Video Display Terminals:
Radiation Issues

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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.

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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

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

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 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	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

OCCUPATIONAL MEDICINE: State of the Art Reviews—
Vol. 14, No. 1, January–March 1999. Philadelphia, Hanley & Belfus, Inc.

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.

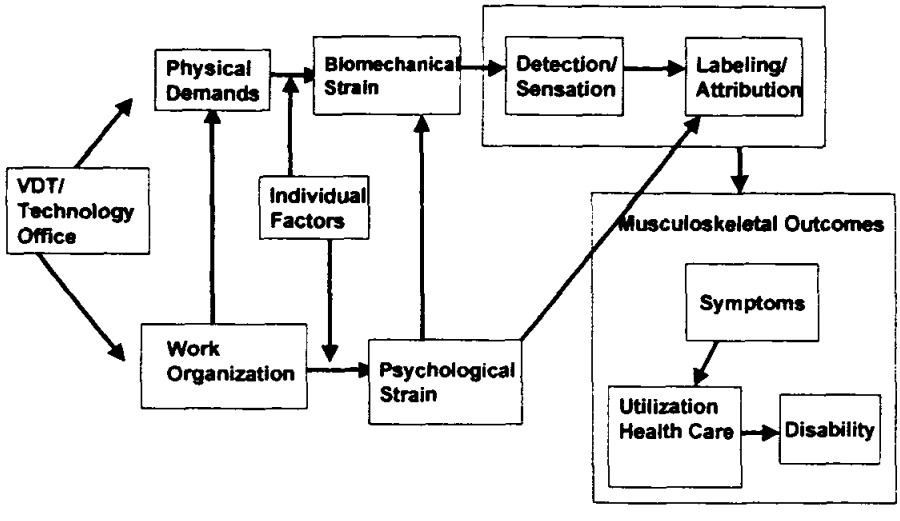

FIGURE 1. Model describing the paths from office technology to musculoskeletal outcomes. (Adapted from Sauter SL, Swanson NG: An ecological model of musculoskeletal disorders in office work. In Moon S, Sauter SL (eds): Beyond Biomechanics: Psychosocial Aspects of Musculoskeletal Disorders in Office Work.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

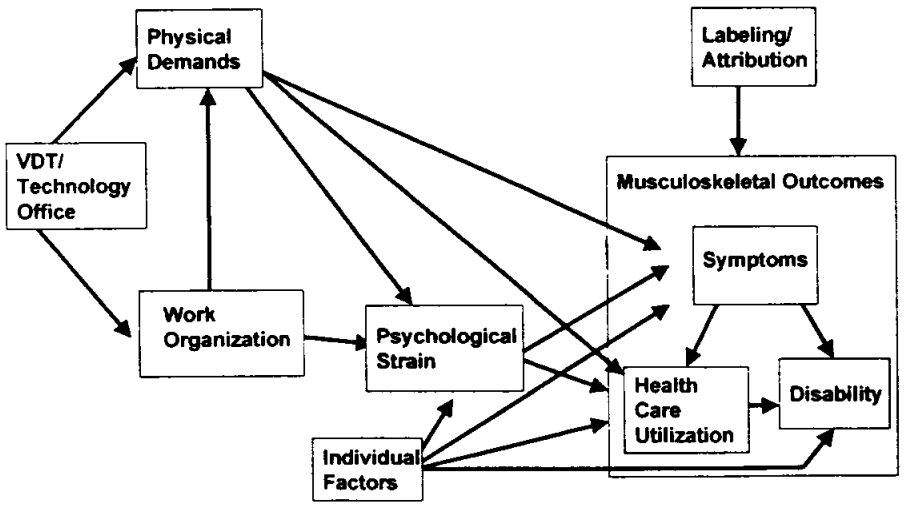

FIGURE 2. Modified model describing the analytic paths from office technology to musculoskeletal outcomes.

- 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

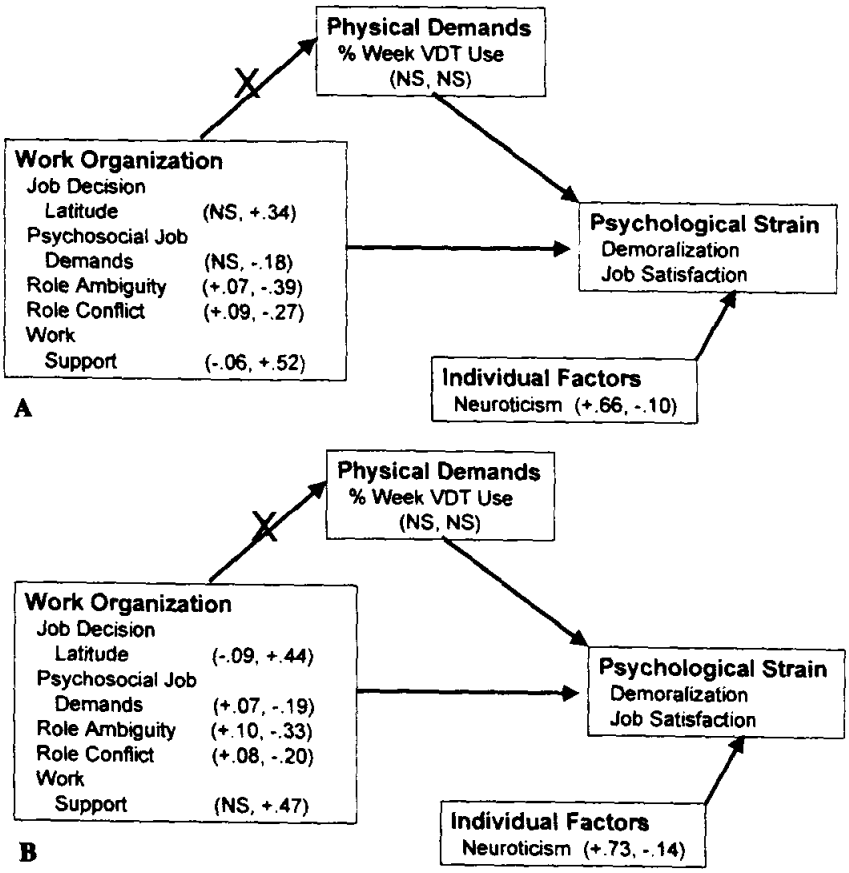

FIGURE 3. Paths from office technology to psychological strain outcomes. **A**, For men (n = 439). **B**, For women (n = 249). Path coefficients for demoralization and satisfaction are in parentheses. X = no significant effects for specified path, VDT = video display terminal, NS = not significant.

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

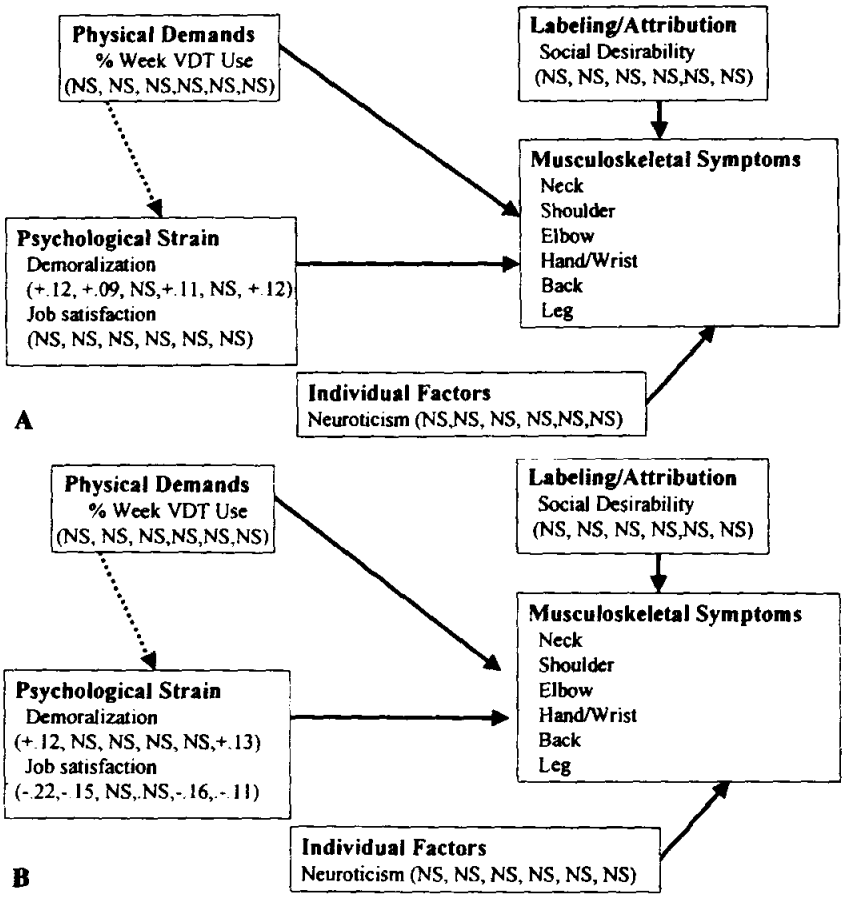

FIGURE 4. Paths from physical demands and psychological strains to musculoskeletal symptom/duration outcomes. **A**, For men (n = 439). **B**, For women (n = 249). The path coefficients (in parentheses) from left to right are for each musculoskeletal region from neck to leg. Dashed arrow = a path whose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

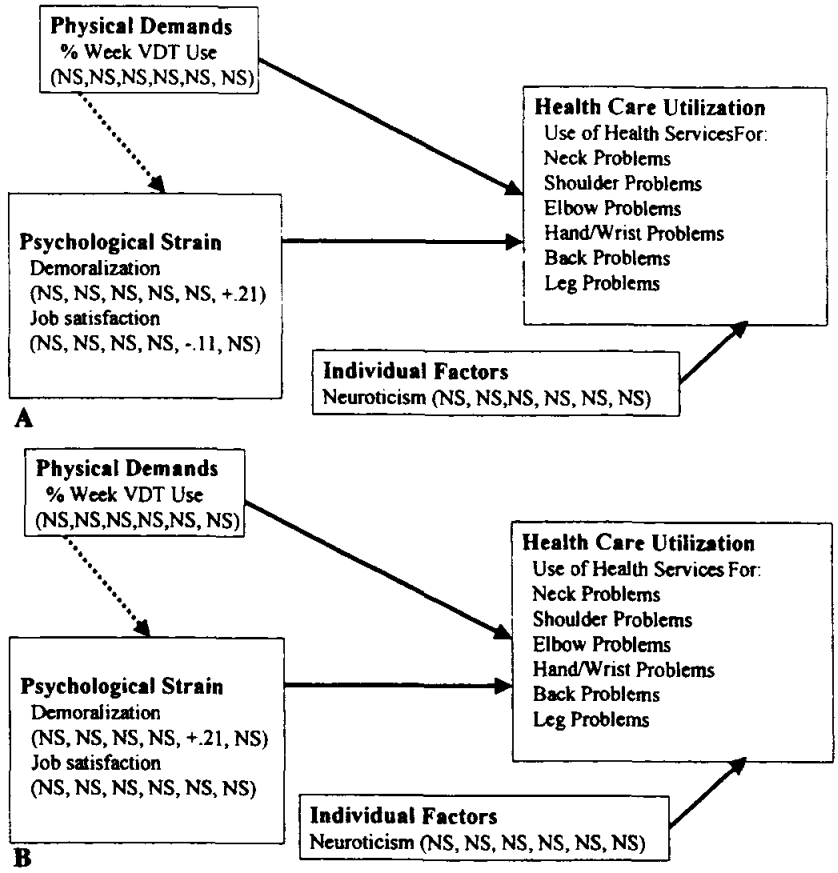

FIGURE 5. Paths from physical demands and psychological strains to health care utilization outcomes due to musculoskeletal injuries. **A**, For men (n = 439). **B**, For women (n = 249). The path coefficients (in parentheses) from left to right are for each musculoskeletal region from neck to leg. Dashed 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 ($\beta = 0.061$, $p = 0.253$).

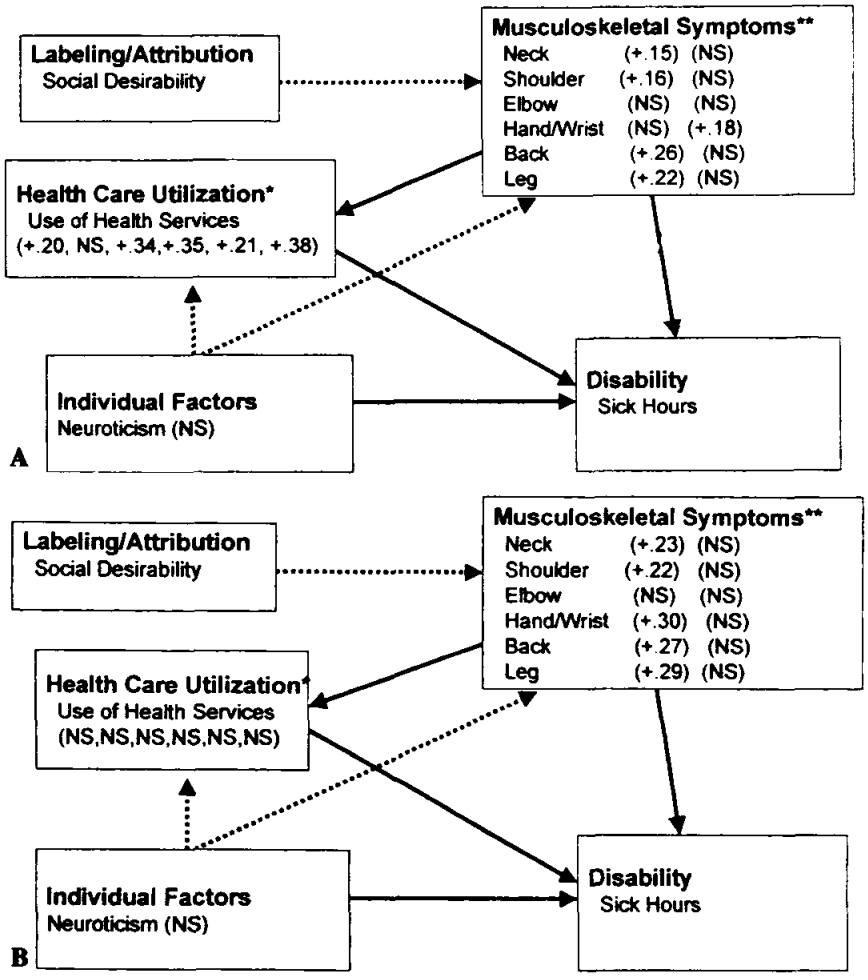

FIGURE 6. Paths from musculoskeletal symptom/duration and health care utilization to disability. **A**, For men (n = 439). **B**, For women (n = 249). * The path coefficients correspond to the unique effect of each musculoskeletal region on sick hours. ** The first column of path coefficients corresponds 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.

ACKNOWLEDGEMENT

The authors wish to thank the Office Ergonomics Research Committee, the National Institute for Occupational Safety and Health, and the National Institute for Aging for support in preparing this chapter.

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