deserve special attention.

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# General summary

In **Chapter 1** the background of the studies included in this thesis is presented. The main objective of this thesis was to investigate the dose-response relationship between the duration of computer use at work and the occurrence of arm-wrist-hand and neck-shoulder symptoms. In addition, the relative contribution of risk factors related to work exposure, leisure time exposure and individual characteristics for the occurrence of arm-wrist-hand and neck-shoulder symptoms among office workers is determined. A number of reasons justify this research endeavor. Firstly, nowadays office work and computer use are almost synonyms. In 2004, 3.3 million workers reported to frequently use a computer at work. This means that this research project focuses on roughly half of the working population in the Netherlands. Secondly, one out of three workers experienced regular or prolonged symptoms in the arm-wrist-hand or neck-shoulder region in the past 12-months. Thirdly, these symptoms are associated with reduced well-being, reduced productivity and medical consumption. These symptoms thus impact individuals, companies, and societies.

In **Chapter 2** a systematic review of longitudinal studies is presented in which the association between the duration of computer use at work and the onset of arm-wrist-hand and neck-shoulder symptoms among office work was evaluated. In total nine longitudinal studies were included. The available evidence was assessed based on the methodological quality of the studies and the consistency of results amongst studies. Evidence for an increased risk of a long duration of computer use at work on the onset of arm-wrist-hand and neck-shoulder symptoms among office workers was only found for the duration of mouse use at work and arm-wrist-hand symptoms. Indications for a dose-response relationship were found for this relationship. Based on the limited number of high quality studies that were performed, moderate evidence instead of strong evidence was concluded for this association. The empirical findings were in line with a pathophysiological model in which sustained muscle activation plays an important role. The main limitation of the studies included in the systematic review was the reliance on self-reported duration of computer use instead of objective measurements. In theory, the use of self-reports can lead to underestimation of the strength of association in case of non-differential misclassification, while in the case of differential misclassification overestimation can also occur.

In **Chapter 3** the reliability and validity of a questionnaire which measures workstation characteristics and work postures during computer use is described**.** In this questionnaire pictures have been added to the questions to clarify the items. Since web-based questionnaires were used, participants could compare their own postures to the pictures. A group of 84 office workers filled out the questionnaire twice, with an in-between period of two weeks. For a subgroup of workers (n=38) additional on-site observations and multiple manual goniometer measurements were performed. It appeared that most self-reported variables related to work posture had acceptable test-retest reliability over a period of two weeks. However, self-reports showed low to moderate agreement with observed work postures. The percentages agreement ranged between 26% and 71% for agreement between questionnaire and manual goniometer measurements. For 9 out of 12 tested items the percentage agreement was below 50%. The use of self-reports on work posture during computer use might  explain the lack of association in epidemiological studies between work posture or workstation characteristics and the onset of arm-wrist-hand and neck-shoulder symptoms among office workers. In addition, these findings question whether workstation characteristics are related to work postures during computer use. This might also question whether preventive efforts focusing on changing workstation characteristics in order to change work postures during computer use can be effective in the primary prevention of arm-wrist-hand and neck-shoulder symptoms.

In **Chapter 4** the reliability and validity of the self-reported duration of computer use at work is described. Contrary to previous research, a questionnaire with predefined categories is used, since it is known that self-report is, in general, low in precision. In the reliability study, 81 office workers filled out the questionnaire twice with an in-between period of two weeks. In the validity study self-reported data on the duration of computer use at work of 572 office workers were compared to data from software registrations. Imperfect test-retest reliability of self-reports resulted in at least 25% of misclassification of exposure. Moreover, using self-reports resulted in more than 80% of misclassification if compared to the gold standard. Approximately a third of all subjects overestimated their daily duration of computer use by more than 2 hours. No clear indications of differential misclassification by symptom status, registered duration of computer use at work, individual characteristics, job title or psychosocial factors at work could be found.

In **Chapter 5** the background and study design of the PROMO study (Prospective Research on Musculoskeletal disorders in Office workers) is described. The PROMO study was a prospective cohort study among 1951 office workers, with a follow-up of 24 months. Data on exposure and outcome was collected using web-based self-reports. Outcome assessment took place every three months during the follow-up period. Data on the duration of computer use at work were collected at baseline and continuously during follow-up using a software program. The advantages of the PROMO study included the 24-month follow-up period, the repeated measurement of both exposure and outcome, the measurement of a broad range of potential risk factors (i.e. physical and psychosocial risk factors, and individual characteristics), and the objective measurement of the duration of computer use at work. The data collected in the PROMO study formed the input for Chapters 6 and 7.

In **Chapter 6** the association between the duration of computer use at work and the onset of arm-wrist-hand and neck-shoulder symptoms is evaluated. One of the main features of this study was that objective data on the duration of computer use at work were collected by means of software registrations. Contrary to the expectation that registered exposure data would show stronger associations with the onset of arm-wrist-hand and neck-shoulder symptoms than self-reported exposure data, no association between the registered duration of computer use at work and arm-wrist-hand symptoms, nor between the registered duration of computer use at work and neck-shoulder symptoms was found. Positive associations were only found for self-reported data on the duration of computer use at work.

In **Chapter 7** risk factors related to physical work exposures, psychosocial work exposures, physical leisure time exposures and individual characteristics are evaluated and the impact of the identified risk factors on population level is estimated. An increased risk for the onset of arm-wrist-hand symptoms was found for at least 4 hours per day of self-reported computer use at work, never squeezing firmly with hands at work, often / always using computer and telephone at the same time, moderate to low reward, low task variation, at least 4 hours per day of self-reported computer use during leisure time, female gender, higher age (i.e. 49 – 68 years), moderate to high levels of overcommitment, BMI exceeding 24 kg / $m^2$, and having had disabling symptoms in arm-wrist-hand or neck-shoulder region in the past year. The strength of the associations was in general low, with the exceptions of disabling arm-wrist hand symptoms in the past year (RR 3.9, 95% CI 3.0 – 5.1), and at least 4 hours per day of self-reported computer use at work (RR 2.0, 95% CI 1.2 – 3.2). An increased risk for the onset of neck-shoulder symptoms was found for at least 4 hours per day of self-reported mouse use at work, often / always performing repetitive hand movements (excluding computer use), sometimes / often / always using computer and telephone at the same time, arm support during keyboard use, low task variation, female gender, medium age (i.e. 40 – 48 years), work continuation during formal breaks, having an acquaintance experiencing disabling symptoms, and having had disabling neck-shoulder symptoms in the past year. The strength of associations was low, with the exception of disabling neck-shoulder symptoms in the past year (RR 5.3, 95% CI 4.4 – 6.3). Previous symptoms had a large impact on population level (PAF 0.33, 95% CI 0.26 – 0.41, for the onset of arm-wrist-hand symptoms; PAF 0.44, 95% CI 0.39 – 0.51, for the onset of neck-shoulder symptoms). In addition, at least 4 hours per day of self-reported computer use at work had a considerable impact on the onset of arm-wrist-hand symptoms (PAF 0.46, 95% CI 0.11-0.68), and arm support during keyboard use on the onset of neck-shoulder symptoms (PAF 0.38, 95% CI 0.12-0.56). In this study a range of potentially modifiable risk factors for the onset of arm-wrist-hand and neck-shoulder symptoms among office workers was identified. These risk factors had in general a weak association with the onset of arm-wrist-hand and neck-shoulder symptoms (i.e. RRs of 1.2 to 1.7). Moreover, subjects had on average 3 of these potentially modifiable risk factors, and a strong association between the number of potentially modifiable risk factors and the onset of arm-wrist-hand and neck-shoulder symptoms was found.

In **Chapter 8** the results of the performed studies in this thesis are summarized, possible explanations for the findings are given and methodological strengths and weaknesses of the performed studies are discussed. Weak or absent associations between the registered duration of computer use at work and the onset of arm-wrist-hand and neck-shoulder symptoms in the current and other prospective cohort studies challenge the existence of a causal relation between the duration of computer use at work and the onset of arm-wrist-hand and neck-shoulder symptoms. The results of the current thesis also question whether pathophysiological theories that focus on local tissue injury or local physiological events can explain symptom onset among office workers. Future research should include theories that explicitly take symptom perception into account to gain more insight in the mechanism underlying symptom onset. More prospective cohort studies are needed, for which the following recommendations can be made: objective data for the duration of computer use at work should be used, more refined exposure estimates of computer use at work should be used, and the time window between exposure and outcome should be investigated. In order to prevent the onset of arm-wrist-hand and neck-shoulder symptoms among office workers multiple risk factors should be targeted at the same time.

# Samenvatting

[redacted]

In **Hoofdstuk 1** wordt de achtergrond van de studies in dit proefschrift beschreven. De belangrijkste doelstelling van dit proefschrift was het onderzoeken van een mogelijke dosis-respons relatie tussen de duur van computergebruik op het werk en het optreden van arm-pols-hand en nek-schouder klachten te onderzoeken. Daarnaast richtte dit proefschrift zich op het bepalen van het relatieve aandeel van risicofactoren ten aanzien van blootstelling tijdens het werk, blootstelling tijdens de vrije tijd en individuele kenmerken voor het optreden van arm-pols-hand en nek-schouder klachten bij kantoormedewerkers.
Een aantal redenen onderstrepen de maatschappelijke relevantie van bovenstaande onderzoeksdoelstellingen. In de eerste plaats zijn kantoorwerk en computergebruik bijna synoniemen. In 2004 gaven 3,3 miljoen werknemers aan regelmatig een computer te gebruiken op het werk. Hieruit volgt dat dit proefschrift zicht richt op de helft van de werkzame bevolking in Nederland. In de tweede plaats geven 1 op de 3 werknemers in Nederland aan regelmatig of langdurig klachten te ervaren in de arm-pols-hand of nek-schouder regio in de afgelopen 12 maanden. In de derde plaats leiden deze klachten tot een lager welzijn, tot lagere productiviteit op het werk en tot medische consumptie. Hieruit volgt dat arm-pols-hand en nek-schouder klachten van belang zijn voor individuen, bedrijven en overheden.

In **Hoofdstuk 2** wordt een systematisch literatuuroverzicht van longitudinale studies gepresenteerd waarin de relatie tussen de duur van computergebruik op het werk en het optreden van arm-pols-hand en nek-schouder klachten bij kantoormedewerkers wordt onderzocht. In totaal werden 9 longitudinale studies gevonden. De sterkte van het bewijs werd gebaseerd op de consistentie van de resultaten en de methodologische kwaliteit van de studies. Uitsluitend voor de duur van muisgebruik op het werk en het optreden van arm-pols-hand klachten werd bewijs gevonden van een verhoogd risico. Tevens zijn er aanwijzingen gevonden voor een dosis-respons relatie. Sterk bewijs was niet aanwezig vanwege het geringe aantal studies dat beschikbaar is. De bevindingen worden ondersteund door een pathofysiologisch werkingsmechanisme waarin aanhoudende spieractiviteit een belangrijke rol speelt. De grootste beperking van de studies die in het literatuuroverzicht zijn opgenomen, is het gebruik van de zelfgerapporteerde duur van computergebruik op het werk in plaats van de objectief gemeten duur van computergebruik op werk. Het gebruik van de zelfgerapporteerde duur kan in theorie leiden tot het onderschatten van de sterkte van het effect indien er sprake is van non-differentiële misclassificatie, terwijl in het geval van differentiële misclassificatie ook overschatting van het effect plaats kan vinden.

De betrouwbaarheid en validiteit van een vragenlijst voor het meten van werkplekkenmerken en werkhoudingen achter de computer wordt beschreven in **Hoofdstuk 3.** In deze vragenlijst zijn plaatjes toegevoegd om de vragen te verduidelijken. Deelnemers vulden de vragenlijst in via internet. Hierdoor konden ze de vragenlijst invullen terwijl ze achter de computer zaten en hun eigen werkhouding vergeleken met de plaatjes. In totaal hebben 84 kantoormedewerkers de vragenlijst tweemaal ingevuld binnen een periode van twee weken. Bij een deel van de groep (n=38) zijn aanvullende metingen gedaan: observaties op de werkplek en metingen van de werkhouding met behulp van een manuele goniometer. Uit de resultaten bleek dat de meeste vragen die gerelateerd zijn aan de werkhouding tijdens computergebruik voldoende test-hertest betrouwbaarheid hadden. Echter, de zelfgerapporteerde gegevens lieten zwakke tot matige relaties zien met gemeten werkhoudingen. De percentages overeenstemming lagen tussen 26% en 71% voor de overeenstemming tussen de vragenlijstgegevens en de metingen met de manuele goniometer. Bij 9 van de 12 geteste vragen lag het percentage overeenstemming onder 50%.

In **Hoofdstuk 4** wordt de betrouwbaarheid en validiteit van de zelfgerapporteerde duur van computergebruik op het werk beschreven. In tegenstelling tot voorafgaande studies worden voorgedefinieerde categorieën gebruikt, omdat het bekend is dat zelfrapportage een lage precisie heeft. In het betrouwbaarheidonderzoek vulden 81 kantoormedewerkers tweemaal de vragenlijst in binnen een periode van twee weken. In het validiteitonderzoek werd de zelfgerapporteerde duur van computergebruik op het werk van 572 kantoormedewerkers vergeleken met de geregistreerde duur van computergebruik door een software programma. De resultaten van het betrouwbaarheidsonderzoek lieten zien dat random meetfouten leidden tot 25% misclassificatie van blootsteling. Het gebruik van zelfrapportages in vergelijking met registraties door een software programma leidde tot nog meer misclassificatie, namelijk 80%. Ongeveer een derde van alle deelnemers overschatte de duur van computergebruik op het werk met meer dan 2 uur per dag. Er waren geen duidelijke aanwijzingen voor differentiële misclassificatie door de aanwezigheid van arm-pols-hand of nek-schouder klachten, door de geregistreerde duur van computergebruik, door individuele kenmerken, door functieomschrijving, en door psychosociale factoren op het werk.

In **Hoofdstuk 5** wordt de achtergrond en het onderzoeksontwerp van de PROMO studie (Prospective Research On Musculoskeletal disorders among Office workers) beschreven. De PROMO studie was een prospectieve cohort studie met een loopduur van 24 maanden. Gegevens over blootstelling en uitkomst zijn verzameld via vragenlijsten op het internet. De aanwezigheid van klachten is elke 3 maanden gemeten. De duur van computergebruik op het werk is continu gemeten met behulp van een software programma. De sterke punten van de PROMO studie zijn de lange loopduur (24 maanden), de herhaalde meting van zowel blootstelling als uitkomst, de grote verscheidenheid aan potentiële risicofactoren die opgenomen waren in het onderzoek (dat is: fysieke en psychosociale risicofactoren, en ook individuele kenmerken), en de objectief gemeten duur van computergebruik op het werk. De gegevens uit de PROMO studie vormen de basis voor de Hoofdstukken 6 en 7.

In **Hoofdstuk 6** wordt de relatie tussen de duur van computergebruik op het werk en het optreden van arm-pols-hand en nek-schouder klachten beschreven op basis van een longitudinale studie bij 1951 kantoormedewerkers. Een belangrijk kenmerk van deze studie was de objectieve metingen van de duur van computergebruik op het werk middels een software programma. De verwachting was dat de geregistreerde blootstellingdata sterkere relaties met het optreden van klachten zouden laten zien dan de zelfgerapporteerde blootstellingdata. Tegen de verwachting in lieten de geregistreerde data geen relatie zien met het optreden van zowel arm-pols-hand als nek-schouder klachten. Een verhoogd risico op het optreden van klachten werd uitsluitend gevonden met de zelfgerapporteerde duur van computergebruik op het werk.

In **Hoofdstuk 7** worden risicofactoren met betrekking tot fysieke en psychosociale blootstelling tijdens het werk, fysieke blootstelling tijdens de vrije tijd, en individuele kenmerken geëvalueerd en de impact van de geïdentificeerde risicofactoren op populatieniveau geschat. Een verhoogd risico voor het optreden van arm-pols-hand klachten was aanwezig voor ten minste 4 uur per dag zelfgerapporteerd computergebruik op het werk, nooit stevig knijpen met de handen op het werk, vaak / altijd computer en telefoon tegelijkertijd gebruiken op het werk, middelmatige tot lage waardering, lage taakvariatie, ten minste 4 uur per dag zelfgerapporteerd computergebruik tijdens vrije tijd, vrouwelijk geslacht, hogere leeftijd (49 – 68 jaar), bovenmatige toewijding aan het werk, BMI > 24 kg / $m^2$, en klachten in de arm-pols-hand of nek-schouder regio in het afgelopen jaar welke leidden tot beperkingen. De sterkte van de verbanden was over het algemeen laag, met als uitzondering arm-pols-hand klachten in het afgelopen jaar welke leidden tot beperkingen (RR 3.9, 95% BI 3.0-5.1) * en ten minste 4 uur per dag zelfgerapporteerd computergebruik op het werk (RR 2.0, 95% BI 1.2-3.2).
Een verhoogd risico voor het optreden van nek-schouder klachten was aanwezig voor ten minste 4 uur per dag zelfgerapporteerd muisgebruik op het werk, vaak / altijd repeterende handelingen op het werk (exclusief beeldschermwerk) verrichten, soms / vaak / altijd tegelijkertijd computer en telefoon op het werk gebruiken, steunen van armen tijdens

toetsenbordgebruik, lage taakvariatie, vrouwelijk geslacht, middelmatige leeftijd (40 – 48 jaar), doorwerken tijdens formele pauzes, een bekende in de kennissenkring met arm-pols-hand of nek-schouder klachten welke leiden tot beperkingen, en nek-schouder klachten in het verleden welke leidden tot beperkingen.
Het hebben gehad van klachten en gerelateerde beperkingen in het verleden had een grote impact op populatieniveau (PAF 0.33, 95% BI 0.26-0.41 * voor het optreden van arm-pols-hand klachten en PAF 0.44, 95% BI 0.39-0.51, voor het optreden van nek-shouder klachten). Daarnaast had ten minste 4 uur per dag zelfgerapporteerd computergebruik op het werk een grote impact op het optreden van arm-pols-hand klachten (PAF 0.46, 95% BI 0.11-0.68), en steunen tijdens toetsenbord een grote impact op het optreden van nek-schouder klachten (PAF 0.38, 95% BI 0.12-0.56).
In dit onderzoek zijn een reeks risicofactoren gevonden voor het optreden van arm-pols-hand en nek-schouder klachten bij kantoormedewerkers, welke mogelijk beïnvloed kunnen worden middels preventieve interventie. Deze risicofactoren hadden een zwakke relatie met klachten (i.e. RR 1.2 – 1.7). Echter, deelnemers hadden gemiddeld 3 risicofactoren die mogelijk beïnvloed kunnen worden, en een sterke associatie tussen het aantal aanwezige risicofactoren en het optreden van klachten was aanwezig.

* Afkortingen: RR = Relatief Risico; BI = Betrouwbaarheidsinterval; PAF = Populatie Atrributief Risico

In **Hoofdstuk 8** worden de resultaten van de uitgevoerde studies samengevat, verklaringen voor de bevindingen werden gegeven, en de methodologische plus- en minpunten van de studies worden kritisch belicht. Zwakke of afwezige verbanden tussen de geregistreerde duur van computergebruik (en muisgebruik) op het werk en het optreden van arm-pols-hand klachten in de huidige longitudinale studie en in andere longitudinale studies stellen het bestaan van een causale relatie tussen de duur van computergebruik op het werk en het optreden van arm-pols-hand en nek-schouder klachten ter discussie. De resultaten van dit proefschrift zetten ook vraagtekens bij verklaringen voor het optreden van arm-pols-hand en nek-schouder klachten bij kantoormedewerkers door pathofysiologische theorieën op basis van lokale schade of lokale fysiologische veranderingen. Vervolgonderzoek zou ook theorieën moeten meenemen die zich expliciet richten op het waarnemen van klachten om meer inzicht te krijgen in de mechanismen die leiden tot het optreden van klachten. Er zijn meer longitudinale studies nodig, waarin de volgende aanbevelingen meegenomen moeten worden: gebruik van objectieve gegevens voor het meten van (de duur van) computergebruik, verdere verfijning van de blootstellingschatting van computergebruik op het werk, en analyse van het tijdsbestek dat nodig is tussen blootstelling en uitkomst. Om het optreden van arm-pols-hand en nek-schouder klachten bij kantoormedewerkers te voorkomen zullen meerdere risicofactoren op hetzelfde moment beïnvloed moeten worden.

Curriculum Vitae

| | |
|---|---|
| 1980 | Born in Hoogeveen, The Netherlands |
| 1998 | Graduated from secondary school at Menso Altingh College in Hoogeveen, The Netherlands |
| 2002 | MSc Pedagogical Sciences with a major in Human Movement Science at the Rijksuniversiteit Groningen, The Netherlands |
| 2002 – 2007 | PhD fellow at the Body@Work TNO-VUmc research center, Amsterdam, The Netherlands |
| 2007 | MSc Epidemiology via postgraduate epidemiology program at the VU University medical center, Amsterdam, The Netherlands |
| 2007 – present | Consultant and project manager at ErgoDirect BV, Almere, The Netherlands |

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