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**PHYSICAL WORKLOAD AS A RISK FACTOR FOR
SYMPTOMS IN THE NECK AND UPPER LIMBS:
EXPOSURE ASSESSMENT AND ERGONOMIC
INTERVENTION***

Ritva Ketola

Department of Physiology, University of Kuopio, Kuopio

Department of Physiology, Finnish Institute of Occupational Health, Finland

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ABBREVIATIONS

ANSI	American National Standard
EMG	Electromyography
HAL	Hand Activity Level
handPEO-method	Portable Ergonomic Observation-method for hand-intensive jobs
ICC	Intraclass Correlation Coefficient
MVC	Maximal Voluntary Contraction
NIOSH	National Institute of Occupational Safety and Health
OCRA	Concise Exposure Index
OSHA	Occupational Safety & Health Administration
PRIM	Project on Research and Intervention in Monotonous Work
RCT	Randomized Controlled Trial
RULA	Rapid Upper Limb Assessment method
VDU	Video Display Unit
WHO	World Health Organization

This review is based on the following original publications, which will be referred to in the text as Studies 1-4:

1. Korhonen, T., Ketola, R., Toivonen, R., Luukkonen, R., Häkkänen, M. and Viikari-Juntura, E. (2003) Work-related and individual predictors for incident neck pain among office employees working with video display unit work. *Occupational and Environmental Medicine* **60**, 1-8.
2. Ketola, R., Toivonen, R., Häkkänen, M., Luukkonen, R., Takala, E-P. and Viikari-Juntura, E. (2002) Effect of ergonomic intervention in work with video display units. *Scandinavian Journal of Work, Environment & Health* **28**, 18-24.
3. Ketola, R., Toivonen, R., Luukkonen, R., Takala, E-P. and Viikari-Juntura, E. (2003) Expert assessment of ergonomics at video display unit (VDU) workstation: repeatability, validity and responsiveness to changes International Archives of Occupational and Environmental Health. Submitted.
4. Ketola, R., Toivonen, R. and Viikari-Juntura, E. (2001) Interobserver repeatability and validity of an observation method to assess physical loads imposed on the upper extremities. *Ergonomics* **44**, 119-131.

CONTENTS

1. INTRODUCTION	6
2. REVIEW OF THE LITERATURE	7
2.1. Risk factors for work-related musculoskeletal disorders	7
2.1.1. Neck and shoulder	8
2.1.2. Elbow, wrist and hand	9
2.1.3. Low back	10
2.1.4. Video display unit (VDU) work as a risk factor for musculoskeletal disorders	12
2.2. Assessment of physical work load	15
2.2.1. Work load assessment methods	15
2.2.2. Assessment of upper extremity work load	16
2.2.3. Assessment of VDU work ergonomics	18
2.2.4. Repeatability and validity of the assessment methods	19
2.3. Ergonomic interventions in VDU work	20
2.3.1. Intervention studies in VDU work	20
2.3.2. Methodological considerations	24
3. THEORETICAL FRAMEWORK OF THE STUDY	25
4. AIMS OF THE STUDY	26
5. METHODS	26
5.1. Study group of VDU workers (Studies 1, 2 and 3)	26
5.2. Jobs observed in industry	27
5.3. Questionnaire study among VDU workers (Study 1)	27
5.4. Intervention study in VDU work (Study 2)	27
5.5. Assessment of ergonomics in VDU work (Study 3)	28
5.6. Method to observe risk factors for upper limb disorders (Study 4)	299
5.7. Statistical methods	29
5.7.1. Incident neck pain	29
5.7.2. Ergonomic interventions	29
5.7.3. Expert assessment method in VDU ergonomics	30
5.7.4. Assessment method for upper limb risk factors	30
6. RESULTS	31
6.1. Risk factors for incident neck pain (Study 1)	31
6.2. Ergonomic intervention in VDU work (Study 2)	31
6.2.1. Changes in workstation ergonomics	31
6.2.2. Changes in the rating of workstation ergonomics	31
6.2.3. Changes in daily ratings of discomfort.....	31
6.3. Repeatability, validity and responsiveness to change in expert assessment of VDU workstation ergonomics (Study 3)	31
6.4. Inter-observer repeatability and validity of a method to observe risk factors for upper limb disorders (Study 4)	33
7. DISCUSSION	35
7.1. Main findings and comparison to earlier studies	35
7.1.1. Risk factors for incident neck pain	35
7.1.2. Ergonomic intervention in VDU work	36
7.1.3. Expert assessment of the ergonomics of the VDU workstation	36
7.1.4. A method to observe risk factors for upper limb disorders	37
7.2. Methodological aspects	38

7.2.1. Study population and participation rates	38
7.2.2. Study design	38
7.2.3. Health outcomes	39
7.2.4. Self-assessment of work load factors in VDU work	39
7.2.5. Expert assessment	40
8. CONCLUSIONS	40
9. REFERENCES	41
10. AUTHOR BIOGRAPHY	46

Ketola, R. (2004) Physical workload as a risk factor for symptoms in the neck and upper limbs: Exposure assessment and ergonomic intervention. *Journal of Sports Science and Medicine* 3, Suppl. 5, 1-46.

ABSTRACT

The aims of this study were to investigate work related and individual factors as predictors of insident neck pain among video display unit (VDU) workers, to assess the effects of an ergonomic intervention and education on musculoskeletal symptoms, and to study the repeatability and validity of an expert assessment method of VDU workstation ergonomics. A method to assess the risk factors for upper limb disorders was developed, and its validity and repeatability were studied.

The annual incidence of neck pain was 34.4%. A poor physical work environment and placement of the keyboard were work-related factors increasing the risk of neck pain. Among the individual factors, female sex was a strong predictor.

The randomized intervention study included questionnaire survey, a diary of discomfort, and ergonomic rating of the workstations. The subjects (n=124) were allocated into three groups. The intensive and the education groups had less musculoskeletal discomfort than the control group at the 2-month follow-up. After the intervention, the level of ergonomics was distinctly higher in the intensive ergonomic group than in the education or control group.

Two experts in ergonomics analyzed and rated the ergonomics of workstations before and after intervention. The validity of the assessment method was rated against the technical measurements, assessment of tidiness and space, and work chair ergonomics. The intraclass correlation coefficient between ratings of the two experts was 0.74. Changes in the location of the input devices and the screen, as well as the values of tidiness and space and work chair ergonomics showed a significant association with the ratings of both experts.

The method to assess the loads imposed on the upper limbs was validated against the expert observations from the video, continuous recordings of myoelectric activity of forearm muscles, and wrist posture, measured with goniometers. Inter-observer repeatability and validity were good or moderate.

Both intensive ergonomics approach and education in ergonomics have effects in reducing discomfort in VDU work. In attempts to improve the ergonomics of VDU workstation, the best result will be achieved with cooperative palaning in which both workers and prationers are actively invoved. The assessment methods for VDU work ergonomics and upper limb load studied here can be utilized in a repeatable manner.

KEY WORDS: Human engineering, computer terminals, neck pain, upper extremity, workload, risk factors, risk assessment, randomized controlled trials, observation, video recording

1. INTRODUCTION

In the European Union 45% of the workforce used computers for more than a quarter of their work time in 2000 (European Commission, 2001). And since then, the proportion of computer users has increased enormously.

The increasing hours of computer use, together with poor work-rest cycle control, have been associated with musculoskeletal discomfort in the neck-shoulder area and upper limbs, especially in the use of input devices, such as a keyboard or a mouse (Punnett and Bergqvist, 1997). In addition, the use of graphics software and non-keyboard input devices, e.g. the mouse, has increased rapidly, causing new demands for the design of office work places. Computer use in sustained non-neutral postures, such as neck rotation and shoulder abduction, has been identified as a risk factor for neck-shoulder symptoms. Postural stress caused by

poor workstation ergonomics, such as inappropriate location of the screen, keyboard or mouse, have been associated with musculoskeletal problems (Bergqvist et al., 1995b; Karlqvist et al., 1998; Tittiranonda et al., 1999a). However, the evidence of risk factors is based mainly on cross-sectional studies.

Redesign, improvements in ergonomics, and educating the users, have generally been recommended as solutions for the prevention of musculoskeletal disorders in video display unit (VDU) work (Moon and Sauter, 1996). A limited number of well-designed intervention studies with control groups has been published to evaluate the effectiveness of ergonomic interventions in the office environment (Westgaard and Winkel, 1997). There is some evidence that keyboard and mouse users may experience a reduction in upper limb and neck pain when using certain alternative keyboards or types of mouse compared to the conventional

ones (Punnett and Bergqvist, 1997). A training program in ergonomics, workstation adjustment, and frequent breaks at VDU work have been shown to decrease the prevalence of musculoskeletal disorders and discomfort (Bayeh and Smith, 1999; Brisson et al., 1999; Mekhora and Liston, 2000; Aarås et al., 2001a).

The ergonomics in VDU work is determined by several factors, e.g. layout and dimensions of the workstation as well as anthropometrics and the personal preferences of the worker (Gerr, 2000). The ergonomics can be estimated by using technical measurements of the workstation and of work postures (Aarås et al., 1997; Karlqvist, 1997; Burgess-Limerick et al., 1999). However, technical measurements are often time-consuming and may not be feasible for assessing workstations for the evaluation of an extensive ergonomic intervention. One option is to resort to expert assessment for the evaluation. The trained eye of an expert can quickly merge several variables, e.g. layout factors, the dimensions of the workstation, and characteristics of the work posture, to arrive at an overall ergonomic assessment based on a brief observation (Gerr et al., 2000; Moffet et al., 2002). An expert rating is also possible without any technical equipment. Even though an expert assessment of VDU ergonomics is a commonly used method, not much is known about its repeatability and validity.

The high number of repetitive strain injuries in some occupations reflects the need to identify the risk factors of these disorders. Several methods have been developed for this purpose. The use of checklists allows rapid screening of various physical load factors. Other possibilities are observation at regular intervals, and continuous observation (Keyserling et al., 1993; Fransson-Hall et al., 1995; Karhu et al., 1977). Work cycles reported or presumed to be stressful are usually selected for screening by a checklist, and the ensuing result reveals the presence or absence of the selected physical load factors at predetermined levels. In order to obtain a complete view of e.g. upper limb load in various jobs, all work cycles should be identified and observed.

The objectives of the present study were to investigate risk factors for neck pain among VDU workers, to assess the effects of an ergonomic intervention on the level of musculoskeletal symptoms, and to study the repeatability and validity of an assessment method of VDU ergonomics. Furthermore, a method to assess the risk factors for upper limb disorders was developed and its validity and repeatability were investigated.

2. REVIEW OF THE LITERATURE

2.1. Risk factors for work-related musculoskeletal disorders

Work-related diseases may be caused, aggravated, accelerated, or exacerbated by workplace exposures, and they may impair working capacity. 'Work-related musculoskeletal disorders' are defined as disorders and diseases of the musculoskeletal system, which have been proven or assumed to have at least a partly work-related background (WHO, 1985). These disorders constitute a heterogeneous group, but it is still possible to identify some generic work risk factors, e.g. repetitive or force-demanding tasks, awkward postures, features of workplace design, cognitive demands, as well as organizational arrangements and psychosocial factors (Bernard, 1997; Salvendy, 1997). Several conceptual models have been proposed; they describe relationships between workload factors and musculoskeletal disorders (Winkel and Westgaard, 1992; Armstrong et al., 1993; Panel on Musculoskeletal Disorders and Workplace, 2001). According to the model generated by an expert group on work-related musculoskeletal disorders, the load factors are organized into two broad categories: workplace factors and personal characteristics (Figure 1).

Workplace factors include external physical loads associated with job performance, as well as organizational and social factors. External loading resulting from the work is transmitted through biomechanical forces imposed on the limbs and trunk, and creates internal loading on the body tissues and anatomical structures. Relevant biomechanical factors include body posture, physical exertion, and movements. Biomechanical loading is affected by individual factors such as anthropometry, strength and skills, transmitting external loads to internal loads on anatomical structures. When the load exceeds the mechanical tolerance or the ability of the structure to withstand the load, tissue damage occurs. The resulting pain, discomfort, impairment, and disability arise from the interaction of the workplace factors and the physical and psychological characteristics of the individual. Organizational and social factors at work may affect the external demands of the work and the individual's response to the demands. The impact of the organizational and social factors on the individual is mediated through cognitive and perceptual mechanisms. These mechanisms vary from one individual to another (Panel on musculoskeletal disorders and workplace, 2001).

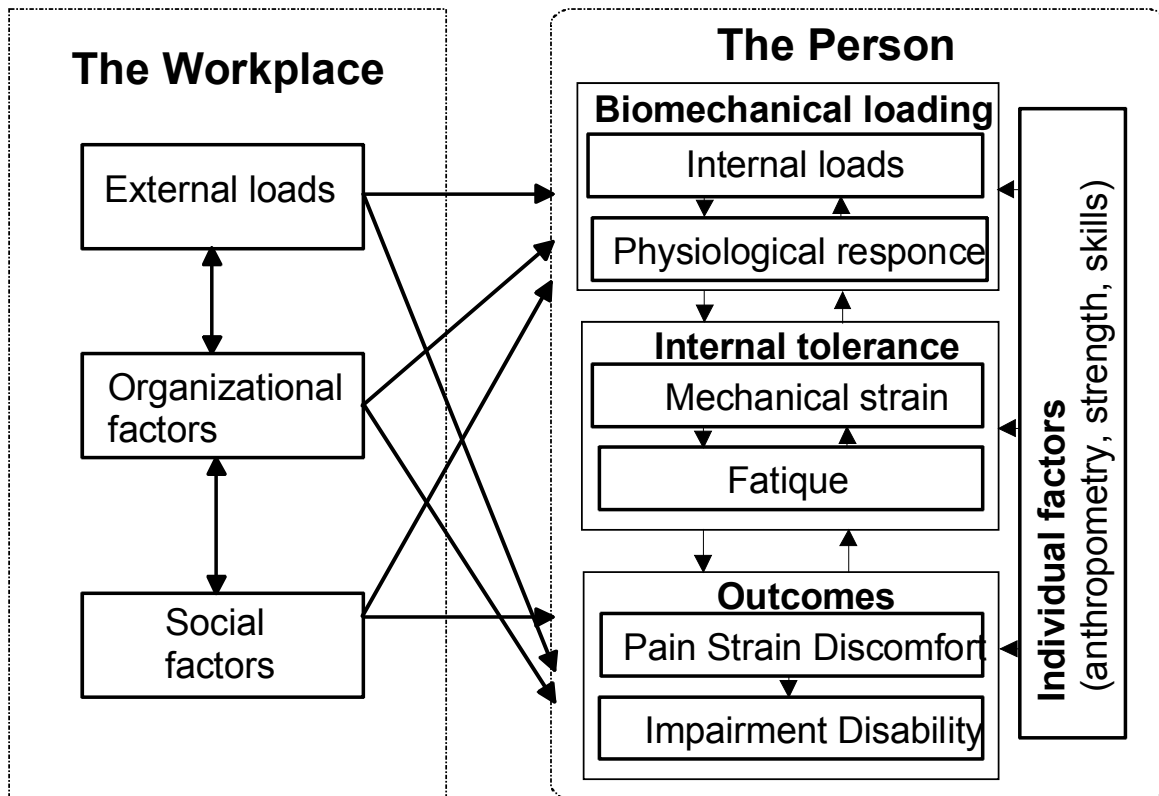


Figure 1. Conceptual model of work-related musculoskeletal disorders (adapted from the review by the Panel on musculoskeletal disorders and workplace, 2001)

In this thesis 'work load' has been used as a general term to describe workplace factors that are independent of the worker (e.g. duration of work tasks, workstation dimensions) and external exposure at work (e.g. determinants of work posture, weights of objects). The expression 'risk factor' is used as a general term for those factors at work, which are associated with an increased risk of musculoskeletal disorders. These risk factors have in most cases been first observed empirically and then confirmed by epidemiological studies.

2.1.1. Neck and shoulder

This literature review focuses separately on the risk factors of neck and shoulder disorders, even though many studies focus on both areas simultaneously. In addition, the dividing line between the neck and shoulder area is ambiguous (Kuorinka et al., 1987; Sluiter et al., 2001).

In Finland the 1-month prevalence of neck pain in persons aged over 30 years was 26% for men and 40% for women in a recent countrywide population study, 'Health 2000' (Aromaa and Koskinen, 2002). The prevalence rates of neck and shoulder pain among the workforce (aged 25-64 years) have been 50% for men and 64% for women (Piirainen et al., 2000). These percentages are based on the self-reports of the persons studied, and are without exception higher than those of clinical

entities in studies with outcomes based both on symptoms and physical examinations (Andersen et al., 2002; Aromaa and Koskinen, 2002).

Neck

Neck disorders are multifactorial. Several work-related factors have an influence on their development. In the NIOSH (National Institute of Occupational Safety and Health in the USA) review (Bernard, 1997), it was concluded that repetitive upper limb motion and repeated neck movements, forceful upper limb movements involving the same muscle groups, static loading of the neck-shoulder muscles, and extreme neck postures at work are related to neck disorders. In their comprehensive review, Ariens et al., (2000) reported a relationship between neck pain and neck flexion, arm force, abducted arm posture, duration of a fixed, sedentary sitting posture, twisting or bending of the trunk, hand-arm vibration, and ergonomic design of the work place. In a later prospective study, Ariens et al., found that sitting at work for more than 95% of the working time is a risk factor for neck pain. They found also a trend for a positive relationship between neck flexion and neck pain (Ariens et al., 2001a). A longitudinal study by Viikari-Juntura et al., (2001) indicated that duration of work with a hand above shoulder level was associated with radiating neck pain.

Besides the physical job characteristics mentioned above, a relationship has been found between neck pain and high job demands (Andersen et al., 2002), low co-worker support and job control, high and low skill discretion, and low job satisfaction (Ariens et al., 2001b). Limited possibilities to influence one's personal work situation, low support from supervisors, and psychosocial distress have also been found to predict neck pain in follow-up studies (Eriksen et al., 1999; Leclerc et al., 1999; Kaergaard and Andersen, 2000).

Of the individual characteristics, age has been shown to predict frequent neck pain (Leclerc et al., 1999; Viikari-Juntura et al., 2001). Of the health behavioral factors, smoking has been found to be a risk factor for neck pain (Kaergaard and Andersen, 2000), whereas evidence of the effects of physical exercise has been inconsistent (Hildebrandt et al., 2000; Miranda et al., 2001a).

In several studies, women have had a higher prevalence of neck disorders (Bernard, 1997; Leclerc et al., 1999). This gender difference may result from the different types of jobs of women and men. On the other hand, even when the job is the same, men and women may perform the work in a different way. This may be due to differences in anthropometry and the ability to generate force (Viikari-Juntura et al., 2001). Moreover, women may cumulate risk factors related to working conditions and household work.

Shoulder

In the studies reviewed by van der Windt et al., (2000), the 12-month prevalence of shoulder pain varied from 6- 40% in different working populations. In the Mini-Finland Survey consisting of 7,217 adults (aged ≥ 30 years), 30% reported having had shoulder pain during the previous month (Mäkelä et al., 1999).

In the review of van der Windt (2000) as well as in a prospective study, it was found that risk factors for shoulder pain were related to heavy physical workload, awkward postures, and long work experience. According to van der Windt et al., and a follow-up study by Cassou et al., (2002) also repetitive movements, the use of vibrating tools, and duration of employment were associated with of shoulder pain. In a case-referent study, a relationship has also been found between shoulder disorders and severe upper arm flexion or abduction (>90 degrees). As the number of work cycles with awkward postures (duration of severe flexion or abduction is 10% or more of the work cycle) increased, also the risk of shoulder disorders increased (Punnett et al., 2000).

Van der Windt et al., (2000) argue that psychosocial factors are important in both the development and persistence of shoulder problems. Job dissatisfaction, high psychosocial demands and a poor social work environment, together with a poor personal capacity to cope with these factors, may increase work-related stress. Stress may cause a higher level of muscle tone and strengthen the relation between physical load and shoulder symptoms.

Most studies have not shown any major gender difference in the prevalence of shoulder pain, although some discrepancy has been reported. In a study among newspaper employees, the risk of shoulder pain was more than twice as high for the women than for the men (Bernard et al., 1994). Other individual factors associated with shoulder pain are age and body mass index (Miranda et al., 2001b).

2.1.2. Elbow, wrist and hand

Pain in the upper limbs is a problem in the industrialized countries (Bernard, 1997; Buckle, 1997; Riihimäki and Heliövaara, 2002). In Finland, the most common occupational disease group (for which compensation is paid by an insurance company) is the repetitive strain injury of the upper limb. A total of 1,488 cases were reported in 2001. The incidence rate was 6.3 cases per 10,000 employed workers. The highest incidence rate was found in the food-processing industry, where 94 cases per 10,000 employed workers were reported (Karjalainen et al., 2002).

Physical risk factors that have been found to have an association with upper limb disorders are high demands of force (Stetson et al., 1993), repetitive movements, non-neutral postures, cold temperature, and hand-arm vibration. Especially combinations of these risk factors have been associated with upper limb disorders (Silverstein et al., 1987b; Punnett, 1998; Muggleton et al., 1999; Viikari-Juntura and Silverstein, 1999; van der Windt et al., 2000). The specific disorder that has been studied the most is the carpal tunnel syndrome. Fewer studies have been carried out on epicondylitis, wrist tendinitis, and hand-arm vibration syndrome.

Carpal tunnel syndrome

A combination of the risk factors (force and repetition, force and posture) has been found in the reviews to be strongly associated with carpal tunnel syndrome. There is also evidence that repetition and force separately are related to the carpal tunnel

syndrome (Bernard, 1997; Viikari-Juntura and Silverstein, 1999; Leclerc et al., 2001). Also vibration has been associated with the carpal tunnel syndrome even though the mechanism by which vibration contributes to the development of the syndrome is not completely understood. Investigating the effect of vibration alone is difficult, since it is usually associated with the use of hand-held vibrating tools, the use of hand force, and non-neutral postures (Hagberg, 2002). It is also possible that a cold environment and local mechanical pressure can increase the risk for the carpal tunnel syndrome. Individual factors such as female gender, obesity, and older age have been found to increase the risk for the syndrome (Viikari-Juntura and Silverstein, 1999).

Epicondylitis

Epicondylitis has been identified as a work-related disease in a number of studies. It has been reported that the highest incidence of epicondylitis occurs in occupations and jobs which are manually intensive and have high work demands (e.g. meat-packing, construction work) (Kurppa et al., 1991; Viikari-Juntura, 1995; Lewis et al., 2002). According to a longitudinal study by Leclerc et al., (2001) there is an evidence of an association between forceful work and epicondylitis. Also work tasks implying a combination of risk factors (force and repetition, force and posture), especially at high exposure levels, increase the risk for epicondylitis (Bernard, 1997). The only individual factor that has been associated with epicondylitis is age (Viikari-Juntura et al., 1991; Leclerc et al., 2001).

Hand/wrist tendinitis

According to the literature review of Bernard et al., (1997) there is an association between hand/wrist tendinitis and repetition, force, and posture (each of the risk factors alone). And when they occur in combination (e.g. highly repetitive and forceful hand/wrist exertion), there is strong evidence of an association with hand/wrist tendinitis. A cross-sectional study by Latko et al., (1999) demonstrates a link between repetitive work and tendinitis (Latko et al., 1999). Of the individual factors, a higher risk of hand-wrist disorders has been found among women and newly employed workers (Häkkinen et al., 2001). The presence of psychosomatic problems has also been shown to be a strong predictor of wrist tendinitis (Leclerc et al., 2001).

Hand-arm vibration syndrome

People in occupations involving a high level of exposure to vibration from tools are liable to the hand-arm vibration syndrome. The reviews of

studies on vibration have shown evidence of a clear association between a high level of exposure to vibration and the hand-arm vibration syndrome (Bernard, 1997; Palmer et al., 2000). In a follow-up study Kihlberg and Hagberg (1997) found that low-frequency impact vibration was transmitted to the elbows and shoulders and had an effect on those areas, whereas high-frequency impact vibration transmitted to the hand and wrist may predominantly cause symptoms there. Furthermore, Sakakibara and Yamada (1995) showed that hand-arm vibration activates the sympathetic nervous system and induces vasoconstriction in the feet even though they are not directly exposed to vibration. However, Hagberg (2002) concluded in his review that even though there is strong evidence that jobs with vibrating machines or tools are associated with musculoskeletal disorders, there is not sufficient evidence that vibration per se would be a risk factor for musculoskeletal disorders.

Reference values for physical load factors as risk factors for neck/shoulder, and elbow/wrist/hand disorders based on recent reviews and some original studies are presented in Table 1.

Local mechanical pressure

Whenever there is contact between the body and external objects, mechanical stress on tissues should be considered. Local stress can cause injury to both the skin and underlying structures, most commonly nerves, bursae and blood vessels. Common areas that should be considered include the hand, palm, wrist, elbow and armpit (Kuorinka and Forcier, 1992).

Psychosocial risk factors

In addition to physical risk factors at work, also psychosocial risk factors have been shown to be determinants of upper limb disorders. A cross-sectional study by Devereux et al., (2002) showed that workers highly exposed to both physical and psychosocial risk factors in their work were more likely to report upper limb symptoms than workers highly exposed to only one or the other. According to the literature review by Bongers et al., (2002) high job demands and low job control, low decision latitude, and low social support have been shown to be related to upper limb disorders.

2.1.3. Low back

The 1-month prevalence of low-back pain was about 36% among the women and 30% among the men (persons aged ≥ 30 years) in the Health 2000 study (Aromaa and Koskinen, 2002). Prevalence rates among the working population (aged 25-64 years)

Table 1. Reference values for physical load factors as risk factors for neck/shoulder, and elbow/wrist/hand disorders based on recent reviews and some original studies

	Neck/Shoulder	Elbow/Wrist/ Hand
Repetition / recovery	<ul style="list-style-type: none"> • Repetitive upper extremity motions (Bernard, 1997) • Repetitive neck movements (Bernard, 1997) (Ariens et al., 2000) • Repetitive work under time constraints (Cassou et al., 2002) • >15 shoulder movements·min⁻¹ (Andersen et al., 2002) • Increased levels of muscle activity with few periods of low activity (micro-pauses) during repetitive movements (van der Windt et al., 2000) • Lack of recovery time during ≥ 80% of working time (Andersen et al., 2002) 	<ul style="list-style-type: none"> • Cycle time <30s or ≥50% of cycle time repeating the same sub-cycle (Silverstein et al., 1986) • Cycle time <1min (high risk) or 10s (highest risk) (Leclerc et al., 2001) • Overall level of hand activity above 6.6 rated with 1-10 visual-analog scales (Latko et al., 1999) • High repetition (Bernard, 1997) • Manually intensive work (Kurppa et al., 1991)
Force	<ul style="list-style-type: none"> • Forceful arm and hand movements with same muscle groups (Bernard, 1997) • Used force ≥10% of MVC (Andersen et al., 2002) • Heavy physical work load (van der Windt et al., 2000) • Used arm force (Ariens et al., 2000) • Static loading of neck-shoulder muscles (Bernard, 1997) 	<ul style="list-style-type: none"> • Gripping force >4kg (Silverstein et al., 1986) • Lifting>16kg·h⁻¹ or 6-15kg>1 time·h⁻¹ for 50% of working time (Devereux et al., 2002) • Forceful repetitive work (Viikari-Juntura and Silverstein, 1999)
Posture	<ul style="list-style-type: none"> • Sitting at work >95% of working time (Ariens et al., 2001a) • Neck flexion >20° >70% of working time (Ariens et al., 2001a) • Neck flexion >45° >10 % of working time (Ariens et al., 2001a) • Neck flexion >20° ≥ 66% of work cycle time (Andersen et al., 2002) • Rotated neck >1 h·day⁻¹, arm above shoulder level >1 h·day⁻¹ (Miranda et al., 2001b) • Arm flexion/abduction >90° >10% of work cycle (Punnett et al., 2000) • Awkward and static postures (van der Windt et al., 2000) • Extreme neck postures (Bernard, 1997) • Duration of work with a hand above shoulder level (Viikari-Juntura et al., 2001) 	<ul style="list-style-type: none"> • Posture combinations, no clear limits (Bernard, 1997) • Use of pinch grip, extreme wrist posture >1/3 of working time (Stetson et al., 1993) • Extreme forearm, wrist and finger postures (Viikari-Juntura and Silverstein, 1999)
Vibration	<ul style="list-style-type: none"> • Hand-arm vibration (van der Windt et al., 2000) • Low-frequency vibration when using a hand-held power tool (Kihlberg and Hagberg, 1997) • Hand-arm vibration (Ariens et al., 2001a) 	<ul style="list-style-type: none"> • High-frequency vibration when using a hand-held power tool (Kihlberg and Hagberg, 1997) • Hand-arm vibration (Viikari-Juntura and Silverstein, 1999)

have been nearly identical: 34% for women and 32% for men (Piirainen et al., 2000).

There is strong evidence that work-related risk factors, namely lifting, whole body vibration, heavy physical work, and bending or twisting the back are associated with an increased risk for low-back pain. Psychosocial factors and mental stress are related to low-back pain and affect the reporting of back injuries. The evidence for individual factors such as height, weight, smoking, physical fitness, trunk muscle performance, and mobility is less consistent (McDonald, 2000) with regard to non-specific low-back pain. However, there is strong evidence for an association between height and sciatic pain (Heliövaara, 1987).

2.1.4. Video display unit (VDU) work as a risk factor for musculoskeletal disorders

The most visible feature of changing work has been the enormous increase of computerized work in the industrialized countries. Despite the low level of physical load, a great number of computer users have musculoskeletal problems, especially in the neck, shoulders, wrists, and hands. Punnett and Bergqvist (1997) reviewed 56 epidemiological studies published on VDU work before 1997. Most of these studies were cross-sectional, but several trends were detected between features of computer work and musculoskeletal problems (Punnett and Bergqvist, 1997).

Time spent in VDU work

In VDU work, visual information is presented on a screen, and the information is handled by manual input devices like the keyboard and mouse. All the equipment is stable in the same position on the table, and the worker is therefore required to keep the same static posture while working. Concentrating on the work may prevent the worker from becoming aware of early signals of fatigue (Aarås et al., 2000). Insufficient recovery after local muscle fatigue is believed to be essential in the genesis of muscular pain in static work (Sjøgaard et al., 2000). The time spent with computers has been shown to be associated with discomfort especially in the neck-shoulder area (Karlqvist et al., 1996; Tittiranonda et al., 1999a; Blatter and Bongers, 2001; Fredriksson et al., 2002). In a prospective study Gerr et al., (2002) showed that for over 50% of the study participants who used computers for over 15 hours per week reported musculoskeletal symptoms in their first year in a new job. Jensen et al., (1998; 2002) found that workers, who used a computer almost all the time at work, reported more repetitive movements than those who used it less. Jensen hypothesized that the repeated hand movements when using the

keyboard and mouse could explain the association between the symptoms and time spent in computer work.

Screen

In VDU work, the muscular activity of the neck and shoulders resists the gravity acting on the forward flexed head while the worker views the screen. The bones and joints of the upper limb have to be stabilized by the muscles to enable exact movements of the fingers and hands. If there is no mechanical support for the forearm, the shoulder muscles must hold the weight of the whole upper limb, and this further increases muscle tension (Takala, 2002). Muscle tension increases even more if the worker performs the task in a non-neutral posture. It has been shown that computer use in sustained non-neutral neck or shoulder postures, such as rotated neck or the abducted shoulder is a risk factor for neck pain (Karlqvist et al., 1998; Tittiranonda et al., 1999a). It has also been shown that visual discomfort and musculoskeletal strain, particularly in the neck and shoulders, are associated with computer screen height (Bergqvist et al., 1995a; Villanueva et al., 1997; Burgess-Limerick et al., 1999; Psihogios et al., 2001). Computer ergonomics researchers have disputed on how the computer screen should be placed in relation to the worker's eyes. A higher monitor placement has been associated with strenuous neck extension caused by visual demands (Burgess-Limerick et al., 1999). On the other hand, an extreme low location is often associated with musculoskeletal stress caused by neck flexion (Turville et al., 1998; Fries Svensson and Svensson, 2001). However, the benefit of a lower placement is reduced eye irritation, as the open surface of the eyes is smaller and lacrymation is better (Sotoyama et al., 1996). Finally, the results of a field study support the midlevel (~20° viewing angle) placement of the screen (Psihogios et al., 2001).

Mouse and keyboard

Arm or hand disorders in VDU work have been reported to be less frequent than neck or shoulder disorders (Gerr et al., 2002). VDU operators have nevertheless been shown to have two to nine times higher rates of hand/wrist disorders than would have been expected if they had done industrial work with low physical exposure (Punnett and Bergqvist, 1997).

In most cases, VDU work includes the use of both a mouse and a keyboard. Although the use of the mouse has increased significantly during the past decade, knowledge of the impact of mouse use on the musculoskeletal system is limited. Some studies

indicate increased musculoskeletal symptoms in relation to the duration of mouse use (Fogleman and Brogmus, 1995). Contrary findings regarding the effects of the duration of mouse use on symptoms have also been described, but these results have been challenged (Cook et al., 2000).

A typical VDU work posture described during mouse use is that the mouse is kept away from the midline of the body, the arm is unsupported, and the shoulder abducted and outward rotated (Karlqvist et al., 1996; Aarås et al., 1997). Mouse users have also been reported to adopt working postures in which the wrist is extended and in ulnar deviation (Aarås and Ro, 1997). These non-neutral postures have earlier been shown to be harmful, for example in industrial work, and they are presumed to be risk factors also in VDU work (Malchaire et al., 1996). There is still a lack of prospective studies on mouse use and upper extremity disorders.

In a cross-sectional study Cook et al., (2000) found a relationship between arm abduction in mouse use and neck symptoms. Among CAD workers, the higher prevalence of shoulder, elbow, wrist and hand pain has been found in the hand operating the mouse compared to the contralateral side (Jensen et al., 1998). The authors suggested that this result was probably due to mouse use per se, even though a causal relationship can not be verified with a cross-sectional study design. However, working with the hands and forearms supported and in a nearly neutral position, when using a mouse, decreased neck, shoulder, and arm pain (Aarås et al., 1997; Lintula et al., 2001; Marcus et al., 2002).

The use of input devices influences the activation of the arm and hand muscles. A computer mouse and a keyboard demand different hand-eye coordination. For a trained typist, keyboard use requires no hand-eye coordination and, therefore, may result in a highly automated process. The use of a computer mouse, in contrast, requires positioning of the mouse, and controlling the relation between the mouse and the cursor on the screen. The computer mouse use, therefore, requires extensive hand-eye coordination and may thus be more difficult to automate (Ferrel et al., 2001). Increased muscular activity has been found in the neck during the use of the mouse compared with the use of the keyboard (Laursen et al., 2002). Laursen et al., demonstrated also that mental stress factors increased the activity of the neck muscles more during the use of the mouse than during the use of the keyboard.

It has been shown that fast repetitive finger movements in VDU work activate co-contraction in the neck and upper limb muscles. There is also lack

of variation in the activation of muscle motor units in the work tasks with finger clicks (Kitahara et al., 2000). It has therefore, been suggested that the worker should limit repetitive movements in VDU work, especially when using a mouse. In order to decrease repetitive movements with the mouse hand, workers are commonly guided to switch the mouse to the other hand. Unfortunately, this might not help because contralateral activity may occur in the muscles (Birch et al., 2000). Workers with disorders in their mouse hand should use the keyboard more. To get more variation in muscle activation, a selection of input devices (e.g. including possibilities for non-hand input alternatives) should also be available (Aarås and Ro, 1997).

Keyboard operation inherently requires repetitive hand motion in order to depress the keys. It has been shown that keying requires ulnar deviation and extension of the wrist and forearm pronation. Use of the keyboard can also increase intracarpal pressure, if the wrist deviates sufficiently from a neutral position (Punnett and Bergqvist, 1997). Several commercially available alternative keyboard designs have been tested with mixed results. It has been found that the split-keyboard, open keyboard and alternative geometric keyboard have a minimal impact on comfort, self-reported fatigue and productivity (Swanson et al., 1997; Tittiranonda et al., 1999b; Zecevic et al., 2000; Simoneau and Marklin, 2001). Hedge et al. (1999) have examined the effects of a downward-tilting keyboard tray on wrist posture, seated posture, and self-assessed musculoskeletal discomfort. They found significant improvements in wrist posture, seated posture, and upper body discomfort among persons using the downward-tilting keyboard compared to the conventional keyboard.

The location of the keyboard on the table might be even more important with regard to work posture than the keyboard model. Marcus et al., (2002) found that a seated posture with the keyboard low and some distance away from the worker is associated with a lower risk of neck-shoulder and upper limb symptoms than a posture with the keyboard at or above elbow height and close to the worker. Summary of physical risk factors for neck/shoulder and elbow/wrist/hand symptoms in VDU work is shown in Table 2.

Psychosocial load factors

Organizational factors of the work, such as increased work pressure, high work speed, and lack of job security or decision-making opportunities, as well as low possibilities for development at work, may contribute to an increased occurrence of work-

Table 2. Summary of physical risk factors for neck/shoulder and elbow/wrist/hand symptoms in VDU work

	Neck/shoulder	Elbow/wrist/hand
VDU work time in general, repetition	<ul style="list-style-type: none"> • Continuous VDU working time (Fredriksson et al., 2002) • VDU work time >15 h·week⁻¹ in workers during first year at a new job (Gerr et al., 2002) • Computer use almost all the time at work (Jensen et al., 2002) • Repeated movements without notable postural variation (Jensen et al., 1998) • Repeated movements (same finger, hand or arm movements many times·min⁻¹ at least 75% of working time) (Jensen et al., 1998) 	<ul style="list-style-type: none"> • Duration of employment in the same job using VDU (Jensen et al., 2002) • Repeated movements (same finger, hand or arm movements many times·min⁻¹ at least 75% of working time) (Jensen et al., 1998) • Computer use almost all the time at work (Jensen et al., 2002) • Computer use >20 h·week⁻¹ and limited rest break opportunity (Bergqvist et al., 1995a)
Mouse work demands	<ul style="list-style-type: none"> • Mouse use per se (Jensen et al., 1998) • Increased muscular activity in neck extensor muscles when using mouse in comparison with use of keyboard (Laursen et al., 2002) • Arm abduction when using mouse (Cook et al., 2000) • Non-neutral position of arm (Aarås et al., 2001a) • 'Non-optimally located' mouse (Karlqvist et al., 1996) 	<ul style="list-style-type: none"> • At least 5.6 hours of mouse use / week (Karlqvist et al., 1996) • Repeated movements when operating the mouse (arm >2.5/min, elbow >10/min, wrist > 10/min) (Jensen et al., 1998) • Static posture when operating the mouse (wrist ulnarly deviated and extended) (Jensen et al., 1998) • Mouse use time (Fogleman and Brogmus, 1995) • Non-neutral position of arm (Aarås et al., 2001a) • 'Non-optimally located' mouse (Karlqvist et al., 1996)
Keyboard work demands	<ul style="list-style-type: none"> • Conventional keyboard design (geometric design reduced symptoms) (Tittiranonda et al., 1999c) • Keyboard above elbow level (Bergqvist et al., 1995a) <ul style="list-style-type: none"> • Elbow height lower than 'J' key height, wrist extension (Marcus et al., 2002) 	<ul style="list-style-type: none"> • Conventional keyboard design (geometric design reduced symptoms) (Tittiranonda et al., 1999c)
Screen	<ul style="list-style-type: none"> • Disturbing reflections on the computer screen (Jensen et al., 2002) • Computer screen height (< 20° viewing angle) (Psihogios et al., 2001) 	<ul style="list-style-type: none"> • Disturbing reflections on the computer screen (Jensen et al., 2002)
Sitting posture	<ul style="list-style-type: none"> • Sitting at work >95% of time, neck flexion >20°>70% of time, neck flexion >45° >10 % of time (Ariens et al., 2001a) 	
Workplace design	<ul style="list-style-type: none"> • Telephone shoulder rest (Marcus et al., 2002) 	<ul style="list-style-type: none"> • No support for forearm (Bergqvist et al., 1995a) (Lintula et al., 2001)

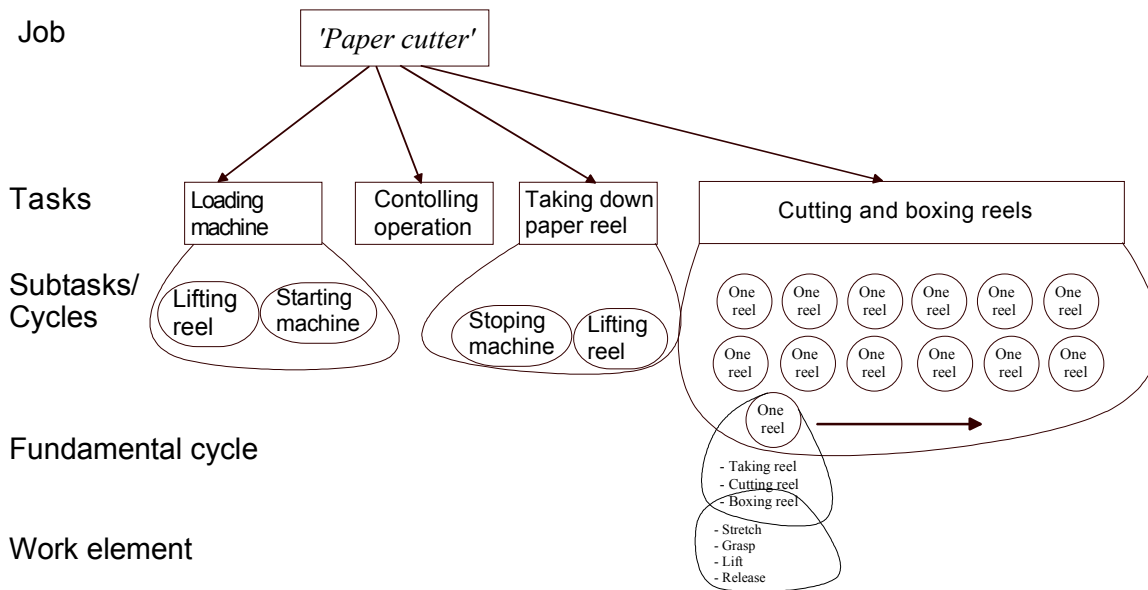


Figure 2. Example of job with work tasks, subtasks, work cycles, fundamental cycles, and work elements in a paper cutter's work (concepts adapted from Kilbom, 1994c).

related musculoskeletal complaints in VDU work (Tittiranonda et al., 1999a; Seppälä, 2001).

2.2. Assessment of physical work load

Selection of job sample for assessment

In order to obtain a complete view of the work load in various jobs, all work tasks, subtasks and cycles should be identified (Figure 2). It is important for the prevention of musculoskeletal disorders, that repetitive work is defined and quantified. However, also force and posture need to be assessed. Moreover, the engaged body parts and the duration of exposure should be specified (Kilbom, 1994c). A common feature of the different types of assessment methods is that their use is straightforward in repetitive or monotonous jobs in which a limited number of short cycles are repeated throughout the workday. In such cases an assessment can easily be done using a random sample of the work cycles. Many industrial jobs belong to this category.

If a job is highly variable and consists of tasks and subtasks, cycles and fundamental cycles with a wide variation of contents, frequency, and duration (e.g. job of paper cutter in Figure 2), random sampling is often not a feasible method. In such work, work load assessment could be done for each separate task and the mean and cumulative load can be calculated when the frequency and duration of the different tasks are known (Winkel and Mathiassen, 1994). However, sometimes assessment of peak loads is also relevant.

2.2.1 Work load assessment methods

General approaches to estimate physical work load factors include the use of job titles, workers' self-reports, checklists, interviews and observations by trained persons, and direct measurements by some form of instrumentation. The optimal choice of method depends on the level of specificity and accuracy required by the study, features of the method, and the load factors of the jobs under study (Panel on musculoskeletal disorders and workplace, 2001).

Job title

The job titles which have been used to describe work load in many studies give only vague or inaccurate estimations of exposure (Winkel and Mathiassen, 1994). They may indicate homogenous exposure for some parameters, such as repetitiveness and force demands, while other parameters, such as posture, may vary widely among workers in the same job (Silverstein et al., 1987a). In addition, individual variation in exposure can be wide with the same person at the same job at various time points (Balogh et al., 1999). Using job titles as an exposure indicator involves a risk of error, and should not be used in studies where accurate exposure levels are needed.

Self-reports of workers

The self-reports of workers are useful alternatives for evaluating physical loads. Either with spontaneous self-reports or by completing questionnaires, diaries or checklists, workers may

report the work load factors in their job or work environment. Self-reports permit assessment of exposures in the past and present, and may be structured with task-specific questions or organized to cover the job as a whole. Self-reported data can take various forms; they may include duration, frequency, and intensity of exposure (Panel on musculoskeletal disorders and workplace, 2001). In some studies, self-reports have been well in accordance with the results of observations or direct measurements of the corresponding exposures (Torgén et al., 1999). However, subjective assessments are prone to be influenced by other factors than the task or workplace investigated. The validity and repeatability of self-reported exposure may be too low in relation to the needs of epidemiological studies and ergonomic interventions (Wiktorin et al., 1993; Hansson and Westerholm, 2001).

Checklists and qualitative approaches by an expert

A trained observer can use checklists or qualitative approaches and make notes about work load based on direct or video-assisted observation. The documentation and description can be done simply in terms of predetermined activities by a catalogue of action, or by recording the postures of the upper limbs or back. With the aid of checklists, a categorical decision can be made for each factor (i.e. presence or absence of a load factor). A large number of checklists and qualitative approaches have been developed in the past decades (Stetson et al., 1991; Kilbom, 1994a; Panel on Musculoskeletal Disorders and Workplace, 2001). These tools allow the rapid screening of various exposure factors. Work cycles reported by the worker or presumed to be stressful by the experts are usually selected for screening with a checklist. Checklists and qualitative approaches are not likely to provide sufficiently detailed information for an effective risk assessment of the musculoskeletal disorders.

Systematic observation methods for measuring work load

Numerous observation methods have been described in the literature, ranging from a work place walk-through to highly detailed methods (Corlett et al., 1979; Armstrong et al., 1982). The technology used in observation methods ranges from paper and pen to complicated computerized methods (Li and Buckle, 1999). Observation can be done either directly on the work site, or afterwards from the video, or video recordings can be used to assist the observation. The most common observation techniques used to characterize repetition, posture and force level are based on either time study

(continuous observation) or work sampling (observation at regular intervals) (Fransson-Hall et al., 1995; Fransson-Hall et al., 1996; Karhu, 1977). Both of these techniques require a trained observer to characterize the ergonomic factors, and they are very time-intensive and time-consuming.

Overall evaluation of work posture and ergonomics

Many of the existing methods for assessing work load factors are used for research purposes. The methods are often so complicated that only researchers or well-trained analysts are able to use them. The practitioners, on the other hand, need a tool that is fast and easy to use. The tool should be user-friendly and flexible to accommodate the numerous and complex tasks that the practitioners may encounter. It is also known that practitioners prefer to use descriptive words or single numbers to describe the load rather than define e.g. specific angles in the body or upper limb posture (Li and Buckle, 1999). An exposure assessment method meant to be used by the practitioners should be able to tell whether an ergonomic intervention is necessary for the job. The assessment method should also function as an evaluation tool for an implemented intervention. The future exposure assessment methods will need to combine both the experts' views and the practitioners' needs in order to enable the development of a method that is both practical and valid for its purpose.

Direct measurements

Work tasks vary considerably by technology, type of physical load and loaded body parts, and the distribution and duration of the loading (Winkel and Mathiassen, 1994). When one compares methods, the most accurate data on physical exposure (load level, repetition, and load duration) are gained from direct measurements (e.g. electromyography, goniometres, and biomechanical measurements). The costs of applying these exact methods are high, and the methods are often limited to specific body parts, and only a small number of persons can be measured. In order to limit the costs and to obtain a complete view of the physical loading, a combined exposure data from questionnaires, interviews, expert assessment, and observation methods may be required (Juul-Kristensen et al., 2001).

2.2.2. Assessment of upper extremity work load

In 1994 Kilbom published a guideline, based on a literature review, to provide assistance in the primary and secondary prevention of upper extremity disorders associated with repetitive work (Kilbom, 1994b; 1994c). Since their publication, the guideline and the scientific background for the

articles have been frequently cited. The risk assessment models presented by Kilbom have influenced numerous other guidelines. A quantification of repetitiveness has been generally used as a first step in a risk assessment approach. The definition for repetitiveness used by Silverstein et al., (1986) has been incorporated in the guideline. According to it, work can be considered to be repetitive when the cycle time is less than 30 seconds, or more than 50% of the cycle time (regardless of cycle duration) is involved performing the same type of fundamental cycles. For guiding practitioners Kilbom proposed more detailed definitions for the assessment of repetition in the shoulder, elbow, wrist, and finger areas. She defined the risk of a disorder to be high if the frequency of repetitive movements or contraction for the shoulder is more than 2.5, for the upper arm or elbow more than 10, for the forearm or wrist more than 10, and for the fingers more than 200 per minute. The presence of other risk factors (high external force, high speed of motion, high static load, extreme posture, lack of training, high work demands) increases 'high risk' for any category to 'very high risk'. If a repetitive work task has been identified, or an upper limb disorder has been diagnosed, the task should be analyzed with regard to its total duration, e.g. per day or week. According to this guideline a potential problem arises if the task assessed as repetitive is performed for more than 60 minutes during the workday (Kilbom, 1994b).

The scientific basis for this latter value of task duration (60 min) per day and the reference values for repetitive motions for the various joints of the upper limb is, however, relatively weak. Yet the guideline has proved to be useful to practitioners (Kukkonen et al., 2001).

Assessment methods

The semi-quantitative 'Upper extremity checklist' of Keyserling et al., (1993) was developed as a shop-floor screening tool to determine the presence of risk factors associated with upper limb disorders. The risk factors to be evaluated are repetitiveness, local mechanical contact pressure, forceful manual exertions, awkward postures, and use of hand tools. Local mechanical contact pressure and forceful manual exertions are classified with a dichotomous scale. The assessment of repetitiveness, awkward postures, and use of hand tools is time-based. The observation is ended with a calculation of the total risk score. In the evaluation of the checklist, the classification of shop-floor representatives and experts in ergonomics was compared. There were several disagreements between the results of the

shop-floor representatives and those of the experts (used as a golden standard). There was a lack of consistency between the observation of repetitiveness, pinch grip, and awkward postures (Keyserling et al., 1993). The validity study as a whole presented some problems: the interval between the observations of the shop-floor representatives and the experts in ergonomics was several months and the two observer groups used partly different checklists. However, the checklist by Keyserling includes all common risk factors for upper limb disorders, and the description and classification of the factors is feasible and distinct.

The handPEO method (Portable Ergonomic Observation method) is a further development of the PEO method (Fransson-Hall et al., 1995; Fransson-Hall et al., 1996). The basic PEO method is a computerized observation method which quantifies lifting, carrying, pushing and pulling tasks and the duration, frequency, and holding time for work postures of the upper limbs, back and neck. In the hand PEO method, the work analysis begins with detailed interview of the worker about the work tasks. After the interview the work is recorded on video. In the analysis, the work operations (use of hand tools, power tools, using the hand as a hitting tool, using the hand for support, for manual handling, manual assembly) and the hand gripping (finger grip, whole hand grip) are registered continuously. The duration of each separate work operation or hand grip, the sum of all holding times during the registration period are computed. The HandPEO has proven to be a very sensitive measure and its inter-observer repeatability has been considered acceptable (Fransson-Hall et al., 1996). The number of simultaneously observed parameters is fewer in the handPEO than in the basic PEO method. For a hand-intensive job, performed at a high rate and with a large variety of work operations, it may still be impossible to obtain an exact result. The handPEO appears to be a more suitable and precise tool for hand-intensive jobs than the basic PEO method, but in practice it is a demanding and cumbersome method for the observer.

The RULA (Rapid Upper Limb Assessment) method (McAtamney and Corlett, 1993) is designed for the assessment of trunk and upper limb load and is meant particularly for sedentary jobs (Hedge et al., 1999). The range of movements for each upper body part (head, trunk, upper and lower arm, wrist) is divided into sections that are categorized. In addition to posture recordings, the RULA also considers the load on the musculoskeletal system caused by static or repetitive muscle work and force

exertion, so that an action list can be produced. The validity of the RULA method has not been reported. In addition, its sensitivity and predictive value for quantifying the actual risk of musculoskeletal injuries has not yet been assessed. Because the RULA method has been planned for static sedentary jobs, its use for dynamic industrial jobs is limited.

The OCRA method is designed to analyze repetitive upper limb movements and the physical risk factors for upper limb work-related disorders. Every work task involving repetitive movements is analyzed for each worker or a group of workers. In the first stage, the work arrangements are described and measured (distribution of work and pauses, duration of repetitive tasks, sequences of technical actions). In the second stage, every selected task is analyzed for repetitiveness, force, awkward postures and movements, recovery time, and additional hazards. In the third stage, all data gathered are combined and the OCRA index is calculated. From the calculated OCRA value the risk is assessed as acceptable, conditionally acceptable and not acceptable. The validity of the OCRA method has been poorly reported. In addition, the OCRA method is not very easy to learn or apply due to the numerous factors to be assessed and calculated (Colombini, 1998; Occhipinti, 1998).

A research program called 'Project on Research and Intervention in Monotonous Work' (PRIM) was initiated in Denmark in 1994 as a prospective cohort study on work-related musculoskeletal disorders. A group-based, task-related exposure assessment strategy was created. Monotonous, repetitive jobs with an estimated similarity in physical exposure were aggregated and 103 exposure groups were formed. The subjects from the exposure groups were randomly sampled for exposure, and task-related exposure levels were quantified by 43 single exposure items using a real-time, video-based observation method that allowed computerized estimates of repetitiveness, body postures, force, and velocity. In combination with the questionnaire-based data on task distribution, the duration of exposure was calculated at the individual level.

Some methodological problems came up in the use of this grouped exposure assessment. Despite efforts to optimize group homogeneity, the within-group variance was greater than the between-group variance for several variables of shoulder posture (Fallentin et al., 2001; Andersen et al., 2002). A task-based exposure-assessment strategy was used successfully to solve some of the main problems associated with the assessment of physical exposure at work. The great within-group variance in

exposure may eventually require individual assessment of exposure.

Several comprehensive methods for assessing upper limb work load have been established in different studies. The large number of the observation methods using different criteria for upper extremity repetitiveness, force and posture is a major problem making it difficult to compare the respective data (Juul-Kristensen et al., 1997). In addition, most of the methods are time-consuming and not feasible to be used by the occupational health staff in the field. Several methods are also suited only for jobs in which a limited number of short cycles are repeated throughout the workday. There is a need for methods that can be applied to a wide range of jobs, from highly repetitive to more varied ones with a longer cycle duration.

2.2.3. Assessment of VDU work ergonomics

The EU Council Directive 90/270/EEC of 29 May 1990 defines the minimum safety and health requirements for work with display screen equipment. Since then several guidelines have been published to apply the principles of this directive at workplaces. Plenty of practical advice is published in the Internet as well.

Methods based on the EU Council Directive

A Finnish ergonomic checklist for VDU work, 'Ergonomic Improvements to the Computer Workstation', has been designed to be used by computer users themselves or by experts in ergonomics. The checklist emphasizes three items: the layout and environmental conditions of the work room, adjustments of the workstation, and breaks during work. All questions are dichotomous, requesting a 'yes' or 'no' answer. After 'no' answers the worker is advised to define the problem further and to think what to do. At the end of the checklist there are questions on working time, visual environment, and use of spectacles. The method applies a participatory approach and its aim is to activate the worker to identify the ergonomic problems with the workstation and to solve them. An English version of the checklist is available from <http://www.occuphealth.fi/ergonomia/2003>.

The method for the assessment of ergonomics in VDU work ('Näppära') is a rapid screening tool for identifying problems for further assessment and corrective actions. The questions and observations are dichotomous, requesting compliance or non-compliance. The items labeled as non-compliance are subject to further actions. One output of the assessment is an index indicating the percentage of compliance items out of all items. This index can be

used as a 'benchmark' of the level of ergonomics in each office. The advantage of this method is that it is rapid and simple to use, and the findings indicate clearly the points for intervention. The method has been developed in co-operation with researchers, occupational health practitioners, safety inspectors, and office workers (Rasa and Ketola, 2002).

The development of the two methods mentioned above started with the research and consultation activities of the Finnish Institute of Occupational Health. The basis for these methods is the Council Directive 90/270/EEC.

Other methods

In Germany a project called SANUS has produced a handbook on the safety aspects of computer work based on international norms and standards (Burmester, 1997). It contains several checklists for the assessment of physical and psychological hazards in office work. Standards and legislative obligations have been included. The presentation and language are rather technical, and the users therefore need substantial training in using the method. This may reduce the practical usability of this system for the prevention of problems in office work.

A Swedish researcher group (Hansson et al., 2001) has developed an ergonomics checklist for use as a part of the exposure assessment in an epidemiological study of VDU users. The objective of the checklist is to facilitate structured assessment of the background factors at the workplace, workstation design, working techniques, and work postures. The protocol for the first three parts of the list is filled in during the observation at the workplace, while the work postures are recorded on video and subsequently analyzed in the laboratory. The items regarding workstation design, working techniques, and work postures are classified into predefined categories. The items are later aggregated into various 'non-optimal' conditions according to known risk factors and the opinion of the researcher group regarding 'harmful' conditions. In the main study, data on 853 persons have been collected and the preliminary results have been reported in Swedish (Hansson et al., 2001). The analyzing and reporting of the study is still going on.

The OSHA in the USA serves as a checklist on the Internet (<http://www.osha.gov>) to be used by employers and employees to identify, analyze, and control hazards predisposing to musculoskeletal disorders at a computer workstation. A printed version is also available. The checklist consists of 33 dichotomous questions. A 'no' answer indicates that there are problems to be solved. The afore-

mentioned Finnish checklist includes the same risk factors as the OSHA checklist. The OSHA checklist does not actively suggest searching for possible solutions.

2.2.4. Repeatability and validity of the assessment methods

The quality of an assessment or observation method in measuring physical exposure depends on the repeatability and validity of the method. An observation method is repeatable if the results are coherent when the observations are duplicated. Intra-observer repeatability means the number of identical results obtained in repeated observations of the same work situation by the same observer at different points of time. Inter-observer repeatability means the extent to which two or more observers give identical results when observing the same work situation. Several factors influence the repeatability of an observation method: the basis for observation (real work situation - video document), potential learning effect of the observers, and the statistical method used to verify similarities between the observations (Kilbom, 1994a; Ovreteit, 1998).

The repeatability of a method is a necessary condition for producing valid data, but it is not a sufficient condition. Validity is the extent to which a measure or piece of data reflects what it is supposed to measure or give information about. In the literature, usually four classes of validity have been mentioned: face validity, criterion validity, content validity, and construct validity (Ovreteit, 1998).

Face validity means that the data gathering method appears to measure what it claims to measure. A simple test of face validity is to review the literature or to ask someone knowledgeable about the phenomenon, if the person thinks that the measure represents the phenomenon. For example, the definition for repetitive work (work is defined to be repetitive when the cycle time is less than 30 seconds or more than 50% of the cycle time involves performing the same type of fundamental cycles) is collectively accepted and has been used by researchers in ergonomics for the past two decades (Silverstein et al., 1986; Keyserling et al., 1993; Kilbom, 1994c).

Criterion validity means the degree of agreement between observations and other, more accurate measurements or data gathering methods, or the measure produces data which correlates with the data from another method which is accepted as a valid measure of the phenomenon studied (Kilbom, 1994b; Ovreteit, 1998). The criterion validity for posture observation has been estimated e.g. with reference to measurements with opto-electronic

systems, inclinometers and goniometers (Keyserling, 1986a; Keyserling, 1986b; Keyserling et al., 1991; Fransson-Hall et al., 1995; Leskinen et al., 1997; Juul-Kristensen et al., 2001). In general, criterion validity depends on the actual work posture in relation to the class limit, the viewing angle of the observer, the size of the posture class categories, the number of observation variables, the duration of observation, and the experience of the observer (Fallentin et al., 2001; Juul-Kristensen et al., 2001).

Content validity means that the measure comprehensively covers all the aspects it is intended to measure (e.g. the quality of workstation measure covers all aspects of the quality of a workstation). The content validity of a phenomenon being measured is often linked to a conceptual model of the factor. In the PRIM study (Fallentin et al., 2001), several variables were used to quantify the complicated phenomenon of repetitiveness. One was the number of movements per minute for different joints based on guidelines suggesting threshold limits for an acceptable number of movements (Genaidy et al., 1993; Kilbom, 1994b). Two other items were duration of exertion (total cycle time) and number of exertions (fundamental cycles) per minute.

Construct validity refers to the extent to which the measurement corresponds to theoretical constructs concerning the phenomenon under study. The phenomenon can be expressed as a hypothetical construct or 'mini theory'. The assessment of construct validity is mainly assessment of the coherence and logic of the construct, with respect to all relevant information about the phenomenon.

Good validity is a basic prerequisite for the selection of a method from several alternative methods. Validity has been tested for few observation methods only.

2.3. Ergonomic interventions in VDU work

2.3.1. Intervention studies in VDU work

Evidence from the literature suggests that a number of important risk factors, both physical and psychosocial, are associated with the development of musculoskeletal disorders in VDU work. A wide variety of workplace ergonomic interventions has been implemented in many different settings to reduce these disorders (Table 3). During the past decade the study frame of randomized controlled trials (RCT) has been recommended in intervention studies. However, few well-designed RCTs or controlled interventions have been carried out in the office environment (Punnett and Bergqvist, 1997).

This review of interventions in VDU work includes recently published randomized controlled

trials. In addition, some articles on the placement and design of the mouse, keyboard and screen have been reviewed. A summary of the intervention studies reviewed in this section is presented in Table 3.

Ergonomic improvements and training

Aarås and colleagues have recently published a series of articles on an intervention study on VDU work. They studied two intervention groups and one control group of VDU workers using a prospective parallel group design. There was no randomization of the subjects into the intervention groups. The interventions were implemented three times serially on a two-year time scale and consisted of a new lighting system and workplace design, an optometric examination, and corrections if needed. The intervention groups reported significantly improved lighting conditions and visual comfort. Headache and shoulder pain were also reduced in the two intervention groups. The control group reported no improvement in any of these health outcomes (Aarås et al., 2001b). After 3.5 years of follow-up, the control group underwent the same intervention in terms of the new lighting system, new workplace design, and an optometric examination and corrections if needed. This group reported a significant reduction in visual discomfort after the intervention. After 6 years of follow-up the control group still reported low levels of shoulder and neck pain, and the two earlier intervention groups continued to report visual comfort (Aarås et al., 2001b).

Nevala-Puranen et al., (2003) carried out an intervention study among newspaper employees using VDU at work. The study compared the effects of two different intervention models: redesign of the VDU environment only (n=8), and redesign of the environment and advice given on work techniques (n=9). All the subjects selected for the interventions had musculoskeletal pain in their forearms on at least 30 days during the past 12 months. Work posture, viewing angle and distance to the screen, muscular activity in the shoulder and forearm, and musculoskeletal pain were measured before and after the 7-month intervention. A statistically significant difference was found between the groups in the change in shoulder flexion and the muscular activity of the right trapezius and right extensor carpi radialis between the baseline and 7-month follow-up. The reduction of pain symptoms in the neck, shoulders and elbows was greater in the redesign and advice group than in the redesign of the environment only group.

In a study by Brisson et al., (1999) a pretest-posttest design with a reference group was used with

Table 3. Intervention studies in VDU work.

Study	Total initial participants Follow-up time	Study design	Intervention	Results
Ergonomic improvements and training				
Aarås et al., 2001b	– n=150 – 6 years	– prospective, parallel group design – 3 intervention groups (n=50, n=50, n=50)	– new lighting system – new workplaces – optometric corrections if needed	in intervention groups reduction of – visual discomfort – shoulder pain – neck pain
Nevala-Puranen et al., 2003	– n=20 – 7 months	– longitudinal intervention study – 2 intervention groups (n=8, n=7)	– improvements in ergonomics – improvements and advice in ergonomics	reduction of – neck, shoulder and elbow pain in both groups
Brisson et al., 1999	– n=627 – 2 weeks – 6 months	– pretest-posttest study – 1 intervention group (n=284) – 1 control group (n=343)	– ergonomic training program	in ergonomic training group improvements – in postural stressors and in musculoskeletal disorders (more frequent in workers under 40 years)
Bayeh and Smith, 1999	– n=80 – 6 months – 12 months	– longitudinal intervention study – 3 intervention groups (n=32, n=24, n=25)	– layout changes – layout changes and new workstation accessories – layout changes, new workstation accessories and new chair	reduction of – self-reported discomfort in all 3 groups
Breaks from computer work				
Henning et al., 1997	– two work sites (n=73, n=19) – 2 and 3 weeks – 4 and 6 weeks	– clinical trial – 2 intervention groups (n=73, n=19)	– frequent breaks	– at the smaller work site (n=19), productivity, eye, leg and foot comfort increased – no effect at the major work site (n=73)

Mouse design and arm support				
<i>Aarås et al., 2001a</i>	– n=67 – 6 months + 6 months	– prospective, parallel group design – 1 intervention group (n=33) – 1 control group (n=34)	– alternative (Anir-mouse) mouse in use	in alternative mouse group reduction of – shoulder pain – neck pain – forearm pain – hand and wrist pain
<i>Lintula et al., 2001</i>	– n=21 – 6 weeks	– work site intervention – 2 intervention groups (n=7, n=7) – 1 control group (n=7)	– arm support for the hand operating the mouse (intervention group I) – arm support for both hands (intervention group II) – no arm supports (control group)	when using arm supports for both hands reduction of – wrist extension – trapezius load – discomfort
Keyboard design and placement				
<i>Tittiranonda et al., 1999a</i>	– n=80 – 6 months	– randomized, placebo-controlled trial – 4 treatments groups (n=20, n=20, n=20, n=20)	– comparison of 4 different keyboards	reduction of – hand and arm pain when using alternative geometry keyboards
<i>Rempel et al., 1997</i>	– n=20 – 12 weeks	– randomized clinical trial – 1 intervention group (n=10) – 1 control group (n=10)	– different keys-witch design	in intervention group reduction of – hand pain
<i>Dowler et al., 2001</i>	– n=67 – participants used as own controls	– controlled intervention study – 1 intervention group (n=67)	– reduction of seated work positions by changing the keyboard location	– a lower muscle activity in trapezius muscles when keyboard was tilted downwards
Screen				
<i>Psihogios et al., 2001</i>	– n=20	– clinical trial – 2 intervention groups (n=10, n=10) – 2 control persons in both groups	– changes in screen location	– preferred screen location generally corresponded to the location in which less neck discomfort was reported

random allocation into administrative and geographic units. The study population was composed of 627 workers employed in a large university and in another institution involved in university services. A six-hour training program in ergonomics was carried out. The training focused on decreasing postural stressors (neck twisting and flexion and wrist deviation) through the use of accessories and adjustments of the workstation. The measurements involved direct observation of the workstations, a self-administered questionnaire, and a physical examination. In both groups, measurements were performed 2 weeks before and 6 months after the training. Improvements in postural stressors occurred more frequently in the intervention group, and these positive changes tended to be more frequent in workers under 40 years of age. The prevalence of musculoskeletal disorders decreased among the workers under 40 years of age in the experimental group, from 29% to 13% determined by questionnaire and from 19% to 3% determined by physical examination. In the other groups, there was no significant change in the prevalence of musculoskeletal disorders (Brisson et al., 1999).

In their non-randomized longitudinal intervention study, Bayeh and Smith (1999) examined the effect of training and impact of ergonomic interventions on workers' health in VDU-intensive work. They used three levels of interventions: 1) ergonomic training and customized workstation adjustments, 2) specific workstation adjustments, 3) acquisition of a new ergonomic chair. Health data were gathered from 80 volunteer participants before the intervention and, 6 and 12 months after the intervention. Reductions in self-reported musculoskeletal discomfort were found in all three ergonomic interventions.

Mouse design and arm support

It has been shown that mouse users have an outward rotated position in the shoulder joint and pronation in the forearm. These postures may impose high static loads on the upper limb and cause discomfort and pain (Karlqvist et al., 1994). Aarås et al. (2001a) carried out an intervention study aimed at improving the posture of the upper limb when using a computer mouse. They compared a newly designed alternative mouse with a traditional mouse. They found in an EMG study that the muscle load of the forearm was lower, and the positions of the forearm and wrist more neutral when using the alternative mouse compared to the traditional mouse (Aarås and Ro, 1997). In a subsequent intervention study, half of the study participants used the alternative mouse (Anir

mouse) and the other half the traditional mouse. After six months a significant reduction of neck, shoulder, forearm, wrist and hand pain was reported among the participants who used the alternative mouse. Aarås concluded that the effects of this single intervention might be due to reduced shoulder abduction and elimination of full forearm pronation. Later on an identical intervention (the alternative mouse in use) was carried out using the former control group as the intervention group (Aarås et al., 2001a). After 6 months, also this group reported a reduction of shoulder, forearm, wrist and hand pain.

In addition to mouse design, forearm support has been considered to decrease muscle load in the upper limb. Aarås et al., (1998) reported that supporting the user's whole forearm on the table top in front of the computer seems to reduce static trapezius load. Lintula et al., (2001) studied the effects of added arm supports on wrist angles and musculoskeletal strain in the neck and upper limb. The electrical activities in the shoulder and arm muscles were studied during typing and use of the mouse. Twenty-one women were randomized into 3 groups: arm support for the mouse hand; arm supports for both hands; and control group. Measurements were carried out before and after a 6-week intervention. Wrist extension of the mouse hand, muscle activity of the trapezius muscle, and ratings of subjective discomfort indicated that supporting both arms was a better solution than supporting only the mouse hand.

Keyboard design and placement

Several researchers have suggested that the conventional linear keyboard design may contribute to the development of upper limb disorders (Punnett and Bergqvist, 1997). The traditional keyboard requires an awkward upper limb posture: forearm pronation, wrist ulnar deviation and extension. Tittiranonda and colleagues carried out a 6-month randomized controlled trial evaluating the effects of four computer keyboard models on hand pain severity, functional hand status, and comfort. 80 computer users with musculoskeletal disorders participated in this study during a period of 6 months. The study subjects were randomized into three intervention groups: split ('adjustable') keyboard; geometric keyboard ('comfort'); and 'natural' keyboard and one conventional keyboard ('placebo') group. Compared to the placebo keyboard group, the natural keyboard group, and to a lesser extent also the adjustable keyboard group demonstrated an improving trend in pain severity and hand function after 6 months of keyboard use. A significant correlation was also found between

reduction in pain severity and satisfaction with the keyboard. However, there were no improvements in the clinical findings from the upper limbs. The authors concluded that keyboard users may experience a reduction in hand pain after using an alternative geometry keyboard for several months (Tittiranonda et al., 1999c).

Since the beginning of the 20th century the place of the keys on the keyboard of typewriters has been in QWERTY order. Also on computer keyboards the QWERTY order predominates, but not without criticism. A considerable number of inventions and studies have sought to find a new keyboard design in which the keys are in an alternative order (Punnett and Bergqvist, 1997).

Rempel et al., studied an alternative keyboard key-switch design. This randomized clinical trial evaluated the effects of the key-switch design on computer users with hand paresthesia. 20 computer users were randomly assigned to a conventional layout keyboard group, and to an alternative keyboard group (different key-switch design). Various outcome measures were assessed during 12 weeks of use. The subjects who were assigned the alternative keyboard experienced a decrease in hand pain between weeks 6 and 12 when compared with the conventional keyboard users. They also demonstrated an improvement in the Phalen test time. Keyboard assignment had no significant effect on the change in hand function or median nerve latency (Rempel et al., 1999).

Dowler et al., focused on developing a new approach to seated work positions by changing the keyboard location. The study population comprised of 67 office workers who used a computer as a major tool during their work day. At first two sitting postures were defined as 'neutral'. In the first posture the keyboard was placed on a 15° downward-tilting tray (negative slope) and the upper arm forearm angle was 115°. In the second 'neutral' position the keyboard was located on a normal work desk and the upper arm - forearm angle was 90°. The purpose was to compare the muscle tension between the two defined working postures with the ANSI posture (American National Standard, 1988), and the users' own daily used posture. The study subjects worked in each of the four work postures in a random order. Muscle tension was measured by using surface EMG from the shoulder and forearm muscles before and 30 days after every work session. It was found that muscle load in the shoulder and forearm muscles was lowest in the first neutral work position (keyboard at 15° downward-tilting angle, upper arm - forearm angle 115°) (Dowler et al., 2001).

Screen

The appropriate screen location is a subject of constant debate. Generally, visual strain is associated with higher placement, and musculoskeletal strain is associated with lower placement of the screen. Seeking a resolution for the debate, Psihogios et al., (2001) compared the results of laboratory-based monitor placement studies to recommendations and outcomes from viewing preference and neutral posture studies. The results showed that the screen height at the workplace was associated with postures similar to those in the laboratory studies. Additionally, the preferred screen location generally corresponded to the location in which less neck discomfort was reported. There is consistent evidence to support mid-level (~20° viewing angle) or somewhat higher placement as a rule-of-thumb, considering the preferred gaze angle and musculoskeletal aspects. However, optimal placement may be lower for some individuals (e.g. those using bifocals) or for specific tasks.

Breaks from computer work

In a study of Henning et al. (1997) computer workers at two work sites (n = 73, n = 19) were advised to take three 30-second and one 3-minute break from computer work each hour, in addition to the regular rest breaks. Some workers were asked to perform stretching exercises during the short breaks. Mood and musculoskeletal discomfort were assessed at each work site over a 2- or 3-week baseline period and a 4- or 6-week treatment period, respectively. Worker productivity measures were obtained from the company records. No improvement in productivity or well-being was found at the larger work site. At the smaller work site, productivity, eye, leg and foot comfort all improved when the short breaks included stretching exercises.

2.3.2 Methodological considerations

A common hypothesis is that ergonomic interventions at the workplaces can reduce the incidence of musculoskeletal disorders and the disability due to them. However, the use of randomized controlled trials in intervention studies has been rare, and the results have been meagre. In addition, only few of the lately reported intervention studies in VDU work have followed the standards of reporting randomized controlled trials (Begg et al., 1996). Most of the studies reviewed here had a control group that was compared to one or two groups of workers, subjected to an intervention. Some groups have been used as their own controls. In some studies, the control group has been established by unusual means, e.g. by two-group time-staggered interventions.

Symptom ratings, such as pain or strain scores, changes in muscle load or musculoskeletal symptoms, have been the primary outcome measures. The reviewed studies have generally demonstrated positive impacts of changes in workstation design, tool design, or training on upper limb or neck/shoulder symptoms.

Intervention research using an RCT design is laborious to carry out because the field setting often poses limitations. In many cases it is difficult to establish an adequate control group. If the control group is missing, there are many threats to the internal validity of the study. The intervention often focuses on the persons with the most problems (Ovretveit, 1998). Due to the cyclical nature of musculoskeletal complaints, the workers may temporarily show improvements in health, independent of the intervention. Variables that affect the outcome, e.g. age, gender, work load, and activities outside work, can be represented differently when different populations are compared.

A random selection of the subjects to intervention and control groups is desirable, including blinding of the subjects and researchers to the group assignment. Such a design is generally not achievable in ergonomic intervention research, because the group membership of subjects is, in practice, given. However, group randomization is in many circumstances an alternative study design. In addition, people should know that they are taking part in an intervention, even if they do not know whether they are in a control or in an experimental group, and this may affect the outcome (the Hawthorne effect). Westgaard and Winkel (1997) state that the best way to decrease the Hawthorne effect is to arrange a non-effective intervention for the control group, e.g., by introducing workplace modifications that look good, but do not change the physical exposure.

Another criterion for a fair intervention is a reasonable size of the experimental and control groups. Adequate sample sizes are needed to show that an intervention is effective in increasing positive health outcomes (Westgaard and Winkel, 1997; Ovretveit, 1998).

In order to ascertain changes in ergonomics or in musculoskeletal health, a long enough follow-up time is needed. No absolute limits have been set, but a follow-up time of one year or at least 6 months has been proposed (Westgaard and Winkel, 1997). A long follow-up time makes the controlling of all confounding factors in field conditions (e.g. changes in exposure over time, different exposures to different workers and turnover) very demanding. Furthermore, ethical considerations limit the

possibility to perform a long intervention in the work life. Some outcomes and impacts may take time to become evident. However, a shorter observation time may provide valuable information e.g. of acute physiological responses such as the development of fatigue or discomfort.

If the purpose of an intervention is to describe the effects of a change in physical exposure on musculoskeletal health, both exposure and health outcome variables must be properly assessed and described. The documentation of an intervention study should state clearly the original purpose of the intervention, the intervention process, and the results. The measurements used in the intervention should be presented properly in order to facilitate their use in later research.

3. THEORETICAL FRAMEWORK OF THE STUDY

An impressive number of studies in the past decade have linked physical and organizational factors at work to musculoskeletal signs and symptoms. It has been evidenced that worker groups with specific work-related factors are at an increased risk for musculoskeletal disorders (Panel on Musculoskeletal Disorders and Workplace, 2001). The mechanisms in the development of musculoskeletal disorders are not yet completely understood. Several models attempting to explain the exposure – response process have been presented.

The framework of this thesis is based on the conceptual model of Moon and Sauter (1996). According to this model (Figure 3) musculoskeletal symptoms are related to the work technology which includes both the nature of tools, work place characteristics and work processes. As shown in the model, work technology is linked directly to physical demands, as illustrated by the physical connection between the worker and the tool, to workstation ergonomics, as well as to work organization. The link between work organization and physical demands implies that the physical demands of work are affected by organizational demands; for example, increased specialization leads to increased repetition. The model also shows a link between work organization and psychosocial strain, which in turn, influences biomechanical strain. It is suggested that complex cognitive processes mediate the relationship between biomechanical strain and the development of musculoskeletal symptoms. Finally, the model shows the reciprocal effects of musculoskeletal disorders on psychological strain and work organization (Moon and Sauter, 1996).

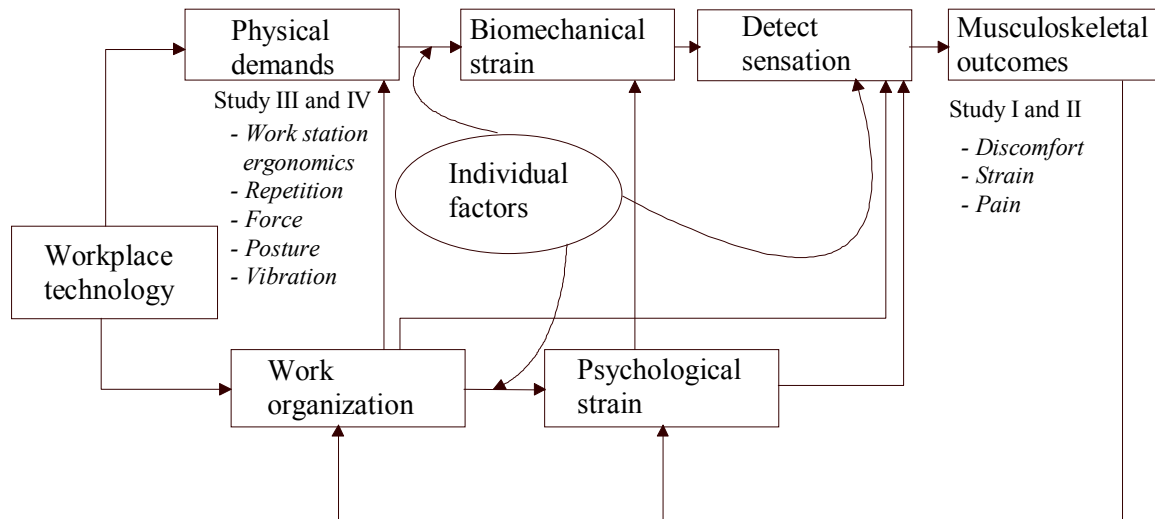


Figure 3. Conceptual model of the pathways leading to musculoskeletal disorders at work, adapted from Moon and Sauter (1996).

In this thesis Studies 3 and 4 concentrated on the evaluation of the physical demands and workload in VDU work and industrial work. Study 1 examined the incidence of neck pain in VDU work and the Study 2 focused on the effect of ergonomic improvements on musculoskeletal outcomes.

4. AIMS OF THE STUDY

The aims of this study were to investigate risk factors for neck pain among VDU workers, to assess the effects of an ergonomic intervention on the level of musculoskeletal symptoms, and to study the repeatability and validity of an assessment method of VDU ergonomics. Furthermore, a method to assess the risk factors for upper limb disorders in industrial work was developed, and its validity and repeatability were investigated.

The specific aims were:

1. To investigate work-related and individual factors as predictors for incident neck pain among office employees engaged in VDU work (Study 1).

2. To study the effects of an intensive participatory ergonomic intervention and education on the level of musculoskeletal discomfort and strain, and the prevalence of pain among VDU workers (Study 2).

3. To investigate the repeatability and validity of an expert assessment, and to determine to what extent an expert assessment of VDU workstation ergonomics is related to certain workstation characteristics, and responds to changes in these characteristics (Study 3).

4. To investigate the inter-observer repeatability and validity of an assessment method to identify risk factors for upper limb disorders (Study 4).

5. METHODS

5.1. Study group of VDU workers (Studies 1, 2 and 3)

Work-related and individual predictors for incident neck pain

A longitudinal study was conducted in three municipal administrative units. Data were collected via structured questionnaires mailed to the subjects. The source population in the study on the incidence of neck pain consisted of all the full-time employees whose job included VDU work for more than 4 hours per week ($n=515$). Altogether 416 workers participated in the baseline survey in 1998 (response rate 81%). From the baseline respondents, the subjects of interest were those who reported local or radiating neck pain for less than 8 days during the preceding 12 months. These subjects were classified as 'healthy' at baseline ($n=232$). This cohort was studied 12 months later, the response rate being 78% ($n=180$). At follow-up in 1999 the incident cases were those workers who reported local neck pain or radiating neck pain for at least 8 days during the preceding 12 months (Figure 4). The employees were mainly secretaries, technicians, architects, engineers and draftspersons.

Ergonomic intervention in VDU work and expert assessment of ergonomics

The study population for the interventions was selected from among those in the baseline group who returned the questionnaire ($n=461$) on the basis of reported musculoskeletal symptoms, mouse usage and age, according to the following criteria:

- symptoms in the neck, shoulders, or upper limbs in at least one and at most eight out of 11 anatomical areas during the preceding month
- mouse use for more than 5% of the VDU working time
- age < 61 years.

The subjects fulfilling the inclusion criteria (n=124) were allocated into three groups (intensive ergonomics, education in ergonomics, and control) using stratified random sampling. The three administrative units were used as a stratum. The success of the randomization was checked with regard to age, sex, VDU work time, mouse usage, and symptoms in the neck. At the beginning of the study there were 109 participants, in the 2-month follow-up 107, and in the 10-month follow-up 102 participants. For the assessment of ergonomics, video recordings were made and digital photographs taken of the subjects (n=107) during their usual daily tasks (Figure 4).

5.2. Jobs observed in industry

In this study a semiquantitative, time-based method for assessing six physical load factors was developed and validated. The jobs observed were selected from a food-processing plant and a paper mill. The jobs of 14 workers in 5 occupations (5 women and 9 men) were selected for observation. There were 4 meat cutters, 3 sausage packers, and 2 sausage sprayers in the food-processing plant, and 4 paper cutters and 1 pulp maker in the paper mill. All the workers had at least two years' experience in their current work.

5.3. Questionnaire study among VDU workers (Study 1)

In the questionnaires, 11 work-related and 11 individual variables were used as potential predictors for neck pain. The selection of variables was based on our hypotheses and earlier evidence. The following variables were selected:

Work-related factors (self-assessments and measurements by the employees in their own offices)

1. The self-rated proportion of time used for VDU work as a percentage of the total work time.
2. Physical work environment: lighting, temperature, quality of air, size of the work room, and acoustic conditions.
3. Ergonomics of the workstation: work chair, work desk, screen, keyboard, mouse and document holder.
4. Viewing distance between the eyes and the mid-point of the screen.

5. Distance between the upper edge of the screen and the horizontal eye level.
6. Distance between the g-h-point of the keyboard and the edge of the desk.
7. Deviance between the g-h-point of the keyboard and the mid-line of the body.
8. Distance between the mid-point of the mouse and the edge of the desk.
9. Deviance between the mid-point of the mouse and the mid-line of the body.
10. Breaks during VDU work.
11. The extent to which the subjects were able to influence their own work load in terms of amount of work and work pace.

Individual factors

The following items were included:

1. Sex
2. Age
3. Frequency of physical exercise
4. Smoking
5. Health status
6. Mental stress
7. Mental strain
8. Depression
9. Job satisfaction
10. Time used for domestic chores
11. Time used for hobbies imposing static load on the neck-shoulder region.

5.4. Intervention study in VDU work (Study 2)

Intervention procedure

At baseline two experts in ergonomics collected data on the workplace layout and dimensions before the intervention, and 2 and 10 months after the intervention. They were blinded to the group assignment of the study subjects. The outcome measures were musculoskeletal discomfort collected by diary 2 and 10 months after the intervention. In addition, pain and strain symptoms were inquired with a questionnaire 12 months after the preliminary survey, i.e. about 7-10 months after the intervention (Figure 4).

Diary and questionnaires

The participants were asked to keep a diary on discomfort three times during a workday: in the morning, at noon, and at the end of the workday. The structured diary consisted of questions on discomfort in different anatomical areas. The rating of discomfort had five levels ranging from 1="feel good" to 5="feel very uncomfortable". A human figure was used to define the anatomical areas. The subjects filled out the diary for two weeks

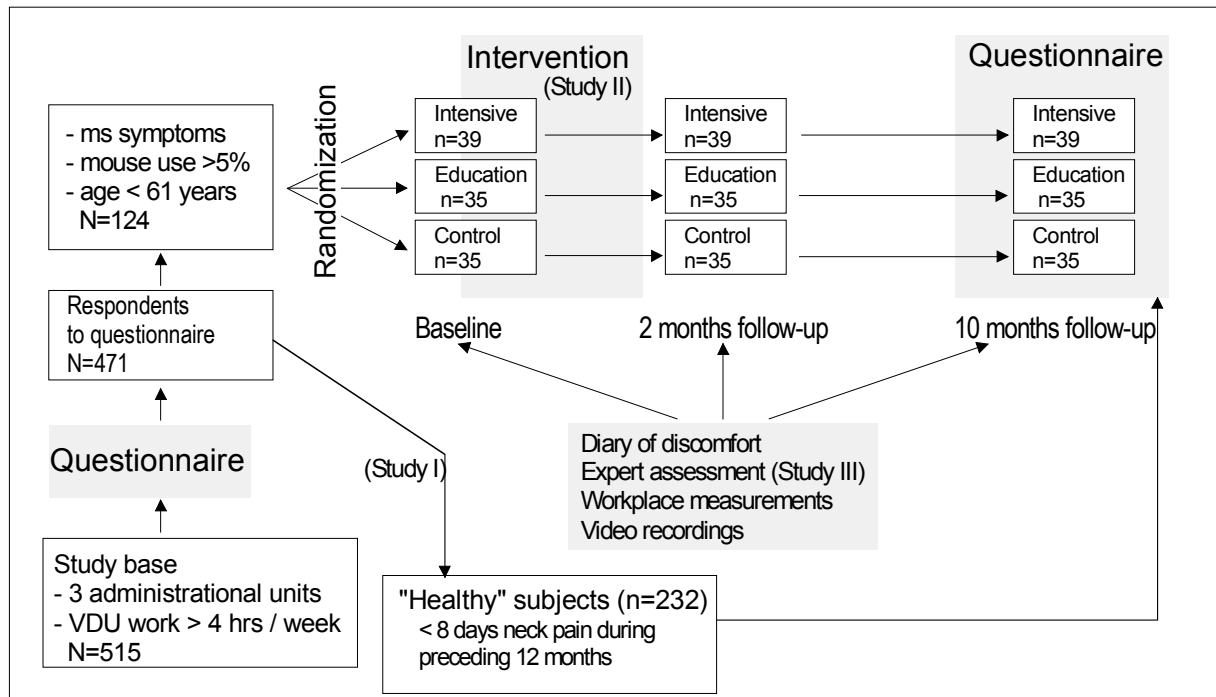


Figure 4. The study procedure in the investigation of musculoskeletal symptoms and the effect of ergonomic intervention among VDU workers.

before the intervention, at the 2-month follow-up, and at the 10-month follow-up. The questionnaires, before the intervention and at the 10-month follow-up, included questions on musculoskeletal strain and pain.

Interventions

In the intensive ergonomics group two physiotherapists visited the work site of every member of the intensive ergonomics group. Potential improvements based on the workers' own views as well as on the physiotherapists' observations were then discussed and carried out. The best solution was sought first of all, by adjusting and altering the existing furniture and work equipment. The worker was encouraged to participate actively in the redesign and rearrangement of his or her workstation. The workers were also advised to be aware of their work postures and to take short pauses in their work. The ergonomics evaluation and the implementation of the immediate changes to a workstation took about 1.5 – 2 hours. In addition, the workers received a one-page leaflet on general ergonomics in VDU work.

In the education group the workers attended a 1-hour training session in ergonomics. A specialist in ergonomics instructed the workers concerning the principles of ergonomics in VDU work. The workers

were given the same leaflet as the intensive group, and were encouraged to evaluate their own workstation, to make changes, and to ask for new equipment and furniture if needed. Moreover, the workers were instructed to take short pauses and adopt relaxed working postures. All subjects in the education group attended the training. The members of the control group got only the one-page leaflet on ergonomics during the study.

5.5. Assessment of ergonomics in VDU work (Study 3)

Video recordings were made of the subjects during their usual daily tasks by the two experts in ergonomics at the baseline, and at the 2-month and 10-month follow-ups. A continuous 4-minute extract was chosen from the video recordings of each subject at both time points to illustrate the ergonomics of the workstation and the subject's most common work postures. Two experts gave individually an overall rating of ergonomics with a scale from 4=poor to 10=excellent. The experts' assessment was based on common knowledge of musculoskeletal risk factors in VDU work and the present, general knowledge of ergonomics. The rating was made individually, and the experts had no written instruction or checklists. The technical measurements of the workstation (i.e. place of the

mouse, screen, keyboard) were made at the same time as the video recordings.

Simultaneously with the video recordings, five to ten digital photographs were taken of each workstation and workplace. A researcher analyzed the photographs taken at each time point in a random order (totally 216 workstations) to assess tidiness and available space at the workplace. The researcher gave an overall rating of tidiness and space with a scale from 4=poor to 10=excellent. For each worker, the type of the work chair was recorded and photographs were taken of the chairs without the worker sitting in the chair. A physiotherapist experienced in the ergonomics of office chairs classified the chairs with a scale from 4=poor to 10=excellent according to their ergonomic properties (e.g. design, adjustments, sitting comfort).

5.6. Method to observe risk factors for upper limb disorders (Study 4)

Two occupational nurses (observers 1 and 2) made the observations using the method developed in this study. The observers worked simultaneously but independently.

Simultaneously with the observation, the working was recorded on video, surface electrodes were used to record the electrical activity (EMG) of the forearm muscles and the range of motion in flexion-extension, and the radial-ulnar deviation of the wrist was measured by goniometers. Estimations of the use of force based on the EMG recordings served as validity criteria for the observed use of force. The angles measured by the goniometers were used as criteria for the nonneutral postures of the wrist. A work cycle was considered to include high grip force if the grip force estimated by EMG exceeded the limit value of 44 N for at least 30% of the cycle time. Similarly, the cycle was considered to involve a nonneutral wrist posture if the wrist angle was nonneutral ($>20^\circ$ extension, flexion, ulnar, or radial deviation) for at least 30% of the cycle time. Because the preliminary results suggested a difference in the results for short and long cycles, the final analysis of use of hand force was performed for all cycles, and separately for short (≤ 30 s) and long (>30 s) cycles. The validity of the two observers' observations of repetitiveness, pinch grip and elevation of the upper arm was assessed against the observation of the expert from the video.

5.7. Statistical methods

5.7.1. Incident neck pain

Cross-tabulations and logistic regression models were used as main methods for analysing the associations between neck pain and the potential work-related and individual risk factors. To construct a multivariable model, a forward selection strategy was used. The inclusion of the variables for the first model was based on testing the significance of the potential predictors as groups of variables, adjusting for age, sex and VDU work time for work-related variables, and for age and sex for individual variables. From each group of variables, those with $p < 0.2$ were selected for further analyses. Based on the first steps of modelling, the physical work environment, the distance of the keyboard among the work-related factors, and smoking among the individual factors, were included in the further stages of analysis. Finally, the first level interactions were tested. The significant interactions, (sex with age and mental stress with frequency of physical exercise), were added to the model of direct effects.

5.7.2. Ergonomic interventions

When studying the effects of interventions in VDU work, one-way analysis of variance was used to test differences in the ratings of ergonomics between the three intervention groups. Each time point was handled separately. In cases in which the F-test was statistically significant, unpaired t-test for comparisons between two groups (intensive vs. control and education vs. control) was applied. A 5 % level was considered to be statistically significant.

Musculoskeletal strain and maximal discomfort from the follow-up questionnaire and diary were kept as continuous outcome variables when the analysis of covariance was applied. The baseline value of the outcome variable, the initial rating of ergonomics, and the baseline value of work load (keyboard and mouse events) were included in the models as covariates. Due to missing data on work load, this modelling was carried out also without work load. The adjusted means of the outcomes and their standard errors were calculated and the statistical significance of the differences in adjusted means between the groups was tested for with one-sided Dunnett's test. The two intervention groups were contrasted against the control group.

Musculoskeletal pain from the 10-month questionnaire was handled as binary variables, and logistic regression models were applied when the pain was modeled to find the association between pain and type of intervention. The baseline value of the outcome variable was used as a confounder in these models.

5.7.3. Expert assessment method in VDU ergonomics

The inter-observer repeatability for the expert assessment method was estimated by calculating the intraclass correlation coefficient between the ratings of the two experts at the baseline. Associations between expert assessments and workstation characteristics at baseline were studied using the simple linear regression model. The effect of the change in workstation characteristics during the follow-up time on the expert assessment was studied using a linear regression model.

5.7.4. Assessment method for upper limb risk factors

Inter-observer repeatability was assessed by calculating the proportion of specific agreement and

Kappa-coefficient (κ). The validity of the observations of the observers was assessed against the observation of the expert. For force, EMG measurements, and for wrist posture, goniometer measurements, were also used as validity criteria. Sensitivity, specificity and kappa coefficients were computed for each physical load factor. In our study, sensitivity was the probability that the observer finds a truly loading factor of a work cycle. The specificity means that the observer finds no loading factor when there really is none. The classification of Kappa values was done according to the method of Landis and Koch (1977). Values of $\kappa < .40$ were regarded as poor, from $.40$ to $.75$ as moderate to good, and $>.75$ as excellent.

Table 4. Odds ratios for predictors of neck pain among Finnish office workers in 1998-99 (logistic regression model with interactions, adjusted for the time used in VDU work; n=137)

<i>Predictors</i>	<i>Neck pain</i>	
	<i>OR</i>	<i>95% CI</i>
<i>Work-related predictors</i>		
Physical work environment:		
Mean score > 3	1.0	
Mean score ≤ 3	2.4	1.0 to 6.0
Distance of the keyboard from the edge of the table:		
Good (≥ 15 cm)	1.0	
Poor (< 15 cm)	1.9	0.8 to 4.3
<i>Individual predictors</i>		
Sex:		
Male	1.0	
Female	6.7	1.4 to 30.9
Age (years):		
25 - 43	1.0	
44 - 51	2.7	0.6 to 12.5
52 - 61	2.5	0.5 to 12.1
Smoking:		
Never-smoker	1.0	
Current/Ex-smoker	1.5	0.6 to 3.6
Mental stress:		
None / little	1.0	
Some / fairly much / much	0.5	0.2 to 1.4
Frequency of physical exercise (times/week):		
≥ 2	1.0	
≤ 1	0.8	0.2 to 2.7
<i>Interactions</i>		
Age x Sex:		
25 - 43 x Male	1.0	
44 - 51 x Female	0.1	0.0 to 0.7
52 - 61 x Female	1.1	0.1 to 10.3
Mental stress x Frequency of physical exercise:		
None / little x ≥ 2	1.0	
Some / fairly much / much x ≤ 1	6.7	1.0 to 43.6

6. RESULTS

6.1. Risk factors for incident neck pain (Study 1)

Of the 180 VDU workers who had no neck pain at baseline, 62 (34.4%) developed local or radiating neck pain during the 12-month follow-up period. The incidence of local neck pain was 13.3% (n=24) and the incidence of the radiating pain was 14.4% (n=26). The incidence of combined local and radiating neck pain was 6.7% (n=12).

The risk of neck pain was about two-fold for workers who rated their physical work environment as poor, in comparison to those who rated their work environment as good. Each item of the environment score showed a positive association with the outcome as follows: lighting (OR = 1.4), temperature (OR = 1.2), quality of air (OR = 1.7), size of the work room (OR = 1.5), and acoustic conditions (OR = 1.4); none of the items were significant alone. Also poor placement of the VDU keyboard increased the risk of neck pain, and the women had an almost three-fold risk of neck pain compared to the men. Current or ex-smokers had an almost two-fold, though not significant, risk compared to the never smokers.

Table 4 shows the multivariate model with significant interactions. There was an interaction between mental stress and physical exercise: the workers with a higher level of mental stress and lower frequency of physical exercise had an almost seven-fold risk compared to those with a lower stress level and higher exercise frequency. The risk associated with the physical work environment became higher, whereas that for the distance of the keyboard and smoking turned out to be lower, as compared with the model with the direct effects only. The interactive effects of sex and age showed that the women had a higher risk than the men, except in the age group of 44-51 years.

6.2. Ergonomic intervention in VDU work (Study 2)

6.2.1. Changes in workstation ergonomics

The most common changes in the workstations detected or measured by two blinded experts were changes in screen or keyboard height, or the acquisition of accessories. Of the latter, wrist and forearm supports were typically acquired in the intensive ergonomics group. Adjustments were made to the chair or mouse location in all groups.

6.2.2. Changes in the rating of workstation ergonomics

The means for the ratings of ergonomics did not differ between the groups at baseline. In the 2- and 10-month follow-up the level of ergonomics was rated significantly higher in the intensive group than in the education or the control group (Table 5).

6.2.3. Changes in daily ratings of discomfort

In the 2-month follow-up the intensive group had less discomfort than the control group in the neck, right and left neck/scapular region, right and left shoulder/upper arm, and upper back (adjustment for the baseline measurements of musculoskeletal discomfort, work load, and ergonomics). As compared with the workers in the control group, the education group had less discomfort in the neck, right neck/scapular region, both shoulders/upper arms, and upper back. The results showed the same trend in the 10-month follow-up, but there were no significant differences between the groups (Table 6).

Adjusted only for the baseline measurements of discomfort and initial ratings of ergonomics, two months after the intervention the intensive group had less discomfort than the control group in the neck, right neck/scapular region, right and left shoulder/upper arm, left fingers, and upper back. As compared with the control group, the education group had less discomfort in the neck, right neck/scapular region, right forearm, and upper back. The results showed the same trend in the 10-month follow-up, but there were no significant differences between the groups.

6.3. Repeatability, validity and responsiveness to change in expert assessment of VDU workstation ergonomics (Study 3)

Table 5. Ratings of workstation ergonomics (workstation settings and postural stressors) before the intervention and at 2- and 10-month follow-up (scale 4 -10).

Group	Before intervention			Follow-up (2 mo)			P- Value	Follow-up (10 mo)			
	N	Mean	SD	N	Mean	SD		n	Mean	SD	P- Value
Intensive	39	6.7	0.2	39	7.7	0.2	.001 ^a	37	8.0	0.1	.002 ^a
Education	35	6.8	0.2	35	6.7	0.2	.73 ^b	33	7.1	0.2	.60 ^b
Control	35	6.7	0.2	33	6.8	0.2	.	32	7.3	0.2	.

^a= unpaired t-test between intensive and control group

^b= unpaired t-test between education and control group

Table 6. Musculoskeletal discomfort (mean \pm SE) in 2 months and 10-month follow-up (adjusted for the baseline value of discomfort and expert rating of ergonomics) (n=85)

Body area	2-month follow-up						10-month follow-up										
	Intensive group (n=28)			Education group (n=31)			Control group (n=26)			Intensive group (n=28)			Education group (n=31)			Control group (n=26)	
	Mean	SE	p ^a	Mean	SE	p ^b	Mean	SE		Mean	SE	p ^a	Mean	SE	p ^b	Mean	SE
Head	2.5 \pm	0.2	.088	2.7 \pm	0.2	.30	3.0 \pm	0.2		2.7 \pm	0.2	.13	2.8 \pm	0.2	.26	3.0 \pm	0.2
Eyes	2.6	0.2	.24	2.8	0.2	.54	2.9	0.2		3.0	0.2	.38	3.1	0.2	.49	3.2	0.2
Neck	2.7	0.2	.014	2.7	0.1	.013	3.3	0.2		2.9	0.2	.24	3.0	0.1	.30	3.2	0.2
Right neck-shoulder	2.5	0.1	.007	2.5	0.1	.002	3.1	0.2		2.7	0.2	.37	2.6	0.2	.27	2.9	0.2
Left neck-shoulder	2.3	0.2	.17	2.3	0.1	.11	2.6	0.2		2.6	0.2	.69	2.6	0.2	.65	2.6	0.2
Right shoulder	2.2	0.2	.022	2.4	0.1	.12	2.8	0.2		2.6	0.2	.53	2.5	0.2	.36	2.7	0.2
Left shoulder	1.9	0.1	.025	2.1	0.1	.15	2.4	0.2		2.2	0.2	.61	2.4	0.2	.86	2.3	0.2
Right forearm	2.1	0.1	.077	2.0	0.1	.009	2.5	0.2		2.3	0.2	.36	2.1	0.2	.14	2.5	0.2
Left forearm	1.9	0.1	.57	1.9	0.1	.59	2.0	0.1		2.1	0.2	.56	2.0	0.2	.48	2.2	0.2
Right wrist	2.1	0.2	.13	2.0	0.2	.062	2.4	0.2		2.5	0.2	.87	2.1	0.2	.31	2.3	0.2
Left wrists	1.9	0.1	.19	1.9	0.1	.26	2.1	0.1		2.1	0.2	.86	2.1	0.2	.86	2.0	0.2
Right fingers	1.9	0.1	.075	2.1	0.1	.38	2.3	0.1		2.1	0.2	.31	2.2	0.2	.35	2.3	0.2
Left fingers	1.8	0.1	.017	1.9	0.1	.092	2.3	0.1		2.1	0.2	.72	2.1	0.2	.73	2.1	0.2
Upper back	2.2	0.1	.001	2.4	0.1	.005	2.9	0.1		2.6	0.2	.24	2.5	0.2	.17	2.9	0.2
Low back	2.3	0.2	.13	2.5	0.2	.40	2.7	0.2		2.5	0.2	.55	2.7	0.2	.75	2.6	0.2

^a= one-sided Dunnett's test between intensive and control group ^b= one-sided Dunnett's test between education and control group.

The mean values (standard deviation) of the expert ratings of workstation ergonomics at the baseline were 6.7 (0.9) and 6.8(1.1) for expert 1 and expert 2, respectively. The intraclass correlation coefficient between the ratings of workstation ergonomics of the two experts was 0.74 at the baseline.

Workstation tidiness and space explained about 30%, and the work chair about 15% of the expert ratings. The technical measurements had minor effects on the assessments. Four dimensions of VDU workstations (distance between the mouse and the front edge of the table, viewing angle to the first text line of the screen, vertical distance between the eye and floor, distance between g-h keys and the table front edge) showed a statistically discernible ($p < 0.05$) association with the assessments of both experts. In addition, three dimensions (distance of mouse and the point between g-h keys, viewing distance to the first text line of the screen, vertical distance

between the front edge of the seat and keyboard table top) were significantly associated with the assessments of either expert 1 or expert 2. However, each of these individual technical measurements explained only 3- 7%, and at most 11% of the expert ratings.

The results of the linear regression model for responsiveness to change are shown in Table 7. The coefficients of determination (R^2) for each of the models were relatively high, since the baseline value was included as a predictor. However, five VDU characteristic differences (distance between the mouse and the front edge of the table, distance between the mouse and the point between g-h keys, viewing angle to the first text line of the screen, distance between g-h keys and the table front edge, tidiness and space) had a significant effect ($p < 0.05$) on the expert assessment at the 2-month follow-up. Partial coefficients of determination for these differences ranged from 0.027 to 0.088.

Directions of all estimates were congruent for both experts.

6.4. Inter-observer repeatability and validity of a method to observe risk factors for upper limb disorders (Study 4)

The prevalence of positive findings was fairly similar for observers 1 and 2 for all physical load factors except for pinch grip and local mechanical pressure on the left side where the prevalence was lower for observer 2 (Table 8).

Inter-observer repeatability was good or moderate for repetitive use of the hand, hand force, pinch grip, and elevation of the upper arm. For nonneutral wrist posture, the proportion of specific agreement was high although the kappa values were lower. The inter-observer repeatability was poor for local mechanical pressure.

The validity was moderate or good for repetitive use of the hand, use of hand force, pinch grip, and nonneutral wrist posture, when expert observation was used as the reference standard. The validity of elevation of the upper arm was moderate for observer 1 and poor for observer 2. The validity was poor for local mechanical pressure.

Sensitivity and specificity were relatively high for both observers with regard to use of the hand force and pinch grip. Also nonneutral wrist posture showed a high sensitivity and specificity for observer 1. Sensitivity was high and specificity low for both observers for repetitive use of the hand, and for observer 2 for nonneutral wrist posture. In contrast, for elevation of the upper arm and local mechanical pressure, sensitivity was low and specificity high for both observers.

Table 7. Effect of changes in VDU characteristics on expert assessments at the 2-month follow up. Coefficients of determination for a difference in a characteristic (partial R^2) and for the whole model (R^2) are presented.

2-month – Baseline	Expert 1				Expert 2			
	estimate ^a	partial R^2	p-value ^b	model R^2	estimate ^a	partial R^2	p-value ^b	model R^2
Distance between mouse and front edge of table (cm)	0.029	0.039	0.0108	0.430	0.035	0.042	0.0154	0.317
Distance between mouse and the point between g-h keys (cm)	-0.035	0.050	0.0043	0.435	-0.046	0.067	0.002	0.357
Vertical distance between mouse pad and floor (cm)	0.020	0.002	0.5477	0.400	0.092	0.034	0.0262	0.317
Viewing distance to the first text line on the screen (cm)	0.016	0.008	0.2373	0.416	0.036	0.033	0.0253	0.342
Viewing distance to the home row of the keyboard (cm)	-0.016	0.002	0.5246	0.410	-0.019	0.003	0.5357	0.308
Viewing angle to the first text line of the screen (°)	0.049	0.066	0.0005	0.474	0.036	0.027	0.0466	0.332
Viewing angle to the home row of the keyboard (°)	0.066	0.073	0.0002	0.482	0.042	0.029	0.0738	0.338
Vertical distance between the eye and floor (cm)	0.029	0.011	0.1649	0.421	0.047	0.022	0.0771	0.319
Distance between g-h keys and table front edge (cm)	0.059	0.060	0.0013	0.453	0.084	0.088	0.0002	0.408
Left deviation of g-h keys and sagittal plane of the worker (cm)	-0.028	0.008	0.2457	0.424	-0.002	0	0.9615	0.325
Vertical distance between front edge of the seat and keyboard table top (cm)	0.042	0.013	0.1249	0.457	0.095	0.049	0.005	0.392
Ergonomics of the work chair	0.264	0.016	0.0888	0.442	0.322	0.018	0.0968	0.352
Tidiness and space	0.561	0.056	0.0014	0.472	0.541	0.039	0.0151	0.353

^a estimate (coefficient γ in Equation 1) for a difference in a characteristic in the linear regression model.

^b significance for a difference in a characteristic to be in the linear regression model (Equation 1).

Table 8. Inter-observer repeatability and validity of observations for six work load factors in 127 work cycles .

Physical load factor	Prevalence of positive findings %			Interobserver repeatability		Validity						
						Observer 1		Observer 2				
	Observer 1	Observer 2	Expert	Ps	κ (95% CI)	κ_1 (95% CI)	Se ₁	Sp ₁	κ_2 (95% CI)	Se ₂	Sp ₂	
Repetitive use of hand												
• right	64	68	73	.86	.58 (.43 .73)	.50 (.34 .65)	.79	.77	.45 (.28 .62)	.80	68	
• left	51	63	72	.83	.60 (.47 .74)	.51 (.38 .65)	.69	.95	.46 (.30 .62)	.77	.74	
Use of hand force												
• right	54	56	58	.87	.71 (.59 .83)	.70 (.58 .82)	.84	.87	.73 (.60 .85)	.87	.87	
• left	49	58	56	.82	.60 (.47 .74)	.69 (.56 .81)	.80	.90	.59 (.45 .74)	.85	.75	
Pinch grip												
• right	33	26	31	.70	.58 (.43 .74)	.64 (.50 .78)	.76	.88	.69 (.55 .83)	.72	.95	
• left	48	37	42	.77	.61 (.48 .75)	.51 (.36 .66)	.78	.74	.46 (.30 .61)	.83	.58	
Nonneutral wrist posture												
• right	91	80	79	.91	.41 (.20 .62)	.38 (.18 .58)	.97	.33	.42 (.23 .61)	.89	.52	
• left	84	75	80	.87	.34 (.15 .54)	.56 (.37 .74)	.94	.58	.38 (.19 .57)	.83	.58	
Elevation of upper arm												
• right	11	12	9	.71	.68 (.47 .89)	.57 (.33 .81)	.67	.95	.40 (.15 .66)	.55	.92	
• left	12	15	13	.47	.39 (.16 .61)	.45 (.22 .68)	.50	.94	.24 (.02 .46)	.38	.88	
Local mechanical pressure												
• right	16	14	3	.36	.24 (.03 .46)	.20 (.01 .41)	.75	.85	.23 (.0 .47)	.75	.88	
• left	17	6	9	.27	.19 (.02 .40)	.33 (.11 .55)	.58	.87	.46 (.18 .74)	.42	.97	

κ = Kappa, 95% CI = 95% confidence interval, Ps = Proportion of specific agreement, Se = sensitivity, Sp = specificity

When use of hand force was validated against force estimations by EMG, the validity was poor for all observed cycles. For the long cycles (>30 s), the validity was moderate for the right hand and poor for the left hand. For the short cycles, the validity was poor for both hands.

Sensitivity of the observations was high but specificity was low. When the observations of wrist postures were validated against goniometer data, the validity was poor. The sensitivity of the observations was again high, but specificity was low (Table 8).

7. DISCUSSION

7.1. Main findings and comparison to earlier studies

7.1.1. Risk factors for incident neck pain

The cohort study among office employees engaged in VDU work showed that incident neck pain was associated with both work-related and individual factors. An inappropriate physical work environment and poor VDU-related ergonomics, together with individual factors, such as gender, predicted neck pain. In addition, the employees with higher mental stress and less physical exercise had an especially high risk.

Poor placement of the keyboard was a predictor for neck pain. This finding is supported by the study of Aarås (1997) who found that supporting the forearms on the table top in front of the operator reduced significantly the load on both right and left trapezius. Also, the review of Bergqvist (1995b) and the study of Tittiranonda et al., (1999a) give evidence of associations between various aspects of keyboard use and symptoms in the neck-shoulder area and upper limbs.

Most of the evidence concerning the placement of the mouse has been related to hand/wrist disorders (Punnett and Bergqvist, 1997). Only few studies have reported an association between mouse location and neck pain (Aarås and Ro, 1997; Karlqvist et al., 1998). In the present study the placement of the mouse was not a significant risk factor either. The workers did not perform very mouse-intensive work: in the questionnaire the respondents reported to have used the mouse only 28% of the VDU working time, which might affect the result strongly.

High location of the computer screen (<20° below the horizontal line of vision) had a tendency for being a risk factor for neck pain. Visual discomfort and musculoskeletal strain, particularly in the neck and shoulders, have been shown to be associated with screen height (Bergqvist and Knave,

1994; Villanueva et al., 1996). Among the subjects with presbyopia, a higher monitor placement has been associated with neck extension caused by visual demands when using bifocals. On the other hand, an extremely low location is often associated with musculoskeletal stress caused by neck flexion (Turville et al., 1998; Fries Svensson and Svensson, 2001). However, the benefit of lower placement is a reduction of eye irritation, when the open surface of the eyes is smaller and the lachrymation is better. A recent field study on relatively young (mean = 37 years) who did not use bifocals supports the midlevel placement (~20° viewing angle) (Psihogios et al., 2001). According to the used criterion, the midlevel location or any lower placement was regarded as acceptable. This criterion was thought to be feasible for our study, as the subjects were older (mean age= 47 years), used commonly bifocals, and therefore may have benefited from a relatively lower location of the screen.

The physical work environment was a significant predictor in our study. This variable included five aspects: lighting, temperature, quality of air, size of the work room, and acoustic conditions of the work environment. The mean of the five components was calculated to represent the status of the physical work environment. However, also each component individually showed a positive association with the outcome. It has been suggested that especially lighting conditions are important for the reduction of visual discomfort in VDU work. Visual discomfort, in turn, has correlated highly with neck pain (Aarås et al., 2001b). Of the thermal conditions in VDU work, draught has been reported to be a problem in connection with discomfort in the neck-shoulder region (Fanger and Christensen, 1986). The quality of indoor air was also associated with neck pain in our study.

The risk for neck pain was significantly higher for the women than for the men. This is in agreement with earlier studies. Woman's smaller stature and lower strength of the shoulder muscles have been suggested to partly explain the sex difference (Mäkelä et al., 1999). In VDU work, gender differences have been found, for example, in the use of computer mouse. Women work with a higher relative musculoskeletal load, and apply, for instance, higher forces to the mouse, and use a greater range of motion, than do men (Wahlström et al., 2000). On the other hand, female sex may entail risk factors which were not measured in the study (Mergler, 1999). In our study, the different types of work tasks as such may be one explanation for the effect of sex on the results. The work tasks of the

women in our study were more monotonous, such as assisting and secretarial tasks.

7.1.2. Ergonomic intervention in VDU work

The intensive and the education groups had less musculoskeletal discomfort than the control group at the 2-month follow-up. However, the long-term effects in discomfort, strain or pain were not seen at the 10-month follow-up. After the intervention, the level of ergonomics based on a blind assessment, rated by two researchers, was distinctly higher in the intensive ergonomics group than in the education or control group. Furthermore, most changes in workstation dimensions and accessories took place in the intensive ergonomics group. This suggests that the changes made to the workstations had a positive impact on ergonomics. The scale used in the assessments was from 4 to 10. Already in the beginning, the ergonomic situation in most workstations was satisfactory, and this might fade out the contrast in the workstation before and after interventions, thus making it invisible on the scale from 4 to 10.

The modifications in workstation ergonomics included mainly adjustments of the screen, mouse, keyboard, forearm supports, and chair. These modifications changed the postures and movements of the head, neck and shoulder/upper arm. Since the positive effects were seen primarily in the shoulder/upper arm, neck and upper back area, it is possible that the effects were brought about by these changes.

Most of the amendments were done already before the 2-month follow-up, but a part of the ergonomic improvements were implemented out after the follow-up. In the interventions done in actual workplaces, it is not possible to blind the participants, so they know that they are in the intervention group. Therefore the placebo effect can not be totally avoided.

Mekhora and Liston (2000) modified VDU workstations to comply with the dimensions calculated by a computer application based on the anthropometry of the workers. It was assumed that changes in workstation dimensions could help to reduce the discomfort level of the participants by changing their work postures. Gerr et al., (2000) on their part found that work postures were not greatly affected by workstation dimensions. They pointed out that a large proportion of computer users do not work in so-called neutral postures. People, while sitting, use a range of different postures. Feelings of discomfort or fatigue also modify the sitting posture. Good workstation design supports a good posture and helps the workers to vary their postures during VDU work. In our study we utilised a participatory

approach and personal guidance to take into account the individual preferences of workers and changes in their work tasks.

In a controlled intervention study, Brisson et al., (1999) found a training program in ergonomics to be an effective tool to improve the ergonomics of VDU workers' workstations. Also another intervention of showed training to be useful in optimizing the ergonomics in VDU work (Menozzi et al., 1999). In our study the level of ergonomics did not differ between the education and the control group. The short 1-hour training may not have been sufficient to activate the workers to improve their workstation ergonomics. Workers may need concrete help and guidance, as in the intensive group, to plan and implement changes in their workstations.

Although there were only some improvements in the level of ergonomics in the education group, this group reported less discomfort than the control group. It is possible that the workers had adopted better working techniques or had found other ways to better organize their work, or took more pauses. Frequent short breaks from VDU work have been shown to reduce musculoskeletal discomfort and other complaints (Henning et al., 1997).

This study concentrated only on physical ergonomics. However, in order to make ergonomic interventions more effective, also psychosocial and organizational factors deserve deeper attention.

7.1.3. Expert assessment of the ergonomics of the VDU workstation

The ergonomics in VDU work is defined by several factors in workstation layout and dimensions, as well as the personal preferences of the worker (Marcus and Gerr, 1996; Bildt et al., 2001). In recent studies the main issues of VDU ergonomics have dealt with workstation arrangements, posture of the upper limbs, support for the forearms, line-of-sight angle, and sitting posture (Karlqvist et al., 1994; Aarås et al., 1997; Burgess-Limerick et al., 1999; Gerr and Letz, 2000; Hedge et al., 1999; Lintula et al., 2001; Marklin and Simoneau, 2001). The level of ergonomics can be estimated by using technical workstation measurements. However, the use of technical measures is often time-consuming. One option is to use an expert assessment for the overall assessment of ergonomics. To investigate the validity of the overall expert assessment we chose a group of essential workstation characteristics to represent ergonomics in VDU work.

Eleven of these characteristics were single measures of the workstation or the work posture (location of input devices and screen, sitting height). They are correlated with each other and they may

have an effect on various aspects of the work posture. For example, the location of the keyboard and the mouse are dependent on each other. The design of the keyboard affects the location of the mouse; moreover, the location of the mouse and sitting height affect the shoulder and arm posture. The technical measurements had minor effects on the expert assessments.

Two of the characteristics were ratings of the tidiness and space of the workplace and the ergonomics of the work chair, which were the most important explanatory factors for the expert assessment. This result was anticipated, since the space available is a basic element of the ergonomics of a workstation (council directive 90/270/EEC). The contents of the general European Union regulations have obviously determined well the concept of good ergonomics for the experts. An independent researcher assessed the tidiness and space. On the basis of photographs only, without a deeper understanding of the work tasks, it is difficult to assess whether there is enough space at the workstation. The experts had access to video extracts showing more about the tasks than what was seen in a single photograph.

According to the European Union directive of ergonomic requirements in VDU work, a good chair is adjustable and stable and allows the worker to change his/her posture easily (council directive 90/270/EEC). In modern offices almost all the work chairs comply with these minimum requirements. The ease of adjusting the chair and sitting comfort are still different in different types of chairs. The classification of the work chairs in our study was made according to their ergonomic properties without seeing seated worker. The ergonomics of the work chair had a strong impact on the assessments of both experts.

The changes in single work characteristics in the 2-month period were relatively small. Still, many of these changes showed a significant association with the ratings. For example, moving the mouse location towards the keyboard (i.e. shortening the distance between the mouse and the g-h keys) during the follow-up time had a positive effect on the expert ratings. Likewise, moving the mouse and the keyboard away from the front edge of the table, increasing the line-of-sight angle to the first row of the screen, and replacing the chair by one with better ergonomic properties, had all positive effects on the expert ratings. These changes may bring along a more neutral neck and shoulder position, a possibility to support the forearm on the table top, and a well-supported comfortable sitting posture. The ergonomics rating at the 2-month follow up was

also related to improved tidiness and better spatial arrangements, which further emphasize the importance of general order and functionality at the workstation.

7.1.4. A method to observe risk factors for upper limb disorders

A semiquantitative, time-based method to assess the presence of commonly agreed risk factors of upper limb disorders (Figure 3) was developed and validated. In the validation study, inter-observer repeatability was found to be acceptable for five of the six physical load factors. Observations of repetitive use of the hand, use of hand force, pinch grip, nonneutral wrist posture, and elevation of the upper arm showed moderate or good validity when expert observations were used as a reference standard. When observations were validated against force estimations (EMG) and wrist goniometer data, the validity was poor. The criteria for the threshold values for the intensity levels of the physical load factors were derived from the literature. The 1/3 limit for durations of risk factors was chosen arbitrarily except for the duration of nonneutral wrist postures (Keyserling et al., 1993).

The prevalence of positive findings estimated by EMG for the use of hand force was 80% for the right hand and 66% for the left hand. The observers and the expert found a considerably lower prevalence of high-force cycles. The observers as well as the expert clearly underestimated the use of hand force. Assessments of the use of force are made by observing for the movements and actions of a worker, i.e. looking for indirect evidence of the use of force. It is obvious that there are force production situations, e.g. static postures, in which such evidence is hard to see.

In our study a work cycle was classified as a high hand-force cycle if the worker handled objects >4.5 kg for more than one-third of the cycle time. When force estimations by EMG were used as a reference standard for the use of hand force, the kappa-values showed poor validity. Training for the observation was done against the expert observations, i.e. EMG measurements were not utilized at all in the training. In addition, the problem with the EMG measurements was that they were scaled to represent momentary usage of hand force during work even though the observation was estimated as a mean force during the cycle. In the PRIM study, a scale from 1-5 was used according to the percentage of maximum muscular strength. The estimates were based on the estimated external force in combination with the actual positions of the wrist joint. The inter-observer reliability was found to be

satisfactory (Fallentin et al., 2001). Juul-Kristensen et al., (2001) used the same observation criteria in her study of force demands in repetitive work and showed that the estimated peak force demand corresponded well with the measured peak EMG-level.

Both observers underestimated nonneutral wrist postures when the goniometer measurements were used as a reference standard, and this resulted in a poor validity of this item. Few previous studies have compared observed wrist postures with goniometer measurements in field conditions. In the study of Juul-Kristensen et al., (2001) the differences between observed wrist postures and goniometer measurements were small. A common difficulty in her and our study was that specifying the zero-point (reference position) was difficult. For instance, during gripping (both pinch and power grip) the metacarpals extend in relation to the forearm. If the sensor of the goniometer is placed on a metacarpal, gripping will always result in extension of the wrist.

Moreover, forearm rotation causes zero drift errors and cross-talk in goniometer measurements, which was not taken into consideration in this study (Buchholz and Wellman, 1997).

Although different nonneutral wrist postures differ with regard to their effects on the wrist, e.g. carpal tunnel pressure, all of them have been considered less desirable than the neutral posture (Viikari-Juntura and Silverstein, 1999). We did not differentiate between the direction of wrist deviation in our criterion for nonneutral wrist posture and used only one threshold value of 20°. In some studies, different reference values have been used for the different directions of deviated postures. Deviated postures of the wrist occur at work in combination rather than alone. It is therefore difficult for the observer to estimate each of the different postures in real work situations.

7.2. Methodological aspects

7.2.1. Study population and participation rates

As regards the validity of the results in the study on incident neck pain (Study 1), the crucial question would be related to a possible bias caused by a low participation rate. The drop-out rates in various longitudinal studies of musculoskeletal disorders have ranged from 7%-57% (Bildt et al., 2001). The response rates in our study were 81% in the baseline survey and 78% in the follow-up, corresponding to drop-out rates of 19%-22%. All in all, our response rates are among the highest ones in longitudinal studies, resulting in an overall participation rate of 63%. The non-respondents to the follow-up

questionnaire did not differ from the respondents with regard to most explanatory variables. However, the respondents seemed to be more stressed than the non-respondents.

In the ergonomic intervention study (Study 2) 124 subjects fulfilled the inclusion criteria. Fifteen subjects were not able or declined to participate. Thus, at the beginning of the study there were 109 participants. In the 2-month follow-up there were 107 participants, and in the 10-month follow-up 102. The primary reasons for dropping out were long sick leaves or leaving the job. The dropout rates can be considered low.

In the validation study of the exposure observation method (Study 4) a total of 127 work cycles of 14 workers in five occupations were studied, one to four workers representing one occupation. The cycles of a specific job are likely to be fairly similar, which may have helped the observers in their assessment and made the inter-observer repeatability and validity higher than they would have been had all cycles been from different jobs. The limited range of jobs also limited the variability in our data.

7.2.2. Study design

The study population for this prospective study was the entire population of those full-time working employees whose job included VDU work for more than 4 hours per week ($n=515$). Altogether 416 workers participated in the baseline survey in 1998 (81%). Of the baseline respondents, the subjects of interest were those who reported local or radiating neck pain for less than 8 days during the preceding 12 months. These subjects were classified as 'healthy' at baseline ($n=232$). This cohort was studied 12 months later, the response rate being 78% ($n=180$). At follow-up in 1999 the incident cases were those who reported local neck pain or radiating neck pain for at least 8 days during the preceding 12 months. The strength of the study was that all three groups (intensive ergonomics, education in ergonomics, control) were comparable as regards demographic characteristics and occupational factors measured at the baseline. The subjects were chosen to the three groups by individual randomization using the administrative unit as a stratum. Hence cultural differences between the units were controlled for. On the other hand, it was practically impossible to prevent personal interaction between the groups. The changes in workstation dimensions, and the slight improvement in ergonomics in the control group may be due to contamination by information from the intensive or education group, or may simply be a continuous development of workplaces. The observed effect of the intervention

may therefore be an underestimation of the true effect.

Moreover, technical problems resulting in loss of work load data for a third of the subjects, might have weakened the power of our analysis. The loss of measurements was, however, evenly distributed among the groups.

The main purpose of the ergonomic intervention of the present study was to activate VDU workers to identify problems in their own workstation and to find ergonomic solutions themselves. The role of the physiotherapists during the participatory process was to work as facilitators rather than actors.

7.2.3. Health outcomes

In first study the workload factors and workstation dimensions were used as explanatory variables and neck pain as the outcome. Pain is an unpleasant sensory and emotional experience in one or more parts of the body. Pain is always subjective. Many people report pain in the absence of tissue damage or any likely physiological cause. When the question is about musculoskeletal pain, it is often widely spread and not easy to locate.

Hence, it is difficult, if not impossible, to measure pain objectively. Self-reported symptoms collected with questionnaires have been the outcome in the majority of epidemiological studies on musculoskeletal disorders. The criteria for the duration and localization of the pain have varied in different studies. Standardized questionnaires such as the Nordic Questionnaire have been developed in order to facilitate comparison between studies. Nordic questionnaires have been widely used and can be considered as an international standard. In the present study, a slightly modified version of the Nordic Questionnaire was used.

When defining the incidence of a symptom, such as neck pain, one has to consider which cases are truly incident cases. For the identification of a symptom-free study population, a relevant time - period without symptoms before the occurrence of a new episode of pain has to be defined. No consensus of the optimal length of such a time period exists in the literature. A commonly used symptom-free time-period has been 12 months. The reporting of symptoms in the past year has proven to be more reliable than reports of recent symptoms (e.g. in the past month). In general, the Nordic questionnaire has high repeatability and sensitivity and, hence, it is a highly utilizable tool in screening and surveillance (Palmer, 2000).

In the ergonomic intervention study, pain and strain symptoms during the preceding 3 months and

daily discomfort were used as outcomes. Sensations of discomfort and strain are more reversible than pain. It is a common hypothesis, as yet unproven, that discomfort and strain are predecessors of pain.

7.2.4. Self-assessment of work load factors in VDU work

Most of the questions concerning pain, workload factors or workstation dimensions in this dissertation have been validated. The measures specific to VDUs, such as location of the screen, keyboard and mouse, were based on the measurements done by the subjects themselves. This might be a source of error if there were low agreement between the dimensions based on the measurements of the study subjects and those of the professional ergonomists. An earlier validation study has found good agreement between self-reported locations and direct measurements (Karlqvist et al., 1996).

However, the keyboard and the mouse are used in parallel, their placements being dependent on each other. The design of the keyboard affects the location of the mouse, and the location of the mouse affects the shoulder and arm posture. For example, mouse users may benefit from a shorter keyboard without a number pad (Tittiranonda et al., 1999c). It should also be noted that the actual work posture is not exclusively affected by these workstation dimensions (Gerr et al., 2000).

The physical work environment included five aspects: lighting, temperature, quality of the air, size of the workroom, and acoustics of the work environment. For each subject, the mean of the five components was calculated to represent the status of the physical work environment. The variables of the physical work environment were self-reported. Although this assessment preceded incident neck pain, there is a possibility of an error, if those who in the follow-up reported neck pain had a different perception of their work environment at baseline.

The various risk factors for musculoskeletal pain have depended on the duration of VDU work. The analyses were adjusted for the proportion of the total working time spent at the computer. The time used for VDU work was measured as the self-reported proportion of total working time during the preceding month. In a study among newspaper workers it was found that the workers overestimated their time working with the VDU when compared with that based on observation (Bernard et al., 1994). However, these validations concerned typing only, whereas in our study the definition for VDU work was use of the keyboard or other input or control device, including short periods of thinking and checking the results on the screen. The

preliminary results of our own validation among a sample of workers support the findings of Bernard et al., in that the workers tended to overestimate their VDU working time.

7.2.5. Expert assessment

The inter-examiner repeatability between the two experts in assessing the level of ergonomics in VDU work, and in industry, was good; this may be due to the fact that in both studies (1 and 4) both experts had the same educational background. Therefore they obviously shared a similar idea of ergonomics and risk factors for musculoskeletal disorders already at the start of the study. The training period converged the experts' assessments further. Thus, when carrying out the study, they obviously based their assessments on the same criteria even if the personal weighting of single criteria might have been different.

The inter-observer repeatability for the studied VDU ergonomic assessment was high and the ratings of the experts correlated with the work place characteristics. There is no golden standard for the validation of an assessment of the ergonomics in VDU work. The values of the technical measures can be questioned. However, in practical ergonomics, an expert assessment is probably more useful than time-consuming measurements and sophisticated calculations.

When validating the observation method to assess the physical loads imposed on the upper limbs, force estimations by EMG served as a reference standard for the use of hand force. In the results, kappa-values showed poor validity. Two factors can explain these contradictory results. Firstly, the training for observation was done against the expert observations, i.e. direct measurements of EMG were not utilised at all in the training. Secondly, the problem with the EMG measurements was that they were scaled to represent momentary use of hand force during work. A biomechanical model of the hand would have provided a more reasonable estimate of hand force, taking into account various factors, e.g. anatomical differences, different postures of the hand and forearm, and the non-linear relation between the myoelectric activity of a muscle and force production.

Both observers underestimated nonneutral wrist postures when the goniometer measurements were used as a reference standard, and this resulted in a poor validity of this item. The use of the wrist goniometer in field conditions entails several problems. For instance, during gripping (both pinch and power grip) the metacarpals extend in relation to the forearm. If the sensor of the goniometer is placed on a metacarpal, gripping will always result in

extension of the wrist. Moreover, forearm rotation causes zero drift errors and cross-talk in goniometer measurements, which was not taken into consideration in this study.

This method, validated in industry, combines some features of checklists and continuous observation methods. Continuous observation is needed to make a decision on the fulfilment of the time aspect of the criteria. Contrary to many other continuous methods, there is no need to assess the level of a risk factor during the observation. Instead, the entire cycle is observed, after which a dichotomous estimation (above or below reference level) is given. This simplifies the continuous observation and decreases the labouriousness of the method.

8. CONCLUSIONS

1. In the prevention of neck disorders in office work with a high frequency of VDU tasks, attention should be given to the work environment in general, as well as to the more specific aspects of VDU workstation lay-out. In addition, our study gave further evidence that physical exercise may help prevent neck disorders among sedentary employees.
2. Both the intensive ergonomics approach and education in ergonomics reduce discomfort in VDU work. One way to improve the level of physical ergonomics in VDU workplaces is to initiate a co-operative action in which both workers and occupational health practitioners are actively involved.
3. The inter-observer repeatability for the studied method was high, and the ratings of the experts correlated with the work place characteristics. There is no golden standard for validating the assessment of the ergonomics in VDU work. The values of the technical measures can be questioned. In practical ergonomics, an expert assessment is probably more usable than time-consuming measurements and sophisticated calculations.
4. Inter-observer repeatability and validity were acceptable in the semiquantitative, time-based method developed to assess the presence of the most commonly occurring risk factors of upper limb disorders. This observation method is meant to be used by health and safety professionals or engineers in actual workplaces. The used reference values for the proportional duration of some physical load factors need further

consideration. Studies should be carried out to assess the limits that best differentiate between safe and hazardous jobs.

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10. AUTHOR BIOGRAPHY

RITVA KETOLA

Employment

Senior researcher

Finnish Institute of Occupational Health, Helsinki

Degrees

PhD, Occupational Physiotherapist

Research interests

Ergonomics, musculoskeletal health

Email:ritva.ketola@ttl.fi

✉ Ritvo Ketola

Finnish Institute of Occupational Health,

Topeliuksenkatu 41 A FIN-00250 Helsinki, Finland