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INTRODUCTION

This publication is a compendium of NIOSH publications and reports on video display terminals (VDTs). It updates and supersedes the NIOSH document *Publications on Video Display Terminals (Revised)* dated June 1991.

This publication is divided into two Parts:

- Part I consists of full or partial text of selected NIOSH documents on video display terminals. The first document (pages 3-14) provides an overview of the various occupational health issues relating to VDT use. Each of the subsequent documents addresses a specific issue.

- Part II contains a comprehensive bibliography of NIOSH documents on video display terminals. It is divided into two sections: (A) NIOSH-authored documents (which include numbered publications, testimony, journal articles, health hazard evaluations, and miscellaneous reports) and (B) NIOSH-funded documents (which include grant and contract reports). Each document citation includes the title and year of publication and bibliographic or ordering information (see below). Those documents listed in Part II that are reproduced in Part I are noted with the following statement: *(Full [or partial] text included in Part I.)*

All documents listed in Part II may be obtained in one of the following ways:

1. Copies of any document cited with an "NTIS NO" may be ordered from the National Technical Information Service (NTIS) using the order form on page 133. NTIS prices are listed as price codes (e.g., A03). The actual prices corresponding to those codes are shown on the price schedule on page 134. NTIS prices are subject to change without notice.

2. Copies of journal articles, book chapters, and proceedings may be obtained from public or university libraries using the bibliographic information shown in the citation.

Part I

Full or Partial Text of Selected NIOSH References on Video Display Terminals

Environmental and Occupational Medicine, Third Edition, edited by William N. Rom. Published by Lippincott–Raven Publishers, Philadelphia, 1998.

CHAPTER 100

Occupational Health Aspects of Work with Video Display Terminals

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In 1973, Hultgren and Knave first recognized the potential health risks of video display terminal (VDT) use. Since that time, VDTs have become almost ubiquitous in the workplace, and an enormous amount of research has examined their effects on both the design of jobs and the health of workers. The National Institute for Occupational Safety and Health (NIOSH), alone, has conducted several dozen health hazard evaluations and published more than 50 scientific reports on the subject (1). It is not possible to address all of the research findings to date in this chapter; rather, the chapter focuses on key studies to summarize current views on the risks of VDT use. Ergonomic and organizational countermeasures are also discussed. While closure is emerging on some issues (e.g., effects on vision), uncertainty in other areas seems to be increasing. For example, it is becoming increasingly apparent that musculoskeletal disorders among VDT users are not a simple function of biomechanics alone. Data strongly suggest that psychosocial factors play an important etiologic role, although their relative importance and mechanisms of effect are not well understood.

This chapter addresses four health end points: visual system dysfunction, musculoskeletal disorders, stress, and adverse pregnancy outcomes. For each end point we summarize findings on the nature, prevalence, and causes of health or functional disturbances in VDT work; a description of recommendations, as available, for control of these effects is also provided.

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VISUAL SYSTEM DYSFUNCTION

Until recent years, visual system disturbances such as sore, aching, irritated, or tired eyes, and blurred or double vision were at the focus of health concerns in VDT work. Headache is often included in this cluster. Together, these types of disturbances are often referred to loosely as asthenopia, visual fatigue, or simply eyestrain, the expression used in this chapter.

Reviews of field studies of VDT operators suggest that prevalence rates of 50% or more for at least occasional experience of certain eyestrain symptoms are typical (2–4). By far, ocular discomfort symptoms, as opposed to visual imperception, are the most common problems. In one of the first NIOSH studies of VDT users, for example, 75% of VDT users reported occasional aching or burning eyes at work, whereas 39% reported blurred vision (5). (The rates were 27% and 5%, respectively, for frequent or constant problems.) In perhaps the largest epidemiologic study of VDT users ever conducted (over 20,000 Italian workers), burning eyes was the most common symptom (reported by more than 30% of participants). Only half this number reported blurred vision (6).

Eyestrain problems are by no means unique to VDT work. They were described in antiquity (7) and have proliferated in modern times with the increasing near vision job demands associated with the expanding information sector of the economy. Carmichael and Dearborn (8) recognized this growing problem in 1947: "There is probably no single way in which the demands made by modern industrial civilization upon the human organism differ more from those of earlier times than in the requirements made upon the eyes" (p. 1). In this regard, many studies of VDT users have shown that prevalence rates for eyestrain are often comparable to the rates among clerical workers who do not use VDTs (5,9,10).

Health Implications

While eyestrain from VDT use can be a painful and debilitating problem, there is little evidence of pathophysiologic or enduring functional changes in the visual system that can be connected with VDT use. In a comprehensive review of studies seeking objective correlates (e.g., changes in accommodation, vergence, heterophoria, acuity, flicker sensitivity) of reported eyestrain among VDT users, the World Health Organization (WHO) found little consistent evidence of dysfunction (4). In contrast, other studies found shifts in tonic accommodation and vergence following near work and VDT work [see Tyrell and Leibowitz (11) for a review]. Also, the potential for color perception abnormalities following video display viewing is generally acknowledged, but such effects are not known to persist.

With regard to organic disease of the eyes, cataract development in VDT work was once a major concern. This possibility has been discounted, however, by the National Research Council (3), and findings of several subsequent epidemiologic studies have been generally supportive of this position (12–15). In the above-mentioned Italian epidemiologic study of 20,000 VDT users (16), researchers found no connection between the use of video terminals and the early appearance of cataracts, nor with any of nine other pathologic ophthalmic conditions (ocular hypertension, hypertensive retinopathy, etc.). Electromagnetic radiation is the only known VDT-dependent risk factor for cataractogenesis. WHO (4), however, claimed that radiation emissions from VDTs cannot be considered as a credible cause of cataract formation in VDT operators.

In a 1990 reappraisal of risks to the eyes, the WHO concluded, "There is no evidence of damage or permanent impairment to the visual system of persons working with VDTs" (30). This WHO conclusion was based almost entirely on cross-sectional or acute exposure studies. There are, however, some prospective findings that provide supportive evidence. A 2-year study of Dutch telephone operators, for example, showed no deterioration in optometric measures of visual function (17). A more recent, 6-year longitudinal study of visual health comparing VDT users to controls in Australia concluded that there is no convincing evidence to support the hypothesis that VDT use could be harmful to the eyes (18). In comparing year 1 and year 4 data, the study showed no significant differences in the two groups in visual acuity, or in abnormalities of the lens (opacities), cornea, aqueous humor, iris, or pupil. Age, however, seemed to be related to some of the eye abnormalities.

Etiology and Control

As suggested above, eyestrain is a rather imprecise concept. Symptoms are nonspecific and objective signs are lacking. Duke-Elder and Abrams (19) define eyestrain in terms of the symptoms resulting from the "conscious striving" to see. According to this definition, any aspect of the visual environment or of the individual that impairs the legibility or visibility of a visual display is liable to lead to eyestrain.

As summarized below, knowledge exists on ways to maximize the visual quality of displays and on appropriate vision correction to minimize eyestrain among VDT users. Application of this technology alone, however, may be only partially effective in controlling eyestrain from VDT use. The reason is that psychological or motivational factors can intervene to influence the conscious efforts of seeing. This is probably one explanation why eyestrain is unlikely when reading a newspaper or interesting novel, even though the print may be small or of poor quality. In this regard, the very nature of VDT jobs must be considered in assessing potential for eyestrain in VDT work. A recent survey of Swedish public employees found, for example, that eye discomfort among VDT users was related to work organization factors such as lack of work control, high work pace, and time pressure (20).

There are three classes of variables that could influence the legibility and visibility of VDT displays: (1) visual capabilities of VDT users, (2) physical characteristics of the video display, and (3) workplace lighting (which interacts with display characteristics). Only a synopsis of key measures to optimize these variables for VDT work is possible here. Numerous texts provide a more extensive treatment of this subject, as well as quantitative design specifications for high-quality displays (2,21–25).

Vision Correction

Miscorrected or uncorrected problems may be an important cause of eyestrain among VDT users (26–28). Hypermetropes and presbyopes may be at special risk (27,28). In correcting the vision of VDT users it is of primary importance to remember that the viewing distance for VDT images is usually greater, in the neighborhood of 48 to 65 cm (29), than the distance for reading hard copy. This poses a special problem for presbyopes who use reading glasses or bifocals because the video display is usually at an intermediate distance between the far point of near vision and the near point of far vision. Such persons often require special lenses to see clearly without extraordinary effort. Similarly, the customary (lower lens) placement of the near-vision bifocal is often problematic, necessitating an uncomfortable backward tilt and forward flexion of the head for display viewing.

WHO recommends an eye examination for all VDT operators before they begin work, and subsequent examinations beyond age 40 years, especially for persons who report musculoskeletal or eyestrain symptoms (30). WHO recommends that the examiner be trained in visual ergonomics and that examinations include both refraction and visual acuity. WHO cautions against the tinting of eyeglasses for control of glare in the VDT environment. This action could result in unsatisfactory foreground-background contrast on the video display.

DESIGN FEATURES

Video display and workplace design features are believed to influence visibility, legibility, and comfort video display viewing. The American National Standard for Human Factors Engineering of Visual Display Terminal (21) provides perhaps one of the most comprehensive and authoritative guidelines to maximize these parameters. This standard, prepared by the American National Standards Institute (ANSI) and the Human Factors and Ergonomics Society is presently undergoing revision, and an update is anticipated in 1997 or 1998.

Display Characteristics

Character Contrast

A strong character-to-background contrast ratio is one of the most important conditions for comfortable viewing of a video display. In this regard it is critical that screen reflections, both sharp and diffuse, be minimized. The best solution is to reduce excess or stray room lighting (see Workplace Lighting, below); alternatively, filters that can be placed over the display may attenuate reflections. However, these filters (examples include "micromesh" filters, "neutral density" filters, "polarizing" filters) should not be employed without prior testing, since character brightness or sharpness also may be excessively reduced.

Character Sharpness

Character blur can lead to excessive and futile efforts of the eye to bring characters into focus. The culprit may be an aging VDT, a maladjusted focus control, or excessive character brightness (character brightness is often increased intentionally to overcome contrast problems), resulting in radiation of light ("bloom") around the edge of characters, which creates blur.

Character Design

Small or tightly spaced characters and unusual fonts are difficult to discern and create problems in distinguishing among characters, impairing legibility and comfort.

Image Stability

Image instability may result in blur or annoying flicker of the display. VDT images that are created using cathode ray tube technology are inherently unstable, owing to the screen "refresh" process necessary to create the image. However, this type of problem is becoming increasingly rare as VDT technology improves. Excessive character brightness, resulting, possibly, from efforts to improve contrast, increases the ability to detect the instability in video displays.

Color

Characters formed by colors at the ends of the spectrum (blues and reds), are less visible than green, yellow, and white characters. Excessive numbers of colors on the display may also add to confusion, and when the colors are widely separated on the spectrum (e.g., simultaneous use of both reds and blues), some blurring may be perceived.

Image Contrast Polarity

At present, there seems to be little consensus that displays with dark characters on a light background are more or less stressful to the eyes than displays with light characters on a dark background.

Workplace Lighting

The lighting requirements for reading from hardcopy and from video displays are different. Within limits, increases in ambient illumination increase the legibility of paper documents, and in this regard a bright visual environment is desirable in the conventional office setting. A bright office environment, however, creates a risk in VDT work, since it increases the opportunity for screen reflections (diffuse or sharp glare), which are at best annoying and at worst obscure the display. A number of measures, including reorienting VDTs, selective removal of light fixtures, or use of partitions or blinds, may be helpful in controlling room lighting in offices where VDTs are used. The ANSI (21) guidelines suggests the use of a mixture of general and task lighting in the VDT workplace. Task or local lighting can improve the visibility of printed matter, while not impairing the visibility of the video display.

With regard to lighting systems for VDT use, "lensed-indirect up-lighting systems" that distribute the light over a broad area of the ceiling to provide diffuse office lighting was rated more favorably, produced fewer glare problems, and resulted in improved eye comfort in comparison to a parabolic down-lighting system, which uses ceiling recessed fixtures and louvers that direct the light downward (31).

MUSCULOSKELETAL DISORDERS

Musculoskeletal discomfort is as prevalent as, or more prevalent than, eyestrain in VDT work, and has become the primary focus of VDT-related health concerns in recent years. Early NIOSH studies showed a prevalence rate exceeding 75% for the "occasional" experience of back, neck, and shoulder discomfort among VDT users (5,32). In a later NIOSH survey of nearly 1,000 VDT users in two state agencies (33), prevalence rates of 20% to 25% for "almost daily" discomfort in the upper torso were observed. A 1989 NIOSH Health Hazard Evaluation of newspaper employees found that 40% of the 834 participants reported symptoms that met the study case definition for any cumulative trauma disorder during the past year (34). In two more recent NIOSH studies of VDT users, one in the newspaper industry and one in the telecommunications industry, prevalence rates for upper extremity disorders defined by symptoms alone were of a similar magnitude (35,36). (Prevalence rates based on objective signs were reduced to approximately one-half the rates for symptom measures.)

The neck, back, and brachial plexus seem to be a primary site of musculoskeletal discomfort among VDT users. A 1982 Bell System study (10) found neck discomfort to be exceeded only by headache in VDT operators. Neck discomfort was also the only symptom that distinguished VDT operators from controls. Neck pain, followed by shoulder pain, was the most prevalent musculoskeletal symptom in a study of more than 1,500 VDT users in Massachusetts (37). Analyzing VDT users' responses to questionnaires published in a safety and health trade journal, Evans (38) found "painful/stiff neck or shoulders" to be the most common complaint (53% of 4,000 respondents). In the Italian study of more than 20,000 VDT users, back pain and, second, neck pain, were the most prevalent musculoskeletal symptoms (6). Neck-shoulder problems were also most prevalent in studies conducted by Bergquist et al. (39). Recent NIOSH studies indicate, however, that pain at the hand and wrist is also prevalent (36,40). With regard to upper extremity problems in VDT work, much of the current scientific attention seems to focus on carpal tunnel syndrome. Yet NIOSH research suggests that the risk of carpal tunnel syndrome per se in VDT work may be relatively low (35).

As with eyestrain, numerous studies fail to show a significant increase in musculoskeletal symptoms among VDT users in comparison to controls performing related tasks (5,41–43). A recent Scandinavian study found increased risk only for hand and wrist problems (39). (However, most of the studies showed that the prevalence of musculoskeletal discomfort were high in absolute terms for both VDT and non-VDT operators.)

Health Implications

Regarding the long-term health risks associated with musculoskeletal discomfort in VDT use, WHO (4) has concluded that injury from repeated stress to the musculoskeletal system is possible. Dramatizing this possibility, an epidemic of repetition strain injury (RSI) affecting VDT operators swept Australia in the last decade. Five-year prevalence rates approaching 35% were recorded in some Australian organizations (44). Japan experienced a similar phenomenon during the 1970s (45). Some earlier studies suggested that disabling musculoskeletal disorders are becoming a problem among VDT users in the United States (46,47). A recent report by the Office Ergonomic Research Committee (48) indicated that repeated traumas are still growing but their growth rate started to slow down in 1993 and 1994. However, current recording systems make it difficult to determine whether musculoskeletal injuries to VDT users are increasing or decreasing, and the relative contribution of these types of injuries to the rather dramatic increase in cumulative trauma disorders in the United States during the 1980s and 1990s.

Hadler (49) and others (50–54) have argued that musculoskeletal discomfort reported by VDT users represents merely use-associated fatigue or pain, and not underlying pathology. These sources argue that cultural or social conditioning fosters illness beliefs and behaviors among persons who suffer musculoskeletal discomfort (a process referred to as "social iatrogenesis") and that disability then ensues. According to Cleland (52) and The Royal Australian College of Physicians (54), these conditioning forces involve, in part, widely held but false assumptions in the medical and legal community about the seriousness of musculoskeletal discomfort and its relationship to biomechanical demands of VDT work.

Beliefs that musculoskeletal discomfort among VDT users is a benign condition, or that the epidemic spread of disabling musculoskeletal disorders among VDT users is not related to physical job demands, have been challenged by a number of investigators (55–57). Contrary to this viewpoint, several studies have suggested a link between biomechanical stresses and musculoskeletal problems in VDT and keyboard work. Duncan and Ferguson (58) found awkward postures of the upper extremities to be significantly more common among telegraphers with diagnosed myalgia or cramp than among their asymptomatic peers. Hunting and associates (59) reported that deviant postures and lack of arm-hand support were associated with increased discomfort and clinical signs (e.g., pain with palpation and isometric contraction) in both VDT operators and typists. Maeda and colleagues (60) found relatively strong correlations of upper extremity and head tilt angles with arm-hand and shoulder discomfort among accounting machine operators.

Subsequent NIOSH research adds to this evidence. In one study, up to 38% of the variance in musculoskeletal discomfort among VDT data entry operators could be explained by objective measures of posture and workstation ergonomics (33). In a NIOSH study of newspaper employees (34), typing time and speed were significant predictors of upper extremity symptoms. A second NIOSH study among newspaper workers also found a relationship between typing time and hand/wrist disorders (36). Other factors such as static work postures, hand positions, use of lower arm support, repeated work movements, and keyboard or VDT vertical positioning were found to be associated with various upper-body muscular problems (61).

Etiology and Control

Some VDT operators commonly remain seated in fixed, sometimes awkward postures for long periods of time, possibly resulting in increased biomechanical stresses on the back, neck, shoulders, and upper extremities. Additionally, repetition is a concern. Keystroke rates as high as 20,000 per hour are not uncommon for some VDT operators. Some of the biomechanical stresses imposed on VDT operators are subject to control through the careful design and configuration of workstations (chair, table, VDT, etc.). This section begins by discussing measures for reducing biomechanical stresses at the VDT workstation. More detailed, technical specifications are available from several authoritative sources (21,24,62,63). Below is a selective set of chair and workstation characteristics that should be considered in the design of VDT workstations.

Chair Characteristics

Back Rest

A slightly reclining posture is not uncommon for VDT operators and can help to minimize the muscular effort of continuous sitting in an upright posture (64). A slight recline may also reduce lumbar disk forces during sitting (65). To accommodate a reclining posture in VDT work, it is important that the chair have a tall back rest, and that the back rest tilt backward independently of the seat pan. A slightly protruding lumbar support is important in either the upright or reclining seated posture. Vertical adjustability of the back rest will help ensure proper positioning of the lumbar support.

Arm Rests

Adjustable arm rests may help to reduce loads in the back, neck, and shoulders that are created when the arms and hands are suspended over the keyboard (66).

Chair Base

Chairs with five spokes or castors in the base will help to ensure stability.

Seat Pan

Height adjustability of the seat pan will help to achieve a comfortable working level vis-à-vis the keyboard (about elbow level).

Footrest

It is believed that seat pan heights above popliteal height may create uncomfortable thigh pressure or possibly circulatory impairment in the lower extremities. In this regard, many chairs do not adjust low enough for women of small stature, and a footrest may therefore be necessary.

Padding

Padding can be helpful to minimize pressure points at the chair pan, back rest, and arm rests. A rounded ("waterfall") forward edge of the seat pan may also be desirable in this regard.

Workstation Characteristics

Keyboard Height

It is generally believed that loads on the shoulders and elbow flexors can be minimized by positioning the keyboard (home row) at elbow height or perhaps slightly lower (33,67). Some evidence indicates, however, that slight elevation of the table or keyboard may be inconsequential, or even preferred by some workers (68,69).

Knee Envelope

With a thick keyboard or tabletop (e.g., a desk with a pencil drawer), it may be impossible to lower the keyboard to a comfortable height without sacrificing leg room. Restriction of leg and knee room by the table top, table legs, or "modesty panels" beneath the table may lead to highly constrained or awkward working postures. (Constrained postures may also result when the work surface area is too small or designed in such a way as to prevent flexibility in positioning of the keyboard, video display, or other work materials.)

Display Height

Height adjustability of the VDT above the work surface can help minimize biomechanical stresses from awkward head postures in viewing the display. There is general agreement that the primary viewing area of the display should not be positioned above the horizontal line of sight. Views differ on the permissible declination of line of sight; but extreme, downward head tilt should probably be avoided.

Arm/Hand Rests

Cushioned and broad support surfaces (e.g., chair arm rest or wrist rest) for the upper extremities can help to minimize compression or irritation at the wrist, forearm, or elbow.

Adjustability

Implicit in the foregoing discussion is that adjustability of chair and worktable components is important for achieving a comfortable working posture. Not uncommonly, important components of workstations are not adjustable or the mechanisms are difficult to operate. This becomes a special concern when the same furniture is used by several workers. For example, it is unlikely that the workers will bother readjusting the heights of chairs to fit their individual needs unless the chairs have an automatic mechanism that can be operated from the sitting position.

In addition to workstation design, the importance of work organization cannot be overstated as a control measure for biomechanical stresses in VDT work. Work organization (i.e., the way tasks are performed and managed) represents a form of administrative influence over the exposure of VDT operators to biomechanical stressors, including repetition. Examples of promising organizational interventions for VDT jobs include increased rest pauses (70), job rotation, or expansion of jobs to include nonkeyboard work. Work organization is closely intertwined with factors that influence the psychosocial environment and stress at work. Thus, in addition to an influence on exposure to biomechanical stressors, work organization may influence musculoskeletal comfort via other mechanisms.

Work Organization

One of the most significant developments in the study of work-related musculoskeletal disorders has been the implication of psychosocial factors as causal agents. In the most general use of the term, psychosocial factors refer to aspects of the job or individual, or of broader socioeconomic conditions, that result in psychological demands on the individual (and hence can lead to psychological stress). Among the conditions in the workplace that lead to psychological demand and stress are aspects of work organization such as the scheduling of work, aspects of job design (e.g., the complexity of tasks), co-worker and supervisory relationships, management practices, and organization climate/culture. To date, over a dozen major studies have established significant associations between these types of organizational factors and musculoskeletal problems in VDT work (5,36,40,61,71–74). For example, in a NIOSH study of upper-extremity disorders among telephone directory assistance operators, factors such as heavy information processing demands, lack of supervisory support, and time pressure were predictive of objective signs of tendinitis and other neuromuscular and skeletal conditions (35). More recently, Lim (75) found that work pressure and lack of control over work pace were predictive of discomfort, especially in the neck and shoulder regions.

Although extant data strongly suggest an influence of workplace psychosocial stressors on musculoskeletal problems in VDT workers, the mechanisms underlying these effects are still uncertain. In recent years, theoretical frameworks to explain these linkages have been developed by several investigators (75–78). Mechanisms that are common to most of these models are discussed in the following sections. Although knowledge regarding these mechanisms is incomplete, all of these suspected effects stem originally from work organization problems in the VDT workplace.

Physical Mechanisms

As discussed above, it is probable that work organization directly influences biomechanical demands. For example, the complexity of a VDT task is directly related to the degree of repetition in the task (e.g., data entry work is less complex and more repetitive than general secretarial work), thereby influencing biomechanical stresses to the upper extremities. Psychological demand and job stress also vary as a function of task complexity, but their association with biomechanical stress is merely coincidental in this case.

Psychophysiologic Mechanisms

It is well established that VDT or keyboard work can give rise to muscle tension in excess of the demands of keying (79–81). This effect is part of the generalized autonomic adjustment of the body to stress, which also includes increased catecholamine secretion, reduced peripheral circulation, and a variety of other psychophysiologic responses (82). The possible contribution of these effects, especially stress-related muscle tension, to musculoskeletal function and comfort among VDT users is a subject of study by several investigators (81,83,84).

Perceptual and Cognitive Mechanisms

A broad body of research in health psychology suggests that cognitive factors, including psychological stress, are influential in the detection symptoms and in the attribution of symptoms as job-related disease

(85,86). It is plausible that these processes are instrumental in the development of musculoskeletal problems in VDT work; e.g., stress-related arousal may sharpen sensitivity to normally subthreshold musculoskeletal sensations. [Note: This mechanism would incorporate the iatrogenic hypothesis posed by Hadler (49) and others.] However, to date no studies have directly investigated this mechanism in the context of VDT work and health.

JOB STRESS

Until the advent of the industrial revolution, goods were produced by craft workers. Craft workers participate in all aspects of the production process and exercised considerable control over the pace of the job and the way it was performed. With the advent of mass production technology, the organization of work changed dramatically. Mechanization created more standardized, narrow, and repetitive job tasks. Individual control over the work process was replaced by machine pacing and piece work, and workers' identification with the final product was reduced. Occupational stress researchers have come to recognize these conditions as the building blocks for ill health (87).

The nature of office work has been changing in a similar manner. Prior to the advent of the typewriter, office work could still be classified largely as "craft" work. Clerical workers or secretaries were fully and independently responsible for all of the transactions and support functions in the office, the work was varied, and multiple skills were required. Although this form of office work can still be found today, the information age and the mechanization of office work—abetted by the typewriter—resulted in major changes in the nature of office jobs. [See Giuliano (88) for an excellent review of the evolution of office work.] The industrial office functions much like a manufacturing assembly line. Documents are delivered and processed in a serial fashion by successive groups of clerks or information specialists, each performing a very narrow or specialized operation in a standardized fashion. Few workers understand, or could perform, all steps of the job. Piecework, creating heavy workload demand, is common.

Computerization holds the potential for a positive transformation of industrial office work. VDTs make it easier for a single person to create, modify, store, retrieve, deliver, or otherwise process information (i.e., accomplish a skilled and varied task that may otherwise have required numerous separate transactions involving several persons). For example Johansson and Aronsson (89) reported that VDTs enabled agents to obtain a more complete picture of an insurance case and to independently process a claim.

In many cases, however, the introduction of computerization to the office has served only to intensify negative attributes of industrial-age office work. Computerization, for example, has subjected office workers to electronic monitoring of their performance, creating implicit or explicit expectations for heightened productivity and perceptions of increased supervisory control.

Early NIOSH investigations (5,32) were among the first to examine systematically the change in the content and organization of office work associated with the introduction of VDT technology. These studies showed that, in contrast to peers who did not use VDTs, VDT users reported increased work pressure, reduced autonomy, and increased management control over work processes. Furthermore, both studies showed increased disruptions in working relationships between VDT users and their peers and supervisors.

Subsequent studies and reviews of the literature (see refs. 4 and 90 for a comprehensive review) tend to confirm the general pattern of results observed in the earlier NIOSH investigations (although these are effects evident mainly for clerical work). More recent studies highlight additional VDT work-related stress factors, including concerns with computer breakdown and response delays, physical immobility (13), excessive repetition (91), and electronic performance monitoring. For example, electronic performance monitoring of telecommunications workers was associated with increased problems with supervisors and higher levels of reported stress. The combination of electronic performance monitoring was especially problematic when performance standards were enforced, and monitored employees who were barely able to meet the performance standard were the most affected.

Health Effects

There is growing evidence that long-term exposure to the types of unfavorable working conditions that have been observed among some VDT users might have serious health consequences. Accumulating epidemiologic data, for example, suggest that the combination of heavy work-load demands and reduced worker autonomy or control may create a risk for affective disorders and cardiovascular disease.

Although an unusual prevalence of chronic, stress-related psychological or somatic disorders has yet to be documented among VDT users, acute disturbances have been reported in many investigations. A high prevalence of irritability, anxiety, and depressive states among VDT operators was reported in several early studies (32). VDT work is associated with complaints of daily psychological stress. Cardiovascular and neurohormonal responses indicative of increased autonomic arousal have also been reported in persons who perform various types of VDT work. Schleifer and Okogbaa (92) found suppression of sinus arrhythmia and significant elevations in both diastolic and systolic blood pressure when VDT operators worked under incentive pay compensation schedules. Elevations in both blood pressure and catecholamine excretion among VDT operators were reported in relation to faulty computer function (89). Additionally, Tanaka and colleagues (93) reported age-related elevations in catecholamine excretion under conditions of demanding VDT work (e.g., poor display quality).

Recent prospective studies have improved upon the quality of studies of stress and health in VDT work (39,94). In a longitudinal study of office workers, Carayon et al. (94) were able to show that task clarity and ambiguity of job future were associated with worker strain over the 3-year periods. Furthermore, the study also showed that there were different job factors in addition to the above two factors associated with worker strain at each time period (i.e., each year) of the study.

In some sense it may be inappropriate to identify many of these later investigations as studies of VDT work, i.e., implying that the outcomes noted are VDT-related or VDT-specific. Unlike conditions in the 1980s where VDT users worked side by side with office workers who did not use VDTs (thereby enabling studies to reliably attribute outcomes to VDT use), computerization and VDT work is an integral aspect of modern office work and a growing feature of many other jobs. Thus, it is becoming progressively more difficult to disentangle, both methodologically and conceptually, the influence of VDTs from the conditions of modern work.

Controlling Stress in VDT Work

The National Research Council (3) concluded that stress and dissatisfaction in VDT work have resulted from failure to apply to jobs "well-established principles of good design and practice" (p. 2). These principles have been summarized in generic form by NIOSH (97), and described in more specific terms for application in VDT use by Galitz (96), the WHO Regional Office for Europe (90), and Sauter (95).

There is strong convergence among the prescriptions offered by these sources for the design of VDT work. Most sources emphasize, for example, that VDT jobs should be challenging, within the limits of workers' capabilities, and have inherent meaning and value to workers. In this regard, tasks should be sufficiently varied or complex to sustain interest and to utilize acquired skills. Additionally, tasks should have closure, so that each work cycle can be associated with a distinct and meaningful work product. By way of example, most VDT data entry jobs represent the antithesis of most of these conditions.

Most sources emphasize also that the job should provide some opportunities for worker discretion about the way work is organized and performed (e.g., prioritizing, scheduling, and pacing tasks or subtasks). In VDT work it is important that this discretion extend to the physical configuration or design of the workstation.

A third key concern is the social environment at work. VDT jobs and facilities should be designed to enable interpersonal interaction for purposes of both emotional support and concrete assistance in performing tasks. Teamwork or task sharing may help serve this end and help sustain interest in work. Modern offices are often configured in open layouts in which individual office cubicles are created by movable partitions. Depending on the types and positioning of the partitions, this type of open layout can be conducive to workplace interaction. However, this design needs to be balanced against the need for privacy.

Equal in importance to the design of the job is the manner in which VDT technology is introduced to the workplace. Most recommendations emphasize the need for (a) early communications to workers to avoid stressful misunderstandings or uncertainty, (b) early participation of workers to impart a sense of control and to utilize their subject matter expertise, (c) gradual change emphasizing steps with the greatest potential for success and confidence building, (d) training and social or technical support to minimize error and frustration, and (e) avenues of redress to deal with problems while they are still benign (96).

Based on events at the Federal Express Corporation, Westin (98) provides an excellent case example of the design of VDT jobs that conform to these general guidelines. Key to the success of the project was (a) the early formulation of a corporate "people-technology" policy, which espoused, "It is the policy of Federal Express Corporation to systematically incorporate human factors, ergonomics, and job/task design criteria with the development or modification of electronic technology applications"; and (b) development of a standing, labor-management task force to carry out this mandate. Examples of job design specifications under the people-technology policy include teamwork, rotating and combining tasks, and increased deregulation and individual control of work. Importantly, the task force whose responsibility it was to ensure that all design criteria were met was composed of management representatives from all relevant departments (e.g., facilities management, management information systems, safety and health, human resources, risk management), as well as worker participants from the affected production areas.

REPRODUCTIVE EFFECTS

Video display terminals were first associated with adverse reproductive outcomes in 1980, when a cluster of birth defects was observed among women using VDTs at the Toronto Star newspaper (99). The appearance of several clusters led several investigators to conduct epidemiologic studies of the reproductive risk of VDT work (100–115).

Three characteristics of VDT use have been proposed as possible explanations for the observed association between VDT use and adverse pregnancy outcomes:

physical stress, psychological stress, and exposure to electromagnetic fields. Electromagnetic field exposure has been regarded as the most plausible mechanism for possible reproductive effects of VDTs. Two types of electromagnetic fields are produced by the VDT: extremely low frequency (ELF) and very low frequency (VLF) fields. Some review articles offer a detailed review of the literature on VDT use (116) or electromagnetic field exposure (117,118) and reproductive health. This chapter summarizes the VDT literature (100–115). As discussed below, these studies have largely shown no relationship between VDT use and adverse pregnancy outcomes.

Health Effects

Most of the large epidemiologic studies of pregnancy outcomes among office workers have not shown a relationship between VDT use and spontaneous abortion. Of the ten studies of spontaneous abortion, eight have shown no relationship to VDT use (100–107). Most of these studies examined potential risk in relation to weekly hours of VDT use and did not attempt to distinguish between specific risk factors (physical stress, psychological stress, and electromagnetic fields) that might be associated with the VDT. One study that did collect data on job stress and ergonomic work load found that neither factor was correlated significantly with spontaneous abortion (103). A greater risk of spontaneous abortion for women in clerical jobs who reported using a VDT for 20 hours or more during pregnancy was found in one study (108). However, two other studies that examined risk by occupational title did not observe an increased risk for clerical workers (104,106).

Two studies have been conducted that made measurements of electromagnetic fields produced by the VDT (105,109). In one study that measured the electromagnetic fields in the workplace of both VDT users and nonusers, no increased risk of spontaneous abortion was found (105). Measurements of the electromagnetic fields indicated that women seated at VDTs had higher VLF magnetic field exposures than the nonusers or the general population. ELF magnetic field exposures were similar for women seated at VDTs and women who did not use VDTs and also fell within the range of residential exposures. A second study conducted laboratory measurements of electromagnetic fields of the VDTs and found an increased risk of spontaneous abortion among women who used VDT models with ELF magnetic fields measurements over 3 mG at a distance of 50 cm (109). These high emitting VDTs had ELF fields that were about three times higher than the average levels found in other studies in the United States, Canada, Australia, and Sweden (105,116,119,120), suggesting that the exposures VDT operators in this study may not be typical of most VDT users.

Birth defects were also associated with VDT use in some cluster reports, but this association with VDT use was not observed consistently in the five epidemiologic studies that examined birth defects (111). Two studies found no increased risk of major malformations among moderate or heavy VDT users (108,111). A third study found no increased risk for major malformations as a group but found a significantly higher risk for hydrocephalus (110). A fourth study observed an increasing risk of major malformations with increasing weekly hours of VDT use but no greater risk for specific defects (101). A fifth study found an overall excess risk of malformations as well as an increased risk of renal defects (106). Most of these studies had relatively low statistical power to detect increased risks for specific defects, and none measured the electromagnetic fields.

Some investigators have also examined the relationship of VDT use with low birth weight, preterm delivery, or fecundity (15,106,112–115). Most found no increased risk associated with VDT use (106,112–114). One study found a slight, elevation in risk for intrauterine growth retardation in association with more VDT use (104). Another found a slightly increased risk associated with prolonged waiting time to pregnancy among women with greater VDT use (115).

In summary, the weight of the evidence thus far indicates that VDTs in themselves do not increase the risk for adverse pregnancy outcomes. To examine further whether high electromagnetic field exposure constitutes a risk factor for adverse pregnancy outcomes, future studies should focus on populations with higher electromagnetic field exposures than VDT users. In these studies, electromagnetic field exposures should be measured and fully characterized in the workplace to account for all sources of exposure.

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Work With Video Display Terminals and the Risk of Reduced Birthweight and Preterm Birth

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To determine whether the use of video display terminals (VDTs) is associated with an increased risk of reduced birthweight (RBW) and preterm birth, a cohort of telephone operators who used VDTs at work was compared to a cohort of non-VDT-users. Among 2,430 women interviewed, 713 eligible singleton live births were reported. Exposure was estimated from company records and a representative sample of electromagnetic fields was measured at the VDT workstations. For RBW (≤2,800 g), we found no excess risk associated with any VDT use during pregnancy (odds ratio [OR] = 0.9; 95% confidence interval [CI] = 0.5–1.7). For preterm birth (≤37 weeks), we similarly found no excess risk (OR = 0.7; 95%CI = 0.4–1.1). The risks estimated did not change substantially when hours working with VDTs were used as exposure variables. By contrast, increased risks were found for several known risk factors for LBW and preterm birth. We conclude that occupational VDT use does not increase the risk of RBW and preterm birth. Am. J. Ind. Med. 32:681–688, 1997. *© 1997 Wiley-Liss, Inc.*†

***KEY WORDS:** computer terminals; electromagnetic fields; pregnancy; pregnancy outcome; birthweight; infant, premature*

INTRODUCTION

The potential effects of working with video display terminals (VDTs) on perinatal outcomes have been of continuing interest since the first clusters of adverse pregnancy outcomes were reported in 1980. Most studies, however, have reported only equivocal associations of VDTs with low birthweight (LBW), preterm birth, and birth defects [Delpizzo, 1994].

Since 1986, eight studies have been published in which the association between VDTs and LBW was investigated [Ericson et al., 1986a,b; McDonald et al., 1988; Nurminen et al., 1988; Windham et al., 1990; Nielsen et al., 1992; Parazzini et al., 1993; Bracken et al., 1995]. In these studies, exposure to VDTs was estimated by using either job titles or self-reported interview data. Most odds ratios (ORs) for delivering a low-birthweight infant were within the range of 0.5–1.1 and did not suggest an LBW-VDT association. The study by Windham et al. [1990] reported an OR of 1.6 (95%CI = 0.9–2.9) for intrauterine growth retardation (IUGR), suggesting an effect of VDT exposure on fetal growth. A decreased risk of LBW was suggested for the offspring of women who used VDTs at home or at work for 1–20 hr/week [Bracken et al., 1995].

Birthweight has long been considered the perinatal outcome of primary interest because of its effect on infant survival. Recently, however, Wilcox et al. [1995] concluded that although most preterm infants are LBW, prematurity rather than LBW has the predominant effect on infant survival. Relatively little is known about the effect of VDTs on preterm birth. Two studies on VDTs and preterm birth reported crude ORs of 1.2 [Nurminen et al., 1988; Windham et al., 1990]. Two other studies, by McDonald et al. [1988] and Nielsen and Brandt [1992], reported adjusted ORs of 1.1 (90%CI = 1.0–1.2) and 1.1 (95%CI = 0.9–1.5), respectively.

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Ericson and Källén [1986b] reported an OR of 2.3 (95%CI = 1.4–3.9) for the combined category of birth defects, very low birthweight (VLBW) and perinatal mortality among women who worked with VDTs of more than 20 hr/week. Other studies did not suggest an association between VDT use and birth defects [McDonald et al., 1988; Goldhaber et al., 1988; Brandt et al., 1990].

This paper describes the second part of a study in which we examined the association between working with VDTs and adverse perinatal outcomes in two groups of female telephone operators with similar work situations. We obtained data on VDT use from the employers' records and measured electric and magnetic fields (EMFs) at a sample of the operators' workstations. In the first part of this study, the use of VDTs and exposure to VDT characteristic EMFs were found not to be associated with an increased risk of spontaneous abortion [Schnorr et al., 1991].

MATERIALS AND METHODS

Study Population

The study population consisted of 2,430 married women aged 18–33 years who were employed as either directory-assistance operators or general telephone operators (reached by dialing 0) at two companies in eight southeastern states. The directory assistance (VDT-exposed) operators used VDTs to provide telephone numbers to customers. The comparison group of general (unexposed) operators primarily assisted customers in placing long-distance calls. Two VDT models were used by the VDT-exposed operators during the study period: International Business Machines (IBM) model 4978 and Computer Consoles Inc. (CCI) model 4500. The unexposed operators used units containing a light-emitting diode (LED) or neon glow tube (NGT) to display the numbers, rather than a VDT. Typically, both VDT-exposed and unexposed operators worked 7 hr/day in front of the equipment. Both groups of operators were monitored by a supervisor and by a computer that recorded the number and length of calls. Education and salary levels were similar for both VDT-exposed and -unexposed operator positions. We did not observe any differences in work practices between the two groups other than the presence or absence of VDTs.

Data Collection

A telephone interview was used to collect lifetime reproductive histories, including the outcome of all pregnancies inside and outside the study period, defined as the period from January 1, 1983 through December 31, 1986. Birthweight and gestational age questions were asked as follows: "How much did he/she weigh at birth?" and "Did the doctor say your baby was born early, late or on time? If early or late, how many weeks?" Use of VDTs at home was obtained by self-report during the interview. Data were also collected on potential confounders or effect modifiers including race, age, smoking habits, pregnancy complications, medical history, and interpregnancy interval. Interpregnancy interval was defined as the time between the end date of the previous pregnancy and the estimated start date of the last menstrual period before the index pregnancy. For validation purposes, birth certificates were collected for live births and medical records were requested for infants with a reported birth defect.

VDT-exposed operators used VDTs exclusively whereas unexposed operators only used units containing a LED or NGT. Neither group of operators had any other duties. Thus, company records of dates of employment as a VDT-exposed or unexposed operator and interview data on dates of pregnancy were used to ascertain the women's use of VDTs for each trimester of pregnancy. For VDT-exposed operators, we also used weekly payroll records to calculate the hours of VDT use during each study pregnancy.

In 1990, the EMFs emitted by the two models of VDTs and the LED/NGT equipment in use during the study period were measured [Schnorr et al., 1991; Tell, 1990]. Both VDT operators and LED/NGT operators were exposed to extremely low-frequency electric and magnetic fields (ELF, 45–60 Hz) in the same range as reported average home exposures. The abdominal ELF geometric means were with the range of 0.4–0.8 V/m for the electric field and 32.4–62.4 mA/m for the magnetic field. VDT-exposed operators were exposed to above-background levels of very low-frequency electric and magnetic fields (VLF, approximately 15 kHz). Their measured abdominal VLF geometric means were with the range of 0.1–0.5 V/m for the electric field and 4.0–17.4 mA/m for the magnetic field.

Outcome Definitions

Pregnancies that met the following criteria were included in the analyses: the pregnancy resulted in a singleton live birth during the study period, and the mother was employed for at least 1 day as a VDT-exposed operator or -unexposed operator during the first 28 weeks of pregnancy. The estimated date of the last menstrual period was considered the start date of each pregnancy. Gestational age was calculated as the number of weeks between the estimated last menstrual period and the date of birth. Reduced birthweight (RBW) was defined as ≤2,800 g. We chose this cutpoint for RBW due to small numbers of live births that met the traditional LBW definition of <2,500 g. Preterm birth was defined as a live birth of 21–37 weeks gestation. The criteria identified by Erickson et al. [1984] were used to define and identify infants with major birth defects. These birth defects are included in codes 740.0–759.9 of the International Classification of Disease (ICD), Ninth Revision, and are considered to affect survival, require substantial medical care, result in marked physical or psychological handicaps, or interfere with a baby's prospect for life.

Definition of VDT Use

VDT use was initially defined as a dichotomous variable for the entire pregnancy and for each trimester separately. Pregnancies or trimesters in which the mother worked as a VDT-exposed operator at any time were classified as exposed. If the mother worked as a unexposed operator only, the pregnancy or trimester was classified as unexposed. From payroll records, we calculated the actual hours of VDT work for each study pregnancy of a VDT-exposed operator by trimester and for the total pregnancy. Analysis of actual hours worked was crucial because work hours might have varied depending on the stage of pregnancy when hired, the timing of vacations, the amount of leave used, and the number of hours worked on a given day. We generated a trimester-specific index of weekly hours of VDT use by dividing the days of VDT use in each trimester by the days pregnant in each trimester. Similarly, we calculated hours of VDT use per week for the entire pregnancy. Pregnancies in which the mother worked as a unexposed operator only were assigned 0 hr of VDT use.

Statistical Analysis

Frequency distributions and stratified analyses were used to assess evidence of confounding and interaction by demographic, medical, and lifestyle variables. Of these variables, age, race, parity, gravidity, alcohol consumption, smoking, infant gender, gestational age (RBW analysis only), previous RBW or preterm live birth prior to the study period, other adverse pregnancy outcomes prior to the study period, diabetes, maternal weight gain during pregnancy, thyroid condition, hypertension medication during pregnancy, pre-eclampsia or toxemia, and interpregnancy interval were included as potential confounders in initial multivariable analyses. All these variables were also examined for interaction with VDT exposure. We used multiple logistic regression analysis to determine the relative odds of RBW and the relative odds of preterm birth. Multiple linear regression analysis was used to assess the effect of VDT use on continuous birthweight. To address the issue of correlated outcomes (multiple pregnancies per woman), we analyzed our linear and logistic regression models with the quasi-likelihood generalized estimating equations of Zeger and Liang [1986]. The effect of VDT exposure on risk of preterm birth was also analyzed in a proportional hazards model, and the marginal analysis approach of Wei et al. [1989] was used to account for multiple pregnancies per woman. For these

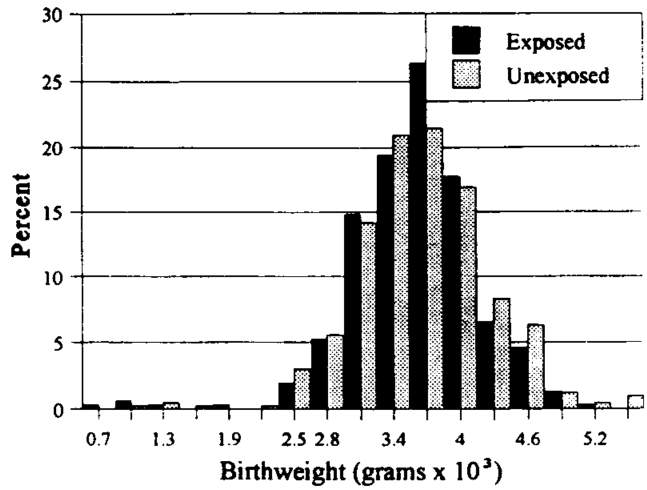

FIGURE 1. Crude distribution of birthweight in percentages by VDT use. Low birthweight and reduced birthweight cutoffs are at 2.5 (2,500 g) and 2.8 (2,800 g), respectively.

survival analyses, all pregnancies that ended after 20 weeks gestation during the study period were included, regardless of outcome. Analyses of residuals, multicollinearity, and goodness-of-fit were conducted to confirm that the final models did not violate analytic assumptions. Multivariable analyses of major birth defects and perinatal death were not conducted due to small sample sizes. PC-SAS® software was used for all statistical procedures [SAS Institute, 1989, 1994].

RESULTS

Details about response rates and demographic characteristics of the study population were reported previously [Schnorr et al., 1991]. Of the initial 5,544 employees found in company records, 94.9% of the 4,475 women we contacted agreed to participate. Among the 2,430 married women interviewed, 713 pregnancies from 647 women met our criteria of ending in a singleton live birth during the study period and employment of at least 1 day as a telephone operator. Of the 707 eligible pregnancies, there were 304 pregnancies in which the woman was exposed to VDTs at work at any time during pregnancy and 403 unexposed pregnancies. The 284 VDT-exposed operators and 363 unexposed operators were similar in age, lifetime number of pregnancies, and percentage employed at the study company at the time of the interview. VDT-exposed operators had worked slightly longer than unexposed operators at the study company (8.2 vs 7.6 years). The proportion with more than a high school education was higher among unexposed operators (36.2% vs 27.1%), as was the proportion of Hispanic women (9.1% vs 2.5%).

Figure 1 shows the crude distribution of birthweight in the study population. The percentage of RBW infants was

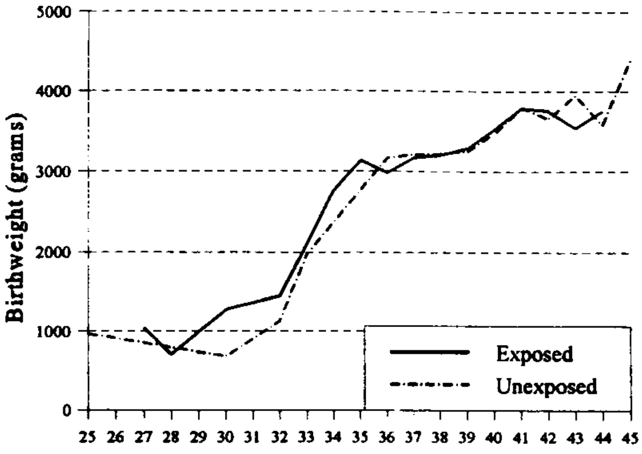

FIGURE 2. Birthweight and gestational length by VDT use.

8.9% (n = 27) in the exposed and 9.7% (n = 39) in the unexposed pregnancies. The distribution of mean birthweight by gestational age for exposed and unexposed pregnancies is depicted in Figure 2. No substantial differences appear to be present between the exposure groups. The logistic regression model for RBW included the dichotomous VDT exposure variable and independent risk factors, i.e., prematurity, race, smoking, use of diuretics, RBW infant prior to the study period, and interpregnancy interval (Table I). None of these risk factors appeared to be a confounder of exposure: crude and adjusted odds ratios for VDT use are equal. No significant interactions with exposure were found. No association was found between VDT use and reduced birthweight (OR = 0.9; 95%CI = 0.5–1.7). When the average number of hours per week (categorized as 0, 1–25, and >25 hr/week) of VDT use in the total pregnancy was substituted in the model, the coefficients for the other risk factors did not vary substantially. In this analysis, reduced birthweight did not appear to have a consistent relationship with hours of VDT use during pregnancy. The point estimates suggest the possibility of a decreased risk of RBW for women working with VDTs no more than an average of 25 hr/week, and a slightly increased risk (OR = 1.4, 95%CI = 0.7–3.1) for women working more than 25 hr/week. A similar pattern was found when trimester-specific hours worked per week (i.e., hr/week in first, second, or third trimester) were substituted into the model.

Two restricted analyses were performed to investigate the slightly increased risk of RBW for women working with VDTs for more than 25 hr/week. First, to determine whether degree of employment contributed to the increased estimate, we performed an analysis restricted to the pregnancies of study participants who had worked an average of 4 or more days/week (4 or more working days/week is roughly comparable to the 25+ hr/week category for continuous VDT exposure, in which exact hours of VDT-exposed operator work were available). Restricting the analysis to those women working 4 or more days/week showed no increased risk of RBW among women using VDTs (OR = 0.7, 95%CI = 0.4–1.4). A second analysis was restricted to

TABLE I. Crude and Adjusted Odds Ratios (OR) With 95% Confidence Intervals (CIs) for Reduced Birthweight (≤2800 g) Associated with Occupational VDT Use and Other Variables in the Logistic Model

Variable	No. of pregnancies	Crude OR	95%CI	Adjusted OR[a]	Adjusted 95%CI
VDT use during pregnancy					
None	392	1.0		1.0	
Any	303	0.9	(0.5–1.5)	0.9	(0.5–1.7)
VDT use (hr/wk), total pregnancy[b]					
0	394	1.0		1.0	
1–25	116	0.5	(0.2–1.1)	0.4	(0.1–1.0)
>25	120	1.4	(0.7–2.6)	1.4	(0.7–3.1)
Born premature (≤37 weeks)					
No	627	1.0		1.0	
Yes	68	9.9	(5.5–17.8)	12.9	(6.6–25.3)
Race					
White	499	1.0		1.0	
Other	196	3.5	(2.1–5.9)	4.4	(2.3–8.4)
Cigarettes smoked per day					
0	540	1.0		1.0	
1–9	77	1.3	(0.6–2.7)	1.5	(0.6–3.6)
10+	78	2.1	(1.1–4.1)	5.0	(2.3–11.3)
Use of diuretics during pregnancy					
No	675	1.0		1.0	
Yes	20	2.5	(0.8–7.6)	4.3	(1.1–16.4)
Reduced birthweight infant prior to study period					
No	623	1.0		1.0	
Yes	72	3.6	(2.0–6.7)	3.3	(1.5–7.3)
Interpregnancy interval					
First pregnancy	210	1.0	(0.6–1.7)	4.3	(1.8–10.3)
0–12 mo	128	1.9	(1.1–3.4)	3.4	(1.5–8.1)
12–48 mo	217	1.0		1.0	
49+ mo	140	1.2	(0.6–2.2)	1.6	(0.6–4.0)

[a]Adjusted for all covariates.
[b]When these VDT exposure variables were substituted in the model, covariate coefficients did not vary substantially. Because of missing data, the total number of pregnancies varied between the two analyses.

third-trimester unexposed operators. The point estimates for unexposed RBW risk were similar to those generated in the presence of VDT exposure (OR = 0.8, 95%CI = 0.3–2.3 for 4 or more days/week; OR = 0.2, 95%CI = 0.01–2.5 for 1–4 days/week).

The covariates in the linear regression model for birthweight were similar, but not identical, to those found in the logistic regression model. The model contained all logistic model covariates except for use of diuretics. Additionally, the linear model contained the covariates infant gender, hypertension medication during pregnancy, diabetes, and thyroid disorder. Again, none of these additional risk factors changed the relationship between VDT use and birthweight substantially. Adjusted least-squares mean birthweights and standard errors were 3,440 ± 27 and 3,475 ± 24 g for exposed and unexposed pregnancies, respectively.

The distribution of gestational age is shown in Figure 3. The percentages of preterm infants were 7.9% (n = 24) and 11.2% (n = 45) for exposed and unexposed pregnancies, respectively. The logistic regression analysis for preterm birth resulted in an exposure odds ratio identical to the crude estimate (OR = 0.7) for women who worked with VDTs (95%CI = 0.4–1.1). The following risk factors, however, were associated with preterm birth: pre-eclampsia or toxemia, diabetes, and a previous preterm infant prior to the study period (Table II). No significant interactions with exposure were found. The substitution of continuous exposure variables in the preterm model did not have a substantial effect on the relationship between exposure and outcome, nor did it change the coefficients of the other risk factors. Proportional hazards analysis of preterm birth resulted in the same model as for logistic regression. The risk ratio (RR) for VDT use during pregnancy was 0.7 (95%CI = 0.4–1.1), which is identical to the logistic regression odds ratio (Table II).

Of the 652 women in the study population, 60 (9.2%) had more than one live birth during the study period, 59 had two births, and one woman had three. Since these multiple births are not independent events, we adjusted for correlation between births by using the quasi-likelihood generalized estimating equations derived by Zeger and Liang [1986]. The coefficients and standard errors from these analyses did not differ from those of the logistic regression models for RBW and preterm birth. Also, the birthweight linear regression coefficients and standard errors did not differ substantially after adjustment for correlated outcomes. When we examined the effect of correlated outcomes on the proportional hazards analysis of preterm birth with the marginal analysis approach of Wei et al. [1989] the data were only sufficient to analyze the unadjusted RR for VDT use. The exposure coefficient from this analysis ($\beta = -0.33$, standard error [SE] = 0.25) was very similar to the analogous coefficient from the proportional hazards model ($\beta = -0.36$, SE = 0.25), which ignores correlation effects.

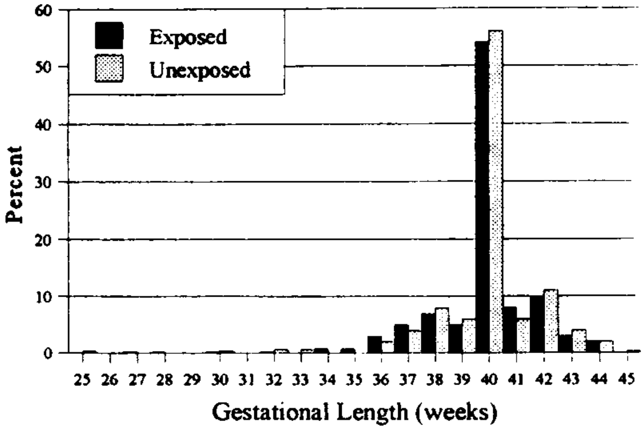

FIGURE 3. Crude distribution of gestational length in percentages by VDT use.

Because the mean values for VLF and ELF emissions at the CCI terminals were higher than the values at the IBM terminals, we conducted analyses for RBW and preterm birth with separate exposure variables for IBM and CCI users. These analyses indicated no differences in risk of RBW or preterm birth between women using an IBM or a CCI unit.

Major birth defect rates, defined as the total number of major birth defects divided by the total number of live births, are generally estimated at 2–3% in the US [Bloom, 1981]. In this study, the rate of self-reported major birth defects was 2.3% (n = 7) in the exposed group and 1.0% (n = 4) in the unexposed group. For the 11 birth defects reported, medical records were obtained for, and confirmed, only three of the self-reported major birth defects. One additional major birth defect was discovered in the review of these records (Table III). Birth certificates were available for 93% (n = 663) of the eligible study pregnancies. However, only one of the eleven major birth defects reported was confirmed by birth certificate. No additional major birth defects were discovered in reviewing the birth certificates.

The perinatal death rate, defined as

$$\frac{\text{(Total number of fetal deaths after 28 or more weeks gestation + infant deaths within 7 days after birth)}}{\text{(Total number of live births plus still births during the study period)}}$$

was 1.0% in the exposed group (two stillbirths and one infant death) and 0.5% in the unexposed group (one stillbirth and one infant death).

DISCUSSION

We did not find an increased risk of RBW and preterm birth among women who worked with VDTs. The risk of delivering an RBW infant was not increased for women who used VDTs during pregnancy, nor was the mean birthweight

TABLE II. Crude and Adjusted ORs[a] and Adjusted RRs[b] With 95% Confidence Intervals (CI) for Preterm Birth (≤37 weeks) Associated With Occupational VDT Use and Other Variables

				Logistic[a]		Proportional hazards[b]	
Variable	No. of pregnancies	Crude OR	95%CI	Adjusted OR	95%CI	Adjusted RR	95%CI
VDT use during pregnancy							
None	400	1.0		1.0		1.0	
Any	304	0.7	(0.4–1.1)	0.7	(0.4–1.1)	0.7	(0.4–1.1)
VDT use (hr/wk), total pregnancy[c]							
0	403	1.0		1.0		1.0	
1–25	116	0.9	(0.5–1.8)	0.8	(0.4–1.7)	0.8	(0.4–1.5)
>25	120	0.7	(0.3–1.4)	0.6	(0.3–1.3)	0.7	(0.3–1.3)
Pre-eclampsia or toxemia							
No	654	1.0		1.0		1.0	
Yes	50	2.2	(1.0–4.7)	2.4	(1.1–5.3)	2.2	(1.1–4.5)
Diabetes (diagnosed before or during the study period)							
No	687	1.0		1.0		1.0	
Yes	17	9.1	(3.4–24.5)	9.0	(3.3–24.9)	6.1	(2.8–13.1)
Preterm infant prior to study period							
No	657	1.0		1.0		1.0	
Yes	47	3.2	(1.5–6.5)	2.9	(1.3–6.1)	2.3	(1.2–4.4)

[a]OR, odds ratio from logistic regression analysis.
[b]RR, risk ratio from proportional hazards analysis.
[c]When these VDT exposure variables were substituted in the model, covariate coefficients did not vary substantially. Because of missing data, the total number of pregnancies varied between the two analyses.

TABLE III. Distribution of Self-Reported Major Birth Defects

Birth defect (ICD 9 code)	VDT user (n = 304)	Non-VDT user (n = 403)
Cleft palate (749.0)	2	0
Club foot (745.7)	1	0
Congenital cataract (743.3)	0	2
Congenital multiple exostosis (756.4)	1	0
Hypospadias (752.6)	1	2
Anomaly of epiglottis or trachea (748.3)[a]	2	0
Total number of major birth defects[b]	7	4

[a]Determination of major vs. minor status not conclusive due to incomplete records.
[b]Multiple heart defects (ventricular septal defect and interruption of aortic arch, ICD 9 745.4 and 747.11) were identified after studying the medical record of one child for a self-reported minor birth defect. These defects are not included in self-reported major birth defect totals and rates in Results.

meaningfully decreased. These results did not change when analyses were performed with continuous or trimester-specific measures of VDT exposure, when monitor type was considered, or when adjustments were made for multiple pregnancies per woman. Although we did not find an association between VDT use and RBW, we confirmed associations with RBW in our logistic or linear models for a number of previously reported risk factors: prematurity, infant gender, nonwhite (primarily African-American) race, smoking more than 9 cigarettes per day, hypertension medication during pregnancy, diabetes, thyroid disorders, RBW infant before the study period, first pregnancy, and short interval between pregnancies (≤12 months).

For prematurity, we did not find an increased risk for women working with VDTs for any measure of exposure we evaluated. Again, previously reported risk factors affected prematurity in our study: pre-eclampsia or toxemia, diabetes diagnosed before or during pregnancy, and a preterm infant prior to the study period. Diabetes and pre-eclampsia/toxemia are risk factors for preterm birth, as labor is often induced early in these women. The number of children with birth defects and the number of perinatal deaths were too small to analyze in multivariable analyses, but the data do not suggest an unusual or specific excess in either the exposed or unexposed groups.

Selection bias seems to be an unlikely explanation for these results. The participation rate was high and minimizes the impact of nonparticipant demographic differences on our results. The demographic characteristics of study participants did not differ greatly by exposure status. All the women worked for the same company for comparable salaries in similar work situations.

Information on birthweight and gestational age was collected from questionnaires and birth certificates. We were able to obtain birth certificates for 663 (93%) of the births included in the study. Birthweight data were available from all these birth certificates, and gestational age from 633 (89%) of the study births. Because birth certificates were not available for all reported births, and maternal reports of birthweight and gestational age are considered of good quality [Selevan, 1980], we decided to use self-reported data in our analyses. Agreement between self-reports and birth certificates was good for birthweight: 81% of the exposed and 83% of the unexposed mothers' reports differed by <100 g from birth certificate data. For gestational age, reports from 83% of the exposed and 81% of the unexposed participants differed by ≤2 weeks from the birth certificate records.

Differential misclassification of exposure status is also unlikely, since VDT use was ascertained and calculated from company records. Home VDT use was infrequent during the study period: only 0.9% of the exposed women and 2.2% of the unexposed women reported VDT use at home.

With the exception of possible confounding based on employment level, in the multivariable analyses, neither interaction nor confounding of the association between VDT use and RBW or preterm birth occurred. Factors that increased risk for RBW or preterm birth in these models were unrelated to VDT exposure. Weinberg [1993, 1995] and Nurminen [1995] have suggested that previous pregnancy outcomes should not be treated as confounders because of their potential association with previous exposure. It is possible that risk factors such as hypertension medication during pregnancy, preterm birth before the study period, or an RBW infant before the study period may be associated with exposure, although inclusion or exclusion of these factors from our models did not meaningfully affect the exposure risk estimates, and multicollinearity between these factors and VDT exposure was not detected.

Our study design did not allow us to address the possible confounding effects of physical and psychological stress, prepregnancy weight and height, and passive smoking. However, we consider the work-related physical and psychological stress of VDT-exposed and -unexposed telephone operators to be similar, based on work practices and responsibilities.

Although we chose a 2,800-g cutpoint for RBW due to small numbers of live births that met the traditional LBW definition of <2,500 g, we reanalyzed our data with the 2,500-g cutpoint and compared these results to national LBW rates. The 2,500-g LBW analysis resulted in an exposure OR of 1.0 and a broader 95%CI (0.4–2.4). Birthweights of <2,500 g were reported by 3.6% of the exposed women and by 4.3% of the unexposed women in our study, while the U.S. population rate is 7.1% [Centers for Disease Control, 1994]. The relatively low LBW rates in this study may have resulted from the demographic characteristics of the study population (primarily middle class, married, age 18–33 years).

We found a decreased point estimate for the risk of delivering a RBW infant among women working with a VDT of 1–25 hr/week, consistent with the findings of Bracken et al. [1995], who found a decreased risk for women working with a VDT of 1–20 hr/week. On the other hand, we found a slightly elevated point estimate for women who used a VDT more than 25 hr/week. In an analysis restricted to those women who worked 3 or more days/week, however, there was actually a decreased risk among VDT users compared to nonusers. In a second analysis, restricted to third-trimester unexposed operators, point estimates for RBW were similar to those generated for RBW in the presence of VDT exposure. This finding suggests that the apparent increased risk among women who used VDTs more than 25 hr/week compared to all non-VDT users may actually reflect other differences between women who work full-time during pregnancy as compared with those who do not and that these differences are not necessarily related to VDT exposure.

In our study, use of diuretics during pregnancy was associated with RBW, which has not been previously reported. Of the 20 women in our study who used diuretics, nine reported the use of hypertension medication during pregnancy. Hypertension has been associated with LBW in previous studies [Velentgas et al., 1994] and hypertension medication use was determined to be a risk factor for RBW in our linear analysis. Thus, in our data, use of diuretics and hypertension medication may represent surrogate measures for hypertensive disorders.

The strengths of this study include the use of payroll records to assess the number of hours worked with VDTs during pregnancy, as opposed to using job titles or self-reported exposure; the measurement of EMFs at the workplace; and the similarity of the two study groups for factors other than VDT use.

Our findings are similar to those reported in previous studies [Ericson et al., 1986a,b; McDonald et al., 1988; Nurminen et al., 1988; Windham et al., 1990; Nielsen et al., 1992; Parazzini et al., 1993; Bracken et al., 1995]. Exposure to ELF (45–60-Hz) and VLF (15-kHz) electromagnetic fields produced by VDTs was not associated with low birthweight, preterm birth, birth defects, and perinatal death. The lack of an association suggests that exposure to EMFs produced by VDTs was too low to cause the outcomes studied but does not imply a lack of association between all EMF exposures and adverse reproductive outcomes. We conclude that in this study, the occupational use of VDTs was not associated with reduced birthweight or preterm birth.

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VIDEO DISPLAY TERMINALS AND THE RISK OF SPONTANEOUS ABORTION

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Abstract *Background.* The relation between spontaneous abortion and the use of video display terminals (VDTs) is of great public health concern. Previous investigators of this issue have reported inconsistent findings.

Methods. To determine whether electromagnetic fields emitted by VDTs are associated with an increased risk of spontaneous abortion, a cohort of female telephone operators who used VDTs at work was compared with a cohort of operators who did not use VDTs. To obtain reliable estimates of exposure, we determined the number of hours of VDT use per week from company records and measured electromagnetic fields at VDT workstations and, for purposes of comparison, at workstations without VDTs. Operators who used VDTs had higher abdominal exposure to very-low-frequency (15 kHz) electromagnetic fields (workstations without VDTs did not emit very-low-frequency energy). Abdominal exposure to extremely-low-frequency fields (45 to 60 Hz) was similar for both operators who used VDTs and those who did not. Among 2430 women interviewed, there were 882 pregnancies that met our criteria for inclusion in the study.

Results. We found no excess risk of spontaneous abortion among women who used VDTs during the first trimester of pregnancy (odds ratio = 0.93; 95 percent confidence interval, 0.63 to 1.38), and no dose–response relation was apparent when we examined the women's hours of VDT use per week (odds ratio for 1 to 25 hours per week = 1.04; 95 percent confidence interval, 0.61 to 1.79; odds ratio for >25 hours per week = 1.00; 95 percent confidence interval, 0.61 to 1.64). There continued to be no risk associated with the use of VDTs when we accounted for multiple pregnancies, conducted separate analyses of early abortion, late abortion, and all fetal losses, or limited our analyses to spontaneous abortions for which a physician was consulted.

Conclusions. The use of VDTs and exposure to the accompanying electromagnetic fields were not associated with an increased risk of spontaneous abortion in this study. (N Engl J Med 1991; 324:727-33.)

CONCERN about the potential reproductive effects of using video display terminals (VDTs) was first raised in 1980, when adverse pregnancy outcomes among several clusters of women who used VDTs were reported.[1-5] Most subsequent epidemiologic analyses of the use of VDTs and pregnancy outcome had equivocal results or found no effect.[6-14] Two studies found a significantly increased risk of spontaneous abortion among women who used VDTs more than 15 hours[15] or more than 20 hours[16] per week. Only a few studies were initially designed to investigate the effects of VDTs on reproduction.[11-13] All the studies estimated the extent of VDT use on the basis of responses to interview questions[11-16] or data on job titles.[6-10,14,15] None measured the electromagnetic fields produced by the VDTs.

A VDT containing a cathode-ray tube to generate a visual display emits both extremely-low-frequency (approximately 45 to 60 Hz) and very-low-frequency (approximately 15 kHz) electromagnetic fields. Extremely-low-frequency fields have been found to be associated with spontaneous abortion in two studies that showed a seasonal pattern of abortions in families with electrically heated beds[17] or ceiling-cable electric heat.[18] Studies of the relation of very-low-frequency electromagnetic fields and spontaneous abortion in humans have been limited primarily to studies of the effects of VDTs.[6-16]

In this study we examined the hypothesis that electromagnetic energy produced by VDTs might cause spontaneous abortions. By selecting two groups of full-time female telephone operators with similar work situations, we intended to minimize any potential ef-

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fect of physical and psychological stress. We obtained data on VDT use from the employers' personnel records and measured electromagnetic fields at a sample of the operators' workstations.

METHODS

Study Population

The study population consisted of women employed as directory-assistance operators and general telephone operators (reached by dialing zero) at two companies in eight southeastern states. The directory-assistance operators used VDTs to provide telephone numbers to customers, whereas the comparison group of general operators primarily assisted customers in placing long-distance calls. The general operators used units containing a light-emitting diode or neon glow tube to display the numbers, rather than a VDT. Typically, both directory-assistance and general operators worked an 8½-hour day, which included 1 hour for lunch and two 15-minute breaks. Both groups of operators sat in front of their equipment for the entire workday. A computer automatically routed incoming calls to the next available operator, so the time between calls was usually less than a second. Both groups of operators were monitored by a supervisor and by a computer that recorded the number and length of calls. During the study period, 50 directory-assistance offices and approximately 36 general-operator offices were in operation at the two companies. Education and salary levels were similar for both directory-assistance–operator and general-operator positions. Although there may have been some differences in work practices between the two groups, we did not observe any. The primary difference was the presence or absence of the VDT.

Recruitment and Interviews of Study Subjects

To maximize the number of pregnancies in the study population, we set the following criteria: a woman was eligible for participation in the study if she was 18 to 33 years of age (born after June 30, 1953) and married at any time during the study period. In addition, a woman had to be employed full time at any time between January 1, 1983, and August 1, 1986, as a directory-assistance or general operator. We used employers' personnel records to identify women who met the eligibility criteria for age and employment. These women were then telephoned at home and asked to participate in the study. Because the personnel records did not include marital status, we screened out unmarried women during the interviews. A valid phone number was obtained by visiting the home if it could not be obtained from the telephone company or directory-assistance services.[19] The study was described to both the interviewers and the potential participants as a study of the outcomes of pregnancy among office workers. The 25-minute telephone interviews, conducted between July 1987 and August 1988, were used to obtain lifetime reproductive histories. For each pregnancy during the study period, information on the consumption of alcohol and cigarettes, use of medications and other treatments, and medical conditions was recorded.

Definition of a Study Pregnancy

Only pregnancies that met the following criteria were included in the study: the pregnancy resulted in a live birth, stillbirth (fetal loss after 28 weeks' gestation), or spontaneous abortion (fetal loss at 28 weeks' gestation or earlier); the operator was employed for at least one day as a directory-assistance operator or general operator during the first 28 weeks of pregnancy; the pregnancy ended between January 1, 1983, and December 31, 1986, for spontaneous abortions, or between May 1, 1983, and December 31, 1986, for live births and stillbirths. The latest date for live births and stillbirths eligible for inclusion in the study had originally been set at April 30, 1987. After December 1986, however, VDTs began to be introduced into the general operators' workstations. Since after this date general operators would have been exposed to VDTs, only pregnancies that ended on or before December 31, 1986, were included in our analyses.

The date of the last menstrual period, obtained during the interview, was considered the beginning date of each pregnancy. The pregnancies of two women who reported using an intrauterine device at the time of conception were excluded from analyses because of the high rate of spontaneous abortion among women who become pregnant while using this method of contraception.

Validation of Data on Spontaneous Abortions

To identify possible recall differences in subject-reported data on outcome, we collected state vital records on each live birth reported during the study period. We then compared the number of previous terminations reported on the birth certificate with the number reported in the interview. In addition, we asked each woman if she had consulted a physician regarding the spontaneous abortion and conducted a separate analysis including only data on spontaneous abortions reported to a physician.

Definition of VDT Use

Directory-assistance operators used VDTs exclusively and had no other duties, whereas general operators used units containing a light-emitting diode or neon glow tube exclusively and had no other duties. Thus, company records on dates of employment as a directory-assistance or general operator could be used to ascertain the women's use of VDTs. We used personnel records and interview data on dates of pregnancy to determine whether the women had used a VDT during each pregnancy (exposure status).

We defined VDT use in two ways. First, we defined VDT use as a dichotomous variable (yes or no). If the woman had worked as a directory-assistance operator at any time during the first trimester (defined as the first 13 weeks of pregnancy), a pregnancy was classified as exposed. If the woman had worked only as a general operator during the first trimester, a pregnancy was classified as unexposed. Second, to examine the possibility of a dose–response relation, we used weekly payroll records to calculate the hours of VDT use during each study pregnancy. From payroll records, we calculated each woman's actual hours of work with a VDT during her pregnancy. Information on actual hours worked was crucial, because the total number of hours a woman worked with a VDT depended on the stage of her pregnancy when she was hired, the timing of vacations, the amount of sick leave used, and the number of hours worked in a given day. For pregnancies during which the woman worked as a directory-assistance operator, we constructed two indexes of continuous exposure. For the first index, we calculated the woman's hours of VDT use per week in the first trimester, the period of greatest risk for spontaneous abortion, as follows:

$$\text{hours of VDT use per week} = \frac{\text{hours of VDT use during first trimester}}{\text{hours of pregnancy during first trimester}} \times 168 \text{ hours per week.}$$

For the second index, we calculated each woman's hours of VDT use per week during the first 28 weeks of gestation (the entire period of risk for a spontaneous abortion in our study). For both indexes, a pregnancy that terminated early had fewer hours of VDT use (numerator), as well as a smaller denominator. Pregnancies during which the mother worked only as a general operator during the first trimester or the first 28 weeks were assigned zero hours per week of VDT use.

Statistical Analysis

We defined the rate of spontaneous abortion as the number of reported spontaneous abortions divided by the total number of reported spontaneous abortions plus reported live births. Multiple logistic-regression analysis[20] was used to assess the effect of VDT use on the incidence of spontaneous abortion while controlling for the effects of other variables.[19] All potential confounders were examined for interaction with exposure to a VDT. We performed separate analyses for early spontaneous abortion (≤8 weeks' gestation) and late spontaneous abortion (9 to 28 weeks). In addition, analyses were performed that included stillbirths and excluded spontaneous abortions not reported to a physician.

A problem with the analysis of studies of pregnancy outcome is that the outcomes of several pregnancies in the same woman are not independent events. To address the problem of correlated outcomes, we performed additional analyses for each measure of VDT exposure, as proposed by Zeger and Liang.[21] In these analyses, a class of generalized estimating equations is used that takes into account the correlation of pregnancy outcomes for the same woman and adjusts odds ratios and their corresponding standard errors.

Measurements of Electromagnetic Fields

Only two models of VDT were used by the directory-assistance operators during the study period: International Business Machines (IBM) model 4978 and Computer Controls, Inc. (CCI), model 4500. In 1990, we visited 8 of the 50 directory-assistance offices and measured electromagnetic fields at 6 randomly selected VDTs at each site, for a total of 48 VDTs (24 IBM and 24 CCI).

Only a single model of light-emitting diode and a single model of neon glow tube, both made by Western Electric, were used by the comparison population of general operators. After December 1986, the end of the study period, VDTs were introduced into the general-operator offices. Therefore, in 1990, when we measured the fields emitted by the light-emitting diodes and neon glow tubes, we disabled all VDTs in the offices, so that only emissions from the light-emitting diodes and neon glow tubes were measured. Twenty-four light-emitting-diode and 24 neon-glow-tube units were randomly selected for measurement at two sites.[19]

A VDT containing a cathode-ray tube can produce several types of electromagnetic energy, including x-rays and electric and magnetic fields at both extremely low and very low frequencies. To detect x-ray emissions, an x-ray monitor (Stoms meter) was slowly passed over every accessible surface of VDT and non-VDT units. Several background measurements were made at each office. The electric fields and magnetic fields in the very-low-frequency and extremely-low-frequency bands were measured with two field-strength meters (Holaday Industries models HI 3600-01 and HI 3600-02). With the operator absent, the very-low-frequency and extremely-low-frequency emissions were measured at a distance of 30 cm from each side of the unit. While the operator was seated at her terminal, exposure measurements were taken at her face, chest, and abdomen. Detailed measurements of very-low-frequency and extremely-low-frequency emissions were made at one of the six units at each site. These measurements included the spatial variation of the strength of the electric and magnetic fields between 10 cm and 100 cm from the screen and the rate of change in the very-low-frequency magnetic-flux density per unit of time (dB/dt).[22] Geometric means and geometric standard deviations were calculated for data on emissions and exposure for all VDTs, light-emitting diodes, and neon-glow-tube units.

Results

Of 5544 subjects identified from company records, we could not contact 19.3 percent (Table 1). Of the 4475 women contacted, 4246 (94.9 percent) agreed to participate (76.6 percent of the women initially identified). Both groups of operators had similar rates of participation. Of the 4246 women who agreed to participate, 2430 were married during the study period and were interviewed in detail.

Of the women we interviewed, 730 had one or more pregnancies that met our criteria for inclusion ("eligible pregnancies"). The two groups of operators were similar in mean age, mean lifetime number of pregnancies, race, education, percentage currently employed at a company included in the study, and mean years employed by a company included in the study (Table 2). The proportion of Hispanic women was higher among general operators. The 730 women in the study had 882 eligible pregnancies, which included 16 pregnancies with twins. The proportions of live births, spontaneous abortions, and stillbirths were similar for directory-assistance and general operators (Table 3). The overall crude rates of spontaneous abortion for all reported pregnancies were 14.8 percent for VDT-exposed pregnancies and 15.9 percent for unexposed pregnancies. In both groups, the rate of reported spontaneous abortion was highest during the second and third months of gestation (Fig. 1).

The rate of spontaneous abortion for pregnancies during which the mother had 1 to 25 hours of VDT use per week in the first trimester was slightly but not significantly higher than that for women with no hours of use per week (17.2 vs. 15.6 percent) (Table 4). The rate of spontaneous abortion for women with more than 25 hours of VDT use per week was similar to that for women with no hours of use per week (15.4 vs. 15.6 percent). A similar pattern was observed when we analyzed hours of VDT use during the first 28 weeks of gestation.

The final multiple logistic-regression model included the dichotomous VDT-exposure variable, spontaneous abortion before the study period, cigarette smoking, thyroid disorder, and alcohol consumption (Table 4). The analysis showed no association between VDT use in the first trimester and spontaneous abortion (odds ratio = 0.93; 95 percent confidence interval, 0.63 to 1.38). When we substituted the other two VDT-exposure variables (hours of VDT use per week in the first trimester and in the first 28 weeks) in the model, we continued to find no increased risk with VDT use (Table 4). These results did not change

Table 1. Response Rate of Potential Study Participants, According to Job Category.*

Category	Directory-Assistance Operators	General Operators	All Operators
	number (percent)		
Agreed to participate	2118 (78.3)	2128 (75.0)	4246 (76.6)
Unable to contact	483 (17.9)	586 (20.6)	1069 (19.3)
Ineligible	21 (0.8)	24 (0.8)	45 (0.8)
Declined	83 (3.1)	101 (3.6)	184 (3.3)
Total	2705	2839	5544

*Directory-assistance operators used VDTs in their work, whereas general operators did not. Because of rounding, percentages may not total 100.

Table 2. Characteristics of Study Participants, According to Job Category.*

Characteristic	Directory-Assistance Operators (N = 323)	General Operators (N = 407)
Mean age†	29.6	29.6
Mean lifetime no. of pregnancies	2.6	2.6
Mean duration of work at study company (yr)	8.2	7.7
Currently employed at study company (%)†	50.8	57.0
White (%)	71.5	68.3
Hispanic (%)	2.8	8.6
More than a high-school education (%)	28.9	35.3

*Directory-assistance operators used VDTs in their work, whereas general operators did not. For eligibility criteria, see Methods.

†As of July 1, 1987.

when the hours of VDT use per week were modeled as a continuous variable.

Only 17.1 percent of the women (n = 125) had more than one pregnancy during the study. The maximal number of pregnancies during the study was four (for six women). Adjustment for multiple pregnancies with the correlated-outcome method of Zeger and Liang[21] did not significantly affect the coefficients in our final models (odds ratio for VDT exposure as a dichotomous variable = 0.94; 95 percent confidence interval, 0.61 to 1.44).

Logistic-regression analyses of data for early and late spontaneous abortion showed no effect of VDT use. The odds ratios were 0.84 (95 percent confidence interval, 0.51 to 1.38) for early spontaneous abortion and 1.05 (95 percent confidence interval, 0.58 to 1.88) for late spontaneous abortion. When all fetal losses, including the nine stillbirths that occurred after 28 weeks' gestation, were included in the model, there was a negligible change in the odds ratio for VDT use (odds ratio = 0.99; 95 percent confidence interval, 0.68 to 1.44). When we eliminated the 10 spontaneous abortions that were not reported to a physician, we found only a minimal change in the odds ratio (odds ratio = 0.90; 95 percent confidence interval, 0.61 to 1.35).

Although our analyses demonstrated no significant association between the use of VDTs and spontaneous abortion, we found that several other factors were associated with an altered risk of spontaneous abortion, notably a history of spontaneous abortion, consumption of more than eight alcoholic drinks per month, smoking more than 20 cigarettes a day, and the presence of a thyroid disorder (Table 4). The coefficients for these factors did not vary substantially when we substituted different VDT-use variables in the model. The exclusion of these factors individually or in combination did not change the relation between VDT use and spontaneous abortion.

None of the measurements of x-ray emissions from the VDT and non-VDT units differed from background levels. The VDTs in this study emitted extremely-low-frequency electromagnetic energy at 45 Hz (the CCI units) and 60 Hz (the IBM units) and very-low-frequency energy in the range of 15 kHz. Geometric means for very-low-frequency emissions from the front of the VDTs and for abdominal exposure were statistically higher for the VDTs than for the non-VDT units ($P<0.05$) (Table 5). The neon-glow-tube and light-emitting-diode displays do not produce very-low-frequency fields above background levels. The rate of change in the magnetic-flux density of the very-low-frequency fields for the VDT units ranged between 9.0 and 38.0 mT per second. Although the mean extremely-low-frequency emissions were significantly higher for VDT units than for non-VDT units, there was substantial overlap in individual measurements of operator exposure. The measurements of spatial variation in the extremely-low-frequency range showed that the electrical environment in the room contributed to the operators' exposure.[22] Because mean values for very-low-frequency and extremely-low-frequency emissions at the CCI terminals were, in some cases, higher than the values at the IBM terminals, we conducted an additional analysis that included separate exposure variables for pregnancies during which the women used CCI or IBM terminals. This analysis showed no difference in the risk of spontaneous abortion between women using a CCI unit (odds ratio = 0.92; 95 percent confidence interval, 0.58 to 1.47) and those using an IBM unit (odds ratio = 0.98; 95 percent confidence interval, 0.58 to 1.64).

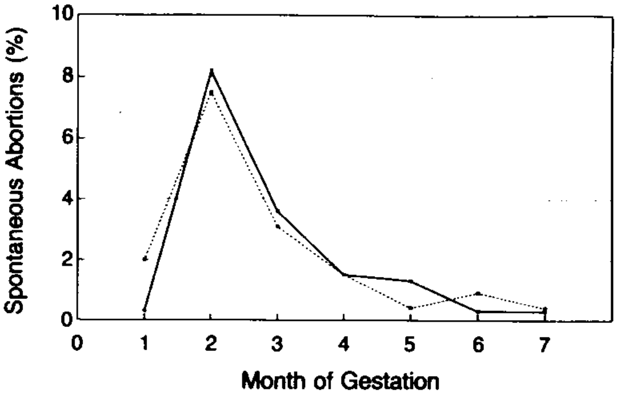

Figure 1. Rate of Spontaneous Abortion According to Month of Gestation and VDT Use.

The denominator for each month of gestation was obtained by subtracting the number of spontaneous abortions in the previous period from the previous denominator. The solid line represents pregnancies during which the woman used a VDT (exposed pregnancies), and the dotted line pregnancies during which the woman did not use a VDT (unexposed pregnancies).

Table 3. Outcome of Eligible Pregnancies, According to Job Category.*

Outcome	Directory-Assistance Operators	General Operators	All Operators
	number (percent)		
Live birth	307 (83.9)	430 (83.3)	737 (83.6)
Stillbirth	5 (1.4)	4 (0.8)	9 (1.0)
Spontaneous abortion	54 (14.8)	82 (15.9)	136 (15.4)
Total	366	516	882

*Directory-assistance operators used VDTs in their work, whereas general operators did not. For a definition of pregnancies included in the study, see Methods. Because of rounding, percentages may not total 100.

Discussion

In this study we found no increase in the risk of spontaneous abortion associated with the occupational use of VDTs. We did not observe an increased risk associated with three different measures of VDT use or with the VDT model used, after adjusting for confounders, or after accounting for more than one pregnancy in the same woman. Separate analyses of early spontaneous abortion, late spontaneous abortion, all fetal loss, and spontaneous abortions reported to a physician also failed to identify an increased risk of spontaneous abortion associated with VDT use. Al-

Table 4. Unadjusted Rates of Spontaneous Abortion and Adjusted Odds Ratios for Occupational VDT Use and Other Variables in the Final Logistic Model.*

Variable	No. of Pregnancies	Spontaneous Abortion Rate (95% CI)	Odds Ratio (95% CI)	P Value
		%		
Spontaneous abortion before study period				
No	709	12.8 (10.3–15.3)	1.0	
Yes	167	25.7 (19.1–32.3)	1.64 (0.98–2.77)	0.06
No. of alcoholic drinks/mo				
None	716	16.6 (13.9–19.3)	1.0	
1–8	143	4.9 (1.4–8.4)	0.22 (0.10–0.49)	<0.01
>8	17	47.1 (23.4–70.8)	2.81 (0.99–8.04)	0.05
Cigarettes smoked/day				
None	671	14.2 (11.6–16.8)	1.0	
1–19	144	14.6 (8.8–20.4)	1.09 (0.64–1.84)	0.76
≥20	61	29.5 (18.1–40.9)	2.89 (1.50–5.56)	<0.01
Thyroid disorder (diagnosed during or before first trimester)				
No	853	14.8 (12.4–17.2)	1.0	
Yes	23	34.8 (15.3–54.3)	2.75 (1.09–6.94)	0.03
VDT use in first trimester				
No	510	15.7 (12.5–18.9)	1.0	
Yes	366	14.8 (11.2–18.4)	0.93 (0.63–1.38)	0.73
Other VDT-exposure variables†				
VDT use in first trimester (hr/wk)				
None	499	15.6 (12.4–18.8)	1.0	
1–25	128	17.2 (10.7–23.7)	1.04 (0.61–1.79)	0.88
>25	169	15.4 (10.0–20.8)	1.00 (0.61–1.64)	0.99
VDT use in first 28 wk (hr/wk)				
None	494	15.8 (12.6–19.0)	1.0	
1–25	119	18.5 (11.5–25.5)	1.18 (0.69–2.04)	0.54
>25	179	14.5 (9.3–19.7)	0.90 (0.55–1.47)	0.67

*Odds ratios compare the odds of spontaneous abortion for a pregnancy with the specified risk factor with the odds for a pregnancy without that risk factor. Each odds ratio is adjusted for all the other risk factors in the model. CI denotes confidence interval. P values are for the comparison between pregnancies in each category and the reference group (odds ratio = 1.00).

†When these VDT-exposure variables were substituted in the model, confounder coefficients did not vary substantially and the relation between VDT use and spontaneous abortion remained unchanged. Because of missing data, the total number of pregnancies varied in each analysis.

though the upper confidence limit on the odds ratio (1.39) cannot exclude a moderate positive association, there were no other indications of a causal association, such as a trend toward increased risk with increasing hours of VDT use. The overall rates of spontaneous abortion among the VDT users (14.8 percent) and among those who did not use VDTs (15.9 percent) were within the range in published data (11 to 20 percent).[23] Although we found no association between VDT use and spontaneous abortion, we did find significant associations with spontaneous abortion for three previously reported risk factors: heavy alcohol consumption, cigarette smoking, and the presence of a thyroid disorder.[23-26]

Because information on the outcomes of pregnancy was reported by the women themselves, there was a possibility of differences in recall between the two groups. The 2430 women we interviewed reported a total of 203 spontaneous abortions between 1983 and 1986. The women who reported 77 (38 percent) of these spontaneous abortions had subsequent live births, which provided us with the opportunity to confirm previous spontaneous abortions from information recorded on birth certificates. We found that 89 percent (49 of 55) of the spontaneous abortions reported by general operators and 86 percent (19 of 22) of the spontaneous abortions reported by directory-assistance operators were recorded in subsequent vital records. We discovered only one spontaneous abortion that had not been reported in the interview. Although we were able to review only spontaneous abortions that were followed by live births (38 percent of all spontaneous abortions), the consistent findings in both the exposed group and the comparison group argue against differences in the recall of spontaneous abortions as a logical explanation for our negative findings.

Differences in the rate or timing of induced abortions between the exposed and the comparison group are unlikely explanations for our negative findings. We identified all reported induced abortions among directory-assistance or general operators during the study period. The rates of induced abortion in VDT-exposed pregnancies (4.8 percent) and unexposed pregnancies (5.3 percent) were similar, as was the gestational age at the time of the induced abortion (mean number of weeks at abortion, 9.6 and 7.9, respectively).

Since the ascertainment period for live births and stillbirths (May 1, 1983, through December 31, 1986) differed slightly from that for spontaneous abortions (January 1, 1983, through December 1, 1986), our study contained proportionally fewer full-term pregnancies during the later months of 1986. If the

Table 5. Geometric Mean (GM) and Standard Deviation (GSD) of Measurements of Electromagnetic Fields.*

Type of Unit	Very Low Frequency		Extremely Low Frequency	
	E field (V/m)	H field (mA/m)	E field (V/m)	H field (mA/m)
	GM (GSD)			
Frontal emissions (operator absent)				
VDT				
CCI	4.2 (1.54)†	98.9 (2.61)†	1.9 (1.63)†	313.6 (1.22)†
IBM	3.3 (2.07)	22.1 (4.68)	1.8 (1.93)	236.1 (2.14)
Non-VDT				
LED	0.1 (1.16)	1.6 (1.01)	0.4 (1.10)	72.3 (1.68)
NGT	0.1 (2.05)	1.4 (1.04)	0.5 (1.40)	30.3 (1.72)
Abdominal exposure (operator present)				
VDT				
CCI	0.5 (1.68)†	17.4 (1.74)†	0.8 (3.61)†	62.3 (1.59)
IBM	0.1 (1.71)	4.0 (1.85)	0.4 (1.70)	57.7 (2.12)
Non-VDT				
LED	0.1 (1.35)	2.0 (1.15)	0.4 (1.18)	62.4 (2.79)
NGT	0.2 (1.64)	1.6 (1.00)	0.4 (1.92)	32.4 (2.01)

*E denotes electric, H magnetic, CCI Computer Controls, Inc., and IBM International Business Machines. For details, see Methods. Non-VDT units were units with light-emitting diodes (LED) or neon glow tubes (NGT).

†P<0.05 for the comparison of VDT units (IBM and CCI units combined) with non-VDT units (LED and NGT units combined).

two groups of operators had a different number of pregnancies during the later months of 1986, the number of spontaneous abortions in one group could have been artificially increased. To examine this possibility, we reanalyzed the data after eliminating the 11 spontaneous abortions that occurred after April 30, 1986, and found no increased risk (odds ratio = 0.86; 95 percent confidence interval, 0.57 to 1.30).

Differences in VDT use outside the workplace are not a likely explanation for our findings. We examined data from the interviews on home VDT use and found that only 1.9 percent of the VDT-exposed pregnancies and 2.2 percent of the unexposed pregnancies involved VDT exposure at home.

When we compared payroll records with data on VDT use from the interviews, we found that approximately 52 percent of general operators who did not use a VDT while pregnant reported such use in the interview. Only 4 percent of directory-assistance operators who used a VDT while pregnant reported no use. A likely reason for this overreporting by the general operators is that they may have mistakenly referred to the light-emitting-diode or neon-glow-tube equipment as a VDT in the interview. If this is the reason for the overreporting, studies of different populations might have fewer errors in reported VDT use than documented here. However, the discrepancy between reported and record-based VDT use indicates that the accuracy of self-reported data may vary. When we analyzed the data according to women's reports of VDT use, we still observed no effect on the rate of spontaneous abortion (odds ratio = 0.85; 95 percent confidence interval, 0.56 to 1.29).

Elements of the study design did not allow us to address certain other questions directly. First, we could not assess whether early (subclinical) fetal loss might be affected by VDT use. The data shown in Figure 1, however, suggest that the incidence of the earliest recognized losses was similar for the exposed and unexposed pregnancies. Second, we could not assess effects of VDT use on older or unmarried women, since our study was limited to married women from 18 to 33 years of age. Such women make up the majority of pregnant women in the United States. Third, we studied a population that used only two models of VDT; the electromagnetic fields produced by the VDTs in our study were similar to those reported for other VDTs, however.[27-29] Finally, we selected the directory-assistance and general operators because of the similar levels of physical and psychological stress in their jobs. Therefore, this study could not address the association between spontaneous abortion and physical or psychological stress — two factors that may accompany the use of VDTs.

Although concern has been expressed that VDTs may produce harmful levels of electromagnetic energy, our research found that VDT operators had abdominal exposure to extremely-low-frequency fields (45 to 60 Hz) in the same range as exposures in the home. Studies of exposure to extremely-low-frequency electromagnetic fields have found average exposures to magnetic fields in the home between 40 and 200 mA per meter,[30-32] and average electric-field exposures of 2.5 V per meter.[32] Although VDT operators were exposed to very-low-frequency fields (in the range of 15 kHz), light-emitting-diode or neon-glow-tube units used by the general operators produced no measurable emissions in this range.

The strengths of this study include the similarity of the VDT-user group and the comparison group, the use of record-based data on the extent of VDT use during each pregnancy, and the direct measurement of electromagnetic fields. When we examined our data for potential biases, we found none that were likely to have substantively influenced the results. We conclude that in this study, the use of VDTs and exposure to the electromagnetic fields they produce were not associated with an increased risk of spontaneous abortion.

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AN INVESTIGATION OF ELECTRIC AND MAGNETIC FIELDS AND OPERATOR EXPOSURE PRODUCED BY VDTs: NIOSH VDT EPIDEMIOLOGY STUDY

FINAL REPORT

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NOTE

Portions of this report have been adapted from material contained in the User Manual for the Holaday Industries, Inc. Model HI-3600 VDT radiation survey meter which was developed under contract by Richard Tell Associates, Inc. for Holaday Industries, Inc.

AN INVESTIGATION OF ELECTRIC AND MAGNETIC FIELDS AND OPERATOR EXPOSURE PRODUCED BY VDTs: NIOSH VDT EPIDEMIOLOGY STUDY

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AN INVESTIGATION OF ELECTRIC AND MAGNETIC FIELDS AND OPERATOR EXPOSURE PRODUCED BY VDTs: NIOSH VDT EPIDEMIOLOGY STUDY

Summary

This report addresses the subject of electric and magnetic field emissions of video display terminals (VDTs), both radiofrequency (RF) and extremely-low frequency (ELF), at AT&T and Bellsouth telephone operator facilities. The study represents one component of a larger study of possible reproductive effects in VDT operators being conducted by the National Institute for Occupational Safety and Health (NIOSH). The purpose of this study was to assess the strength of the electric and magnetic fields produced by the different types of displays to which participants in the NIOSH study could have been exposed. Because of the study design used in the epidemiology investigation, the exposure evaluation included a study of the fields associated with VDTs and two other forms of displays which do not use cathode-ray-tube technology; these two non-VDT types of displays represent the equipment used by the control population in the NIOSH study. The non-VDT displays were designated as either NGT (nixie glow tube) or LED (light emitting diode) and the VDTs were designated as CCI or IBM, after the names of their manufacturers (Computer Consoles, Inc. and International Business Machines).

A study of 96 displays, selected at random, and located in nine cities, was conducted during April 23 through May 6, 1990. The comprehensive survey included measurements of very-low-frequency (VLF) RF electric and magnetic field emissions associated with the horizontal deflection circuits of the VDTs, at a distance of 30 centimeters (cm) from all accessible surfaces of each VDT. In addition, measurements of the ELF electric and magnetic fields produced by the vertical deflection circuits associated with the vertical refresh of the screen display were measured at a distance of 30 cm. The deflection frequencies were also measured. The amount of electrical current induced in the body by exposure to VDT electric field emissions was determined and contrasted with those currents

normally induced in individuals by exposure to environmental levels of radio broadcast station signals. For completeness, measurements of the waveforms of the electric and magnetic fields were made for comparison with recommended limits used in Sweden for the time-rate-of-change of magnetic fields. Each display selected for the study was also scanned for the presence of low-energy x-ray emissions.

Instrumentation used in the project consisted of commercially available instruments designed specifically for VDT type field measurements manufactured by Holaday Industries, Inc. Separate instruments, the Model HI-3600-01 and Model HI-3600-02, were used to measure the electric and magnetic fields in the VLF and ELF bands respectively. Prior to the field study, each instrument was subjected to a thorough evaluation relative to its calibration accuracy and all data collected in the study were appropriately corrected for individual instrument response.

It was found that the two different types of VDTs produced essentially the same horizontal deflection frequency, the CCI units with a nominal frequency of 15 kHz and the IBM units nominally 16 kHz. Vertical deflection frequencies were observed to be nominally 45 Hz for the CCI displays and 60-Hz for the IBM units. The results of the study showed that VLF electric and magnetic field strengths at 30 cm from the VDT screens fell predominantly in the range of 1.3-8.5 volts per meter (V/m) and 4.0-161 milliamperes per meter (mA/m) respectively. A single value of 47 V/m was the one outlier compared to the rest of the VLF electric field measurements. Measurement of field strengths in the VLF range for the NGT and LED displays were significantly less, electric fields being about 0.12-1.2 V/m and magnetic fields in the range of 1.3-1.7 mA/m at 30 cm from the displays. The strength of the fields decreases extremely rapidly with increasing distance from the VDT screen. Hence, exposure of individuals using VDTs is strongly related to how far they sit away from the VDT. Clearly, VDT exposure to RF emissions can become more a function of the manner in which the VDT is used by the operator, in particular the distance that the operator sits from the display, than of the emission characteristics of the unit.

A survey of the ELF electric and magnetic fields found that the field strengths were generally in the range of 0.61-6.4 V/m and 71-571 mA/m at 30 cm in front of the screens of the VDTs.

Electric fields produced by VDTs can be strongly perturbed by the presence of objects near the VDT, including the operator. The degree to which the operator's body can influence the local strength of the electric field was examined in operators positioned at each of the 96 displays showing that facial exposure is typically greater than that which the rest of the body receives. Because of the complicated manner in which the human body couples with the electric and magnetic fields produced by the VDT as a source, a more fundamental dosimetric parameter, for quantifying exposure, may be the current which is induced in the body by the very nonuniform exposure fields. A study of induced currents in all 96 operators found that, in terms of the magnitude of the currents, an individual's exposure to ambient levels of AM radio broadcast station signals generally results in significantly greater induced currents; hence, in this sense, VDTs represent a relatively minor contribution to everyday exposure.

The magnetic field waveform data indicated that the time-rate-of-change of the magnetic field, represented mathematically by the expression dB/dt, for locations 50 cm in front of the screen of the VDTs evaluated, ranged from 0.22 to 37.6 millitesla per second; the largest values were associated with the horizontal deflection system in the VDTs.

Examination of the measured electric and magnetic field strength values obtained in this study shows that in no instance do either of the two fields, determined at the position of the operator, exceed any of the standards for public exposure to RF fields from any country in the world, including applicable guidelines in the United States. In addition, the values of dB/dt at a point 50 cm in front of the screen, corresponding to the distance specified by a recent recommendation in Sweden, were, with two exceptions, less than that value presently used by the Swedes as a procurement specification for importing VDTs in Sweden. Based on the findings of this study, it is concluded that typical personnel exposures to VDT, NGT or LED electric or magnetic field emissions in the telephone offices investigated are relatively low, within the range of other exposure data on VDTs reported by other researchers, and are substantially less than any electric and magnetic field exposure limits developed for radiation protection purposes by organizations within the United States and many other countries.

On a comparative basis, the non-VDT type displays are distinctly different in terms of operator exposure levels when compared to the two types of VDTs used by operators in this study for VLF fields; the NGT and LED displays, not possessing internal magnetic field deflection systems, simply do not produce VLF fields above instrumentation background levels. For ELF fields, such a distinction is less clear. For example, the LED displays produced operator ELF magnetic field exposures which were similar to the values found for operators of both the CCI and IBM VDTs, however, the NGT ELF magnetic fields were significantly less than those produced by either of the VDTs. When taken as a whole, operators of non-VDT displays (NGTs + LEDs) would have, on average, been exposed to lower ELF magnetic fields than their counterpart operators at VDT units. For ELF electric fields, the NGT displays produced operator exposure values less than those for the CCI units but similar to those found for the IBM VDTs. It is concluded that, for the most part, the ELF electric fields appear to be principally a function of the room electrical environment, probably being more representative of electrical wiring systems used in the building than of any peculiar characteristic of the display. The ELF electric fields found for the CCI VDTs as a group appear, however, to be demonstrably above those values found for the rest of the displays, including the IBMs.

Conclusions

This report has elaborated on how VDT's work and how, through the action of the various electronic circuits, incidental electric and magnetic emissions are produced. A substantial amount of data on the characteristics of these emissions, including field strengths, frequencies and waveform peculiarities has been provided showing that VDTs are at the same time not unusual sources of exposure of individuals to electric and magnetic fields and yet, are unique in some respects. More specifically, VDTs can lead to exposures not dissimilar to that experienced near common television receivers. Television sets were found to possess even stronger emissions in some cases. But the unique character of the electric and magnetic field waveforms and exact frequency spectra (the spectrum caused by the fundamental flyback frequency and its associated harmonics) do make the VDT different in these respects.

Taken as a class, the non-VDT type displays are distinctly different in terms of operator exposure levels when compared to the two types of VDTs used by operators in this study for VLF fields. Table 15 is a simplified summary of the measurement results for frontal emissions, chest exposure and induced currents for the NGT, LED, CCI and IBM displays. The NGT and LED displays, not possessing internal magnetic field deflection systems, simply do not produce VLF fields above instrumentation background levels. For ELF fields, such a distinction is less clear. For example, the LED displays produced operator ELF magnetic field exposures which were similar to the values found for operators of both the CCI and IBM VDTs. For ELF electric fields, the NGT displays produced operator exposure values less than those for the CCI units but similar to those found for the IBM VDTs. It is concluded that, for the most part, the ELF electric fields appear to be principally a function of the room electrical environment, probably being more representative of electrical wiring systems used in the building than of any peculiar characteristic of the display. The ELF electric fields found for the CCI VDTs as a group appear, however, to be demonstrably above those values found for the rest of the displays, including the IBMs. Table 15 summarizes the measurement results in a simplified format for easier comparison between the NGT, LED, CCI and IBM displays for frontal emissions, chest exposure and keyboard induced currents. The results imply that the greatest difference in overall exposure would exist between operators of the NGT and CCI displays; in terms of VLF field exposure, both the NGT and LED displays are markedly lower than either the CCI or IBM VDTs.

Nevertheless, when compared to other sources of electric and magnetic fields commonly found in the workplace and the home environment, it was suggested that personal exposure to VDT produced fields could be compared by examining the electrical currents which are induced in the body by alternating electric and magnetic fields. Use of the induced current as an index of exposure, despite the fact that it does not differentiate various waveforms, facilitates the comparison of exposures caused by a wide variety of sources, especially sources which lead to highly nonuniform exposure over the body, like that of a VDT. When viewed in this context, it is found that induced currents can be categorized as those caused by exposure to the electric field and those caused by the magnetic field. While the currents induced by the electric field generally lead to currents which flow throughout the body and through body contact, like the feet or hands, to grounded surfaces, those currents that are magnetically induced generally circulate about the periphery of the body or exposed object (arm, hand, abdomen, etc.).

Measurements of currents flowing between operators of the displays examined and ground showed that very measurable differences exist between the VDTs (both CCI and IBM types) and the non-VDT displays represented by the NGT and LED displays. The VDTs produced consistently significantly greater induced currents.

By considering the currents typically induced by AM radio broadcast stations, as an example, it was found that normal exposure to VDT's in the workplace is not significantly different from that induced virtually all of the time by ambient radio station signals to which everyone is exposed. Exposures in the vicinity of some low frequency communications and radio-navigation stations which use high powers and frequencies very similar to the VDT range could cause substantially greater induced currents than caused by the VDT.

When the field strengths found near VDT's are compared to various standards which specify maximum safe human exposure to electric and magnetic fields one is also impressed by the generally wide margin which exists between the limits and VDT exposure levels. Examination of the measured electric and magnetic field strengths reported in summary Tables 5-8 and in Appendix B shows that in no instance do either of the two RF fields, determined at the position of the operator, exceed any of the standards in Table 12, even the extremely stringent Polish and Czechoslovakian standards for the general public. Based on this finding, it is concluded from measurements on 96 displays comprised of both VDT and non-VDT type displays that typical personnel exposures to electric and magnetic fields are (1) relatively low, (2) within a relatively confined range of magnitudes reported by many researchers, (3) are not highly dissimilar to exposures commonly encountered from radio stations and other devices routinely found in the home or workplace and (4) are generally substantially less than any electromagnetic field exposure limits developed for radiation protection purposes by organizations within the United States and many other countries. In addition, measures of dB/dt, the time-rate-of-change of the magnetic field, were found to be, with three exceptions for the units examined, nominally equal to or less than the recommended limit for VDTs imported in Sweden.

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Table 5. Statistical summarization of data on emission field strengths, operator exposure levels and induced currents for 24 NGT displays. Indicated values are the geometrical means and (geometrical standard deviations).

NGT Emission Field Strength Statistical Summary, N=24

Position	VLF-E (V/m)	VLF-H (mA/m)	ELF-E (V/m)	ELF-H (mA/m)
Top	0.137 (1.814)	1.38 (1.036)	1.19 (1.687)	30.0 (1.691)
Front	0.077 (2.05)	1.36 (1.044)	0.470 (1.400)	30.3 (1.724)
Bottom	0.056 (1.987)	1.38 (1.036)	0.351 (1.328)	32.7 (1.826)
Back	0.059 (1.505)	1.38 (1.036)	0.452 (1.436)	33.6 (1.737)
Left side	0.044 (1.353)	1.39 (1.023)	0.282 (1.223)	43.7 (1.787)
Right side	0.048 (1.204)	1.37 (1.034)	0.388 (1.175)	44.2 (1.772)

NGT Operator Exposure Statistical Summary, N=24

Position	VLF-E (V/m)	VLF-H (mA/m)	ELF-E (V/m)	ELF-H (mA/m)
Abdomen	0.177 (1.636)	1.6 (1.0)	0.405 (1.92)	32.4 (2.01)
Chest	0.099 (1.653)	1.6 (1.0)	0.308 (1.530)	33.0 (1.877)
Face	0.147 (1.515)	1.6 (1.0)	0.813 (1.417)	32.6 (1.808)

NGT Induced Current Statistical Summary, N=24

Hand Location	Induced Current (μA)
Hands on keyboard	0.019 (1.021)
Finger touching screen	0.018 (1.024)
Hand placed flat on screen	0.019 (1.022)

Table 6. Statistical summarization of data on emission field strengths, operator exposure levels and induced currents for 24 LED displays. Indicated values are the geometrical means and (geometrical standard deviations).

LED Emission Field Strength Statistical Summary, N=24

Position	VLF-E (V/m)	VLF-H (mA/m)	ELF-E (V/m)	ELF-H (mA/m)
Top	0.160 (1.391)	1.6 (1.0)	1.270 (1.885)	69.6 (1.855)
Front	0.114 (1.161)	1.604 (1.012)	0.376 (1.103)	72.3 (1.682)
Bottom	0.196 (1.147)	3.811 (1.439)	0.409 (1.059)	62.2 (2.01)
Back	0.524 (1.582)	1.6 (1.0)	12.2 (1.534)	79.0 (1.607)
Left side	0.113 (1.092)	1.620 (1.026)	0.449 (1.229)	59.2 (2.83)
Right side	0.110 (1.052)	1.621 (1.026)	0.471 (1.309)	55.2 (2.61)

LED Operator Exposure Statistical Summary, N=24

Position	VLF-E (V/m)	VLF-H (mA/m)	ELF-E (V/m)	ELF-H (mA/m)
Abdomen	0.081 (1.346)	1.97 (1.150)	0.351 (1.175)	62.4 (2.79)
Chest	0.059 (1.475)	1.53 (1.067)	0.299 (1.107)	69.6 (2.70)
Face	0.073 (1.957)	1.39 (1.025)	0.317 (1.105)	80.4 (2.57)

LED Induced Current Statistical Summary, N=24

Hand Location	Induced Current (μA)
Hands on keyboard	0.014 (1.009)
Finger touching screen	0.008 (1.007)
Hand placed flat on screen	0.009 (1.009)

Table 7. Statistical summarization of data on emission field strengths, operator exposure levels and induced currents for 24 CCI displays. Indicated values are the geometrical means and (geometrical standard deviations).

CCI Emission Field Strength Statistical Summary, N=24

Position	VLF-E (V/m)	VLF-H (mA/m)	ELF-E (V/m)	ELF-H (mA/m)
Top	3.06 (1.31)	61.4 (3.11)	3.23 (1.588)	401. (4.11)
Front	4.22 (1.54)	98.9 (2.61)	1.85 (1.633)	314. (1.216)
Bottom	0.302 (3.45)	15.9 (3.04)	1.65 (4.654)	172. (2.23)
Back	2.46 (1.75)	62.2 (2.11)	4.25 (1.762)	507. (2.10)
Left side	0.749 (1.55)	82.6 (1.332)	2.09 (2.56)	504. (2.13)
Right side	1.10 (1.95)	82.5 (1.461)	8.49 (1.678)	487. (1.712)

CCI Operator Exposure Statistical Summary, N=24

Position	VLF-E (V/m)	VLF-H (mA/m)	ELF-E (V/m)	ELF-H (mA/m)
Abdomen	0.544 (1.683)	17.4 (1.741)	0.845 (3.610)	62.30 (1.590)
Chest	1.05 (1.399)	14.8 (1.903)	1.020 (1.987)	80.6 (1.653)
Face	1.41 (1.424)	41.7 (1.597)	1.90 (1.894)	81.6 (1.597)

CCI Induced Current Statistical Summary, N=24

Hand Location	Induced Current (μA)
Hands on keyboard	4.13 (4.42)
Finger touching screen	14.6 (3.10)
Hand placed flat on screen	87.8 (2.19)

Table 8. Statistical summarization of data on emission field strengths, operator exposure levels and induced currents for 24 IBM displays. Indicated values are the geometrical means and (geometrical standard deviations).

IBM Emission Field Strength Statistical Summary, N=24

Position	VLF-E (V/m)	VLF-H (mA/m)	ELF-E (V/m)	ELF-H (mA/m)
Top	0.177 (1.567)	27.5 (2.01)	0.560 (1.483)	232. (2.62)
Front	3.26 (2.07)	22.1 (4.68)	1.78 (1.929)	236. (2.14)
Bottom	0.086 (1.745)	2.21 (1.32)	0.839 (2.31)	46.9 (2.08)
Back	0.151 (1.455)	16.4 (2.10)	0.708 (1.889)	140. (1.909)
Left side	0.139 (1.755)	11.8 (2.57)	0.453 (2.03)	306. (1.888)
Right side	0.115 (1.566)	15.6 (1.391)	1.25 (2.31)	205. (1.928)

IBM Operator Exposure Statistical Summary, N=24

Position	VLF-E (V/m)	VLF-H (mA/m)	ELF-E (V/m)	ELF-H (mA/m)
Abdomen	0.142 (1.710)	3.98 (1.852)	0.429 (1.698)	57.7 (2.12)
Chest	0.328 (1.864)	4.23 (2.13)	0.506 (1.780)	66.6 (2.12)
Face	0.543 (1.682)	6.72 (3.00)	0.779 (1.867)	76.4 (1.918)

IBM Induced Current Statistical Summary, N=24

Hand Location	Induced Current (μA)
Hands on keyboard	0.377 (4.65)
Finger touching screen	6.64 (1.968)
Hand placed flat on screen	69.1 (1.600)

Table 11. A summary of VDT electromagnetic field emission data from the technical literature.[+]

No. Units	Band	VDT/TV	RMS E Field Strength (V/m) Mean(+/- SD)++	Min.	Max.	RMS H Field Strength (mA/m) Mean(+/- SD)	Min.	Max.	Reference
44	VLF	VDT				50.0 (45.5)	0.72	172.8	Paulsson(1984)
3	VLF	VDT				56.7 (46.5)	25	110	Harvey(1983b)
5	VLF	VDT	12.4(13)	4	35				Harvey(1984a)
54	VLF	VDT	0.48*	0.05	2.64				Harvey(1984b)
38	VLF	VDT			20**				Marha(1983)
21	VLF	VDT	6.92(2.13)	3.0	10.2	49.3 (14.5)	30	76	Guy(1987a)
11	VLF	VDT	0.83(0.83)	0.22	2.7	27.8 (26.6)	0.26	76	Roy(1983)
11	VLF	VDT(color)	1.31(0.83)	0.39	3.1	33.4 (23.0)	7.3	78	Joyner(1984)
39	VLF	VDT	1.96(2.98)	0.2	15	20.4 (17.6)	0.3	76	Joyner(1984)
39	VLF	VDT	6.4 (1.5)		47				Boivin(1986)
52	VLF	TV	8.6 (0.5)		21				Boivin(1986)
3	ELF	VDT				85.3 (26.9)	54	103	Stuchly(1983)
7	ELF	VDT				260 (52.6)	200	350	Juutilainen(1986)
4	ELF	VDT	12.0(12.4)	3	30				Harvey(1982)
3	ELF	VDT				293 (234)	120	560	Harvey(1983b)
5	ELF	VDT	30.0(24)	10	65				Harvey(1984a)
86	VLF	VDT		<1	4.4				Canada(1983)

* Equivalent median unperturbed field strengths derived from a measurement of perturbed field.
** Measured at 20 cm in front of the screen
\+ Measured at 30 cm in front of the screen.
++ Arithmetic means and standard deviations given in this table

Table 12. Selected standards for exposure to radiofrequency fields pertinent to the VDT frequency range. E = electric field strength; H = magnetic field strength; B = magnetic field flux density; Occ = occupational; GenP = general public.

Standard/ref	Occ	GenP	E(V/m)	H(A/m)*	B(μT)	f(MHz)
ACGIH(1990)	X		614	1.63	1.98	0.03-3
ANSI(1982)	X	X	632	1.58	1.98	0.3 -3
Australia(1985)	X		194	0.515	0.647	0.3 -9.5
Australia(1985)		X	87	0.23	0.29	0.3 -9.5
Canada(Stuchly, 1989)	X		600	4.0	5.0	0.01-1.2
Canada(Stuchly, 1989)		X	280	1.8	2.3	0.01-1.2
Czech(Czerski, 1985)	X		50	-	-	0.03-30
Czech(Czerski, 1985)		X	5	-	-	0.03-30
IRPA(1988)	X		614	1.6/f $^{1/2}$	2.0/f $^{1/2}$	0.1 -1
IRPA(1988)		X	87	0.23/f $^{1/2}$	0.24/f $^{1/2}$	0.1 -1
Italy(Grandolfo, 1986)	X		140	0.36	0.45	0.1 -10
Germany(1986)	X	X	1500	2500	3141	0.03**
MASS(1983)		X	275	0.729	0.916	0.3 -3
NATO(1979)	X		1000	2.6	3.3	0.01-1
NRPB(1989)	X	X	614	4.89/f	6.14/f	0.03-1
Poland(Szmigielski, 1989)	X		70	10	12	0.1 -10
Poland(Szmigielski, 1989)		X	20	-	-	0.1 -10
Portland(1987)		X	283	0.707	0.888	0.1 -3
Seattle(1989)		X	283	0.707	0.888	0.1 -3
Telecom (1986)	X	X	87	0.23	0.288	0.010 - 10
USAF(1987)	X	X	632	1.58	1.98	0.01-3
USSR(1984a)	X		50	5.0	6.3	0.06-1.5
USSR(1984b)		X	25	-	-	0.03-0.3

* 1A/m = 12.57 mG in free space and most biologic media

** Values given are for 30 kHz but vary according to formula in standard.

Video Display Terminals:
Radiation Issues

William E. Murray

During the past decade, the use of video display terminals (VDTs) in information processing and related applications has grown exponentially. Recent estimates place the number of terminals in the workplace at more than ten million. Along with this rapid growth there has been a concomitant increase in concern about the radiation emissions from the VDT. Several types of radiation can be emitted by the terminal. Cataracts, reproductive problems, and skin rashes have been reported by VDT operators and are alleged to result from radiation exposure. However, measurements of the radiation emissions, when compared to the present occupational exposure standards, lead to the conclusion that the terminal does not present a radiation hazard to the VDT operator.

The video display terminal (VDT) has found widespread use in information processing and related applications. It is estimated that over ten million units are being used and the number is growing rapidly. With this widespread use of VDTs has come concern that radiation emitted by the terminals may pose a health hazard to the operators.

This article will discuss information that has been gathered in the past few years related to the health effects of VDTs. Particular emphasis will be given to the issues that continue to be raised by VDT users. It is important to know the questions that are being asked by the operators and how to address them.

Radiation Emissions

The first and most obvious issue is "Does the VDT emit electromagnetic radiation and, if so, what types are emitted?" Of course, the video terminal is expressly designed to produce one type of electromagnetic radiation–light. However, certain components of the terminal can produce several other types of radiation including:

- X-ray,
- ultraviolet (UV),
- infrared (IR),
- radiofrequency (RF),
- extremely low frequency (ELF),
- electrostatic fields,
- ultrasound.

The cathode ray tube (CRT) operates at high voltage, usually between 11 and 18 kilovolts (kV)

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for a black-and-white or monochromatic unit. Much higher voltages (over 25 kV) are present in color units. Most of the video terminals now on the market are the monochromatic type. But, even at these somewhat lower voltages, there is a potential for x-ray emission. Electrostatic fields are also associated with the operation of the CRT.

The visible image is produced when the electron beam interacts with the phosphor coating on the inside front surface of the CRT. These phosphors may also emit near-UV and near-IR radiation.

> ***"Three specific health problems are generally attributed to the operators' exposure to radiation emitted from VDTs."***

Radiofrequency (RF) radiation is generated by the flyback transformer. This device controls the horizontal deflection system and operates at frequencies between 15 and 20 kilohertz (kHz). There are other circuits that can produce RF radiation but the flyback transformer is the major source. Extremely low frequency (ELF) radiation (0-500 Hz) is also present around the terminals and is associated with the vertical deflection system and modulations of the above-mentioned electrostatic field.

Many people are concerned about microwaves being emitted by the terminals. However, the highest measurable frequencies VDTs produce are about 30 megahertz (MHz). This is far below the microwave region, which starts at 300 MHz.

Ultrasonic radiation (ranging from 15 to 20 kHz) is also associated with the flyback transformer. Since this is sonic rather than electromagnetic radiation, some people hear this frequency as a high pitched noise.

Health Concerns

Three specific health problems are generally attributed to the operators' exposure to radiation emitted from VDTs. The first concerns the visual system: users fear they will get cataracts. (In fact, NIOSH's initial radiation survey was prompted by the occurrence of cataracts in two reporters, both male and under the age of 35, who used VDTs at a large eastern newspaper.[1])

Second, there are potential reproductive implications for VDT users. Questions have been raised about the occurrence of clusters of birth defects, miscarriages, and spontaneous abortions among female VDT operators at several worksites in the United States and Canada.[2]

Third, a number of cases of facial skin rashes among VDT operators have been reported in Norway, Great Britain, and Canada.[2] The rashes, usually appearing on the cheeks, are not serious but do result in itching, mild erythema (skin injury), and minor desquamation (peeling of the skin). The symptoms usually subside overnight. NIOSH has noted cases of self-reported skin problems in some of its field studies, but no detailed medical information is available concerning these reports.[3]

From both animal and human studies, we know that the above three types of health problems can result from exposure to a high level of radiation. Ionizing, ultraviolet, and RF/microwave radiation can cause cataracts. Both ionizing and RF/microwave radiation can cause birth defects and miscarriages. Recent animal studies suggest that ELF (magnetic field) is embryotoxic.[4] However, prior research into these problems suffers from internal inconsistencies and inaccuracies in dosimetry. Efforts to reproduce these results are underway in other laboratories. Skin injury can result from exposure to ultraviolet, infrared, or ionizing radiation. However, these health problems also occur in the general population, which has no occupational exposure to radiation.

The key question is, given that the types of radiation that can be emitted by the terminals are associated with health problems, is there a scientific basis for claims by VDT operators?

To answer this question, the radiation emitted by these terminals must be measured. After the levels of radiation to which operators are exposed have been determined, the measured levels must be compared to existing occupational exposure standards (see Table 1) and to the thresholds for biological effects available in the pertinent literature.

Radiation Surveys

Radiation surveys have been conducted by NIOSH in a dozen locations, measuring the emissions from several hundred video terminals.[1,5] The results of these field surveys, summarized in Table 2, will be discussed in more detail below.

Additionally, measurements have been made by Bell Laboratories, the Duke University School of Medicine, the University of Washington, and the Food and Drug Administration (FDA).[6-9] Still other surveys have been conducted in Canada and Western Europe.[10-13]

In all of the NIOSH field surveys, the X-radiation levels were below background levels. The FDA tested 125 terminals under laboratory conditions and found ten units that did leak measurable amounts of X-rays. Eight of these ten units were above the X-ray performance standard for television receivers.[9] However, these terminals were never marketed. Any X-rays that they emitted would have been very soft, low-energy X-rays.

TABLE 1: Occupational Radiation Exposure Standards

Radiation type	Occupational standard	Reference
X-Ray	2.5 mrem/hr	OSHA (16)
Ultraviolet (near)	1000 uW/cm^2	ACGIH (14)
Visible	2920 fL	ACGIH (14)
Radiofrequency		
Electric field (10-100,000 MHz)	40,000 V^2/m^2*	OSHA (17)
Magnetic field (10-100,000 MHz)	0.25 A^2/m^2*	OSHA (17)
Electric field (10-3000 kHz)	377,000 V^2/m^2**	ACGIH (14)
Magnetic field (10-3000 kHz)	2.65 A^2/m^2**	ACGIH (14)
Ultrasound	80 dB	ACGIH (14)

*Far-field equivalent of 10 mW/cm^2

**Far-field equivalent of 100 mW/cm^2

Making RF radiation measurements with field survey instrumentation is problematic. NIOSH has asked the FDA to conduct a spectrum analysis of two typical terminals. In such an analysis, the intensity of RF radiation is measured as a function of frequency. The flyback transformer and associated horizontal deflection system (which operates at around 15 to 20 kHz) are the major sources of RF radiation. The FDA study found that 95 percent of the RF energy emitted by the tested terminals was in the frequency range from 15 to 250 kHz.[9]

There is an inherent difficulty in measuring RF radiation at these frequencies, even with the sophisticated analysis done in the FDA study. When an operator is seated in front of a VDT, this distance is relatively short compared to the RF wavelength (that can be as long as 20,000 meters). At such short distances the operator and the source interact with each other, making accurate measurement difficult. Previous studies have not accounted for this source-operator interaction and this component of exposure. New techniques, which use a metal phantom to simulate the operator, have overcome this difficulty.[8,13] These studies have confirmed the FDA finding that most of the RF energy is in the 15 to 250 kHz frequency range.

"There is an inherent difficulty in measuring RF radiation at these frequencies. . . . "

There is no Federal occupational standard for this frequency range; the OSHA standard only covers frequencies down to 10 MHz. However, the American Conference of Governmental Industrial Hygienists (ACGIH) has established a standard down to 10 kHz.[14] The maximum operator exposures from the terminals tested were less than the ACGIH standard by a factor of five or more. However, much higher levels are present very close to the VDT surface,[8] but so close to the screen that it is unlikely the operator would ever be exposed to them.

Other recent studies have examined the electric and magnetic field component in the ELF spectral region.[12,13] The measured electric and magnetic field strengths are similar in magnitude to ELF

TABLE 2: Summary of Maximum Radiation Levels and Number of Video Display Terminals Surveyed by NIOSH

EMR Region	X-Ray Radiation	Ultraviolet Radiation	Visible Radiation	Infrared Radiation	Radiofrequency Radiation E-field	Radiofrequency Radiation H-field
Number Terminals Measured	286	141	163	5	208	208
Maximum Measured Values	0.3 mR/hr	0.65 uW/cm^2	250 fL	ND	5000 V^2/m^2	0.09 A^2/m^2

levels present around common household appliances—well below the thresholds for any known biological hazards. No occupational exposure standard for ELF radiation has been established in the United States.

The electrostatic fields around the terminals are highly variable and drop off rapidly as the distance from the CRT face increases. At the operator's position, the average value is about 5 to 10 kilovolts per meter.[15] The health significance of such exposures is not known and no related occupational standard has been established in the United States.

The ultraviolet radiation emitted by VDTs ranges between 300 and 400 nanometers (nm). Since the VDT phosphor is designed to produce visible radiation, not much ultraviolet radiation is emitted. Measured levels are generally a factor of 1,000 or more *below* the present ACGIH standard.[14]

NIOSH has performed very few infrared measurements because the levels were below the detection limits of NIOSH instruments in its first survey.[1] Moreover, few phosphors produce radiation in this region (760 to 800nm), and the emissions would therefore be at a very low level.

Ultrasound measurements have been reported by FDA.[9] In the FDA report, the levels were well below the occupational standard recommended by ACGIH.[14]

Long Term Risks

What happens if a person uses a VDT day in and day out over 20 or 30 years? Are the present standards adequate to protect workers exposed to radiation from VDTs over their lifetimes? For answers, we look to the current literature and critically examine the effects and thresholds. In establishing occupational standards, human epidemiologic data and chronic, long-term animal studies are emphasized. In fact, where available, this information has been used for setting standards.

For ionizing radiation, for example, much information is available and the standard is quite adequate. In some of the other spectral regions (nonionizing), however, not as much information is available. Based on present knowledge, the existing standards seem to be adequate. We are constantly learning more about the effects of radiation exposure, especially long-term exposure. The more we learn, the better our knowledge serves as a basis for setting occupational health standards.

Other Concerns

The following are some of the other concerns often expressed by VDT operators:

- "What if the VDT malfunctions?"
- "What if my terminal gives off more radiation than most?"
- "What happens as these terminals get older?"
- "Does it make a difference if I work in a room where there are many terminals?"

These are legitimate concerns because the operators believe that there is some potential for an increased radiation emission under these circumstances.

It is true that a malfunction can increase the radiation emission from a VDT. The FDA performs malfunction testing and has demonstrated that X-ray emission can increase as the CRT voltage increases.[9] However, with a serious malfunction, the terminal may operate for a short time, but eventually the image will become unusable, and the VDT will be removed for repair. With regard to raising the CRT voltage, NIOSH was told by a design engineer that if the CRT voltage were increased by 25 percent, the terminal would not be usable. The VDT is a sensitive electronic device and has stringent design requirements and engineering specifications under which it operates. Although hard data are not available, scientists at NIOSH believe that a severe malfunction would make the VDT unusable, and it would be taken out of service, thereby rendering it harmless as a source of radiation.

> ***"Does it make a difference if I work in a room where there are many terminals?"***

As to the other questions, surveys done by the NIOSH have not shown large differences in the radiation emissions between individual terminals or between different brands or models. The employees' exposure does not seem to increase as the terminals become older or with multiple terminals present.

Conclusions

The radiation levels emitted by a video display terminal are below the occupational exposure standards existing in the United States. In many cases, the levels are below the detection capability of the survey instrumentation used. Considering the radiation measurements, biological injury thresholds, and occupational exposure standards, the VDT does not present a radiation hazard to the VDT operator.

There is no scientific evidence that the occurrence of cataracts, birth defects, miscarriages, or skin rashes is related to radiation exposure from VDTs. Thus, there is no justification for providing additional (radiation) shielding of the VDT or lead aprons for the operators or for transferring pregnant women to other jobs to reduce their radiation exposure.

The instrumentation required to measure the radiation emissions from a VDT either in the field or in a laboratory setting is quite sophisticated and expensive. Special training and experience are required to use the instruments correctly and interpret the results of radiation testing. In light of the low level of radiation emissions from VDTs, routine surveys are not warranted.

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OFFICE TECHNOLOGY AND MUSCULOSKELETAL DISORDERS: BUILDING AN ECOLOGICAL MODEL

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Just as a shift from infectious to chronic disease epidemiology required new approaches for understanding the origins and patterns of disease, so too will we need to develop new ways of understanding the origins and patterns of illnesses and diseases produced by changes in technology from a human-mediated work process to a computer-mediated work process.[1]

There are no accurate statistics on the number of workers in the United States who routinely use computers in their jobs. Estimates of the number of people engaged in computer-mediated work also are difficult to determine. However, based on the number of workers in occupations known to use computers to some degree, a conservative estimate is that about half of the 120 million workers in the U.S. are now spending some time during the workday at a computer keyboard. With the continued rapid expansion of computer technology to all sectors of the economy, the numbers will only increase.

The effects of the physical aspects of the computer work environment on worker health have long been a concern; studies since the 1970s have indicated a link between ergonomic aspects of the work environment and musculoskeletal and other problems.[8,16,21,25,26,30] Although this research has prompted significant improvements in the design of office equipment and environments, musculoskeletal problems among computer users are still common. Thus, attention has increasingly turned to other occupational risk factors, namely work organization factors, which may, in

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conjunction with physical risk factors, play a role in the etiology of musculoskeletal disorders. Work organization is defined here as the way in which work is structured and managed, and it encompasses factors such as job design, the scheduling of work, interpersonal aspects of work, career issues, management practices, and organizational characteristics.[24] In this definition, work organization includes what have more commonly been called psychosocial factors or job stressors (e.g., job content factors such as skill usage and control; interpersonal relationships).

There is uncertainty regarding the ways in which work organization may be etiologically linked with musculoskeletal disorders. Models proposing a number of potential pathways have been developed but largely remain untested.[7,31-33,35] The ecological model of Sauter and Swanson will guide the analyses reported in this chapter.[32]

AN ECOLOGICAL MODEL OF MUSCULOSKELETAL DISORDERS IN OFFICE WORK

Although this ecological model was developed with office work and musculoskeletal disorders as the primary foci, it is a holistic approach that is applicable to other types of work environments and health outcomes. The model suggests various ways in which work organization and physical factors may act singly or in concert to result in musculoskeletal symptoms and disorders (Fig. 1). The major pathways include the following:

- Physical demands imposed by the job may lead to biomechanical strain and subsequent musculoskeletal outcomes.
- Changes in the way that work is organized (e.g., scheduling, job demands) can change the physical demands of the job, leading to musculoskeletal outcomes.
- Changes in work organization may create stress, which may result in increased biomechanical strain (e.g., increases in muscle tension) and an increased risk of musculoskeletal problems.

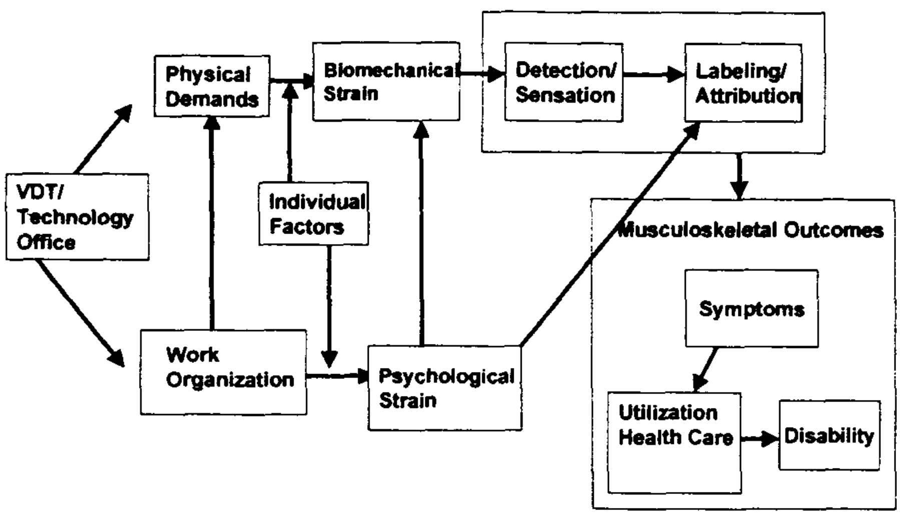

FIGURE 1. Model describing the paths from office technology to musculoskeletal outcomes. (Adapted from Sauter SL, Swanson NG: An ecological model of musculoskeletal disorders in office work. In Moon S, Sauter SL (eds): Beyond Biomechanics: Psychosocial Aspects of Musculoskeletal Disorders in Office Work. London, Taylor & Francis, 1996, pp 3–21.)

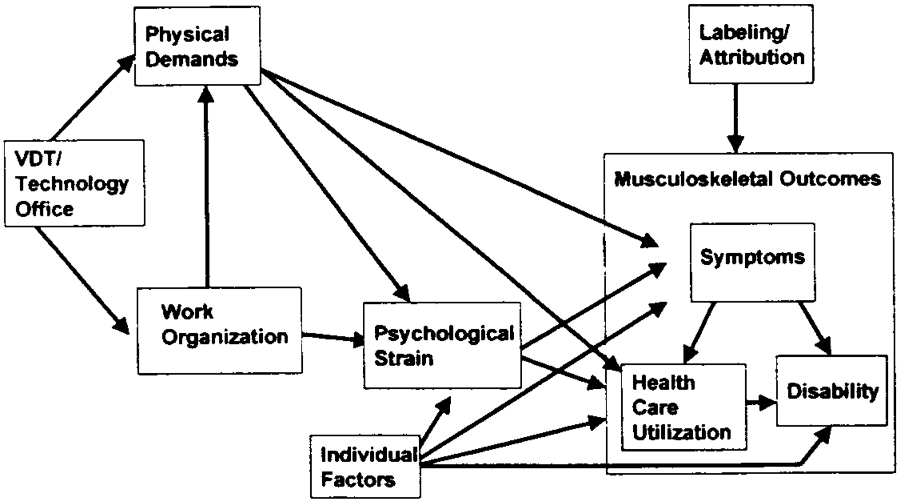

FIGURE 2. Modified model describing the analytic paths from office technology to musculoskeletal outcomes.

- Work organization factors may create psychological strain, which in turn may affect the detection and labeling/attribution of musculoskeletal symptoms (e.g., symptoms may be more readily detected in boring, repetitive, narrow jobs where there is little stimulation to compete with symptoms for attention).

Individual factors such as age or gender may modify the effects of physical or work organization/psychosocial demands (e.g., older workers may be more susceptible to injury under conditions of high work demands). Finally, the model recognizes that musculoskeletal outcomes encompass a range of factors, including symptom reporting, health care utilization, and disability.

The data set in the present study contains measures of physical demands, work organization, psychological strain, labeling/attribution, symptoms, health care utilization, and disability. Figure 2 shows the model and pathways that these variables allow us to test. Although several of the pathways listed above are tested, pathways dependent on measurement of biomechanical strain cannot be tested fully given the lack of that measure in the data set.

THE STUDY POPULATION

The data for this analysis come from the Ergonomics and Your Health Project,[19] in which 1779 workers at a large aerospace manufacturing company in the Northeast completed a self-administered survey, on company time, in 1992. The overall response rate was 64%, and data from the questionnaire have been linked with administrative data including workers' compensation and sick hours.

The sample for this analysis excluded nonsalaried or factory/shop floor workers and workers not using a video display terminal (VDT). The response rate for salaried (office) workers, the focus of this analysis, was 65%. A total of 282 women and 523 men completed the questionnaire. A group of 117 salaried engineers were excluded from the analysis because of the inability to reliably define their physical demands. These engineers spent all or none of their time at the VDT depending on whether they were designing a new work process, implementing a new work process, modifying an existing production set-up, or solving a problem on the shop floor. The engineers exclusively worked on the floor or in the office. Excluding this group did not change results and yielded an analytic sample of 249 women and 439 men.

MEASURES USED IN PATH MODELS

This section discusses the specific domains of the ecological model that are depicted in Figure 2.

Physical demands are measured as the amount of time spent during an average week working in front of the VDT. Observers—industrial engineers and occupational safety and health staff—working in the business units where computers were being used determined the amount of time. Individuals were classified into one of five groups (0–29 hours per week, 30–49 hours, 50–79 hours, 80–100 hours, and variable hours). The "variable group" comprised the engineers and was deleted.

Work organization is measured with a set of psychosocial measures.

1. *Job decision latitude* is an index specified by Karasek and is a combination of decision authority (have freedom to make decisions, can choose how to perform work, have a lot of say on the job) and skills discretion (keep learning new things, can develop skills, job requires skill, task variety, repetitious, job requires creativity).[17] It assesses the amount of control a person has over what is done and how it is done.

2. *Psychological job demands* is a measure of the amount of effort required to carry out the work (excessive work, conflicting demands, insufficient time to do work, work fast, work hard) developed by Karasek.[17]

3. *Role ambiguity* is a measure of the lack of clarity in work responsibilities and duties (clear on responsibilities, what others expect of you is predictable, work objectives well defined, clear what others expect) developed by Kahn and colleagues.[9]

4. *Role conflict* is a measure of conflicting demands placed on the worker (people equal in rank and authority, people in a good position to see what you do, and people whose request should be met ask you to do things that conflict) developed by Kahn.[9]

5. *Work-related social support* measures the amount of instrumental and emotional support provided by coworkers and supervisors during the workday (people go out of their way to make work life easier, easy to talk with people, people can be relied upon when things get tough, people willing to listen to personal problems) developed by House.[14,15]

We attempted to reduce the number of work organization measures by examining the intercorrelation between the scales. This led to combining skill discretion and decision authority ($r = 0.65$) into job decision latitude and coworker and supervisor support ($r = 0.40$) into work support based on conceptual congruence. Although psychological job demands and role ambiguities are statistically correlated ($r = 0.42$), we felt they were conceptually different enough to warrant not combining them. The remainder of the correlations were low, ranging from 0.05–0.2.

Psychological strain is measured with two scales. *Global demoralization* is a 27-item nonspecific psychological distress measure developed by Dohrenwend for use in community studies.[11] *Job satisfaction* measures the satisfaction the worker has with 10 facets of the job (job as whole, pay, people work with, boss/supervisor, type of work, chances of promotion, skills use, workstation, tools use, and job security). It is based on earlier Quality of Employment Survey measures.[9]

Individual factors are measured with two variables. *Age* is a continuous measure. *Neuroticism* measures the tendency of a person to report symptoms or other problems in life. It is a 48-item measure developed by Costa and McCrae.[10]

Labeling/Attribution is assessed with a measure of *social desirability*. The 13-item measure is derived from the original 64-item Crowne-Marlowe measure.[29] People who score higher on social desirability tend to try to present themselves in a positive light and are less likely to report symptoms.

Musculoskeletal outcomes are measured in three separate domains.

1. *A symptom/duration measure* was created for each of six musculoskeletal areas (neck, shoulder, elbow, hand/wrist, back, and leg) by multiplying symptom frequency by duration. Each series of questions for a musculoskeletal region has an initial skip question ascertaining the presence or absence of symptoms. Workers reporting no symptoms were assigned a score of zero to retain them in the analysis.

2. *Health care utilization* was measured by combining responses to a series of questions about health care visits (seeing a physician, nurse, physician assistant, nurse practitioner, chiropractor, physical therapist, therapeutic masseuse, surgeon) and treatment (having surgery for current musculoskeletal problem). Weighting facilitated combining the items into a single meaningful scale. Seeing a provider once during the past year was considered much less significant than two to five times (weighted 3) or more than five times (weighted 6). Having surgery was also weighted as 6, and seeing a surgeon was weighted as 3.

3. *Disability* was measured by the number of sick hours in the year following survey administration. The data were obtained through administrative records and are the actual recorded sick hours linked to each individual observation.

TESTING HYPOTHESES USING PATH ANALYSIS

Path analysis forces the person to think ecologically about the effects of office technology on musculoskeletal outcomes. We propose to test the series of hypotheses listed in Table 1; these hypotheses represent the arrows shown in the analytic framework in Figure 2. We leave untested certain hypotheses (e.g., work organization has a direct effect on musculoskeletal symptoms) because we did not feel a priori justification existed; no plausible mechanisms are extant to justify a direct path. All analyses were completed using Stata software.[36] Because preliminary

TABLE 1. Statement of Hypotheses

1. Work organization (lower job decision latitude, lower work support, higher psychological job demands, higher role ambiguity and conflict) is associated with greater levels of video display terminal (VDT) use as a percent of total work time.
2. Work organization, greater VDT use as a percent of total work time, and more neuroticism are associated with higher levels of global demoralization.
3. Work organization, greater VDT use as a percent of total work time, and more neuroticism are associated with lower levels of job satisfaction.
4. Greater VDT use is associated with more social desirability.
5. Greater VDT use, more psychological strain (higher global demoralization, low job satisfaction), more social desirability, and neuroticism are associated with higher levels of musculoskeletal symptom/duration scores.
6. Greater VDT use as a percent of total work time, psychological strain, neuroticism, and higher levels of musculoskeletal symptom/duration scores are associated with more health care utilization due to musculoskeletal problems.
7. Neuroticism, a higher level of musculoskeletal symptom/duration scores, and more health care utilization due to musculoskeletal problems are associated with more sick days.

TABLE 2. Description of Sample: Means for All Variables in Path Models by Gender

	Male (n = 439)	Female (n = 249)
Age	39.4 (9.90)	37.9 (11.20)
Physical demands		
% VDT Use (≥ 50%)	48.7 (50.04)	70.7 (45.61)
Work organization		
Job decision latitude	3.73 (0.64)	3.46 (0.66)
Psychological job demands	3.39 (0.73)	3.39 (0.73)
Role ambiguity	2.09 (0.66)	2.02 (0.68)
Role conflict	1.78 (0.62)	1.77 (0.65)
Work support	15.46 (2.27)	15.63 (2.50)
Individual factor		
Neuroticism	2.34 (0.47)	2.55 (0.51)
Psychological strain		
Global demoralization	0.75 (0.45)	0.95 (0.56)
Job satisfaction	2.88 (0.49)	2.90 (0.51)
Social desirability		
Social desirability	1.68 (0.20)	1.70 (0.21)
Musculoskeletal symptom/duration		
Neck region	3.74 (6.21)	7.33 (3.75)
Shoulder region	2.60 (5.83)	4.79 (9.21)
Elbow region	1.56 (4.67)	2.10 (5.90)
Hand region	2.51 (5.54)	5.43 (8.18)
Back region	4.38 (6.56)	6.99 (9.15)
Leg region	3.70 (7.41)	4.44 (8.01)
Health care utilization associated with		
Neck problems	1.12 (2.94)	1.95 (4.71)
Shoulder problems	1.53 (3.00)	2.64 (4.72)
Elbow problems	0.90 (2.03)	1.80 (3.35)
Hand problems	1.09 (2.88)	2.09 (4.04)
Back problems	1.66 (3.14)	2.12 (3.88)
Leg problems	2.08 (3.95)	2.71 (4.60)
Disability		
Sick hours	11.92 (24.07)	25.72 (42.72)

( ) = Standard deviation, VDT = video display terminal

analyses revealed gender differences in findings, all results are presented by gender. Table 2 shows all variables used in the path analysis by gender.

To test the ecological framework, we used path analysis by multiple linear regression.[3] Testing for the significance of any path is a parsimonious way of hypothesis testing.[2] A significance level of 0.05 was considered appropriate for this preliminary test. Indirect and direct effects are calculated providing estimates of the total effect (the sum of the direct and indirect—the product of all effects along a path—effects) for each office and individual domain to the musculoskeletal outcomes.[27] The utility of path analysis resides not only in its ability to partition variance but in testing the appropriateness of the structure of the model.[12]

We present our findings as a series of path diagrams for men and women with the significant direct effects shown. All the variables are standardized (subtract mean and divide by standard deviation) before being entered into the regression equations. Six separate regression models were estimated for men and women. Because of the high intercorrelation between demoralization and neuroticism (r = 0.74), entering both in one model causes collinearity problems. Thus, neuroticism is only included in models with job satisfaction. Because multiple measures of work organization and psychological strain are used, we present multiple findings within single-path diagrams. Age was considered the only significant confounder and therefore is introduced in all models. There are few differences between models. Where differences exist (e.g., two significant correlations differing by 0.03), we report the lower value. Thus, our effect estimates are conservative.

FINDINGS

Paths to Individual Psychological States

Work organization does not predict physical demands for men or women (Fig. 3). Physical demands do not predict global demoralization or job satisfaction. Psychosocial work organization predicts global demoralization and job satisfaction. For each measure the relationship is as predicted; for example, positive aspects of work organization are positively associated with job satisfaction and negatively associated with demoralization. Two measures used in job strain research—job decision latitude and psychological

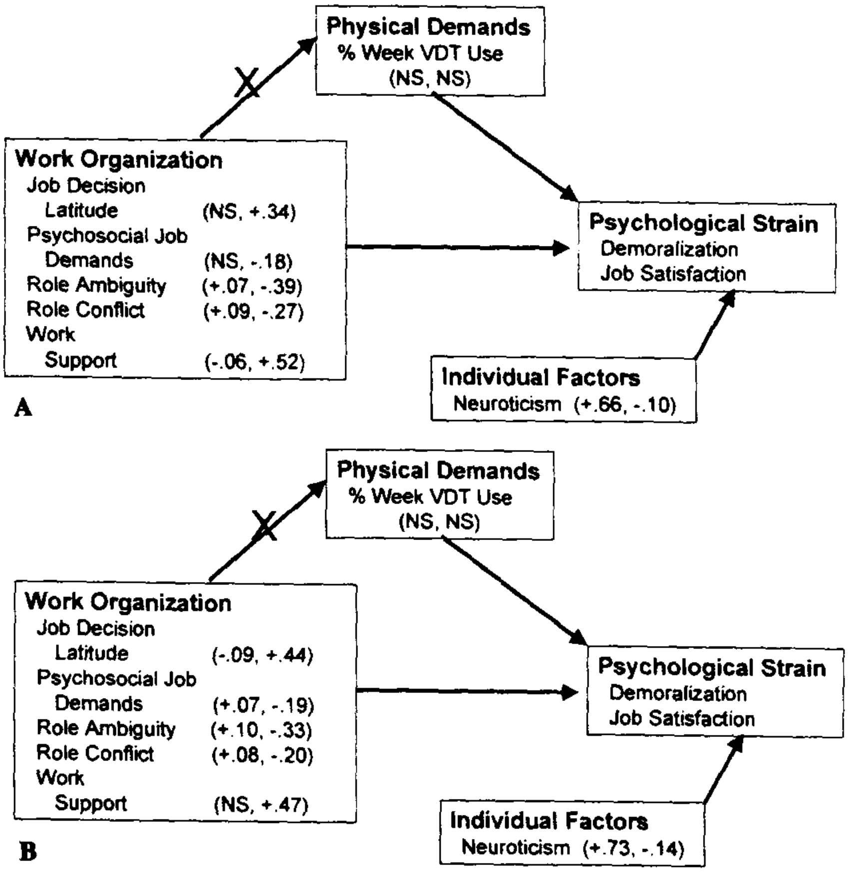

FIGURE 3. Paths from office technology to psychological strain outcomes. **A**, For men (n = 439). **B**, For women (n = 249). Path coefficients for demoralization and satisfaction are in parentheses. X = no significant effects for specified path, VDT = video display terminal, NS = not significant.

job demands—did not predict demoralization for men.[18] Neuroticism was very highly correlated with global demoralization (partial correlation ranges 0.6–0.7).

Paths to Musculoskeletal Outcomes

Musculoskeletal symptom/duration outcomes are not predicted by percent VDT use or social desirability for men or women (Fig. 4). The lack of a relationship between physical demands and VDT use is counterintuitive, because research has shown using the VDT for at least half of the day predicts musculoskeletal disorders (WRMDs). In fact, in other analyses of this data set where a more restrictive case definition for WRMDs was used, greater than 50% VDT use increased the risk of hand/wrist WRMDs by 87%.[19] In our analysis we did not adopt the National Institute for Occupational Safety and Health's criteria for defining a self-reported case of WRMDs, e.g., excluding workers who report that the symptoms were not work-related and did not occur on the current job.[23] This has

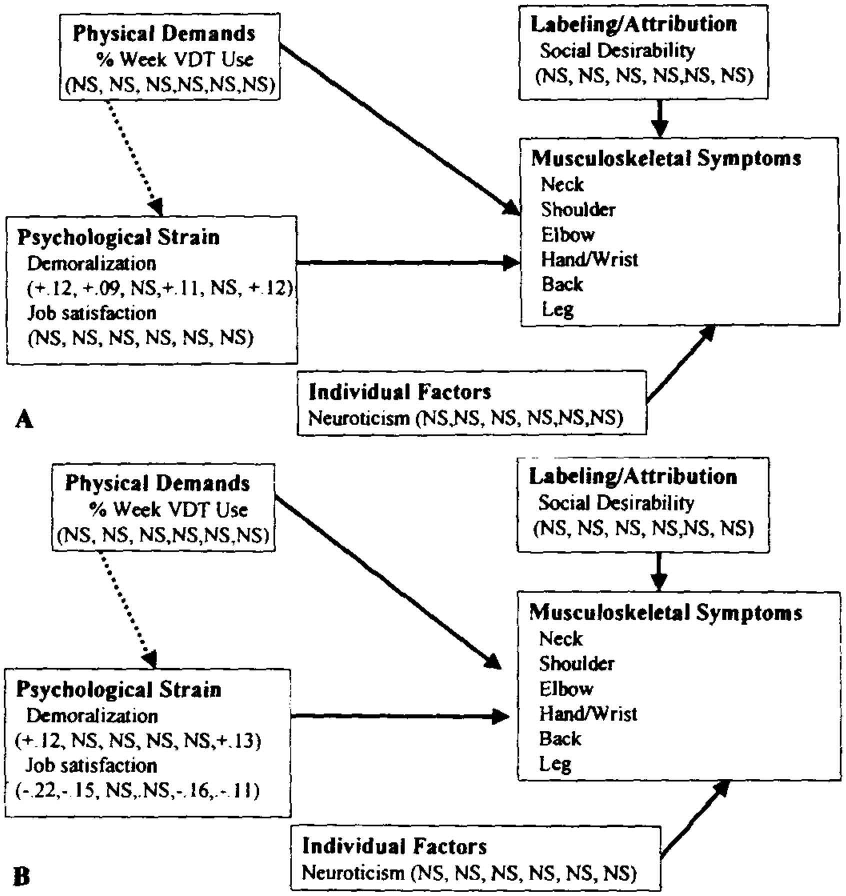

FIGURE 4. Paths from physical demands and psychological strains to musculoskeletal symptom/duration outcomes. **A**, For men (n = 439). **B**, For women (n = 249). The path coefficients (in parentheses) from left to right are for each musculoskeletal region from neck to leg. Dashed arrow = a path whose effects have been shown in a prior figure, VDT = video display terminal, NS = not significant.

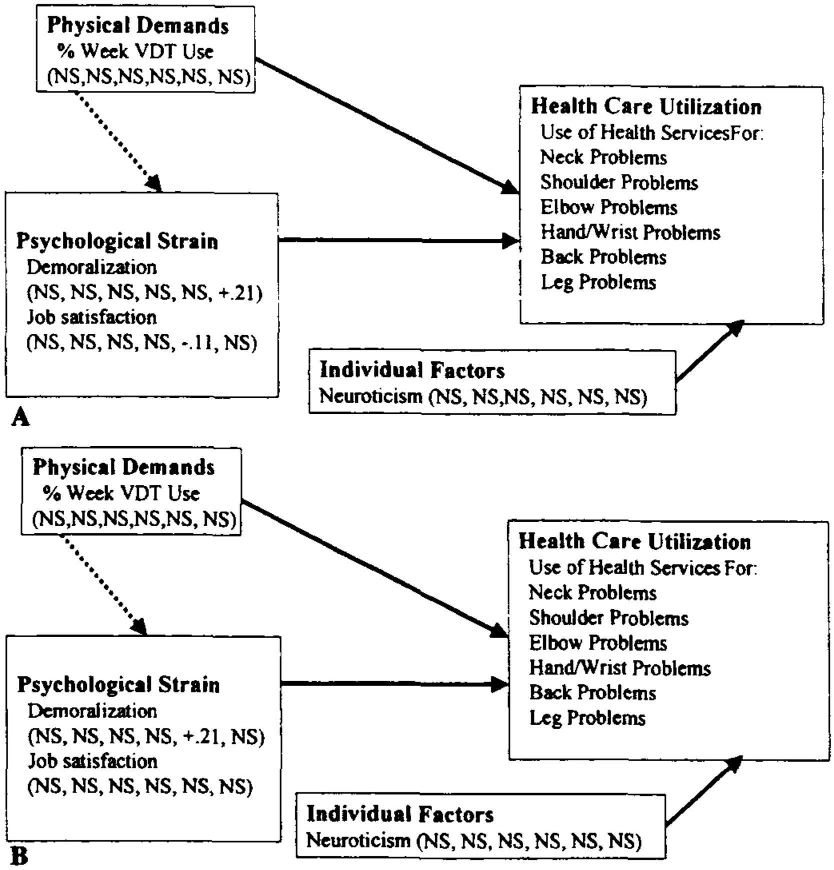

FIGURE 5. Paths from physical demands and psychological strains to health care utilization outcomes due to musculoskeletal injuries. **A**, For men (n = 439). **B**, For women (n = 249). The path coefficients (in parentheses) from left to right are for each musculoskeletal region from neck to leg. Dashed arrow = a path whose effects have been shown in a prior figure, VDT = video display terminal, NS = not significant.

the potential to attenuate the effects of work. In future analyses we intend to separate the effects of nonwork demands through the introduction of new paths.

Global demoralization predicts neck and leg symptoms for both men and women; the higher the general psychiatric morbidity, the higher the level of symptom/duration. Men who are demoralized are more likely to report shoulder and hand/wrist symptoms. Job dissatisfaction is a strong predictor of neck, shoulder, back, and leg symptoms for women but not men.

Health care utilization associated with musculoskeletal injuries is not predicted by physical demands, psychological strain, or neuroticism for men or women (Fig. 5) For men demoralization predicts health care use associated with leg symptoms, while job dissatisfaction predicts back symptom health care utilization. Musculoskeletal symptoms predict health care utilization for both men and women (Fig. 6). Women with hand/wrist symptoms are more likely to seek health care, but there is no significant relationship for men ($\beta = 0.061$, $p = 0.253$).

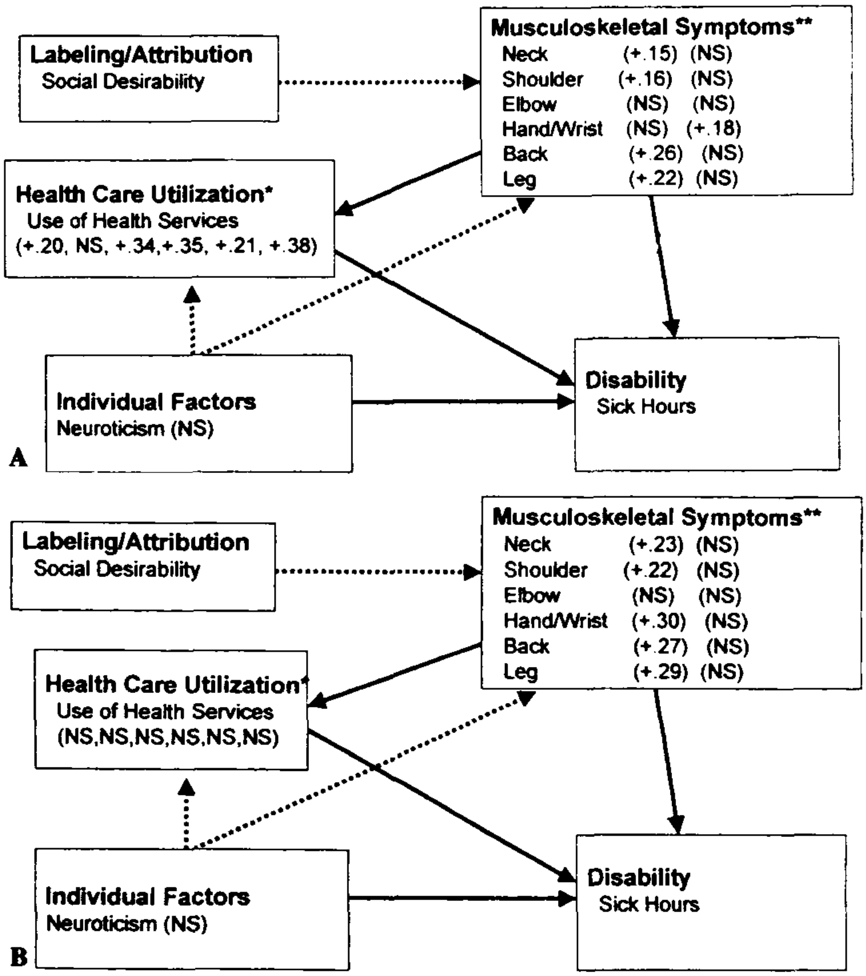

FIGURE 6. Paths from musculoskeletal symptom/duration and health care utilization to disability. **A**, For men (n = 439). **B**, For women (n = 249). * The path coefficients correspond to the unique effect of each musculoskeletal region on sick hours. ** The first column of path coefficients corresponds to the impact of each symptom on health care use; the second of each symptom on sick hours. Dashed arrow = a path whose effects have been shown in a prior figure, NS = not significant.

Disability, measured by sick hours, is predicted by health care utilization **only** for men. Health care use associated with all musculoskeletal regions except the shoulder is associated with more sick hours. Musculoskeletal symptoms do not directly predict sick hours for men or women; rather, they indirectly influence sick hours for men through health care use.

Estimating the Total Impact on Musculoskeletal Outcomes

An advantage to path analysis is that you can estimate direct and indirect effects. In this chapter we are interested in the direct and indirect effects of work organization

TABLE 3. Summary of Direct and Indirect Effects in Path Models for Hand/Wrist Musculoskeletal Region for Men and Women

	Men								
	Effects on Symptoms			Effects on Health Care Use			Effects on Disability		
	Direct	Indirect	Total	Direct	Indirect	Total	Direct	Indirect	Total
VDT use	0.0322	0.0028	0.0349	0.0320	0.0026	0.0346		0.0180	0.0180
Role ambiguity		0.0117	0.0117		0.0045	0.0045		0.0036	0.0036
Neuroticism		0.0761	0.0761		0.0103	0.0103	0.0076	0.0168	0.0245
Global demoralization	0.1140		0.1140	0.0077	0.0077	0.0154		0.0252	0.0252
Social desirability	-0.0100		-0.0100		-0.0007	-0.0007		-0.0020	-0.0020
Musculoskeletal symptoms				0.0677		0.0677	0.1747	0.0234	0.1981
Health care use								0.3448	0.3448

	Women								
	Effects on Symptoms			Effects on Health Care Use			Effects on Disability		
	Direct	Indirect	Total	Direct	Indirect	Total	Direct	Indirect	Total
VDT use	0.0867	-0.0047	0.0820	0.0413	0.0246	0.0659		0.0132	0.0132
Role ambiguity		0.0056	0.0056		0.0011	0.0011		0.0008	0.0008
Neuroticism		0.0616	0.0616		0.0229	0.0229	0.2275	0.0089	0.2365
Global demoralization	0.0834		0.0834	0.0057	0.0253	0.0310		0.0121	0.0121
Social desirability	-0.0150		-0.0150		-0.0046	-0.0046		-0.0021	-0.0021
Musculoskeletal symptoms				0.3037		0.3037	0.1312	0.0115	0.1426
Health care use							0.0378		0.0378

Note: Total effects are the sum of the direct and indirect effects.
VDT = video display terminal

and physical demands on musculoskeletal symptoms, health care use associated with musculoskeletal symptoms, and sick hours. We do not present all effects but have chosen several illustrative paths. We choose only two musculoskeletal regions (hand/wrist and back), one work organization factor (role ambiguity), and one psychological strain (global demoralization) to illustrate the total effects. Care should be taken in interpreting effect sizes in Tables 3 and 4 because paths contributing to an effect may be nonsignificant even though correlations are large. Below, we point out instances where this occurs.

MUSCULOSKELETAL SYMPTOMS

For men global demoralization has the largest total effect on hand/wrist symptom/duration scores (Table 3). While VDT use and global demoralization have similar effects on musculoskeletal symptoms among women, the paths used to calculate effects are nonsignificant (see Figs. 3 and 4). A similar pattern of effects exists for the back musculoskeletal region (Table 4).

HEALTH CARE USE

For women health care use associated with hand/wrist problems is being driven by hand/wrist musculoskeletal symptom/duration scores (see Table 3). The effect of VDT use among women is comparable to the effect of musculoskeletal symptom/duration scores for men, illustrating a striking gender difference; again, these paths are nonsignificant. All other effects are small. For both men and women with

TABLE 4. Summary of Direct and Indirect Effects in Path Models for Back Musculoskeletal Region for Men and Women

	Men								
	Effects on Symptoms			Effects on Health Care Use			Effects on Disability		
	Direct	Indirect	Total	Direct	Indirect	Total	Direct	Indirect	Total
VDT use	0.0255	0.0017	0.0272	-0.0159	0.0089	-0.0070		0.0015	0.0015
Role ambiguity		0.0078	0.0078		0.0057	0.0057		0.0021	0.0021
Neuroticism							0.0080	-0.0216	-0.0296
Global demoralization	0.0715		0.0715	0.0684	0.0192	0.0876		0.0266	0.0266
Social desirability	0.0037		0.0037		0.0010	0.0010		0.0006	0.0006
Musculoskeletal symptoms				0.2682		0.2682	0.1103	0.0575	0.1678
Health care use								0.2143	0.2143
	Women								
	Effects on Symptoms			Effects on Health Care Use			Effects on Disability		
	Direct	Indirect	Total	Direct	Indirect	Total	Direct	Indirect	Total
VDT use	-0.1028	-0.0055	-0.1083	0.0194	-0.0406	-0.0212		0.0005	0.0005
Role ambiguity		0.0124	0.0124		0.0231	0.0231		-0.0009	-0.0009
Neuroticism		0.0725	0.0725		0.1741	0.1714	0.1353	-0.0069	0.1284
Global demoralization	0.0981		0.0981	0.2096	0.0261	0.2357		-0.0093	-0.0093
Social desirability	0.0042		0.0042		0.0011	0.0011		0.0000	0.0000
Musculoskeletal symptoms				0.2658		0.2658	0.0030	-0.0108	-0.0079
Health care use							-0.0407		-0.0407

Note: Total effects are the sum of the direct and indirect effects.
VDT = video display terminal

back problems, musculoskeletal symptom/duration scores drive health care use (see Table 4). However, for women with back problems demoralization is a major effect along with the symptom/duration scores. While the effect size for neuroticism among women is large, we emphasize the nonsignificance of this factor in the path models.

Disability

For men health care use associated with hand/wrist problems is driving sick hours (see Table 3). For women the major effect is with hand/wrist musculoskeletal symptoms/duration scores. For back musculoskeletal problems, sick hours or lost productivity is driven by both health care use associated with back problems and the back symptom/duration scores in men (see Table 4).

DISCUSSION AND IMPLICATIONS

We proposed and tested an ecological model for understanding the origins of musculoskeletal injuries.[32] Work organization has consistent effects on psychological strain but small total effects on musculoskeletal symptoms, health care utilization, and disability for men and on musculoskeletal symptoms and health care use for women. The patterns of effects do not vary substantially across musculoskeletal regions for office workers, potentially indicating a general influence of work organization, i.e., work organization would not be expected to target a specific body region. This is consistent with findings of other studies.[5,13,20]

A well-validated measure of social desirability did not relate to the symptom/duration measure. This finding was consistent across musculoskeletal regions. A striking finding is the **lack** of strong and consistent neuroticism effects. McCrae and Costa describe neuroticism as a stable trait of adult life that reflects a person's tendency to report certain types of symptoms.[22] Although strongly related to global demoralization for both men and women, neuroticism was only modestly associated with musculoskeletal symptoms. The lack of a gender difference builds on earlier work to suggest that worker reports of musculoskeletal symptoms and health care use are not influenced by this underlying personality trait.[19]

The path models show that health care use associated with musculoskeletal injuries is not determined by mental health or individual traits that may lead one to seek care. Rather, symptoms drive health care utilization; the higher the level of symptom/duration, the more likely the worker will seek care. The implication for employers and practitioners is that to reduce health care costs they must reduce musculoskeletal injuries through job redesign, ergonomics, or changes in work scheduling.

The gender difference in the relationship between lost productivity as measured by sick hours was surprising. While WRMDs, especially of the hand/wrist, are more prevalent among women, this does not translate into greater lost productivity. These findings are strengthened by the prospective relationship between symptoms and lost productivity. While we have no data to account for the lack of relationship between health care use and sick hours for women, there are several plausible reasons for the observed effect:

- Use of onsite health services that do not require use of sick time could be higher among women.
- Because women seek treatment for symptoms earlier than men, their treatment for symptoms may not require extended absences.[37]
- Women, in general, are more likely to use sick time for family care, which could explain why women have a higher mean sick hour usage (see Table 2) not related to health care use associated with musculoskeletal symptoms.[6]

There are several limitations to the current analysis. For example, the cross-sectional design precludes the examining of temporal ordering (e.g., to definitively state psychological strain is producing musculoskeletal symptoms rather than the reverse). Additionally, physical demands are measured in a limited way, and biomechanical strain measures are absent.

Implications for Research

Musculoskeletal cumulative trauma disorders are difficult to diagnose, and there is continued debate on the most appropriate case definition. Musculoskeletal injuries as a class of injuries have many causes. These factors make the conduct of epidemiologic studies more challenging.[19] Future research should (1) incorporate a double-blind prospective design in which subjects are recruited prior to exposure and disease; (2) attempt to develop new measures of work organization that capture the important elements of computer-mediated work (e.g., cognitive demands, online communication and support); (3) develop more complete assessments of the range of musculoskeletal outcomes (e.g., using workers' compensation and functional health measures of disability); and (4) incorporate nonwork demands into the model.

The use of multiple indicators of musculoskeletal outcomes is a new approach to understanding the broader health impact of office environments. Perhaps the single most important new development is the multiple pathways uncovered between musculoskeletal symptom/duration, health care use, and sick days. This linkage has direct implications for the cost of doing business and should be a central research topic in the future. While there may never be resolution on the measurement of WRMD cases, showing the cost drivers and nondrivers will help in business decisions.

Implications for Intervention

The data do not strongly support reducing the amount of time at VDTs as a method for reducing musculoskeletal outcomes or lost productivity due to disability. While there is a dose-response relationship between VDT use and musculoskeletal symptoms,[28] recent research indicates that this relationship can be modified by work organization interventions such as more frequent rest breaks.[34]

Clearly the broader ecological model identifies the importance of preventing injuries to reduce health care costs and lost productivity. This is supported by our findings that symptoms—not VDT use, neuroticism, or psychological strain—are linked with health care utilization and lost productivity. Therefore, interventions targeting reduction of symptom development are needed. Although the role of psychological strain in musculoskeletal symptom/duration experience is well described,[4,5,13,33] the key predictors of psychological strain in our model are not easily changed without more widespread organizational change.

The role of providers in health care delivery can be important, as the gender differences shown in Figure 6 illustrate. Why men and women show these differences in lost productivity are intriguing. While there is much literature on differential treatment of men and women by providers, this probably does not explain the observed gender differences. Rather, women may choose to use sick hours to manage family crises rather than for injuries that did not require immediate attention. This suggests that the appropriate interventions are changes to the benefits programs to provide other supports for family crises. Given the known gender differences in health care behavior, encouraging all workers with symptoms to seek care earlier rather than changing provider behavior could be critical in reducing the impact of symptoms on lost productivity. An alternative may be to train supervisors and give them incentives to encourage workers to seek care when symptoms begin instead of waiting until they can no longer work.

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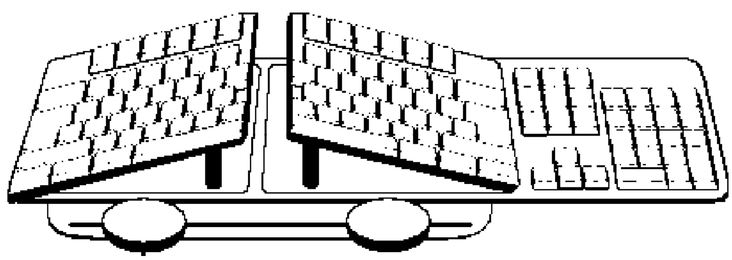
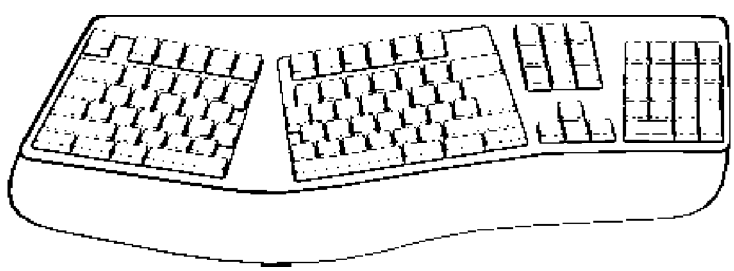
Alternative Keyboards





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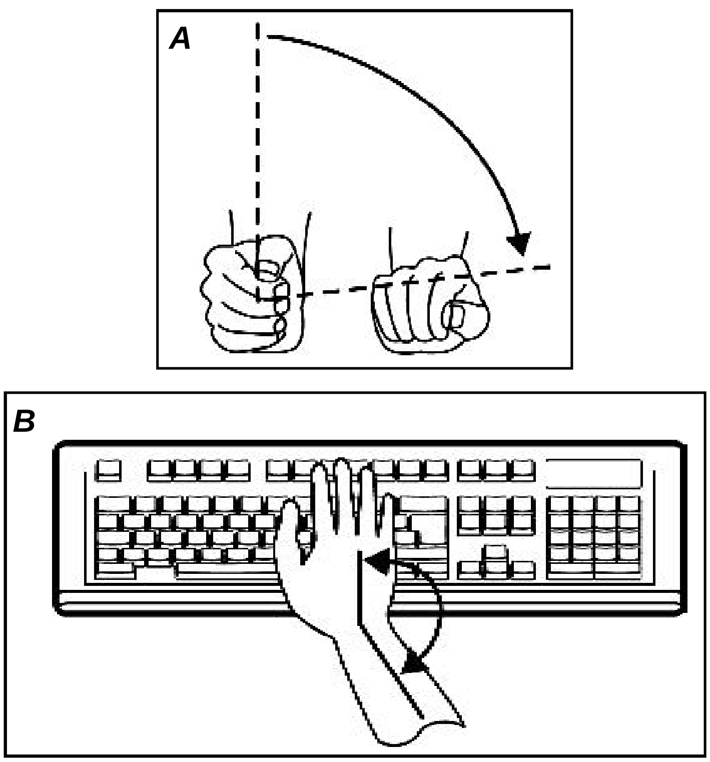
Purpose

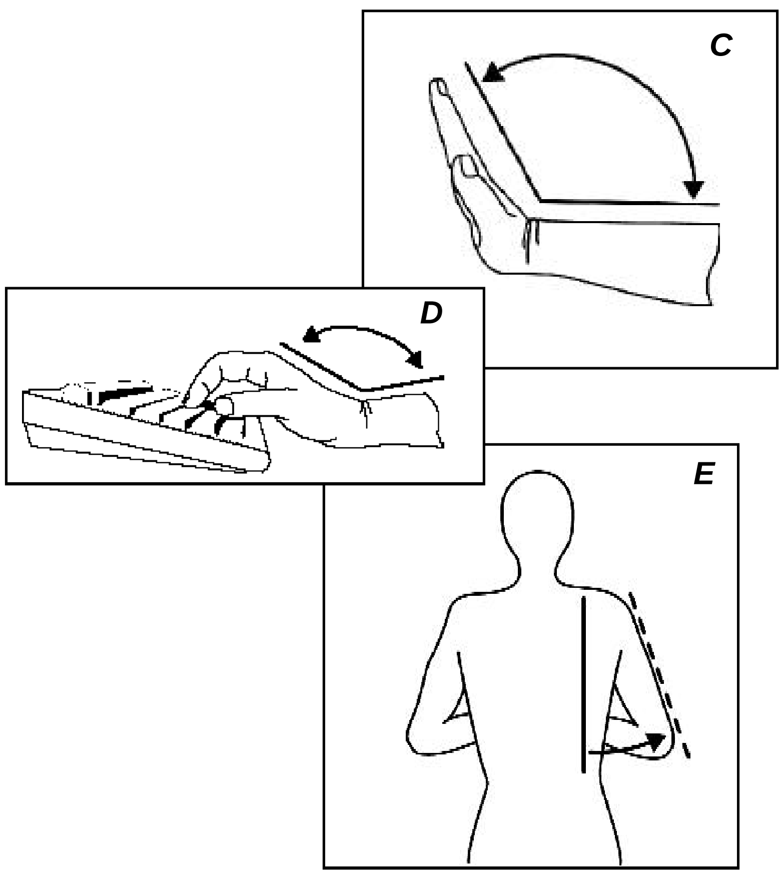
To date, there is little information to assist people interested in purchasing alternative keyboards. While the scientific evidence about whether alternative keyboards prevent musculoskeletal disorders is inconclusive at this time, this document provides basic information about common alternative keyboard designs and their effects on work posture.

Why Redesign the Keyboard?

When typing, holding the hands and wrists in a neutral work posture--where the hands are extended straight without significant bending at the wrist-- is thought to reduce the risk of musculoskeletal problems. Computer users sometimes use awkward or non-neutral work postures when working on the traditional keyboard. They rotate their forearms so that



their palms are facing the keyboard (A), and they often bend their hands outward (B) and upward (C & D). Sometimes, workers also hold their elbows slightly away from their bodies (E) while keying, particularly when the keyboard surface is too high. Alternative keyboards can help keep wrists straight as shown on the following pages.

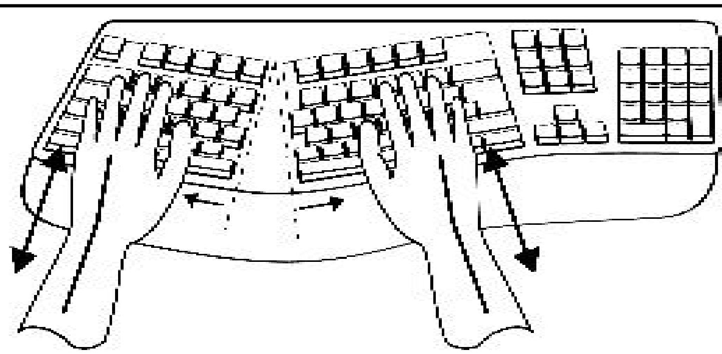


What’s Different About Alternative Keyboards?

Alternative keyboards use different designs to attempt to change the user’s posture. The following are some of the more common designs.

Split keyboards

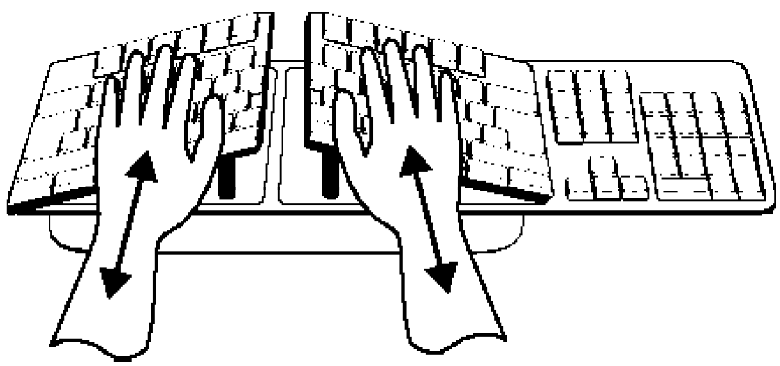
Split keyboards are designed to straighten the wrist. This can be done in two ways: by increasing the distance between the right and left sides of the keyboard or by rotating each half of the keyboard so that each half is aligned with the forearm. Some alternative keyboards combine these two methods.



Split and Rotated Keyboard with Wrist Rest

Tented keyboards

On tented keyboards, the two keyboard halves are tilted up like a tent. This feature is a variation of the split keyboard and reduces the rotation of the forearms.



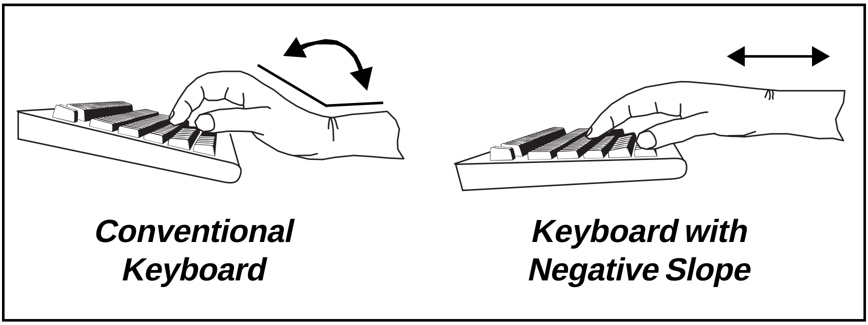
Split and Tented Keyboard

Built-in wrist or palm rests

Built-in wrist or palm rests help prevent bending the hands up by providing support that straightens the wrists. It should be noted that questions do remain about the usefulness of wrist or palm rests. For example, it is unclear whether they increase pressure on the wrists, relieve loads on shoulder and upper back muscles, or interfere with typing.

Adjustable negative slope

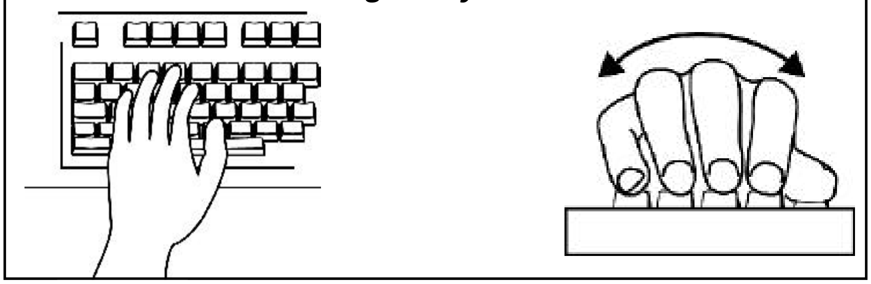
Keyboards with a negative slope also help prevent bending the hand too far up by allowing the user to raise the front edge of the keyboard, or to slope the keyboard backward, thus straightening the wrist.



Key position

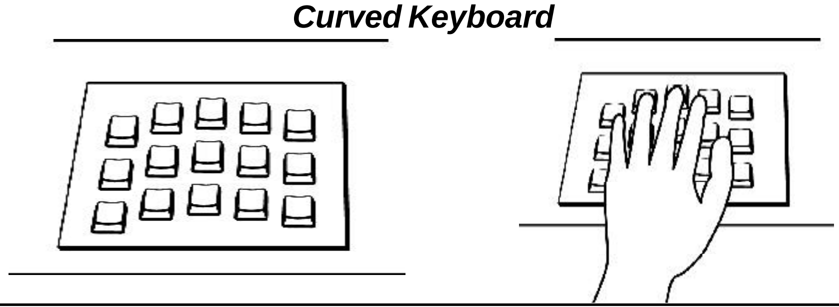
Some alternative keyboard designs have attempted to "fit" the different lengths of the fingers by curving the rows of keys or by placing the keys in concave wells. This is believed to allow the fingers to work in a more relaxed posture (see illustrations on next page).

Straight Keyboard



Concave Well Keyboard

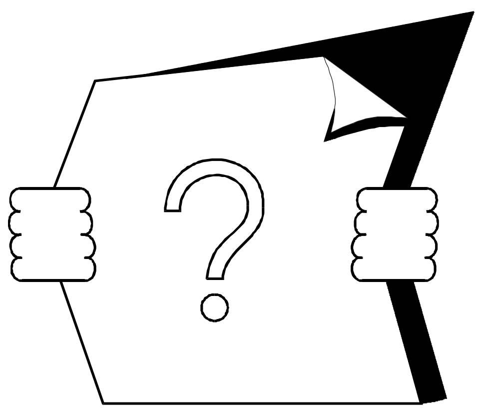
Curved Keyboard



Do Alternative Keyboards Prevent Injuries?

Alternative keyboards have been shown to promote neutral wrist posture. Yet, available research does not provide conclusive evidence that alternative keyboards reduce the risk of discomfort or injury.

Thus, further research is needed before specific keyboard features can be recommended with great confidence.



What if I Want to Use an Alternative Keyboard?

If alternative keyboards are to be used in the workplace, the following suggestions may be helpful in making purchasing decisions.

Determine whether the keyboard is compatible with existing hardware and software and whether the keyboard can accommodate other input devices, such as trackballs and mice.

Assess how the keyboard will fit with the workstation. Some alternative keyboards are extra wide, long, or high and may not fit on standard keyboard trays. Such keyboards may also prevent the tray from retracting under the work surface. Additionally, some alternative keyboards, particularly tented versions, must be placed on surfaces that are lower than those required for the conventional keyboard to achieve proper working posture.

Evaluate whether the keyboard will affect the performance of the user. Some alternative keyboard designs and adjustments make it difficult to see the keys. This is particularly important for users who rely on key visibility, such as "hunt and peck" typists. Also, check whether the job requires use of the numeric keypad and specialized keys, because some alternative keyboards eliminate or reconfigure these keys.

Allow users to try a keyboard on a trial basis before buying it. It would seem reasonable to try the keyboard for at least one to two weeks, since studies show that this amount of time is necessary to adapt to alternative keyboards.

Alternative keyboards are like other office equipment, furniture or accessories. Preferences will vary and one type will not "fit" everyone or every type of task. Allow users to try a number of different alternative keyboards before making decisions about which ones to buy. If a user wants to retain his or her conventional keyboard, respect that decision.

Expect frustration until users become familiar with the new keyboards. Frustration frequently results from diminished productivity as workers get used to new equipment.

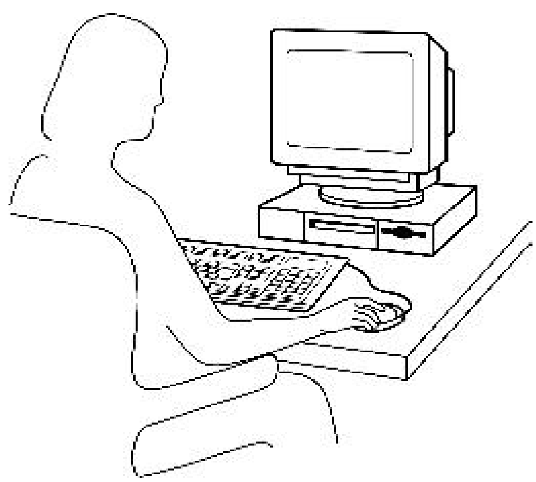
Involve a specialist in the decision-making process. This specialist should have both knowledge and experience in office ergonomics. If a computer user has discomfort or musculoskeletal symptoms, a health professional should also be involved in making the decision to purchase an alternative keyboard.

Integrate a new alternative keyboard into the work process carefully. Make sure that users are trained in the appropriate use of the product, since many alternative keyboards can be used incorrectly. If the keyboard is adjustable, encourage users to change the adjustments gradually from the conventional (flat) configuration.

What Can Be Done to Prevent Musculoskeletal Injuries?

A keyboard is only one part of a computer workstation setup that may influence comfort. Other important factors include: workstation and chair adjustability; placement of equipment, accessories, and work materials; lighting; and the design and organization of work tasks.

Because computer work is highly repetitive and promotes static postures, it can cause discomfort over long periods of time. It is important to break up long sessions of keyboard work with frequent rest breaks or with other tasks that require movements different from those used to type or operate the mouse.



Keep in mind that it is essential to examine the entire work environment to determine all possible causes of discomfort. In other words, it is unlikely that changing only one workplace element, such as a keyboard, will eliminate all discomfort and disorders.

In addition, each workplace should have a comprehensive ergonomics program in place to protect all workers.

Call NIOSH at

1-800-35-NIOSH

(1-800-356-4674)

or visit the NIOSH Homepage at

http://www.cdc.gov/niosh/homepage.html

to receive:

- **A bibliography** on alternative keyboard research.
- Information on **implementing an ergonomics program** (request *Elements of Ergonomics Programs: A Primer Based on Workplace Evaluations of Musculoskeletal Disorders* DHHS (NIOSH) Publication No. 97-117).
- **More information** on workplace safety and health issues.

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A review of physical exercises recommended for VDT operators

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This paper presents an evaluation of exercises that have been recommended for the prevention of musculoskeletal discomfort among VDT/office workers. 127 individual exercises were analysed for their suitability for performance in VDT workplaces. Additionally, each exercise was judged in terms of its safety and its compliance with principles of physiotherapy. Results showed that, in the majority of cases, the prepared instructions for the exercises were satisfactory and the exercises could be readily performed at the workstation. However, over a third of the exercises were conspicuous and potentially embarrassing to perform, and half would significantly disrupt the work routine. Additionally, a number of the exercises posed potential safety hazards, exacerbated biomechanical stresses common to VDT work, or were contraindicated for persons with certain health problems. These findings suggest a need for greater attention to both the practical and the therapeutic aspects of exercises promoted for VDT users.

Keywords: Exercise; office work; musculoskeletal discomfort

Introduction

Widespread study of video display terminal (VDT) users has raised concerns regarding the potential for musculoskeletal disorders among these individuals. In a review of the literature[1], the World Health Organization found that "... musculoskeletal discomfort was commonplace during work with VDTs ...." and that "injury from repeated stress to the musculoskeletal system is possible". In addition to the health implications, it is likely that musculoskeletal discomfort in VDT work is associated with performance impairments[2,3].

A review of current literature suggests that the primary emphasis for reducing musculoskeletal strain in VDT work has been on improving the workstation/environment by applying well-established ergonomic principles[4–7]. However, Winkel[8] suggests that ergonomically designed workstations are an incomplete prescription for preventing musculoskeletal discomfort in VDT work because they do not correct for a major contributory factor, namely, constrained postures. Constrained sedentary postures during VDT work may create static loading leading to muscle fatigue, impediment of circulation in the lower extremities, and stresses on joints, chronically stretched muscles and other tissues.

Winkel's contention that ergonomically designed workstations are an incomplete prescription for preventing musculoskeletal discomfort is supported by several studies showing that optimal workstation design does not eliminate the accumulation of musculoskeletal discomfort in VDT work[9,10]. What is needed, according to Winkel, is more dynamic activity to relieve the stresses of sedentary work[8].

This type of thinking no doubt underlies the proliferation of exercise programmes designed to reduce musculoskeletal discomfort arising from VDT work. However, there has been insufficient study of these exercise programmes, in the context of VDT/office work, to ascertain their effectiveness.

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An effective office exercise programme should satisfy two criteria. First, the exercises must be 'usable' (ie, they must be designed to maximize VDT users' ability and motivation to perform them). Second, the exercises must be sound from a physiotherapeutic/safety perspective (ie, they must effectively combat the stresses of VDT work, and performance of the exercises must not pose added safety or health risks). The purpose of this paper is not to advocate the substitution of exercises for job redesign (eg, changes in work routines which result in increased physical activity). Exercises should be regarded as a complement to, not a substitute for, improving the design of jobs to relieve the musculoskeletal stresses of VDT work.

In the present paper, we review exercises proposed for VDT users with regard to the usability and physiotherapeutic/safety criteria. For the usability assessment, it was assumed that exercises which are easy to learn, do not call undue attention to the individual, and can be easily integrated into the work routine, would be most readily utilized by VDT users. Assessments regarding physiotherapeutic value were restricted to judgements regarding potential safety or health risks associated with performance of a particular exercise because, unlike the apparent benefits of these exercises, potential risks have not been addressed.

Ultimately, the suitability of any set of exercises for office workers can be firmly established only through empirical study. The rationale behind the present review is to provide some basis for selection of exercises until empirical data emerge on their effectiveness.

Method

Identification of exercises for review

A total of 14 exercise programmes for VDT users and office workers were identified in the literature:

1 Austin[11]
2 Australian National University[12]
3 Australian Occupational Health and Safety Unit[13]
4 Dahl[14]
5 Emanuel and Glonek[15]
6 Gore and Tasker[16]
7 Joyce and Peterson[17–19]
8 Krames Communication[20,21]
9 Lacey[22]
10 Lee and Humphrey[23]
11 Lee and Waikar[24]
12 *Los Angeles Times*[25]
13 Pragier[26]
14 Sauter *et al*[7]

Two of the programmes[15,23] were designed for microscope operators. Because both microscopy and VDT work involve sedentary work and static postures of the upper extremities and neck/shoulder region, it was presumed that the types of musculoskeletal stresses experienced would be similar.

Of the 14 exercise programmes identified, only 12 were actually evaluated. The exercise programme of Lee and Humphrey[23] was not evaluated since it is identical to that of Emanuel and Glonek[15], except for the duration of the exercises. The exercises of the Australian Occupational Safety and Health Unit[13] were general relaxation exercises which did not target specific muscle groups.

Three sources[16–21] offered multiple exercise programmes. Gore and Tasker[16] offered 45 distinct exercises, organized into five separate exercise programmes (A–E). The programmes were virtually identical in terms of the musculoskeletal structures targeted. Therefore, we selected only programme A for analysis. The Joyce Institute[17–19] has three exercise programmes whose contents overlap. Only the unique exercises in these programmes were reviewed. The same procedure was used for the review of the two programmes by Krames Communications[20,21]. Similarly, because the majority of the Lee and Waikar[24] exercises were identical to those of Emanuel and Glonek[15], only the Lee and Waikar exercises which did not duplicate those of Emanuel and Glonek were included in the analysis.

Exercises which did not target specific musculoskeletal structures (ie, general relaxation exercises or eye exercises) were not included in the analysis. In all, 127 separate exercises were evaluated.

Evaluation procedure Table 1 lists each of the exercises analysed, the source, the exercise instructions, and a listing of the primary muscle groups and structures recruited. (The exercise instructions provided in Table 1 were abbreviated to economize on space. Most instructions included illustrations of a model performing the exercise. The analysis of the exercises was based on the original instructions and illustrations.)

The exercises were classified according to the body part targeted: (1) neck; (2) shoulder; (3) elbow/lower arm; (4) lower back/hip; and (5) knee/lower leg. Many exercises affected muscles from more than one body part. Each of these exercises was categorized under the body part primarily affected.

After classification, each exercise was analysed along a number of dimensions which potentially influenced its usability and physiotherapeutic value. The procedures for these assessments are described below.

Usability assessment

Each exercise was evaluated along five dimensions reflecting the presumed willingness and ability of VDT users to perform them at work. These dimensions were: (1) specificity of instructions; (2) location most suitable for performance; (3) conspicuousness; (4) time requirement/disruption of the work task; and (5) ease of learning/performance. The operational definitions and rating factors used for each of the evaluation end-points are as follows.

Specificity of instructions This dimension refers to the ease with which the instructions can be understood and followed. Three rating categories were utilized: good, fair or poor.

Location most suitable for performance Because the exercises vary in their time and space requirements, not

Table 1. Panel A. Neck Exercises.

	Author	Name of Exercise	Exercise Instructions	Muscle Groups Recruited	Anatomical Structures Stretched	Specif. of Instr.	Space or Location	Conspicuous?	Time Reqmt.	Ease of Perform.	Comments
1	Australian National University	Exercise 2	1) Stand as tall as possible, then 2) relax and go loose like a rag doll. (10 to 20 times).	Lower cervical and thoracic extensors, neck flexors (phase I only)	Upper cervical extensors, anterior ligaments of the lower cervical and upper thoracic spine (phase I), cervical and thoracic extensors, scapular adductors, elevators and upward rotators, posterior ligaments of the cervical and thoracic spine (phase II)	fair	work area	highly	mini	simple	a b c d 1 3
2	Sauter	Head Nods	Nod head (not entire neck) in "yes" motion.		Upper cervical extensor muscles, posterior ligaments of the cervical spine and facet joints	good	chair	somewhat	micro	simple	a b c 1 3
3	Gore and Tasker	The Pigeon	Standing or sitting, keep eyes looking forward. Without dropping head, pull face in to make double chin. Hold for count of 6. Repeat 10 times.	Lower cervical, thoracic and lumbar extensors, neck flexors	Upper cervical extensors, anterior ligaments of the lower cervical and upper thoracic spine	good	chair	no	mini	simple	
4	Krames Comm	Neck Glide	1) Glide head back, as far as it will go. Keeping head and ears level. 2) Now glide head forward. Repeat 3 times.	Phase I: Lower cervical, thoracic and lumbar extensors, neck flexors Phase II: Upper cervical extensors and neck flexors	Phase I: Anterior ligaments of the lower cervical and thoracic spine, upper cervical extensors Phase II: Posterior ligaments of the lower cervical and thoracic spine, lower cervical and thoracic extensors	good	chair	no	micro	simple	
5	LA Times	Dorsal Glides (Turkey)	Sit up straight and pull shoulders back. Slide head straight back on neck, keeping face pointed forward (Turkey Position). Isolate movement to head and neck. Repeat slowly 5 times.	Lower cervical, thoracic and lumbar extensors, scapular adductors, elevators and upward rotators, neck flexors	Anterior ligaments of the lower cervical and thoracic spine, upper cervical extensors	good	chair	no	micro	simple	
6	Joyce & Peterson	Cable Stretch	Sit relaxed, with feet flat on floor. Imagine a cable attached to the top of the head pulling you up. Hold for count of 3; relax. Repeat 3 times.	Lower cervical, thoracic and lumbar extensors, neck flexors	Anterior ligaments of the lower cervical and thoracic spine, upper cervical extensors	good	chair	no	micro	simple	
7	Pragler	Exercise a-1	Tuck the chin in, shoulders back and "sit tall". Hold the position for a count of 3; relax.	Lower cervical, thoracic and lumbar flexors/extensors, scapular adductors, elevators and upward rotators, neck flexors	Anterior ligaments of the lower cervical and thoracic spine, upper cervical extensors	good	chair	no	micro	simple	
8	Emanuel and Glonek	Neck Rotations	Rotate head and neck 3 times clockwise and 3 times counterclockwise.		Anterior and posterior cervical and thoracic rotators, neck upper back extensors and flexors, scapular elevators, anterior, lateral and posterior ligaments of the cervical and thoracic spine	fair	chair	somewhat	micro	simple	a b c 1 3 4

The exercise instructions have been abbreviated to economize on space. Most instructions included illustrations of a model performing the exercise. The analysis of the exercises was based on the original instructions and illustrations.

Key

1 Exercise reproduces physical stresses of VDT work
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3 Exercise stretches already overstretched structures
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a Acute neck pain
b Degenerative disc disease
c Moderate to severe osteoporosis
d Acute lower back pain
e Second and third trimesters of pregnancy
f Acute inflammatory or arthritic conditions of the shoulder
i Acute inflammatory or arthritic conditions of the elbow/forearm complex
j Hand/wrist disorders, such as carpal tunnel syndrome
k Acute lateral epicondylitis
l Spinal stenosis
m Arthritic conditions of the hips and/or knees

Table 1. Panel A. Neck Exercises (cont.)

	Author	Name of Exercise	Exercise Instructions	Muscle Groups Recruited	Anatomical Structures Stretched	Specif. of Instr.	Space or Location	Conspicuous?	Time Reqmt.	Ease of Perform.	Comments
9	Australian National University	Exercise 5	Tuck chin in. Circle head in one direction, then in other. Repeat 10-15 times.	Cervical and thoracic flexors, sidebenders, rotators, extensors	Anterior and posterior cervical and thoracic rotators, neck/upper back flexors and extensors, scapular elevators, anterior, lateral and posterior ligaments of the cervical and thoracic spine	fair	chair	somewhat	mini	simple	a b c 1 3 4
10	Dahl	Unnamed	Rotate head to one side, then to the front, and to other side.	Cervical and thoracic rotators, neck flexors	Cervical and thoracic rotators, posterior and lateral ligaments of the cervical and thoracic spine and facet joints	*	chair	somewhat	micro	simple	a b c
11	Sauter	Head Turns	Close eyes and very slowly turn head from shoulder to shoulder (with head positioned upright).	Cervical and thoracic rotators, neck flexors	Cervical and thoracic rotators, posterior and lateral ligaments of the cervical and thoracic spine and facet joints	good	chair	somewhat	micro	simple	a b c
12	Krames Comm.	Head and Neck	Turn head slowly from one side to the other, holding each turn for a count of 3. Repeat 5-10 times.	Cervical and thoracic rotators, neck flexors	Cervical and thoracic rotators, posterior and lateral ligaments of the cervical and thoracic spine and facet joints	good	chair	somewhat	mini	simple	a b c
13	LA Times	Turkey with Rotation	Hold turkey position (see exercise 5) and slowly turn head to point of stretch sensation, first left, then right 3-5 times.	Cervical and thoracic rotators, neck flexors	Cervical and thoracic rotators, posterior and lateral ligaments of the cervical and thoracic spine and facet joints	fair	chair	somewhat	micro	simple	a b c
14	Gore and Tasker	Headrest	Sitting, lock fingers behind head, drop chin to chest. Slowly turn head to right and hold for count of 10. Relax. Repeat to left. Do 3 times on each side.		Upper thoracic and cervical extensors and rotators, posterior and lateral ligaments of thoracic cervical spine and facet joints	good	chair	somewhat	mini	simple	a b c 1 3 4 Alternative exercise to stretch the upper cervical muscles should be chosen that does not produce extreme flexion and rotation of lower cervical and upper thoracic spine.
15	Joyce & Peterson	Neck/Head	Slowly tip head from side to side 3 times. Bring head to upright, then turn it and look over shoulder 3 times to each side. Drop chin to chest, then raise it as far as possible 3 times.	Cervical and thoracic rotators, anterior and posterior cervical and thoracic rotators, neck flexors and extensors	Upper thoracic and cervical extensors, lateral, anterior and posterior ligaments of the thoracic and cervical spine and facet joints, cervical flexors, neck side benders, scapular elevators, anterior and posterior cervical and thoracic rotators	good	chair	somewhat	mini	simple	a b c 1 3 4
16	Austin	Neck	Let head drop slowly to left, then to right. Slowly drop chin to chest, then raise chin as high as possible. Turn head all the way to left, return to normal, then turn all the way right. Return to normal position.	Anterior and posterior cervical and thoracic rotators, neck flexors and extensors	Upper thoracic and cervical extensors, lateral, anterior and posterior ligaments of the thoracic and cervical spine and facet joints, cervical flexors, neck side benders, scapular elevators, anterior and posterior cervical and thoracic rotators	good	chair	somewhat	micro	simple	a b c 1 3 4

*As the Dahl exercises were translated from Danish to English for the authors, the specificity of the instructions was not evaluated

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Table 1. Panel A. Neck Exercises (cont.)

	Author	Name of Exercise	Exercise Instructions	Muscle Groups Recruited	Anatomical Structures Stretched	Specif. of Instr.	Space or Location	Conspicuous?	Time Reqmt.	Ease of Perform.	Comments
17	Australian National University	Exercise 4	Place one hand on opposite shoulder. Pull shoulder down while bending head toward other shoulder. Repeat on other side. Repeat 5-10 times.		Neck side benders, scapular elevators, lateral ligaments of the upper thoracic and cervical spine and facet joints	fair	chair	somewhat	mini	simple	a b c 3 4 Avoid rapid stretching. May produce moderate loading on cervical discs if performed in forward, flexed head posture.
18	Gore and Tasker	Tension Neck	Standing, place left hand on back of neck. Point left elbow to ceiling and keep there. Drop chin on chest and turn head to right without lifting chin. Tilt right ear to right and hold for count of 10. Relax. Repeat with right hand, turning head to left. Do 3 times each side.		Neck side benders, scapular elevators, posterior and lateral ligaments of the upper and cervical spine and facet joints	fair	work area	highly	mini	simple	a b c 3 4 Avoid rapid stretching.
19	LA Times	Upper Trapezius Stretch	Grasp seat or leg of chair with right hand to pull shoulder down slightly. Lean head to left until stretch is felt on right side of neck. Lean body to left to increase stretch. Hold 15 seconds. Repeat on other side.		Neck side benders, scapular elevators	good	chair	somewhat	mini	simple	a b c 4 Avoid rapid stretching.
20	LA Times	Levator Scapulae Stretch	Grasp seat or leg of chair with right hand to pull shoulder down slightly. Move head forward, rotate and lean to left until stretch from neck to top of shoulder blade is felt. Lean body to left to increase stretch. Hold 15 seconds. Repeat on other side.		Neck side benders, scapular elevators, posterior and lateral ligaments of the upper thoracic and cervical spine and facet joints	fair	chair	somewhat	mini	simple	a b c Avoid rapid stretching. May produce moderate loading on cervical discs if performed in forward, flexed head posture.
21	Pragler	Exercise a-3	Keeping shoulders down, bend the head over towards the shoulder to stretch the muscles of the neck. Hold that position for a count of 3, and then bring head slowly back to the center.		Neck side benders, scapular elevators, lateral ligaments of the upper thoracic and cervical spine and facet joints	poor	chair	no	micro	simple	a b c 4 Avoid rapid stretching. May produce moderate loading on cervical discs if performed in forward, flexed head posture. Enhance safety by tucking chin during side bending.
22	Sauter	Nose Drawing	Close eyes and imagine pen attached to nose. Moving head, draw a large circle. Within circle, draw a plus. Go over it several times. Draw a "X" and go over it several times. Try drawing other objects, or writing name.	Neck sidebenders, rotators, flexors and extensors	Neck sidebenders, rotators, flexors and extensors; posterior and lateral ligaments of the cervical and thoracic spine and facet joints	good	chair	somewhat	mini	simple	a b c 1 3 4
23	Dahl	Unnamed	Lift shoulders towards ears in a shrug, then relax and let them fall back.	Scapular upward rotators and adductors	Scapular downward rotators	*	chair	somewhat	micro	simple	
24	Joyce & Peterson	Shoulder Shrug	Sit straight and bring shoulders up toward ears. Hold for count of 3. Relax. Repeat twice.	Scapular upward rotators and adductors	Scapular downward rotators	good	chair	somewhat	micro	simple	
25	Joyce & Peterson	Shoulder Roll	Sit upright. Lower chin. Slowly make 3 circles with shoulders, then gradually tilt head backward. Make 3 slow circles with shoulders. Stretch upward for count of 3, and relax.	Scapular upward rotators and adductors	Scapular downward rotators cervical flexors and extensors	fair	chair	somewhat	mini	simple	a f 1 3

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Table 1. Panel B. Shoulder Exercises

	Author	Name of Exercise	Exercise Instructions	Muscle Groups Recruited	Anatomical Structures Stretched	Specif. of Instr.	Space or Location	Conspicuous?	Time Reqmt.	Ease of Perform.	Comments
26	Krames Comm.	Shoulders	Roll shoulders forward 5 times using wide circular motions. Then roll shoulders backward 5 times. Repeat cycle 5-10 times.	Scapular upward rotators and adductors, scapular downward rotators and shoulder abductors	Scapular downward rotators and abductors, scapular upward rotators and adductors	good	chair	somewhat	mini	simple	f 1 3
27	Pragler	Exercise a-6	Circle shoulders backward three times, with arms relaxed by sides.	Scapular upward rotators and adductors, scapular downward rotators and shoulder abductors	Scapular downward rotators and abductors, scapular upward rotators and adductors	good	chair	somewhat	micro	simple	f 1 3
28	Austin	Shoulder Roll	Slowly roll shoulders forward 5 times in circular motion. Then roll back with same circular motion.	Scapular upward rotators and adductors, scapular downward rotators and shoulder abductors	Scapular downward rotators and abductors, scapular upward rotators and adductors	good	chair	somewhat	micro	simple	f 1 3
29	Australian National University	Exercise 3	Circle shoulders backwards and forwards 10-20 times.	Scapular upward rotators and adductors, scapular downward rotators and shoulder abductors	Scapular downward rotators and abductors, scapular upward rotators and adductors	fair	chair	somewhat	mini	simple	f 1 3
30	Sauter	Shoulder Circles	With arms at sides, raise shoulders up, and rotate forward in circular motion several times. Repeat several times in backwards direction.	Scapular upward rotators and adductors, scapular downward rotators and shoulder abductors	Scapular downward rotators and abductors, scapular upward rotators and adductors	good	chair	somewhat	micro	simple	f 1 3
31	Emanuel and Glonek	Shoulder Rotations	Bend elbows and rotate shoulders 4 times forward and 4 times backward.	Scapular upward rotators and adductors, scapular downward rotators and shoulder abductors	Scapular downward rotators and abductors, scapular upward rotators and adductors	fair	chair	somewhat	micro	simple	f 1 3
32	Austin	Arm Circles	Raise arms to side with elbows straight. Slowly rotate arms in small circles, forward and backward.	Scapular upward rotators, shoulder adductors, scapular downward rotators and abductors, shoulder abductors	Scapular downward rotators and abductors, scapular upward rotators and adductors	good	chair	highly	mini	simple	f
33	Krames Comm.	Arm Circles	Raise the arms to the sides, elbows straight. Slowly rotate arms in small circles forwards, then backwards. Lower arms, then repeat 3 times.	Scapular upward rotators, shoulder adductors, scapular downward rotators and abductors, shoulder abductors	Scapular downward rotators and abductors, scapular upward rotators and adductors	good	chair	highly	mini	simple	f
34	Lacey	Upper Arms	Let arms fall to side and rotate hands in circular motion. Put arms up, interlock fingers overhead. Push arms forward, then stretch arms back, pulling ribcage up. Hold arms straight out, rotate them in circular motion. Flex upper arms as in making a muscle.	Wrist flexors, wrist/finger extensors, forearm supinators and pronators, wrist ulnar and radial deviators; shoulder flexors, abductors, external rotators, horizontal abductors and internal rotators	Wrist flexors, wrist/finger extensors, forearm supinators and pronators, wrist ulnar and radial deviators, shoulder extensors, adductors and internal rotators, external rotators and abductors	fair	chair	highly	mini	simple	f j 1 3

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Table 1. Panel B. Shoulder Exercises (cont.)

	Author	Name of Exercise	Exercise Instructions	Muscle Groups Recruited	Anatomical Structures Stretched	Specif. of Instr.	Space or Location	Conspicuous?	Time Reqmt.	Ease of Perform.	Comments
35	Dahl	Unnamed	Sit forward in chair. Slump forward, straighten up and arch back, raise arms as high above head as possible, then slump forward again.	Phase II: Cervical, thoracic and lumbar extensors, scapular adductors, elevators and upward rotators, shoulder flexors and external rotators	Phase I: Shoulder extensors and internal rotators, posterior ligaments of the cervical, thoracic and lumbar spine. Phase II: Cervical, thoracic and lumbar flexors, scalpular adductors, elevators and upward rotators	*	chair	highly	micro	simple	a b c d e 1 3
36	Pragler	Exercise b-7	Push one arm up toward ceiling with hand stretched out. Repeat with other arm.	Scapular adductors and upward rotators; shoulder flexors and abductors, thoracic extensors and external rotators	Shoulder extensors and adductors	good	chair	highly	micro	simple	f
37	Krames Comm.	Reaching High	Raise arms over head, stretching as high as possible. Then bring arms back down. Rest a moment. Repeat 2 times.	Scapular adductors and upward rotators, shoulder flexors and abductors, thoracic extensors	Shoulder extensors, adductors and internal rotators	good	chair	highly	micro	simple	f
38	Gore and Tasker	Reach for the Sky	Standing, stretch arms above head and hold for count of 6. Drop arms. Repeat 5 times.	Scapular adductors and upward rotators, shoulder flexors and abductors, thoracic extensors	Shoulder extensors, adductors and internal rotators	good	work area	highly	mini	simple	f
39	Austin	Reach	Slowly raise arms and draw stomach in. Let arms drop. Repeat twice.	Scapular adductors and upward rotators, shoulder flexors and abductors, thoracic extensors, abdominal flexors	Shoulder extensors, adductors and internal rotators	fair	chair	highly	mini	simple	f
40	Sauter	Arm Stretch	Stretch left arm over head, and right arm towards floor. Hold for several moments. Repeat several times, then reverse arms and repeat.	Scapular adductors and downward and upward rotators, shoulder flexors and abductors, thoracic extensors, neck rotators and flexors	Shoulder extensors and adductors, trunk lateral flexors	good	chair	highly	mini	simple	a b c f 1 3 4
41	LA Times	Windmills	Bring head into Turkey Position (see exercise 5), with arms at sides. Point one thumb forward, one thumb back. With arms straight, move them in direction thumbs are pointing. Repeat, moving arms in opposite direction. Do 3-5 times.	Scapular adductors, downward and upward rotators, shoulder flexors, abductors, external rotators, extensors, adductors and internal rotators, elbow extensors, forearm supinators and pronators, thoracic extensors	Scapular downward and upward rotators, shoulder extensors, adductors, internal rotators, flexors, abductors and external rotators, elbow flexors, forearm pronators and supinators	fair	chair	highly	micro	simple	a f 1 3
42	Australian National University	Exercise 1	With arms bent across chest, push elbows back while stretching head up. Repeat 7-15 times.	Scapular adductors, upward rotators, shoulder vertical and horizontal abductors, external rotators		poor	chair	somewhat	mini	simple	

*As the Dahl exercises were translated from Danish to English for the authors, the specificity of the instructions was not evaluated

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Table 1. Panel B. Shoulder Exercises (cont.).

	Author	Name of Exercise	Exercise Instructions	Muscle Groups Recruited	Anatomical Structures Stretched	Specif. of Instr.	Space or Location	Conspicuous?	Time Reqmt.	Ease of Perform.	Comments
43	Austin	Shoulder Stretch	Bring right hand to upper back from above. Bring left hand to upper back from below and hook fingers of two hands. Repeat on other side.	Scapular adductors, downward and upward rotators, shoulder flexors, abductors, external rotators, extensors, adductors and internal rotators, elbow flexors, thoracic extensors	Scapular downward and upward rotators, shoulder extensors, adductors, internal rotators, flexors, abductors and external rotators	fair	chair	highly	micro	difficult	f i j 1 3
44	Joyce & Peterson	Arm Rotation	Extend arms straight ahead at shoulder level. Rotate them so the back of the hands face and touch each other. Hold to count of 3. Then rotate hands so palms face upward with sides of hands touching. Hold to count of 3. Repeat 2 more times.	Shoulder external rotators, flexors, shoulder internal rotators, forearm supinators and pronators	Shoulder internal rotators, external rotators, forearm pronators and supinators	fair	chair	highly	micro	simple	f k 1 3 Arm extension may actually increase neck/shoulder strain.
45	Joyce & Peterson	Give Me Five	Hold arms straight out in front. Make fist. Slowly point knuckles to floor. Hold for count of 3. Slowly straighten out fingers. Then point fingers toward ceiling and hold for count of 3. Repeat 3 times.	Shoulder external rotators, flexors and abductors, scapular adductors and upward rotators, thoracic extensors, finger flexors, wrist and finger extensors	Shoulder internal rotators, extensors and adductors, scapular downward rotators, wrist extensors	good	chair	somewhat	mini	simple	f j 1 3 Arm extension may actually increase neck/shoulder strain
46	Gore and Tasker	Fall Back	Sitting up straight, raise arms above head and clasp hands together. Looking forward, let arms and shoulders fall backwards over back of chair. Hold for slow count of 10. Relax. Repeat 3 times.	Shoulder flexors and abductors, scapular adductors and upward rotators	Shoulder extensors and adductors, anterior ligaments of the thoracic spine and facet joints	good	chair	somewhat	mini	simple	b c d e f 2 Potential for chair tipping backwards.
47	Dahl	Unnamed	Sit forward in chair. Raise arms above head and bend backward over back support.	Shoulder flexors and abductors, scapular adductors and upward rotators	Shoulder extensors and adductors, anterior ligaments of the thoracic spine and facet joints, cervical flexors	*	chair	somewhat	micro	simple	b c d e f 2 Potential for chair tipping backwards.
48	Gore and Tasker	Forwards Lean	Standing, push chair against desk. Stand about 1 meter behind chair, place hands on back of chair while keeping elbows straight, drop head forward between arms while keeping back straight. Hold for count of 10. Relax. Repeat 5 times.		Shoulder extensors and adductors, hip extensors/knee flexors (hamstrings), lumbar extensors, posterior ligaments of the lumbar spine and facet joints, cervical extensors	fair	work area	highly	mini	simple	a b c d e 1 2 3 4 Rolling chair potentially dangerous.
49	Krames Comm.	Upper Back Stretch	Raise hands to shoulders. Using the arms push shoulders back. Keep elbows down. Hold for 15 seconds. Repeat 3 times.	Scapular adductors, upward rotators, shoulder vertical and horizontal abductors, external rotators	Scapular abductors, downward rotators, shoulder internal rotators and horizontal adductors	fair	chair	somewhat	mini	simple	f
50	Austin	For your Arms	Bend elbows, keeping arms parallel to floor, fingers in front of chest. Push arms way out to sides with arms straight. Repeat 5 times.	Scapular adductors, upward rotators, shoulder vertical and horizontal abductors	Scapular abductors, downward rotators, shoulder internal rotators and horizontal adductors	poor	chair	highly	micro	simple	f

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Table 1. Panel B. Shoulder Exercises (cont.)

	Author	Name of Exercise	Exercise Instructions	Muscle Groups Recruited	Anatomical Structures Stretched	Specif. of Instr.	Space or Location	Conspicuous?	Time Reqmt.	Ease of Perform.	Comments
51	Joyce & Peterson	Trapezius Squeeze	Raise arms up and to the sides, with palms facing out. Squeeze shoulder blades together and hold 3 sec. Relax. Repeat 2 more times.	Scapular adductors, upward rotators, shoulder vertical and horizontal abductors, external rotators	Scapular abductors, downward rotators, shoulder internal rotators and horizontal adductors	good	chair	highly	micro	simple	f
52	LA Times	Shoulder Blade	Bring head into Turkey Position (see exercise 5). Hold arms up, elbows bent, with palms facing forward at shoulder height. Pull hands back as if to touch little fingers together. Repeat 3-5 times.	Scapular adductors, upward rotators, shoulder vertical and horizontal abductors, external rotators	Scapular abductors, downward rotators, shoulder internal rotators and horizontal adductors	fair	chair	somewhat	micro	simple	f
53	Joyce & Peterson	Executive Stretch	Lock hands behind head and bring elbows back. Lean back in chair, stretching and arching spine. Hold to count of 3. Relax. Repeat twice.	Scapular adductors, upward rotators, shoulder vertical and horizontal abductors, external rotators, cervical and thoracic extensors	Scapular abductors, downward rotators, shoulder internal rotators and horizontal adductors	good	chair	somewhat	mini	simple	a d f
54	Pragler	Exercise a-2	Hands behind head, tuck chin in and push the back of the head into the hands. Hold that position for a count of 3; relax.	Scapular adductors, upward rotators, shoulder vertical and horizontal abductors, external rotators, cervical and thoracic extensors	Scapular abductors, downward rotators, shoulder internal rotators and horizontal adductors	fair	chair	somewhat	micro	simple	a f
55	Austin	Pectoral Stretch	Grasp hands behind neck and press elbows as far back as possible. Relax. Repeat.	Scapular adductors, upward rotators, shoulder vertical and horizontal abductors, external rotators, cervical and thoracic extensors	Scapular abductors, downward rotators, shoulder internal rotators and horizontal adductors	good	chair	somewhat	micro	simple	a f
56	Dahl	Unnamed	Interlace fingers, turn palms forward, raise arms above head, lower them behind the neck, then down in front of the body again.	Scapular adductors, upward rotators, shoulder flexors and abductors, arm extensors, cervical and thoracic extensors	Scapular abductors, downward rotators, shoulder internal rotators, horizontal and vertical adductors, extensors and internal rotators, scapular adductors, downward rotators	*	chair	somewhat	micro	simple	f i j 1 3
57	Pragler	Exercise b-2	Rotate both shoulders backwards, keeping arms relaxed by sides.	Scapular upward rotators and adductors	Scapular downward rotators	good	chair	somewhat	micro	simple	
58	Pragler	Exercise b-3	Clap hands in front of body, keeping elbows bent and tucked in by sides.	Shoulder external rotators, scapular adductors, downward rotators	Shoulder internal rotators, scapular upward rotators	good	chair	highly	micro	simple	f
59	Gore and Tasker	Triangle	With arms by sides, turn palms outward and move arms backward as far as possible. Hold for count of 10. Relax. Repeat 3 times.	Shoulder external rotators, scapular adductors, downward rotators, horizontal adductor	Shoulder internal rotators, scapular upward rotators, anterior chestwall	good	chair	somewhat	mini	simple	f 3
60	Pragler	Exercise b-1	Pull shoulders back, arms at sides. Hold for count of 3.	Cervical and thoracic extensors, scapular adductors, elevators and upward rotators	Anterior ligaments of the lower thoracic spine, anterior chestwall	good	chair	no	micro	simple	

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d Acute lower back pain
e Second and third trimesters of pregnancy
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i Acute inflammatory or arthritic conditions of the elbow/forearm complex
j Hand/wrist disorders, such as carpal tunnel syndrome
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Table 1. Panel B. Shoulder Exercises (cont.)

	Author	Name of Exercise	Exercise Instructions	Muscle Groups Recruited	Anatomical Structures Stretched	Specif. of Instr.	Space or Location	Conspicuous?	Time Reqmt.	Ease of Perform.	Comments
61	Sauter	Upper Arm Relaxer	Slowly open and spread arms to sides as when stretching and yawning. Fold arms back toward body tightly. Repeat a few times.	Shoulder external rotators, scapular adductors, downward rotators, shoulder internal rotators, scapular abductors, horizontal abductors and adductors	Shoulder internal and external rotators, scapular upward rotators	fair	chair	somewhat	micro	simple	f 3
62	Pragier	Exercise a-4	Bring arms over the back of the chair with the hands clasped. Stretch arms down towards the floor. Hold for a count of 3 then relax.	Scapular adductors, downward rotators	Scapular upward rotators	fair	chair	somewhat	micro	moderately difficult	d f
63	Sauter	Shoulder Blade Pinch	Move forward slightly in chair. Place hands on edges of chair behind buttocks and try to touch elbows together behind back. Relax and repeat a few times.	Scapular adductors, downward rotators	Scapular upward rotators and abductors	good	chair	somewhat	micro	simple	d f
64	Pragier	Exercise b-8	Push arm forward at shoulder height with the hand stretched out. Repeat with the other arm.	Scapular adductors and downward rotators, shoulder extensors, elbow flexors, wrist extensors, scapular abductors and upward rotators, shoulder flexors, elbow extensors	Scapular abductors and upward rotators, shoulder flexors, elbow extensors, wrist flexors, scapular adductors and downward rotators, elbow flexors	fair	chair	highly	micro	simple	f 1 3
65	Austin	Upper Back Stretch	Sit with hands on shoulders. Try to cross elbows in front. Relax. Repeat.	Scapular abductors, shoulder horizontal adductors, and external rotators	Scapular adductors, shoulder horizontal abductors and internal rotators	good	chair	highly	micro	simple	f 1 3
66	Austin	Middle-Upper Back Stretch	Hold right arm just above elbow with left hand. Gently pull elbow toward left shoulder. Hold 5 seconds. Repeat other side.	Scapular abductors, shoulder horizontal adductors	Scapular adductors, shoulder horizontal abductors	good	chair	somewhat	micro	simple	f 1 3
67	Austin	Hug Yourself	Cross arms in front of chest and reach fingertips towards shoulder blades.	Scapular abductors, shoulder horizontal adductors	Scapular adductors, shoulder horizontal abductors	fair	chair	highly	micro	simple	f 1 3

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Table 1. Panel C. Elbow/Lower Arm Exercises.

	Author	Name of Exercise	Exercise Instructions	Muscle Groups Recruited	Anatomical Structures Stretched	Specif. of Instr.	Space or Location	Conspicuous?	Time Reqmt.	Ease of Perform.	Comments
68	Gore and Tasker	Eiffel Tower	Straighten fingers and spread apart as far as possible. Bring whole length of fingers together, but keep palms as far apart as possible. Hold for count of 10. Relax. Repeat 3 times.		Finger flexors, anterior ligaments of the MP joints, finger adductors	poor	chair	somewhat	mini	simple	i j
69	Australian National University	Exercise 12	Raise arms above head with palms and heel of hands together. Slowly pull hands down in front of chest with hands together. Repeat 5-10 times.	Shoulder flexors, abductors and external rotators	Finger flexors, anterior ligaments of the finger joints, shoulder extensors, adductors and internal rotators	good	chair	highly	mini	simple	i j
70	Gore and Tasker	Palm Press	Place palms together, point fingers to ceiling. Keeping palms together, try to push heels of hands towards floor and hold for count of 10.		Finger flexors, anterior ligaments of the finger joints	fair	chair	somewhat	micro	simple	i j
71	Dahl	Unnamed	Place palms together and press one hand backwards with the other. Change hands.		Finger flexors, anterior ligaments of the finger joints	*	chair	somewhat	micro	simple	i j
72	Austin	Wrist Flex	Put elbow on table with hand raised. With other hand, hyperextend wrist so that the back of the first hand is aiming to the top of the forearm. Repeat with opposite hand.		Finger flexors, anterior ligaments of the finger joints	fair	chair	somewhat	micro	simple	j
73	Krames Comm.	Wrist Flex	Put your right elbow on a table, hand raised. With your left hand, gently bend your right hand back toward the forearm. Hold 5 seconds. Repeat on the other side.		Finger flexors, anterior ligaments of the finger joints	good	chair	somewhat	micro	simple	i j
74	Dahl	Unnamed	Bend wrist backward. With other hand, grasp tips of fingers and pull hand backward. Repeat with other hand.		Finger flexors, anterior ligaments of the finger joints	*	chair	no	micro	simple	i j
75	Joyce & Peterson	Thumb Stretch	Stretch right hand out. Gently pull the thumb down and back. Hold 5 sec. Relax and repeat 2 times. Repeat with left hand.		Thumb flexors and adductors	fair	chair	somewhat	mini	simple	i j
76	Krames Comm.	Wrist	Hold hands in front of body. Raise and lower hands to stretch muscles in forearm. Repeat several times	Wrist/finger extensors, shoulder flexors	Wrist extensors and flexors	poor	chair	somewhat	micro	simple	f i 1 3 Arm extension may actually increase neck/shoulder strain.
77	Australian National University	Exercise 9	Lift arms forward, slowly clench fists, open and spread fingers. Repeat 10-20 times.	Finger flexors and extensors, shoulder flexors	Finger flexors and extensors	good	chair	somewhat	mini	simple	f i 1 Arm extension may actually increase neck/shoulder strain.
78	Krames Comm.	Finger Fan	Hold hands out in front of body, palms down. Spread fingers apart as far as possible. Hold for 5 seconds, then make a tight fist. Repeat 3 times.	Finger flexors and extensors, finger abductors	Finger flexors and extensors, finger adductors	good	chair	somewhat	micro	simple	i j 1 3

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Table 1. Panel C. Elbow/Lower Arm Exercises (cont.)

	Author	Name of Exercise	Exercise Instructions	Muscle Groups Recruited	Anatomical Structures Stretched	Specif. of Instr.	Space or Location	Conspicuous?	Time Reqmt.	Ease of Perform.	Comments
79	Dahl	Unnamed	Spread and stretch fingers as much as possible, then make a fist.	Finger flexors and extensors, finger abductors	Finger flexors and extensors, finger adductors	*	chair	no	micro	simple	i j 1 3
80	Austin	Fingers	With palms down, spread thumb and fingers as far apart as possible. Hold for count of 5. Relax. Repeat.	Wrist/finger extensors, finger abductors	Finger flexors, finger adductors	good	chair	no	micro	simple	i j
81	Sauter	Palm Push-Ups	Place tops of hands under front edge of worktable. Push up with hands (not arms) for a moment. Then place palms in similar position on top of desk and push down. Drop hands to sides and wiggle hands a bit. Rest in lap for a few seconds.	Finger extensors, wrist extensors		good	chair	no	micro	simple	k
82	Australian National University	Exercise 10	Lift arms forward, circle hands at wrist, then reverse. Drop hands to sides, repeat circling. Raise arms above head, repeat circling. Do 5 times each direction, each position.	Wrist flexors, wrist/finger extensors, forearm supinators/pronators, wrist ulnar and radial deviators, shoulder flexors, abductors and external rotators	Wrist flexors, wrist/finger extensors, forearm supinators/pronators, wrist ulnar and radial deviators, shoulder extensors, adductors and internal rotators	good	chair	highly	mini	simple	f i j k 1 3 May increase joint stress in the wrist. Arm extension may actually increase neck/shoulder strain.
83	LA Times	Forearm Stretch	Bend elbow so palm is facing forward. Make fist. Bend wrist so palm surface points to floor. Turn hand so it points away from body, then straighten forearm and turn arm inward. Hold 15 seconds. Repeat 3-5 times.	Wrist/finger flexors, forearm pronators	Wrist/finger extensors, forearm supinators	fair	chair	somewhat	mini	simple	i j k 1 3
84	Australian National University	Exercise 11	Bend wrist and fingers of one hand towards palm, applying pressure with other hand. Repeat with other hand. Do 5-10 times.		Wrist extensors	fair	chair	no	mini	simple	i j
85	Sauter	Finger Curls	Holding forearms outstretched in front, bend fingers (not hands) downward and curl them into a fist. Open fist and bend fingers up slightly. Repeat once or twice. Return fingers to neutral position and stretch them apart. Drop arms and hands to sides and gently wiggle them about for a moment. Return hands to lap and rest them for a few seconds.	Finger flexors and extensors	Finger flexors and extensors	good	chair	somewhat	micro	simple	i j 1 3

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Table 1. Panel D. Lower Back/Hip Exercises.

	Author	Name of Exercise	Exercise Instructions	Muscle Groups Recruited	Anatomical Structures Stretched	Specif. of Instr.	Space or Location	Conspicuous?	Time Reqmt.	Ease of Perform.	Comments
86	Sauter	Back Arch	Move forward slightly in chair and place hands on edges of chair. Straighten up slowly, raising chest up and out. Hold momentarily. Relax. Repeat a few times.	Upper cervical, thoracic and lumbar extensors, scapular adductors, elevators and upward rotators, neck flexors	Upper cervical extensors Phase II: anterior ligaments of the upper cervical, thoracic and lumbar spine	good	chair	somewhat	micro	simple	a b d f l
87	Austin	Knee Kiss	Sit in chair. Pull one leg to chest, grasp with both hands and hold for count of five. Repeat with opposite leg.	Arm flexors, shoulder extensors	Hip extensors, lower cervical and thoracic extensors and posterior ligaments of the cervical, thoracic and lumbar spine	good	chair	highly	mini	difficult	b c d e f l l m 2 4 Rolling chair potentially hazardous. Difficult to perform in most office attire, or for obese individuals.
88	Krames Comm.	Legs	Grasp shin of one leg and pull slowly toward chest. Hold 5 sec. Repeat several times with both legs.	Arm flexors, shoulder extensors	Hip extensors, lower cervical and thoracic extensors and posterior ligaments of the cervical, thoracic and lumbar spine	good	chair	highly	mini	difficult	b c d e f l l m 2 4 Rolling chair potentially hazardous. Difficult to perform in most office attire, or for obese individuals.
89	Austin	Back Relaxer	Sit on chair. Drop neck, shoulders and arms, then bend down between knees, as far as possible. Return to upright position. Straighten out and relax.		Thoracic and lumbar extensors, posterior ligaments of the thoracic and lumbar spine	good	chair	highly	mini	simple	b c d e 1 2 3 Awkward to perform. Rolling chair potentially hazardous. Difficult to perform in most office attire. Difficult to perform for obese or pregnant individuals.
90	Krames Comm.	Lower Back Stretch	Lower head and slowly roll body as far as possible toward knees. Hold for 10 seconds. Push self up with leg muscles. Repeat 3 times.		Thoracic and lumbar extensors, posterior ligaments of the thoracic and lumbar spine	fair	chair	highly	mini	moderately difficult	b c d e 1 2 3 Awkward to perform. Rolling chair potentially dangerous (as noted in brochure). Difficult to perform for obese or pregnant individuals.
91	Lee and Waikar	Bending	Bend trunk forward as far as possible, letting arms hang loose. Stretch trunk back, placing hands on small of back.		Phase I: Thoracic and lumbar extensors, posterior ligaments of the thoracic and lumbar spine, hip extensors and knee flexors (hamstrings) Phase II: Anterior ligaments of the lumbar spine and hip joints, trunk and hip flexors	good	work area	highly	mini	moderately difficult	b c d e 1 2 3 Awkward and difficult to perform for obese or pregnant individuals.
92	Dahl	Unnamed	Sit forward in chair. 1) Slump forward, 2) straighten up and arch back, then slump forward again.	Neck flexors Phase II: Lower cervical, thoracic and lumbar extensors	Phase I: Lower cervical, thoracic and lumbar extensors, scapular adductors, elevators and upward rotators, posterior ligaments of the cervical, thoracic and lumbar spine Phase II: Upper cervical flexors, anterior ligaments of the lower cervical and thoracic spine	*	chair	no	micro	simple	a b c d e 1 3
93	Joyce & Peterson	Pelvic Tilt	Sit straight in chair. Tighten abdominal muscle. Slowly tilt pelvis by pressing waist into back of chair. Hold 3 sec. Relax. Tilt pelvis in other direction by arching back. Repeat 2 more times.	Phase I: Trunk flexors, hip extensors. Phase II: Trunk extensors and hip flexors	Phase I: Thoracic and lumbar extensors, and posterior ligaments of the lumbar and thoracic spine. Phase II: Hip extensors	good	chair	no	micro	simple	b c d e 4 Avoid strong pelvic tilt contractions as they may increase stress to the lumbar discs.

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Table 1. Panel D. Lower Back/Hip Exercises (cont.)

	Author	Name of Exercise	Exercise Instructions	Muscle Groups Recruited	Anatomical Structures Stretched	Specif. of Instr.	Space or Location	Conspicuous?	Time Reqmt.	Ease of Perform.	Comments
94	Sauter	Pelvic Tilt	Imagine you have a tail and are trying to tuck it between your legs by tilting the pelvis up. Hold 1-2 sec. Repeat a few times.	Trunk flexors and hip extensors	Posterior ligaments and extensors of the lumbar spine	good	chair	no	micro	simple	b c d e 4 Avoid strong pelvic tilt contractions as they may increase stress to the lumbar discs.
95	Joyce & Peterson	Glute Clench	Sit straight, tighten both buttock and abdominal muscles, hold for 5 seconds. Relax, then repeat 2 more times.	Trunk flexors and hip extensors		fair	chair	no	micro	simple	b c d e 4 Avoid strong pelvic tilt contractions as they may increase stress to the lumbar discs.
96	Austin	Windmill	Sit in chair. Place feet apart on the floor. Bend over and touch right hand to left foot with left arm extended up. Alternate sides repeatedly.	Anterior and posterior trunk rotators, thoracic, lumbar and hip extensors, trunk side benders	Anterior and posterior trunk rotators, thoracic, lumbar and hip extensors, trunk side benders, posterior and lateral ligaments of the thoracic and lumbar spine	good	chair	highly	mini	difficult	a b c d e f l 1 2 3 4 Avoid rapid stretching. Difficult to perform for obese or pregnant individuals. Rolling chair potentially hazardous. Difficult to perform in most office attire.
97	Austin	Trimming the Waist	Interlace fingers behind neck. Lift right knee and touch left elbow to right knee. Alternate sides 5 times.	Hip flexors, anterior and posterior trunk extensors and rotators	Anterior and posterior trunk rotators, thoracic, lumbar and hip extensors, trunk side benders, posterior and lateral ligaments of the cervical, thoracic and lumbar spine	good	chair	highly	mini	moderately difficult	a b c d e f 1 2 3 4 Rapid stretching not recommended. Rolling chair potentially hazardous.
98	Dahl	Unnamed	Sit forward in chair. Put hands on seat behind body, extend and raise both legs. Relax.	Hip and trunk flexors, knee extensors	Hip extensors and knee flexors (hamstrings)	*	chair	somewhat	micro	moderately difficult	b c d e f l 1 2 3 4 Hip flexors are often already tight as a result of the sedentary nature of VDT work. Rolling chair potentially hazardous.
99	Joyce & Peterson	Knee Raises	Sit upright in chair. Tighten abdominal muscles and raise knees 2 inches. Hold 3 sec. Relax. Repeat 2 times.	Hip and trunk flexors, trunk anterior and posterior rotators		good	chair	somewhat	mini	moderately difficult	b c d e 1 3 4 Hip flexors are often already tight as a result of the sedentary nature of VDT work. Rolling chair potentially hazardous.
100	Austin	Side Stretch	Interlace fingers. Lift arms over head and press backwards as far as possible. Lean to the left, then to the right.	Trunk side benders, shoulder flexors, abductors and internal rotators, scapular adductors, elevators and upward rotators	Trunk side benders, shoulder extensors, adductors and internal rotators, posterior and lateral ligaments of the thoracic and lumbar spine	good	chair	highly	micro	simple	b c d e f l j 1 3 4
101	Australian National University	Exercise 7	Arms by side, creep hand down thigh toward knees. Repeat on other side. Do 5-10 times.	Trunk side benders	Trunk side benders, lateral ligaments of the thoracic and lumbar spine	fair	work area	highly	mini	simple	b c d e l 1 4 Rapid stretching not recommended.
102	Gore and Tasker	Sideways Bend	Standing with arms at sides, bend sideways so right arm goes down right leg. Return to upright and repeat on left side. Repeat 5 times each side.	Trunk side benders	Trunk side benders, lateral ligaments of the thoracic and lumbar spine	good	work area	highly	mini	simple	b c d e l 1 4 Rapid stretching not recommended.
103	Lee and Walker	Side Bending	Bend to left as far as possible, letting left arm hang loose. Repeat on right side.	Trunk side benders	Trunk side benders, lateral ligaments of the thoracic and lumbar spine	good	work area	highly	mini	simple	b c d e l 1 4 Rapid stretching not recommended.

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	Author	Name of Exercise	Exercise Instructions	Muscle Groups Recruited	Anatomical Structures Stretched	Specif. of Instr.	Space or Location	Conspicuous?	Time Reqmt.	Ease of Perform.	Comments
104	Pragler	Exercise b-4	Bend to left and stretch left arm down side. Repeat to right.	Trunk side benders	Trunk side benders, lateral ligaments of the thoracic and lumbar spine	good	work area	highly	mini	simple	b c d e l 1 4 Rapid stretching not recommended.
105	Sauter	Chair Rock	Place feet squarely on floor with hands at side of chair. Rock slowly to left, looking over right shoulder, then to the right, looking over left shoulder. Do several times.	Anterior and posterior cervical, thoracic, and lumbar rotators	Anterior and posterior cervical and thoracic and lumbar rotators, posterior and lateral ligaments of the cervical, thoracic and lumbar spine	good	chair	highly	micro	simple	a b c d 4 May produce moderate loading on cervical discs if performed with forward head posture.
106	Austin	Trunk Twists	Turn at trunk. Turn head in direction of trunk. Twist 3 times in each direction.	Anterior and posterior trunk rotators, shoulder abductors and external rotators, scapular adductors, elevators and upward rotators, neck rotators	Anterior and posterior trunk rotators, posterior and lateral ligaments of the thoracic and lumbar spine, shoulder internal rotators	good	chair	highly	micro	simple	a b c d e f l 1 3 4 Raised arms (as shown in the brochure) produce additional loading on lumbar and thoracic discs.
107	Emanuel and Glonek	Trunk Rotations	Rotate entire upper body in a clockwise direction 3 times. Repeat counter-clockwise 3 times.	Anterior and posterior trunk rotators, trunk side benders, trunk/hip flexors and extensors	Anterior and posterior trunk rotators, trunk side benders, trunk/hip flexors, anterior and lateral ligaments of the lumbar and thoracic spine and hip joints	fair	work area	highly	micro	simple	b c d e l 1 4
108	Australian National University	Exercise 6	Place palms across the small of back, bend and arch spine. (5-10 times)	Abdominals (eccentric)	Anterior ligaments of the lumbar spine and hips, trunk and hip flexors	poor	work area	somewhat	mini	simple	b d e l
109	Gore and Tasker	Disc Reliever	Standing up straight with feet slightly apart, place hands in hollow of back. Focus eyes on a point straight ahead. Bend backwards over hands without bending knees, then straighten up. Repeat 10 times.	Abdominals (eccentric)	Anterior ligaments of the lumbar spine and hips, trunk and hip flexors	good	work area	somewhat	mini	moderately difficult	b d e l
110	Austin	Derriere Firmer	Place hands on chair, feet flat on floor, lift hips and buttocks up. Tighten buttocks and hold for 5 sec. Sit back and relax. Repeat twice.	Hip adductors/extensors, back extensors, scapular adductors, arm and shoulder extensors	Hip/trunk flexors, shoulder flexors	good	chair	highly	mini	difficult	b c d e f l 2 Arm strength limits ability to perform. Rolling chair potentially hazardous. May be difficult for obese or pregnant individuals to perform.

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Table 1 Panel E. Knee/Lower Leg Exercises.

	Author	Name of Exercise	Exercise Instructions	Muscle Groups Recruited	Anatomical Structures Stretched	Specif. of Instr.	Space or Location	Conspicuous?	Time Reqmt.	Ease of Perform.	Comments
111	Dahl	Unnamed	Standing, extend one leg backwards and upwards. Grab foot and pull upwards. Repeat with other leg.		Knee extensors, anterior ligaments of the hip, hip flexors	*	work area	highly	mini	difficult	b c d e m 2 Support should be provided when performing standing portion of the exercise. Difficult to perform in most office attire, or in high-heeled shoes.
112	Australian National University	Exercise 14	Hands on hips, one foot in front of other, rock forward and backward slowly 10-20 times. Repeat with other leg.	Hip abductors and extensors, knee extensors	Plantar flexors, hip flexors and external rotators, anterior ligaments of the hips	fair	work area	highly	mini	moderately difficult	m
113	Dahl	Unnamed	Standing, take long step forward and bend knee. Keep heel of rear foot on floor. Bend front knee joint further to lower body downward. Repeat with other leg.	Hip abductors and extensors, knee extensors	Plantar flexors, hip flexors and external rotators, anterior ligaments of the hip	*	work area	highly	mini	moderately difficult	m 2 Support should be provided. Difficult to perform in most office attire, or in high-heeled shoes.
114	Gore and Tasker	Calf Lengthener	Stand with one leg behind the other in lunge position, keeping heel of back foot on floor, lean forward onto front leg. Hold for count of 10. Repeat 3 times per leg.	Hip abductors and extensors, knee extensors	Plantar flexors, hip flexors and external rotators, anterior ligaments of the hip	good	work area	highly	mini	moderately difficult	m 2 Support should be provided. May be hazardous for individuals with ankle problems. Difficult to perform in most office attire, or in high-heeled shoes.
115	Australian National University	Exercise 8	With one foot in front of other, lean forward from hip, supporting arm on forward thigh. Circle free arm. Repeat other side. Do 5-10 times.	Hip abductors and extensors, knee extensors	Plantar flexors, hip flexors and external rotators, anterior ligaments of the hip	poor	work area	highly	mini	moderately difficult	m 2 Support should be provided. Difficult to perform in most office attire, and in high-heeled shoes.
116	Australian National University	Exercise 13	Standing with hands on hips, place feet apart and rock from side to side, bending alternate knees 10-20 times.	Hip abductors and extensors, knee extensors		fair	work area	highly	mini	simple	m
117	Pragler	Exercise b-5	Walk on the spot, letting shoulders and arms hang loose.	Hip abductors and extensors, knee extensors		good	work area	somewhat	mini	simple	m
118	Dahl	Unnamed	Walk up stairs rather than using the elevator.	Hip abductors and extensors, knee extensors, hip flexors, hamstrings		*	extra-work area	no	major	simple	c d m 4
119	Pragler	Exercise b-6	Hop on left foot, then on right foot.	Plantar flexors, knee extensors, hip extensors/abductors		good	work area	highly	micro	moderately difficult	c d e m 4 Exercise creates too much impact through knees, hips and back. Difficult to perform in high-heeled shoes.
120	Emanuel and Glonek	Stretching	Stand on tip toes, extend hands as far as possible overhead. Lower arms slowly to side of body, continuing to extend arms as far as possible.	Plantar flexors, knee extensors, scapular adductors and upward rotators, shoulder flexors, abductors, and external rotators, thoracic extensors	Shoulder extensors, adductors and internal rotators, abdominals	fair	work area	highly	mini	simple	f 2 Difficult to perform in high-heeled shoes.

*As the Dahl exercises were translated from Danish to English for the authors, the specificity of the instructions was not evaluated

Key

1 Exercise reproduces physical stresses of VDT work
2 Exercise poses one or more safety hazards
3 Exercise stretches already overstretched structures
4 Exercise places additional loads on lumbar and/or thoracic discs

a Acute neck pain
b Degenerative disc disease
c Moderate to severe osteoporosis
d Acute lower back pain
e Second and third trimesters of pregnancy
f Acute inflammatory or arthritic conditions of the shoulder
i Acute inflammatory or arthritic conditions of the elbow/forearm complex
j Hand/wrist disorders, such as carpal tunnel syndrome
k Acute lateral epicondylitis
l Spinal stenosis
m Arthritic conditions of the hips and/or knees

Table 1. Panel E. Knee/Lower Leg Exercises (cont.)

	Author	Name of Exercise	Exercise Instructions	Muscle Groups Recruited	Anatomical Structures Stretched	Specif. of Instr.	Space or Location	Conspicuous?	Time Reqmt.	Ease of Perform.	Comments
121	Emanuel and Glonek	Relaxing	Let arms hang loose, try to relax arms, shoulders and knees. Bounce up and down on toes for a few seconds.	Plantar flexors		good	work area	somewhat	mini	simple	2 Difficult to perform in high-heeled shoes.
122	Austin	Strengthen the Quadriceps	Bring legs straight out in front of body in L-shaped position. Hold 5 sec. Relax. Repeat.	Knee extensors, hip flexors, back flexors	Hip extensors and knee flexors (hamstrings)	good	chair	somewhat	micro	difficult	b c d e 1 2 4 Hip flexors already tight as a result of sitting for long periods. Rolling chair potentially hazardous.
123	Dahl	Unnamed	Sitting, extend one leg and flex the foot up and down. Repeat with other leg.	Ankle dorsiflexors, invertors and evertors, knee extensors	Hamstrings	*	work area	somewhat	micro	simple	m
124	Sauter	Leg Reach and Toe Circles	While seated, hold onto chair and raise and extend one leg out in front. Draw a couple of circles in the air with foot, using toe as pointer. Slowly bend knee and bring it about one third of way toward chest. Extend leg again and relax. Repeat exercise with each leg several times.	Ankle dorsiflexors, invertors and evertors, knee extensors	Hamstrings, hip extensors	good	chair	highly	mini	simple	b c d e m 4 May be difficult to perform by obese or pregnant individuals. Difficult to perform in most office attire.
125	Joyce & Peterson	Legs/Ankles/Feet	While sitting, slowly rotate each foot from ankle three times in one direction, then three times in the other. Point toes downward as far as possible. Hold three seconds. Then point toes straight up and hold three seconds. Repeat three times.	Ankle dorsiflexors, invertors and evertors		good	work area	no	mini	simple	
126	Pragler	Exercise a-5	Sitting in chair, lift right leg, hold out straight, then move foot up and down from ankle 10 times. Circle foot to right 10 times, then to left 10 times. Repeat with left leg.	Ankle dorsiflexors, invertors and evertors, knee extensors	Hamstrings	good	chair	no	mini	simple	
127	Sauter	Foot Presses	Sitting erect in chair, press down alternately with ball and heel of right foot several times. Repeat with other foot.	Ankle dorsiflexors, plantar flexors		good	chair	no	micro	simple	

*As the Dahl exercises were translated from Danish to English for the authors, the specificity of the instructions was not evaluated

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Table 2. Proportion of exercises, by body part, falling within each of the useability assessment categories.

	Specificity of Instructions			Location			Conspicuousness			Time Requirement			Ease of Performance		
	Good	Fair	Poor	Chair	Work Area	Extra Work Area	No	Some-what	Highly	Micro	Mini	Major	Simple	Mod. Dif-ficult	Difficult
Neck	0.61	0.35	0.04	0.92	0.08	0.00	0.24	0.68	0.08	0.52	0.48	0.00	1.00	0.00	0.00
Shoulder	0.56	0.38	0.05	0.95	0.05	0.00	0.02	0.52	0.45	0.64	0.36	0.00	0.95	0.02	0.02
Elbow/Lower Arm	0.53	0.33	0.13	1.00	0.00	0.00	0.28	0.61	0.11	0.61	0.39	0.00	1.00	0.00	0.00
Lower Back/ Hip	0.78	0.17	0.04	0.68	0.32	0.00	0.16	0.20	0.64	0.40	0.60	0.00	0.60	0.24	0.16
Knee/Lower Leg	0.69	0.23	0.08	0.24	0.71	0.06	0.24	0.24	0.53	0.24	0.71	0.06	0.59	0.29	0.12
All Exercises	0.63	0.31	0.06	0.80	0.19	0.01	0.16	0.46	0.38	0.51	0.48	0.01	0.85	0.09	0.06

all are suitable for performance at the workstation, or even in the workplace. Each exercise was categorized according to the location most suitable for performance. Three categories were utilized: chair, work area and extra-work area.

- *Chair* The exercise can be performed while seated at the workstation.
- *Work area* The exercise can be performed in close proximity to the workstation.
- *Extra-work area* The exercise does not lend itself to performance at the work area due to the required postures, or the inappropriateness of work attire for such an activity.

Conspicuousness This dimension is important because it addresses the issues of modesty and fear of embarrassment. Highly conspicuous exercises may be less likely to be accepted by VDT users, or may not be performed as instructed. Three categories were defined: highly conspicuous, somewhat conspicuous, or not conspicuous.

- *Highly conspicuous* Potentially embarrassing to the user or dramatically different from routine movements.
- *Somewhat conspicuous* Somewhat obvious to others, but socially acceptable and not embarrassing because of the similarity to common movements (eg, spontaneous stretch associated with fatigue).
- *Not conspicuous* Neither obvious nor embarrassing.

Time requirement/disruption of the work process The exercises varied in the amount of time required to perform them, or in the degree to which they could interrupt work. Excessive or repeated disruption of work may interfere with the work rhythm and impair performance, leading to lack of acceptance by employers or individual VDT users. Three categories were defined: microbreaks, minibreaks and major breaks.

- *Microbreak* Very short break required (ie, less than 10–15 s), entailing no significant interruption of work.
- *Minibreak* A break of less than 1–2 min in duration is required; interruption of the work task is usually necessary.
- *Major break* The exercises can be performed only during a formal break from the task/work area lasting several minutes or more.

Ease of learning and performance This dimension refers to the complexity of the exercises, a factor also potentially affecting acceptance and performance of the exercise routine by VDT users. Three rating categories were defined: simple, moderately difficult, or difficult.

Physiotherapeutic assessment

The potential for three types of problems was considered in the analysis of each exercise. The 'Comments' column in Table 1 notes limitations pertinent to these issues (see also Table 3)

Aggravation of pre-existing health conditions Some medical conditions (eg, acute low back pain) may be aggravated by exercise or may limit performance of an

Table 3. Proportion of exercises, by body part, falling within each of the physiotherapeutic assessment categories.

	Reprods physical stresses of VDT work	Stretches over-stretched structures	Places additional loads on discs	Poses one or more safety hazards	Health contra-indications
Neck	0.36	0.44	0.40	0.00	0.72
Shoulder	0.45	0.50	0.05	0.07	0.93
Elbow/Lower Arm	0.39	0.33	0.00	0.00	1.00
Lower Back/Hip	0.60	0.40	0.68	0.36	1.00
Knee/Lower Leg	0.06	0.00	0.23	0.41	0.82
All Exercises	0.40	0.38	0.26	0.15	0.90

exercise. These conditions are noted in the 'Comments' column of Table 1.

Replication/exacerbation of physical stresses associated with the task Some exercises reproduce or exacerbate postural or biomechanical demands of the job. Examples are exercises which stretch spinal muscles and ligaments already overstretched as a result of sitting for long periods in a fixed spinal posture, or wrist hyperextension-flexion exercises which may exacerbate the physical demands of keyboard work.

Safety/therapeutic/performance issues Exercises were also analysed for their potential to create a safety hazard when performed in an office setting (eg, use of mobile office furniture as props), or by certain populations of users (eg, obese or pregnant individuals). Additionally, it was noted when an exercise would be awkward or impossible to perform in typical women's office attire (eg, dress or skirt; high heels).

The usability of physiotherapeutic-safety judgements were arrived at by consensus among the authors. The authors first performed the evaluations individually, then met as a group to resolve any differences. (Each author's area of expertise is as follows: K Lee, biomechanics; N Swanson and S Sauter, office ergonomics; R Wickstrom, biomechanics and physical therapy (RPT); A Waikar, biomechanics; M. Mangum, exercise physiology.)

Results

Nature of the exercises

The exercises were rather unevenly distributed among the classified body parts: neck (n = 25), shoulder (n = 42), elbow/lower arm (n = 18), lower back/hip (n = 25) and knee/lower leg (n = 17). For the most part, the underlying objectives of the evaluated exercises were to relax or stretch chronically tense muscles, to increase flexibility or mobility, and to improve circulation.

Usability and physiotherapeutic assessments

Below is a summary of the usability and physiotherapeutic ratings for the exercises, organized according to targeted body part. The specific rating of each of the 127 exercises on all usability and physiotherapeutic dimensions is presented in Table 1. Tables 2 and 3 give the proportion of exercises receiving each rating within each usability/physiotherapeutic dimension (also organized according to targeted body part).

Implicit in our evaluation is the assumption that those exercises that are least conspicuous, disruptive and most easily performed (preferably at the work station) are most likely to be adopted in a typical office workplace. Our assessment of the utility of these exercises may vary somewhat depending upon employers' willingness to set aside special breaks and places for individual or group exercises by workers. However, even then, some workers may not perform the exercises because of embarrassment or difficulty in performance.

Neck exercises (Table 1, panel A)

Usability assessment There are 25 neck and upper-back exercises designed to offset problems that are very common to VDT operation such as stiffness or soreness associated with long-term shoulder retraction during data entry tasks. All exercises can be performed easily, 61% had good instructions, and all but two (1, 18) can be performed while seated. Approximately half (52%) of the exercises can be performed without significant disruption of the work routine, and most (92%) were judged to be fairly inconspicuous (ie, mimicked natural movements).

Physiotherapeutic assessment Some of the exercises may be somewhat uncomfortable or difficult to perform by individuals with acute neck pain, degenerative disc disease, osteoporosis, etc. Over one third (36%) of the exercises reproduced the physical stresses of VDT work, most further stretching muscles and ligaments which were already overstretched owing to sitting in a flexed spinal posture for long periods of time. Additionally, over one third (40%) of the exercises may place additional loads on already loaded cervical and thoracic discs.

Shoulder exercises (Table 1, panel B)

Usability assessment There are 42 shoulder exercises designed to stretch and relieve tension in the upper back and to enhance the range of motion of the shoulders. Over half (56%) of the exercises have good instructions and all but two exercises (38, 48) can be performed while seated. However, one third (36%) of the exercises are somewhat disruptive of work since they require several minutes to perform, and nearly half (45%) of the exercises were judged to be highly conspicuous. All but two exercises (43, 62) are simple to perform.

Physiotherapeutic assessment Most (88%) of the shoulder exercises may be contraindicated for individuals with acute inflammatory or arthritic conditions of the shoulder (see, for example, Figure 1 (a)). Nearly half (45%) of the exercises reproduce some of the physical stresses of VDT work, primarily in further stretching chronically stretched structures. Three exercises (46–48), all of which require the use of a chair as a prop, pose potential safety hazards because the required exercise movements may cause the chair to roll, or to tip backwards.

Elbow/lower arm exercises (Table 1, panel C)

Usability assessment There are 18 elbow/lower arm exercises, many designed to enhance the flexibility of the fingers and wrists. About half (53%) have good instructions, all can be performed while seated, and many (61%) can be performed without significant disruption of the work routine since they require only a few seconds to perform. Most (89%) of the exercises are inconspicuous or only moderately conspicuous. None are difficult to perform.

Physiotherapeutic assessment Most (83%) of the exercises may be problematic for individuals with hand/wrist disorders owing to the extreme postural angles

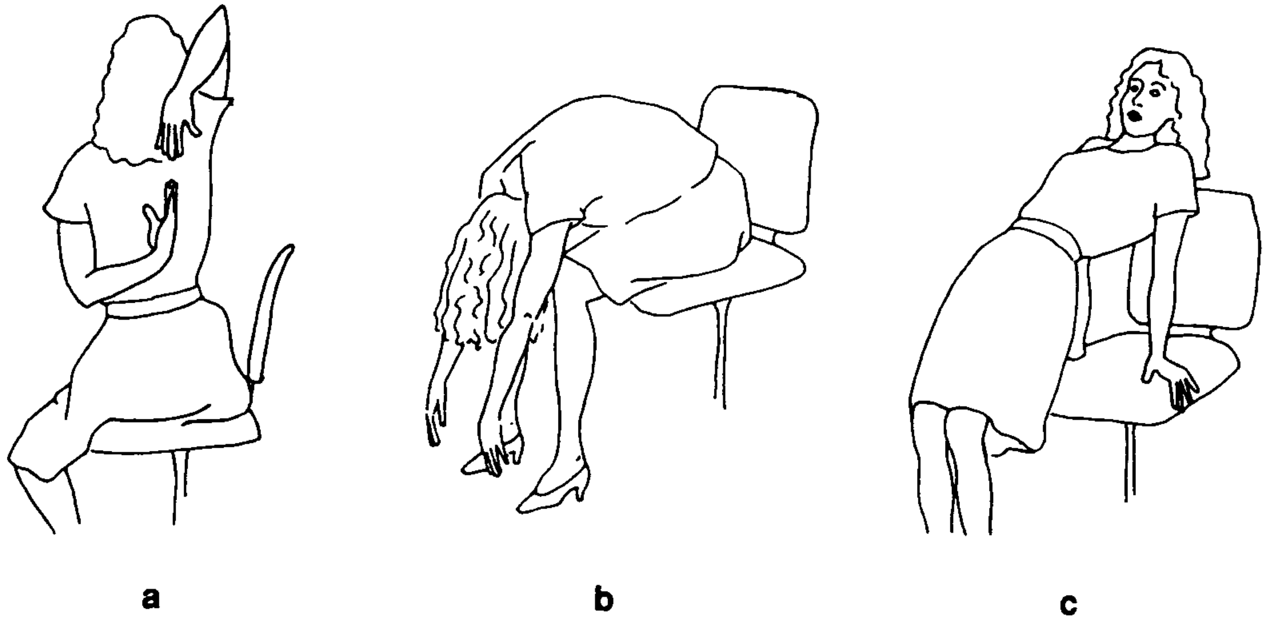

Figure 1 Examples of exercises which (a) had the potential to exacerbate existing health conditions, (b) replicated the stresses of VDT work, or (c) posed potential safety hazards

created in the performance of the exercises. For example, exercises 72–74 require that the wrist of one arm be manually hyperextended with the other hand. Additionally, most of the exercises may be contraindicated for individuals with arthritic conditions of the hands and wrist, and several others (76, 77, 81–83) may be contraindicated for those with lateral epicondylitis or inflammatory conditions of the shoulder. Additionally, three exercises (76, 77, 82) involve static arm extensions of some duration which may actually exacerbate the neck/shoulder strain arising from VDT work.

Lower back/hip exercises (Table 1, panel D)
Usability assessment There are 25 lower back/hip exercises designed mainly to stretch the muscles that act directly on the vertebral column (eg, the erector spinae), and also muscles that act as prime movers elsewhere, but impact on the vertebral column and lower back (eg, the hamstrings). The majority (78%) of the exercises had good instructions. However, many are potentially disruptive owing to time and posture requirements (standing, upper body movement). Nearly two thirds (60%) required a break of several minutes to perform, and 64% were judged to be highly conspicuous. Only four (92–95) were inconspicuous. Over one third (40%) of the exercises are moderately difficult or difficult to perform, especially for obese people, as these exercises involve touching the toes, or lifting the legs to the chest, from a seated position.

Physiotherapeutic assessment All of the exercises may be contraindicated for individuals with low back pain, degenerative disc disease or osteoporosis, or for women in the second or third trimesters of pregnancy, as extreme flexion or extension of the lumbar region is often required. A number of the exercises (60%) reproduce the physical stresses of VDT work, primarily in producing additional loads to the lumbar region (see Figure 1 (b)). Over one third (36%) of the exercises posed safety hazards owing to the potential for an office chair, which is used as a support, to roll while the exercise is being performed (see Figure 1 (c)). Additionally, four exercises (87–89, 96) would be difficult to perform in most women's semi-formal office attire.

Knee/lower leg exercises (Table 1, panel E)
Usability assessment There are 17 knee/lower leg exercises. The primary intent of these exercises is to stretch muscles and to offset poor circulation associated with prolonged sitting and constrained postures. Nearly three quarters (69%) of the exercises had good instructions. However, all would disrupt work to some extent since either minibreaks, a standing posture, or use of both hands is required. Over half of the exercises (53%) are highly conspicuous and 41% are moderately difficult or difficult to perform.

Physiotherapeutic assessment Over half of the exercises (64%) are contraindicated for individuals with arthritic conditions of the hips and/or knees. Additionally, exercises 111 and 113–15 create the potential for a fall if adequate support is not provided during performance, and eight exercises (111, 113–15, 119–121, 124) would be difficult or impossible to perform for individuals wearing high heels or typical women's office attire.

Discussion

In general, the results of this evaluation showed that a considerable number of exercises recommended for VDT users have some features which would facilitate their acceptance and performance in a typical office workplace. For example, the instructions for the majority of the exercises were clear, and most of the exercises were simple to perform.

The neck and elbow/lower arm exercises had the best overall evaluations on the five usability criteria. Most had clear instructions (58%), could be performed without leaving the chair (95%), were inconspicuous, or mimicked natural body movements (91%), could be performed in a brief period of time (56%), and were simple to perform (100%). On the other hand, the majority of the lower back/hip and knee/lower leg exercises were disruptive because they were highly conspicuous (58%) and/or required interruption of the work task to perform (ie, required standing posture or several minutes to perform). The shoulder exercises were intermediate in that they were judged positively on all the usability criteria except conspicuousness. A large number of the shoulder exercises (45%) were highly conspicuous, primarily because of the arm movements required.

Surprisingly, quite a high proportion (90%) of the exercises may be contraindicated for individuals with one or more acute or chronic musculoskeletal disorders, such as osteoporosis or lower back pain. Individuals with such conditions are advised to seek medical approval before performing these exercises. Of especial concern, however, was the finding that more than a third of the exercises (40%) appeared to reproduce or exacerbate some of the physical or biomechanical demands of VDT work, and that one out of seven exercises posed one or more safety hazards. The majority of these safety hazards were posed by the lower back/hip and knee/lower leg exercises. More than half (60%) of the back/hip exercises, and nearly half (45%) of the shoulder exercises, replicated the physical demands of VDT work, primarily through further stretching of already overstretched muscles of the spine and upper back.

Because the literature shows that musculoskeletal discomfort in VDT/clerical work is particularly acute for the back, neck and shoulder regions[27–29] it is especially important that exercises for these regions satisfy basic design requirements facilitating their performance in the office environment. The present findings are not very promising in this regard. Many of the shoulder and back exercises were highly conspicuous and disruptive of the work process, and thus may meet with resistance by workers. More worrying was the finding that more than a third of the back exercises appeared unsafe to perform, and a sizable number of the neck, shoulder and back exercises (36–60%) appeared to exacerbate, rather than counteract, the physical/biomechanical stresses of VDT work. Apparently, the development of many of these exercises has proceeded without sufficient appreciation for office biomechanical and safety concerns.

While usability and safety criteria should be considered when designing an exercise programme for VDT users, to be fully effective the exercises must additionally combat the full range of musculoskeletal stressors encountered in VDT work. These stressors, and thus the best combination of exercises, will vary to some extent according to the type of task performed. Table 1 was designed to present the results of our analysis in a manner which facilitates the selection of individual exercises for an exercise programme for VDT users. Following an analysis of the task to determine the muscles stressed by task demands, the "muscle groups" and "anatomical structures" columns of Table 1 can be consulted to select exercises to counteract these stressors. For example, Figure 2 illustrates a posture often assumed during VDT work. This posture results in chronically tensed muscles in the shoulders (ie, scapular elevators), forearms (ie, forearm flexors) and chest (ie, anterior thoracic muscles), as well as overstretched muscles of the back (ie, lumbar, thoracic and cervical regions). Table 1 can be consulted to identify exercises which stretch the chronically tensed muscles in the shoulders, forearms and chest, or contract the chronically stretched muscles of the back.

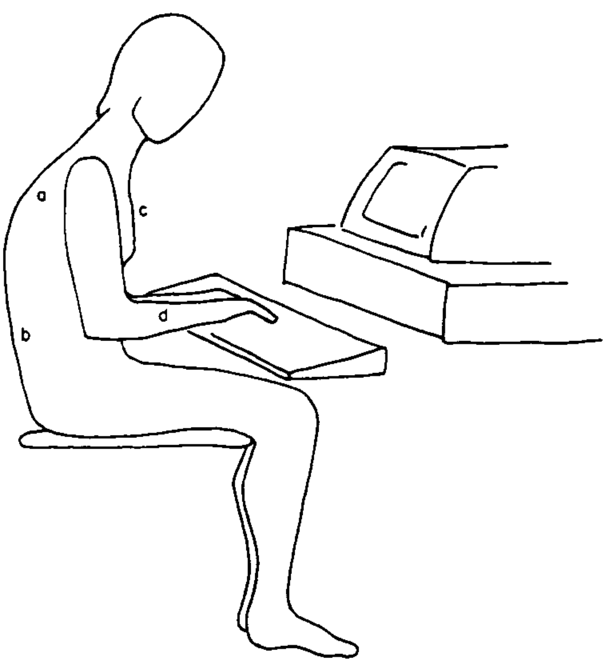

Figure 2 Muscle groups commonly requiring relaxation or activation after periods of continuous VDT work. (a) Chronically tensed scapular elevators require stretching and relaxation. (b) Spinal extensors of the lumbar, thoracic and cervical regions are overstretched and require activation. (c) Muscles of the anterior thoracic region are shortened and require stretching. (d) Forearm flexors are chronically tensed and shortened, and require stretching and relaxation

Regardless of the specific musculoskeletal stressors imposed by a particular VDT task, there are 'generic' stressors common to most VDT work (ie, constrained postures which impart static loads to the neck, back, shoulders and upper extremities, and which impair venous return from the lower extremities). To counteract these generic stressors, any exercise programme for VDT users should include the following components:

1 stretching of chronically shortened and tensed muscles to improve flexibility and circulation, and to reduce muscle fatigue;

2 mobilization of the spine to help relieve stress on the lower back muscles and reduce compressive forces at intervertebral discs;

3 strengthening or contraction of chronically stretched and weakened muscles to increase resistance to fatigue and discomfort, and to promote better posture;

4 improvement of venous return from lower extremities.

The exercise programmes evaluated here focused primarily on the first of these components (stretching/relaxation), and often failed to address the remainder adequately. There is some evidence that strengthening exercises may be more useful than flexibility/relaxation exercises in preventing musculoskeletal discomfort in VDT users[30]. However, such exercises are likely to be far more intrusive and demanding than flexibility or relaxation exercises, and require special employer-designated breaks and exercise areas.

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THE DESIGN OF REST BREAKS FOR VIDEO DISPLAY TERMINAL WORK: A REVIEW OF THE RELEVANT LITERATURE

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Recent studies have demonstrated a daily accumulation of eye and musculoskeletal strain in video display terminal (VDT) workers which is not eliminated by the use of high quality workstations or conventional rest break schedules (e.g., Zwahlen et al., 1984; Schleifer and Amick, 1988). These types of observations have prompted calls for limitations on the period of continuous VDT work. For example, the Swedish National Board of Occupational Safety and Health has suggested an upper limit of 1-2 hours of continuous VDT work. While the logic for such recommendations is substantial, there has been little empirical study of the effects of increased rest breaks, or shortened work periods, in VDT work. There is, however, an extensive literature on the design of rest break schedules in light, repetitive (industrial) work. This literature has been largely ignored in discussions regarding rest break design in VDT work, but is highly relevant since the tasks studied share common stress factors with VDT work (e.g., constrained static postures and the need for continuous attention).

Presented below is a synopsis of the literature on rest breaks in light, repetitive work and of the less developed literature specifically examining rest break effects in VDT/office work. This synopsis is organized in relation to the two main considerations in the design of rest breaks in VDT/office work: i.e., break frequency/duration and content.

BREAK FREQUENCY AND DURATION

Research by the (British) Industrial Fatigue Research Board (IFRB) was the first to demonstrate the benefits of increased rest breaks. Studies conducted by this group showed that productivity increased in assembly tasks when mid-morning and mid-afternoon rest breaks were introduced into the workday (Vernon and Bedford, 1924; Wyatt, 1927; Wyatt and Fraser, 1925). More recently, a study of clerical workers by Bhatia and Murrell (1969) found that 10-minute hourly breaks were favored by the workers, and produced greater productivity gains in comparison to more infrequent 15-minute breaks. Similar effects were shown in a VDT task by Horie et al. (1987). These findings are consistent with conventional wisdom that short, frequent breaks are preferable to longer, more infrequent breaks (Rohmert, 1973).

Additional support for hourly breaks is provided by studies of VDT work which indicate that single, mid-morning and mid-afternoon breaks may have negligible effects (Delvolve and Quennec, 1983; Schleifer and Amick, 1988; Zwahlen et al., 1984). Furthermore, a study by Floru et al. (1986) points to the efficacy of short, hourly breaks in routine VDT work. In this study, 5-minute breaks inserted after a 40-minute period of work were effective in eliminating performance decrements which normally occurred after that period.

Muscle fatigue studies suggest the need for even more frequent breaks in VDT work. VDT work is often characterized by constrained postures and static loads. Two studies (Waersted et al., 1986; Kogi, 1982) reported, respectively, sustained forces reaching 6 and 20 percent of maximum voluntary contraction (MVC) in keyboard tasks. However, data suggest that forces greater than 10 percent MVC cannot be sustained for more than 10-15 minutes without perceptions of fatigue (Bjorksten and Jonsson, 1977).

The need for short, frequent breaks in repetitive VDT work is also suggested by extrapolation from trends in VDT users' discomfort ratings over the workday. An algorithm (yet to be empirically tested) developed by Zwahlen and Adams (1987) predicts that six, 12-minute breaks will prevent musculoskeletal discomfort from exceeding the "quite-a-bit" threshold for 99 percent of the VDT population (for the repetitive task upon which the model was developed). Regarding the frequency of breaks, however, a cautionary note is in order. Too frequent breaks can interfere with work rhythms (Rohmert, 1973), and may increase costs due to disruptions in production.

It is sometimes advocated that workers be given self-discretion in the control of both break duration and frequency. However, the limited number of empirical studies in this area argue against this proposition. When breaks are self-regulated, there is a tendency to work beyond the appearance of performance decrements, or to terminate breaks before recovery is complete (Murrell, 1971; Henning, 1987).

BREAK CONTENT

Productivity gains have been shown when activity or task changes are substituted for rest breaks (Bennett et al., 1974; Miles and Skilbeck, 1944). More recently, attention has turned to the potential benefits of exercise during VDT work. While research in this area is limited, a number of studies suggest that exercises are valuable in reducing acute discomforts (Laporte, 1966; Lee and Humphreys, 1985; Winkel and Jorgensen, 1986) and possibly even chronic disorders (Ferguson and Duncan, 1976) associated with VDT work, or other keyboard work.

CONCLUSIONS

Although more research specific to VDT work and associated health outcomes is needed, the existing literature strongly suggests that frequent rest breaks would benefit both productivity and comfort in VDT work.

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Controlling Glare Problems in the VDT Work Environment

Lawrence M. Schleifer and Steven L. Sauter

The introduction of video display terminals may exacerbate lighting problems already present in the workplace. The sources and characteristics of glare are described. Glare control measures, including the location and design of lighting systems, managing outdoor light and using screen filters and hoods, are reviewed.

Many office workers enjoy using a video display terminal (VDT). This new office technology enables them to accomplish in a matter of seconds or minutes what may have formerly required several hours using a conventional typewriter or business machine. In addition to the promise of reduced effort and increased productivity, the use of a powerful computerized device such as a VDT can give office workers a renewed sense of importance and job satisfaction.

Along with the apparent advantages of using a VDT in office tasks, however, there are some difficulties. Particularly troublesome are lighting problems in the VDT workplace. For example, a bright overhead light fixture or sunlight streaming through an office window are potential sources of visual discomfort for the VDT user. Annoying reflections from the screen of the VDT are another common problem.

While lighting problems are often present even in traditional office environments, the introduction of the VDT has increased the potential for such problems. The purposes of this paper are to help the office worker understand the causes of glare and other lighting-related problems that may occur when VDTs are used, to explain the adverse effects of glare on vision and eye comfort, and to offer practical suggestions for preventing such problems.

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A Review of Related Research

A number of field investigations indicate that glare is a rather common problem in offices where VDTs are used on a regular basis. One of the first investigations indicating this problem was a 1974 Swedish study by Hultgren and Knave[1] showing that most of the operators surveyed complained of glare from windows and ceiling lights, and also reported eyestrain symptoms such as stinging and sore eyes.

> *". . . studies suggest a recurring pattern of discomfort from lighting problems in VDT workplaces."*

In a San Francisco study of VDTs undertaken by the National Institute for Occupational Safety and Health (NIOSH),[2,3] windows and light fixtures were found to be potential sources of glare at 46 of 53 workstations surveyed. Additionally, screen reflections from windows and overhead light sources were present at most of the workstations. A questionnaire survey of VDT users in these offices found that glare was one of the most common complaints, with 80 percent of the individuals reporting being bothered by glare at least occasionally.

Results from a NIOSH-funded study[4] by the University of Wisconsin of several hundred state government VDT users revealed that 67 percent were found to be bothered by screen glare at least occasionally. Screen glare was also found to be a significant predictor of visual discomfort.

In a study of 905 VDT users at New York State office facilities,[5] NIOSH investigators found that 31 percent of the survey participants rated lighting conditions as producing "much glare" and 42 percent were bothered by screen glare.

Overall, these studies suggest a recurring pattern of discomfort from lighting problems in VDT workplaces.

SOURCES OF GLARE PROBLEMS

Light Measurement

Lighting terms can be technical and confusing. It may therefore be helpful at the outset to provide a brief explanation of lighting concepts and terms. ***Illumination*** refers to the amount of light that falls on any surface, such as a desk, table, or document holder. It is usually illumination that is measured when the sufficiency of light in a room or office is assessed. Illumination is measured in units called footcandles (ft.c, English system) or Lux (Lx) in the metric system. One footcandle is approximately ten Lux.

Luminance refers to the amount of light emitted or reflected from any surface—for example, a light fixture, lampshade, or sheet of paper. It is the luminance of an object to which we are referring when we speak of the brightness of an object. Luminance is measured in foot-Lamberts (ft.L, English system) or candles per square meter (cd/m^2) in the metric system. One foot-Lambert equals approximately 3.5 cd/m^2. Note that simply increasing or decreasing the illumination in a room by adjusting the power of a light fixture will not necessarily affect the brightness of all objects in the room in the same way. If objects do not reflect much light (for example, a dark carpet) they will not appear very bright regardless of how much light falls upon them. The luminance of an object is determined by both the amount of light falling upon it and its reflectance (ability to reflect light).

Concept of Glare

Glare is produced by light sources within the field of vision that are of a higher luminance than other objects to which the eyes are adapted. Glare is experienced as a feeling of discomfort or annoyance, or as a reduced ability to discern objects in the visual environment. The latter effect is usually referred to as "disability glare," the former as "discomfort glare." The blinding effect of headlights from an oncoming automobile is a good example of disability glare. The annoying effect of headlight reflections in the rear view mirror is a good example of discomfort glare. Discomfort glare is the most common glare problem in the office environment. A light source cannot cause disability glare unless it is almost directly in a person's line of sight.

A distinction is usually made between "direct glare" from sunlight or a lighting fixture, and "indirect glare" due to reflections from a video screen or glossy surfaces such as a desk, floor, or keyboard. The extent to which direct or indirect glare is a problem depends primarily on the brightness of the light source and how close it is to the line of sight. The closer it is to the line of sight, the less bright it has to be to cause a problem.

Direct Glare

While sources of direct glare are present in any office environment, the presence and use of a video display terminal increase the likelihood of problems caused by direct glare. Instead of looking down at work materials on a desk, the VDT user gazes horizontally at the video screen. Thus direct glare sources such as overhead lights and windows are closer to the line of sight. (That is, they are more likely to be visible to the VDT user as he or she looks at the screen.) In addition, the amount of light required in a VDT work environment is generally somewhat less than that needed in a conventional office. VDTs do not require light from a direct source as does paper. On the contrary, the objective is to prevent light that can cause screen reflections or obscure the text that is displayed. With the eyes adjusted to a somewhat darkened workstation, extra caution is needed to ensure that other objects in the field of view (including the document from which the person is working) are no brighter than need be for adequate visibility, so that they do not glare.

As indicated, one potential source of direct glare in the VDT workplace is unshielded windows. In many cases the windows are left bare in order to supplement ambient lighting or to afford the worker a pleasant view. Unfortunately, the relatively high luminance of sunshine can produce considerable glare for the VDT user.

Another common source of direct glare is the overhead lighting fixtures (called luminaires). The type, location, and luminance of overhead fixtures are important factors to consider. Bright fixtures that are unshielded and located close to the line of sight of the VDT user are very likely to produce visual discomfort.

There are a number of mathematical formulas for quantifying glare levels. A detailed discussion of these formulas is beyond the scope of this article. It should be noted, however, that a purely physical approach to assessing glare or glare potential may not be adequate. Factors such as individual motivation and interest in the task seem to play an important role in whether or not glare is reported.

Indirect or Reflected Glare

Indirect glare (reflection) is probably the most common lighting-related problem for VDT users. Indirect glare occurs when light from bright objects such as light fixtures is reflected from smooth or glossy surfaces, such as highly polished floors, table tops, or VDT screens, into the eyes of the VDT user.

Reflected glare from the VDT screen can be in the form of either a "specular" or a "diffuse" reflection. A specular reflection is a mirror-like reflection in which a sharp image such as the keyboard is reflected from the screen back to the operator. Specular reflections are caused by light from an object reflecting off the smooth glass surface of a VDT screen.

The fact that the VDT screen is slightly convex means that troublesome reflections can result from objects at wide angles to the screen. The common practice of tilting the VDT slightly backwards increases the opportunity for bright reflections from ceiling fixtures.

Diffuse screen reflections do not result from light reflected from the front glass surface of the VDT, but rather from light that penetrates the glass and is reflected off the phosphor layer behind the glass. (It is the phosphor that glows to produce the VDT image.) Because the phosphor layer is rather rough, light is scattered as it reflects back to the operator. No clear reflected image can be seen. Rather, when light is reflected off the VDT, the background of the VDT image simply appears brighter. Diffuse reflections are sometimes called "veiling" reflections because when they occur it appears that a veil of light is cast over the image.

> ***"Indirect glare (reflection) is probably the most common lighting-related problem for VDT users."***

Screen reflections can be disturbing to the VDT user for two reasons. First, a specular reflection can be simply annoying. More commonly, both specular and diffuse screen reflections reduce the contrast in brightness between the characters appearing on the screen and the screen background. That is, light reflected from the screen washes out the characters and makes them difficult to see.

Beyond the VDT screen, there are numerous other surfaces in any office that can reflect glare, including walls, floors, worktables, the document from which one is working, and the stand on which the document is placed. However, the major source of reflected glare in the VDT workplace is the VDT screen.

Glare Sensitivity and VDT User Characteristics

In general, older individuals require more light to see clearly. But increasing the amount of light in the environment increases the opportunity for glare or reflections. Compounding the problem is the increased scattering of light that occurs in the eye of older persons, making glare sources more intolerable. Hence, extra care must be taken in the design of lighting systems in VDT workplaces for older VDT users to provide sufficient light yet prevent glare.

GLARE CONTROL MEASURES

Lighting System Design

There are a number of concrete actions that can be taken to prevent or alleviate problems with glare or reflection. The most desirable means of controlling glare is through proper design of ambient lighting systems. In this regard, the design, location, and amount of light produced by overhead fixtures are critical. In general, the potential for glare and reflection problems is minimized by reducing the level of ambient illumination. While there are no hard and fast rules for specific lighting levels, maintaining the level of light within a range of 200 to 500 Lux should help control reflection and still ensure sufficient light to perform most office tasks. However, as the level of light falls below 500 Lux, supplemental lighting of documents at the VDT workstation may be necessary.

It is helpful to cover the bulbs of overhead fixtures with diffusing lenses, thereby scattering the light and preventing sharp glare sources. However, the lenses most commonly used for this purpose do little to prevent light from reaching the eye or VDT screen. To the extent possible, the fixture should be designed so that it does not project light horizontally into the VDT screen or eye of the operator. Therefore it is preferable to use "baffles" or "parabolic louvers" (which are fitted below fluorescent fixtures) rather than diffusing lenses since the former direct most of the light downward.

The use of indirect lighting systems eliminates the sources of concentrated glare, but the wide reflections off the walls and ceilings can result in stray light reaching the VDT and causing diffuse reflections from the screen. Therefore, it is also important that highly reflective (that is, bright, glossy) surfaces be minimized in the VDT workplace.

Overhead lights should always be positioned so that they are not in the user's field of vision as he or she gazes at the screen. In addition, placement of a lighting fixture directly behind or above the workstation also should be avoided since light may then reflect off the screen or desk top into the VDT user's eyes. A better placement is off to one side of the workstation and as high as possible.

Windows

While many people prefer natural light over artificial light, excessive reliance on windows for office lighting can create problems. If the intensity and angle of sunlight coming through an unguarded office window is not controlled, it is likely that troublesome glare and reflection will result. There are a number of steps, short of removing the windows, that can help minimize these problems. Office windows can be equipped with blinds, drapes, or other shielding devices that control the flow of sunlight. The blinds or drapes should be easy to operate. Several small sections of drapes or blinds are preferable to fewer larger units because the former can more readily accommodate the varying lighting needs and preferences of all the people in the room. Vertical blinds are especially useful since they can be adjusted to prevent light from reaching one workstation while allowing someone else to see out.

VDT Workstation Placement

Proper placement and orientation of the video display unit is one of the simplest ways to reduce glare and reflection. As mentioned, the display unit should be positioned so that no source of bright light will enter directly into a VDT user's line of vision as he gazes at the screen. For example, where windows are present the video display unit should be placed so that the user's line of sight is parallel to the window pane (in other words, the VDT screen is perpendicular to the window). Also, a VDT should be placed so that the path of the user's gaze is parallel to and between rows of overhead fixtures. Screen reflections from any light fixtures directly behind the workstation can be minimized by tilting the display unit downward (or slightly toward) the operator. Finally, the use of office dividers or other types of barriers placed around the VDT workstation can help reduce direct and indirect glare.

> ***"Filters placed in front of the VDT screen can be very effective in controlling reflections from the screen."***

Screen Filters

Filters placed in front of the VDT screen can be very effective in controlling reflections from the screen. One very common type of filter is the "neutral density filter." This filter reduces reflections from the screen phosphor (which are diffuse reflections) by filtering the light as it passes through the filter on the way to screen, and again as the reflected light passes back through the filter toward the operator. Though light from the glowing phosphor also passes through the filter, the image should be easier to see than the reflected light, since the reflected light is filtered twice and the light from the text on the screen is filtered only once. Hence, use of this filter should actually make the text look brighter against the screen background.

On the other hand, the neutral density filter is not effective in controlling specular reflections from the glass surface of the screen faceplate. Such reflections can be reduced by etching the surface of the faceplate or by coating it with a substance that absorbs the light causing the reflection. Neutral density filters are commonly etched or treated in this way, and thus can be highly effective against both specular and diffuse reflections.

One common filter, called a "micro-mesh" filter, helps control both specular and diffuse reflections. This type of filter is comprised of a mesh or honeycomb of nylon fibers that prevent ambient light coming toward the display at a wide angle from passing through to the VDT screen, and thereby reduce bothersome reflections. However, by the same principle, the mesh gridwork can also diminish the legibility of characters on the screen when it is viewed at an angle.

Another type of filter that is highly effective in reducing specular and diffuse reflections is the

"Another simple way to reduce reflection is to place a hood around the screen."

"circular polarizing" filter. The function of this type of filter is difficult to explain in a few words. Suffice it to say that it blocks light in a fashion somewhat similar to the way in which polaroid sunglasses work.

Unfortunately, all filters and screen treatments have drawbacks. Screen or filter coatings can be scratched and produce reflections from finger smudges. Etched surfaces can make characters a bit blurry. Filters that block reflections from the screen also dim the characters a bit. Careful trial and error is a good means of selecting a filter. Many variations of these types of filter are available. The best solution will depend a great deal upon the particular glare problems in a specific workplace.

Hoods

Another simple way to reduce reflection is to place a hood around the screen. Hoods can range from makeshift cardboard flaps to commercially-available devices that attach to the top and sides of the screen. One problem in using a hood is that it may cast shadows on the screen. Also, the hood must be installed in such a way that it does not require the VDT user to adopt an awkward posture when sitting at the terminal.

CONCLUSION

In most places where VDTs are in use, steps will need to be taken to bring glare and reflection problems under control. Many of the control measures described here may be necessary; the most appropriate steps will vary from situation to situation. Do not rely upon any solution or complement of solutions until it is tested in a specific workplace and found effective.

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Part II

NIOSH Bibliography on Video Display Terminals

A. NIOSH-AUTHORED DOCUMENTS

1. NUMBERED PUBLICATIONS

NIOSH numbered publications document the results of NIOSH research. Included in this category are Criteria Documents, Current Intelligence Bulletins, Alerts, Health and Safety Guides, technical reports of scientific investigations, compilations of data, work-related booklets, symposium and conference proceedings, and NIOSH administrative and management reports. The following numbered publications on video display terminals (VDTs) are listed alphabetically by title.

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(Full text included in Part I.)

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2. TESTIMONY

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3. JOURNAL ARTICLES, BOOK CHAPTERS, and PROCEEDINGS

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4. HEALTH HAZARD EVALUATIONS (HHE)

HHE reports are the results of requests from employees, employee representatives, or employers to NIOSH to determine if a hazard exists in the workplace. Each report examines conditions at a specific worksite(s). HHE reports can also be designated as hazard evaluation and technical assistance (HETA) reports, government hazard evaluations (GHE), mining hazard evaluations (MHE), or technical assistance (TA) reports. The following HHE reports on VDTs are list alphabetically by company or agency name.

Appalachian Laboratory for Occupational Safety and Health, Morgantown, WV, April 1983.
GHE No. 81-429-1299. 29 pp.
NTIS NO: PB84-210822 A03

AT&T, Southern Bell and United Telephone, NC, May 1986.
HETA No. 85-452-1698. 17 pp.
NTIS NO: PB87-105458 A03

Baltimore Sun, Baltimore, MD, July 1983.
HETA No. 80-127-1337. 164 pp.
NTIS NO: PB94-207776 A08

Blue Cross of Northern California, Oakland, CA, March 1983.
HETA No. 82-247-1280. 12 pp.
NTIS NO: PB84-210400 A03

Blue Shield of California, San Francisco, CA, January 1980.
TA No. 79-060-843. 64 pp.
NTIS NO: PB84-242775 A04

British Airways, Kennedy Airport, Jamaica, NY, August 1983.
HETA No. 82-100-1349. 14 pp.
NTIS NO: PB85-163400 A03

Environmental Protection Agency, Cincinnati, OH, December 1985.
HETA No. 83-463-1642. 36 pp.
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General Telephone Company of Michigan, Alma, MI, July 1985.
HETA No. 84-297-1609. 19 pp.
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Lexington Herald-Leader, Lexington, KY, October 1980.
TA No. 80-105-757. 10 pp.
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Library of Congress, Washington, DC, March 1992.
HETA: 91-070-2194. 25 pp.
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Los Angeles Times, Los Angeles, CA, January 1993.
HETA: 90-013-2277. 126 pp.
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TA No. 78-000-039. 13 pp.
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Narragansett Electric Company, Providence, RI, October 1981.
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HETA No. 80-146-1044. 20 pp.
NTIS NO: PB83-201699 A03

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HETA No. 89-250-2046. 76 pp.
NTIS NO: PB91-116251 A05

North Clackamas School, District No. 12, Milwaukie, OR, July 1983.
HETA No. 83-014-1343. 14 pp.
NTIS NO: PB85-102903 A03

Oakland Tribune, San Francisco, CA, 1980.
TA No. 79-061-844. 56 pp.
NTIS NO: PB84-241801 A04

Ruan Transport Corporation, Des Moines, IA, January 1986.
HETA No. 85-434-1655. 17 pp.
NTIS NO: PB86-221595 A03

San Francisco Newspaper Agency, Chronicle and Examiner, San Francisco, CA, January 1980.
TA No. 79-062-845. 68 pp.
NTIS NO: PB82-172164 A04

Social Security Administration, Baltimore, MD, January 1983.
HETA No. 82-329-1246. 26 pp.
NTIS NO: PB84-173822 A03

Social Security Administration, Teleservice Centers, Boston, MA and Fort Lauderdale, FL, September 1994.
HETA: 92-0382-2450. 25 pp.
NTIS NO: PB95-169868 A03

Southern Bell, Atlanta, GA, August 1984.
HETA No. 83-329-1498. 21 pp.
NTIS NO: PB85-208379 A03

St. Louis Post-Dispatch, St. Louis MO, February 1994.
HETA 93-0969-2389. 18 pp.
NTIS NO: PB94-171873 A03

U.S. West Communications, Phoenix, AZ; Minneapolis, MN; and Denver, CO; July 1992.
HETA 89-299-2230. 61 pp.
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United Airlines Corp., San Francisco, CA, June 1975.
HHE No. 74-116-202. 16 pp.
NTIS NO: PB-249382 A03

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HETA No. 89-069-2036. 38 pp.
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5. MISCELLANEOUS REPORTS

Miscellaneous reports include all other NIOSH-authored documents not included in the previous four sections.

Arndt R, Sauter S, Dainoff M, Helander M, Kromer K, Snyder H, Schleifer L, Smith M [1984]. Health issues - video display terminals. 64 pp.
NTIS NO: PB88-126115 A04

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NTIS NO: PB87-163416 A06

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NTIS NO: PB85-219335 A02

Schleifer L, Burg J, Hicks K [1985]. Questionnaire survey of VDT operators at the New York State Departments of Motor Vehicle and Taxation and Finance. 28 pp.
NTIS NO: PB86-111242 A03
[For companion report, see citation in Contract reports.]

Schnorr T, Grajewski B, Hornung R, Thun M, Egeland G, Murray W, Conover D, Halperin W [1991]. Investigation of spontaneous abortion among video display terminal users, final report. 24 pp.
NTIS NO: PB91-189209 A03
[For published version of this report, see 1991 journal article by Schnorr et al.]

Smith M [1983]. Psychological stress due to computerized office technology. 18 pp.
NTIS NO: PB89-165062 A03

Smith M [1984]. A review of NIOSH ergonomics VDT research. 22 pp.
NTIS NO: PB89-165112 A03

B. NIOSH-FUNDED DOCUMENTS

1. GRANT and COOPERATIVE AGREEMENT REPORTS

Grant and cooperative agreement (CA) reports are generated primarily from an agreement between NIOSH and a non-governmental organization. They typically describe scientific research conducted by that organization and funded by NIOSH. Grant and CA reports, listed below in alphabetical order by author, may be published either as final reports available from NTIS or as journal articles. For the former, NTIS ordering information is shown; for the latter, bibliographic information is provided to permit retrieval from public or university libraries.

Barr AE [1997]. Effect of VDT mouse design on task and musculoskeletal performance.
Grant No. R03-OH-03260. 5 pp.
NTIS NO: PB97-206239 A01

Barr AE, Ozkaya N, Nordin M, Lee E [1996]. Effect of mouse design on CTD risk and user skill.
Grant No. R03-OH-03260. 4 pp.
NTIS NO: PB97-206254 A01

Emurian HH [1991]. Stress effects of human-computer interactions.
Grant No. R01-OH-02614. 58 pp.
NTIS NO: PB92-136001 A04

Gerr F, Marcus M, Ortiz D [1996]. Methodological limitations in the study of video display terminal use and upper extremity musculoskeletal disorders. American Journal of Industrial Medicine *29*(6):649-656.
Grant No. R01-OH-03160

Marklin RW, Simoneau GG, Monroe J [1997]. An ergonomics study of alternative keyboard designs.
Grant No. R03-OH-03184. 186 pp.
NTIS NO: PB97-206395 A10

McAbee RR, Gallucci BJ, Checkoway H [1993]. Adverse reproductive outcomes and occupational exposures among nurses. An investigation of multiple hazardous exposures. AAOHN Journal *41*(3):110-118.
Grant No. T15-OH-07087

Morgenstern H, Graves M, Kelsh MA [1994]. Occupational epidemiology of carpal tunnel syndrome.
Grant No. R03-OH-02765. 134 pp.
NTIS NO. PB95-269866 A08

Ortiz DJ, Marcus M, Gerr F, Jones W, Cohen S [1997]. Measurement variability in upper extremity posture among VDT users. Applied Ergonomics *28*(2):139-143.
Grant No. R01-OH-03160

Pastore LM, Hertz-Picciotto I, Beaumont JJ [1997]. Risk of stillbirth from occupational and residential exposures. Occupational and Environmental Medicine *54*(7):511-518.
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2. CONTRACT REPORTS

Contract reports are generated primarily from a contractual agreement between NIOSH and a non-governmental organization. They typically describe scientific research contracted and paid for by NIOSH and conducted by that organization.

Guy AW [1987]. Measurement and analysis of electromagnetic field emissions from 24 video display terminals in American Telephone and Telegraph office, Washington, D.C.
Purchase Order No. 85-35744. 40 pp.
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Hurlebaus A, Posner S, Johnson B [1985]. The occupational health implications of video display terminals: a bibliography, 1981-1985.
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NTIS NO: PB91-130500 A13
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Salvendy G [1981]. Proceedings of the international conference on machine-pacing and occupational stress.
Contract No. 210-80-0002. 480 pp.
NTIS NO: PB84-180785 A22

Sauter SI, Gottlieb MS, Jones KC, Dodson VN, Rohrer KM [1983]. Job and health implications of VDT use: initial results of the Wisconsin - NIOSH study. Communications of the Association for Computing Machinery *26*(4):284-294.
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Sauter S, Gottlieb, Rohrer K, Dodson V [1983]. The well-being of video display terminal users, exploratory study.
Contract No. 210-79-0034. 261 pp.
NTIS NO: PB84-240449 A12

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