FINAL REPORT

MUSCULOSKELETAL DISORDERS AMONG VDT OPERATORS

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LIST OF ABBREVIATIONS

CI	Confidence interval
cm	Centimeter
Doc	Document
Ext	Extensor
hr	Hour
kg	Kilogram
KM	Kaplan-Meier
Keybd	Keyboard
VDT	Video display terminal
m	Meter
min	Minute
mon	Monitor
n	Number
NIOSH	National Institute for Occupational Health and Safety
p	Probability
SAS	Statistical Analysis System
SD	Standard deviation
USD	United States Dollars
vs.	Versus
WHO	World Health Organization

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ABSTRACT

This was a prospective epidemiological study of musculoskeletal symptoms and musculoskeletal disorders among newly hired video display terminal (computer) users in the metropolitan Atlanta area. Information collected from study participants included demographic characteristics, personal health information, daily number of hours worked in the office, the number of hours spent typing, and other exposure information. Information about symptoms was collected weekly. An ergonomist visited all study participants and collected standard information about workstation configuration and postures assumed by study participants while typing. Study participants were asked to complete a questionnaire about occupational psychosocial stress. Study participants who reported discomfort meeting study criteria were offered a standard physical examination by a specially trained certified hand therapist. Incident symptoms and incident disorders were recorded separately for the neck and shoulder (neck/shoulder) and the hand and arm (hand/arm). Analyses were conducted separately for the four health outcomes, neck/shoulder symptoms, neck/shoulder disorders, hand/arm symptoms, and hand/arm disorders.

Study Participants Between October 1, 1995, and October 31, 1998, a total of 2546 newly hired employees were contacted at the participating organizations to determine eligibility for this study. Of those contacted, 956 were eligible and were invited to participate. Of those invited, 789 (82.9 percent) agreed to participate and gave written informed consent and 632 (80.1 percent of the 789) completed the personal health questionnaire.

The participants were relatively young and well educated, with nearly 80 percent younger than 40 years of age and more than 60 percent having graduated from college. There was wide variation in household income, with about one-fourth of the population below $25,000 and about one-third at or above $50,000. The single largest occupational category was secretarial. On average, participants reported spending about 38 hours per week at work, 28 hours at their computer workstations, and 20 hours per week keying. Nearly one third of the population reported keying more than 25 hours per week.

Ergonomic Assessments Operator postures were measured with manual goniometers, workstation characteristics were evaluated by observation, and workstation dimensions were obtained by direct measurement. Few strong correlations were observed between worker posture and workstation physical dimensions. The associations that were observed suggested that preference was given to placement of the keyboard with respect to the elbow ($r=0.60$ for the correlation between keyboard height and seated elbow height) in comparison to placement of the monitor with respect to the elbow ($r=0.18$ for the correlation between monitor height and seated eye height). Wrist extension was weakly correlated with keyboard height from the floor ($r=-0.24$) and virtually not at all with keyboard thickness ($r=0.07$). Use of a wrist rest was associated with decreased wrist flexion (21.9° vs. 25.1°, $p<0.01$). Participants who had easily adjustable chairs had essentially the same neck and upper limb postures as did those with non-adjustable chairs. A large proportion of computer operators assumed postures that were non-neutral, with 61% observed in non-neutral shoulder postures and 41% observed in non-neutral wrist postures.

Incidence of Health Outcomes Survival curves for incident musculoskeletal symptoms and disorders were plotted by the Kaplan-Meier method and subgroups were compared in stratified analyses by the log-rank test. Incidence density rates (hazards) for various periods of follow-up

were calculated using the life-table method. The annual incidence rate for neck/shoulder symptoms was 57.5 cases/100 person-years and for neck/shoulder disorders was 35 cases/100 person-years. The most common neck/shoulder disorder was somatic pain syndrome (tension neck syndrome). The annual incidence rate for hand/arm symptoms was 38.8 cases/ 100 person-years and for hand/arm disorders was 21.1 cases/100 person-years. The most common hand/arm disorder was deQuervain's tendonitis.

Analysis of Ergonomic Risk Factors While controlling for potential confounders, keying with an inner elbow angle >121° was associated with reduced risk of both neck/shoulder symptoms and disorders. Keying with elbow height below the height of the "J" key was a associated with increased risk of neck/shoulder symptoms and presence of a telephone shoulder rest increased risk of both neck/shoulder symptoms and disorders. Greater downward head tilt was associated with reduced risk of neck/shoulder symptoms. Horizontal location of the "J" key >=12 cm from the edge of the desk was associated with a lower risk of hand/arm symptoms and disorders. Radial deviation of >5° while using a mouse was associated with increased risk of hand/arm disorders. Hours keying per week was associated with both hand/arm symptoms and disorders, but not with neck/shoulder symptoms or disorders.

Summary The results of this prospective epidemiological investigation provide important new information about 1) ergonomic exposures sustained by those using video display terminals, 2) the prevalence and incidence of specific upper extremity musculoskeletal disorders among video display terminal users over a three year period, and 3) the relationship between ergonomic exposures and musculoskeletal disorders free from methodological problems encountered with more common study designs.

SIGNIFICANT FINDINGS

- Workstation dimensions were only partly related to operator postures; considerable variability in posture could not be accounted for by workstation dimensions alone
- Observed variability in posture was greater than expected when basic geometric principles were applied to observed workstation dimensions
- The correlation between elbow height and keyboard height was stronger than the correlation between eye height and monitor height, suggesting preferential location of the elbow/keyboard in comparison to the eye/monitor
- Reaching for and using the mouse resulted in increased shoulder flexion, shoulder abduction and inner elbow angle
- A large proportion of computer users do not work in neutral postures.
- Upper-extremity musculoskeletal symptoms affected more than half of the individuals using a computer for more than 15 hours per week in their first year at a new job.
- A large proportion of symptomatic individuals met criteria for specific musculoskeletal disorders.
- Hand or arm disorders were less frequent than neck or shoulder disorders
- The most common neck/shoulder disorder was tension neck syndrome (somatic neck pain disorder).
- The most common hand/arm disorder was deQuervain's tendonitis.
- Carpal tunnel syndrome, diagnosed by symptomatic and electrophysiological criteria, was rare in comparison to other disorders, affecting only one out of one hundred computer users in their first year at a new job.
- Inner elbow angle >121° was associated with reduced risk of both neck/shoulder symptoms and disorders.
- Keying with elbow height below the height of the "J" key was a associated with increased risk of neck/shoulder symptoms
- Presence of a telephone shoulder rest increased risk of both neck/shoulder symptoms and disorders
- Greater downward head tilt was associated with reduced risk of neck/shoulder symptoms.

- Horizontal location of the "J" key >=12 cm from the edge of the desk was associated with a lower risk of hand/arm symptoms and disorders.

- Radial deviation of >5° while using a mouse was associated with increased risk of hand/arm disorders.

- Hours keying per week was associated with both hand/arm symptoms and disorders, but not with neck/shoulder symptoms or disorders.

USEFULNESS OF FINDINGS

Control of posture among computers cannot be accomplished by manipulation of workstation dimensions alone. This finding is useful to ergonomists, engineers and furniture designers who want to encourage specific postures among computer users.

The greater correlations between elbow height and keyboard height than between eye height and monitor height suggests that greater attention needs to be given to adjustability of monitor height. This finding is useful to ergonomists, engineers, and furniture designers who want to design office equipment and furniture hat allows for the same degree of control of neck posture as upper limb posture.

Musculoskeletal disorders can be expected to occur commonly (i.e., more than half of users) among computer users. This finding is useful to physicians, employers, workers, ergonomists, and policy makers interested in assessing the magnitude of the problem of musculoskeletal disorders among computer users.

Neck/shoulder ailments are more common than hand/arm ailments among computer users. This finding is useful to physicians and therapists who provide care to those who use computers.

The most common neck/shoulder disorder was tension neck syndrome (somatic neck pain disorder) and the most common hand/arm disorder was deQuervain's tendonitis. This finding is useful to physicians and therapists who provide care to those who use computers.

The identification of ergonomic risk factors among computer users is useful to ergonomists, physicians, employers, insurers, regulators, and employees interested in reducing the risk of musculoskeletal disorders among computer users.

The finding that hours per week of keying is a significant predictor of hand/arm symptoms and hand arm disorders is useful to ergonomists, physicians, employers, insurers, regulators, and employees interested in reducing the risk of musculoskeletal disorders among computer users.

SCIENTIFIC REPORT
INTRODUCTION

Upper extremity musculoskeletal disorders are painful disorders affecting tendons, tendon sheaths, muscles, nerves, bursae, and blood vessels of the hands, arms, shoulders, and neck. When occurring in the workplace in association with certain occupational tasks they are sometimes referred to as disorders associated with repeated trauma or cumulative trauma disorders [Putz Anderson, 1988]. An epidemic of apparently work-related upper-extremity symptoms was called "occupational cervicobrachial disorder" in Japan and "repetition strain injury" in Australia [Gerr et al., 1991]. The prevalence of work-related upper extremity musculoskeletal disorders reported in the United States appears to have increased dramatically during the past ten years. In 1999, the most recent year for which Bureau of Labor Statistics data are available, they accounted for 66% of all work-related illness in the United States [US Dep. Labor, 2000. In 1982, only 18% of all reported occupational illness were in this category. Examples of specific upper-extremity musculoskeletal disorders frequently considered to be work-related include carpal tunnel syndrome, tendonitis of the hand and wrist, epicondylitis, and certain shoulder disorders [Gerr, 1991; Mani and Gerr, 2000].

The toll of these disorders in terms of human suffering as well as their economic consequences is enormous. Work-related disorders of the hand account for more lost work days than any other occupational injury [Blair, 1991]. In addition, in 1987, disorders of the upper-extremity cost United States society over $42 billion in lost wages, medical expenses, and insurance administration costs [Blair, 1991]. Because of the magnitude of this problem, the Occupational Safety and Health Administration (OSHA) has targeted this category of occupational illness as a priority area and has made efforts to guide industry efforts to control them for nearly a decade. Within the past month, OSHA has taken another step to control these occupational ailments by promulgating an "ergonomics" standard intended to reduce the risk of musculoskeletal disorders in industry [OSHA, 2000]. In addition, the National Institute for Occupational Safety and Health (NIOSH), has placed musculoskeletal disorders on its list of ten leading occupational diseases in the United States [NIOSH, 1999].

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; WHO, 1987; Gerr et al., 1996]. According to the United States Census Bureau, about 92.2 million people in the United States age 18 or over used a computer in 1997 and 36.6% of all American households had computers [US Census Bureau, 1999]. In addition, half of all employed adults in the US used a computer on the job in 1997 [US Census Bureau, 1999]. Because exposure to these devices is very common, even relatively small risks associated with their use would have important public health implications.

Although more than one dozen studies have explored the relationship between use of VDTs and occurrence of upper-extremity musculoskeletal disorders, many studies have not found an increased risk. Furthermore, many of those studies that have identified an increased risk for VDT users do not find increasing risk with increasing weekly hours or years of VDT use. The difficulty in interpreting the literature in this field can be traced to the lack of rigor in research methodology and the exclusive reliance on cross-sectional study designs. Below we review (1)

the major studies examining *VDT use* and the occurrence of upper-extremity musculoskeletal disorders.

We describe the literature in which 1) self-report symptoms alone were used as the outcome of interest and 2) objective physical examination was included to define the outcome.

Rossignol et al. [1987] performed a cross-sectional study of 1545 clerical workers in Massachusetts. Exposure and health outcome data were both obtained by questionnaire. Respondents were classified as cases of musculoskeletal disorder if either "almost always" or "missed work" was checked for any of the following conditions: neck pain, shoulder pain, lower back pain, upper back pain, arm pain, pain in hands, fingers, or wrist, or numbness or tingling in hands. When all musculoskeletal disorders were combined, individuals with 7 or more hours of daily VDT use had a significantly elevated odd ratio. However, when the results were stratified by industry group, the relationship between hours of daily VDT use and musculoskeletal symptoms was not consistent across the two industry groups. Neither ergonomic evaluations of workstations nor assessment of occupational psychosocial factors were performed in this study.

Smith et al. [1981] performed a cross-sectional questionnaire study of professional and clerical VDT users and clerical non-VDT users at four newspapers or related operations, and one insurance company. The VDT operators had a participation rate of 50% and the non-VDT operators had a participation rate of 38%. More clerical VDT operators reported job stress than did professionals using VDTs or clerical control subjects. 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 control subjects, the only difference found was that professional VDT users were significantly less likely to report "pain down arm". The results of this study may not be generalizable because of the low participation rate and because it was conducted during labor negotiations in which VDT health and safety was a bargaining issue. These results suggest that occupational stress may be related to the experience or reporting of upper-extremity musculoskeletal symptoms. There was no objective assessment of musculoskeletal disorder among participants nor were ergonomic assessments of posture or workstation physical characteristics performed.

Stellman et al [1987] performed a cross-sectional questionnaire study of 1032 female office clerical workers with a wide range of VDT use. Multiple exposures were assessed, including psychosocial factors, self-reported ergonomic factors, and job satisfaction. Musculoskeletal outcomes were defined by symptom reporting. Full-time VDT users reported significantly more musculoskeletal symptoms that did other clerical workers. They also significantly higher levels of workload demands, repetitious work, and self-reported ergonomic stressors. In addition, 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 for evaluation of associations between use of VDTs, work stress, and musculoskeletal symptoms. No ergonomic assessments were performed.

Starr et al [1982] performed a cross-sectional questionnaire study of 145 directory assistance operators who used video display terminals and 105 comparison subjects also performing

directory assistance tasks but who retrieved listings from printed paper books. The authors indicated that many aspects of the jobs of all participants were similar because they were dictated by nationwide collective bargaining agreements or by standard company practices. However, there were several important differences between the VDT operators and paper retrieval operators. The VDT group was significantly younger than the paper group, had fewer women, and a lower participation rate. Information was obtained about discomfort of the neck, shoulders, upper back, lower back, wrists, elbows, and upper arm. In addition, information about job satisfaction was also obtained. A significantly elevated proportion of VDT operators reported neck discomfort; no significant differences were observed for the other discomfort categories. When the analyses were performed after matching for age between the groups, no significant differences remained. Analyses were also performed to determine possible associations between physical complaints and job satisfaction. Increased physical complaints were associated with lower job satisfaction scores. No multivariate analyses were performed.

Smith et al. [1984] performed a two-phase cross-sectional study of musculoskeletal outcomes among newspaper employees. The musculoskeletal outcomes were obtained with a questionnaire. Results obtained during the first phase were tested in a second group of workers during the second phase. Multiple questions about musculoskeletal symptoms were reduced to two outcome variables, one for pain and stiffness in the arms, hands, and legs and the other for pain and stiffness in the neck, shoulders, and back. Of the 588 workers solicited only 48.1% participated. Univariate analyses demonstrated that VDT users reported significantly more neck, shoulder and back discomfort than did non-users. No significant association was observed between the use category and arm, hand and leg discomfort. Pain or stiffness in the neck, shoulders and back was negatively associated with years of employment and not associated with hours per week of VDT use. No association between arm, hand, or leg symptoms and years of VDT operating experience or hours-per-week of VDT use was observed. When associations between musculoskeletal symptoms and work variables were tested in the second phase of the study, no significant associations were observed. The generalizability of this study is limited by poor participation rates.

The Canadian Labour Congress [1982] performed a cross-sectional questionnaire study of 2330 Canadian office workers. Of the 2330 participants, 1742 were users of VDTs and 588 were non-users. Multiple outcomes were assessed, including musculoskeletal discomfort. Small, but statistically significant increases in reporting of shoulder and neck discomfort were observed among the VDT operators. No significant differences were observed between VDT operators and non-operators for arm or hand and wrist symptoms. Among VDT users, the percent of workers reporting almost daily neck discomfort increased with increasing hours of daily VDT use. The percent of workers reporting almost daily shoulder discomfort also appeared to increase with daily VDT use, however, those with the highest daily hours of VDT use reported less shoulder discomfort than the two use categories below them. No evaluation of occupational psychosocial stress was performed.

Sauter et al. [1983] performed a cross-sectional questionnaire study of 248 VDT users and 85 non-users. For 25% of the VDT users objective measures of workplace physical characteristics were performed. The questionnaire included items and scales designed to measure occupational psychosocial stressors as well as demographics and musculoskeletal symptoms. Univariate

group comparisons as well as multivariate regression was performed. The univariate analyses failed to demonstrate significant differences between the users and non-users for either self report of neck, back and shoulder discomfort or self report of arm, hand, and wrist discomfort. Multivariate analyses were performed only for VDT users. Variables significantly associated with neck, back and shoulder discomfort were job demands, "bothered by" VDT workstation configuration, chair comfort, and use of corrective eyewear. The hours of VDT use per day and adjustability of VDT workstation were not significantly associated with this outcome. Variables significantly associated with arm, hand and wrist discomfort were "bothered by" VDT workstation configuration and chair comfort. Hours of VDT use per day was not significantly associated with this outcome. Because of the cross-sectional design of this study, it is possible that workers experiencing musculoskeletal discomfort would be more likely to be "bothered by" VDT workstation configuration.

Knave et al. [1985] performed a cross-sectional questionnaire study of approximately 400 VDT operators and 150 office workers who did not use VDTs. The exposed group consisted of office workers performing "VDT work" for more than five hours per day at several locations. The frequency and intensity of musculoskeletal discomfort of the hands, forearms, elbows, upper arms, shoulders, neck, and back was obtained. A symptom score based on intensity alone was also constructed. 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 during the past year was also obtained. The musculoskeletal discomfort scores were significantly higher for women than men in the study group, but were not significantly different between VDT users and non-users. A relationship between duration of VDT use and musculoskeletal symptoms was observed for women only.

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 all participants, neither months in current job nor weekly hours of VDT use were associated with upper extremity discomfort. Only body mass index was associated with discomfort of the left arm. 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 was associated with relative keyboard height and relative document distance. This was one of the few studies studies to incorporate some objective measures of ergonomic exposure.

NIOSH investigators performed a cross-sectional study on 834 subjects using VDTs at a large newspaper in the Northeast United States [NIOSH, 1989]. A questionnaire was used to obtain information on demographics, job tasks, psychosocial factors, and experience of musculoskeletal symptoms. Of the 834 subjects participating in the study, 331 (40%) reported symptoms occurring during the past year that met the investigators' case definition for "cumulative trauma disorder". Hand/wrist, elbow/forarm, 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 one analysis. No objective measures were made of ergonomic exposures or of musculoskeletal disorders.

A cross-sectional study of the relationship between musculoskeletal symptoms among computer users and posture and psychosocial factors was performed among 70 computer users in a newspaper editorial department [Faucett and Rempel, 1994]. Musculoskeletal outcomes were obtained with a questionnaire instrument. VDT workstation evaluations were performed with methods similar to those of Sauter et al., [1991[. Measures of occupational psychosocial stress were obtained with the Job Content Instrument [Karasek, 1981] and a set of investigator developed interpersonal relationship scales (e.g., supervisor support and coworker support). None of the postural variables were significantly associated with upper extremity pain severity. Head rotation and keyboard height above elbow height, however, were significantly associated with upper torso pain and stiffness severity. When musculoskeletal outcomes were dichotomized (case vs. non-case), none of the postural variables were significantly associated with case status.

Bergqvist et al [1992] has published the only prospective study of VDT use in relation to musculoskeletal symptoms to date. Workers were surveyed in 1981 and again in 1987. The analysis of new cases of musculoskeletal symptoms revealed that those who used VDTs at the end of the time period were 2.5 - 4 times more likely to have developed hand/wrist or back symptoms than those who did not use VDTs at either time period. There were no significant differences for arm/shoulder or neck symptoms. This study sheds some light on the methodologic limitations of cross sectional studies. Those individuals who dropped out some time during the seven years between surveys were asked if VDT work had "strongly contributed" to their decision to leave the job. Based on the response to this question, the authors estimated that the effect of selective drop out could bias effect estimates toward the null about 20% for back symptoms, 40% for hand/wrist symptoms and < 15% for other outcomes. Although psychosocial stress, age, gender and company type were evaluated as potentially confounding variables in stratified analyses no multivariate analyses were reported. This study did not examine ergonomic variables nor objectively documented musculoskeletal disorders.

The following five studies incorporated objective measures of musculoskeletal disorder. Hunting et al [1981] performed a cross-sectional study of 162 workers using VDTs and 133 comparison subjects. No information about response rates was included in the report. The VDT users were divided into three groups: (1) workers who performed full-time numeric data entry with their right hand only, (2) "conversational" terminals workers who used both hands to operate the keyboard, and (3) workers who performed word processing. A group of office workers who performed work "identical" to that performed by the conversational terminal workers but without use of VDTs was included. Evaluations included questions about musculoskeletal discomfort and work satisfaction, measurement of posture and medical examinations. Analyses of musculoskeletal symptoms were restricted to those reporting pain on a daily basis. Some information about workstation configuration was provided. Upper extremity symptoms appeared to occur more commonly among data entry workers, followed by conversational terminal workers, typewriter workers, and 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 common among data entry terminal operators than among the other groups. Ulnar deviation greater than 20 degrees 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. Finally, when comparison was made between two subgroups performing the same work, one with VDT terminals and one without, those using terminals reported less "quantitative overload", "qualitative overload", "task feedback", and "variety" than those not using terminals. This study suggests that increasing ulnar deviation may be associated with objective examination confirmed musculoskeletal disorder.

NIOSH investigators performed a cross-sectional study of 533 subjects using VDTs in a large telecommunications company [Hales, et al., 1992]. UEMSDs were assessed with both symptom questionnaires and physical examinations. Detailed information on work practice, work organization, and psychosocial aspects of work was also obtained. Information on physical workstation configuration and postural data was obtained by inspection of the workstation and measurements obtained while subjects operated their VDTs. Analyses of associations between physical workstation configuration and postural factors and upper extremity disorders were not performed, however, because of concerns that measurements made at one point in time may not have been representative of the workers past ergonomic exposure and that individuals with symptoms may have changed their workstation or posture in order to accommodate their discomfort. Hours spent at the VDT workstation per day was significantly negatively associated with hand/wrist symptoms. Among the 174 directory assistance operators for which keystroke per day data was 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 with one or more upper-extremity disorder. The results of this study underscore the methodological limitations of even well-conducted cross-sectional studies.

NIOSH investigators performed a cross-sectional study of 973 subjects employed by a newspaper in California [Bernard et al., 1993]. The survey was performed in two phases; Phase I was a cross-sectional study in which both exposure information and health outcomes were obtained with a questionnaire and Phase II was a nested case-control study in which physical examinations and nerve conduction velocity measurements were performed on subjects chosen on the basis of results from Phase I. Information was obtained about demographics, work practice, job history, work organization, workstation equipment, experience of symptoms, and psychosocial factors. Subjects were eligible for inclusion in the Phase II analyses if they experienced upper extremity symptoms during the year preceding the study and they reported no previous accident or trauma, had onset of symptoms after starting their current job, duration of symptoms of greater than one week or occurrence at least once per month during the past year, and severity of at least "moderate" (the middle value) on a five category scale of severity. Workstation equipment variables were not included in the data analyses because numerous changes that were made prior to and during the study led the investigators to conclude that "we could not adequately assess relationships of symptoms to workplace equipment or layout." Neck symptoms were associated with reporting of greater number of hours on deadline, increased work variance, more time on the telephone, and the perception that management did not value the importance of ergonomics. Shoulder symptoms were associated with reporting of less participation in job decision making, greater number of years employed at the newspaper, and greater job pressure. 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. Women reported more symptoms than men at all three locations.

Phase II results were applicable only to hand/wrist disorders defined on the basis of both symptoms and examination findings. Hand wrist disorders defined in this way were associated with percent of time spent typing on the computer keyboard, categorized into quintiles, and female gender. This study also highlights the methodological limitations of simultaneous ergonomic exposure assessment and ascertainment of musculoskeletal health in a cross-sectional study.

A cross-sectional study of the relationships between individual, organizational, and ergonomic factors and musculoskeletal health outcomes was performed among 260 VDT users [Bergqvist, et al., 1995a]. Health outcomes included symptoms and examination confirmed clinical diagnoses. Methods for assessing ergonomic variables were not described. The postural variables evaluated were "extreme hand positions", listed as (wrist) flexion, extension, and ulnar deviation, and "visual angle to VDT". In addition, the height difference between the keyboard and the elbow was measured. Neck/shoulder discomfort and the diagnosis of tension neck syndrome were significantly associated with reports of "too highly placed keyboard". "Intense" neck and shoulder discomfort was associated with "too highly placed VDT" but the association was not statistically significant. The outcome arm/hand discomfort was non-significantly associated with low keyboard placement. Work with the hand in "non-neutral position" was significantly associated with arm/hand discomforts but not with any arm/hand diagnosis. The authors noted that some paradoxical associations were observed, including odds ratios significantly *below* unity for the associations between table "inadjustability" and shoulder disorders and frequent overtime and cervical diagnoses. The authors concluded that the cross-sectional design of the study may have resulted in observation of "reverse associations" i.e., associations that result when those with musculoskeletal conditions modify their exposure circumstances as a response to it.

A cross sectional study of VDT use and musculoskeletal disorders was performed by Bergqvist et al., [1995b] among 353 office workers, 310 of whom were current VDT users. VDT use was self-reported. Questionnaires administered in 1981 and 1987 were used to provide an estimate of total accumulated hours of VDT work since beginning VDT use. Musculoskeletal discomfort was assessed with the Nordic questionnaire. Clinical evaluations were performed and the outcomes defined as "tension neck diagnosis", "cervical syndrome or cervical degenerative disease", "any 'shoulder diagnosis'", and "any 'arm/hand diagnosis'" [Bergqvist et al., 1995b p. 755]. Potential confounders on which data were collected included "children at home", smoking, "negative affectivity", "stomach related stress reactions", and "tiredness-related stress reactions". Organizational factors assessed included "limited or excessive peer contacts", limited rest break opportunity, limited work task flexibility, and frequent overtime. Ergonomic factors assessed included "static work posture", non-use of lower arm support, hand in non-neutral position, repeated movements with risk of tiredness, insufficient leg space under table, height difference keyboard-elbow, high visual angle to VDT, and specular glare on VDT. None of the operational definitions of the ergonomic factors were provided nor did the references given in the paper include such definitions. The authors report that those performing data entry work (as opposed to other VDT tasks) in combination with limited rest break opportunities had an OR of 4.8 (95%

CI 1.3-18.1) for neck/shoulder discomfort in comparison to those performing no VDT work with unlimited rest break opportunities. They also reported that those keying more than 20 hours per week (regardless of work type) who had limited rest break opportunities *and* non-use of lower arm support had an OR of arm/hand diagnoses of 4.6 (95% CI 1.2-17.9) in comparison to those who did no VDT work, and who had unlimited rest break opportunities, and who did use lower arm support. The authors also concluded that data entry work was associated with discomfort of the arms and hands if "the keyboard was placed low – generally below the elbow position".

Critique of the Literature

Significant shortcomings in the literature relating musculoskeletal diseases to use of VDTs specifically, and to occupational factors, generally, limit its usefulness.

Ascertainment of Exposure and Outcome The majority of research relating upper extremity disorders to work has used qualitative descriptions of ergonomic exposure or simply industry or job title rather than objective measurement of critical ergonomic variables. Most studies of VDT operators have utilized relatively crude measures of exposure, such as self-reported hours per day of VDT work or total years of VDT use. Relationships between these exposure measures and the occurrence of upper extremity symptoms or disorders have been inconsistent. Even when similar case definitions and methods were used, as in two large studies by NIOSH [Hales, et al., 1992; Bernard et al., 1993], inconsistent associations between exposures and outcomes have been observed.

Only three studies have objectively evaluated operator upper extremity posture among VDT operators as a potential risk factor for either symptoms or examination confirmed disorders; one study found no association with the outcome and two did find such associations. Physical workstation characteristics and force required to depress keys have not been examined as possible risk factors. NIOSH investigators performing large cross-sectional studies were unable to associate several postural measures and physical workstation characteristics with upper extremity musculoskeletal disorders because they may have changed as a function of the symptom experience of subjects during the year prior to data collection. More precise estimates of exposure by (1) objective measurement of posture and workstation configuration and (2) subject maintenance of a record of VDT use variables during the proposed study period will allow for more precise estimates of exposure-effect relationships.

Relatively few large studies of VDT operators have utilized objective 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 worksites [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 World Health Organization has noted that epidemiologic evidence suggests only that upper extremity discomfort, not upper extremity disease, is associated with use of VDTs [WHO, 1987]. Objective documentation of musculoskeletal disorders requires physical assessment, and in special cases, nerve conduction measurement.

Inclusion of more objective assessment in a study of musculoskeletal health will allow documentation of overt inflammatory disorders and physiologically important nerve compression and provide information about the risk of disease in addition to discomfort.

In a recent meta-analysis of the literature relating upper extremity musculoskeletal disorders to work, Stock [1990] found that all but four published studies failed to meet her criteria for validity. None of the acceptable studies were of VDT users. The majority of these papers failed to ascertain either exposure or health outcome in an objective manner. Gerr et al. [1991] have also reviewed the literature relating workplace factors to musculoskeletal disorders of the upper-extremity and concluded that studies employing quantitative, objective measures of both exposure and outcome are needed.

Study Design Virtually every study of upper extremity musculoskeletal disorders among VDT users currently available in the peer-reviewed published literature has been cross-sectional in design. This design is subject to sample distortion because of selective loss from the study population of workers with greatest effects. This results in a bias towards the null. Few investigators have attempted to estimate the magnitude of this problem. Evidence of this effect in the literature comes from the finding that groups with longer durations of exposure or greater hours per day of VDT use have a *lower* prevalence of disease or reported symptoms [Smith et al., 1984; Canadian Labor Congress, 1982]. Although mentioned by several authors, the magnitude of this problem is unknown. Its magnitude can only be determined with a prospective study in which the occurrence of upper extremity disorders is assessed among those leaving the jobs requiring VDT use.

Cross-sectional studies also result in poor estimates of past exposure. Either current exposure is assumed to represent past exposure or subject recall must be relied upon. However, two recent studies [Hales, et al., 1992; Bernard et al., 1993] in which such estimates were attempted were thwarted by methodologic problems. Specifically, equipment use may have changed during the years preceding the study such that workers with symptoms were were more likely to have changed their posture or equipment. Prospective assessment of exposure to office equipment would allow more valid estimates of association.

An additional problem with cross-sectional studies is the difficulty in interpreting associations between reported occupational psychosocial factors and musculoskeletal outcomes. Because psychosocial factors and musculoskeletal outcomes are assessed simultaneously in a cross-sectional study, it is plausible to hypothesize that many of the psychosocial outcomes resulted from the experience of musculoskeletal pain or disease, rather than acting as a risk factor. Only in a study in which occupational psychosocial factors are assessed prior to the development of musculoskeletal symptoms or disorders can the true temporal sequence of these factors be assessed.

Many of the early studies of these disorders were anecdotal case series in which the author's opinion about work-relatedness was the sole criteria for inclusion. Indeed, virtually all studies in which performance of so-called unaccustomed work was described as a risk factor were anecdotal in nature. Remarkably, however, the concept of unaccustomed work as a risk factor

for upper-extremity musculoskeletal disease has become widely accepted despite the absence of any rigorous epidemiologic evidence of the association.

Another factor limiting interpretation of the literature is the use of cross-sectional study design. In many studies, duration of exposure has been inversely associated with prevalence of upper-extremity musculoskeletal disorders [Smith *et al.*, 1984; Hales et al., 1992]. This observation is inconsistent with the popular concept of "cumulative trauma" as an explanation for these disorders. It obviously may be a result of selective survival.

Confounding. Another potential difficulty with the literature is the failure to control for potential confounding. Potential confounders include age, gender, body mass index, and hormonal status [Kelsey 1982; Stevens et al., 1984; Nathan et al., 1992; Cannon et al., 1981]. These variables can be obtained easily during study of workers. Occupational stress, sometimes also called psychosocial stress, is a potential confounder that has been associated with certain occupational tasks [Sauter et al., 1983; Stellman et al., 1987] as well as with reporting of discomfort [Bernard et al., 1993] and objectively ascertained musculoskeletal disorders [Hales et al., 1992]. It is more difficult to measure than many other potential confounders. Some attention has been paid to this factor in the VDT literature. These results have been inconsistent, however. Associations have been found between psychosocial factors and the occurrence of upper extremity symptoms. Associations between psychosocial factors and physical examination confirmed upper-extremity disorders were inconsistent in two recent NIOSH studies. Future studies should account for this potential confounder by using well-established instruments for measuring its magnitude.

Research Needs and Significance of the Current Study

Given the relative lack of high quality epidemiologic evidence relating occupational use of VDTs to the development of musculoskeletal disorders, additional research aimed at clarifying exposure-effect relationships by performing well conducted epidemiologic studies is necessary.

Research to determine associations between VDT use and upper extremity disorders will contribute maximally to our understanding only if measures of both exposure (ergonomic factors) and adverse health effect (occurrence of musculoskeletal disorder) are standard, objective, and valid. Studies performed longitudinally will permit identification of incident cases and minimize bias from selective survival that appear to affect cross-sectional studies. In addition, estimates of exposure-response relationships can be made with greater precision in a prospective study because exposure assessment can be repeated quickly following changes to the workstation. Associations between psychosocial factors and upper extremity musculoskeletal disorders can be estimated in a prospective study in a manner free from cause-effect reversal bias. Cross-sectional studies of the musculoskeletal health effects of VDT use are subject to multiple biases and have produced conflicting results. Prospective study is now needed to clarify relationships between ergonomic and psychosocial factors associated with use of VDTs and the development of actual musculoskeletal disorders. The duration from first exposure to onset of disease, an essentially unknown quantity (entity), can be determined with a prospective study design.

MATERIALS AND METHODS

The Materials and Methods section is organized into four major sections, 1) overview of study design, 2) study participant eligibility and recruitment procedures, 3) data collection instruments and procedures, and 4) analyses.

OVERVIEW OF STUDY DESIGN

This was a prospective epidemiological study of musculoskeletal symptoms and musculoskeletal disorders among newly hired persons working with personal computers or computer terminals in office settings. Participants were recruited from among eight large employers in the metropolitan Atlanta area. The Emory University Human Investigations Committee approved the study protocol and written informed consent was obtained from all participants at the time of enrollment. At enrollment, study participants were asked to complete a questionnaire that solicited information about demographic characteristics and personal health history. Also at the time of enrollment, study participants were given the first pre-printed "diary" and asked to record daily the number of hours worked in the office, the number of hours spent typing, and other exposure information. This instrument also was used to collect information about symptoms, but on a weekly basis. The diary was collected weekly and reviewed by study personnel. Within approximately two weeks of enrollment, an ergonomist visited the study participant and collected standard information about the workstation configuration and the posture assumed by the study participant while typing. Approximately four weeks after enrollment, study participants were asked to complete a questionnaire that collected information about occupational psychosocial stress.

Study participants who reported discomfort that met the study definition of neck/shoulder symptoms or hand/arm symptoms on the exposure and symptom diary were offered a standard physical examination by a specially trained certified hand therapist. The physical findings obtained by the therapist were compared to criteria for case-definitions of specific musculoskeletal disorders to determine whether the participant was "diagnostic" for that particular disorder. Symptoms were analyzed separately from disorders. Health outcome results from the neck and shoulder were pooled into two separate outcome categories (neck/shoulder symptoms and neck/shoulder disorders) as were results from the hand and arm (hand/arm symptoms and hand/arm disorders). Consequently, the primary health outcomes of interest were hand-arm symptoms, hand-arm disorders, neck-shoulder symptoms and neck-shoulder disorders. Study participants were followed for each of these outcomes separately until the outcome occurred, the participant withdrew from the study, or the study ended.

Development of a symptom or disorder of one anatomic area (e.g., the neck-shoulder region) was not considered a basis for ceasing data collection concerning the other anatomic area (e.g., the hand-arm region). Likewise, development of symptoms in a given anatomic area, if the examination was not diagnostic, did not result in cessation of data collection related to disorders in the same area. Study participants were followed for a maximum of 38 months. The data collected allowed for 1) descriptions of ergonomic exposures and occupational psychosocial stresses 2) calculation of the incidence rate of musculoskeletal symptoms and disorders among computer users, and 3) analyses of associations between ergonomic factors and the development of upper extremity musculoskeletal symptoms and disorders.

STUDY PARTICIPANT ELIGIBILITY AND RECRUITMENT PROCEDURES

At each of the participating organizations, a newly hired worker eligible for participation in the study was one who 1) anticipated using a single computer keyboard for 15 hours or more per week and 2) anticipated using a computer keyboard for at least as many hours per week as in his/her previous job. No other criteria were used to determine eligibility for participation (i.e., no criteria were applied to age or any other demographic characteristic to determine eligibility of potential study participants). Those who had upper extremity musculoskeletal symptoms at the time of entry were excluded from analyses of incident symptoms (of that anatomic location) and those who had upper extremity musculoskeletal disorders at the time of entry were excluded from analyses of incident upper extremity musculoskeletal disorders (of that anatomic location).

Participants were recruited from among eight large employers in the metropolitan Atlanta area. Participating organizations included insurance and financial companies, telecommunications companies, food product producers, hospitals, and universities. Several of the participating organizations provided Emory investigators with a list of all newly hired employees on a weekly basis. Each new employee was contacted by a study staff member by phone to discuss possible involvement in the study and to determine eligibility. For those participating organizations not providing a list of newly hired employees, study staff arranged to participate in new employee orientation to present information about the study and recruit study participants. At one participating organization, information about the study was presented at the time of a pre-placement clinical examination provided to all new employees.

DATA COLLECTION INSTRUMENTS AND PROCEDURES

Demographic and personal health history questionnaire

At the time of enrollment, study participants were asked to complete a questionnaire designed to obtain information about past occurrences of musculoskeletal symptoms and disorders, past or current illness potentially associated with musculoskeletal or neurological impairment (e.g., arthritis, diabetes, thyroid illness), medication use, menopausal status (for female participants only), tobacco use, and past computer use. A copy of the questionnaire used to obtain this information ("Personal Health Questionnaire") is included as Appendix 1.

Weekly exposure and symptoms diary

At the time of enrollment, study participants were instructed on the use of a data collection instrument designed to obtain information about their workload, symptoms of pain or discomfort, job stress, and non-occupational activities. Information was to be recorded daily about hours worked in the office, hours spent keying, and number of short (10 minutes or less) and long (greater than 10 minutes) breaks from the workstation. On the same instrument, participants recorded information weekly about discomfort or pain in the upper limbs, neck, and shoulder. A study participant who experienced discomfort also was instructed to indicate the intensity of the discomfort on a 0-10 point visual analog scale, to indicate whether he/she took medication (e.g., Tylenol, Motrin, etc.) for the discomfort, and to provide an answer to the question "What do you think caused the pain?" At the end of the week, study participants were asked to respond to the question "How stressful has your job been?" by checking one of four responses ranging from "Very stressful" to "Not stressful at all". Questions designed to quantify time spent in aerobic activities as well as hand-intensive activities also were included on the weekly exposure and symptom diary. Study participants were asked to enter information on the diary every day that

they were enrolled in the study. A copy of the weekly exposure and symptom diary ("Weekly Checklist") is included as Appendix 2.

Occupational Psychosocial Questionnaire

Approximately four weeks after enrollment, study participants were asked to complete a questionnaire ("Occupational Questionnaire") intended to collect information about occupational psychosocial stress. The questionnaire was based on the instrument used by NIOSH in several studies of computer users [Hales et al., 1992; Bernard et al., 1993]. Variables of interest included job variety, cognitive demands, support from supervisors, coworkers, and family, work pressure, employment security, and the experience of hostility from others. A copy of the occupational psychosocial questionnaire ("Occupational Questionnaire") is included as Appendix 3.

Ergonomic assessment procedures

An ergonomic evaluation of each participant and workstation was generally performed within two weeks of enrollment into the study. The evaluation consisted of: 1) an assessment of physical workstation characteristics, 2) linear measurement of workstation dimensions, and 3) measurement of postural angles using manual goniometry. Evaluations were performed by one of two trained ergonomists. Approximately 25 individuals who were not participants in the study were evaluated by both ergonomists during a training period. At the end of the training period the maximum difference in angular measurement between the ergonomists was less than 2 degrees.

Using a standard checklist ("Ergonomic Assessment", Appendix 4), each workstation was examined for physical characteristics such as presence of specific items (e.g., document holder, mouse or other pointing device), and the adjustability of specific equipment. For the purposes of this assessment, an easily adjustable chair was one equipped with a hand operated pneumatic/hydraulic height adjusting mechanism that could be operated from the seated position. Following completion of the checklist, linear measurements (e.g., seated elbow height, table surface height) were recorded. Two additional variables were calculated using the measured data: the height of the "J" key from the floor (= floor to keyboard table surface + keyboard table surface to surface of "J" key) and the height of the vertical midpoint of the monitor screen from the floor (= floor to table surface + table surface to vertical midpoint of monitor screen). A list of all measures obtained and workstation characteristics assessed is included as Table 1.

For postural measurements, each participant was asked to perform his/her usual key-entry task in his/her usual keying position and was measured, separately, while using: 1) the alphanumeric portion of the keyboard, 2) the numeric keypad, and 3) the mouse (or other pointing device). A standard form was used to record these results. The specific postural angles measured during use of each of the text/data entry or pointing devices are shown in Table 2. Bilateral measures were obtained for the alphanumeric keyboard whereas unilateral measures were obtained for the keypad and mouse devices. Gaze angle, head tilt angle, and head rotation angle were measured after the participant was instructed to look at the center of the monitor and again after the participant was instructed to look at a source document, in its usual location, if one was used during typing.

A six-inch goniometer (North Coast Medical, Inc., San Jose, CA) was used to measure wrist angles and a modified twelve-inch goniometer (North Coast Medical, Inc., San Jose, CA) was used to measure shoulder, elbow, and head and neck angles. The modified goniometer had two carpenter's levels attached to one of the arms, one in a perpendicular orientation and one in a parallel orientation, so that measurements could be made relative to true vertical and horizontal. All postural angles were recorded to the nearest degree. Goniometer pivot and arm placements for each of the postural measurements are provided in Table 3. The locations of pivot and arm placements were based on those published in occupational ergonomic [Maeda et al., 1982; Sauter et al., 1991] and physical rehabilitation literature [Lastayo et al., 1994]. The postural measurement methods used were tested by the investigators prior to use in this study and found to have minimal inter-rater variability and good reliability regardless of time-of-day or day-of-week in a test-retest validation study [Ortiz et al., 1997]. In addition, on repeated measures, within-participant variability was significantly smaller than between- participant variability, demonstrating that changes over time for individual participants were significantly smaller than differences in posture between participants. Specifically, the ratio of the variability between subjects to the variability within subjects ranged from nearly eightfold for ulnar deviation to seventy-seven-fold for gaze angle [Ortiz et al., 1997, p. 142].

For purposes of clarity and data analyses, degrees of wrist ulnar deviation, wrist extension, shoulder flexion, and shoulder abduction were recorded as positive values whereas degrees of wrist radial deviation, wrist flexion, shoulder extension and shoulder adduction were recorded as negative values. Gaze angles and head tilt angles above the horizontal were recorded as positive values and those below the horizontal were recorded as negative values. Head rotation angles to the left of the body midline were recorded as positive values and those to the right were recorded as negative values.

In order to determine the proportion of persons working in "non-neutral postures" operational definitions were created. The recommendations [OSHA] that 1) "wrists and hands be in a straight position" was operationally defined as wrist extension between -25° and 25° and wrist ulnar deviation between -15° and 15°; 2) "upper arms should not be elevated or extended" was operationally defined as shoulder flexion of 25° or less; and 3) "forearms parallel to floor and elbows at sides" was operationally defined as inner elbow angle of 90°, plus or minus 25°, and shoulder abduction of 15° or less. Postures outside of these ranges are referred to as "non-neutral".

Health outcomes assessment

Symptoms The occurrence of musculoskeletal symptoms was assessed at entry into study with questions on the Demographic and Personal Health History Questionnaire and weekly thereafter during the follow-up period with questions on the weekly exposure and symptoms diary ("Weekly Checklist"). Study participants were asked if they experienced "any discomfort such as pain, aching, burning, numbness or tingling in your neck, shoulders, elbows/forearms, hands/wrists, or fingers." Those who experienced discomfort were asked to indicate the location of the discomfort (neck or shoulders vs. arm or hand) and to rate the severity of the worst discomfort during the previous week on a visual analog scale ranging from 0-10. Separate visual analog scales were used to rate discomfort of the neck or shoulder region and the forearm or hand regions. In addition, the question "Did you take any medication for this discomfort this

past week?" was asked separately for the neck or shoulder area and the hand or arm area. Study participants were classified as having experienced musculoskeletal symptoms if they 1) reported musculoskeletal discomfort on any day of the week with a severity of 6 or greater on the visual analog scale or 2) reported musculoskeletal discomfort on any day of the week which they controlled with medication (over-the-counter or prescription). The occurrence of symptoms was determined separately for the neck/shoulder region and the hand/arm region.

Disorders Subjects who met criteria for musculoskeletal symptoms at entry or during follow-up were offered a standard targeted physical examination performed at the workplace by an occupational therapist with certification in hand therapy. The examination result was recorded on a standard form ("Physical Examination Recording Form", Appendix 5). Only the symptomatic body region and the same area on the contralateral side were examined. Case definitions of musculoskeletal disorders suitable for use in epidemiological studies were developed by two members of the study team during the startup phase of the project. The case definitions were designed to be similar to those used in clinical practices as well as consistent with past studies of work-related upper extremity musculoskeletal disorders. The specific health outcomes and the case definitions used are provided in Appendix 6. Symptoms and physical examination findings were used to identify all musculoskeletal disorders except carpal tunnel syndrome and ulnar neuritis. The definitions of carpal tunnel syndrome and ulnar neuritis both required prolongation of sensory latency across the wrist in addition to characteristic symptoms. Sensory latencies were obtained at the study participant's place of work with a battery-powered portable nerve conduction monitor (Nervepace S200, NeuMed Inc., Lawrenceville, NJ, USA). All sensory latencies were obtained with skin temperature above 32°C. A small proportion of latencies was not obtained because participants refused the nerve conduction evaluation.

ANALYSES

Ergonomic data

Among eligible participants, those who had completed questionnaire forms documenting demographic and job characteristics and had undergone ergonomic evaluation of their workstations performed were included in the analyses. Means and standard deviations were calculated for continuous measures. Proportions were calculated for categorical data. Student's t-test and analysis of variance were used to determine the statistical significance of relationships between categorical and continuous ergonomic variables and Pearson's correlation coefficient was used to characterize associations between pairs of continuous variables. Since right side and left side postural measures were highly correlated, only results for the right side are reported.

Psychosocial data

Individual items were combined into scales as defined by Sauter and Hurrell (personal communication). Means, standard deviations, and Chronbach's alphas were calculated for each of the scales. To explore the relative contribution of each of the individual items to the reliability of the scale, Chronbach's alphas were calculated for each scale after removal of each of the variables. If the reliability of a scale was substantially improved by removal of an item, then the scale minus that item was used in the analyses.

Descriptive health outcome results

Measures of the occurrence of musculoskeletal symptoms and disorders were calculated at entry into the study (one-week period prevalence) and after various durations of follow-up. The prevalence of symptoms at entry was calculated by dividing the number of individuals reporting symptoms by the total population of subjects enrolled. The prevalence of disorders at entry was calculated by dividing the number of individuals with examination-confirmed disorders by the total population of subjects enrolled minus those who were not examined. The exclusion of symptomatic participants who were not examined will slightly under-estimate the prevalence of disorders since approximately two-thirds of individuals who were symptomatic were found to have a disorder. Individuals with prevalent symptoms or disorders at enrollment were excluded from calculation of the corresponding incidence figures.

Survival curves for incident musculoskeletal symptoms and disorders were plotted by the Kaplan-Meier method. The time unit of analysis was one week. Kaplan-Meier curves were truncated at 90 weeks of observation or at the time that fewer than 5 subjects were available for observation. Incidence density rates (hazards) for various periods of follow-up were calculated using the life-table method.

Multivariate survival analyses (Cox proportional hazards models) were implemented using the SAS PROC PHREG procedure [SAS, 1990]. The four different outcomes of interest were modeled separately (i.e. neck or shoulder symptoms, exam-confirmed neck or shoulder disorders, arm or hand symptoms, and exam-confirmed arm or hand disorders). Survival among men and women also were modeled separately and additional analyses were conducted removing individuals with pre-existing medical conditions of diabetes, arthritis, bursitis, tendonitis and carpal tunnel syndrome. Ethnicity was dichotomized as white (referent group) or non-white (including Hispanic) for the multivariate analyses; age was trichotomized as under 30 years (referent), 30 to 39 years, and 40 years and older. Height was examined by dichotomizing at the shortest tenth percentile and, alternatively, at the tallest tenth percentile. Only results for the shortest tenth percentile are presented here. Other variables examined include body mass index (BMI) dichotomized at the 80^{th} percentile for gender (28.8 kg/m^2 for men and 28.5 kg/m^2 for women), household income, education, current smoking, whether children under 6 resided in the participant's household and, among women, whether the participant was postmenopausal or taking hormonal medications.

Individuals who dropped out of the study contributed person-time until the week they dropped out and were censored. Symptomatic individuals who were not examined (because they refused an examination or were unable to schedule one) contributed person-time to the disorder analyses until the week before they developed symptoms and then were censored. A total of 64 individuals were not examined after developing incident symptoms. Censoring of survival time for these individuals will underestimate the incidence of musculoskeletal disorders since 70% of individuals with neck/shoulder symptoms who were examined were found to have a disorder and 64% of individuals with hand/arm symptoms who were examined were found to have a disorder. Data from ten individuals whose incident musculoskeletal symptoms or disorders were due to an acute injury (e.g. motor vehicle accident) were censored the week prior to the injury. When data from a weekly diary were missing (less than 1% were missing), the values were imputed from the previous week's diary.

Ergonomic risk factors and musculoskeletal symptoms and disorders

Four separate analyses were conducted. The purpose of each was to identify ergonomic factors that were associated with survival to one of the four primary outcomes (neck/shoulder symptoms, hand/arm symptoms, neck/shoulder disorders, and hand/arm disorders), while controlling for other ergonomic and non-ergonomic factors. We also evaluated effect-measure modification of ergonomic factors by hours keying. To maximize the number of events included in the analyses, outcomes from the left and right sides of the body were included in each of the four analyses. Because most of the ergonomic exposures were highly symmetric, only measurements made on the right side were used as independent variables in the models. To test for possible bias of the observed associations resulting from this approach, the final models obtained from analyses that included all outcomes (i.e., left and right side) were re-run after exclusion of participants with only left sided outcomes so that associations observed between right sided exposures and right sided outcomes could be compared to associations observed when bilateral outcomes were used.

Screening Potential Confounders

To guide the choice of covariates from the large number of potential non-ergonomic confounders, these variables were grouped *a priori* by type (i.e., demographic, anthropometric, socioeconomic, past computer use, physical activity, psychosocial) and screened for association with survival time to each of the four outcomes within these groups. Groups of potential confounders (separated into time-independent and time-dependent categories) were:

Time-independent potential confounders

- Demographic
  - Age
  - Sex
  - Smoking
  - Race/ethnicity
  - Children under age 6 in the home
- Anthropometric
  - Height
  - Body mass index
- Socioeconomic
  - Income index
  - Education
- Past computer use
  - Total years keying 15 hours per week
  - Total years keying 20 hours per week
  - Total years keying 25 hours per week

Time-dependent potential confounders

- Activity
  - Weekly aerobic activity
  - Weekly hand-intensive activity
  - Weekly evaluation of job stress

Weekly proportion of days with five breaks <10 minutes
Weekly proportion of days with five breaks >= 10 minutes
Psychosocial
High information processing demands
Routine work lacking decision-making opportunities
Job future
Workplace hostility
Ability to step away from the workstation
Total support at work
Job variance
Job variety
Work pressure

Time-independent potential confounders. Factors such as age, sex, and height were categorized and first screened by examining the univariate relationships between the categories and survival to each of the four outcomes using the SAS LIFETEST procedure [SAS 1990, Kleinbaum 1996]. Equality of survivorship across categories of each variable was examined using Kaplan-Meier survival curves, log-log survival curves, and the log-rank test [Kleinbaum 1996]. If the p-value for the log-rank test was <=0.20, the variable was retained for inclusion in the multivariate analysis. If the log-log survival curves crossed, indicating that the relationship between a given factor and survival varied with time, then a variable representing this time-dependence was created and used in subsequent models [Kleinbaum 1996]. All of the variables remaining within each group were entered into a Cox proportionate hazards model [SAS PHREG, SAS, 1990]. Each variable was then eliminated from the model individually and the likelihood ratio test was used to compare the log likelihood of the full model to that of each reduced model. If the p-value for the likelihood ratio test was <=0.15, then the variable was retained for inclusion in subsequent modeling steps. The exceptions were age, sex, and hours keying weekly, which were forced into each model.

Time-dependent potential confounders. Non-psychosocial time-dependent potential confounders were first examined in univariate extended Cox regression models, comparing the log likelihood of the model containing the variable to the null model [Collett, 1994]. All those that were associated with the hazard of the outcome such that the p-value for the likelihood ratio test was <=0.20 were then added to the model containing the time-independent variables that had met the screening criteria described above. The time-dependent variables were then individually eliminated from the model and the likelihood ratio test was conducted with a p-value of <=0.15 as the criterion for retention. Because some of participants experienced one or more of the outcomes before the psychosocial questionnaire was administered in the fourth week of participation, true prospective information on the psychosocial variables was not available for the entire study population. Therefore, psychosocial potential confounders were examined separately (using the same criteria as for other time-dependent variables) in smaller datasets created to include information from only those participants who completed the psychosocial questionnaire prior to development of musculoskeletal symptoms.

A model was then fit with all the potential confounder variables that met the screening criteria for a given outcome. The result was the analytic model to which the ergonomic exposures would be added.

Screening Ergonomic Exposures

Some of the numerous ergonomic exposures were biologically plausible risk factors for only one body part. To explore the relationships among these exposures and between these exposures and survival to each outcome, ergonomic measures were grouped *a priori*. This was done in order to understand relationships between ergonomic factors that may be correlated with one another. Groupings for ergonomic exposures (separated into separate categories for hand/arm symptoms and disorders and neck/shoulder symptoms and disorders) were:

Ergonomic exposures included in analyses of hand/arm symptoms and disorders

- Keyboard use
  - Keyboard wrist extension
  - Keyboard wrist ulnar deviation
  - Presence of a wrist rest
  - Distance from table edge to "J" key
- Mouse use
  - Mouse wrist ulnar deviation
  - Mouse wrist extension
- Other
  - Height of the "J" key above the table (cm)
  - Presence of a sharp leading edge
  - Average key activation force

Ergonomic exposures included in analyses of neck/shoulder symptoms and disorders

- Keyboard use
  - Keyboard to elbow height difference (i.e., "J" key height from floor minus elbow height from floor)
  - Distance from table edge to "J" key
  - Keyboard inner elbow angle
  - Keyboard shoulder flexion angle
  - Keyboard shoulder abduction angle
- Mouse use
  - Mouse inner elbow angle
  - Mouse shoulder flexion
  - Mouse shoulder abduction
- Other
  - Presence of a chair armrest
  - Monitor head tilt angle
  - Monitor head rotation angle
  - Presence of a telephone shoulder rest

To allow for assessment of non-linear relationships between exposures and survival time, continuous ergonomic exposure variables were categorized. Most were categorized into

quartiles. For each variable, quartiles were collapsed when hazard ratios (analyses described below) were similar between adjacent categories. The goal was to have the fewest number of categories necessary to adequately represent the relationship between the exposure and survival time. Some posture variables were more naturally categorized by *a priori* concepts of "neutrality". For example, the comparison group for monitor head rotation was neutral head position (–10 degrees to 10 degrees) rather than a range based on quartiles. Exposure variables were categorized before exposure-outcome relationships were examined. Because each of the four main analyses were conducted separately, the categorization scheme of some variables was not the same across the four main outcomes.

The ergonomic variables, all of which were time-varying (because participants were re-measured after a change in workstation equipment or configuration), were screened to determine whether they were related to survival time to each outcome. Each variable was categorized and Cox regression models were fit to examine unadjusted associations with survival. These crude associations are reported in Tables 13-16. Next, to eliminate the effects of possible collinearity among ergonomic risk factors within each group in the *a priori* list (shoulder abduction, for example, might be collinear with inner elbow angle), Cox models were then fit with all possible pairs of ergonomic variables for each outcome. If indications of collinearity were observed for a given pair (i.e., if models could not converge or estimated hazard ratios or confidence intervals were exceptionally large [Kleinbaum, 1996]), then only one of the two ergonomic risk factors suspected of being collinear was included in subsequent models of associations with that outcome. Each ergonomic factor that met these criteria was then added separately to a model containing the non-ergonomic potential confounders identified for the given outcome in the screening described above. If the likelihood ratio test comparing this model to the one containing only the non-ergonomic variables had a p-value <=0.30, then the ergonomic variable was retained for inclusion in the final analytic models.

Interaction with hours keying

Effect-measure modification by hours keying, which was reported weekly, was examined by fitting Cox regression models with an ergonomic exposure factor, a variable representing hours keying, and an interaction term. If the interaction term was statistically significant at the 0.05 level, then it was retained for inclusion in the initial multivariable models which included that ergonomic factor.

Initial multivariable models

Next, for each outcome, we fit separate models for each of the ergonomic exposure variables that remained after the initial screening. Each model included 1) the non-ergonomic potential confounders that met the screening criteria, and, if statistically significant, 2) the interaction term between the ergonomic risk factor and hours keying. Because each ergonomic exposure variable was modeled separately, the hazard ratio represents the adjusted relationship between the ergonomic exposure variable and the outcome, adjusted only for non-ergonomic potential confounders. These adjusted hazard ratios are also reported in Tables 13-16.

Final multivariable models

We fit separate Cox regression models for each of the four health outcomes (neck/shoulder symptoms, neck/shoulder disorders, arm/hand symptoms, arm/hand disorders). Models included

the non-ergonomic potential confounders retained from the screening procedures described above for that outcome, any statistically significant interaction terms between ergonomic factors and hours keying, and all ergonomic exposures that met the screening criteria. First, the statistical significance of the interaction term in the full model was examined using the likelihood ratio test. If it was not significant at the 0.05 level, the interaction term was dropped from the analysis. To examine confounding by non-ergonomic factors, each was eliminated from the model individually and changes in the hazard ratio for each ergonomic exposure was examined. If the hazard ratio for any ergonomic exposure changed by >=10%, then the variable that had been eliminated was considered a confounder of the relationship between that exposure and time to the outcome and it was included in all future models containing that exposure. With the exception of age, sex, and hours keying, which were included in all models, non-ergonomic non-confounders were dropped sequentially from the analysis. Then each ergonomic factor was individually eliminated from the full model. Following each elimination the likelihood ratio test was used to determine whether the variable was associated at a probability below 0.10 with survival to the outcome. Ergonomic variables that were not so associated with survival were dropped from the model. Final models contained variables representing 1) statistically significant ($p<0.10$) ergonomic predictors of survival to health outcome, 2) statistically significant interactions between ergonomic predictors and weekly estimates of hours keying, 3) age, sex, and hours keying weekly, and (4) non-ergonomic confounders of associations between ergonomic factors and survival to the outcome.

Finally, to assess possible confounding by the psychosocial variables of the relationship between ergonomic exposures and survival to each of the four outcomes, models were fitted for the smaller datasets from which participants who completed the psychosocial questionnaire *after* developing symptoms were excluded. Consequently, the analysis of survival to neck/shoulder symptoms included 368 of 632 participants (58.2%) who had such prospective information on psychosocial factors and the analysis of survival to neck/shoulder disorders included data from 399/632 participants (63.1%). The analysis of survival to hand/arm symptoms included 419 of 632 participants (66.3%) and the analysis of survival to hand/arm disorders included 439 of 632 participants (69.5%). The psychosocial variables which were retained after screening procedures were added to the final models described above. The psychosocial variables were then removed sequentially from these models and changes in the hazard ratios for each of the ergonomic exposures calculated. A psychosocial variable was considered a confounder of an ergonomic exposure if its removal resulted in a change of 10% or more in the hazard ratio for that ergonomic variable.

RESULTS

Organization of the Results Section is similar to the organization of the Methods Section. Provided first are descriptions of the recruitment of study participants and the exclusion criteria that were applied to identify study populations for each analysis. Next, descriptive statistics for study population demographics, the ergonomic assessment, and the psychosocial assessment are presented. Completing this section are the results of analyses of the health outcomes experienced by study participants and of the ergonomic risk factors associated with musculoskeletal symptoms and disorders.

STUDY PARTICIPANTS

Recruitment

Between October 1, 1995, and October 31, 1998, a total of 2546 newly hired employees were contacted at the participating organizations to determine eligibility for this study. Of those contacted, 956 were eligible and were invited to participate. The most common reasons for ineligibility were that current computer use was expected to be less than past computer use, that current computer use was expected to be less than 15 hours per week, or that the use of multiple computers was expected. Of those invited, 789 (82.9 percent) agreed to participate and gave written informed consent and 632 (80.1 percent of the 789) completed the personal health questionnaire.

Characteristics of the study population

Descriptive characteristics of the study population are provided in Table 4. The participants were relatively young and well educated with nearly 80 percent younger than 40 years of age and more than 60 percent having graduated from college. There was wide variation in household income with about one-fourth of the population below $25,000 and about one-third at or above $50,000. The single largest occupational category was secretarial. On average, participants reported spending about 38 hours per week at work, 28 hours at their computer workstations and 20 hours per week keying (data not presented in Table 4). Nearly one third of the population reported keying more than 25 hours per week. Many participants had past experience keying for a substantial portion of their workweek before entering the study. Study participants averaged 3.3 years of typing 25 or more hours per week prior to entering the study.

ERGONOMIC ASSESSMENT RESULTS

Results of the ergonomic assessment presented in this section are limited to the 379 participants enrolled between October 1, 1995, and January 1, 1998. Demographic and personal characteristics of this group are nearly identical to those of the entire study population.

Workstation physical attributes

Physical attributes of the workstations are reported in Table 5. Nearly all workstations (94.2%) had a mouse; "other" pointing devices (trackballs, touchpads, etc.) were uncommon (2.4%). An easily adjustable chair was present at 61% of workstations. The keyboard was positioned on the table or desk surface at 68% of workstations and below the surface at 26% of workstations. A document holder was present at 39% of workstations.

Workstation dimensions

Measures of workstation dimensions are presented in Table 6. Of note was the occurrence of a negative value (-7.5 cm.) for the "monitor height from table surface" variable. This particular workstation had its monitor partially embedded in the table work surface thereby resulting in a monitor screen midpoint that was lower than the table surface.

Linear measures and head/neck postures

Measures of workstation dimensions and of head and neck postures of computer operators obtained while they keyed are presented in Table 7. Seated elbow height from floor (73.9 cm, SD=4.2 cm) was very similar to keyboard height from floor (74.1 cm, SD=4.3 cm, Table 7). Seated eye height from floor (116.8 cm, SD=4.4 cm) was, on average, 10.6 cm greater than monitor height from floor (106.2 cm, SD=8.3 cm, Table 7). The head rotation angle while viewing the monitor varied from –43.0° to 41.0° (SD=11.6) and was centered around zero degrees (mean=1.4° right of midline). The head rotation angle for viewing a document (for those who used documents) ranged from –64.0° to 72.0° (SD=27.9) and was centered 9° to the left of midline. Both mean gaze angle and mean head tilt angle were more downward (i.e., became more negative) upon shifting visual attention from monitor to document. However, the change in mean gaze angle when shifting between these two visual targets (25.2°) was considerably larger than the change in mean head tilt (9.2°) when shifting between these two visual targets, suggesting that changes in visual gaze were preferred over changes in head tilt.

Upper limb posture

Means, standard deviations, and ranges of wrist, elbow, and shoulder postures of the right upper limb are presented as a function of input device use (i.e., keyboard, keypad, and mouse) in Table 8. Wrist extension while using the keyboard was considerably "non-neutral" (mean wrist extension=24.3°, SD=9.6°), with 41% of participants having wrist extension either greater than 25° or less than -25°. In contrast, wrist ulnar deviation was more likely to be near neutral while using the keyboard, with only 4% of participants having wrist ulnar deviation greater than 15° or less than -15° (mean wrist ulnar deviation=5.0°, SD=7.3°). Mean inner elbow angle was 113° (SD=13.3°) with 40% of participants having inner elbow angles greater than 115°. Mean shoulder abduction was 14° (SD=5.3°), with 32% of participants having shoulder abduction greater than 15°. Finally, mean shoulder flexion was 29° (SD=10.4°), with 61% of participants having shoulder flexion greater than 25°.

Mean wrist ulnar deviation decreased very slightly when moving from keyboard to keypad to mouse (5.0° vs. 1.5° vs. 1.0°, Table 8), while wrist extension remained essentially unchanged (24.3° vs. 24.7° vs. 23.0°, Table 8). Inner elbow angle, shoulder abduction, and shoulder flexion angles all increased with mouse use in comparison to keyboard use. All angle changes are consistent with the operator reaching for the mouse, typically located to the right of the keyboard.

When stratified by keyboard location (above work surface, on work surface, below work surface), differences in upper limb postures were small, although some were statistically significant. Specifically, wrist extension was significantly greater when the keyboard was located below the table surface than when it was on the table surface (27.3° vs. 23.3°, $p<0.05$)

and shoulder flexion was significantly smaller when the keyboard was located below the table surface than when it was on the table surface (23.7° vs. 30.6°, $p<0.05$). No systematic differences were observed for wrist ulnar deviation or shoulder abduction across the keyboard location conditions.

Correlation analyses

Results of correlation analyses are presented in Table 9. Average elbow height was very similar to, and moderately correlated with average keyboard height ($r=0.60$). However, the correlation between eye height and monitor height was considerably poorer ($r=0.18$) than that between elbow height and keyboard height. A moderately strong correlation was observed between monitor height from floor and gaze angle when viewing the monitor ($r=0.70$) and a weak correlation was observed between monitor height from floor and head tilt angle ($r=0.32$). A strong correlation was observed between monitor gaze angle and a variable constructed of the difference between eye height from the floor and monitor height from the floor ($r=0.82$, not shown in Table 9). The calculated eye-monitor difference variable was much more poorly correlated with head tilt angle ($r=0.31$, not shown in Table 9) than with gaze angle.

Inner elbow angle was moderately correlated with shoulder flexion angle ($r=0.66$). More modest correlations were observed for inner elbow angle and distance of the "J" key from the desk edge ($r=0.29$, not shown in Table 9) and inner elbow angle and vertical distance between the elbow and the keyboard ($r=0.43$).

Wrist extension had virtually no correlation with keyboard thickness (i.e., key height from surface, $r=0.07$) and had only weak correlation with the inner elbow angle ($r=0.24$). Even when stratified by use of a keyboard wrist rest, no correlation was observed between wrist extension and keyboard thickness ($r=0.05$ for subjects without wrist rest; $r=0.15$ for subjects with wrist rest; results not shown in Table 9). Wrist extension also increased only slightly as the vertical distance between the elbow and the keyboard increased ($r=0.18$). Finally, wrist ulnar deviation was not correlated with shoulder abduction ($r=-0.06$) but was weakly correlated with inner elbow angle ($r=-0.23$).

Shoulder flexion angle was moderately correlated with keyboard height from floor ($r=0.36$), elbow height from floor ($r=0.39$), and distance of the "J" key from the desk edge ($r=0.40$, result not shown in Table 9). No correlation was observed between shoulder flexion angle and the vertical distance between the elbow and the keyboard ($r=-0.03$). Shoulder abduction was slightly correlated with shoulder flexion ($r=0.22$).

Additional ergonomic analyses

Mean values for the five upper limb postural angles and the monitor gaze angle and the monitor head tilt angle were calculated for the 232 participants who had an easily adjustable chair and the 147 participants who had a chair that was not easily adjustable. No significant differences were observed for any of the postural measures as a function of chair adjustability (data not shown).

Mean values for head postures while viewing a document (gaze angle, head tilt angle and head rotation angle) were calculated for the 115 participants who used a document holder and the 257 participants who did not use a document holder (thirty four of the 149 participants who had a

document holder at their workstations did not use it and were therefore not included in this analysis). The mean gaze angle was -24.3° (SD=12.1°) for participants who used a document holder and -42.3° (SD=9.9°) for participants who did not use a document holder ($p<0.01$). The mean head tilt angle was 7.6° (SD=8.6°) for participants who used a document holder and -2.9° (SD=12.0°) for participants who did not use a document holder ($p<0.01$). Finally, the mean head rotation angle was 11.1° (SD=28.4°) for participants who did not use a document holder and 3.7° (SD=26.2°) for participants who did use a document holder ($p<0.02$).

Mean wrist extension angle was significantly smaller among the 101 participants who reported using a keyboard wrist rest (mean wrist extension=21.9°, SD=9.8°) than among the 278 participants who reported not using a wrist rest (wrist extension=25.1°, SD=9.5°, $p<0.01$). Wrist ulnar deviation was not related to use of a keyboard wrist rest (data not shown).

PSYCHOSOCIAL ASSESSMENTS RESULTS

A total of 478 study participants completed the psychosocial ("Occupational") questionnaire. Means, standard deviations, and Chronbach's alphas are presented in Table 10 for each of the psychosocial variables (scales) constructed by combining results from several individual items. The alphas provided for each individual item are those calculated for the scale after removal of that item. In general, Chronbach's alphas showed that the scales had good reliability, ranging from 0.54 to 0.83. The reliability of the variable "JOB VARIETY" improved considerably after removal of the question "How often do you see projects or jobs through to completion?". The variable "JOB VARIETY2" (i.e., JOB VARIETY minus the question "How often do you see projects or jobs through to completion?") was used in analyses examining possible confounding by psychosocial variables.

When the three variable related to *support* were combined into a single scale (i.e., SUPERVISOR SUPPORT + COWORKER SUPPORT + SUPPORT FROM FRIENDS, SPOUSE, RELATIVES), removal of the variable "SUPPORT FROM FRIENDS, SPOUSE, RELATIVES" resulted in a considerable improvement in reliability (data not shown). Hence, a new variable "TOTAL SUPPORT AT WORK" (i.e., SUPERVISOR SUPPORT + COWORKER SUPPORT) was created and used in the analyses (alpha = 0.72, Table 10).

Two single-item psychosocial variables used in the analyses were not included in Table 10 because Chronbach's alpha could not be calculated. These variables enquired about hostility in the work environment ("How often do you face hostility or abuse from customers, clients, or coworkers?") and the freedom to step away from the workstation ("Can you get up and step away from your workstation when you choose or only at scheduled times?").

HEALTH OUTCOME RESULTS

Populations for analyses of health outcomes

Because analyses were conducted separately for each of the four health outcomes: neck/shoulder symptoms, neck/shoulder disorders, hand/arm symptoms, and hand/arm disorders, a separate dataset was created for analysis of each outcome by applying exclusion criteria to the dataset which included all 632 participants who completed the personal health questionnaire (Figures 1-2).

For the two analyses for which the outcome was self-reported symptoms, the first exclusions were those participants who reported on the personal health questionnaire having had neck/shoulder or hand/arm pain (rated at 6 or greater on a visual analog scale of 1 to 10 or pain for which they took medication) in the week before beginning their job [Neck/shoulder symptoms: 63/632 (10%). Hand/arm symptoms: 24/632 (3.8%)]. Data from those remaining participants who failed to complete any weekly diaries then were excluded [Neck/shoulder symptoms: 31/569 (5.4%). Hand/arm symptoms: 34/608 (5.6%)]. A total of 538 participants were included in analyses of incident neck/shoulder symptoms and 574 participants were included in analyses of incident neck/shoulder disorders. Participants who did not have an ergonomic assessment prior to reporting symptoms were excluded from the final analyses of associations between ergonomic factors and health outcomes [Neck/shoulder symptoms: 74/538 (13.8%). Hand/arm symptoms: 47/574 (8.2%)] . Finally, those who did not use a mouse as the computer pointing device were also eliminated from the analyses [Neck/shoulder symptoms: 28/464 (13.8%). Hand/arm symptoms: 31/527 (5.9%)].

If the outcome was a diagnosed disorder, the participants who reported on the personal health questionnaire that they had had pain in the area of interest during the week prior to beginning the new job were scheduled for a physical examination. We excluded data from participants who were diagnosed with a disorder at the outset of their participation in the study or who were lost to follow-up before the physical examination could be conducted [Neck/shoulder disorders: 47/632 (7.4%). Hand/arm disorders: 16/632 (2.5%)]. Next, participants who did not complete any weekly diaries were excluded [Neck/shoulder disorders: 31/585 (5.3%). Hand/arm disorders: 34/616 (5.5%)]. A total of 554 participants were included in analyses of incident neck/shoulder disorders and 582 participants were included in analyses of incident hand/arm disorders. Subjects who had missing ergonomic assessment data or who were diagnosed with a disorder before the ergonomic assessment could be conducted were excluded from analyses of the relationship between ergonomic factors and musculoskeletal disorders [Neck/shoulder disorders: 51/554 (9.2%). Hand/arm disorders 29/582 (5.0%)]. Finally, we excluded data from participants who did not use a mouse pointing device [Neck/shoulder disorders 31/503 (6.2%). Hand/arm disorders: 33/553 (6.0%)].

Neck/shoulder symptoms and disorders: Crude analyses

Prevalence. At the time of entry into the study, 63 (10 percent) of the 632 subjects met criteria for neck or shoulder symptoms (Table 11). Of the 63 participants who met criteria for neck or shoulder symptoms, examinations could be scheduled for 53. A majority of the 53 examined participants (70 percent) met criteria for one or more neck/shoulder disorder. The prevalence of any neck/shoulder disorder at the time of entry into the study was 5.9 percent (37/622). Nearly all participants with one or more neck/shoulder disorder met criteria for somatic pain syndrome. Only 3 symptomatic individuals met criteria for rotator cuff tendonitis, the next most common neck or shoulder disorder (prevalence = 0.5 percent).

Incidence. After exclusion of the 63 study participants who were found to have neck/shoulder symptoms at the time of entry, 569 (632-63) participants were eligible for inclusion in analyses of incident symptoms. Of the 569 eligible participants, 31 did not complete diaries resulting in 538 participants available for analyses of incident symptoms. While being followed prospectively, 183 of the 538 study participants met criteria for new onset neck/shoulder

symptoms. A Kaplan-Meier survival curve for neck/shoulder symptoms is presented in Figure 3. The slope of the survival curve is greatest early in the study and decreases over time with 46 percent of the incident cases occurring during the first month of follow-up (data not shown). The one month incidence rate for neck/shoulder symptoms was about 18 cases/100 person-months and the annual incidence rate for neck/shoulder symptoms was 57.5 cases/ 100 person-years (Table 11).

After exclusion of the 37 study participants who were found to have neck/shoulder disorders and the 10 for whom examinations could not be scheduled, 585 (632-47) participants were eligible for inclusion in analyses of incident disorders. Of the 585 eligible participants, 31 did not complete diaries resulting in 554 participants available for follow-up of incident disorders. Of the 554 participants followed for incident disorders, 199 reported incident symptoms and examinations could be performed on 161 of them. Seventy-three percent (117/161) met criteria for one or more disorder (Table 11). A survival curve for neck/shoulder disorders is presented in Figure 3. As was seen for neck/shoulder symptoms, the slope of the survival curve of neck/shoulder disorders is greatest early in the study and decreased over time. The proportion of incident neck/shoulder disorders occurring during the first month of follow-up was 45 percent (data not shown). The 1 month incidence rate for any neck/shoulder disorder was 10.8 cases/100 person-months and the annual incidence rate for any neck/shoulder disorder was 35 cases/100 person-years (Table 11). The proportions of symptoms-positive participants with specific disorders are provided in Table 11. The types of disorders observed during follow-up were similar to those seen at entry. Somatic pain syndrome accounted for 111 of 117 incident cases of neck/shoulder disorder. Because this disorder was much more common than all other neck/shoulder disorders, the incidence rates for it were very similar to those for all neck/shoulder disorders, with an annual incidence rate of 33.2 cases/100 person-years.

Neck/shoulder symptoms and disorders: Stratified analyses

Survival curves for neck/shoulder symptoms stratified by gender and age are presented in Figures 4-5. Women were significantly more likely to experience neck/shoulder symptoms than were men (log rank test; $p<0.01$). After six months of follow-up, 42 percent of women had experienced neck/shoulder symptoms whereas only 27 percent of men had experienced neck/shoulder symptoms and at one year of follow-up 48 percent of women had experienced neck/shoulder symptoms whereas only 36 percent of men had experienced neck/shoulder symptoms. The survival experience of study participants less than 30 years of age was better (log rank test; $p=0.055$) than that of older participants (Figure 5). After six months of follow-up, 31 percent of the study participants less than 30 years of age had experienced neck/shoulder symptoms whereas 41 percent of the subjects 30-39 years old and 41 percent of the subjects aged 40 years and older had experienced neck/shoulder symptoms. After one year of follow-up, 38 percent of the study participants less than 30 years of age had experienced neck/shoulder symptoms where as 48 percent of the 30-39 year-old subjects and 49 percent of the 40 year-old and greater subjects had experienced neck/shoulder symptoms. No statistically significant differences in the experience of neck/shoulder symptoms were observed between white and black participants. Survival curves for neck/shoulder disorders show nearly identical patterns by gender, age, and race as the survival curves for neck/shoulder symptoms. The survival experience of study participants was not related to number of years of computer use. Participants

with longer experience keying more than 25 hours/week had neither more neck/shoulder symptoms nor more neck/shoulder disorders than those with less experience.

Hand/arm symptoms and disorders: Crude analyses

Prevalence. Prevalent hand/arm symptoms and disorders were infrequent at the time of entry into the study (Table 12). At entry only 24 (4 percent) of the 632 participants met criteria for arm or hand symptoms. Examinations were performed on 22 of these symptomatic participants and 14 (64 percent of those examined) were found to meet criteria for one or more arm or hand disorder resulting in a prevalence of 2 percent. Details for specific disorders of the hand/arm are given in Table 12. Of the 22 persons examined for arm or hand symptoms, 8 (36 percent) met criteria for deQuervain's disease (extensor tendonitis of the first dorsal compartment), 6 (27 percent) met criteria for digital flexor tendonitis, and 5 (23 percent) met criteria for extensor tendonitis of the second dorsal compartment. Four or fewer cases of each of the remaining hand/arm disorders were observed.

Incidence. After exclusion of the 24 study participants who were found to have hand/arm symptoms at the time of entry, 608 (632-24) participants were eligible for inclusion in analyses of incident symptoms. Of the 608 eligible participants, 34 did not complete diaries resulting in 574 participants available for analyses of incident symptoms. While being followed prospectively, 141 of the 574 study participants met criteria for new onset of hand or arm symptoms. A Kaplan-Meier survival curve for hand/arm symptoms is presented in Figure 6. The slope of the survival curve for hand/arm symptoms was only slightly greater during the first few months of follow-up than later in the study. The slope for hand/arm symptoms was not as great as the slope for neck/shoulder symptoms nor did the slope decrease as much over the follow-up period. The one month incidence rate for hand/arm symptoms was about 8.6 cases/100 person-months and the 12 month incidence rate for hand/arm symptoms was 38.8 cases/ 100 person-years (Table 12). The proportion of incident symptom cases occurring during the first month of follow-up was 32 percent (data not shown).

After exclusion of the 14 study participants who were found to have hand/arm disorders and the 2 for whom examinations could not be scheduled, 616 (632-16=616) participants were eligible for inclusion in analyses of incident disorders. Of the 616 eligible participants, 34 did not complete diaries resulting in 582 participants available for follow-up of incident disorders. Of the 582 participants followed for incident disorders, 146 reported incident symptoms and examinations could be performed on 120 of them. Sixty-eight percent (81/120) met criteria for one or more disorder (Table 12). A survival curve for hand/arm disorders is presented in Figure 6. The shape of the survival curve for hand/arm disorders was very similar to that of the survival curve for hand/arm symptoms. The 1 month incidence rate for any hand/arm disorder was 4.9 cases/100 person-months and the 12 month incidence rate was 21.1 cases/100 person-years (Table 12). The proportion of incident hand/arm disorders occurring during the first month of follow-up was 32 percent (data not shown). Of the 120 study participants examined during the follow-up period, nearly half (47 percent) met criteria for extensor tendonitis of the first dorsal compartment (deQuervain's tendonitis). The incidence rate for this disorder at 1 month was 3.6 cases/100 person-months and at 1 year was 14.7 cases/100 person-years. Carpal tunnel syndrome was rare in this study population. There were only with only 3 incident cases during the follow-up period, representing an annual incidence of only 0.9 cases/100 person-years.

Hand/arm symptoms and disorders: stratified analyses

Survival curves for hand/arm symptoms stratified by gender and age are presented in Figures 7-8. Women were significantly more likely to experience hand/arm symptoms than were men (log rank test; $p<0.05$). At six months of follow-up, 29 percent of women had experienced hand/arm symptoms whereas only 18 percent of men had experienced hand/arm symptoms and at one year of follow-up 40 percent of women had experienced hand/arm symptoms whereas only 25 percent of men had experienced hand/arm symptoms. No statistically significant differences were observed in survival by age group, however some suggestion of an increased risk for participants 40 years of age and older was observed. No statistically significant differences in the experience of hand/arm symptoms was observed between white and black participants. Survival curves for hand/arm disorders showed nearly identical patterns by gender, age, and race.

Survival curves for hand/arm symptoms stratified by years of previous computer use greater than 25 hours/week are presented in Figure 9. Compared to those with the least prior experience, participants with more years of keying 25 or more hours weekly had significantly shorter survival to hand/arm symptoms (log rank test; $p<0.05$). Increasing duration of past computer keying at this level was associated increased risk of hand/arm symptoms. For example, at six months of follow-up, 19 percent of participants with no previous experience keying 25 or more hours/week met criteria for hand/arm symptoms whereas the corresponding percentages for participants with experience of >0-<4 years, >=4-<8 years, and >=8 years were 28 percent, 31 percent, and 34 percent, respectively. Similar results were observed for hand/arm disorders. At six months of follow-up, 10 percent of participants with no previous experience keying 25 or more hours/week met criteria for hand/arm disorders whereas the corresponding percentages for participants with previous experience of >0-<4 years, >=4-<8 years, and >=8 years were 17 percent, 18 percent, and 20 percent, respectively.

Crude and covariate-adjusted associations between ergonomic exposures and incident musculoskeletal symptoms and incident musculoskeletal disorders

Neck/Shoulder Symptoms

Crude and covariate-adjusted associations between ergonomic risk factors and incident neck/shoulder symptoms are presented in Table 13. Statistically significant increases in the crude hazard ratios were observed for participants with keyboard to elbow height differences greater than zero (i.e., elbow below the keyboard; HR=1.47, 95% CI=1.01-2.14) and for those whose phone was equipped with a telephone shoulder rest (HR=1.85; 95% CI=1.03-3.30). A significant decrease in risk was observed among those with inner elbow angle greater than 121° (HR=0.50, 95% CI=0.30-0.82).

Those with keyboard shoulder flexion angles greater than 35° (the highest quartile) had lower risk than those with keyboard flexion angles of less than 23° (the lowest quartile, HR=0.66, 95% CI=0.37-1.18). A crude hazard ratio of 0.71 (95% CI=0.45-1.13) was observed for those whose keyboard was located with the "J" key greater than 17 cm from the table (or desk) edge in comparison to those whose keyboards were closer to the edge of the table. When compared to the lowest quartile, the crude hazard ratios for the remaining three quartiles of mouse shoulder flexion angle ranged from 1.23 to 1.66. However, no trend with increasing shoulder flexion angle was apparent. Only small changes were observed in the hazard ratios when adjusted for

age, sex, height, and hours keying per week with the exception of keyboard inner elbow angle, which got stronger with adjustment.

Neck/Shoulder Disorders

Crude and covariate-adjusted associations between ergonomic risk factors and incident neck/shoulder disorders are presented in Table 14. While the results for neck/shoulder disorders were similar to those for neck/shoulder symptoms, the only crude associations to achieve statistical significance were the presence of a telephone shoulder rest (HR=2.78, 95%CI=1.46-5.32) and the presence of chair armrests (HR=0.60, 95% CI=0.36-0.97). A non-significant increase in risk was observed for those participants with a keyboard to elbow height difference between 0 and 2.3 centimeters (HR=1.56, 95% CI=0.90-2.70). However, individuals with elbow height more than 2.3 centimeters below the "J" key height were not at increased risk (HR=0.91, 95% CI=0.48-1.69). A non-significant decrease in risk was observed for those with keyboard inner elbow angle greater than 121° (HR=0.64; 95% CI=0.35-1.18). A crude hazard ratio of 1.76 (0.87-3.55) was observed for monitor head tilt angles greater than three degrees.

With the exception of keyboard inner elbow angle, only small changes were observed in the hazard ratios in comparison to the crude associations when adjusted for age, sex, years keying greater than 20 hours per week and hours keying per week. A significant interaction between keyboard inner elbow angle and hours keying per week was observed. Similar to the crude analysis, those with a keyboard inner elbow angle greater than 121° were at lower risk of neck/shoulder disorders. However, this protective effect diminished with increasing hours keying per week (data not shown).

Hand/Arm Symptoms

Crude and covariate-adjusted associations between ergonomic risk factors and incident hand/arm symptoms are presented in Table 15. The only ergonomic risk factor significantly associated with hand/arm symptoms was the distance of the "J" key from the edge of the table or desk. Study participants whose keyboards were place with the "J" key more than 12 centimeters from the table edge were at lower risk than those with keyboards placed closer to the table edge (HR=0.61, 95% CI=0.40-0.92). Study participants with keyboards that had the "J" key more than 3.5 cm above the table surface were more likely to report hand/arm symptoms than those with lower "J" keys but the association was not statistically significant (HR=1.54, 95% CI=0.96-2.49). Consistent with this finding was a non-significant increase in risk among participants with keyboard wrist extension angles greater than 30° in comparison to those with wrist extension angles of 30° or less (HR=1.28, 95% CI=0.81-2.01). When associations between ergonomic risk factors and hand/arm symptoms were adjusted for age, sex, smoking, education, years keying greater than 20 hours per week, and hours keying per week only small changes were observed in the hazard ratios in comparison to the crude associations.

Hand/Arm Disorders

Crude and covariate-adjusted associations between ergonomic risk factors and incident hand/arm disorders are presented in Table 16. Similar to hand/arm disorders, study participants whose keyboards were located with the "J" key more than 12 centimeters from the table edge were significantly less likely to report symptoms than those with keyboards placed closer to the table edge (HR=0.47, 95% CI=0.27-0.83). No consistent association was observed between keyboard

wrist extension and hand/arm disorders. In comparison to those with neutral wrist angles while using the mouse (-5° to 5°), those with more than 5° of wrist radial deviation (i.e., <-5° wrist ulnar deviation) has a significant increase in risk of hand/arm disorders (HR=1.99, 95%CI=1.09-3.63). Greater key activation force (i.e., >48 gms) was associated with a non-significant increase in risk of experiencing hand/arm disorders (HR=1.81, 95% CI=0.89-3.70). When associations between ergonomic risk factors and hand/arm disorders were adjusted for age, sex, smoking, body mass index, and hours keying per week only small changes were observed in the hazard ratios in comparison to the crude associations.

Final multivariable models of ergonomic exposures and incident musculoskeletal symptoms and incident musculoskeletal disorders

Neck/Shoulder Symptoms. The final multivariable model of neck/shoulder symptoms is presented in Table 17. Ergonomic exposure variables were included in the final multivariable model if their hazard ratios deviated from 1.0 with a probability of <0.10. Elevated risks were observed for keyboard height from floor greater than elbow height from floor, mouse inner elbow angle >137°-148°, monitor head tilt angle >3°, and the presence of a telephone shoulder rest. A protective effect was observed for keyboard inner elbow angle >121° but was attenuated with increasing levels of weekly hours keying. For example, those with angles >121° had a nearly 75 percent lower risk of neck/shoulder symptoms at 10 hours keying weekly whereas at 20 and 30 hours keying, the relative hazards were only approximately 55 and 30 percent lower, respectively (Table 21).

The presence of a telephone shoulder rest resulted in a doubling of the hazard of neck/shoulder symptoms (HR=2.05, 95% CI=1.14-3.71). While the second quartile of mouse inner elbow angle was associated with a statistically significant increase in the risk compared to the lower two quartiles (combined), the fourth quartile was not associated with increased risk of neck/shoulder symptoms.

Controlling for the ergonomic factors as well as sex and weekly hours keying, age 30 years and older was a significant predictor of neck/shoulder symptoms (HR=1.79, 95% CI=1.19-2.70). Women had a slight but not statistically significant higher risk than men (HR=1.31, 95% CI=0.83-2.06). Independent of keyboard inner elbow angle, weekly hours keying was not a statistically significant predictor of neck/shoulder symptoms.

Neck/shoulder Disorders. The final multivariable model of neck/shoulder disorders is presented in Table 18. Ergonomic exposure variables were included in the final multivariable model if their hazard ratios deviated from 1.0 with a probability of <0.10. An elevated risk was observed for presence of a telephone shoulder rest. Participants using a telephone shoulder rest had nearly three times the hazard of neck/shoulder disorders compared to participants who did not use a shoulder rest while telephoning (HR=2.71, 95% CI=1.40-5.23). A protective effect was observed for keyboard inner elbow angle >121° but it was attenuated with increasing levels of weekly hours keying. For example, the approximately 75 percent lower hazard observed at 10 hours keying was reduced to a 50 percent lower hazard at 20 hours. Keyboard inner elbow angle was not protective for participants keying 30 or more hours per week (Table 22).

Controlling for the ergonomic factors as well as sex and hours keying, participants aged 40 years and over had a higher risk for neck/shoulder disorders (HR=1.75, 95%CI=1.04-2.93). Women had a slight, but not statistically significant, higher risk (HR=1.37, 95% CI=0.77-2.44).

Hand/arm symptoms. The final multivariable model of hand/arm symptoms is presented in Table 19. Ergonomic exposure variables were included in the final multivariable model if their hazard ratios deviated from 1.0 with a probability of <0.10. Ergonomic factors that were significantly associated with hand/arm symptoms were the presence of a keyboard wrist rest and the distance of the "J" key from the table edge. The risk of hand/arm symptoms was modestly but statistically significantly elevated among those using a keyboard wrist rest (HR=1.66, 95% CI=1.03-2.67). The risk of hand/arm symptoms was significantly decreased among those with the keyboard "J" key 12 or more cm from the table or desk edge (HR=0.50, 95% CI=0.32-0.80) compared to those keying with the keyboard "J" key closer to the edge.

Controlling for the ergonomic factors as well as sex, and weekly hours keying, participants aged 40 and above were marginally associated with increased hazard of hand/arm symptoms (HR=1.55, 95% CI=0.99-2.43). The approximately 60 percent higher risk for women compared to men also was marginally significant. The association between female sex and hand/arm symptoms was only apparent after approximately eight weeks of follow-up (data not shown). Independent of age, sex, and the ergonomic predictors, weekly hours keying was significantly associated with hand/arm symptoms (HR=1.04, 95% CI=1.02-1.06). This hazard ratio represents the increased risk associated with each additional hour of keying per week. For perspective, using the HR estimate of 1.04 per hour of keying, a difference of 20 keying hours per week would result in more than doubling of the risk for hand/arm symptoms (HR=2.19 per 20 keying hours).

Hand/Arm Disorders. The final multivariable model of hand/arm disorders is presented in Table 20. Ergonomic exposure variables were included in the final multivariable model if their hazard ratios deviated from 1.0 with a probability of <0.10. Ergonomic factors that were significantly associated with hand/arm disorders were presence of a keyboard wrist rest, wrist radial deviation when using a computer mouse, and the distance of the "J" key from the table edge. Consistent with the results for hand/arm symptoms, the risk for hand/arm disorders was significantly decreased among those with the keyboard "J" key 12 cm or more from the table or desk edge (HR=0.38, 95% CI=0.20-0.71). The risk of hand/arm disorders was significantly increased among those using a keyboard wrist rest was nearly double that of participants not using a wrist rest (HR=1.96, 95% CI=1.05-3.65). Mouse wrist ulnar deviation of less than -5° (i.e., more than 5° of wrist *radial* deviation) was associated with significantly increased hazard of hand/arm disorders (HR=1.82, 95% CI-1.03-3.22).

Controlling for the ergonomic factors as well as sex, and weekly hours keying, participants aged 40 years and over had a moderate, but not statistically significant, higher hazard for hand/arm disorders (HR=1.58, 95%CI=0.89-2.82). The risk for hand/arm disorders among women was more than twice that for men (HR=2.18, 95% CI=1.09-4.34). Consistent with the findings for hand/arm symptoms, each hour increase in weekly hours keying was associated with a 4 percent increase in the risk of hand/arm disorders (HR=1.04, 95% CI=1.02-1.06).

Additional Analyses

Finally, when analyses were performed to assess for possible confounding by psychosocial variables of the relationship between ergonomic variables and survival to each of the four outcomes, no psychosocial variables met criteria for confounding and none were included in the four final models. Furthermore, when analyses were limited to health events occurring on the right side only, no meaningful change in any of the hazard ratios was observed (data not shown). The models reported are those run on datasets that included all health outcomes, regardless of body side.

DISCUSSION

ERGONOMIC ASSESSMENTS

Relationships between workstation dimensions and operator posture

The strengths of the relationships between workstation dimensions and operator posture were heterogeneous. For example a relatively strong associations was observed between gaze angle and monitor height but no association was observed between wrist extension and keyboard thickness (before and after stratifying by use of wrist rests) and only a modest association was observed between inner elbow angle and the height of the elbow above the keyboard. Similarly, shoulder flexion was only modestly associated with keyboard height.

A much stronger correlation was observed between elbow height and keyboard height than between eye height and monitor height. These results suggest that current office furniture design and/or adjustment practice preferentially locates the height of the elbow at or near keyboard height without similar attention to the height of the eyes with respect to the monitor height. This apparent inattention to monitor placement has been described by others [Arndt, 1983].

Relationship between workstation characteristics and operator posture

Having an easily adjustable chair (one equipped with a pneumatic/hydraulic mechanism that could be operated from a seated position) had no observable association with the postures measured. The authors did not collect information about actual use of the chair adjustment. It is possible that the subset of participants who actually used the chair adjustment or had high quality posture training had different postures than those who did not. Regardless, the absence of differences in postural measures as a function of chair adjustability indicates that, at least, among participants in the current study, the simple provision of an adjustable chair was not sufficient to influence working posture.

Use of wrist-rests as well as location of the keyboard (above, on, or below the work-surface) had small but statistically significant associations with specific postures. Wrist extension was greater among those not using a wrist rest than among those who were using one. Wrist extension was also greater among those whose keyboards were located below the work surface in comparison to those for whom the keyboard was located on the work surface.

Inspection of the results of postural measures for the upper limb as a function of input device shows that reaching with the upper limb occurred while participants operated the mouse. Specifically, when compared to the posture at the keyboard, the inner elbow, shoulder abduction, and shoulder flexion angles were increased for mouse use. Wrist ulnar deviation was decreased only slightly and wrist extension was essentially unchanged with mouse use. Only one other paper was identified in the peer reviewed literature in which postural measures were obtained among mouse users [Karlqvist et al., 1994]. In that study, similar changes were observed in the elbow and shoulder angles between mouse and keyboard use.

Comparison with other studies

The postures observed among participants in the current study are generally consistent with those reported by other investigators. Comparisons between other studies which provide similar ergonomic measures and the current study appear in Table 23. In particular, remarkable similarity between the current study and that of Hales et al. [1992] was observed, with no major

differences on any of the ergonomic measures. Several small differences were observed between the current results and those of Grandjean et al. [1983]. Specifically, the inner elbow, shoulder abduction, and shoulder flexion angles appear to differ slightly between the two populations. One possible explanation for the differences in results observed between these two studies is that participants in the study by Grandjean et al. were working in their "preferred body posture" while those in the current study were not necessarily so positioned. Preferred body postures were achieved by Grandjean, et al. by providing fully adjustable workstations to all study participants and by providing intensive training and personal assistance to study participants wishing to change their workstations. In contrast, participants in the current study were observed as they worked in their usual jobs with workstations provided by their employers. Differences in posture between these two conditions are not unexpected.

In comparison to results observed by Sauter et al. [1991], the mean shoulder abduction angle was greater and the mean shoulder flexion angle smaller among participants in the current study. These dissimilarities appear to be due to differences in the methods used to perform the measurements. The numerical difference between seated elbow height and keyboard height (*i.e.*, elbow height from floor - keyboard height from floor) was about 9 cm larger in the study by Sauter et al. than in either the current study or that of Hales et al. This may reflect actual differences in populations or workstations across these studies or may be due to dissimilar methods.

HEALTH OUTCOME RESULTS

Newly hired workers anticipating computer use of greater than 15 hours per week were evaluated at entry to determine the prevalence of musculoskeletal symptoms and disorders. Participants free of symptoms at entry were followed prospectively for the evaluation of incident symptoms, and the participants free of disorders at entry were followed prospectively to determine the incidence of musculoskeletal disorders. The strengths of this study are the prospective design and the use of a standard clinical examination protocol with well-defined criteria to identify specific musculoskeletal disorders.

Virtually all previous studies of musculoskeletal symptoms or disorders among VDT users have been cross-sectional in design. The only other longitudinal study in the literature [Bergqvist et al., 1992] assessed prevalent musculoskeletal symptoms at two points in time six years apart. Individuals were not followed during the intervening six years. Therefore, it is impossible to determine the incidence of musculoskeletal symptoms which may have occurred and resolved during the six year interval.

In the current study 10 percent of newly hired computer users reported prevalent (i.e., during the past week) neck or shoulder symptoms and four percent reported prevalent hand or arm symptoms. When these individuals were examined clinically with a standard protocol, 70 percent of participants with neck/shoulder symptoms met criteria for a neck/shoulder disorder (almost all of these were somatic pain syndrome). Sixty-four percent of participants with hand/arm symptoms met criteria for a hand/arm disorder. The majority of the hand/arm disorders were tendon-related, with the most common being deQuervain's tendonitis (i.e., dorsal compartment 1 extensor tendonitis).

The prevalence of musculoskeletal symptoms found in this study are somewhat lower than those reported in other studies of VDT users in the literature. These differences in prevalence may reflect differences in the time periods used to calculate period prevalence, populations studied, and criteria used for ascertainment of symptom. For example, Berqvist et al. [1995] found 62 percent of VDT users reported neck or shoulder discomfort in the past year and Bernard et al. [1994] found 26 percent of users reported neck discomfort and 17 percent reported shoulder discomfort in the past year. When the time period in the Berqvist et al. [1995] study was narrowed to include only those symptoms that interfered with work during the previous seven days (the time period used in the current study), the prevalence of neck or shoulder symptoms dropped to seven percent. In the study of Berqvist et al. [1995], the prevalence of hand or arm discomfort in the past year was 30 percent and in the study of Bernard et al. [1994], the prevalence of hand or wrist discomfort in the past year was 22 percent. When the time period in the Bernard et al. [1994] study was narrowed to include only those symptoms prevalent in the previous seven days, the prevalence of hand or wrist symptoms was reduced to 11 percent. In addition to these differences in the time period used to calculate prevalence, both Bergqvist et al. [1995] and Bernard et al. [1994] studied subjects who were well-established in jobs requiring computer use, whereas in the current study prevalence data are provided for study subjects with widely varying prior experience who were just starting such jobs.

In the current study, the prevalence of examination confirmed neck or shoulder disorders at entry was 6 percent and the prevalence of examination confirmed hand or arm disorders was 2 percent. Few studies in the literature have incorporated examination criteria into their definitions of musculoskeletal disorders and even fewer present the data in a format that allows for calculation of prevalence. Examination by a physiotherapist was incorporated into the Berqvist et al. [1995] study resulting in a prevalence of 22 percent for neck diagnoses and 9 percent for hand/arm diagnoses. In a study of telephone operators using VDTs, [Hales et al., 1994], the prevalence of examination confirmed neck disorders was 9 percent and examination confirmed hand/wrist disorders was 12 percent.

Very few study participants met criteria for carpal tunnel syndrome. Identification of subjects with carpal tunnel syndrome in the current study required both characteristic symptoms and a prolonged median sensory nerve conduction latency measured from wrist to index finger. Use of symptoms and electrophysiological measurements, as performed in the current study, has recently been recommended as the preferred method for identification of carpal tunnel syndrome in epidemiological studies [Rempel et al., 1998]. Among 22 study participants examined because they reported symptoms compatible with carpal tunnel syndrome at entry into the study, three met criteria for carpal tunnel syndrome (13.6 percent of those examined; prevalence = 0.5 percent). During the follow-up phase of the study, only three additional study participants met the study case definition for carpal tunnel syndrome (incidence rate = 0.9 cases/100 person years). This is contrary to the widely-held perception that carpal tunnel syndrome is common among computer users.

Our observations regarding the prevalence of carpal tunnel syndrome are not inconsistent with the few studies of VDT users that have attempted to estimate its prevalence. In a study of musculoskeletal disorders among communication workers using VDTs, Hales et al. [1993, 1994] examined 517 study participants of whom four subjects (one percent) met symptom and clinical

examination criteria for carpal tunnel syndrome. In a study of computer users at a large newspaper, eight of 130 symptomatic participants who were examined met a physical examination-based case definition of carpal tunnel syndrome (6 percent of those examined; estimated prevalence of 1.3 percent) [Bernard et al., 1993, Bernard et al., 1994]. Measures of median and ulnar nerve conduction velocity were also performed during that study, however, the results were not reported in a way that allows enumeration of carpal tunnel syndrome cases by electrophysiological criteria. A well-defined case definition of carpal tunnel syndrome, including nerve conduction measures, was used by Franzblau et al. [1993] in a study of VDT users. However, the small sample size (n=26) precludes stable estimation of carpal tunnel syndrome prevalence from that study. We are aware of no studies that have attempted to estimate the incidence of carpal tunnel syndrome among computer users.

The incidence of musculoskeletal symptoms (among those asymptomatic at entry) was high and was concentrated in the first months of follow-up. The annual incidence of neck or shoulder symptoms was 57.5 cases/100 person-years and the annual incidence of hand or arm symptoms was 38.8 cases/100 person-years. A large proportion of these cases occurred in the first month of follow-up; 46 percent of neck/shoulder symptom cases and 32 percent of hand/arm symptom cases occurred during the first month. The early occurrence of these symptoms is contrary to the notion that these symptoms are due to "cumulative trauma". However, when the risk of hand/arm symptoms was stratified by previous computer experience, individuals with no previous computer work greater than 25 hours per week had significantly lower risk of experiencing symptoms during the study. There were no differences observed in the risk of neck/shoulder symptoms by prior computer use. Therefore, our data offers evidence for a cumulative effect of previous computer use on the occurrence of hand/arm symptoms but not on the occurrence of neck/shoulder symptoms.

A large proportion of study participants who were symptomatic met criteria for specific musculoskeletal disorders. Not surprisingly, the temporal patterns for the incidence of disorders were similar to the temporal patterns for the incidence of the corresponding symptoms. In addition, the stratified analyses of disorders by age, gender and previous computer use yielded results nearly identical to the stratified analyses of the corresponding symptoms. .

One limitation of the study is that individuals entered the follow-up period with prior exposure to computer use. The survival experience in this study of individuals with previous computer use not greater than 25 hours/week represents our best approximation of the natural history of the development of musculoskeletal symptoms and disorders among VDT users. The risk of developing a hand/arm symptom or disorder during the study was significantly lower for those individuals with previous computer use not greater than 25 hours per week . The risk of developing neck/shoulder symptoms or disorders was not related to duration of previous computer use.

ERGONOMIC FACTORS AND INCIDENT MUSCULOSKELETAL SYMPTOMS AND DISORDERS

These results of the current study among computer users suggest that a seated posture in which the keyboard is low and some distance away from the operator is associated with a lower risk of musculoskeletal symptoms and disorders than one in which the keyboard is at or above elbow

height and close to the operator. Other elements of operator posture observed in this study to reduce risk include supporting of the arms on either the desk surface or chair arm rests and removal of telephone handset shoulder rests. Radial deviation while using the mouse increased risk. Furthermore, even after controlling for the effects of posture, hours keying per week was a risk factor for hand/arm symptoms and disorders. Some of these results are contrary to the common conception of "good computer ergonomics" often described as a position in which the arm is perpendicular to the floor, the elbow is maintained at a right angle, the forearm is parallel to the floor, and the keyboard is located at or above elbow height and near the edge of the desk or drawer on which it is placed.

Individuals with inner elbow angles >121° were less likely to develop neck/shoulder symptoms and disorders. Because shoulder flexion has previously been observed to be collinear with inner elbow angle, it was not included in any models that also included inner elbow angle [Gerr et al., 2000]. As a result, no estimation of its independent effect on symptoms or disorders was obtained. Study participants with inner elbow angles >121° had a mean shoulder flexion angle of 38° (SD=8.6°). Elbow height lower than "J" key height was a marginally significant risk factor for neck/shoulder symptoms and a statistically significant risk factor for neck/shoulder disorders. Presence of a telephone shoulder rest was associated with a two-fold increased risk of both neck/shoulder symptoms and neck/shoulder disorders.

While no association was found between wrist extension and hand/arm symptoms or disorders, keyboards with the "J" key 3.5 or more centimeters above the table surface were associated with a significant increase in hand/arm symptoms. A keyboard meeting this criterion would, it seems, increase wrist extension. Therefore, the fact that no association with wrist extension was observed is somewhat surprising. It may be that the measure of wrist extension used in the current study was a more variable estimator of actual wrist extension than was the measure of "J" key height from the table surface. This possibility is supported somewhat by the observation that wrist extension is among the more variable of the postural measures used in this study [Ortiz et al., 1997]. It is possible that wrist extension would have been associated with hand/arm symptoms or disorders had a more precise measure been used.

Also surprising was the observation that the presence of a wrist rest was associated with increased risk of both hand/arm symptoms and hand/arm disorders, despite the fact that it should reduce the effective height of the "J" key with respect to the location of the operator's hands and wrists. However, the association was essentially observed only among the small number of participants who both had a wrist rest and had keyboards positioned so that the "J" key was less than 12 centimeters from the edge of the desk. Horizontal location of the "J" key less than 12 centimeters from the edge of the desk was associated with increased risk of both hand/arm symptoms and hand/arm disorders. Under such circumstances, the wrist rest used by those who developed symptoms and disorders was narrower than the common 7.5 centimeter wrist rest width. Given this observation, we do not believe that these results indicate that wrist rests of 7.5 centimeter or greater width are a risk to computer users.

Hours per day of keyboard activity was associated with hand/arm symptoms and hand/arm disorders. The hazard ratio for both hand/arm symptoms and hand/arm disorders was 1.04 per hour of keying weekly. Assuming a linear relationship, the risk of both hand/arm symptoms and

hand/arm disorders increases 2.2 fold with an increase of 20 hours per week of keying. Neither wrist posture nor elbow posture was retained in multivariable models of hand/arm symptoms or hand/arm disorders.

Comparison to prior studies

Few field-based epidemiological studies of the relationship between posture and musculoskeletal symptoms or disorders among computer users are available in the peer-reviewed biomedical literature. None have examined the relationship between posture and musculoskeletal disorders using data collected from a prospective study. The few cross sectional studies that are available have produced inconsistent results.

Hunting et al [1981] performed a cross-sectional study of 162 workers using VDTs and 133 comparison subjects. Contrary to observations made in the current study, ulnar deviation greater than 20° was associated with increased abnormalities on physical examination for some categories of VDT work, greater keyboard height was associated with musculoskeletal discomfort of neck, shoulder, and arms, and increased head inclination was associated with increased discomfort and clinical abnormality. Consistent with the current study was the observation that working with hands and forearms supported was associated with decreased reporting of neck, shoulder and arm pain.

Starr et al. [1985], performed a cross-sectional investigation of the relationship between monitor viewing angle, neck angle, trunk angle, upper arm angle, forearm angle, hand angle, and elbow angle and self-reported symptoms of back and upper limb discomfort among 100 video display terminal operators. Contrary to the current study, discomfort increased with downward monitor viewing angle. No other associations were observed.

Sauter et al. [1991] performed a cross-sectional study of discomfort and VDT use among 539 data entry VDT operators. A subsample of 40 VDT users was assessed with measurement of worker posture and workstation dimensions. Consistent with the current study, keyboard height less than elbow height was associated with less frequent discomfort. Inconsistent with the current study was their observation that right wrist ulnar deviation was associated with musculoskeletal symptoms (no association was observe in the current study). Also inconsistent with the current study was the observation that, among the full study population, neither months in current job nor weekly hours of VDT use were associated with upper extremity discomfort.

A cross-sectional study of the relationship between musculoskeletal symptoms among computer users and both posture and psychosocial factors was performed among 70 computer users in a newspaper editorial department [Faucett and Rempel, 1994]. Musculoskeletal outcomes were assessed with a questionnaire instrument. VDT workstation evaluations were performed with methods similar to those of Sauter et al., [1991]. Contrary to the current study, none of the postural variables were significantly associated with upper extremity pain indices. Head rotation and keyboard height above elbow height, however, were significantly associated with upper torso pain and stiffness severity. When musculoskeletal outcomes were dichotomized (case vs. non-case), none of the postural variables were significantly associated with case status.

A cross-sectional study of the relationships between individual, organizational, and ergonomic factors and musculoskeletal health outcomes was performed among 260 VDT users [Bergqvist, et al., 1995]. Consistent with the current study, neck/shoulder discomfort and the diagnosis of tension neck syndrome were significantly associated with reports of "too highly placed keyboard" and neck and shoulder discomfort was associated (but not significantly) with "too highly placed VDT". Work with the hand in "non-neutral position" (which was not clearly defined) was significantly associated with arm/hand discomforts but not with any arm/hand diagnosis.

Numerous methodological differences may account for the discrepancies in associations observed between the current study and those reported in the literature. Unlike the studies reviewed above, the current study was prospective in design with measures of posture obtained before the onset of symptoms. The possibility that computer users change posture when symptoms occur may bias results in cross sectional studies obscuring true temporal associations between exposure and health effect. The sample sizes of the studies described above were often much smaller than that of the current study, resulting in diminished power to observe associations of modest magnitude. Less complete control of confounding in some previous studies also may account for differences in results. Finally, imprecise measures of postural variables may have attenuated some results in previous studies.

STRENGTHS AND WEAKNESSES OF THE CURRENT STUDY

In the current study, manual goniometry was used to measure posture and measurements were performed at a single point in time (unless a change in the workplace was reported in which case measures were repeated). Manual goniometry was chosen because of its rapidity, reliability, low cost, and high acceptability to both study participants and their employers. The complete assessment of the workstation and the worker's posture was accomplished in about 20 minutes. Other, more labor and equipment-intensive methods, such as video analysis, are more costly and require more time for set-up, data collection, and analyses of raw data. The feasibility of this and other sophisticated methods for evaluation of posture among several hundred computer users located in multiple sites appears limited. Manual goniometry is a well established and valid method of measuring posture in ergonomics, anthropometry, and physical therapy [Sauter et al., 1991; Maeda et al., 1982; Lastayo and Wheeler, 1994; Ortiz et al, 1997]. When used to assess computer operators, it has been shown to have good agreement with more costly, time consuming, and complex video analyses of posture [Wrigley et al., 1991]. Furthermore, the use of goniometers allows for comparison of the results obtained in the current study with those found by other investigators who also used this method [Grandjean et al., 1983, Sauter et al., 1991, Faucett and Rempel, 1994, Hales et al., 1992].

The specific postural measurement methods used in this study were tested by the investigators prior to their use and found to have minimal inter-rater variability and good reliability regardless of time-of-day or day-of-week in a test-retest validation study [Ortiz et al., 1997]. In addition, on repeated measures, within-participant variability was significantly smaller than between-participant variability, demonstrating that changes over time for individual participants were substantially smaller than differences in posture between participants. These findings suggest that single time point measures are adequately representative of operator posture over time. The stability of postural measures among keyboard users has also been reported by others [Hunting et

al., 1980]. In addition, in order to account for some of the dynamic elements of posture during computer use, upper extremity postures were measured while operators used the numeric keypad and the mouse as well as the alphabetic keyboard and head postures were measured while operators viewed a document, if present, as well as the computer monitor.

While postures were measured during use of the computer mouse, the amount of mouse use was not well quantified in the current study. It is possible that some associations between musculoskeletal outcomes and mouse posture were attenuated as a result of not accounting for differences in mouse use among study participants.

RECOMMENDATIONS

In light of the results of the current study, the seated position traditionally recommended for computer users with upper arms perpendicular to the floor, elbows kept at a right angle, forearms parallel to the floor, and the keyboard at or above elbow height and near the edge of the desk or tray appears to result in increased risk of musculoskeletal symptoms and disorders among computer users. Despite the widespread promulgation of this posture, it appears to have gained near universal acceptance without epidemiological evidence of its efficacy and it should now be viewed with skepticism. Clinical trials of various seated postures should be performed to assess their effectiveness for reduction of risk of musculoskeletal symptoms and disorders among computer users.

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TABLE 1.
Ergonomic variables obtained during the study

WORKSTATION FEATURES
Wrist rest present
Shoulder rest used
Arm rest present on chair
Sharp leading edge of desk or table
Key activation force (grams)

POSTURE WHILE USING KEYBOARD or MOUSE
Wrist ulnar deviation
Wrist extension
Shoulder flexion
Shoulder abduction
Inner elbow angle
Head tilt angle
Head rotation angle

LINEAR MEASUREMENTS
Difference between "J" key height and elbow height while keying
Edge of "J" key from edge of desk

Table 2. Upper limb postural angles measured for keyboard, keypad and mouse.

Postural Angle	Keyboard	Keypad	Mouse
Wrist ulnar deviation	x	x	x
Wrist extension	x	x	x
Inner elbow angle	x		x
Shoulder flexion	x		x
Shoulder abduction	x		x

Table 3. Placement of goniometer pivot and arms for each postural measurement. (Postural angles measured in degrees)

Wrist ulnar/radial deviation
- Pivot placed on midpoint between ulnar and radial styloid processes
- First arm placed at the midline of dorsal aspect of the forearm
- Second arm aligned with the midline of the long finger metacarpophalangeal joint

Wrist flexion/extension
- Pivot placed on the radial styloid process
- First arm aligned with the radius
- Second arm aligned with the midline of the index finger metacarpophalangeal joint

Elbow angle
- Pivot placed on lateral epicondyle of the humerus
- First arm aligned with the acromion process of the shoulder
- Second arm aligned with the ulnar styloid process

Shoulder flexion/extension
- Pivot placed on lateral aspect of acromion process of the shoulder
- First arm aligned vertically (carpenter's level for reference)
- Second arm aligned with the lateral epicondyle of the humerus

Shoulder abduction/adduction
- Pivot placed on posterior aspect of acromion process of the shoulder
- First arm aligned vertically (carpenter's level for reference)
- Second arm aligned with posterior midline of upper arm

Gaze angle
- Pivot placed on the ectocanthus of the eye
- First arm aligned vertically (carpenter's level for reference)
- Second arm aligned with center of video display screen

Head tilt angle
- Pivot placed on tragion
- First arm aligned horizontally (carpenter's level for reference)
- Second arm aligned with the infraorbitale of the eye

Head rotation angle
- Pivot placed on center of the head
- First arm aligned with the sagittal plane
- Second arm aligned with the nose

Table 4. Characteristics of the VDT-users population (N = 632)

Characteristic	Freq.	Percent
Sex		
Proportion female	448	70.9
Age (years)		
< 20	3	0.5
20 – 29	252	39.9
30 – 39	236	37.3
40 – 49	115	18.2
50 – 59	26	4.1
Ethnicity		
White, non-Hispanic	363	57.4
Black, non-Hispanic	221	35.0
Hispanic	16	2.5
Native American	1	0.2
Asian/Pacific Islander	22	3.5
Other	9	1.4
Education		
High school graduate	49	7.8
Technical training	31	4.9
Associate degree or some college	159	25.2
College graduate	393	62.2
Annual household income (USD)		
Under $15,000	26	4.3
$15,000 – 24,999	131	21.7
$25,000 – 34,999	133	22.0
$35,000 – 49,999	105	17.4
$50,000 – 74,999	125	20.7
$75,000 or over	84	13.9
Unknown	28	*
Occupation		
Executive	14	2.3
Professional	171	27.9
Technical	26	4.2
Sales	54	8.8
Secretarial	349	56.8
Handedness		
Proportion right handed	562	89.1
Pregnancy status**		
Proportion pregnant	12	1.3
Proportion possibly pregnant	4	0.6
Menopause status**		
Proportion post-menopausal	46	10.5
OCP or estrogen hormone status**		
Proportion taking hormones	152	33.9

(Table 4 continued on next page)

Table 4. Characteristics of the VDT-users population (continued)

Characteristic	Freq.	Percent
Proportion of current smokers	79	12.8
Body mass index (kg/m^2)		
<18.5	15	2.4
18.5-24.9	359	58.0
25.0-29.9	153	24.7
30.0-34.9	60	9.7
35.0-39.9	22	3.6
>= 40	10	1.6
Unknown	13	*
Work practices		
Hours at office per week***		
<35 hours	99	16.6
35 - <40 hours	299	50.3
>= 40 hours	197	33.1
Hours keying per week***		
<15 hours	192	32.3
15 - <20 hours	122	20.5
20 - <25 hours	103	17.3
25 - <30 hours	78	13.1
>= 30 hours	100	16.8
Previous years in jobs with computer hours >=25***		
None	226	38.0
>0 - <4 years	159	26.7
>=4 – <8 years	123	20.7
>=8 years	87	14.6
Average weekly aerobic activity***		
None	197	33.1
< 30 minutes	161	27.1
30 min- < 1 hr	73	12.3
1 hr - <1.5 hrs	44	7.4
1.5 hrs-< 2 hrs	40	6.7
2 hrs- < 3 hrs	41	6.9
3 hrs or more	39	6.5
Average weekly hand intensive activity (non-occupational)***		
None	156	26.2
< 30 minutes	114	19.2
30 min- < 1 hr	83	13.9
1 hr - <1.5 hrs	50	8.4
1.5 hrs-< 2 hrs	35	5.9
2 hrs- < 3 hrs	52	8.8
3 hrs or more	105	17.7

* Number excluded from %ages
** Results limited to females only, N=448
*** Results limited to subjects completing weekly checklists N=595

Table 5. VDT workstation physical attributes (N=379)

Attribute present	Number	Percent (%)
Mouse	357	94.2
Other pointing device	9	2.4
Keyboard wrist-rest	101	26.6
Mouse wrist-rest	18	4.7
Headphones	49	12.9
Adjustable chair	232	61.2
Chair arm rest	265	69.9
Sharp leading edge	155	40.9
Adjustable keyboard height	48	12.7
Document holder present	149	39.3
Keyboard positioned on table surface	259	68.3
Keyboard positioned below table surface	98	25.9
Keyboard positioned above table surface	22	5.8

Table 6. VDT workstation dimensions (N=379)

Measure	Mean	Median	SD	Range
Table height (cm.)	70.7	72.0	4.4	58.0 - 79.5
J key height from table (cm.)	3.4	3.0	0.6	2.0 - 7.0
J key height from floor (cm.)	74.1	75.5	4.3	62.0 - 81.7
Monitor height from table surface (cm.)	35.4	36.0	8.7	-7.5 - 62.0
Monitor height from floor (cm.)	106.2	106.7	8.3	54.0 - 138.8
Edge table to J key (cm.)	14.3	12.5	7.1	5.0 - 42.5
Document height from floor (cm.) *	79.2	74.5	11.4	58.7 - 130.0

* N = 372, **N = 375

Table 7. VDT workstation/worker linear measures and head and neck postures (N=379)

Measure	Mean	Median	SD	Range
Linear measures (cm.)				
Elbow height from floor	73.8	74.0	4.2	59.0 - 84.0
Eye height from floor	116.8	117.0	4.4	105.0 - 127.0
Eye to midpoint of monitor	64.7	63.5	11.5	38.0 - 117.5
Eye to midpoint of document *	60.6	60.0	9.6	31.0 - 99.5
Head and neck posture (degrees)**				
Head rotation angle, monitor	-1.4	0.0	11.6	-43.0 - 41.0
Head rotation angle, document *	8.8	18.0	27.9	-64.0 - 72.0
Gaze angle, monitor	-11.5	-12.0	8.8	-43.0 - 25.0
Gaze angle, document *	-36.7	-40.0	13.5	-72.0 - 28.0
Head tilt angle, monitor	9.5	10.0	7.0	-19.0 - 26.0
Head tilt angle, document *	0.3	3.0	12.1	-50.0 - 30.0

* N = 372 (Excludes individuals who do not use a document)

** Head rotation left = +; head rotation right = -;
Gaze angle above horizontal = +; gaze angle below horizontal = -:

Table 8. Upper limb posture as a function of input device, right side (all values in degrees).

Posture	Keyboard (N = 379)			Keypad (N = 375)			Mouse (N = 346)		
	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
Wrist ulnar deviation	5.0	7.3	-15 to 30	1.5	7.6	-25 to 24	1.0	7.7	-19 to 26
Wrist extension	24.3	9.6	-20 to 50	24.7	10.6	-9 to 60	23.0	8.8	-4 to 45
Inner elbow	112.7	13.3	81 to 152	-	-	-	136.5	16.6	78 to 170
Shoulder abduction	14.0	5.3	3 to 34	-	-	-	27.0	9.7	-15 to 57
Shoulder flexion	28.6	10.4	-6 to 62	-	-	-	34.3	13.8	-13 to 68

Table 9. Correlation matrix for selected postural angles and linear measures (right side)

	Wrist extens (kybd)	Wrist uln dev (kybd)	Elbow angle (kybd)	Shldr abduct (kybd)	Shldr flexn (kybd)	Gaze angle (mon)	Head tilt angle (mon)	Gaze angle (doc)	Head tilt angle (doc)	Key height from surface	Key height from floor	Monitor height from floor	Elbow height	Elbow height - key height	Eye height
Wrist extension (keybd)	1.00														
Wrist ulnar dev (kybd)	-0.14	1.00													
Inner elbow angle (kybd)	0.24	-0.23	1.00												
Shoulder abduction (kybd)	-0.14	-0.06	-0.06	1.00											
Shoulder flexion (kybd)	-0.09	-0.17	0.66	0.22	1.00										
Gaze angle (monitor)	-0.04	-0.05	0.00	0.22	0.13	1.00									
Head tilt angle (monitor)	0.06	-0.06	-0.05	0.06	-0.10	0.22	1.00								
Gaze angle (document)	0.06	0.03	-0.10	-0.08	-0.08	0.22	0.06	1.0							
Head tilt angle (document)	0.10	0.05	-0.13	-0.07	-0.17	0.10	0.40	0.5	1.00						
Key height from surface	0.07	-0.05	0.07	-0.01	0.00	0.04	0.05	0.1	0.12	1.00					
Key height from floor	-0.24	0.00	-0.01	0.14	0.36	0.04	0.00	-0.1	-0.18	0.00	1.0				
Monitor height from floor	0.00	0.03	-0.03	0.12	-0.01	0.70	0.32	0.1	0.10	-0.03	0.1	1.00			
Elbow height from floor	-0.08	0.03	0.38	0.07	0.39	-0.10	-0.08	-0.2	-0.23	-0.06	0.6	0.14	1.00		
Elbow height - key height	0.18	0.04	0.43	-0.08	0.03	-0.15	-0.09	-0.0	-0.05	-0.06	-0.4	-0.03	0.43	1.00	
Eye height from floor	0.05	0.09	0.10	-0.18	-0.16	-0.28	0.01	-0.1	-0.12	-0.05	0.2	0.18	0.46	-0.26	1.00

Kybd=keyboard, mon=monitor, doc=document

TABLE 10. OCCUPATIONAL PSYCHOSOCIAL QUESTIONNAIRE RESULTS (N = 478)

SCALE OR VARIABLE	Chronbach's Alpha*	Mean	Standard Deviation
JOB VARIANCE	0.76	9.4	2.5
How often is there a marked increase in your workload?	0.73	3.1	1.0
How often is there a marked increase in the amount of concentration required on your job?	0.63	3.2	1.0
How often is there a marked increase in how fast you have to think?	0.67	3.1	1.1
JOB VARIETY	0.57	8.6	1.6
How much variety is there in your job?	0.39	2.1	0.6
How often do you see projects or jobs through to completion?	0.71	2.6	0.6
How repetitious are your duties?	0.43	2.0	0.6
How similar are the tasks you perform in a typical working day?	0.40	1.9	0.6
JOB VARIETY2 (JOB VARIETY excluding "projects")	0.71	6.0	1.4
How much variety is there in your job?	0.67	2.1	0.6
How repetitious are your duties?	0.59	2.0	0.6
How similar are the tasks you perform in a typical working day?	0.59	1.9	0.6
SUPERVISOR SUPPORT (SUPPORT1)	0.83	11.9	3.1
How often does your supervisor go out of his/her way to make your work life easier?	0.77	2.7	1.0
How often can your supervisor be relied on when things get tough at work?	0.75	3.1	0.9
How often is your supervisor willing to listen to your personal problems?	0.82	2.7	1.1
How easy is it to talk to your supervisor?	0.78	3.4	0.9
COWORKER SUPPORT (SUPPORT2)	0.75	11.5	2.6
How often do other people at work go out of their way to make your work life easier?	0.66	2.6	0.9
How often can other people at work be relied on when things get tough at work?	0.63	2.8	0.9
How often are other people at work willing to listen to your personal problems?	0.71	2.6	1.0
How easy is it to talk to other people at work?	0.75	3.4	0.7
TOTAL SUPPORT AT WORK (SUPPORT1 + SUPPORT2)	0.72	23.3	5.1
SUPPORT FROM FRIENDS, SPOUSE, RELATIVES	0.76	13.0	2.5
How often do your spouse, friends, relatives go out of their way to make your work life easier?	0.70	2.8	1.0
How often can your spouse, friends, relatives be relied on when things get tough at work?	0.64	3.1	0.9
How often are your spouse, friends, relatives willing to listen to your personal problems?	0.70	3.4	0.8
How easy is it to talk to your spouse, friends, relatives	0.76	3.7	0.5

TABLE 10. OCCUPATIONAL PSYCHOSOCIAL QUESTIONNAIRE RESULTS (CONTD.)

FUTURE EMPLOYMENT SECURITY	0.63	14.7	3.5
How certain are you that you will have opportunities for promotion and advancement in the next few years?	0.52	3.2	1.4
How certain are you that your job skills will be of value five years from now?	0.45	3.9	1.1
How certain are you that you will still be working at your present job six months from now?	0.57	3.8	1.3
If you lost your job, how certain are you that you could support yourself?	0.66	3.9	1.3
HIGH INFORMATION PROCESSING DEMANDS	0.54	8.3	1.6
I can easily see or hear the info I have to use in my job	0.49	1.8	0.6
The info I have to look at or listen to is presented too rapidly	0.50	2.0	0.5
The info I receive is organized for me in ways that seem natural and easy to deal with.	0.41	2.4	0.7
I often feel mentally overburdened on my job	0.47	2.0	0.6
ROUTINE WORK LACKING DECISION MAKING OPPORTUNITIES	0.68	7.8	1.7
I can perform the activities associated with my job without thinking about them.	0.58	2.9	0.7
Most of the decisions I make are routine and easy to make.	0.50	2.4	0.7
There are set rules that I follow over and over again.	0.68	2.5	0.8
WORK PRESSURE	0.76	9.1	3.0
People cannot afford to relax	0.71	2.7	1.2
Constant pressure to keep working	0.58	3.1	1.3
Sense of urgency about everything	0.74	3.2	1.2

The value next to individual items is the alpha for the scale when that item is not included in the calculation of the scale variable value.

Table 11. Prevalence and incidence of neck/shoulder symptoms and examination confirmed disorders

	AT ENTRY				DURING FOLLOW UP						
			% of	Prevalence			% of	Incidence Rate (S.E.)			
	N	Freq.	Exams	(S.E.)	N	Freq.	Exams	1 mo.	3 mo.	6 mo.	12 mo.
Neck/Shoulder symptoms	632	63	---	10.0 (1.2)	538	183	---	17.8 (1.9)	32.1 (2.8)	48.1 (3.6)	57.5 (4.1)
Neck/Shoulder disorders (total)	622	37	69.8	5.9 (0.9)	554	117	72.6	10.8 (1.5)	19.7 (2.1)	28.7 (2.8)	35.0 (3.2)
Radicular pain syndrome	622	1	1.9	0.2 (0.2)	554	6	3.7	0.6 (0.4)	1.2 (0.5)	1.7 (0.7)	1.9 (0.8)
Somatic pain syndrome	622	36	67.9	5.8 (0.9)	554	111	68.9	10.6 (1.5)	19.0 (2.1)	27.6 (2.7)	33.2 (3.2)
Rotator cuff tendinitis	622	3	5.7	0.5 (0.3)	554	7	4.3	0.2 (0.2)	0.9 (0.5)	1.4 (0.6)	2.2 (0.8)
Bicipital tendonitis	622	1	1.9	0.2 (0.2)	554	3	1.9	0.0	0.2 (0.2)	0.6 (0.4)	0.9 (0.5)

The sum of individual disorders is greater than the number of persons with any disorder because some individuals had more than one disorder.

Prevalence defined as number of cases at entry per 100 participants at entry
Incidence rate defined as number of new cases per 100 participants followed for the designated time period

Table 12. Prevalence and incidence of hand/arm symptoms and examination confirmed disorders among VDT users.

	AT ENTRY				DURING FOLLOW UP						
			% of	Prevalence			% of	Incidence Rate (S.E.)			
	N	Freq.	Exams	(S.E.)	N	Freq.	Exams	1 mo.	3 mo.	6 mo.	12 mo.
Hand/arm symptoms	632	24	---	3.8 (0.8)	574	141	---	8.6 (1.3)	17.0 (1.9)	29.5 (2.8)	38.8 (3.3)
Hand/arm disorders (total)	630	14	63.6	2.2 (0.6)	582	81	67.5	4.9 (1.0)	9.5 (1.4)	16.3 (2.0)	21.1 (2.5)
Medial epicondylitis	630	1	4.5	0.2 (0.2)	582	5	4.2	0.6 (0.3)	0.6 (0.4)	1.0 (0.5)	1.4 (0.6)
Lateral epicondylitis	630	3	13.6	0.5 (0.3)	582	14	11.7	1.1 (0.5)	1.7 (0.6)	2.8 (0.8)	3.5 (0.5)
Flexor carpi radialis tendinitis	630	4	18.2	0.6 (0.3)	582	17	14.2	1.1 (0.5)	1.9 (0.6)	3.8 (0.9)	4.9 (1.2)
Flexor carpi ulnaris tendinitis	630	3	13.6	0.5 (0.3)	582	10	8.3	0.8 (3.8)	1.3 (0.5)	2.2 (0.8)	2.9 (0.9)
Digital flexor tendinitis	630	6	27.3	1.0 (0.4)	582	33	27.5	2.2 (0.7)	3.8 (0.9)	6.4 (1.3)	8.7 (1.6)
Ext. tendinitis - dorsal comp 1	630	8	36.4	1.3 (0.4)	582	56	46.7	3.6 (0.8)	6.8 (1.2)	11.2 (1.7)	14.7 (2.1)
Ext. tendinitis - dorsal comp 2	630	5	22.7	0.8 (0.4)	582	22	18.3	1.5 (0.5)	2.5 (0.7)	5.1 (1.1)	5.8 (1.3)
Ext. tendinitis - dorsal comp 3	630	0	0.0	0.0	582	0	0.0	----	---	---	---
Ext. tendinitis – dorsal comp 4	630	4	18.2	0.6 (0.3)	582	16	13.3	1.1 (0.5)	2.1 (0.7)	3.6 (1.0)	4.6 (1.2)
Ext. tendinitis - dorsal comp 5	630	2	9.1	0.3 (0.2)	582	9	7.5	0.6 (0.3)	1.5 (0.6)	2.3 (0.8)	2.6 (0.9)
Ext. tendinitis - dorsal comp 6	630	4	18.2	0.6 (0.3)	582	12	10.0	0.8 (0.4)	1.9 (0.6)	2.8 (0.8)	3.5 (1.0)
Intersection syndrome	630	0	0.0	0.0	582	1	0.8	---	---	---	---
Trigger finger	630	0	0.0	0.0	582	4	3.3	0.4 (0.3)	0.6 (0.4)	1.0 (0.5)	1.2 (0.6)
Carpal tunnel syndrome	630	3	13.6	0.5 (0.3)	582	3	2.5	0.2 (0.2)	0.6 (0.4)	0.8 (0.4)	0.9 (0.5)
Ulnar neuritis	630	0	0.0	0.0	582	1	0.8	---	---	---	---

The sum of individual disorders is greater than the number of persons with any disorder because some individuals had more than one disorder.

Prevalence defined as number of cases at entry per 100 participants at entry
Incidence rate defined as number of new cases per 100 participants followed for the designated time period

TABLE 13. Crude and covariate-adjusted hazard ratios for ergonomic risk factors and neck/shoulder symptoms (N=436).

ERGONOMIC RISK FACTOR	N	CRUDE HR (95% CI)	ADJUSTED* HR (95% CI)
Keyboard to elbow height difference (cm)			
<= 0	236	1.0	1.0
> 0	200	**1.47 (1.01-2.14)**	1.31 (0.82-2.09)
Keyboard inner elbow angle (degrees)			
<= 121	332	1.0	1.0
> 121	104	**0.50 (0.30-0.82)**	**0.16 (0.04-0.60)**
Keyboard shoulder abduction angle (degrees)			
<= 10	116	1.0	1.0
10 to 14	138	1.13 (0.70-1.82)	1.12 (0.69-1.82)
15 to 17	75	0.94 (0.52-1.69)	0.88 (0.49-1.59)
> 17	107	0.85 (0.50-1.47)	0.94 (0.54-1.63)
Keyboard shoulder flexion angle (degrees)			
<= 22	117	1.0	1.0
23 to 28	102	1.36 (0.82-2.25)	1.41 (0.85-2.34)
29 to 35	113	1.13 (0.68-1.89)	1.16 (0.69-1.96)
> 35	104	0.66 (0.37-1.18)	0.73 (0.40-1.31)
Distance from table edge to "J" key (cm)			
<= 17	204	1.0	1.0
> 17	232	0.71 (0.45-1.13)	0.73 (0.46-1.17)
Mouse inner elbow angle (degrees)			
<= 137	218	1.0	1.0
>137 to 148	111	1.41 (0.93-2.01)	1.51 (0.99-2.31)
> 148	107	0.84 (0.50-1.41)	0.86 (0.51-1.43)
Mouse shoulder abduction angle (degrees)			
<= 21	110	1.0	1.0
22 to 27	123	0.81 (0.49-1.35)	0.80 (0.48-1.34)
28 to 33	102	0.84 (0.49-1.45)	0.89 (0.52-1.53)
> 33	101	1.16 (0.70-1.91)	1.12 (0.67-1.86)
Mouse shoulder flexion angle (degrees)			
<= 25	111	1.0	1.0
26 to 34	113	1.23 (0.72-2.12)	1.29 (0.75-2.22)
35 to 44	109	1.66 (0.97-2.86)	**1.73 (1.00-2.98)**
> 44	103	1.26 (0.72-2.28)	1.28 (0.72-2.26)
Monitor head tilt angle (degrees)			
<= 3	113	1.0	1.0
> 3	323	1.53 (0.91-2.57)	1.52 (0.90-2.55)
Monitor head rotation angle (degrees)			
<=10	344	1.0	1.0
>10	92	1.09 (0.70-1.52)	1.17 (0.75-1.84)
Presence of a chair armrest			
No	97	1.0	1.0
Yes	339	0.73 (0.49-1.09)	0.80 (0.53-1.20)
Presence of a telephone shoulder rest			
No	404	1.0	1.0
Yes	32	**1.85 (1.03-3.30)**	1.72 (0.96-3.08)

* Adjusted for age, sex, height, hours keying per week
Hazard ratios in bold indicate p<0.05 Wald test

TABLE 14. Crude and covariate-adjusted hazard ratios for ergonomic risk factors and neck/shoulder disorders (N=472).

ERGONOMIC RISK FACTOR	N	CRUDE HR (95% CI)	ADJUSTED* HR (95% CI)
Keyboard to elbow height difference			
<= 0	256	1.0	1.0
0-2.3	99	1.56 (0.90-2.70)	1.57 (0.90-2.73)
> 2.3	117	0.91 (0.48-1.69)	0.93 (0.50-1.75)
Keyboard inner elbow angle (degrees)			
<=121	360	1.0	1.0
> 121	112	0.64 (0.35-1.18)	**0.42 (0.18-0.98)@**
Keyboard shoulder abduction angle (degrees)			
<= 10	127	1.0	1.0
11 to 14	147	1.23 (0.68-2.25)	1.11 (0.72-1.70)
15 to 17	86	0.66 (0.29-1.53)	1.08 (0.67-1.76)
> 17	112	1.01 (0.52-1.96)	0.87 (0.53-1.43)
Keyboard shoulder flexion angle (degrees)			
<= 21	121	1.0	1.0
22 to 28.5	115	1.27 (0.65-2.45)	1.17 (0.74-1.85)
28.6 to 35	121	1.47 (0.78-2.77)	1.13 (0.73-1.76)
> 35	115	0.66 (0.31-1.43)	0.88 (0.54-1.41)
Distance from table edge to "J" key (cm)			
<= 12.5	249	1.0	1.0
12.5	223	0.79 (0.49-1.27)	0.77 (0.47-1.25)
Mouse inner elbow angle (degrees)			
<=137	237	1.0	1.0
>137-148	119	1.43 (0.84-2.44)	1.35 (0.79-2.32)
>148	116	0.78 (0.41-1.51)	0.75 (0.39-1.44)
Mouse shoulder abduction angle (degrees)			
<= 21	120	1.0	1.0
22 to 27	137	1.06 (0.56-1.98)	1.04 (0.55-1.95)
28 to 33	105	0.87 (0.42-1.78)	0.97 (0.47-2.01)
> 33	110	1.32 (0.69-2.51)	1.43 (0.74-2.76)
Mouse shoulder flexion angle (degrees)			
<= 25	120	1.0	1.0
26 to 34	120	0.98 (0.51-1.88)	1.01 (0.53-1.95)
35 to 44	117	1.08 (0.55-2.13)	1.15 (0.58-2.28)
> 44	115	0.98 (0.50-1.92)	0.93 (0.47-1.84)
Monitor head tilt angle (degrees)			
<= 3	119	1.0	1.0
> 3	353	1.76 (0.87-3.55)	1.63 (0.81-3.32)}
Monitor head rotation angle (degrees)			
0 to 10	371	1.0	1.0
> 10	101	1.11 (0.64-1.96)	1.25 (0.71-2.21)
Presence of a chair armrest			
No	107	1.0	1.0
Yes	365	**0.60 (0.36-0.97)**	0.65 (0.39-1.08)
Presence of a telephone shoulder rest			
No	439	1.0	1.0
Yes	33	**2.78 (1.46-5.32)**	**2.54 (1.32-4.92)**

* Adjusted for age, sex, years keying greater than 20 hours per week, and hours per week keying

@ Also adjusted for the interaction term of *keyboard inner elbow angle* by *hours keying per week*. Hazard ratio calculated with *hours keying per week* set to its median value

Hazard ratios in bold indicate $p<0.05$ Wald test

TABLE 15. Crude and covariate-adjusted hazard ratios for ergonomic risk factors and hand/arm symptoms (N=496).

ERGONOMIC RISK FACTOR	N	CRUDE HR (95% CI)	ADJUSTED HR (95% CI)*
Keyboard wrist extension angle (degrees)			
<= 30	386	1.0	1.0
>30	110	1.28 (0.81-2.01)	1.14 (0.71-1.84)
Keyboard wrist ulnar deviation angle (degrees)			
-5 to 5	273	1.0	1.0
< -5	35	1.05 (0.50-2.24)	0.93 (0.43-1.99)
5 to 10	121	1.02 (0.61-1.68)	1.07 (0.64-1.78)
> 10	67	1.12 (0.63-2.00)	1.23 (0.68-2.22)
Distance from table surface to "J" key (cm)			
<= 3.5	420	1.0	1.0
>3.5	76	1.54 (0.96-2.49)	1.52 (0.92-2.50)
Distance from table edge to "J" key (cm)			
<= 12	248	1.0	1.0
>12	248	**0.61 (0.40-0.92)**	**0.64 (0.42-0.98)**
Presence of a wrist rest			
No	349	1.0	1.0
Yes	147	1.32 (0.86-2.02)	1.29 (0.84-1.99)
Mouse wrist ulnar deviation angle (degrees)			
-5 to 5	286	1.0	1.0
<-5	95	1.12 (0.69-1.83)	1.29 (0.77-2.18)
> 5	115	0.92 (0.54-1.57)	1.13 (0.64-1.97)
Mouse wrist extension angle (degrees)			
<= 17	133	1.0	1.0
17 to 23	121	0.62 (0.34-1.12)	0.68 (0.37-1.22)
>23 to 30	155	0.87 (0.52-1.44)	0.93 (0.55-1.57)
> 30	87	0.97 (0.55-1.72)	1.05 (0.58-1.91)
Average key activation force (gm)			
<= 48	123	1.0	1.0
>48	373	1.32 (0.80-2.18)	1.07 (0.64-1.80)
Presence of a sharp leading edge on table surface			
No	333	1.0	1.0
Yes	163	1.11 (0.73-1.69)	1.29 (0.84-1.99)

* Adjusted for age, sex, smoking, education, years keying greater than 20 hours per week, and hours per week keying

Hazard ratios in bold indicate $p<0.05$ Wald test

TABLE 16. Crude and covariate-adjusted hazard ratios for ergonomic risk factors and hand/arm disorders (N=520).

ERGONOMIC RISK FACTOR	N	CRUDE HR (95% CI)	ADJUSTED HR (95% CI)*
Keyboard wrist extension angle (degrees)			
10 to 25	273	1.0	1.0
-10 to 10	43	1.28 (0.49-3.34)	1.25 (0.47-3.28)
25 to 30	88	0.65 (0.27-1.57)	0.80 (0.32-1.97)
> 30	114	1.58 (0.87-2.88)	1.39 (0.74-2.64)
Keyboard wrist ulnar deviation angle (degrees)			
-5 to 5	290	1.0	1.0
<-5	34	1.08 (0.42-2.77)	0.92 (0.35-2.45)
5 to 10	123	0.80 (0.43-1.59)	0.86 (0.43-1.72)
> 10	73	0.85 (0.39-1.86)	0.83 (0.37-1.83)
Distance from table surface to "J" key (cm)			
<= 3.5	442	1.0	1.0
>3.5	78	1.61 (0.87-3.00)	1.54 (0.80-2.94)
Distance from table edge to "J" key (cm)			
<= 12	258	1.0	1.0
>12	262	**0.47 (0.27-0.83)**	**0.52 (0.29-0.93)**
Presence of a wrist rest			
No	362	1.0	1.0
Yes	158	1.37 (0.78-2.38)	1.36 (0.77-2.39)
Mouse wrist ulnar deviation angle (degrees)			
-5 to 5	301	1.0	1.0
<-5	96	**1.99 (1.09-3.63)**	**2.03 (1.09-3.80)**
> 5	123	1.22 (0.62-2.43)	1.35 (0.67-2.73)
Mouse wrist extension angle (degrees)			
<=17	137	1.0	1.0
17 to 23	125	0.64 (0.30-1.35)	0.66 (0.31-1.39)
>23 to 30	166	0.78 (0.40-1.53)	0.80 (0.40-1.58)
> 30	92	0.77 (0.39-1.66)	0.72 (0.31-1.65)
Average key activation force (gm)			
<= 48	131	1.0	1.0
>48	389	1.81 (0.89-3.70)	1.66 (0.81-3.41)
Presence of a sharp leading edge on table surface			
No	347	1.0	1.0
Yes	173	0.96 (0.55-1.66)	1.03 (0.59-1.82)

* Adjusted for age, sex, smoking, body mass index, and hours keying per week
Hazard ratios in bold indicate $p<0.05$ Wald test

TABLE 17. Adjusted associations between ergonomic factors and neck/shoulder symptoms.

Variable	Hazard Ratio	95% CI	P-value*
Ergonomic Exposures			
Keyboard height > elbow height (vs. <=elbow height)	1.42	0.96-2.10	0.08
Keyboard inner elbow angle >121° (vs. <=121°)	0.16	0.04-0.62	0.01@
Keyboard inner elbow angle by hours keying/week interaction	1.05	1.00-1.10	0.04@
Mouse inner elbow angle >137°-148° (vs. <=137°)	1.67	1.09-2.55	} 0.04
Mouse inner elbow angle >148° (vs. <=137°)	0.94	0.56-1.59	
Monitor head tilt angle >3° (vs. <=3°)	1.58	0.94-2.65	0.09
Presence of telephone shoulder rest	2.05	1.14-3.71	0.02
Adjustment Factors			
Age >= 30 years (vs. <30 years)	1.79	1.19-2.70	0.01
Female sex (vs. male)	1.31	0.83-2.06	0.25
Weekly hours keying (per hour)	1.01	0.99-1.03	0.24@

Hazard ratios are adjusted for all variables in table.

* P-value for the likelihood ratio chi-square except where indicated.

@ P-value for the Wald chi-square.

TABLE 18. Adjusted associations between ergonomic factors and neck/shoulder disorder.

Variable	Hazard Ratio	95% CI	P-value*
Ergonomic Exposures			
Keyboard inner elbow angle >121° (vs. <=121°)	0.11	0.02-0.66	0.02@
Keyboard inner elbow angle by hours keying/week interaction	1.07	1.01-1.14	0.02@
Presence of telephone shoulder rest	2.71	1.40-5.23	0.008
Adjustment Factors			
Age >= 40 years (vs. age < 40 years)	1.75	1.04-2.93	0.04
Female sex (vs. male)	1.37	0.77-2.44	0.27
Weekly hours keying (per hour)	1.01	0.99-1.04	0.24@

Hazard ratios are adjusted for all variables in table.

* P-value for the likelihood ratio chi-square except where indicated.
@ P-value for the Wald chi-square.

TABLE 19. Adjusted associations between ergonomic factors and hand/arm symptoms.

Variable	Hazard Ratio	95% CI	P-value**
Ergonomic Exposures			
Presence of a keyboard wrist rest	1.66	1.03-2.67	0.04
Keyboard "J" key >=12 cm from table edge (vs. <12 cm)	0.50	0.32-0.80	0.003
Adjustment Factors			
Age >= 40 years (vs. age < 40 years)	1.55	0.99-2.43	0.07
Female sex* (vs. male)	1.63	0.93-2.87	0.08
Weekly hours keying (continuous)	1.04	1.02-1.06	<0.001

Hazard ratios are adjusted for all variables in table.

* If survival time <=8 weeks, coded as sex=0. If survival time >8 weeks, coded as female=1, male=0.

** P-value for the likelihood ratio chi-square.

TABLE 20. Adjusted associations between ergonomic factors and hand/arm disorders.

Variable	Hazard Ratio	95% CI	P-value *
Ergonomic Exposures			
Presence of a keyboard wrist rest	1.96	1.05-3.65	0.04
Mouse wrist ulnar deviation <-5° (vs. >5°)	1.82	1.03-3.22	0.05
Keyboard "J" key >= 12 cm from table edge (vs. <12 cm)	0.38	0.20-0.71	0.002
Adjustment Factors			
Age >=40 years (vs. age <40 years)	1.58	0.89-2.82	0.13
Female sex (vs. male)	2.18	1.09-4.34	0.02
Weekly hours keying (continuous)	1.04	1.02-1.06	<0.001

Hazard ratios are adjusted for all variables in table.

* P-value for the likelihood ratio chi-square.

TABLE 21.
Interaction of keyboard inner elbow angle and hours keying (neck/shoulder symptoms)

Hours keying	Hazard Ratio *
10	0.27
20	0.44
30	0.72

* Upper quartile of inner elbow angle vs. lower quartile

TABLE 22.
Interaction of keyboard inner elbow angle
and hours keying (neck/shoulder disorders)

Hours keying	Hazard Ratio *
10	0.23
20	0.48
30	0.97

* Upper quartile of inner elbow angle vs. all other quartiles

Table 23. Comparison of current study to previous studies.

Ergonomic variable	Current Study (n=379)	Hales (n=340)	Grandjean (n=59)	Sauter (n=40)
Angular measures (degrees)				
Wrist ulnar deviation	5.0	6	9	12
Wrist extension	24.3	28	--	267
Inner elbow angle	112.7	109	99	101
Shoulder abduction	14.0	--	22	1.5
Shoulder flexion	28.6	29	23	19
Gaze angle, monitor	-11.5	-12	-9	-10
Head tilt angle, monitor	9.5	6	--	**
Linear measures (centimeters)				
Table surface height	70.7	71.1	--	--
Keyboard height	74.1	73.4	79	--
Monitor height	106.2	102.6	103	--
Elbow height	73.9	68.1	--	--
Keyboard ht - elbow ht	0.3	<0.3	--	8.9
Eye height	116.8	113.3	115	--
Eye to screen distance	64.8	68.1	76	--

** Methods not comparable to current study.

FIGURE LEGEND

Figure 1. Neck shoulder symptoms and disorders

Figure 2. Hand-arm symptoms and disorders

Figure 3. KM survival neck/shoulder symptoms and neck/shoulder disorders

Figure 4. KM survival neck/shoulder symptoms by gender

Figure 5. KM survival neck/shoulder symptoms by age

Figure 6. KM survival hand/arm symptoms and hand/arm disorders

Figure 7. KM survival hand/arm symptoms by gender

Figure 8. KM survival hand/arm symptoms by age

Figure 9. KM survival hand/arm symptoms by previous computer use

FIGURE 1

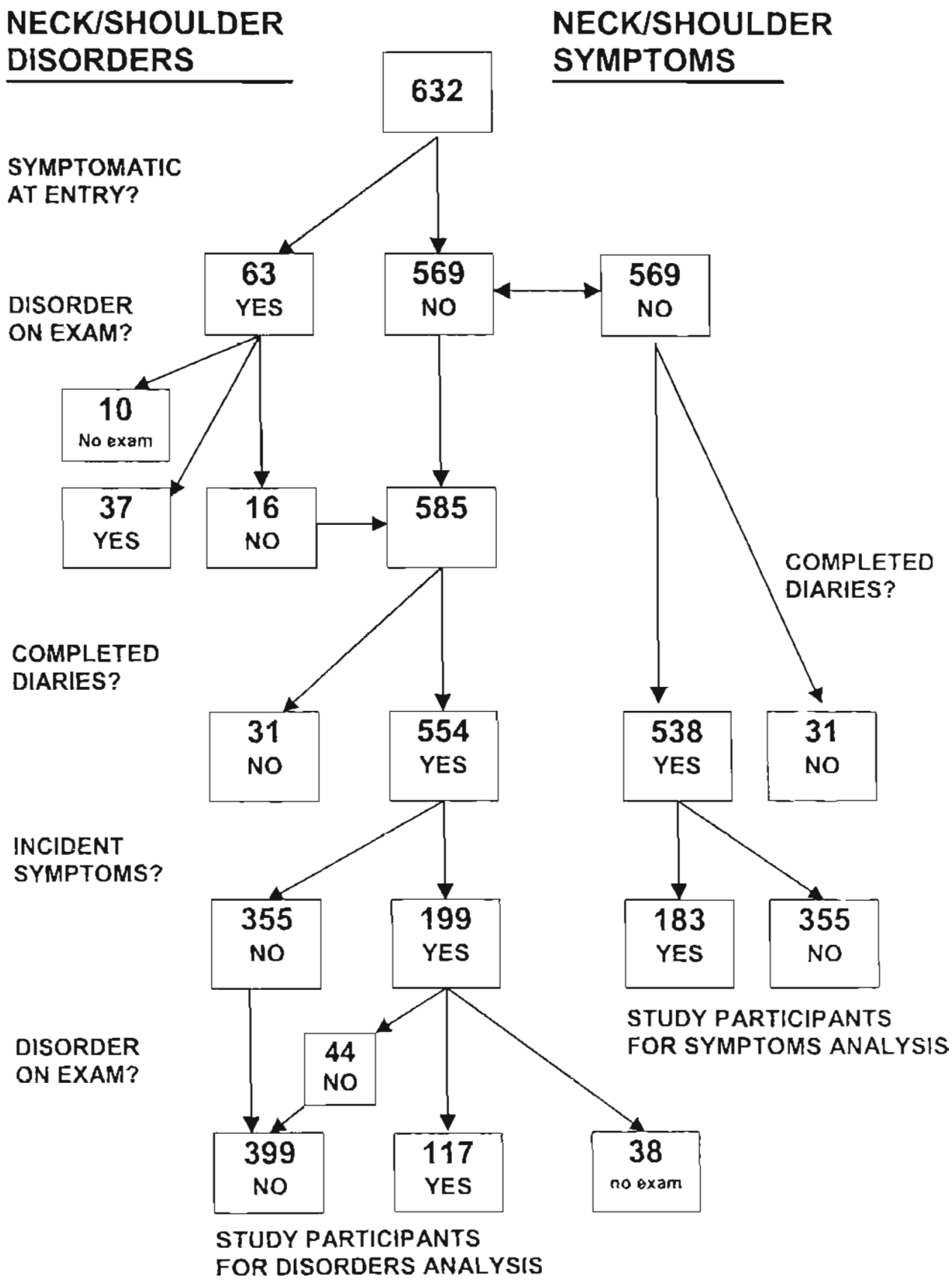

NECK/SHOULDER DISORDERS
NECK/SHOULDER SYMPTOMS
632
SYMPTOMATIC AT ENTRY?
63 YES
569 NO
569 NO
DISORDER ON EXAM?
10 No exam
37 YES
16 NO
585
COMPLETED DIARIES?
COMPLETED DIARIES?
31 NO
554 YES
538 YES
31 NO
INCIDENT SYMPTOMS?
355 NO
199 YES
183 YES
355 NO
STUDY PARTICIPANTS FOR SYMPTOMS ANALYSIS
DISORDER ON EXAM?
44 NO
399 NO
117 YES
38 no exam
STUDY PARTICIPANTS FOR DISORDERS ANALYSIS

FIGURE 2

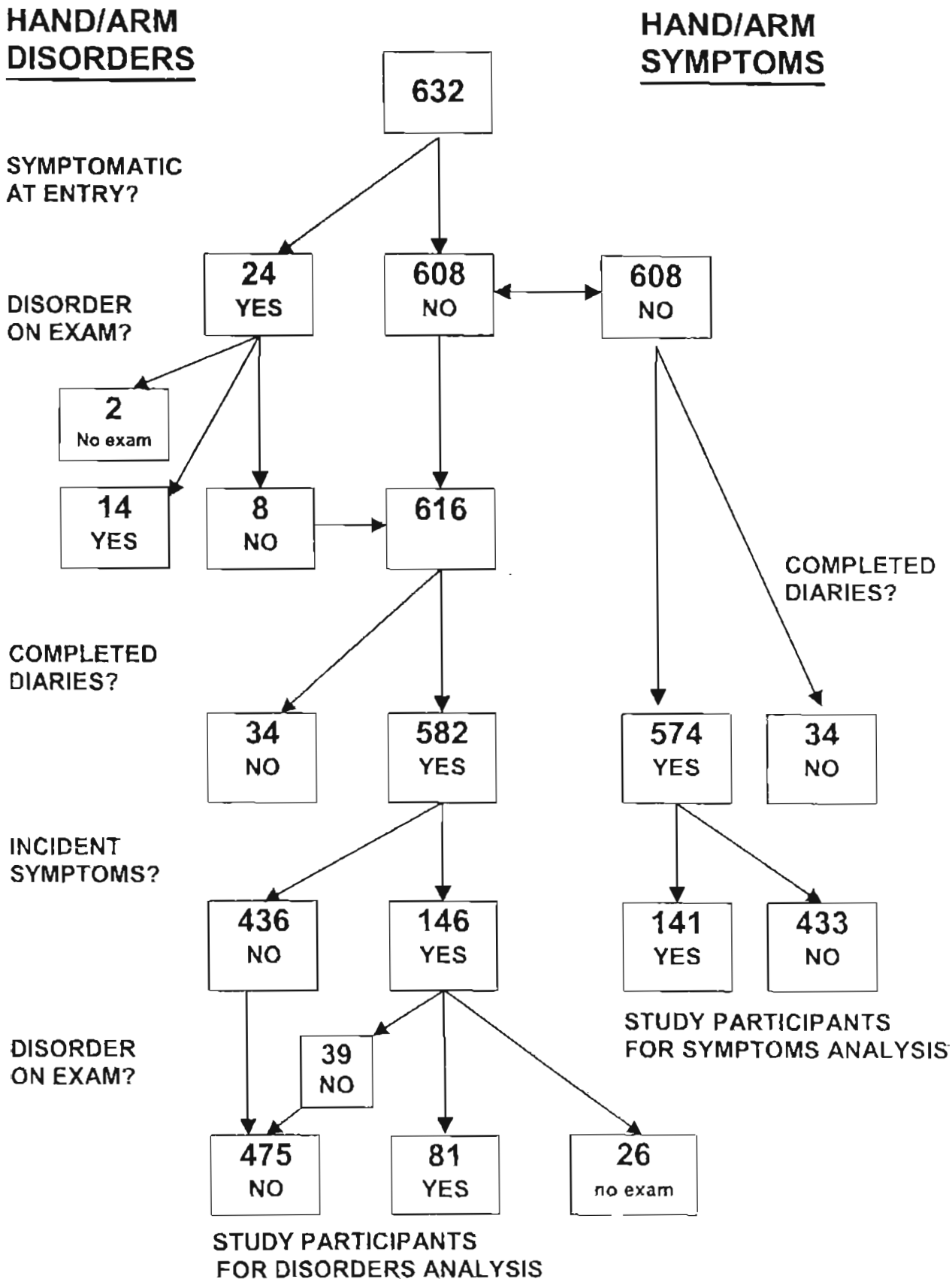

HAND/ARM DISORDERS
HAND/ARM SYMPTOMS
632
SYMPTOMATIC AT ENTRY?
24 YES
608 NO
608 NO
DISORDER ON EXAM?
2 No exam
14 YES
8 NO
616
COMPLETED DIARIES?
COMPLETED DIARIES?
34 NO
582 YES
574 YES
34 NO
INCIDENT SYMPTOMS?
436 NO
146 YES
141 YES
433 NO
STUDY PARTICIPANTS FOR SYMPTOMS ANALYSIS
DISORDER ON EXAM?
39 NO
475 NO
81 YES
26 no exam
STUDY PARTICIPANTS FOR DISORDERS ANALYSIS

Figure 3. KM survival to neck/shoulder symptoms and neck/shoulder disorders

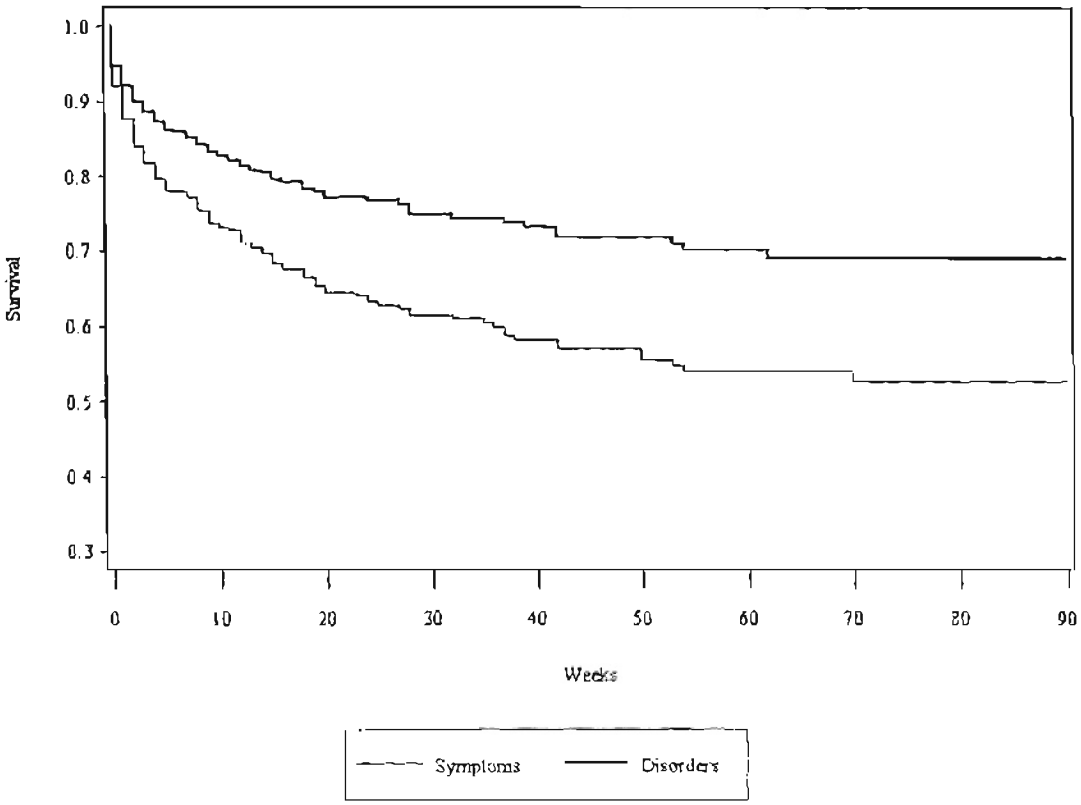


Figure 4. KM survival to neck/shoulder symptoms by gender

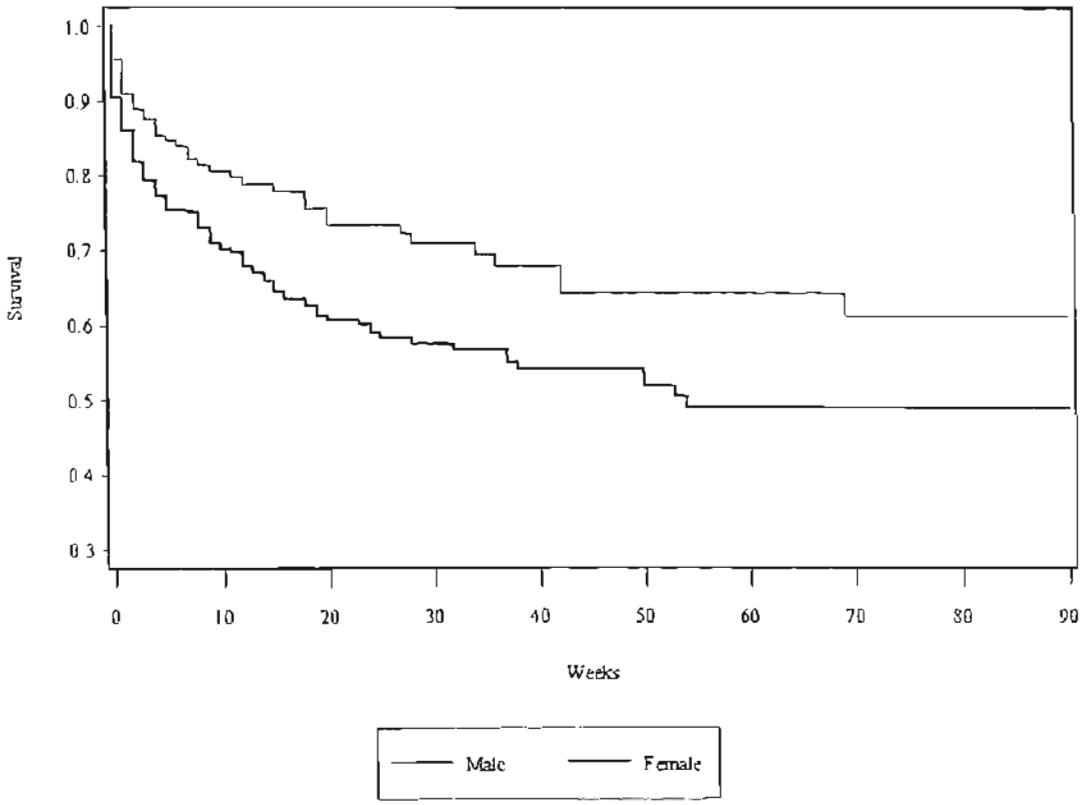


Figure 5. KM survival to neck/shoulder symptoms by age

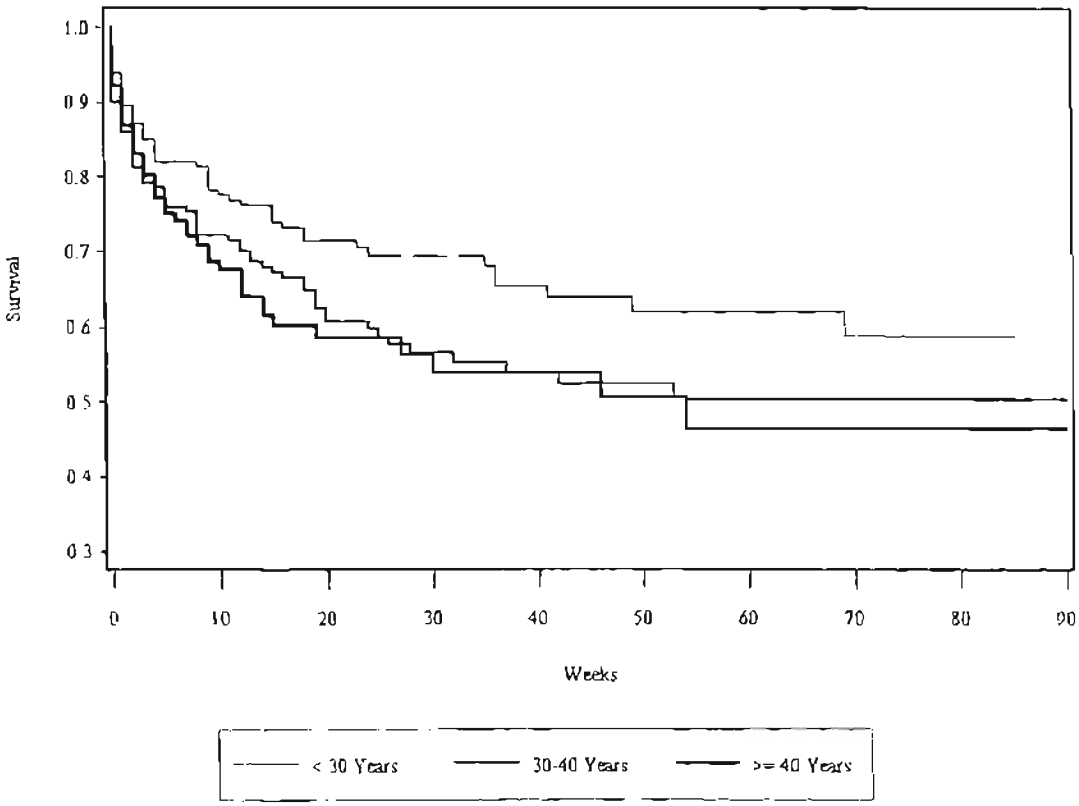


Figure 6. KM survival to hand/arm symptoms and hand/arm disorders

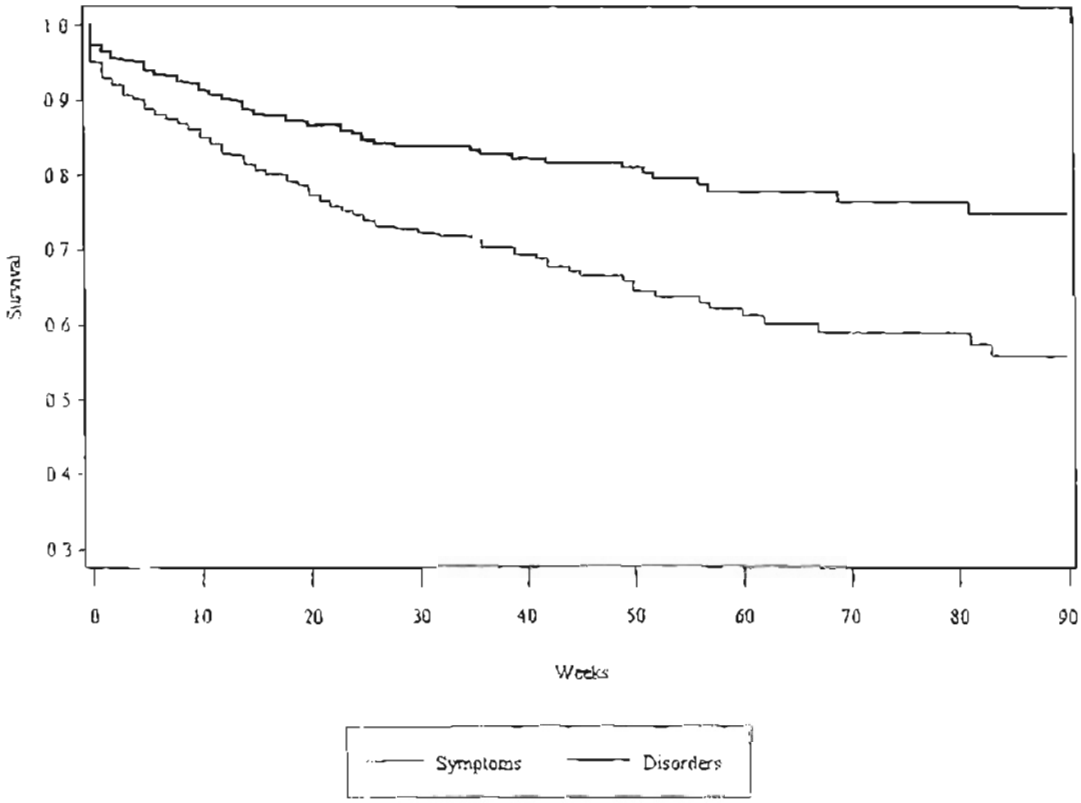


Figure 7. KM survival to hand/arm symptoms by gender

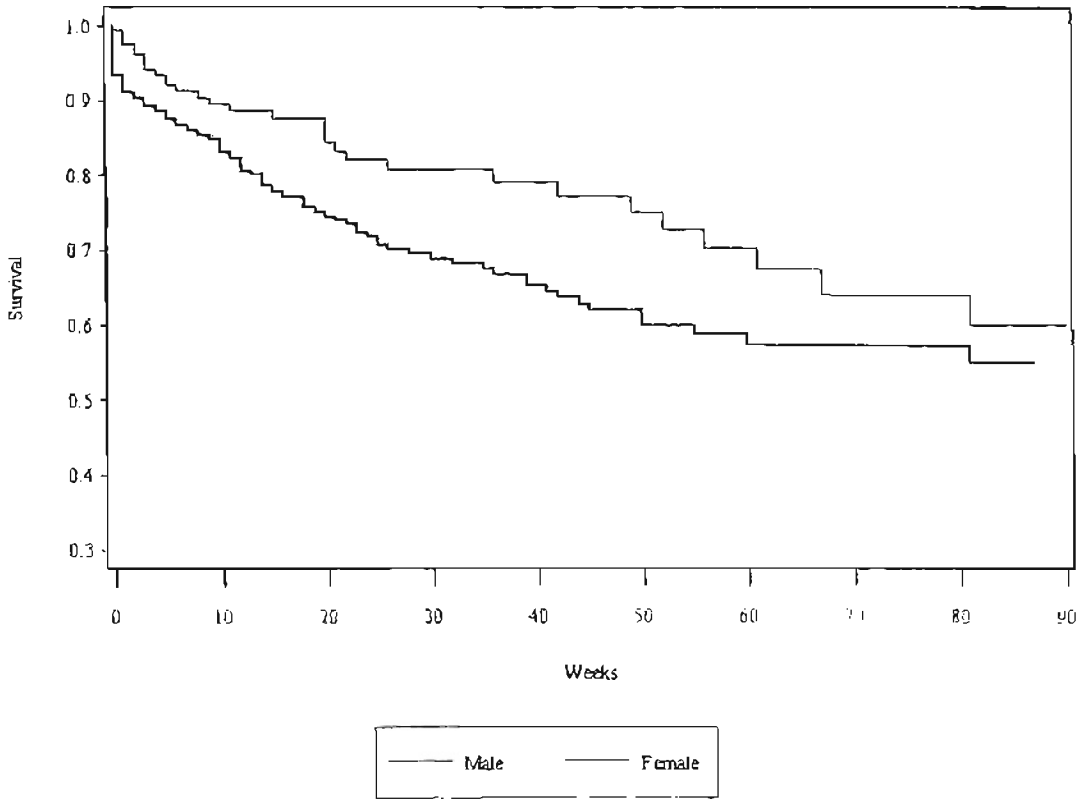


Figure 8. KM survival to hand/arm symptoms by age

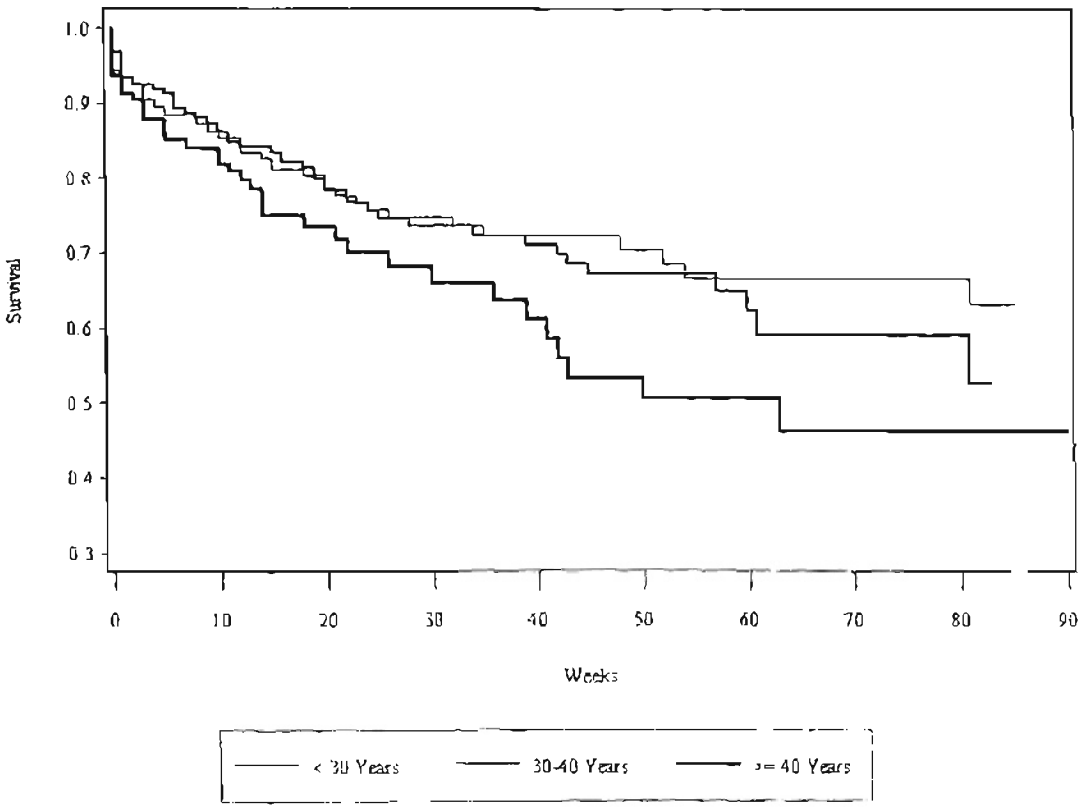
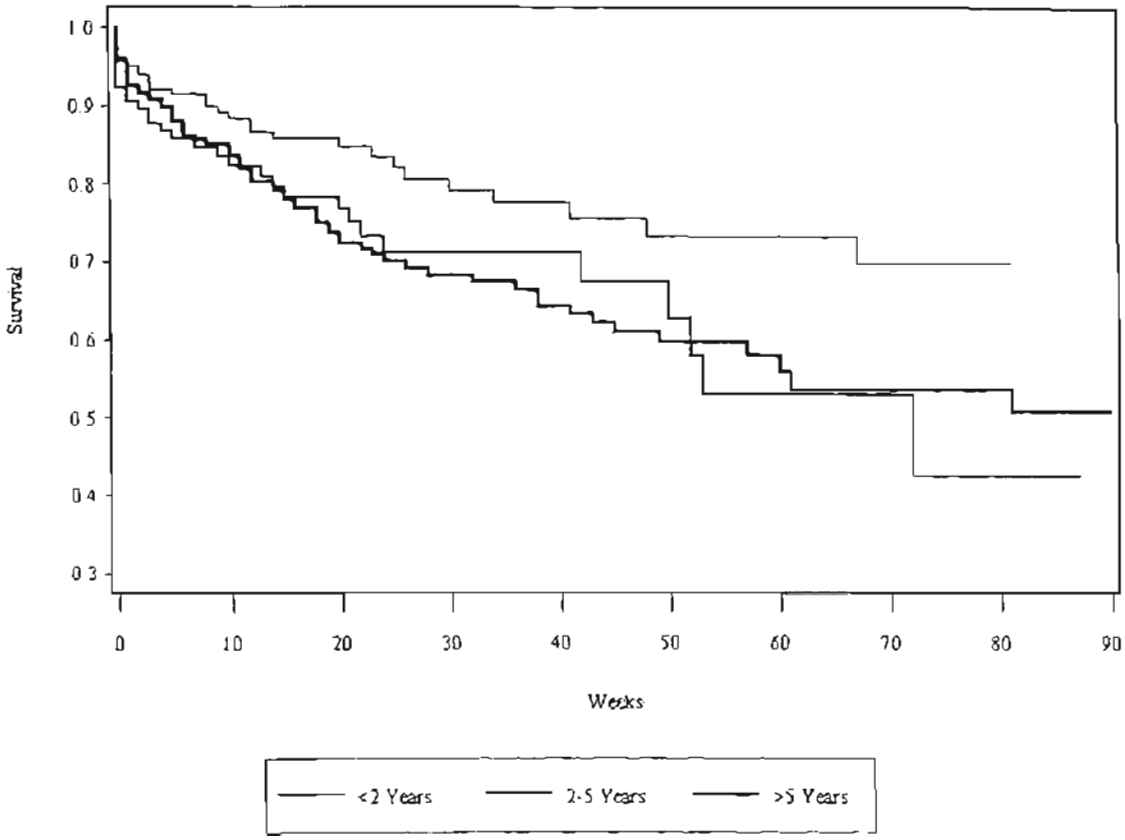


Figure 9. KM survival to hand/arm symptoms by previous computer use



Appendix 1

Personal Health Questionnaire

Subject I.D.

DATE: ☐☐ / ☐☐ / 9☐
m m d d y

EMORY/GEORGIA TECH COMPUTER STUDY

Personal Health Questionnaire

Instructions: Unless otherwise specified, for each of the following questions please place a check mark (√) in the appropriate box.

1 In the week prior to beginning this job did you experience **ANY** discomfort such as pain, aching, burning, numbness, or tingling in your neck, shoulders, elbows/forearms, hands/wrists, or fingers? *The cause of the discomfort (work or non work, accident, etc.) and the length of time you have had it doesn't matter.*

☐[1] Yes *(Go to Q.1A)* ☐[0] No *(Go to Q.8)*

If you checked yes for discomfort in the week prior to beginning this job , please answer the questions in this shaded area.

1A. ***Select the number that best describes how long your discomfort lasted and write it in the appropriate box.***

(1) Less than 2 hours (2) 2 to 4 hours (3) 5 to 7 hours (4) 8 or more hours

	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Neck							
Shoulders							
Elbows/Forearms							
Hands/Wrists							
Fingers							

2 **Discomfort intensity rating**: Place an **X** mark on the line below that represents the **worst** discomfort you experienced during the week prior to beginning this job.

No Discomfort |--------+--------+--------+--------+--------+--------+--------+--------+--------+--------| Unbearable Discomfort
0 1 2 3 4 5 6 7 8 9 10

3 Where did this discomfort occur? ☐[1] Neck ☐[2] Shoulders ☐[3] Elbows/Forearms ☐[4] Hands/Wrists ☐[5] Fingers

4 Did you take any medication for this discomfort the week prior to beginning this job? (aspirin, tylenol, bufferin, motrin, etc.)

☐[1] Yes ☐[0] No

5 What do you think caused the discomfort?_____ ☐ / ☐☐

6 In addition to the discomfort you may have reported in **Question 1, in the past three years** have you experienced any discomfort such as pain, aching, burning, numbness, or tingling in your neck, shoulders, elbows/forearms, hands/wrists, or fingers?

☐[1] Yes *(Go to Q. 7)* ☐[0] No *(Go to Q. 8)*

7 ***Complete one column in the following table for each discomfort you recall. Start with the most recent discomfort.***

	1st Discomfort	2nd Discomfort	3rd Discomfort	4th Discomfort	5th Discomfort
Where was the discomfort? *For each discomfort, check the location that applies.*	☐[1] Neck ☐[2] Shoulders ☐[3] Elbows/Forearms ☐[4] Hands/Wrists ☐[5] Fingers	☐[1] Neck ☐[2] Shoulders ☐[3] Elbows/Forearms ☐[4] Hands/Wrists ☐[5] Fingers	☐[1] Neck ☐[2] Shoulders ☐[3] Elbows/Forearms ☐[4] Hands/Wrists ☐[5] Fingers	☐[1] Neck ☐[2] Shoulders ☐[3] Elbows/Forearms ☐[4] Hands/Wrists ☐[5] Fingers	☐[1] Neck ☐[2] Shoulders ☐[3] Elbows/Forearms ☐[4] Hands/Wrists ☐[5] Fingers
On which side was the discomfort?	☐[1] Left ☐[2] Right ☐[3] Both	☐[1] Left ☐[2] Right ☐[3] Both	☐[1] Left ☐[2] Right ☐[3] Both	☐[1] Left ☐[2] Right ☐[3] Both	☐[1] Left ☐[2] Right ☐[3] Both
Did you seek medical attention for the discomfort?	☐[1] Yes ☐[0] No	☐[1] Yes ☐[0] No	☐[1] Yes ☐[0] No	☐[1] Yes ☐[0] No	☐[1] Yes ☐[0] No

8 Below is a list of medical conditions. Have you seen a doctor in the **past three years** for any of these conditions?

YES	NO	HEALTH CONDITION
☐[1]	☐[0]	Diabetes
☐[1]	☐[0]	Arthritis or any kind of rheumatism
☐[1]	☐[0]	Carpal tunnel syndrome
☐[1]	☐[0]	Slipped or ruptured disc in the neck
☐[1]	☐[0]	Bursitis or tendonitis in neck, shoulders, elbows/forearms, hands/wrists, or fingers
☐[1]	☐[0]	Any disease of muscles
☐[1]	☐[0]	Thyroid trouble or goiter
☐[1]	☐[0]	Kidney failure (dialysis)

9 Are you taking any of the following medications regularly? *Check all medications you are taking.*

- ☐[0] No medications
- ☐[1] Insulin or other diabetes medicine
- ☐[2] Thyroid medications
- ☐[3] Oral contraceptives
- ☐[4] Estrogen (female hormone) replacement therapy
- ☐[5] Other *(Specify)* _____

10. Do you currently smoke at least one cigarette, cigar, or pipeful of tobacco per day? ☐[1] Yes ☐[0] No

11. What is your sex? ☐[1] Male ☐[2] Female

12. What is your date of birth? ☐☐/☐☐/☐☐
m m d d y y

13 How old were you on your last birthday? ☐☐ *years*

14 What group best represents your ethnic background?

- ☐[1] White, not of Hispanic origin
- ☐[2] African American/Black, not of Hispanic origin
- ☐[3] Hispanic
- ☐[4] Native American
- ☐[5] Asian or Pacific Islander
- ☐[6] Other race *(Specify)* _____

15 Were you born in the United States? ☐[1] Yes ☐[0] No

16 What is the highest grade or year of school you completed?

- ☐[1] Elementary to some high school
- ☐[2] High school graduate
- ☐[3] Technical training or trade school
- ☐[4] Associate degree and/or some college
- ☐[5] College graduate with or without graduate school training
- ☐[6] Other *(Specify)* _____

17 Are you currently going to school on a regular basis? ☐[1] Yes ☐[0] No

18 How tall are you? *(Without shoes)* ☐ Feet ☐☐ Inches

19 What is your weight to the nearest whole pound? *(Without shoes)?* ☐☐☐ Pounds

20 Do you have children living at home? ☐[1] Yes *(Go to Q.20A)* ☐[0] No *(Go to Q.21)*

20A How many children are living at home with you? ☐☐

20B How many children who are living at home with you are under age 6? ☐☐

21 Are you left handed or right handed? ☐[1] Left handed ☐[2] Right handed

22 Are you currently pregnant? ☐[3] Not applicable (male) ☐[1] Yes ☐[0] No ☐[2] Possibly

23. Have your periods stopped because of a hysterectomy, the removal of both ovaries, or a natural menopause?

☐[2] Not applicable (Male) ☐[0] No ☐[1] Yes → ***Please check which event caused your period to stop.***

- ☐[1] Hysterectomy, ovaries left
- ☐[2] Hysterectomy, ovaries removed
- ☐[3] Both ovaries removed, no hysterectomy
- ☐[4] Natural menopause

24. Starting with your last job, please complete the following table for all the previous jobs you held **where you used a computer.** If you held more than 7 jobs where you used a computer, place a check here ☐.

	Example	Job 1	Job 2	Job 3	Job 4	Job 5	Job 6	Job 7
Job Title	*Accountant*							
Year of Hire	*1990*							
Years in Job	*5 yrs 2 months*							
Hours of Computer Use Per Week	*20*							

25 What income category listed below best matches your total combined FAMILY income during the past 12 months?

- ☐[1] Less than $15,000
- ☐[2] $15,000 - $24,999
- ☐[3] $25,000 $34,999
- ☐[4] $35,000 - $49,999
- ☐[5] $50,000 - $74,999
- ☐[6] $75,000 and over

26. How many people, including yourself, are supported by this income?

☐☐ People

THANK YOU FOR COMPLETING THIS QUESTIONNAIRE.
PLEASE MAIL IT IN THE PRE-ADDRESSED STAMPED ENVELOPE TO:

Emory/Georgia Tech Computer Study
Emory University
Rollins School of Public Health
Department of Environmental and Occupational Health
1518 Clifton Road, NE
Atlanta, Georgia 30322

Appendix 2

Weekly Checklist

SECTION 1

COMPLETE THESE CHARTS EVERY DAY, INCLUDING DAYS YOU DON'T WORK.

	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Hours worked at office							
Hours at computer workstation-office & home							
Hours spent keying-office & home							
Hours on telephone while keying-office & home							
Number of times you stepped away from your workstation for 10 minutes or less. *(IF 5 TIMES OR MORE ENTER 5)*							
Number of times you stepped away from your workstation for more than 10 minutes including your lunch break. *(IF 5 TIMES OR MORE ENTER 5)*							
Did you experience any discomfort such as pain, aching, burning, numbness, or tingling in your neck, shoulders, elbows/forearms, hands/wrists or fingers? *(IF YES IS CHECKED GO TO NEXT CHART)*	Yes ☐¹ No ☐⁰	Yes ☐¹ No ☐⁰	Yes ☐¹ No ☐⁰	Yes ☐¹ No ☐⁰	Yes ☐¹ No ☐⁰	Yes ☐¹ No ☐⁰	Yes ☐¹ No ☐⁰

IF YOU CHECKED "YES" FOR DISCOMFORT, SELECT THE NUMBER THAT BEST DESCRIBES HOW LONG YOUR DISCOMFORT LASTED AND WRITE IT IN THE APPROPRIATE BOX BELOW.

(1) Less than 2 hours (2) 2 to 4 hours (3) 5 to 7 hours (4) 8 or more hours

	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Neck/Shoulders							
Elbows/Forearms							
Hands/Wrists/Fingers							

SECTION 2

IF YOU REPORTED <u>NECK/SHOULDER</u> DISCOMFORT:

1. Place an X on the line below for the <u>worst</u> neck/shoulder discomfort during the past 7 days.

No Discomfort |----------+----------+----------+----------+----------+----------+----------+----------+----------+----------| Unbearable Discomfort
0 1 2 3 4 5 6 7 8 9 10

2. Did you take any medication for this discomfort this past week? (e.g. tylenol, motrin, etc.) ☐¹ Yes ☐⁰ No

3. What do you think caused the discomfort? _____ ☐ / ☐ ☐

IF YOU REPORTED <u>ELBOW/FOREARM, HAND/WRIST OR FINGER</u> DISCOMFORT:

4. Place an X on the line below for the <u>worst</u> elbow/forearm, hand/wrist, or finger discomfort during the past 7 days.

No Discomfort |----------+----------+----------+----------+----------+----------+----------+----------+----------+----------| Unbearable Discomfort
0 1 2 3 4 5 6 7 8 9 10

5. Did you take any medication for this discomfort this past week? (e.g. tylenol, motrin, etc.) ☐¹ Yes ☐⁰ No

6. What do you think caused the discomfort? _____ ☐ / ☐ ☐

AT THE END OF THIS WEEK PLEASE ANSWER ALL OF THE FOLLOWING QUESTIONS USING YOUR EXPERIENCE FROM THIS <u>PAST WEEK.</u>

7. How stressful has your job been?

☐¹ Very stressful ☐² Somewhat stressful ☐³ Not very stressful ☐⁴ Not stressful at all

ROLLINS SCHOOL
OF PUBLIC HEALTH OF
EMORY UNIVERSITY
GEORGIA TECH RESEARCH INSTITUTE
EOH - Room 272 (A. Edwards)
1518 Clifton Road, N.E.
Atlanta, GA 30322
404-727-3370

Subject I.D.

Week Beginning Monday: ☐☐/☐☐/199☐

THE EMORY/GEORGIA TECH COMPUTER STUDY

WEEKLY CHECKLIST

8. Have there been any changes in your workplace environment?

☐[1] Yes *(GO TO Q.2A)* ☐[0] No *(GO TO Q.3)*

8A. Which of the following changes did you notice?

☐[1] Yes	☐[0] No	Replacement of workstation (desk, chair, keyboard, monitor, or mouse)
☐[1] Yes	☐[0] No	Adjustment in height of chair or keyboard
☐[1] Yes	☐[0] No	New job or major change in job activities or software used
☐[1] Yes	☐[0] No	Replacement of immediate supervisor
☐[1] Yes	☐[0] No	Started second job
☐[1] Yes	☐[0] No	Other changes (specify)_____

9. Have there been any changes in your health or regular use of medication besides the discomfort you may have reported?

☐[1] Yes *(GO TO Q.3A)* ☐[0] No *(GO TO Q.4)*

9A. What health and/or medication changes have you experienced?

_____ ☐☐
_____ ☐☐
_____ ☐☐

10A. List any sports, recreation, or other **physical activity** you have participated in during the past week. Please include only the time you were physically active (For example: jogging, bicycling, swimming, brisk walking, tennis, aerobics, etc.).

Sport, Recreation or Other Physical Activity	Total Time Past Week Hours	Minutes
_____ ☐☐	☐☐ :	☐☐
_____ ☐☐	☐☐ :	☐☐
_____ ☐☐	☐☐ :	☐☐

10B. List any other activities you have participated in during the past week that involved intensive use of the hands? (For example: playing a musical instrument, knitting, gardening, carpentry. etc.)

Activity	Total Time Past Week Hours	Minutes
_____ ☐☐	☐☐ :	☐☐
_____ ☐☐	☐☐ :	☐☐
_____ ☐☐	☐☐ :	☐☐

Appendix 3

Occupational Questionnaire

SUBJECT I.D.

EMORY/GEORGIA TECH COMPUTER STUDY
Occupational Questionnaire

DATE: ☐☐ / ☐☐ / 9☐
m m d d y

Instructions: Unless otherwise specified, for each of the following questions please place a check mark (√) in the appropriate box.

1. What is your official job title?_____ ☐☐

2. What job title most accurately reflects what you do?_____ ☐☐

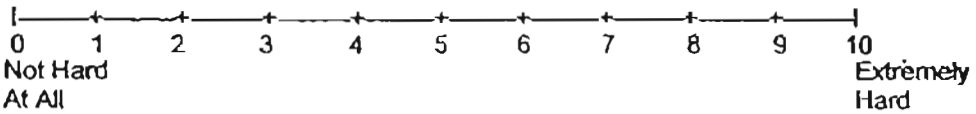
3. What is your typing speed? (Please select the closest answer)
   - ☐[1] Less than 50 words per minute
   - ☐[2] 50 - 65 words per minute
   - ☐[3] More than 65 words per minute

4. When typing at your computer, how frequently do you type when looking at a document?
   ☐[1] Never or Rarely ☐[2] Sometimes ☐[3] Frequently ☐[4] Almost All The Time

5. How frequently do you use a mouse and/or other pointing device?
   ☐[1] Never or Rarely ☐[2] Sometimes ☐[3] Frequently ☐[4] Almost All The Time

6. How frequently do you use a numeric keypad?
   ☐[1] Never or Rarely ☐[2] Sometimes ☐[3] Frequently ☐[4] Almost All The Time

7. How hard do you press on the keyboard when you type?



8. Can you get up and step away from your workstation when you choose or only at scheduled times?
   ☐[1] When you choose ☐[2] Scheduled times

9. Do you have your own workstation? *(Answer yes if co-workers do not normally use your desk and chair.)*
   ☐[1] Yes ☐[2] No

10. How comfortable is the chair at your workstation?

- ☐ 1 Very comfortable
- ☐ 2 Somewhat comfortable
- ☐ 3 Somewhat *un*-comfortable
- ☐ 4 Very *un*-comfortable
- ☐ 5 Don't have one specific chair

11. Have you received training in the proper posture/technique to perform your job tasks?

☐ 1 Yes ☐ 0 No

12. Please indicate whether the following statements about the physical environment of your job are true or false.

	TRUE	FALSE
A. The level of noise in the area(s) in which I work is usually high.	☐ 1	☐ 0
B. The level of lighting in the area(s) in which I work is usually poor.	☐ 1	☐ 0
C. My work area(s) is/are awfully crowded.	☐ 1	☐ 0

13. Is there anything else about the physical environment of your job that affects your health or well being?

☐ 1 Yes *(Specify)* _____ ☐ 0 No

14. The following questions ask HOW OFTEN certain things happen at your job.

A. How often is there a <u>marked increase</u> in your workload?

- ☐ 1 Rarely
- ☐ 2 Occasionally
- ☐ 3 Sometimes
- ☐ 4 Often
- ☐ 5 Very often

B. How often is there a marked increase in the <u>amount of concentration</u> required on your job?

- ☐ 1 Rarely
- ☐ 2 Occasionally
- ☐ 3 Sometimes
- ☐ 4 Often
- ☐ 5 Very often

C. How often is there a marked increase in how fast you have to think?

- ☐ 1 Rarely
- ☐ 2 Occasionally
- ☐ 3 Sometimes
- ☐ 4 Often
- ☐ 5 Very often

15. The following statements are about your job. For each of the statements below please check the response that comes closest to your answer.

A. I can easily see or hear the information I have to use in my job.

☐ 1 Strongly Agree ☐ 2 Agree ☐ 3 Disagree ☐ 4 Strongly Disagree

B. The information I have to look at or listen to is presented too rapidly.

☐ 1 Strongly Agree ☐ 2 Agree ☐ 3 Disagree ☐ 4 Strongly Disagree

C. Most of the decisions I make are routine and easy to make.

☐ 1 Strongly Agree ☐ 2 Agree ☐ 3 Disagree ☐ 4 Strongly Disagree

D. The information I receive is organized for me in ways that seem natural and easy to deal with.

☐ 1 Strongly Agree ☐ 2 Agree ☐ 3 Disagree ☐ 4 Strongly Disagree

E. I can perform the activities associated with my job without thinking about them.

☐ 1 Strongly Agree ☐ 2 Agree ☐ 3 Disagree ☐ 4 Strongly Disagree

F. In my job there are set rules that I follow over and over again.

☐ 1 Strongly Agree ☐ 2 Agree ☐ 3 Disagree ☐ 4 Strongly Disagree

G. I often feel mentally over-burdened on my job.

☐ 1 Strongly Agree ☐ 2 Agree ☐ 3 Disagree ☐ 4 Strongly Disagree

16. The following questions deal with various aspects of your job. Indicate how much of each aspect you have on your job.

A. How much variety is there in your job?

☐ 1 Very Little ☐ 2 A Moderate Amount ☐ 3 Very Much

B. How often do you see projects or jobs through to completion?

☐ 1 Not Often ☐ 2 Moderately Often ☐ 3 Very Often

C. How repetitious are your duties?

☐ 1 Not Repetitious ☐ 2 Somewhat Repetitious ☐ 3 Very Repetitious

D. How similar are the tasks you perform in a typical working day?

☐[1] Not Very Similar ☐[2] Somewhat Similar ☐[3] Very Similar

17. All in all, how satisfied are you with your job?

☐[1] Very satisfied
☐[2] Somewhat satisfied
☐[3] Not too satisfied
☐[4] Not at all satisfied

18. We would like you to think about how often things happen at your job. For each of the statements below, please check the box that comes closest to your answer.

A. How often do you face hostility or abuse from customers, clients, or coworkers?

☐[1] Rarely ☐[2] Sometimes ☐[3] Fairly Often ☐[4] Very Often

B. How often do each of the following people go out of his/her way to make your work life easier?

Your immediate supervisor

☐[1] Rarely ☐[2] Sometimes ☐[3] Fairly Often ☐[4] Very Often

Other people at work

☐[1] Rarely ☐[2] Sometimes ☐[3] Fairly Often ☐[4] Very Often

Your spouse, friends, relatives

☐[1] Rarely ☐[2] Sometimes ☐[3] Fairly Often ☐[4] Very Often

C. How often can each of the following people be be relied on when things get tough at work?

Your immediate supervisor

☐[1] Rarely ☐[2] Sometimes ☐[3] Fairly Often ☐[4] Very Often

Other people at work

☐[1] Rarely ☐[2] Sometimes ☐[3] Fairly Often ☐[4] Very Often

Your spouse, friends, relatives

☐[1] Rarely ☐[2] Sometimes ☐[3] Fairly Often ☐[4] Very Often

D. How often is each of the following people willing to listen to your personal problems?

Your immediate supervisor

☐[1] Rarely ☐[2] Sometimes ☐[3] Fairly Often ☐[4] Very Often

Other people at work

☐[1] Rarely ☐[2] Sometimes ☐[3] Fairly Often ☐[4] Very Often

Your spouse, friends, relatives

☐1 Rarely ☐2 Sometimes ☐3 Fairly Often ☐4 Very Often

19. How easy is it to talk with each of the following people?

Your immediate supervisor

☐1 Very Easy
☐2 Somewhat Easy
☐3 A Little Easy
☐4 Not at all Easy

Other people at work

☐1 Very Easy
☐2 Somewhat Easy
☐3 A Little Easy
☐4 Not at all Easy

Your spouse, friends, relatives

☐1 Very Easy
☐2 Somewhat Easy
☐3 A Little Easy
☐4 Not at all Easy

20. In the future, some jobs will be changing while others will be staying the same. The next six questions are about this topic.

A. How certain are you that you will have opportunities for promotion and advancement in the next few years?

☐1 Uncertain ☐2 A Little Certain ☐3 Somewhat Certain ☐4 Fairly Certain ☐5 Very Certain

B. How certain are you that your job skills will be of value five years from now?

☐1 Uncertain ☐2 A Little Certain ☐3 Somewhat Certain ☐4 Fairly Certain ☐5 Very Certain

C. How certain are you that you will still be working at your present job six months from now?

☐1 Uncertain ☐2 A Little Certain ☐3 Somewhat Certain ☐4 Fairly Certain ☐5 Very Certain

D. If you lost your job, how certain are you that you could support yourself?

☐1 Uncertain ☐2 A Little Certain ☐3 Somewhat Certain ☐4 Fairly Certain ☐5 Very Certain

E. How likely is it that in the next few years your job will be replaced by computers or machines?

☐[1] Uncertain ☐[2] A Little Certain ☐[3] Somewhat Certain ☐[4] Fairly Certain ☐[5] Very Certain

21. Using the scale below, please answer the following questions about your work group.

A. In my group people cannot afford to relax.

☐[1] Strongly Disagree
☐[2] Moderately Disagree
☐[3] Neither Agree Nor Disagree
☐[4] Moderately Agree
☐[5] Strongly Agree

B. In my group, there is constant pressure to keep working.

☐[1] Strongly Disagree
☐[2] Moderately Disagree
☐[3] Neither Agree Nor Disagree
☐[4] Moderately Agree
☐[5] Strongly Agree

C. In my group there is a sense of urgency about everything.

☐[1] Strongly Disagree
☐[2] Moderately Disagree
☐[3] Neither Agree Nor Disagree
☐[4] Moderately Agree
☐[5] Strongly Agree

22. At your job, how often is there a great deal to get done?

☐[1] Rarely
☐[2] Occasionally
☐[3] Sometimes
☐[4] Often
☐[5] Very often

THANK YOU FOR COMPLETING THIS QUESTIONNAIRE.
PLEASE RETURN IT TO THE STUDY'S RESEARCH ASSISTANT WHEN YOUR NEXT WEEKLY CHECKLIST IS COLLECTED OR SEND IT TO THE RESEARCH STUDY OFFICE USING THE PREADDRESSED STAMPED ENVELOPE.

Appendix 4

Ergonomic Assessment

SUBJECT I.D.

EMORY/GEORGIA TECH COMPUTER STUDY
Ergonomic Assessment

DATE: ☐☐ / ☐☐ / 9☐ (m m / d d / y) TIME: ☐☐ : ☐☐

WORKSTATION

Number of Computers ☐1 One ☐2 Two or more

Employee Position: ☐1 Sitting ☐2 Standing

Mouse Present ☐1 Yes ☐0 No

Other Pointing Device ☐1 Yes ☐0 No (Specify) _____

Wrist Rest ☐1 Yes ☐0 No ☐2 Mouse wristrest ☐3 Both

Telecommunications
- Headphones ☐1 Yes ☐0 No
- Shoulder Rest ☐1 Yes ☐0 No

Chair
- Height Adjustable ☐1 Yes ☐0 No
- Arm Rest Present ☐1 Yes ☐0 No

Leading Edge
- Sharp Leading Edge ☐1 Yes ☐0 No
- Height Adjustable ☐1 Yes ☐0 No

Document Holder Present ☐1 Yes ☐0 No ☐2 Yes , not used

POSTURAL MEASUREMENTS (in degrees)

	KEYBOARD LEFT	+	-	KEYBOARD RIGHT	+	-
Wrist Ulnar Deviation	☐☐	☐1	☐0	☐☐	☐1	☐0
Wrist Extension	☐☐	☐1	☐0	☐☐	☐1	☐0
Shoulder Flexion	☐☐	☐1	☐0	☐☐	☐1	☐0
Shoulder Abduction	☐☐	☐1	☐0	☐☐	☐1	☐0
Inner Elbow Angle	☐☐☐			☐☐☐		

	MONITOR		
Gaze Angle	☐☐	☐1 Up	☐0 Down
Head Tilt Angle	☐☐	☐1 Up	☐0 Down
Head Rotation Angle	☐☐	☐1 Left	☐0 Right

POSTURAL MEASUREMENTS (in degrees) continued

	FOR DOCUMENTS		N/A
Gaze Angle	☐☐ ☐[1] Up	☐[0] Down	☐[1]
Head Tilt Angle	☐☐ ☐[1] Up	☐[0] Down	☐[1]
Head Rotation Angle	☐☐ ☐[1] Left	☐[0] Right	☐[1]

	NUMERIC KEYPAD RIGHT	+	-
Wrist Ulnar Deviation	☐☐	☐[1]	☐[0]
Wrist Extension	☐☐	☐[1]	☐[0]

	MOUSE ☐[1] (LEFT)	☐[2] (Right)	+	-
Wrist Ulnar Deviation	☐☐		☐[1]	☐[0]
Wrist Extension	☐☐			
Shoulder Flexion	☐☐		☐[1]	☐[0]
Shoulder Abduction	☐☐			
Inner Elbow Angle	☐☐☐			

LINEAR MEASUREMENTS (in centimeters using leading zeros)

FROM:	TO:	☐☐☐.☐	NOT APPLICABLE ☐[1]
Floor	Elbow Height Typing		
Floor	Eye Height		
Floor	Table Surface/KP		
Table Surface/KP	Surface of "J" Key		
Table Surface/KP	Vertical Midpoint of Monitor Screen		
Table Surface/KP	Vertical Midpoint of Document		
Edge of Table	Edge of "J" Key		
Eye	Vertical Midpoint of Monitor Screen		
Eye	Vertical Midpoint of Document		

FORCE MEASUREMENTS (in grams (1 mm))

Keyboard: (Brand) _____ __ (Model) _____

Resting on: ☐[1] Table Surface ☐[2] Drawer Below Table ☐[3] Platform Below Table ☐[4] Platform Above Table ☐[5] Drawer Above Table

Standard QWERTY ☐[1] Yes ☐[0] No

Other ☐[1] Yes ☐[0] No (Specify, e.g. split, non-detachable)

FORCE MEASUREMENTS (in grams (1 mm)) continued

"5" on Keypad	☐☐☐.☐
"Enter" Key	☐☐☐.☐
"E" Key	☐☐☐.☐
Space Bar	☐☐☐.☐

COMMENTS

TIME: ☐☐:☐☐

Appendix 5

Physical Examination Recording Form

Subject I.D.

EMORY/GEORGIA TECH COMPUTER STUDY
Physical Examination Recording Form

DATE: ☐☐/☐☐/9☐ (m m d d y) Examiner: ☐

EXAMINATION OF THE NECK

DISCOMFORT INTENSITY RATING: Place an **X** mark on the line below that represents the **worst** discomfort you have experienced TODAY.

No Discomfort |——+——+——+——+——+——+——+——+——+——| Unbearable
0 1 2 3 4 5 6 7 8 9 10 Discomfort

When you reported symptoms on your checklist, did you have:

Pain	☐¹ Yes	☐⁰ No
Weakness	☐¹ Yes	☐⁰ No
Numbness	☐¹ Yes	☐⁰ No
Tingling	☐¹ Yes	☐⁰ No
Burning	☐¹ Yes	☐⁰ No

If yes to *numbness*, *tingling*, or *burning*, in what distribution did it occur:

Median nerve	☐¹ Yes	☐⁰ No
Ulnar nerve	☐¹ Yes	☐⁰ No
Radicular	☐¹ Yes	☐⁰ No

(IF YES TO MEDIAN, ULNAR OR RADICULAR DISTRIBUTION, COMPLETE NEUROLOGIC EVALUATION FORM AFTER COMPLETING THIS FORM)

Additional findings and comments

Symptomatic side ☐¹ Right ☐² Left ☐³ Both

Neck Status
- ☐⁰ Negative Exam (Subject stays in study)
- ☐¹ Diagnostic Finding(s) (Neck/shoulders out of study)
- ☐² Positive Finding(s) (Subject stays in study)
- ☐³ No exam (Participant refused-neck/shoulders out)
- ☐⁴ No exam (Other-neck/shoulders out of study)

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☐☐

1. Radicular Pain Syndromes

Spurling's Sign

Left: ☐[1] Positive ☐[0] Negative **Right:** ☐[1] Positive ☐[0] Negative

↓ ↓

Location: ☐[1] C6(Thumb & Index) Location: ☐[1] C6(Thumb & Index)

☐[2] C7(Long) ☐[2] C7(Long)

☐[3] C8(Ring & Little) ☐[3] C8(Ring & Little)

IF POSITIVE OR REPORT OF *NUMBNESS, TINGLING*, OR *BURNING*, COMPLETE *NEUROLOGIC EVALUATION FORM (AFTER COMPLETING THIS EXAMINATION)*

2. Somatic Pain Syndrome

Cervical ROM

Extension: ☐[1] Abnormal ☐[0] Normal

Flexion: ☐[1] Abnormal ☐[0] Normal

Lateral bending

Left: ☐[1] Abnormal ☐[0] Normal **Right:** ☐[1] Abnormal ☐[0] Normal

Rotation

Left: ☐[1] Abnormal ☐[0] Normal **Right:** ☐[1] Abnormal ☐[0] Normal

Palpation - Sternocleidomastoid

Left: ☐[1] Positive ☐[0] Negative **Right:** ☐[1] Positive ☐[0] Negative

Palpation - Trapezius

Left: ☐[1] Positive ☐[0] Negative **Right:** ☐[1] Positive ☐[0] Negative

Subject I.D.

EMORY/GEORGIA TECH COMPUTER STUDY
Physical Examination Recording Form

DATE: ☐☐/☐☐/9☐ (m m d d y) Examiner: ☐

NEUROLOGIC EVALUATION RECORDING FORM

Radicular Pain Syndromes

Spurling's Sign

Left: ☐¹ Positive ☐⁰ Negative ↓

Location: ☐¹ C6(Thumb & Index) ☐² C7(Long) ☐³ C8(Ring & Little)

Right: ☐¹ Positive ☐⁰ Negative ↓

Location: ☐¹ C6(Thumb & Index) ☐² C7(Long) ☐³ C8(Ring & Little)

1. Thoracic Outlet Syndrome

Wright's Maneuver

Left: ☐¹ Positive ☐⁰ Negative **Right:** ☐¹ Positive ☐⁰ Negative

Costoclavicular Compression

Left: ☐¹ Positive ☐⁰ Negative **Right:** ☐¹ Positive ☐⁰ Negative

Elevated Arm Extension Test (EAST)

Left: ☐¹ Positive ☐⁰ Negative **Right:** ☐¹ Positive ☐⁰ Negative

2. Semmes-Weinstein monofilament evaluation

	Index					Long					Little				
	2.83	3.61	4.31	4.56	6.65	2.83	3.61	4.31	4.56	6.65	2.83	3.61	4.31	4.56	6.65
Left:	☐¹	☐²	☐³	☐⁴	☐⁵	☐¹	☐²	☐³	☐⁴	☐⁵	☐¹	☐²	☐³	☐⁴	☐⁵
Right:	☐¹	☐²	☐³	☐⁴	☐⁵	☐¹	☐²	☐³	☐⁴	☐⁵	☐¹	☐²	☐³	☐⁴	☐⁵

FOR NEUROLOGIC SYMPTOMS IN THE DISTRIBUTION OF THE MEDIAN NERVE, COMPLETE SECTIONS 3-6:

3. <u>Carpal Tunnel Syndrome</u>

Report of nocturnal paraesthesia in the Median Nerve distribution

Left: ☐[1] Positive ☐[0] Negative **Right:** ☐[1] Positive ☐[0] Negative

Phalen's

Left: ☐[1] Positive ☐[0] Negative **Right:** ☐[1] Positive ☐[0] Negative

Tinel's

Left: ☐[1] Positive ☐[0] Negative **Right:** ☐[1] Positive ☐[0] Negative

Weakness during manual muscle test of APB

Left: ☐[1] Yes (0-4/5) ☐[0] No (5/5) **Right:** ☐[1] Yes (0-4/5) ☐[0] No (5/5)

Pinch strength dynamometry (lateral pinch)

	Trial 1	Trial 2	Trial 3		Trial 1	Trial 2	Trial 3
Left:	☐☐	☐☐	☐☐	**Right:**	☐☐	☐☐	☐☐

QUANTITATIVE PHALEN'S ASSESSMENT

Semmes-Weinstein monofilament evaluation

	Index					Long					Little				
	2.83	3.61	4.31	4.56	6.65	2.83	3.61	4.31	4.56	6.65	2.83	3.61	4.31	4.56	6.65
Left:	☐[1]	☐[2]	☐[3]	☐[4]	☐[5]	☐[1]	☐[2]	☐[3]	☐[4]	☐[5]	☐[1]	☐[2]	☐[3]	☐[4]	☐[5]
Right:	☐[1]	☐[2]	☐[3]	☐[4]	☐[5]	☐[1]	☐[2]	☐[3]	☐[4]	☐[5]	☐[1]	☐[2]	☐[3]	☐[4]	☐[5]

QUANTITATIVE PHALEN RESULT

Left: ☐[1] Positive ☐[0] Negative **Right:** ☐[1] Positive ☐[0] Negative

Nerve Pace Distal Sensory Latency of the Median Nerve at wrist of the affected hand

	Trial 1	Trial 2	Trial 3
Left:	☐☐.☐ms	☐☐.☐ms	☐☐.☐ms
Right:	☐☐.☐ms	☐☐.☐ms	☐☐.☐ms

4. Anterior Interosseous Nerve Compression

Manual Muscle Test Flexor Pollicis Longus

Left: ☐' Yes (0-4/5) ☐° No (5/5) **Right:** ☐' Yes (0-4/5) ☐° No (5/5)

5. Pronator Syndrome

Manual Muscle test of the Pronator Teres muscle

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

6. Motor function - quantitative grip strength (lbs)

	Trial 1	Trial 2	Trial 3
Left:	☐☐☐	☐☐☐	☐☐☐
Right:	☐☐☐	☐☐☐	☐☐☐

FOR NEUROLOGIC SYMPTOMS IN THE DISTRIBUTION OF THE ULNAR NERVE, COMPLETE THIS SECTION:

Using the digits, the examiner percusses on the patient at the Cubital Tunnel

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Nerve Pace Distal Sensory Latency of the Ulnar Nerve at the Cubital Tunnel of the affected hand

	Trial 1	Trial 2	Trial 3
Left:	☐☐.☐ms	☐☐.☐ms	☐☐.☐ms
Right:	☐☐.☐ms	☐☐.☐ms	☐☐.☐ms

Using the digits the examiner percusses on the patient at the Guyon's Canal

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Nerve Pace Distal Sensory Latency of the Ulnar Nerve at the Guyon's Canal of the affected hand

	Trial 1	Trial 2	Trial 3
Left:	☐☐.☐ms	☐☐.☐ms	☐☐.☐ms
Right:	☐☐.☐ms	☐☐.☐ms	☐☐.☐ms

Subject I.D.

EMORY/GEORGIA TECH COMPUTER STUDY
Physical Examination Recording Form

DATE: ☐☐/☐☐/9☐ (m m d d y) Examiner: ☐

EXAMINATION OF THE SHOULDERS

DISCOMFORT INTENSITY RATING: Place an **X** mark on the line below that represents the **worst** discomfort you have experienced TODAY.

No Discomfort |----+----+----+----+----+----+----+----+----+----| Unbearable Discomfort

0 1 2 3 4 5 6 7 8 9 10

When you reported symptoms on your checklist, did you have:

Pain	☐¹ Yes	☐⁰ No
Weakness	☐¹ Yes	☐⁰ No
Numbness	☐¹ Yes	☐⁰ No
Tingling	☐¹ Yes	☐⁰ No
Burning	☐¹ Yes	☐⁰ No

If yes to *numbness*, *tingling*, or *buming*, in what distribution did it occur:

Median nerve	☐¹ Yes	☐⁰ No
Ulnar nerve	☐¹ Yes	☐⁰ No
Radicular	☐¹ Yes	☐⁰ No

(IF YES TO MEDIAN, ULNAR OR RADICULAR DISTRIBUTION, COMPLETE NEUROLOGIC EVALUATION FORM AFTER COMPLETING THIS FORM)

Additional findings and comments

Symptomatic side ☐¹ Right ☐² Left ☐³ Both

Shoulder Status
- ☐⁰ Negative Exam (Subject stays in study)
- ☐¹ Diagnostic Finding(s) (Neck/shoulders out of study)
- ☐² Positive Finding(s) (Subject stays in study)
- ☐³ No exam (participant refused-neck/shoulders out)
- ☐³ No exam (other-neck/shoulders out of study)

☐☐

1. Rotator Cuff Tendinitis

Supraspinatus point tenderness

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Supraspinatus muscle testing

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Painful arc of motion test

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Apprehension sign

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

2. Bicipital Tendinitis

Palpate the long head of the biceps

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Yergason's Test

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Speed's Test

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Subject I.D.

EMORY/GEORGIA TECH COMPUTER STUDY
Physical Examination Recording Form

DATE: ☐☐/☐☐/9☐ Examiner: ☐
m m d d y

EXAMINATION OF THE ELBOW

DISCOMFORT INTENSITY RATING: Place an **X** mark on the line below that represents the **worst** discomfort you have experienced TODAY.

No Discomfort |----------+----------+----------+----------+----------+----------+----------+----------+----------+----------| Unbearable Discomfort
0 1 2 3 4 5 6 7 8 9 10

When you reported symptoms on your checklist, did you have:

Pain	☐¹ Yes	☐⁰ No
Weakness	☐¹ Yes	☐⁰ No
Numbness	☐¹ Yes	☐⁰ No
Tingling	☐¹ Yes	☐⁰ No
Burning	☐¹ Yes	☐⁰ No

If yes to *numbness*, *tingling*, or *burning*, in what distribution did it occur:

Median nerve	☐¹ Yes	☐⁰ No
Ulnar nerve	☐¹ Yes	☐⁰ No
Radicular	☐¹ Yes	☐⁰ No

(IF YES TO MEDIAN, ULNAR OR RADICULAR DISTRIBUTION, COMPLETE NEUROLOGIC EVALUATION FORM AFTER COMPLETING THIS FORM)

Additional findings and comments

Symptomatic side ☐¹ Right ☐² Left ☐³ Both

Elbow Status
- ☐⁰ Negative Exam (Subject stays in study)
- ☐¹ Diagnostic Finding(s) (Arm out of study)
- ☐² Positive Finding(s) (Subject stays in study)
- ☐³ No exam (participant refused-arm out of study)
- ☐⁴ No exam (other-arm out of study)

_____

_____

_____

☐☐

1. Medial Epicondylitis

Reverse Cozen's Test

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Medial epicondyle point tenderness

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Medial (flexor) muscle mass point tenderness

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

2. Lateral Epicondylitis

Cozen's Test

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Lateral epicondyle point tenderness

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Lateral (extensor) muscle mass tenderness

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Mill's maneuver

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

3. Posterior Interosseous Nerve Entrapment

Pain or ache 3° distal to the lateral epidondyle

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Long finger extension test

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

4. Anterior Interosseous Nerve Compression

Manual Muscle Test Flexor Pollicis Longus

Left: ☐' Yes (0-4/5) ☐° No (5/5) **Right:** ☐' Yes (0-4/5) ☐° No (5/5)

5. Pronator Syndrome

Manual Muscle test of the Pronator Teres muscle

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

6. Motor function - quantitative grip strength (lbs)

	Trial 1	Trial 2	Trial 3
Left:	☐☐☐	☐☐☐	☐☐☐
Right:	☐☐☐	☐☐☐	☐☐☐

Subject I.D.

EMORY/GEORGIA TECH COMPUTER STUDY

Physical Examination Recording Form

DATE: ☐☐/☐☐/9☐ Examiner: ☐

m m d d y

EXAMINATION OF THE WRIST/FINGERS

DISCOMFORT INTENSITY RATING: Place an **X** mark on the line below that represents the **worst** discomfort you have experienced TODAY.

No Discomfort |——+——+——+——+——+——+——+——+——+——| Unbearable Discomfort

0 1 2 3 4 5 6 7 8 9 10

When you reported symptoms on your checklist, did you have:

Pain	☐¹ Yes	☐⁰ No
Weakness	☐¹ Yes	☐⁰ No
Numbness	☐¹ Yes	☐⁰ No
Tingling	☐¹ Yes	☐⁰ No
Buming	☐¹ Yes	☐⁰ No

If yes to *numbness*, *tingling*, or *buming*, in what distribution did it occur:

Median nerve	☐¹ Yes	☐⁰ No
Ulnar nerve	☐¹ Yes	☐⁰ No
Radicular	☐¹ Yes	☐⁰ No

(IF YES TO MEDIAN, ULNAR, OR RADICULAR DISTRIBUTION, COMPLETE NEUROLOGIC EVALUATION FORM AFTER COMPLETING THIS FORM)

Additional findings and comments

Symptomatic side ☐¹ Right ☐² Left ☐³ Both

Wrist/Finger Status
- ☐⁰ Negative Exam (Subject stays in study)
- ☐¹ Diagnostic Finding(s) (Arm out of study)
- ☐² Positive Finding(s) (Subject stays in study)
- ☐³ No exam (participant refused-arm out of study)
- ☐⁴ No exam (other-arm out of study)

_____

_____

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1. Flexor Carpi Radialis (FCR) Tendonitis

Pain on the volar radial side of the wrist with resisted radial deviation and wrist flexion:

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Point tenderness located at the base of the second metacarpal bone on the palmar surface

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Local swelling

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Local warmth

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Redness

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Crepitance

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

2. Flexor Carpi Ulnaris (FCU) Tendonitis

Pain on the volar ulnar side of the wrist with resisted ulnar deviation and wrist flexion

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Point tenderness over the pisiform bone.

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Local swelling

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Local warmth

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Redness

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Crepitance

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

3. Digital Flexor Tendinitis

Pain during resisted wrist and digit flexion

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Point tenderness on the distal volar surface of forearm

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Local swelling

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Local warmth

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Redness

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Crepitance

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Motor function - quantitative grip strength (lbs)

	Trial 1	Trial 2	Trial 3
Left:	☐☐☐	☐☐☐	☐☐☐
Right:	☐☐☐	☐☐☐	☐☐☐

4. Dorsal Compartment 1 (APL and EPB)

Finklestein Exam

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Hitchhiker's Sign

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Localized warmth

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Redness

Left: ☐ Positive ☐ Negative **Right:** ☐ Positive ☐ Negative

Localized swelling

Left: ☐ Positive ☐ Negative **Right:** ☐ Positive ☐ Negative

Crepitance

Left: ☐ Positive ☐ Negative **Right:** ☐ Positive ☐ Negative

5. <u>Dorsal Compartment 2 (ECRL & ECRB)</u>

Pain on the radial side of the wrist with resisted wrist extension and radial deviation

Left: ☐ Positive ☐ Negative **Right:** ☐ Positive ☐ Negative

Point tenderness at the base of the index finger metacarpal (ECRL) or at the base of the long finger metacarpal (ECRB).

Left: ☐ Positive ☐ Negative **Right:** ☐ Positive ☐ Negative

Localized warmth

Left: ☐ Positive ☐ Negative **Right:** ☐ Positive ☐ Negative

Redness

Left: ☐ Positive ☐ Negative **Right:** ☐ Positive ☐ Negative

Localized swelling

Left: ☐ Positive ☐ Negative **Right:** ☐ Positive ☐ Negative

Crepitance

Left: ☐ Positive ☐ Negative **Right:** ☐ Positive ☐ Negative

6. <u>Intersection Syndrome</u>

Point tenderness

Left: ☐ Positive ☐ Negative **Right:** ☐ Positive ☐ Negative

Localized swelling

Left: ☐ Positive ☐ Negative **Right:** ☐ Positive ☐ Negative

Crepitance

Left: ☐ Positive ☐ Negative **Right:** ☐ Positive ☐ Negative

7. <u>Dorsal Compartment 3 (EPL)</u>

Pain on the radial side of wrist with resisted thumb IP extension

Left: ☐ Positive ☐ Negative **Right:** ☐ Positive ☐ Negative

Point tenderness

Left: ☐ Positive ☐ Negative **Right:** ☐ Positive ☐ Negative

Localized swelling

Left: ☐ Positive ☐ Negative **Right:** ☐ Positive ☐ Negative

Localized warmth

Left: ☐ Positive ☐ Negative **Right:** ☐ Positive ☐ Negative

Redness

Left: ☐ Positive ☐ Negative **Right:** ☐ Positive ☐ Negative

Crepitance

Left: ☐ Positive ☐ Negative **Right:** ☐ Positive ☐ Negative

8. <u>Dorsal Compartment 4 (EDC & EIP)</u>

Pain on the dorsal aspect of wrist or forearm with resisted digit extension (EDC) or pain on the dorsal radial side of wrist with resisted index finger extension (EIP)

Left: ☐ Positive ☐ Negative **Right:** ☐ Positive ☐ Negative

Point tenderness

Left: ☐ Positive ☐ Negative **Right:** ☐ Positive ☐ Negative

Localized swelling

Left: ☐ Positive ☐ Negative **Right:** ☐ Positive ☐ Negative

Localized warmth

Left: ☐ Positive ☐ Negative **Right:** ☐ Positive ☐ Negative

Redness

Left: ☐ Positive ☐ Negative **Right:** ☐ Positive ☐ Negative

Crepitance

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

9. Dorsal Compartment 5 (EDM)

Pain on the dorsal side of wrist with resisted little finger extension (EDM)

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Point tenderness

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Localized swelling

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Localized warmth

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Redness

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Crepitance

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

10. Dorsal Compartment 6 (ECU)

Pain on the ulnar side of wrist with resisted ulnar deviation and wrist extension

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Point tenderness located at the dorsal base of the fifth metacarpal

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Localized swelling

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Localized warmth

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Redness

Left: ☐' Positive ☐° Negative **Right:** ☐' Positive ☐° Negative

Crepitance

Left: ☐ Positive ☐ Negative **Right:** ☐ Positive ☐ Negative

11. Distal Flexor Tenosynovitis (Trigger Finger)

Pain over the volar metacarpal head:

	Left		**Right**	
Thumb	☐ Positive	☐ Negative	☐ Positive	☐ Negative
Index	☐ Positive	☐ Negative	☐ Positive	☐ Negative
Middle	☐ Positive	☐ Negative	☐ Positive	☐ Negative
Ring	☐ Positive	☐ Negative	☐ Positive	☐ Negative
Little	☐ Positive	☐ Negative	☐ Positive	☐ Negative

Crepitance in the flexor tendon sheath at the A1 pulley (Positive/Negative)

	Left		**Right**	
Thumb	☐ Positive	☐ Negative	☐ Positive	☐ Negative
Index	☐ Positive	☐ Negative	☐ Positive	☐ Negative
Middle	☐ Positive	☐ Negative	☐ Positive	☐ Negative
Ring	☐ Positive	☐ Negative	☐ Positive	☐ Negative
Little	☐ Positive	☐ Negative	☐ Positive	☐ Negative

Decrease ROM of digit due to locking in either flexion or extension

	Left		**Right**	
Thumb	☐ Positive	☐ Negative	☐ Positive	☐ Negative
Index	☐ Positive	☐ Negative	☐ Positive	☐ Negative
Middle	☐ Positive	☐ Negative	☐ Positive	☐ Negative
Ring	☐ Positive	☐ Negative	☐ Positive	☐ Negative
Little	☐ Positive	☐ Negative	☐ Positive	☐ Negative

Appendix 6

Musculoskeletal Disorder Case Definitions

CASE DEFINITIONS FOR MUSCULOSKELETAL DISORDERS

NECK/SHOULDER

Radicular pain syndrome Positive neck compression test (i.e., Spurling's sign)[Ellenberg et al., 1994; Viikari-Juntura et al., 1989; Gross et al., 1996].

Somatic pain syndrome Abnormal cervical range of motion and pain on palpation of either a) Sternomastoid muscle (unilateral or bilateral) or b) Trapezius muscle (unilateral or bilateral) [Waris 1979].

Rotator cuff tendinitis Positive supraspinatus point tenderness and a) positive supraspinatius muscle test [Yocum, 1983] or b) painful arc of motion test [Levin and Dellon, 1992; Chard et al., 1988].

Bicipital tendinitis Point tenderness on palpation of the long head of the biceps and either positive Speed's test [Gerard and Kleinfield, 1993; Curtis and Snyder, 1993; Bennett 1996; Post, 1988; Waris, 1979]or positive Yergason's test [Gerard and Kleinfield, 1993; Curtis and Snyder, 1993; Bennett 1996; Post, 1988; Waris, 1979, Hoppenfeld, 1976].

Medial epicondylitis Positive Reverse Cozen's Test [Gerard and Kleinfield, 1993] and a) positive medial epicondyle point tenderness or b) positive medial (flexor) muscle mass point tenderness [Waris, 1979].

Lateral epicondylitis a) Positive Cozen's test [Gerard and Kleinfield, 1993] or positive Mill's maneuver [Gerard and Kleinfield, 1993] and b) positive lateral epicondyle point tenderness or positive lateral (extensor) muscle mass tenderness [Hoppenfeld, 1976; Thomson and Szabo, 1989; Viikari-Juntura E, 1984].

Flexor carpi radialis tendinitis Pain at the volar radial side of the wrist with resisted radial deviation and wrist flexion and one or more of the following findings: point tenderness, local swelling, local warmth, redness, or crepitance [Cailliet, 1994; Tubania et al., 1996].

Flexor carpi ulnaris tendinitis Pain at the volar ulnar side of the wrist with resisted ulnar deviation and wrist flexion with resistance and one or more of the following findings: point tenderness, local swelling, local warmth, redness, or crepitance [Cailliet, 1994; Tubania et al., 1996].

Digital flexor tendinitis Pain at the palmar wrist with resisted wrist and digit flexion and one or more of the following findings: point tenderness, local swelling, local warmth, redness, or crepitance [Thomson and Szabo, 1989; Cailliet, 1994].

Extensor tendinitis - dorsal compartment 1 (abductor pollicis longus & extensor pollicis brevis) Positive Finklestein test [Gross et al., 1996; Cailliet, 1994; Tubania et al., 1996; Moore, 1997] or pain on resisted thumb MCP extension (Hitchhiker test).

Extensor tendinitis - dorsal compartment 2 (extensor carpi radialis longus & extensor carpi radialis brevis) Pain on the dorsum of the hand at the base of the second and third metacarpal with resisted wrist extension and radial deviation and one or more of the following findings: point tenderness, local swelling, local warmth, redness, or crepitance [Gross et al., 1996; Thomson and Szabo, 1989; Tubania et al., 1996].

Intersection syndrome Two of the following three findings: point tenderness located on the dorsolateral side of the wrist proximal to the extensor retinaculum, localized swelling proximal to the extensor retinaculum, crepitance.

Extensor tendinitis - dorsal compartment 3 (extensor pollicis longus) Pain on resisted thumb IP extension and one or more of the following findings: point tenderness, local swelling, local warmth, redness, or crepitance [Gross et al., 1996; Thomson and Szabo, 1989].

Extensor tendinitis - dorsal compartment 4 (extensor digitorum communis [EDC] & extensor indicis propriis [EIP]) With the IPs flexed, the subject is instructed to extend and flex the MP joint for 5-10 repetitions. Pain on the dorsal aspect of the wrist or distal forearm with resisted digit extension with the IP joints flexed (EDC) or pain on the dorsal radial side of wrist with isolated resisted index finger extension (EIP) and one or more of the following findings: point tenderness, local swelling, local warmth, redness, or crepitance [Gross et al., 1996; Thomson and Szabo, 1989].

Extensor tendinitis - dorsal compartment 5 (extensor digiti minimi) Pain on the dorsal ulnar side of wrist with isolated resisted small finger extension (EDM) and one or more of the following findings: point tenderness, local swelling, local warmth, redness, or crepitance [Gross et al., 1996].

Extensor tendinitis - dorsal compartment 6 (extensor carpi ulnaris) Pain on the dorsal ulnar side of the wrist with resisted ulnar deviation and wrist extension and one or more of the following findings: point tenderness, local swelling, local warmth, redness, or crepitance [Gross et al., 1996; Thomson and Szabo, 1989].

Distal flexor tenosynovitis (trigger finger) Pain in the flexor tendon sheath at the A1 pulley and either crepitance in the flexor tendon sheath at the A1 pulley or decrease ROM of digit due to locking in either flexion or extension [Waris 1979; Thomson and Szabo, 1989; Cailliet, 1994].

Carpal tunnel syndrome Paresthesias in the distribution of the median nerve and prolonged sensory latency (3.2 ms. at 14 cm distance) of the median nerve across the affected wrist [Rempel et al., 1998; Cailliet, 1977; NeuMed, 1998].

Ulnar neuritis Paresthesias in the distribution of the ulnar nerve and prolonged sensory latency (3.2 ms. at 14 cm distance) of the ulnar nerve [NeuMed, 1998; Dawson et al., 1990].

PUBLICATIONS

Present

Gerr F, Marcus M, Ortiz D. Methodological limitations in the study of video display terminals and upper-extremity musculoskeletal disorders. *American Journal of Industrial Medicine*, 29:649-656; 1996.

Ortiz DJ, Marcus M, Gerr F, Jones W, Cohen S. Measurement variability in upper extremity posture among VDT users. *Applied Ergonomics*, **28**:139-143; 1997.

Gerr F, Ortiz D, Marcus M, White B, Jones W, Cohen S, Gentry E, Edwards A, Bauer E. Computer users' postures and associations with workstation characteristics. *American Industrial Hygiene Association Journal*, **61**:223-230; 2000.

Anticipated

Marcus M, Gerr F, Ensor C, Kleinbaum D, Cohen S, Edwards A, Gentry E, Ortiz D, Monteilh C. A prospective study of computer users: I. Study design and incidence of musculoskeletal symptoms and disorders. Submitted, American Journal of Industrial Medicine, June, 2001.

Gerr F, Marcus M, Monteilh C, Ortiz DH, Gentry E, Edwards E, Ensor C, Kleinbaum D. A prospective study of computer users: II. Ergonomic risk factors for musculoskeletal symptoms and disorders. Submitted, American Journal of Industrial Medicine, June, 2001.

Gerr F, Marcus M, Monteilh C, Gentry E, Ortiz D, Edwards A, Kleinbaum D. Relationship between hours keying and musculoskeletal disorders among video display terminal operators. In preparation, 2001.

INVENTIONS STATEMENT

No inventions resulted from this grant.