

# Methodological Limitations in the Study of Video Display Terminal Use and Upper Extremity Musculoskeletal Disorders

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*Upper extremity musculoskeletal disorders may occur as a result of work with keyboard-equipped video display terminals. Many studies of the associations between keyboard use and upper extremity disorders have appeared in both the human factors and occupational epidemiologic literature. Methodological limitations and inconsistent results have limited conclusions that can be made from these studies, however. Although exposure conditions can be carefully controlled, human factors studies are limited by relatively small sample sizes, short exposure durations, and reliance on outcome measures with unknown relevance to chronic adverse health effects. Epidemiologic studies have been limited by poor ascertainment of both exposure and health outcome. Many have failed to control for any potential confounding. An almost exclusive reliance on cross-sectional study designs has resulted in possible bias from selective survival, exposure-effect reversal, and poor estimates of exposures occurring prior to development of the disorder. Given the inconsistency in the literature and the growing controversy surrounding this issue, prospective study of this question using objective methods for assessment of exposure and health outcome is recommended. This design allows identification of incident cases and minimizes bias from selective survival. In addition, ergonomic and psychosocial variables prior to onset of symptoms can be ascertained periodically. Given estimates for up to 100 million video display terminals to be in use in the United States by the year 2000, clarification of the health effects of their use is critical.*

## INTRODUCTION

Upper extremity musculoskeletal disorders (UEMSDs) are painful conditions affecting tendons, tendon sheaths, muscles, nerves, bursae, and blood vessels of the hands, arms, shoulders, and neck. Examples of specific UEMSDs frequently considered to be work related include carpal tunnel syndrome, tendonitis of the hand and wrist, epicondylitis, and certain shoulder and neck disorders [Gerr et al., 1991; Kasdan, 1991]. Considerable and growing concern

exists in both the lay and scientific communities that video display terminals (VDTs) may place users at increased risk of UEMSDs [Horowitz, 1992; World Health Organization (WHO), 1987]. At this time, an estimated 70 million or more video display-equipped word processing or data entry terminals are in use in the United States alone [Council on Scientific Affairs, 1987]. By the year 2000, 100 million VDTs are projected to be in use. Because exposure to these devices is very common, even relatively small risks associated with their use would have important public health implications. Concern over health effects of use of VDTs has led several municipalities, including New York and San Francisco, to recently introduce legislation intended to safeguard workers who use them.

The relationship between VDT use and UEMSDs has been examined in both human factors laboratory-based studies and observational epidemiologic field studies. However, methodological limitations and inconsistent results

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have led to controversy as to whether use of VDTs increases the risk of UEMSDs. We review here the limitations in methodology in both human factors and epidemiologic studies that may have contributed to inconsistent results and make recommendations for future studies. One of these limitations, the use of proxy or surrogate measures of the health outcomes of interest (UEMSDs), is especially relevant to investigators performing occupational outcomes research.

## HUMAN FACTORS STUDIES

Human factors investigations of keyboard use have been published for almost 70 years [Kroemer, 1972]. In a major review, Kroemer [1972] described time and motion investigation by Klockenberg, published in German in 1926, in which postures usually assumed by typewriter keyboard operators were described as "unnatural, uncomfortable, and fatiguing." Human factors studies of keyboard-intensive tasks are typically performed in a laboratory setting under controlled conditions. Outcomes of interest may include keying speed, error rate, subjective ratings of comfort, and objective measures of muscle activity using surface electromyographic recording. Human factors studies have been frequently used to challenge the safety of conventional word processing and data entry keyboards. However, limitations of these studies include small numbers of subjects studied, short-term exposures under laboratory conditions, and the unknown validity of short-term outcomes as predictors of chronic health effects.

With few exceptions, most human factors investigations of the health effects of alphanumeric keyboard use were performed with small sample sizes. For example, many recent published studies were performed with 12 or fewer subjects [Hagberg and Sundelin, 1986; Bendix and Jessen, 1986; Emmons and Hirsch, 1982; Rempel and Gerson, 1991; Guggenbuhl and Krueger, 1990]. In one study, three participating subjects were each enrolled in different experimental protocols [Zipp et al., 1983]. Essentially, in that study, the sample size for each "experimental" protocol was one subject. A few studies have been performed with larger samples including 135 [Lundervold, 1951] and 51 subjects [Nakaseko et al., 1985]. Studies of this size are uncommon in this literature, however. Studies of small sample size present difficulty with statistical power as well as stability and generalizability of results.

The exposure durations typically used in laboratory-based human factors investigations are quite short. At least one study in which subjects were exposed for only 3 min per experimental trial has been reported [Guggenbuhl and Krueger, 1990]. Exposure periods of 15 min or less are reported commonly [Weber et al., 1984; Bendix and Jessen, 1986; Emmons and Hirsch, 1982; Rempel and Gerson, 1991; Rodbard and Weiss, 1977]. No human factors investigations of keyboard use were found that used an exposure

duration greater than 5 hr [Hagberg and Sundelin, 1986]. Effects observed following short-term exposure to experimental conditions may be of limited relevance to those occurring after long-term exposure to actual "real-world" work conditions.

Because chronic health effects cannot, by definition, occur during or immediately after a short-term exposure, alternate measures of effect must be used. Health outcomes used in laboratory-based human factors investigations of keyboard use have included key rate, error rate, operator preference [Emmons and Hirsch, 1982], discomfort, and electromyographic recordings of motor unit activity [Nakaseko et al., 1985; Zipp et al., 1983; Lundervold, 1951; Hagberg and Sundelin, 1986; Bendix and Jessen, 1986; Guggenbuhl and Krueger, 1990; Erdelyi et al., 1988]. Although these short-term outcomes are of interest, they are of unknown value for predicting chronic health effects among VDT operators.

Human factors investigations have led to various recommendations for keyboard height, break schedules, work postures, and other parameters under control of workstation designers or those responsible for the organization of work. Such recommendations may result in improvement in comfort, reduced muscle activity, and greater productivity in certain settings. However, because the exposure conditions are laboratory based, and both exposure and health outcome are short term, the relevance of the results of such studies for identification of risk factors for chronic health effects in the computerized office environment is unclear. These studies may best be used to identify risk factors of interest to be evaluated in observational epidemiologic studies of individuals using VDTs during their usual employment.

## EPIDEMIOLOGIC STUDIES

Although more than a dozen epidemiologic studies have explored the relationship between use of VDTs and occurrence of upper extremity musculoskeletal symptoms or UEMSDs, inconsistent results have led to considerable controversy as to whether use of VDTs increases the risk of musculoskeletal symptoms or disorders. Many studies have not found an increased risk associated with VDT use. Furthermore, many of the studies that have found an increased risk for VDT users did not find this risk to be related to the duration of VDT use nor the extent of current VDT use.

The difficulty in interpreting the literature in this field can be traced to the limitations in research methodology. Specifically, poor measurement of exposure and health outcome as well as neglect of potentially confounding variables are common. The nearly exclusive reliance on cross-sectional study designs has led to sample distortion bias due to selective survival and ambiguities in temporal sequence of "exposure" and "outcome." In the following review,

we illustrate the methodological limitations of the existing literature and make recommendations for future studies.

## DEFINITION OF EXPOSURE

Many studies of VDT operators have utilized relatively crude measures of exposure, such as self-reported hours per day of VDT work, total years of VDT use, or even simple dichotomization of VDT exposure (i.e., VDT user or VDT nonuser). However, VDT use, per se, may be a poor measure of the etiologically relevant exposure. If the musculoskeletal problems found among VDT users are due to adverse biomechanical conditions associated with their use, then exposures of greater relevance may include the ergonomic characteristics of the workstation, the worker's posture while using the VDT, the rate of keying, and the force used to depress the keys. If one allows the variable VDT use to represent the wide range of biomechanical circumstances of VDT users, many VDT users will be misclassified with respect to exposure. This will weaken observed associations between exposure and adverse health outcome and dilute any true effect that adverse biomechanical circumstances might have among that subgroup of VDT users.

For example, in a study of newspaper and related workers, Smith et al. [1981] categorized subjects as "professional VDT users," "clerical VDT users," and "clerical non-VDT users." No other means of characterizing ergonomic exposure was used. When clerical VDT workers were compared to clerical non-VDT workers, a significantly larger proportion of clerical VDT workers reported upper extremity musculoskeletal symptoms. However, when professional VDT users were compared to clerical non-VDT users, the only difference found was that professional VDT users were significantly less likely to report "pain down arm." These results suggest that factors in addition to "VDT use" may be important contributors to risk.

Stellman et al. [1987] performed a cross-sectional questionnaire study of 1,032 female office clerical workers with a wide range of VDT use. However, VDT exposure was categorized as full-time, part-time, and non-VDT only. Full-time VDT users reported significantly more musculoskeletal symptoms than did other clerical workers. They also reported significantly higher levels of workload demands, repetitious work, and self-reported ergonomic stressors. Finally, they reported that their work had less cognitive meaning, lower job satisfaction, and that they were less able to use their skills and make decisions. Only univariate analyses were performed between the use of VDTs and musculoskeletal outcomes. Neither psychosocial variables nor self-reported ergonomic stressors were evaluated for an association with musculoskeletal outcomes.

Sarr et al. [1982] performed a cross-sectional questionnaire study of 145 directory assistance operators who used VDTs and 105 comparison subjects also performing direc-

tory assistance tasks but who retrieved listings from printed paper books and had no occupational use of VDTs. A significantly elevated proportion of VDT operators reported neck discomfort. No significant differences were observed for discomfort of the upper extremities. When the analyses were performed after matching for age between the groups, no significant differences remained for any symptoms.

## Studies Using More Refined Measures of VDT Use

Other studies have incorporated more detailed measures of VDT use such as hours per day or week or duration of VDT use, but these improvements have not improved the consistency of the findings. Knave et al. [1985] performed a cross-sectional questionnaire study of approximately 400 VDT operators and 150 office workers who did not use VDTs. In addition to current use of a VDT, information about the number of years of VDT work and the number of hours of VDT work performed per week during the past year was also obtained. Musculoskeletal discomfort was significantly higher for women than men in the study group, but was not significantly different between VDT users and nonusers. When stratified by gender and anatomical site, male VDT users reported more back symptoms and female VDT users reported more shoulder symptoms than non-VDT users. Neither hours per week nor years of VDT use were associated with musculoskeletal complaints for females (not reported for males).

Rossignol et al. [1987] performed a cross-sectional study of 1,545 clerical workers in Massachusetts. VDT use was defined as the number of hours of use per day reported by participants. When all musculoskeletal outcomes were combined, individuals with 7 hr or more of daily VDT use had a significantly elevated odds ratio (1.8) compared to non-VDT users. However, when the results were stratified by industry group and type of symptoms, no associations were observed for upper back, arm, hand, or finger symptoms. Associations between VDT use and neck pain, shoulder pain, and lower back pain were found among clerical workers in computer and data processing services, public utilities, and state government but not among clerical workers in banking communications and hospitals. Although the authors attribute inconsistencies across industry to random variation, uncontrolled confounding is likely to have contributed to these results.

## Studies Using Exposure Measures in Addition to VDT Use

Only a few studies have attempted to measure exposure by any means other than some estimate of VDT use and assess its relationship to musculoskeletal outcomes [e.g.,

Hunting et al., 1981; Sauter et al., 1991; NIOSH, 1990, 1992, 1993]. Exposures of interest in addition to VDT use in these studies have included postural variables, physical workstation dimensions, and typing speed.

Hunting et al. [1981] performed a cross-sectional study of 162 workers using VDTs and 133 comparison subjects. Evaluation of exposures included objective measurement of hand-arm posture while keying, in addition to VDT use. Questions about psychosocial aspects of the work environment were included. Upper extremity symptoms occurred more frequently among VDT users than among non-VDT-using traditional office workers. Medical examination findings of "tendomyotic pressure pains" in shoulders and neck, painfully limited head movability, and pain in isometric contraction of the forearm were also more frequent among VDT users than among non-VDT users. Ulnar deviation of the wrist greater than 20° was associated in several analyses with significantly increased abnormalities on physical examination for some of the work categories while for others no association was observed. This suggests that increasing ulnar deviation may be associated with objective examination-confirmed musculoskeletal disorder.

Sauter et al. [1991] performed a cross-sectional study of discomfort, demographic variables, and VDT use among 539 data entry VDT operators. A subsample of 40 data entry VDT users was drawn randomly from this group to undergo detailed objective ergonomic evaluation of worker posture and the physical workstation dimensions. Among those who underwent detailed ergonomic evaluation, right arm discomfort was associated with upper arm angle, relative keyboard height, and right hand ulnar deviation and left arm discomfort were associated with relative keyboard height and relative document distance.

NIOSH investigators [NIOSH, 1990] performed a cross-sectional study on 834 subjects using VDTs at a large newspaper in the northeast United States. Hand/wrist, elbow/forearm, and neck symptoms were significantly associated with self-reported percent of work time spent typing, self-reported typing speed (slow, moderate, fast), and work as a reporter. Shoulder symptoms were associated with time spent typing.

In 1992, NIOSH investigators performed a cross-sectional study of 533 subjects using VDTs in a large telecommunications company. Musculoskeletal health outcomes were assessed with both symptom questionnaires and physical examinations. Detailed information on work practice including the hours per day spent at the VDT workstation and keystrokes per day, work organization, and psychosocial aspects of work was also obtained. Among the 174 directory assistance operators for which keystrokes per day data were available, no significant association with either symptoms or examination-confirmed disorders was observed. Measurements of posture and workstation configuration were made but not used in the analyses due to

changes in workstation characteristics that were made during the course of the study.

In 1993, NIOSH investigators performed a cross-sectional study of 973 subjects employed by a newspaper in California. Information was obtained about work practice, work organization, workstation equipment, experience of symptoms, and psychosocial factors. Neck symptoms were associated with more time on the telephone. Hand-wrist symptoms were associated with reporting of more time spent typing on computer keyboards. Objectively confirmed hand-wrist disorders were associated with percent of time spent typing on the computer keyboard.

### **ASSESSMENT OF OCCUPATIONAL PSYCHOSOCIAL STRESS AND POTENTIAL CONFOUNDERS**

Occupational stress, sometimes also called psychosocial stress, has been associated with VDT use, particularly full-time use [Sauter et al., 1983; Stellman et al., 1987]. Objective physiological measures of stress, such as an increase in heart rate and excretion of catecholamines, have also been found among VDT users [Johansson and Aronson, 1984; Tanaka et al., 1988]. Psychosocial stress has also been associated with the reporting of discomfort [e.g., NIOSH, 1993] and objectively ascertained musculoskeletal disorders [e.g., NIOSH, 1992] among VDT operators. Depending on one's point of view, psychosocial stress can be considered an exposure of interest, a confounder, or an effect modifier among VDT users. If the stress is a consequence of VDT use, then one must consider it as part of the causal pathway from VDT use to musculoskeletal discomfort and consider it a primary exposure of interest. On the other hand, if the stress associated with VDT use is related to the tasks performed or other characteristics of the job that would be obtained even if it did not involve VDT use, then stress must be regarded as a confounder. Finally, if stress is an effect modifier, it will act in combination with the biomechanical circumstances of VDT use to increase the risk of UEMSDs. The effect of the combination of a high-stress job with full-time VDT use would be greater than the sum of the independent effects of VDT use and stress on UEMSDs. Regardless of one's point of view, not considering this variable at all allows its effect on musculoskeletal outcomes to be attributed to the effect of VDT use. Problems in interpretation occur when an effect of VDT use is then ascribed to adverse biomechanical conditions such as workstation characteristics or repetitive exertions. Psychosocial stress, however, is difficult to measure and encompasses a broad range of circumstances. Some attention has been paid to this factor in the VDT literature. Studies that have included psychosocial variables have consistently found associations between such variables and musculoskeletal outcomes. However, the specific psychosocial factors found to be as-

sociated with musculoskeletal outcomes have varied among studies. Associations between specific psychosocial factors and physical examination-confirmed upper extremity disorders have been inconsistent even when identical instruments for assessing psychosocial stress were used [NIOSH, 1992, 1993].

Widespread agreement exists that age and gender are potential confounders of observed associations between VDT use and musculoskeletal outcomes [Kelsey, 1982; Stevens et al., 1984]. Body mass index and hormonal status have also been suggested as risk factors for musculoskeletal disorders [Nathan et al., 1982; Cannon et al., 1981]. Although a number of studies collected information on these potential confounders, some have not controlled for them in the analysis [e.g., Stellman et al., 1987; Smith et al., 1981]. If these potential confounders are not controlled in the analyses, the observed associations may be biased in either direction. For example, Starr et al. [1982] found that neck symptoms were more prevalent among VDT users than nonusers. However, when users and nonusers were matched on age, no differences remained. Alternatively, Knave et al. [1985] found no difference in symptom reporting between VDT users and nonusers. After stratifying by gender, significant associations were observed between symptom reporting and VDT use.

## ASCERTAINMENT OF HEALTH OUTCOME

Relatively few large studies of VDT operators have used objective methods for assessment of upper extremity disorders. Although assessment of symptoms is important, the proportion of symptomatic individuals who actually suffer from an objectively documented musculoskeletal disorder has been shown to vary among working populations [Zeier et al., 1987]. Therefore, symptom prevalence alone may be an unstable indicator of the occurrence of musculoskeletal disorders in a working population. This shortcoming in much of the literature relating upper extremity musculoskeletal problems to occupational exposures has led some authors to suggest that work has only been related epidemiologically to discomfort, and not to true musculoskeletal disease [Hadler, 1990]. Indeed, even the WHO has noted that epidemiologic evidence suggests only that upper extremity discomfort, not disorder of the upper extremity, is associated with the use of VDTs [WHO, 1987]. Objective documentation of musculoskeletal disorders requires physical assessment, and in special cases, nerve conduction measurement. Few studies of VDT users have incorporated objective measures of musculoskeletal disorders.

In the study of office workers by Hunting et al. [1981], upper extremity symptoms appeared to occur more commonly among each of the three groups of VDT users than among the non-VDT users. Medical examination findings of "tendomyotic pressure pains" in shoulders and neck,

painfully limited head movability, and pain in isometric contraction of the forearm were found more frequently among only one group of VDT users. These results suggest that an increased prevalence of symptoms may not always predict an increased prevalence of objective musculoskeletal disorders.

In the NIOSH cross-sectional study of telecommunications workers [NIOSH, 1992], musculoskeletal health outcomes were assessed with both symptom questionnaires and physical examinations. Detailed information on work practice including the hours per day spent at the VDT workstation and keystrokes per day, work organization, and psychosocial aspects of work was also obtained. Hours spent at the VDT workstation per day were significantly negatively associated with hand/wrist symptoms but not with examination-confirmed disorders. Among the 174 directory assistance operators for which keystrokes per day data were available, no significant association with either symptoms or examination-confirmed disorders was observed. Seven psychosocial variables (fear of being replaced by computers, jobs which demand a variety of tasks, increasing work pressure, lack of a production standard, lack of job diversity with little decision-making opportunity, high information-processing demands, and surges in workload) were associated with one or more upper extremity disorder.

The NIOSH investigation of newspaper employees [NIOSH, 1993] included a nested case-control study as well as a cross-sectional study. Symptoms alone were used as the outcomes in the cross-sectional study whereas symptoms, physical examination results, and nerve conduction velocity measurements were examined in the case-control study. Hand-wrist symptoms were associated with reporting of more time spent typing on computer keyboards, a greater number of hours on deadline, and less support from their immediate supervisor. Examination-confirmed hand-wrist disorders were associated with percent of time spent typing on the computer keyboard and female gender. In contrast to the symptom-based outcomes, none of the psychosocial variables were significantly associated with objectively confirmed hand-arm disorders.

## STUDY DESIGN

With only one exception [Bergqvist et al., 1992], every study of UEMSDs among VDT users currently available in the peer-reviewed published literature has been cross-sectional or case-control in design. This is perhaps the most important limitation of the existing literature. This design is subject to sample distortion because of selective loss from the study population of workers with greatest health effects. If exposure is causally related to health effect, this results in a weakening or even a reversal of the observed association between exposure and health outcome. Indeed, this effect may explain why, in some studies, certain measures of VDT

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