Ergonomics, musculoskeletal disorders and computer work

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Abstract
This review summarizes the knowledge regarding ergonomics and musculoskeletal disorders and the association with computer work. A model of musculoskeletal disorders and computer work is proposed and the evidence and implications of the model together with issues for future research is discussed. The model emphasizes the associations between work organization, psychosocial factors and mental stress on the one hand and physical demands and physical load on the other. It is hypothesized that perceived muscular tension is an early sign of musculoskeletal disorder, which arises as a result of work organizational and psychosocial factors as well as from physical load and individual factors. It is further hypothesized that perceptions of exertion and comfort are other possible early signs of musculoskeletal disorders in computer work. Interventions aimed at reducing musculoskeletal disorders due to computer work should be directed at both physical/ergonomic factors and work organizational and psychosocial factors. Interventions should be carried out with management support and active involvement of the individual workers.

Key words
Physical load; psychosocial factors; VDU; VDT.

Introduction
During the last two decades, the number of workers with visual display units (VDU) has increased dramatically. In 2001, approximately 65% of the Swedish workforce used a VDU in their occupation, compared to 30% in 1989 [1]. Since the late 1980s, the use of non-keyboard input devices has increased rapidly and today the market is filled with a large number of different non-keyboard input devices, although the most widely used is still the computer mouse [1,2].

There are only a few published papers that report the incidence of musculoskeletal symptoms and disorders among VDU users. A Finnish study [3] reported the annual incidence of neck pain among VDU users to be 34%. A prospective cohort study from the USA reported the annual incidence of neck/shoulder musculoskeletal symptoms to be 58 cases/100 person-years [4]. Cross-sectional studies of VDU users have reported a prevalence of 10–62% of musculoskeletal symptoms in the neck/shoulder region among VDU users [5–8].

Musculoskeletal symptoms of VDU users are believed to have a multi-factorial aetiology. Non-neutral wrist, arm and neck postures, the work station design and the duration of VDU work as well as psychological and social factors, such as time pressure and high-perceived workload, are believed to interact in the development of these symptoms [9–13]. Several studies have suggested that an increased prevalence of upper extremity musculoskeletal symptoms may be associated with increased computer mouse use [6,14,15].

The aim of this review is to give a summary of the knowledge regarding ergonomics, musculoskeletal disorders and computer work and to present a model that could be used in future research.

Physical load factors
Physical load is defined as factors relating to biomechanical forces generated in the body. In the literature, this has also been defined as ‘mechanical exposure’ to indicate that other factors in the environment are not considered (i.e. lighting, noise, the thermal environment, work organization, psychosocial factors, etc.) [16].

Muscular load
The most common method to assess muscular load within this field has been electromyography (EMG). In the early 1950s, Lundervold [17] used EMG to investigate muscle activity in patients with so-called ‘occupation myalgia’. ‘Occupation myalgia’ was defined as pain in muscles overstrained as a result of unvaried work (i.e. static work). Most of the patients studied had...
typewriting as one of their main job tasks [17]. To quantify EMG in relation to risk, load limits have been proposed based on the 10th, 50th and 90th percentiles of the amplitude distribution of the muscle activity [18]. VDU work is characterized by low levels of muscle activity, especially in the trapezius muscles, and no safe lower limit of muscle activity may exist [16]. Two other EMG measures used are gap frequency (i.e. number of periods with muscle activity below a predefined threshold level per time unit) and muscular rest (i.e. the total time with muscle activity below the predefined threshold level relative to the total duration of the recording time) [19, 20]. Some studies have observed that muscular rest and EMG gaps (short periods of muscle rest) are associated with a higher risk of musculoskeletal symptoms in the neck/shoulder region [21–23]; other studies have failed to show this association [24–26].

Several hypotheses have been proposed for the pathogenesis of work-related musculoskeletal symptoms and pain [27–31]. One suggests that low static contractions during work may result in a recruiting pattern or motor programme, in which only type I muscle fibres are used, and this may lead to selective motor unit fatigue and damage [32]. A similar hypothesis known as the ‘Cinderella hypothesis’ has been proposed by Hägg [28]. In line with these hypotheses is the overload of type I muscle fibres during prolonged static contractions. The theory about an overload of type I muscle fibres has been supported in morphological studies in which ragged-red fibres (injured type I muscle fibres) were observed to be associated with occupational static loads [33,34]. Recent results from experimental studies using intramuscular EMG support the hypothesis of a recruiting pattern with type I muscle fibres that are continuously active during static as well as dynamic arm movements, VDU work and mental stress [35–39]. Observations of motor unit substitution have been reported, that is, when one motor unit is de-recruited and another motor unit is recruited [39,40]. Inter-individual differences in motor unit activity patterns have been observed, with some but not all subjects showing continuously active motor units [39,41]. Mathiassen and Aminoff [42] observed inter-individual differences in the motor response of the trapezius muscle when subjects performed isometric (static) shoulder contractions. They suggested that the different motor responses may explain why individuals with the same exposure do not contract the same type of symptoms, or why some individuals remain healthy.

It has been discussed whether the low levels of muscle activity recorded during light manual and/or VDU work are associated with increased risk of musculoskeletal symptoms, since the levels are probably hard to differentiate from levels during inactive living [26]. A recently proposed hypothesis is the blood vessel–nociceptor interaction hypothesis by Knardahl [29]. The hypothesis pertains to work situations with cognitive tasks and low-level muscle contractions and suggests that blood vessel–nociceptor interactions are of central importance in generating pain. Knardahl’s hypothesis raises the need to rethink the methods and concepts used for studies of myalgia and musculoskeletal symptoms and pain associated with VDU use.

Supporting the forearms and wrists during keyboard and input device work has been proposed as a preventive measure. This has mainly been based on experimental studies observing decreased muscle activity in the trapezius muscle when supporting the forearms [43–45]. Recently published studies with a longitudinal design have also observed that supporting the arms during VDU work is associated with decreased risk of developing neck/shoulder symptoms and disorders [46,47].

Postures and movements

The results from a prospective study by Ariens et al. [48] showed a positive association between sitting at work for more than 95% of the working time and neck pain; a trend was also observed for a positive relation between neck flexion and neck pain. However, another prospective study observed a greater downward tilt to be associated with lower risk of neck/shoulder symptoms and disorders [47].

Non-neutral postures of the shoulder (i.e. flexion and abduction) have been found to be associated with musculoskeletal symptoms of the neck and upper limbs in previous reviews [9,12]. A recently published prospective study found that non-neutral postures of the shoulder were not associated with neck/shoulder or hand/arm symptoms or disorders [47]. In the study by Marcus and colleagues [47], the only posture variable that showed an increased risk for musculoskeletal symptoms and disorders was if the inner elbow angle was < 121°.

Extreme positions of the wrist have been considered to be a risk factor for musculoskeletal symptoms of the hand and wrist [49–51]. A recently published study suggested wrist extension of > 20° increased the risk of carpal tunnel syndrome (CTS) [52], though a prospective study concluded that VDU work does not impose an occupational hazard for CTS [53]. Repetitive work has been associated with an increased risk of musculoskeletal symptoms of the wrist and forearm [51,54–57]. With exposure to both extreme postures and repetitive tasks it has been suggested that the risk increases, compared with exposure to only one risk factor [51].

Force

The forces applied to the computer mouse and keyboard may be a risk factor for musculoskeletal symptoms [58,59]. It has been observed that 3–4 h of computer
mouse work could lead to fatigue in the muscles of the forearm [59]. It is not known if the forces applied to the sides and button of the computer mouse is associated with increased risk for developing musculoskeletal symptom. It has been observed that subjects with more severe musculoskeletal symptoms apply higher force while keyboarding [58].

Visual demands

Eye symptoms and visual discomfort has been associated with VDU work [9,46,60]. Positive results from improved visual conditions and optometric corrections have been demonstrated in a 6-year follow-up study [46]. Current guidelines regarding monitor placement at VDUs suggest that the top of the screen should be at or slightly below eye level. In recent years, lower monitor placements have been proposed [61]; however, there is not enough scientific evidence available to change the current guidelines.

Work organization, psychosocial factors and mental stress

Since the early 1990, the role of work organization and psychosocial factors within the work environment has gained more focus in the study of work-related musculoskeletal disorders. The work organization or work system has been suggested to consist of five important components: organizational structure, people or personnel sub-system, technology or technological sub-system, work tasks, and the relevant external environment [30]. The different elements in the work system are thought to affect psychosocial factors, for example, job demands, decision latitude and social support from managers and colleagues.

Duration and patterns of work

The duration of VDU work has in several studies been identified as a risk factor for musculoskeletal symptoms of the neck and upper limbs [5,9,12,62]. When reviewing the literature, there seems to be more evidence for an association between the duration of VDU work and musculoskeletal disorders in the forearm and hand compared to associations between the duration of VDU work and symptoms/disorders in the neck/shoulder region [47,63,64].

Blangsted et al. [65] studied VDU users in a department at a municipal administration and reported the mean hourly number of mouse clicks to be 230 and the mean hourly number of keystrokes to be 1960. In a subgroup of the NUDATA-cohort, the keying speed in the 75th percentile was measured to be from 8000 to 22000 keystrokes/h [53]. This indicates a large between-subject variability in keying speed and number of keystrokes performed. It is also reasonable to believe that the number of mouse clicks varies to a large extent, depending on occupation, work task and the software used to carry out the work task. The combination of high repetitiveness in the fingers and wrist, the static loading imposed on the thumb to grip the mouse, the prolonged extension and ulnar deviation of the wrist and the long duration may all be contributing to the development of musculoskeletal symptoms in the forearm and hand/wrist. Several studies have also found an increased risk for hand/wrist symptoms among individuals with long daily duration of VDU and computer mouse use [5,9,47,63].

Psychosocial factors and mental stress

A wide range of different instruments have been used to assess psychosocial factors in the work environment, one of the most widely used being the demand–control model developed by Karasek and Theorell [66]. The most common way of assessing psychosocial factors has been through use of questionnaires (i.e. self-judgements). A number of different psychosocial factors have been proposed as risk factors for musculoskeletal symptoms in the neck/shoulder region, for example: high job demands, low decision latitude, time pressure, mental stress, job dissatisfaction, high workload and lack of social support from colleagues and superiors [9–12, 67–78]. Several theoretical models of how psychosocial factors are associated with musculoskeletal symptoms and disorders have been proposed [10,29,31,71,79–82]; for an overview, see Huang et al. [83]. Several of the models suggest that adverse psychosocial factors cause mental stress, which is hypothesized to increase the risk of musculoskeletal symptoms.

The terminology regarding the word ‘stress’ has not always been used consistently by the different research traditions within the field of ergonomics (e.g. psychology and biomechanics). Here, a ‘stressor’ is a factor or condition causing a physiological or psychological response. The definition of ‘stress’ is, therefore, that it is a non-specific response to a stressor, physical or psychological/ mental, consisting of several physiological and/or psychological reactions.

Individual factors

Sex

In almost all scientific studies of work-related musculoskeletal disorders, women are found to be at higher risk than men, regardless of the kind of work or occupation involved. The same difference exists between women and men regarding VDU users [3,5,6,9,12,62,84]. In the study by Ekman et al. [84], in which the aim was to investigate possible differences between women and men
in the reporting of musculoskeletal symptoms among VDU users in the Swedish workforce, the estimated odds ratio for sex (women/men) was 11.9 (95% confidence interval [95% CI] 2.9–50.0). Two explanations for this increased risk for women discussed by the authors were that sex could be a confounder of non work-related factors and that there could be a difference in the occupational exposure among men and women [84]. In a review of epidemiological findings on VDU work and musculoskeletal symptoms, Punnett and Bergqvist [9] stated that women appear to consistently report more neck and upper extremity symptoms than men. No definite explanations were found in the reviewed studies, but differences in household work and childcare, work situation differences and constitutional differences were mentioned as possibilities. In a recent review, Tittiranonda and colleagues [12] suggested that differences in anthropometrics may cause women to work in more extreme postures or using higher relative muscle forces than men. In a cross-sectional study of Swedish VDU users, women reported more symptoms in all body regions than men and were more often exposed to physical and psychosocial conditions that have been considered harmful [62].

**Working technique**

Differences in working technique when performing VDU work have been observed, both in experimental studies [43–45] and in field studies [85]. It has been suggested that individuals with a poor working technique (assessed with an observational checklist) during VDU work, work with higher muscle activity in the forearm and shoulder (trapezius) and their wrist more extended [85].

A concept somewhat similar to working technique is workstyle, which has been conceptualized as a multi-dimensional (i.e. behavioural, cognitive and physiological) stress response to work [86]. Wrist postures, finger movements, speed/jerkiness of movements and force applied while keying are examples of variables included in this construct. Previous research on workstyle has indicated that various dimensions of the construct are associated with pain, symptom severity and functional limitations [58,87].

**A model of musculoskeletal disorders and computer work**

A model of musculoskeletal disorders and computer work is proposed (Figure 1), the model is modified from Sauter and Swanson [81].

Work technology (‘VDU/Office technology’) has a direct path to physical demands, as defined by the physical coupling between the worker and the tool (i.e. workstation ergonomics). There is also a direct path from work technology to work organization. The path from work organization to physical demands suggests that the physical demands from work can be influenced by work organization. Increased time pressure leads to an increased number of keystrokes or implementation of new software leads to increased computer mouse use, which in turn may increase the physical load [88,89]. Individual factors are hypothesized to modify the association between physical demands and physical load. It has been observed that individual factors such as working technique and sex may affect the physical load [43–45,85]. Individual factors are also hypothesized to modify the association between work organization and mental stress. The model also shows a path from work organization to mental stress, which in turn influences musculoskeletal outcomes. Mental stress may increase muscle activity [38,89–94], but also the forces applied to the computer mouse [89], which compounds physical load induced by physical demands. Mental stress has also been hypothesized to moderate the relationship between physical load and musculoskeletal outcomes. A difference between the present model and the original model proposed by Sauter and Swanson [81] is the direct path from mental stress to perceived muscular tension. This association is supported by recent research that has observed mental stress and psychosocial factors to be independent risk factors for neck pain [68,78]. The reason for having a direct path from mental stress to musculoskeletal outcomes, not mediated through physical load, is that the mechanisms behind unspecific musculoskeletal symptoms are not well known. Physical load has a direct path to perceived muscular tension, and this association is also supported by recent findings [95]. Perceived muscular tension is hypothesized to be an early sign (cf. ‘detect sensation’ in the original model by Sauter and Swanson) of musculoskeletal symptoms, which has also been observed in a prospective study of VDU users [96]. Other factors hypothesized to be early signs of musculoskeletal symptoms are perceptions of comfort and exertion. Finally, it is hypothesized that the experience of musculoskeletal disorders feeds back to influence mental stress at work and the work organization.

Neither the model proposed here nor the original model by Sauter and Swanson is complete. None of the models takes environmental factors outside of work into account, for example home life factors that could modify perceptions of mental stress. Productivity is an important outcome that is not accounted for in the model and it is not certain that the factors associated with musculoskeletal symptoms are the same as those associated with decreased productivity. Decreased productivity due to musculoskeletal symptoms among VDU users has been observed [97]. Further research is needed to establish which factors cause perceived muscular tension and other...
possible sensations, such as perceptions of exertion and comfort. The aetiology behind unspecific musculoskeletal symptoms in the neck/shoulder and forearm region is unknown and there is a need for more knowledge regarding the specific mechanisms causing pain in these regions. An excess risk due to the interaction between physical and psychosocial exposure during VDU work has recently been indicated [96] and that is an interesting issue for future research.

New intervention strategies focusing on the individual may be an alternative approach in occupations characterized by intense VDU work, which would entail low force requirements but high physical exposure with regard to precision and repetitive demands. This issue has been addressed by Holte et al. [98] and Holte and Westgaard [98,99], who pointed out that there may be a need to assess factors that focus more on the individual translation of the exposure into an individual response than on the more traditional risk factors such as job strain and physical exposure. Another factor to consider in intervention strategies is working technique in combination with information about the importance of workstation layout and psychosocial risk factors. Ketola et al. [100] investigated the effect of an intensive ergonomics approach and education on workstation changes and musculoskeletal disorders among VDU users. Their study was a randomized controlled trial and the subjects were allocated within three different groups, an intensive ergonomics, an ergonomic education and a reference group. After 2 months of follow-up, less discomfort was reported by the intensive ergonomics and the ergonomic education groups than by the reference group. The authors concluded that cooperative planning in which both employees and practitioners are actively involved (i.e. participatory ergonomics) will achieve the best results when attempts are made to improve physical ergonomics of VDU workstations. Other intervention studies, though not as well designed as the study by Ketola and colleagues [100], have reported similar results for ergonomic improvements [46,101,102]. It has also been suggested that office ergonomics programmes may be effective in reducing worker compensation costs and injury rates due to musculoskeletal disorders [103].

Interventions conducted by the occupational health services could also focus on more than one factor in the proposed model. For example, an intervention could comprise optimization of the workplace layout (modifying the physical demands) in combination with a feedback survey of the psychosocial work environment (modifying the psychosocial factors) and individual training focusing on working technique (modifying the individual factors). This approach would not add any scientific knowledge, other than knowledge about whether the intervention could decrease musculoskeletal symptoms or decrease exposure, but would be a way for the occupational health service to design effective interventions based upon the existing scientific knowledge. Following the suggestions from a recent review [104], this should be carried out by actively involving the individual worker. Management support and active involvement have also been pointed out as important factors to address when designing interventions [104,105].

References

37. Kadefors R, Forsman M, Zoega B, et al. Recruitment of low threshold motor-units in the trapezius muscle in...


102. Nevala-Puranen N, Pakarinen K, Louhevaara V. Ergonomic intervention on neck, shoulder and arm symptoms
of newspaper employees in work with visual display units. *Int J Ind Ergonomics* 2003;31:1–10.

