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# A Prospective Study of Computer Users: I. Study Design and Incidence of Musculoskeletal Symptoms and Disorders

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**Background** *A prospective study of computer users was performed to determine the occurrence of and evaluate risk factors for neck or shoulder (N/S) and hand or arm (H/A) musculoskeletal symptoms (MSS) and disorders (MSD).*

**Methods** *Individuals ($n = 632$) newly hired into jobs requiring $\geq 15$ hr/week of computer use were followed for up to 3 years. At study entry, workstation dimensions and worker postures were measured and medical and psychosocial risk factors were assessed. Daily diaries were used to document work practices and incident MSS. Those reporting MSS were examined for specific MSD. Incidence rates of MSS and MSD were estimated with survival analysis. Cox regression models were used to evaluate associations between participant characteristics at entry and MSS and MSD.*

**Results** *The annual incidence of N/S MSS was 58 cases/100 person-years and of N/S MSD was 35 cases/100 person-years. The most common N/S MSD was somatic pain syndrome. The annual incidence of H/A MSS was 39 cases/100 person-years and of H/A MSD was 21 cases/100 person-years. The most common H/A disorder was deQuervain's tendonitis. Forty-six percent of N/S and 32% of H/A MSS occurred during the first month of follow-up. Gender, age, ethnicity, and prior history of N/S pain were associated with N/S MSS and MSD. Gender, prior history of H/A pain, prior computer use, and children at home were associated with either H/A MSS or MSD.*

**Conclusions** *H/A and N/S MSS and MSD were common among computer users. More than 50% of computer users reported MSS during the first year after starting a new job.* Am. J. Ind. Med. 41:221–235, 2002. © *2002 Wiley-Liss, Inc.*

***KEY WORDS: computer; keyboard; prospective study; musculoskeletal disorders; tension neck syndrome; deQuervain's tendonitis; carpal tunnel syndrome***

## INTRODUCTION

Considerable and growing concern exists in both the lay and scientific communities that computers may place users at increased risk of upper extremity musculoskeletal symptoms (MSS) and disorders (MSD) [WHO, 1987; Horowitz, 1992; Gerr et al., 1996]. According to the United States Census Bureau, about 92 million adults in the United States used a computer in 1997, 37% of all American households had computers, and half of all employed adults in the US used a computer on the job in 1997 [US Census

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Bureau, 1999]. The World Health Organization [1998] has estimated that 150 million computers are in use worldwide.

Although more than twenty field-based epidemiological studies have assessed upper-extremity MSS and MSD among computer users, essentially all have been cross-sectional in design [Gerr et al., 1996]. Consequently, the actual incidence of MSS and MSD among computer users is unknown. Furthermore, only a minority of these studies used objective clinical evaluation to evaluate musculoskeletal health among computer users and several did not include disorder-specific descriptions in reports of their findings [Hunting et al., 1981; Bernard et al., 1994; Hales et al., 1994; Bergqvist et al., 1995].

This report describes the first prospective study of computer users conducted in North America. We describe the study population, report on the prevalence and incidence of MSS and specific MSD at study entry and during follow-up, and examine relationships between the incidence of MSS and MSD and characteristics of the study population available at study entry. In the companion article [Marcus et al., 2002], we report on postural risk factors for MSS and MSD among computer users.

## MATERIALS AND METHODS

### Study Design

Individuals who were newly hired into computer-using jobs were recruited to participate in the study. At entry, participants completed questionnaires documenting demographic and personal health information. Measurements of workstation characteristics and worker posture were conducted at entry and repeated if the participant reported a change in the workstation. These measurements are described in detail elsewhere [Ortiz et al., 1997]. Approximately 4 weeks after entry, participants completed questionnaires regarding occupational characteristics including measures of occupational psychosocial stress. Participants who were free of MSD at entry were followed for up to 3 years during which time they completed a daily ''diary'' documenting the number of hours worked at the computer and their experience of musculoskeletal symptoms. Those who reported symptoms (at entry or during the follow-up period) were administered a standard physical examination to document abnormalities consistent with specific MSD. Study participants were followed until they developed examination-confirmed disorders of the neck or shoulder (N/S) and the hand or arm (H/A), or for a maximum of 38 months.

### Population

Participants were recruited from eight large employers in metropolitan Atlanta. Participating organizations were involved in insurance and finance, telecommunications, food production, health care, and education. Each newly hired employee of a participating organization who 1) anticipated using a computer keyboard for 15 hr or more/week and 2) anticipated using a computer keyboard for at least as many hours/week as in his/her previous job was eligible for participation. Those who reported MSS at the time of entry were excluded from analyses of incident MSS. Symptomatic individuals were examined with a standard protocol and those who met specific criteria for MSD (see the Appendix) at the time of entry were excluded from analyses of incident MSD. The Emory University Human Investigations Committee approved the study protocol and written informed consent was obtained from all participants.

### Personal Health History

At enrollment, study participants were asked to complete a questionnaire about demographic characteristics and personal health history, including past occurrences of musculoskeletal disorders, past or current illness potentially associated with musculoskeletal or neurological impairment (e.g., arthritis, diabetes, and thyroid illness), medication use, menopausal status, and tobacco use. Information was also collected on previous computer use.

### Work Practice Information

Also at enrollment, study participants were given the first pre-printed ''diary.'' They were asked to record daily the number of hours worked in the office, the number of hours spent in typing, and other exposure information. Questions about time spent in aerobic activities and hand-intensive activities also were included. The diary was collected weekly and reviewed by study personnel. When a weekly diary was missing (less than 1% were missing), values from the previous week's diary were used.

### Occupational Psychosocial Questionnaire

Approximately 4 weeks after enrollment, study participants completed a questionnaire to collect information about occupational psychosocial stress. The questionnaire was based on an instrument used by NIOSH in several studies of computer users [Hales et al., 1992; Bernard et al., 1993].

### Health Outcomes Assessment

The occurrence of MSS was assessed with a brief questionnaire completed at study entry and weekly during the follow-up period. 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 to 10. Separate scales were used to rate N/S and H/A discomfort. In addition, the question, ''Did you take any medication for this discomfort this past week?'' was asked separately for N/S and H/A discomfort. Study participants were classified as having experienced MSS if they 1) reported musculoskeletal discomfort on any day of the week with a severity of six or greater on the visual analog scale or 2) reported musculoskeletal discomfort of any severity and reported using medication for control of the discomfort. The occurrence of MSS was assessed separately for the N/S and the H/A.

Subjects who met criteria for MSS at entry or during follow-up were offered a standard physical examination at the workplace performed by an occupational therapist with certification in hand therapy (Cindy Ensor). The examination result was recorded on a standard form. Only the symptomatic body region and the same area on the contralateral side were examined. Case definitions of MSDs suitable for use in epidemiological studies were adapted from existing sources or developed by two of the authors (Cindy Ensor and Fred Gerr) to be similar to those used in clinical practice and consistent with recent recommendations for studies of work-related MSD [Rempel et al., 1998]. The specific health outcomes and the case definitions used are provided in the Appendix. Symptoms and physical examination findings were required for identification of all musculoskeletal disorders except carpal tunnel syndrome (CTS) and ulnar neuritis. For these two conditions, the observation of a prolonged sensory latency across the wrist was required in addition to characteristic symptoms. Sensory latencies were obtained at the study participant's place of work with a portable nerve conduction monitor (Nervepace S200, NeuMed, Inc., Lawrenceville, NJ). All sensory latencies were obtained with skin temperature above 32°C. A small number of participants (n = 3) refused nerve conduction evaluation.

## Analyses

Measures of the occurrence of MSS and MSD were calculated at entry into the study (1-week period prevalence) and after various periods of follow-up. The prevalence of symptoms was calculated by dividing the number of individuals reporting symptoms by the total population of subjects enrolled. The prevalence of disorders 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. Individuals with prevalent symptoms or disorders were excluded from calculation of the corresponding incidence rates.

Survival curves for incident MSS and MSD were plotted by the Kaplan–Meier method. The time unit of analysis was 1 week. Kaplan–Meier curves were truncated at 90 weeks of observation (for better visualization of trends early in the follow-up period) or where fewer than five subjects were available for observation. Incidence density rates (hazards) for various periods of follow-up were calculated using the life-table method [Kleinbaum, 1996]. Individuals who dropped out of the study contributed person-time to the analyses until the week they dropped out and were censored. Symptomatic individuals who were not examined (because they refused or were unable to schedule an examination) contributed person-time to the disorder analyses until the week before they developed symptoms and were then censored. A total of 64 individuals were not examined after developing incident symptoms. Censoring of these individuals will underestimate the incidence of musculoskeletal disorders since 70% of individuals with N/S symptoms who were examined were found to have a disorder and 64% of individuals with H/A symptoms who were examined were found to have a disorder. Ten individuals whose incident MSS or MSD were due to an acute injury were censored the week prior to the injury.

Analyses of associations between risk factors present at entry into the study and musculoskeletal health outcomes were performed with multivariate Cox regression models [SAS, 1990]. The four outcomes of interest were modeled separately (i.e., N/S symptoms, examination-confirmed N/S disorders, H/A symptoms, and examination- confirmed H/A disorders). Occurrences of the outcomes in men and women also were modeled separately. Additional analyses were conducted after excluding data from individuals with pre-existing medical conditions of diabetes, arthritis, bursitis, tendonitis, and CTS. Those individuals who reported MSS during the week prior to entry into the study were excluded from analyses of incident symptoms. However, a history of MSS prior to the week before entry was evaluated as a risk factor for incident symptoms and disorders. Prior history was defined as positive responses to both of the following questions, ''In the past 3 years have you experienced any discomfort such as pain, aching, burning, numbness or tingling in your neck, shoulders, elbows/forearms, hands, wrists, or fingers? Did you seek medical attention for the discomfort?'' Other risk factors measured at entry and evaluated in the multivariate model were ethnicity, age, height, body mass index (BMI), education, household income, current smoking, duration (years) of computer use, whether children under six resided in the participant's household and, among women, whether the participant was postmenopausal or taking hormonal medications. Additional analyses were performed in which variables not associated with a given outcome ($P > 0.05$) were eliminated from the multivariable models.

Ethnicity was dichotomized as white (referent group) or non-white (including Hispanic); age was trichotomized as under 30 years (referent), 30–39 years, and 40 years and older. Height was examined by dichotomizing at the 20th percentile (i.e., the shortest 20% vs. all others) and, alternatively, at the 80th percentile (i.e., the tallest 20% vs. all others). In preliminary analyses, dichotomization at the 80th percentile was not associated with any of the outcomes. Consequently, only results for the 20th percentile are presented here. BMI was dichotomized at the 80th percentile for gender (28.8 kg/m$^2$ for men and 28.5 kg/m$^2$ for women) and years of previous computer use (greater than 20 hr/week) was categorized as less than 2 years (referent), 2–5 years, and greater than 5 years.

## RESULTS

### Recruitment

Between October 1, 1995 and October 31, 1998, 2,546 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 hr/week, or that the use of multiple computers was expected. Of those invited, 789 (83%) agreed to participate and gave written informed consent and 632 (66%) completed the entry questionnaire.

### Study Population

Descriptive characteristics of the study population are provided in Table I. The participants were relatively young and well educated and had a wide range of household incomes. On average, participants reported spending about 38 hr/week at work, 28 hr/week at their computer workstations, and 20 hr/week keying (data not presented in Table I). The single largest occupational category was secre-

**TABLE I.** Characteristics of the Study Population (N = 632)

| Characteristic | Frequency | Percent |
|---|---|---|
| Gender | | |
| Female | 448 | 70.9 |
| Male | 184 | 29.1 |
| Age | | |
| < 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 | | |
| Under $25,000 | 157 | 26.0 |
| $25,000–49,999 | 238 | 39.4 |
| $50,000 or over | 209 | 34.6 |
| Unknown | 28 | [a] |
| Occupation | | |
| Executive | 14 | 2.3 |
| Professional | 171 | 27.9 |
| Technical | 26 | 4.2 |
| Sales | 54 | 8.8 |
| Secretarial | 349 | 56.8 |
| Personal characteristics | | |
| Right handed | 562 | 89.1 |
| Post-menopausal[b] | 46 | 10.5 |
| Hormonal medication[b] | 152 | 33.9 |
| History of neck/shoulder pain | 52 | 8.2 |
| History of hand/arm pain | 37 | 5.9 |
| Children under 6 in household | 97 | 20.7 |
| Body mass index (kg/m$^2$) | | |
| < 18.5 | 15 | 2.4 |
| 18.5–24.9 | 359 | 58.0 |
| 25.0–29.9 | 153 | 24.7 |
| ≥ 30.0 | 92 | 14.9 |
| Unknown | 13 | [a] |
| Height | | |
| < 20th percentile[c] | 120 | 19.0 |
| ≥ 20th percentile | 511 | 81.0 |
| Unknown | 1 | [a] |
| Prior years keying ≥ 20 hr/week | | |
| < 2 | 228 | 36.1 |
| 2–5 | 167 | 37.5 |
| > 5 | 237 | 26.4 |

[a]Number excluded from percentages.
[b]Results limited to females only, N = 448.
[c]< 1.58 m for females; < 1.73 m for males.

tarial. Many participants had past experience of keying for a substantial portion of their workweek prior to study entry.

## Neck/Shoulder Symptoms and Disorders: Unadjusted Analyses

### Prevalence

Of the 63 (10%) participants who met criteria for N/S symptoms at study entry, examinations could be scheduled for 53 (Table II). A majority (70%) of those examined met criteria for one or more N/S disorder. The prevalence of any N/S disorder at the time of entry into the study was 5.9% (37/622). Nearly all participants with one or more N/S disorder met criteria for somatic pain syndrome.

### Incidence

*Symptoms.* After exclusion of the 63 participants who were symptomatic at the time of entry, 569 remained eligible for inclusion in analyses of incident N/S symptoms (Fig. 1). Of the 569 participants, 31 were excluded because they did not complete the daily diaries. Therefore, analyses of incident symptoms were performed on the remaining 538 participants. While being followed, 183 participants met criteria for new onset N/S symptoms. Of the 183 participants, 46 (25%) reported both medication use and symptoms of intensity "6" or greater on the visual analog scale, 94 (51%) reported medication use with symptoms of intensity below "6," and 43 (24%) reported no medication use with symptoms of intensity "6" or greater (data not shown).

The Kaplan–Meier survival curve for N/S symptoms is presented in Figure 2. The slope of the survival curve was greatest early in the study and decreased over time with 46% of the total incident cases occurring during the first month of follow-up (data not shown).

*Disorders.* After exclusion of the 37 participants who were found to have N/S disorders at entry and the 10 for whom examinations could not be scheduled, 585 participants were eligible for inclusion in analyses of incident disorders (Fig. 1). Of the 585, 31 did not complete diaries resulting in 554 participants available for analyses of incident disorders. Of the 554, 199 reported incident symptoms and examinations could be performed on 161 of them. Seventy-three percent of those examined (117/161) met criteria for one or more disorder (Table II). As was seen for N/S symptoms, the slope of the survival curves for N/S disorders was greatest early in the study and decreased over time (Fig. 2). The proportion of incident N/S disorders occurring during the first month of follow-up was 45% (data not shown).

The proportions of examined participants with specific disorders are provided in Table II. The types of disorders observed during follow-up were similar to those seen at entry. Somatic pain syndrome accounted for 95% of incident N/S disorders.

**TABLE II.** Prevalence and Incidence of Neck/Shoulder Symptoms and Examination Confirmed Disorders Among Computer Users

| | At entry | | | | During follow-up | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Incidence rate (SE) | | | |
| | N | Frequency | % of exams[a] | Prevalence (SE) | N | Frequency | % of exams[b] | 1 month | 3 month | 6 month | 12 month |
| 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 tendonitis | 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) |

[a]Fifty-three examinations performed at entry.

[b]One hundred and sixty-one examinations performed during follow-up.

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.

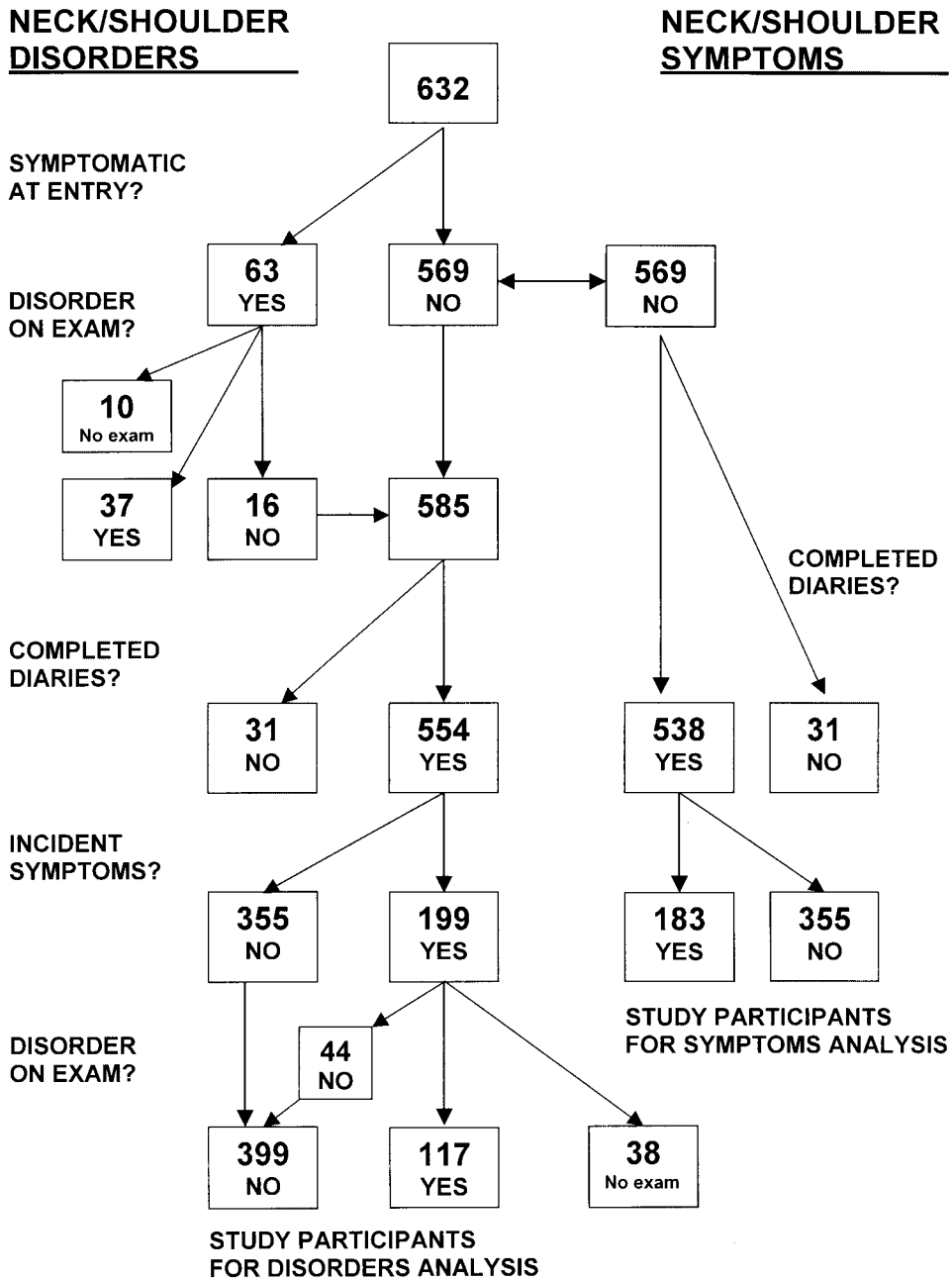


**FIGURE 1.** Flow chart of participant eligibility for analyses of incident neck/shoulder symptoms and disorders.

## Neck/Shoulder Symptoms and Disorders: Multivariate Analyses of Incidence

Results of multivariate analyses of N/S outcomes are displayed in Table III. Because terms for interaction of gender with other covariates were not statistically significant, results presented in Table III are for men and women combined. Female gender was associated with an increased risk of developing N/S symptoms and disorders during follow-up. After 6 months of follow-up, 42% of women and 27% of men had experienced N/S symptoms; at 1 year of follow-up, 48% of women and 36% of men had experienced N/S symptoms (data not shown).

Participants aged 30 years and older had an increased risk of developing N/S symptoms and disorders and non-white participants were somewhat less likely than white participants to develop N/S symptoms and disorders. Individuals who reported a past history of N/S pain requiring medical attention (at least 1 week prior to study

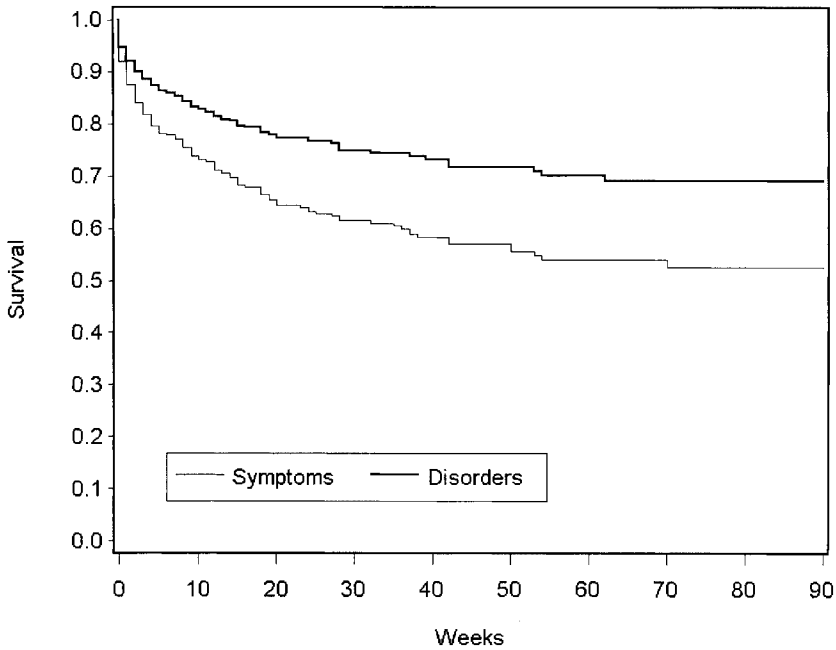


**FIGURE 2.** Kaplan–Meier survival curves for development of neck/shoulder symptoms and disorders among computer users.

entry) were more than three times more likely to develop N/S symptoms and disorders during follow-up. Participants whose height was at or below the 20th percentile were less likely to develop N/S disorders. In general, associations of risk factors with the incidence of N/S disorders were of slightly larger magnitude than those seen for N/S symptoms.

## Hand/Arm Symptoms and Disorders: Unadjusted Analyses

### *Prevalence*

Hand/arm symptoms and disorders were less frequent than N/S symptoms and disorders at study entry. At entry,

**TABLE III.** Relative Risks and 95% Confidence Intervals for Development of Neck or Shoulder Symptoms and Neck or Shoulder Disorders Among Computer Users

| | Neck or shoulder symptoms | | Neck or shoulder disorders | |
|---|---|---|---|---|
| **Variable** | **RR** | **95% CI** | **RR** | **95% CI** |
| Female gender | **1.7** | **1.2–2.6** | **1.9** | **1.1–3.1** |
| Age 30–39 | **1.6** | **1.1–2.4** | **1.8** | **1.1–2.9** |
| Age 40 and older | **1.9** | **1.2–3.0** | **1.9** | **1.1–3.5** |
| Non-white | **0.7** | **0.5–1.0** | **0.6** | **0.4–1.0** |
| Previous history of neck/shoulder pain | **3.3** | **2.1–5.2** | **3.6** | **2.1–6.0** |
| 2–5 years of previous computer use | 1.2 | 0.8–1.7 | 0.7 | 0.4–1.3 |
| $>$ 5 years of previous computer use | 0.9 | 0.6–1.4 | 0.9 | 0.6–1.4 |
| 20th percentile of height | 0.8 | 0.5–1.2 | **0.5** | **0.3–1.0** |
| BMI $>$ 80%ile | 1.2 | 0.8–1.7 | 0.9 | 0.5–1.5 |
| Current smoker | 1.0 | 0.6–1.7 | 1.1 | 0.6–2.0 |
| Income $25,000–$49,999 | 0.9 | 0.6–1.3 | 0.8 | 0.5–1.4 |
| Income $\geq$ $50,000 | 0.8 | 0.5–1.2 | 0.9 | 0.5–1.5 |
| College graduate | 1.2 | 0.8–1.8 | 0.8 | 0.5–1.3 |
| Children under 6 | 1.2 | 0.8–1.8 | 1.3 | 0.8–2.2 |

Figures in bold indicate $P < 0.05$; Likelihood ratio test.

24 (4%) of the 632 participants met criteria for H/A symptoms. Examinations were performed on 22 of these symptomatic participants and 14 (64%) met criteria for one or more H/A disorder resulting in a prevalence of 2%. Details for specific disorders of the H/A are given in Table IV.

## Incidence

*Symptoms.* After exclusion of the 24 study participants who had H/A symptoms at entry, 608 participants remained eligible for inclusion in analyses of incident symptoms (Fig. 3). Because 34 of the 608 eligible participants did not complete diaries, results from 574 participants were actually available for analyses of incident symptoms. While being followed prospectively, 141 of the 574 study participants met criteria for new onset of H/A symptoms. Of the 141, 17 (12%) reported both medication use and symptoms of intensity "6" or greater on the visual analog scale, 74 (52%) reported medication use with symptoms of intensity below "6," and 50 (35%) reported no medication use with symptoms of intensity "6"or greater (data not shown).

A Kaplan–Meier survival curve for H/A symptoms is presented in Figure 4. The slope of the survival curve for H/A symptoms was only slightly greater during the first few months of follow-up than later in the study. Furthermore, during the first few months, the slope for H/A 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 proportion of incident symptom cases occurring during the first month of follow-up was 32% (data not shown).

*Disorders.* After exclusion of the 14 study participants found to have H/A disorders at entry and the two for whom examinations could not be scheduled, 616 participants were eligible for inclusion in analyses of incident disorders (Fig. 3). Of the 616, 34 did not complete diaries resulting in 582 participants available for follow-up of incident disorders. Of the 582 participant, 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 IV).

**TABLE IV.** Prevalence and Incidence of Hand/Arm Symptoms and Examination Confirmed Disorders Among Computer Users

| | At entry | | | | During follow-up | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Incidence rate (SE) | | | |
| | N | Frequency | % of exams[a] | Prevalence (SE) | N | Frequency | % of exams[b] | 1 month | 3 month | 6 month | 12 month |
| 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 tendonitis | 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 tendonitis | 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 tendonitis | 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) |
| Extensor tendonitis | | | | | | | | | | | |
| —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) |
| —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) |
| —Dorsal comp 3 | 630 | 0 | 0.0 | 0.0 | 582 | 0 | 0.0 | — | — | — | — |
| —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) |
| —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) |
| —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 | — | — | — | — |

[a]Twenty-two examinations performed at entry.

[b]One hundred and twenty examinations performed during follow-up.

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.

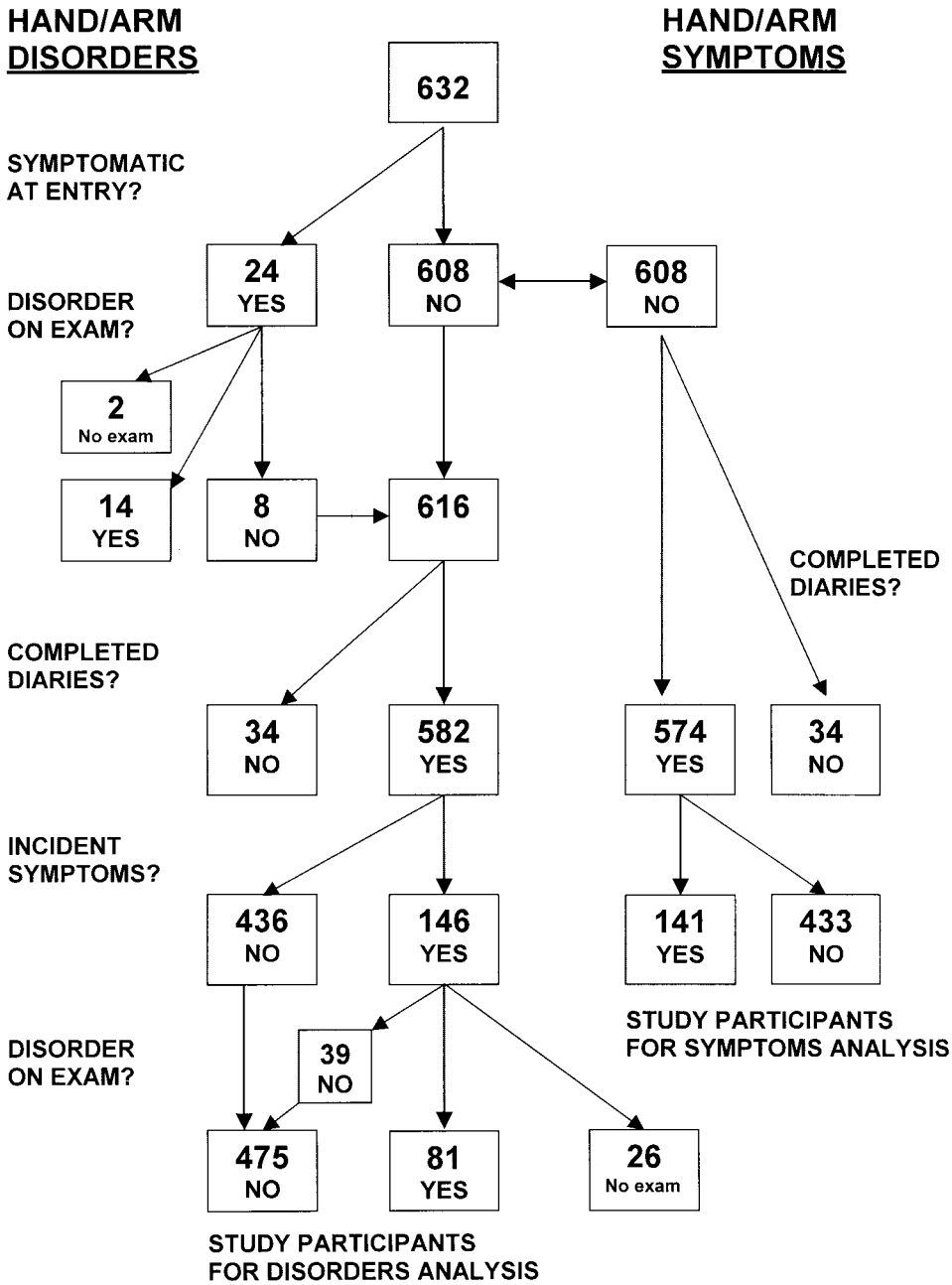


**FIGURE 3.** Flow chart of participant eligibility for analyses of incident hand/arm symptoms and disorders.

The shape of the survival curve for H/A disorders was very similar to the survival curve for H/A symptoms (Fig. 4). The proportion of incident H/A disorders occurring during the first month of follow-up was 32% (data not shown). Of the 120 study participants examined during the follow-up period, nearly half (47%) met criteria for extensor tendonitis of the first dorsal compartment (deQuervain's tendonitis).

Electrophysiologically confirmed CTS was less common than most other disorders, with three incident cases found during the follow-up period and an annual incidence of 0.9 cases/100 person-years. As expected, symptoms in the distribution of the median nerve were more common than confirmed cases of CTS with 26 participants reporting such symptoms during the follow-up period for an annual incidence rate of 6.9/100 person-years (data not shown in Table IV). Three of the 26 participants with incident symptoms in the distribution of the median nerve declined nerve conduction testing resulting in a possible underestimation of the incidence of confirmed CTS.

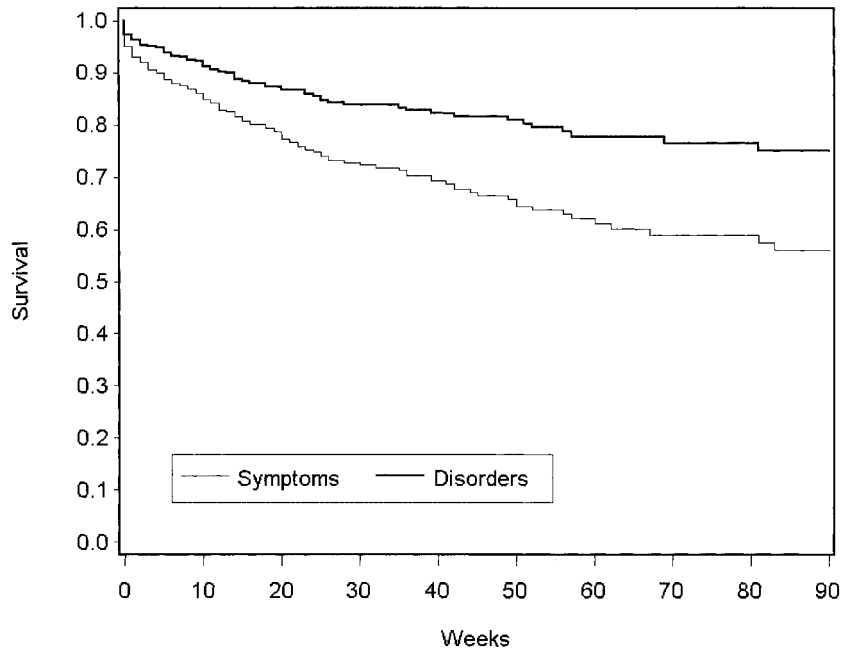


**FIGURE 4.** Kaplan–Meier survival curves for development of hand/arm symptoms and disorders among computer users.

## Hand/Arm Symptoms and Disorders: Multivariate Analyses of Incidence

Results of multivariate analyses of H/A outcomes are displayed in Table V. Interaction terms of gender with other covariates were not statistically significant. Therefore, gender specific results are not presented. Women were more likely to report H/A symptoms and disorders than men. After 6 months of follow-up, 29% of women had experienced H/A symptoms compared to 18% of men and at 1-year of follow-up 40% of women had experienced H/A symptoms compared to 25% of men (data not shown).

**TABLE V.** Relative Risks and 95% Confidence Intervals for Development of Hand or Arm Symptoms and Hand or Arm Disorders Among Computer Users

| | Hand or arm symptoms | | Hand or arm disorders | |
|---|---|---|---|---|
| **Variable** | **RR** | **95% CI** | **RR** | **95% CI** |
| Female gender | **1.6** | **1.0–2.5** | **2.4** | **1.3–4.7** |
| Age 30–39 | 0.9 | 0.6–1.4 | 0.9 | 0.5–1.6 |
| Age 40 and older | 1.3 | 0.8–2.1 | 1.3 | 0.7–2.6 |
| Non-white | 0.8 | 0.5–1.1 | 0.9 | 0.5–1.4 |
| Previous history of hand or arm pain | **2.7** | **1.5–4.8** | 1.7 | 0.8–4.0 |
| 2–5 years of previous computer use | **2.0** | **1.2–3.2** | **2.7** | **1.3–5.5** |
| $>$ 5 years of previous computer use | **2.0** | **1.2–3.3** | **2.3** | **1.1–4.5** |
| 20th percentile of height | 1.0 | 0.6–1.6 | 1.0 | 0.5–1.9 |
| BMI $>$ 80%ile | 1.3 | 0.8–2.0 | 1.1 | 0.6–2.0 |
| Current smoker | 1.2 | 0.7–2.0 | 1.3 | 0.7–2.6 |
| Income $25,000–$49,999 | 1.1 | 0.7–1.7 | 1.5 | 0.8–2.8 |
| Income $\geq$ $50,000 | 0.9 | 0.6–1.5 | 1.3 | 0.6–2.7 |
| College graduate | 0.8 | 0.6–1.2 | 0.8 | 0.5–1.4 |
| Children under 6 | **1.6** | **1.0–2.5** | 1.4 | 0.7–2.8 |

Figures in bold indicate $P < 0.05$; Likelihood ratio test.

A previous history of arm pain, at least 2 years of previous computer use, and children under 6 years of age were associated with increased risks of developing H/A symptoms and at least 2 years of previous computer use was also associated with increased risk of H/A disorders.

## Additional Analyses Conducted for Each Outcome

Analyses excluding those individuals with pre-existing medical conditions (i.e., diabetes, arthritis, bursitis, tendonitis, and CTS) yielded results essentially identical to those for the full cohort. Multivariate models reduced by eliminating variables not associated with the outcome ($P > 0.05$) yielded point estimates and confidence intervals for the remaining variables that were essentially identical to the full models.

## DISCUSSION

This is the first prospective study of musculoskeletal health among computer users in North America. Newly hired workers anticipating computer use of greater than 15 hr/week were evaluated to determine the prevalence of MSS and MSD among them. Participants free of MSS at entry were followed prospectively to determine the incidence of MSS, and participants free of MSD at entry were followed prospectively to determine the incidence of MSD. The strengths of this study include the prospective design and the use of a standard clinical examination protocol with well-defined criteria to identify specific MSD.

Virtually all previous studies of MSS or MSD among computer users have been cross-sectional in design. The only other longitudinal study in the literature [Bergqvist et al., 1992] assessed prevalent MSS at two points in time 6 years apart. Because individuals were not followed during the intervening 6 years, it is impossible to determine the incidence of MSS which may have occurred and resolved during that interval.

In the current study, 10% of newly hired computer users reported prevalent (i.e., during the past week) N/S symptoms and 4% reported prevalent H/A symptoms. When these individuals were examined, 70% of participants with N/S symptoms met criteria for a N/S disorder (almost all of these were somatic pain syndrome) and 64% of participants with H/A symptoms met criteria for a H/A disorder. The majority of the H/A disorders were tendon-related, with the most common being deQuervain's tendonitis.

The prevalence of MSS found among those entering this study are somewhat lower than those reported in other studies of computer users in the literature. This difference may be due to differences in the time periods used in the period prevalence calculations, in populations studied, or in criteria used for ascertainment of symptoms. For example, Bergqvist et al. [1995] found 62% of computer users reported N/S discomfort in the past year and Bernard et al. [1994] found 26% of users reported neck discomfort and 17% reported shoulder discomfort in the past year. When the time period in the Bergqvist et al. [1995], study was narrowed to include only those symptoms that were prevalent in the previous 7 days and that interfered with work, the prevalence of N/S symptoms dropped to 7%. This narrowed time period is the same as that was used in the current study for prevalence calculations. In the study of Bergqvist et al. [1995], the prevalence of hand or arm discomfort in the past year was 30% and in the study of Bernard et al. [1994], the prevalence of hand or wrist discomfort in the past year was 22%. When the time period in the Bernard et al. [1994] study was narrowed to include only those symptoms prevalent in the previous 7 days, the prevalence of hand or wrist symptoms was reduced to 11%.

In the current study, the prevalence of examination-confirmed N/S disorders at entry was 6% and the prevalence of examination confirmed H/A disorders was 2%. Few studies in the literature have incorporated examination criteria into their definitions of MSD and even fewer presented the data in a format that allows for calculation of prevalence. Examination by a physiotherapist was incorporated into the Bergqvist et al. [1995] study, resulting in a prevalence of 22% for neck "diagnoses" and 9% for H/A "diagnoses." In a study of telephone operators using computers [Hales et al., 1994], the prevalence of examination confirmed that the neck disorders were 9% and examination confirmed hand/wrist disorders were 12%.

Carpal tunnel syndrome was among the least common of all disorders observed in this study. Unlike most previous studies of CTS among computer users, the current study required both characteristic symptoms and a prolonged median sensory nerve conduction latency measured from wrist to index finger for identification of subjects with CTS. Use of symptoms and electrophysiological measurements has recently been recommended as the preferred method for identification of CTS in epidemiological studies [Rempel et al., 1998]. Among 22 participants examined for reporting prevalent H/A symptoms at entry into the study, three met the criteria for CTS (13.6% of those examined; prevalence = 0.5%). During the follow-up phase of the study, 120 participants were examined for reporting incident H/A symptoms and an additional three participants met criteria for CTS (2.5% of those examined; incidence rate = 0.9 cases/100 person years). In addition, eight individuals reported a prior history of physician-diagnosed CTS on entry into the study.

While these results appear to be contrary to the common perception that CTS is one of the most common disorders among computer users, our observations regarding the prevalence of CTS are not inconsistent with the few studies that have investigated its prevalence among computer users. In a study of musculoskeletal disorders among communication workers using computers, Hales et al. [1992, 1994]

examined 517 study participants of whom four subjects (1%) met symptom and clinical examination criteria for CTS. In a study of computer users at a large newspaper, 8 of the 130 symptomatic participants who were examined met a physical examination based case definition of CTS (6% of those examined; estimated prevalence of 1.3%) [Bernard et al., 1993, 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 CTS cases by electrophysiological criteria. Well-defined criteria for identification of CTS, including nerve conduction measures, were used by Franzblau et al. [1993] in a study of computer users. However, the small sample size ($n = 26$) precludes stable estimation of CTS prevalence from that study. We are aware of no other studies that have attempted to estimate the *incidence* of CTS among computer users.

This study was not designed to determine whether computer use increases the risk of CTS. A comparison group of office workers who did not use computers would be necessary to address this question. In fact, the incidence of CTS observed among computer users in this study might be in excess of the incidence among a similar but non-exposed population. The number of CTS cases was not large enough to permit assessment of risk factors for that disorder alone.

While the incidence of MSS was greater during the first month of follow-up for both N/S and H/A symptoms, differences were observed between these two outcomes for overall incidence, incidence during the first month of follow-up, and association with previous computer use. Specifically, both the annual incidence and the proportion of cases observed during the first month of follow-up were greater for N/S symptoms than for H/A symptoms. Furthermore, the risk of developing H/A symptoms during follow-up was significantly greater among those who had 2 or more years of previous computer use (more than 20 hr/week) whereas no association was observed between previous computer use and N/S symptoms. These differences in incidence, temporal pattern, and influence of past computer use suggest that the pathophysiology of H/A symptoms is different than that of N/S symptoms.

A large proportion of study participants who were symptomatic met criteria for specific MSD. This proportion ranged from 64 to 73%. 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, multivariate analyses of disorders by demographic factors yielded results similar to the analyses of the corresponding symptoms.

The most common N/S disorder was somatic pain syndrome. This disorder, sometimes referred to as *tension neck syndrome*, was defined as the combination of (a) decreased range of neck flexion/extension, lateral bending, or rotation and (b) pain on palpation of the trapezius or sternomastoid muscles. While these procedures required some clinical judgment by the examiner, the study employed only one experienced occupational therapist (with certification in hand therapy) to maintain consistency across all examinations. Of the 111 individuals who met criteria for somatic pain syndrome, the most common limitation of neck movement was lateral bending and the most common location for pain was the trapezius muscle.

Limitations of the study include a modest participation rate (66% of those eligible) and the inclusion of individuals with prior experience with computers. In a previous study [Marcus and Gerr, 1996], we found evidence that computer users who experience symptoms may reduce their hours of computer use, thereby distorting the exposure-response relationships observed in cross-sectional studies. In this study, we limited enrollment to those who would be using a computer for at least as many hours/week as in their previous job to minimize the potential for inclusion of individuals who had reduced their computer use as a result of prior symptoms.

That 34% of those eligible declined to participate in the demanding protocol is unlikely to bias the results. Limited information on non-respondents indicates that their job titles and anticipated number of hours of computer use/week were no different from those of participants. In addition, this was a prospective study in which only asymptomatic individuals were invited to participate. Finally, the prospective design prevented selective entry of participants based on future health status.

Women were more likely to develop symptoms and disorders than were men. Among women, menopausal status and hormonal medication were not associated with the incidence of MSS or MSD. Others have also noted the higher occurrence of musculoskeletal symptoms among women and the observation has been the subject of a recent review [Punnett and Herbert, 1999]. Symptoms may be more common among women because of increased exposure to etiologic factors, because of increased biological susceptibility, or because of a lower threshold for reporting symptoms than men. In the current analyses, these three possibilities cannot be distinguished. However, the observation that women also were at increased risk of examination-confirmed disorders provides evidence that a difference in reporting threshold cannot entirely explain women's increased risk of musculoskeletal symptoms.

In conclusion, upper-extremity MSS affected more than half of the study participants who used a computer for more than 15 hr/week in their first year at a new job. Women were more likely to experience symptoms than were men. A large proportion of symptomatic individuals met criteria for specific MSD. Hand or arm disorders were less frequent than neck or shoulder disorders. Carpal tunnel syndrome, diagnosed by symptomatic and electrophysiological criteria, affected 1% of computer users in their first year at a new job.

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## APPENDIX: CASE DEFINITIONS FOR MUSCULOSKELETAL DISORDERS

### Neck

#### *Radicular pain syndrome*

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

#### *Somatic pain syndrome*

Abnormal cervical range of flexion, extension, lateral bending, or rotation motion and pain on palpation of either a) sternomastoid muscle (unilateral or bilateral) or b) trapezius muscle (unilateral or bilateral) [Waris, 1979]. Cervical flexion was categorized as abnormal when the chin could not be brought into contact with the chest, extension was categorized as abnormal when a line from the chin to the forehead was less than horizontal, lateral bending was categorized as abnormal when the earlobe was more than 3 cm from the top of the shoulder, and rotation was categorized as abnormal when the chin was more than 3 cm from the acromioclavicular joint of the shoulder [Wetzel and Reider, 1999].

### Shoulder

#### *Rotator cuff tendonitis*

Positive supraspinatus point tenderness and either a) positive supraspinatus muscle test [Yocum, 1983] or b) painful arc of motion test [Chard et al., 1988; Levin and Dellon, 1992]. All assessments of point tenderness required comparison to the contralateral side. Only when discomfort was greater on the symptomatic side was point tenderness considered present.

#### *Bicipital tendonitis*

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

### Elbow

#### *Medial epicondylitis*

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

#### *Lateral epicondylitis*

a) Positive Cozen's test 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; Viikari-Juntura, 1984; Thornson and Szabo, 1989].

### Hand/Arm

#### *Flexor carpi radialis tendonitis*

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 [Calliet, 1994; Tubania et al., 1996].

#### *Flexor carpi ulnaris tendonitis*

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 [Calliet, 1994; Tubania et al., 1996].

#### *Digital flexor tendonitis*

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 [Thornson and Szabo, 1989; Tubania et al., 1996].

### Extensor tendonitis—dorsal compartment 1 (abductor pollicis longus & extensor pollicis brevis)

Positive Finklestein test or pain on resisted thumb MCP extension (Hitchhiker test) [Calliet, 1994; Gross et al., 1996; Tubania et al., 1996; Moore, 1997].

### Extensor tendonitis—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 [Thornson and Szabo, 1989; Gross et al., 1996; 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, and crepitance.

### Extensor tendonitis—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 [Thornson and Szabo, 1989; Gross et al., 1996].

### Extensor tendonitis—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 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 [Thornson and Szabo, 1989; Gross et al., 1996].

### Extensor tendonitis—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 tendonitis—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 [Thornson and Szabo, 1989; Gross et al., 1996].

### 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; Thornson and Szabo, 1989; Calliet, 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 [Cailliet, 1977; NeuMed, 1998; Rempel et al., 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 [Dawson et al., 1990; NeuMed, 1998].

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