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by [Hannan LM](#), [Monteilh CP](#), [Gerr F](#), [Kleinbaum DG](#), [Marcus M](#)

Affiliation: Department of Epidemiology, Rollins School of Public Health, Emory University, Atlanta, Georgia 30322, USA.

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Job strain and risk of musculoskeletal symptoms among a prospective cohort of occupational computer users

by Lindsay M Hannan, MSPH,¹ Carolyn P Monteilh, PhD,² Fred Gerr, MD,³ David G Kleinbaum, PhD,¹ Michele Marcus, PhD^{1,2}

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Objectives Most previous studies of the association between psychosocial stress and musculoskeletal illness among computer users have been cross-sectional and have yielded inconsistent results. The association between a measure of psychosocial stress, “job strain”, and incident neck–shoulder and arm–hand musculoskeletal symptoms was investigated among recently hired computer users.

Methods The participants worked for one of several large employers and were followed prospectively for 6 months. The “job demands” and “decision latitude” subscales of the Job Content Questionnaire were used to estimate the job-strain quadrants and a ratio measure of job strain which was subsequently categorized. Incident musculoskeletal symptoms were obtained with weekly diaries. Proportional hazards models were used to estimate associations between job strain and incident musculoskeletal symptoms.

Results Those in the high-strain quadrant were at increased risk of neck–shoulder symptoms [hazard ratio (HR) 1.65, 95% confidence interval (95% CI) 0.91–2.99] when compared with those in the low-strain quadrant. Those in the highest strain-ratio category were also at increased risk of neck–shoulder symptoms when compared with those in the lowest strain-ratio category (HR 1.52, 95% CI 0.88–2.62). Modification by previous years of computer use was observed, with an elevated risk observed for those in the highest job-strain ratio category who also had low previous computer use (HR 3.16, 95% CI 1.25–8.00). There did not appear to be an association between either measure of job strain and incident arm–hand symptoms.

Conclusions In this cohort, workers who reported high job strain were more likely to develop neck–shoulder symptoms.

Key terms arm; hand; keying; musculoskeletal illness; neck; psychosocial factor; shoulder.

According to the United States (US) Census Bureau, in 1997, there were approximately 92.2 million adult computer users in the United States. Of these people, 63.9 million used a computer at work. It was estimated that approximately half of all adults in the United States used a computer in an occupational setting (1).

Evidence is growing that computer users are at increased risk of experiencing musculoskeletal disorders. In one recent study, the incidence of neck and shoulder musculoskeletal symptoms among computer users was 58 cases/100 person-years, and the incidence of hand and arm musculoskeletal symptoms was 35 cases/100 person-years (2). Given the magnitude of exposure, even

small increases in risk would result in a substantial number of adverse events.

In 1999, work-related musculoskeletal disorders accounted for approximately 66% of all reported occupational illnesses in the United States (3). These disorders have a major impact on both people and society in terms of morbidity, cost of treatment, and lost productivity. According to the US Bureau of Labor Statistics, workers who experience musculoskeletal disorders miss a median of 8 days of work annually, and ≥ 3 weeks of work are missed annually by over 30% of the cases (4).

Numerous risk factors have been examined as possible explanations for the increase in the risk of

¹ Department of Epidemiology, Rollins School of Public Health, Emory University, Atlanta, Georgia, United States.

² Department of Environmental and Occupational Health, Rollins School of Public Health, Emory University, Atlanta, Georgia, United States.

³ Department of Occupational and Environmental Health, College of Public Health, University of Iowa, Iowa City, Iowa, United States.

Correspondence to: Dr Michele Marcus, Department of Epidemiology, Rollins School of Public Health, Emory University, 1518 Clifton Rd, Atlanta, GA 30322, USA. [E-mail: mmarcus@sph.emory.edu]

musculoskeletal disorders among computer users, including operator posture, hours of keying per day, and occupational psychosocial stress. However, these associations have largely been examined in cross-sectional studies, which have many methodological and analytical limitations. With respect to associations between occupational psychosocial stress and musculoskeletal disorders, previous studies (5–12) have been inconsistent.

To clarify further the role of occupational psychosocial stress on the risk of musculoskeletal disorders, we examined the relationship between measures of “job strain” and the risk of incident arm–wrist musculoskeletal symptoms and incident neck–shoulder musculoskeletal symptoms in a prospective cohort of occupational computer users.

Study population and methods

Overview

These analyses were conducted using data obtained during a randomized controlled trial designed to examine the effect of two postural and workstation interventions on incident musculoskeletal symptoms among computer users. To assess occupational psychosocial factors, we administered the Job Content Questionnaire (13, 14) to all of the participants at entry into the study. A brief description of the study procedures is presented in this report, and a complete description of the study methods and results is available elsewhere (15).

At enrollment, the participants completed a standard questionnaire used to collect demographic, occupational, psychosocial, and past medical information. In addition, study staff members measured specific dimensions of the workstation and the posture of the worker. The participants were then assigned randomly to one of the following three experimental groups: the alternate postural intervention group (group A), the conventional postural intervention group (group B), and the no intervention group (group C). Those who were randomized into group A were instructed to use a posture characterized by a keyboard height lower than elbow height, shoulders somewhat extended, elbows bent only slightly, and the use of arm and wrist rests. Those who were randomized into group B were instructed to use a more conventional posture characterized by elbows bent to 90 degrees, forearms parallel to the floor, an upright sitting position, and the use of arm and wrist rests. Those randomized into group C were given no instructions for specific postures (15).

Subsequent to the assignment, any necessary workplace modifications were made to meet the requirements of the assigned experimental group. Incident musculoskeletal health outcomes were assessed weekly during

the follow-up period. As reported elsewhere, no differences in the incidence of hand–arm or neck–shoulder symptoms were observed among the three experimental groups (15). Furthermore, the members of each experimental group (including the no intervention group) received similar amounts of contact with study staff members. In addition, although the participants were aware of their experimental group status, they were not aware which intervention was hypothesized to be the most effective. Our analyses examined the associations between psychosocial job strain, as measured by the Job Content Questionnaire, and incident musculoskeletal outcomes with control for important covariates, including experimental group.

Study population

The participants were recruited from several large employers in the metropolitan Atlanta, Georgia (USA), area. Newly hired employees who anticipated using a computer at work for >15 hours per week were invited to participate. To be eligible, the prospective participants had to have estimated that computer use in the new job would be greater than in any job previously held during the 3 years prior to enrollment, and they also had to use one computer workstation for more than half of the time spent keying in the new job.

Psychosocial risk factors for incident neck–shoulder symptoms were examined only among the participants free of neck–shoulder symptoms at baseline, while the risk factors for incident arm–hand symptoms were examined only among those free of arm–hand symptoms at baseline. If the participants were free of both symptoms at baseline (310 of 337 participants), then they contributed information to both analyses. If a participant reported arm–hand symptoms at baseline, but not neck–shoulder symptoms, he or she was only included in the neck–shoulder analysis, and vice versa. Those who reported experiencing upper-extremity musculoskeletal symptoms in both areas at baseline were excluded from all of the analyses. The definition of upper-extremity musculoskeletal symptoms at baseline was discomfort with an intensity of ≥ 6 on a 0–10 visual analogue scale or discomfort that prompted the taking of analgesic medication in the week prior to entry into the study. The Emory University Human Investigations Committee approved the study protocol, and written informed consent was obtained from all of the participants at the time of enrollment.

Data collection instruments and procedures

Demographic and personal health history questionnaire. At enrollment, the 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 (eg, arthritis, diabetes, thyroid illness), medication use, tobacco use, and past occupational computer use.

Weekly exposure and symptom diary. At enrollment, the participants were instructed in the use of a data collection instrument (the exposure and symptom diary) designed to obtain information about their work, symptoms of pain or discomfort, and nonoccupational activities. Daily, the study participants recorded hours worked in the office, hours spent keying, and the number of short (≤ 10 minutes) and long (> 10 minutes) breaks from the workstation.

On the same instrument, the participants recorded information weekly about discomfort in the upper limbs, neck, and shoulder. A study participant who experienced discomfort was instructed to indicate the intensity of the discomfort on a 0–10 visual analogue scale, to indicate whether he or she took medication (eg, Tylenol®, Motrin®, etc) for the discomfort and to provide an answer to the question “What do you think caused the pain?” Questions designed to quantify time spent in aerobic activities, as well as hand-intensive activities, were also included in the exposure and symptom diary. The participants were asked to enter information on the diary every day that they were enrolled in the study. The diaries were collected weekly and reviewed for completeness by study personnel.

Job-strain assessment

“Job strain” was assessed with the Job Content Questionnaire and defined according to the Karasek job-strain model (13). The 27-item version of the questionnaire was distributed to the participants at the time of their assignment to an experimental group and was collected by staff during a subsequent visit. The questionnaire requires that respondents consider statements about their job tasks and occupational environment (eg, My job requires that I learn new things) and select one of the following four response categories: strongly disagree, disagree, agree, and strongly agree, which were coded with values of 1 (strongly disagree) to 4 (strongly agree).

With the standard methods of scoring, values for the scales of skill discretion, decision authority, decision latitude, psychological job demands, supervisory support, and co-worker support were obtained with the questionnaire (14).

High psychological job demands and low decision latitude have both been hypothesized to be risk factors for adverse psychological and physical outcomes. The job strain model combines these two risk factors into a single metric called “job strain.” The model holds that

job strain is high when psychological job demands are high and decision latitude is low. Dichotomized categories of “decision latitude” (low and high) and “psychological job demands” (low and high), based on the median value of the sample, have commonly been used to create quadrants of job strain: low strain (low psychological job demands and high decision latitude), high strain (high psychological job demands and low decision latitude), active job (high psychological job demands and high decision latitude), and passive job (low psychological job demands and low decision latitude) (13).

In addition to the quadrant system of categorizing job strain, a continuous ratio of “psychological job demands” to “decision latitude” has also been used as a measure of job strain. It is calculated by dividing the measure of psychological job demands by the measure of decision latitude (16). It is compatible with the hypothesis that the relative difference between psychological job demands and decision latitude is a better measure of job stress than the categories created by the quadrant model.

Health outcome assessment. From March 2000 through May 2003, musculoskeletal symptoms for both anatomical regions (neck or shoulder and hand or arm) were ascertained at entry into the study and weekly for up to 6 months for each participant. The 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–shoulders versus arm–hand) and to rate the severity of the worst discomfort during the previous week on a 0–10 visual analogue scale (with verbal anchors of “no discomfort” at 0 and “unbearable pain” at 10). Separate visual analogue scales were used to rate discomfort in the neck–shoulder and the forearm–hand. In addition, the question “Did you take any medication for this discomfort this past week?” was asked separately for the neck–shoulder and for the hand–arm regions.

The participants were classified as having met the study case definition of musculoskeletal symptoms if they reported musculoskeletal discomfort on any day of the week with a severity of ≥ 6 on the visual analogue scale or they reported musculoskeletal discomfort that they controlled with medication (over-the-counter or prescription) on any day of the week. The occurrence of symptoms was determined separately for the neck–shoulder and for the hand–arm. The participants were followed for each outcome separately until they became symptomatic, withdrew from the study, or completed 6 months of follow-up. The appearance of a symptom in one anatomical area did not stop the collection of data for the other anatomical area.

Statistical analysis

The quadrants were defined for job strain by dichotomizing the continuous measures of psychological demands and decision latitude at their median values into "low" and "high" categories. Quadrant assignment was based on the job-strain model. Categories of the ratio measure of job strain were defined according to cut-points obtained from the quartiles of strain obtained for the cases only. This approach assured a homogeneous distribution of cases across the categories.

An unadjusted analysis was performed initially to examine the association between the job-strain quadrant and incident musculoskeletal symptoms by comparing the Kaplan-Meier survival curves for strain quadrants with the log-rank statistic. Hazard ratios (HR) and 95% confidence intervals (95% CI) were then estimated using Cox proportional hazards regression. The dependent variable was time to an incident musculoskeletal symptom in the relevant anatomical region. The number of person-weeks contributed by each participant was defined as the weeks between the completion of the first diary and the last diary prior to exit from the study. When a diary was missing, information reported on the previous week's diary (ie, hours spent in the office, hours spent on the computer, symptom status) was substituted for the missing information. The participants were exited from each cohort (neck-shoulder cohort or hand-arm cohort) at the first occurrence of symptoms that met the study case definition in the relevant area or

on the completion of 6 months of diaries. Those who were lost to follow-up were censored at the time of their last completed diary. To test for differential loss to follow-up as a function of job strain at the time of entry into the study, we examined the associations between baseline psychosocial measures and follow-up status (ie, dropout versus nondropout).

For the multivariate analyses, covariate information was obtained from questionnaires administered at or near the time of entry into the study and from the weekly diaries. Possible confounders were identified by examining demographic, occupational, and medical variables for those that differed across the strain quadrants with a probability of ≤ 0.20 in a chi-square analysis and also examining previous literature. All such potential confounders were included initially as covariates in the multivariate models of the two health outcomes. The potential confounding variables are listed in table 1.

Body mass index (BMI) was calculated from self-reported height and weight. A past history of pain in a specific area was based on responses to a 0-10 visual analogue scale of discomfort and a question about the use of medication in regard to the worst pain experienced by the participant in the anatomical region during the 3 years prior to their entry into the study, excluding the week prior to entry. Those who reported discomfort at a level of ≥ 6 or who took medication for discomfort were categorized as having a history of symptoms in the specific anatomical area.

Table 1. Characteristics of the 337 participants at risk for either neck-shoulder or arm-hand symptoms according to the job-strain quadrant.

Characteristic	Job-strain quadrant								P-value ^a
	Low strain (N=78)		Active (N=99)		Passive (N=91)		High strain (N=69)		
	N	%	N	%	N	%	N	%	
Age									0.81
18-24 years	15	19.2	18	18.2	18	19.8	14	20.3	
25-34 years	34	43.6	53	53.5	39	42.9	33	47.8	
35-44 years	18	23.1	18	18.2	24	26.4	14	20.3	
45-54 years	8	10.3	9	9.1	10	11.0	6	8.7	
55+ years	3	3.9	1	1.0	0	0.0	2	2.9	
Gender									0.002
Male	23	29.5	29	29.3	8	8.8	17	24.6	
Female	55	70.5	70	70.7	83	91.2	52	75.4	
Body mass index									0.38 ^b
Men									
<25 kg/m ³	13	56.5	17	58.6	4	50.0	8	47.1	
25-29.9 kg/m ³	9	39.1	10	34.5	3	37.5	4	23.5	
≥ 30 kg/m ³	1	4.4	2	6.9	1	12.5	5	29.4	
Women									0.54
<25 kg/m ³	39	70.9	40	57.1	46	55.4	31	59.6	
25-29.9 kg/m ³	10	18.2	22	31.4	23	27.7	15	28.9	
≥ 30 kg/m ³	6	10.9	8	11.4	14	16.9	6	11.5	
Height: in the top 20th gender-specific percentile ^c	12	15.6	10	10.2	16	17.8	11	15.9	0.49
Ethnic background: white, not of Hispanic origin ^d	48	62.3	70	71.4	51	56.7	44	63.8	0.001

(continued)

Table 1. Continued.

Characteristic	Job-strain quadrant								P-value ^a
	Low strain (N=78)		Active (N=99)		Passive (N=91)		High strain (N=69)		
	N	%	N	%	N	%	N	%	
Education: college graduate	61	79.2	81	82.7	56	62.2	47	68.1	0.01
Job title									<0.001
Professional	45	57.7	65	65.7	34	37.4	30	43.5	
Office and clerical	24	30.8	20	20.2	56	61.5	29	42.0	
Other	9	11.5	14	14.1	1	1.1	10	14.5	
Income ^e									0.01
<USD 34 999	22	29.0	27	27.8	43	48.9	26	39.4	
USD 34 000–74 999	31	40.8	41	42.3	34	38.6	28	42.4	
≥USD 75 000	23	30.3	29	29.9	11	12.5	12	18.2	
Experimental group status									0.001
Group A	40	51.3	25	25.3	31	34.1	21	30.4	
Group B	14	18.0	41	41.4	40	44.0	23	33.3	
Group C	24	30.8	33	33.3	20	22.0	25	36.2	
Use of hands: right handed ^f	71	92.2	90	91.8	80	88.9	64	92.8	0.81
Smoking: current smoker ^g	5	6.5	8	8.2	9	10.0	6	8.7	0.88
Hand–arm symptoms in past 3 years ^h	12	15.6	26	26.5	11	12.2	15	21.7	0.07
Neck–shoulder symptoms in past 3 years ⁱ	25	32.4	45	45.9	27	30.0	22	32.4	0.10
Frequency of mouse use									0.54
Sometimes or frequently	31	39.7	49	49.5	41	45.1	28	40.6	
Almost all the time	47	60.3	50	50.5	50	54.9	41	59.4	
Typing speed									0.47
<50 words per minute	30	38.5	31	31.3	36	39.6	26	37.7	
50–60 words per minute	34	43.6	50	50.5	46	50.6	36	52.2	
>65 words per minute	14	18.0	18	18.2	9	9.9	7	10.1	
Current use of pain medication ^j	15	19.5	15	15.3	15	16.7	12	17.4	0.91
Arthritis or rheumatism	3	3.9	4	4.1	3	3.3	1	1.5	0.85 ^b
Years keying ≥15 hours/week									0.02
≤4 years	33	42.3	42	42.4	49	53.9	44	63.8	
>4 years	45	57.7	57	57.6	42	46.2	25	36.2	
Mean hours keying/day 1st week									0.07
≤5.25 hours	45	57.7	45	45.5	53	58.2	45	65.2	
>5.25 hours	33	42.3	54	54.6	38	41.8	24	34.8	
Physical activity (1st week)									0.07
1st tertile (low)	27	34.6	28	28.3	37	40.7	34	49.3	
2nd tertile	27	34.6	35	35.4	35	38.5	19	27.5	
3rd tertile (high)	24	30.8	36	36.4	19	20.9	16	23.2	
Hand intensive activity									0.40
Low	58	74.4	67	67.7	71	78.0	48	69.6	
High	20	25.6	32	32.3	20	22.0	21	30.4	
Supervisory support									0.02
1st tertile (low)	20	25.6	34	34.3	27	29.7	36	52.2	
2nd tertile	33	42.3	41	41.4	39	42.9	23	33.3	
3rd tertile (high)	25	32.1	24	24.2	25	27.5	10	14.5	
Co-worker support									0.19
1st tertile (Low)	32	41.0	47	47.5	47	51.7	44	63.8	
2nd tertile	20	25.6	19	19.2	17	18.7	10	14.5	
3rd tertile (High)	26	33.3	33	33.3	27	29.7	15	21.7	

^a Chi-square test.^b Fisher's exact test.^c Missing value: 1 for low strain, 1 for active, 1 for passive, 0 for high strain.^d Missing value: 1 for low strain, 1 for active, 1 for passive, 0 for high strain.^e Missing value: 2 for low strain, 2 for active, 3 for passive, 3 for high strain.^f Missing value: 1 for low strain, 1 for active, 1 for passive, 0 for high strain.^g Missing value: 1 for low strain, 1 for active, 1 for passive, 0 for high strain.^h Missing value: 1 for low strain, 1 for active, 1 for passive, 0 for high strain.ⁱ Missing value: 1 for low strain, 1 for active, 1 for passive, 0 for high strain.^j Missing value: 1 for low strain, 1 for active, 1 for passive, 0 for high strain.

Separate modeling procedures for each outcome (neck–shoulder symptoms and hand–arm symptoms) were performed to examine the associations with both the quadrant and ratio definitions of job strain. Hence four separate multivariate modeling procedures were performed.

A process of backward elimination was performed to identify the actual confounders. The covariates that, when removed, altered the job-strain hazard ratios by more than 10% were considered confounders and were retained in subsequent multivariate models. Age, gender, experimental group, and hours spent keying per week were selected, a priori, for inclusion regardless of their potential to confound the associations between strain and musculoskeletal symptoms in this data set.

For each exposure–outcome combination, an age-adjusted model and a multivariate model were created with adjustment for the additional covariates. The age-adjusted model was adjusted only for age in quartiles (<27 years, 27–31 years, 32–38 years, ≥39 years). Additional covariates were those identified as confounders during the modeling procedure or selected a priori for inclusion as covariates.

Effect modification by covariates was assessed by including variables representing the interaction of the strain indicator variables and a dichotomous measure of the covariate. The likelihood ratio test statistic associated with the interaction terms was then obtained. We decided a priori to test for effect modification by age, gender, hours keying, ethnicity, BMI, income, experimental group, job title, education, history of previous symptoms, supervisory support, co-worker support, and past years of occupational computer use of ≥5 hours.

Multivariate tests for a linear trend across increasing categories of the ratio measure of job strain were performed by substituting the median value for each category for the indicator variable and modeling job strain as a continuous variable in the multivariable analyses. All of the statistical analyses were performed using SAS version 8.2 (SAS Institute, Cary, NC, USA).

Results

Participants

Recruitment and definition of the analytic cohorts. We initially identified 1240 potential participants, based upon lists of new persons hired from human resources departments of the participating organizations. Of this group, 662 were ineligible, 34 could not be contacted, and 97 refused to participate. The majority of the ineligible employees worked too few hours (N=239) or used multiple computers at work (N=147). Other persons were excluded because they reportedly used a second

computer at home for >20 hours each week (N=116), used a laptop computer at work (N=30), did not use a computer at work (N=43), or met additional a priori defined exclusion criteria related to availability or computer use (N=87). A screening questionnaire designed to identify those who experienced either neck–shoulder or arm–hand musculoskeletal symptoms during the week prior to the study entry was distributed to the remaining 447 potential participants still eligible for participation in the study.

Two separate, overlapping cohorts were then assembled to examine neck–shoulder symptoms and arm–hand symptoms. People who met the symptom criteria for the neck–shoulder or the hand–arm during the week prior to completing the screening questionnaire were not eligible for inclusion in the cohort for the symptomatic body part. However, they were included in the cohort for the other location.

Altogether 68 persons were excluded from both cohorts on the basis of recent musculoskeletal symptoms of both the neck–shoulder and arm–hand body regions. An additional 23 persons were ineligible for participation in the neck–shoulder cohort and an additional 4 were excluded from the arm–hand cohort due to symptoms in that body region in the week prior to the study entry. After randomization into one of three experimental groups, 17 persons were excluded from the study because they were unwilling or unable to adopt the specific posture required for the two intervention groups that involved postural changes (groups A and B). For the purposes of this analysis, 25 additional persons were excluded because they did not complete the psychosocial questionnaire. Consequently, the final neck–shoulder cohort consisted of 314 participants, and the final arm–hand cohort consisted of 333 participants.

Demographics. The demographic characteristics of the study sample are presented according to the job-strain quadrant in table 1. Women and minorities, those with office and clerical jobs, and those in the lowest income category were more likely to report employment in jobs with low decision latitude. The participants in the lowest tertile of supervisory support and co-worker support were more likely to report employment in high-strain jobs (high demand and low decision latitude). The participants with >4 years of keying >15 hours per week in previous jobs were more likely to be classified as working in an active or low-strain job than those with ≤4 years' experience.

With a few exceptions, the demographic characteristics of the participants varied less across the job-strain ratio categories than across the job-strain quadrants (results not shown). Those in the arm–hand and neck–shoulder cohorts with the highest job-strain ratios reported less supervisory support than did the participants

with lower job-strain ratios. Those in the highest categories of job-strain ratio were less likely to be in a job described as “professional” than those in lower categories. Differences were also seen in the makeup of the randomly assigned experimental groups. In both cohorts, a higher proportion of participants in the second category of strain was assigned to experimental group C (no postural intervention), while those in the lowest category were more often randomized into experimental group A. For both the hand–arm and neck–shoulder cohorts, no statistically significant differences in follow-up status were observed across either the job-strain quadrant or the job-strain category (results not shown). However, the percentage of dropouts in the second category of job strain in the neck–shoulder cohort was slightly higher than in the other categories. No such pattern was observed for the job-strain quadrants.

Occupational psychosocial strain measures

Scale reliability. A reliability analysis showed that the scales for skill discretion, decision authority, decision latitude, psychological job demands, supervisory support, and co-worker support in the Job Content Questionnaire all had high Cronbach alpha coefficients of internal consistency (ranging from 0.78 to 0.81) (data not shown).

Descriptive statistics. In the cohort of participants eligible for follow-up for incident symptoms in one or both anatomical areas, the median value of the “decision latitude” subscale was 72 (range 30–96) and the median of the “psychological job demands” subscale was 22 (range 10–36). The values for these two scales are dimensionless. Four quadrants of job strain were defined on the basis of the methods described earlier in this report and participants eligible for follow-up for incident symptoms in either anatomical area were classified into the appropriate group of low-strain jobs (N=78), active jobs (N=99), passive jobs (N=91), or high-strain jobs (N=69).

Associations between job strain and musculoskeletal symptoms

During the follow-up, the participants in the neck–shoulder cohort contributed 4345 person-weeks of observation, and 106 participants (33.8%) reported incident neck–shoulder symptoms. Likewise, the participants in the arm–hand cohort contributed 5058 person-weeks of observation, and 69 participants (20.8%) reported incident arm–hand symptoms (table 2). The incidence rate of hand–arm symptoms was 13.6/1000 person-weeks, and the incidence rate for neck–shoulder symptoms was 24.4/1000 person-weeks (table 2).

Job-strain quadrant method. Kaplan-Meier survival curves for incident neck–shoulder and incident arm–hand symptoms among the four quadrants of job strain were plotted (figures 1 and 2). For neck–shoulder symptoms, those with high-strain jobs exhibited poorer survival than those with low-strain jobs, active jobs, or

Table 2. Arm–hand and neck–shoulder outcomes according to the job-strain quadrant.

Outcome	Job-strain quadrant				Total
	Low strain	Active	Passive	High strain	
Arm–hand^a					
Events	13	24	17	15	69
Person-weeks of observation	1305	1395	1386	972	5058
Neck–shoulder^b					
Events	23	26	25	32	106
Person-weeks of observation	1089	1322	1245	689	4345

^a Incidence rate (events per 1000 person-weeks): 10.0 for low strain, 17.2 for active, 12.3 for passive, 15.4 for high strain and 13.6 for total.

^b Incidence rate (events per 1000 person-weeks): 21.1 for low strain, 19.7 for active, 20.1 for passive, 46.4 for high strain and 24.4 for total.

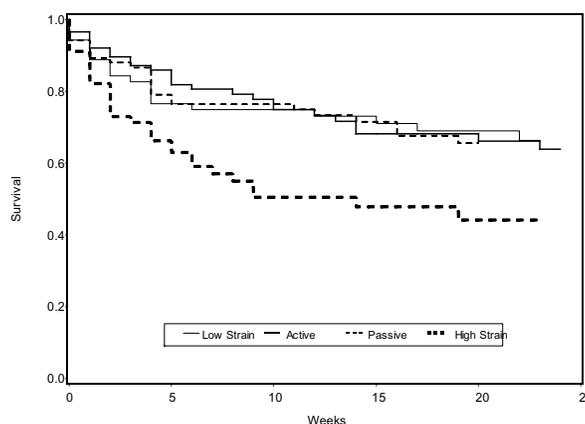


Figure 1. Kaplan-Meier survival curves for the development of neck–shoulder symptoms by strain quadrant.

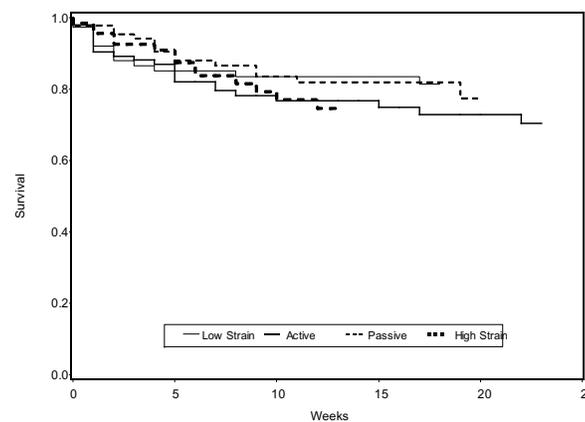


Figure 2. Kaplan-Meier survival curves for the development of arm–hand symptoms by strain quadrant.

passive jobs ($P_{\log\text{-rank}} = 0.01$). Most of the incident symptoms were reported within the first few weeks of the study. Of the 106 incident symptoms reported during the study, 74 (69.8%) were reported before or during week 6. The curves for incident arm-hand symptoms did not show statistically significant differences in survival among the four job-strain quadrants ($P_{\log\text{-rank}} = 0.57$).

The proportional hazards assumption for time-independent covariates and exposures was tested by examining the log-log survival curves with the use of a goodness-of-fit test and fitting a model with a cross-product term for the covariate or exposure and time. The outcomes of these tests suggested that the associations of the outcomes with the covariates and exposures did not vary with time.

The results from the proportional hazards analysis of associations between quadrants of job strain and incident neck-shoulder and arm-hand symptoms are presented in table 3. When compared with participants in a low-strain job, those in a high-strain job had a statistically significantly increased risk of neck-shoulder

Table 3. Associations between the job-strain quadrants and neck-shoulder and arm-hand symptoms. (HR = hazard ratio, 95% CI = 95% confidence interval)

Job-strain quadrant	Age-adjusted model			Multivariate model ^a		
	HR	95%CI	P-value ^b	HR	95%CI	P-value ^b
Neck-shoulder	.	.	0.03	.	.	0.05
Low strain	1.00	.	.	1.00	.	.
High strain	1.88	1.11-3.19	.	1.65	0.91-2.99	.
Active	0.93	0.53-1.61	.	0.79	0.43-1.46	.
Passive	1.00	0.57-1.77	.	0.75	0.39-1.47	.
Arm-hand	.	.	0.43	.	.	0.85
Low strain	1.00	.	.	1.00	.	.
High strain	1.48	0.71-3.08	.	1.28	0.58-2.85	.
Active	1.72	0.89-3.34	.	1.36	0.65-2.85	.
Passive	1.36	0.66-2.79	.	1.12	0.49-2.54	.

^a Adjusted for age, gender, experimental group, history of neck-shoulder or arm-hand symptoms, hours keying per week, supervisory support.

^b Likelihood ratio chi square P-value for indicator strain quadrant variables.

Table 4. Interaction between hours keying and the job-strain quadrant for neck-shoulder symptoms. (HR = hazard ratio, 95% CI = 95% confidence interval)

Job-strain quadrant	Hours keying per day	HR ^a	95%CI
Low strain	≤5.25	1.00	.
Active	≤5.25	1.40	0.61-3.20
Passive	≤5.25	1.67	0.73-3.83
High strain	≤5.25	2.38	1.01-5.61
Low strain	>5.25	2.38	1.01-5.61
Active	>5.25	0.89	0.35-2.24
Passive	>5.25	0.97	0.39-2.42
High strain	>5.25	2.74	1.22-6.20

^a Adjusted for age, history of neck-shoulder pain, gender, experimental group, supervisory support.

symptoms when adjustment was made only for age (HR 1.88, 95% CI 1.11-3.19). After control for age, gender, experimental group, history of neck-shoulder symptoms, hours keying per week, and supervisory support, the risk estimate was slightly attenuated (HR 1.65, 95% CI 0.91-2.99). Active and passive jobs were not associated with a risk of neck-shoulder symptoms in the age-only adjusted analysis although hazard ratios for these job-strain categories were slightly below unity in the multivariate analysis. No category of job strain was significantly associated with a risk of incident arm-hand symptoms.

The association between the job-strain quadrant and the risk of either musculoskeletal outcome did not differ by age, gender, ethnicity, BMI, income, experimental group status, job title, education, history of previous symptoms, supervisory support, co-worker support, or previous occupational computer use. However, the association between job strain and incident neck-shoulder symptoms appeared to be modified by current computer use (≤5.25 hours/day versus >5.25 hours/day). Those in high-strain jobs had statistically significantly elevated risks of neck-shoulder symptoms regardless of computer use when compared with those in low-strain jobs with low computer use (table 4). The participants in low-strain jobs with high computer use had a significantly increased risk of symptoms, while those in active and passive jobs with low computer use showed modest nonsignificant increases in risk. The relationship between strain and arm-hand symptoms showed no such effect measure modification (data not shown).

We also examined the modification of the association between job strain and incident neck-shoulder symptoms by a time-varying measure of weekly computer use. The results were similar to those reported earlier in this report (obtained by using computer use reported in the first week only) although the confidence intervals were extremely large (data not shown).

Job-strain ratio method. Associations between the ratio scale category of job strain and incident neck-shoulder and arm-hand symptoms are shown in table 5. In both the age-adjusted and the multivariate models, the highest ratio scale category of job strain was associated with a nonsignificant increase in risk of approximately 50% for neck-shoulder symptoms when compared with the lowest category. In addition, in both models, a nearly significant trend was observed for the association between the job-strain ratio category and the risk of neck-shoulder symptoms (age-adjusted model $P_{\text{trend}} = 0.05$, multivariate model $P_{\text{trend}} = 0.07$).

In the multivariate model with four categories, when compared with all of the participants in the lower three categories combined, those in the highest category of job-strain ratio had risk of neck-shoulder symptoms that

Table 5. Associations between the job-strain ratio category and neck-shoulder symptoms and arm-hand symptoms. (HR = hazard ratio, 95% CI = 95% confidence interval)

Job-strain ratio category	Age-adjusted model				Multivariate model ^a			
	HR	95%CI	P-value ^b	P _{trend}	HR	95%CI	P-value ^b	P _{trend}
Neck-shoulder			0.14	0.05			0.16	0.07
1st category	1.00	.			1.00	.		
2nd category	0.84	0.49–1.45			0.76	0.41–1.40		
3rd category	1.31	0.77–2.23			1.15	0.63–2.09		
4th category	1.52	0.88–2.62			1.55	0.83–2.89		
Arm-hand			0.82	0.48			0.98	0.88
1st category	1.00	.			1.00	.		
2nd category	1.12	0.56–2.26			1.03	0.48–2.19		
3rd category	1.36	0.70–2.64			1.13	0.55–2.32		
4th category	1.24	0.62–2.46			1.04	0.48–2.26		

^a Adjusted for age, gender, experimental group, neck-shoulder or arm-hand symptoms, hours keying per week, supervisory support.

^b Likelihood ratio chi square P-value for indicator category variables.

was 60% higher (HR 1.64, 95% CI 0.99–2.73) (data not shown). There was no association observed between the levels of the job-strain ratio and the risk of incident arm-hand symptoms.

The relationship between the job-strain ratio category and neck-shoulder symptoms was modified by previous occupational computer use. Among those with <4 years of past computer use (at an intensity of ≥ 15 hours per week), a positive linear trend towards increasing risk was observed across the increasing job-strain ratio categories ($P_{\text{trend}}=0.01$, table 6). However, among those with >4 years of previous occupational computer use (at an intensity of ≥ 15 hours per week), there was no apparent trend across the increasing categories of strain ($P_{\text{trend}}=0.89$). The relationship between strain and arm-hand symptoms showed no such effect modification (data not shown).

Height, BMI, co-worker support, physical activity (time-dependent), hand-intensive activity (time-dependent), previous occupational computer use, ethnicity, education, job title, and income level were not found to be confounders of the relationship between strain and risk of musculoskeletal symptoms for either anatomical region.

We also examined associations between both psychological job demands and decision latitude and the musculoskeletal symptom outcomes. They did not appear to be independent risk factors for either neck-shoulder musculoskeletal symptoms or arm-hand musculoskeletal symptoms (data not shown).

Discussion

Among the members of this occupational cohort, an association was observed between job strain and incident neck-shoulder musculoskeletal symptoms. The

Table 6. Interaction of years of previous employment in which keying was done ≥ 15 hours/week and the job-strain ratio category for neck-shoulder symptoms. (HR = hazard ratio, 95% CI = 95% confidence interval)

Job strain ratio category	Years of previous employment with keying ≥ 15 hours/week	HR ^a	95%CI	P _{trend} ^b
1st category	≤ 4	1.00	.	0.01
2nd category	≤ 4	0.54	0.16–1.82	
3rd category	≤ 4	2.01	0.76–5.30	
4th category	≤ 4	3.16	1.25–8.00	
1st category	>4	2.33	0.92–5.87	0.89
2nd category	>4	1.70	0.70–4.09	
3rd category	>4	1.66	0.67–4.13	
4th category	>4	1.95	0.73–5.22	

^a Adjusted for age, history of neck-shoulder pain, gender, experimental group, supervisory support.

^b Multivariate test for trend found in a stratified analysis.

association persisted after control for confounding by known covariates of musculoskeletal symptoms. Furthermore, because this was a prospective study in which measures of psychological stress were obtained before the onset of musculoskeletal symptoms, the temporal relationship between them is unambiguous (ie, elevated reporting of stress was not a result of incident musculoskeletal symptoms). However, we could not rule out the possibility that the participants who developed symptoms that met our criteria during the course of the study were also symptomatic, but to a less degree, at the time they completed the Job Content Questionnaire. We observed effect modification of the association between job strain and incident neck-shoulder symptoms by current and past computer use. Stronger associations with job strain were found for those with fewer hours per week of computer use or with fewer years of previous computer use. We did not find evidence of an association between job strain and incident arm-hand musculoskeletal symptoms.

Comparison with findings in the literature

Several studies are available in the peer-reviewed literature in which associations between occupational psychosocial stress and musculoskeletal outcomes among computer users were examined. Direct comparisons between our study and the published literature are problematic for several reasons. First, a variety of noncomparable measures of psychosocial stress have been used. Second, nearly all previous studies among computer users have been cross-sectional in design, making less clear the temporal association between measures of stress and musculoskeletal outcomes. Despite these limitations, it is possible to place the current study in the context of the existing literature.

We are aware of only two other studies of stress and musculoskeletal outcomes among computer users that used the Job Content Questionnaire. One was a prospective study of 671 computer users (5), and the other was a cross-sectional study of 374 computer users (6). In the prospective study, an increase in risk of approximately 50% among those with high job strain was observed when the group was compared with those with low job strain. Conversely, in the cross-sectional study, no associations were observed between job strain and either neck–shoulder symptom prevalence or arm–hand symptom prevalence.

Several studies have estimated job stress with scales other than the job-strain metric of the Job Content Questionnaire. In a cross-sectional study of 3475 computer users, associations were examined between stress (defined by quantitative demands and developmental possibilities) and neck symptoms and shoulder symptoms, separately. The odds for neck symptoms was approximately doubled among those with high quantitative demands and low developmental possibilities, while shoulder symptoms were not associated with the measures of stress (7). In a study of 150 computer users in the editorial department of a newspaper, upper-torso disorders, but not upper-extremity disorders, were statistically significantly more frequent among employees who had less decision latitude (as measured by the Job Content Questionnaire) in their work. (8). Among 420 medical secretaries in Sweden (9), those who experienced a poor psychological work environment were more likely to have a musculoskeletal disorder of the neck or shoulder in comparison with those with more favorable psychological work environments.

Among 973 computer users at a large metropolitan newspaper in the United States, time spent working under a deadline was associated with both neck and hand musculoskeletal symptoms (10). In the same study, participants with shoulder musculoskeletal symptoms were more likely to report increased job pressure and lack of participation in job decision making and those with neck

symptoms were more likely to report less work variance.

Among 533 telecommunications workers who used computers, those with neck or shoulder disorders were more likely to report routine work lacking decision-making opportunities, high information processing demands, fear of being replaced by computers, and increasing work pressure. Those with arm or hand disorders were more likely to report high information processing demands (11). Finally, in a study of 218 newspaper workers who used computers, no significant associations were found between demand or control and any musculoskeletal disorder (12).

In summary, the literature is heterogeneous with respect to study design and stress assessment methods. However, the results of the current study appear to support the results of several previous reports in which musculoskeletal outcomes of the neck and shoulder were associated with measures of occupational psychosocial stress. In addition, the results of the current study also strengthen the somewhat inconsistent observation that occupational psychosocial stress is more strongly associated with neck and shoulder musculoskeletal outcomes than with hand–arm musculoskeletal outcomes.

Strengths and weaknesses of the current study

Although the incidence of symptoms was not low in our study, the cohort was modest in size, and therefore the statistical power of the analysis was limited. A larger cohort would have also improved the precision of the subanalyses among the selected strata. This limitation is especially important in the analyses of effect modification.

The use of self-reported symptoms and self-reported use of medication to define incident cases may have been a limitation. Specifically, it is possible that health effects defined by this means are not representative of musculoskeletal disorders defined on the basis of physical signs. However, these symptom-based outcomes have been used in previous studies (2, 17) in which risk factors for musculoskeletal symptoms were very similar to those for musculoskeletal disorders. In addition, this study found a strong association between incident musculoskeletal symptoms and both female gender and a past history of musculoskeletal symptoms (two well-established risk factors for musculoskeletal outcomes) and, therefore, suggests that incident musculoskeletal symptoms are a reasonable surrogate for incident musculoskeletal disorders.

In the neck–shoulder cohort, 79 participants (25.2%) dropped out of the study with no reason given, and 12 (3.8%) dropped out of the study because they were too busy to continue. In the arm–hand cohort, 106 participants (31.8%) dropped out of the study with no reason

given, and 19 (5.7%) dropped out of the study because they were too busy to continue. For both the hand–arm and the neck–shoulder cohorts, no statistically significant differences in follow-up status were observed across either the job-strain quadrants or the job-strain categories. While small and nonstatistically significant differences in dropout as a function of job strain were observed, such differential dropout was unlikely to have created the appearance of an association between stress and musculoskeletal outcomes if one did not exist. In particular, because the slight increase in dropouts occurred in the second job-strain category among members of the neck–shoulder cohort, we do not believe that it affected the observed association between the high (fourth) and the low (first) categories. Furthermore, there was no difference in follow-up status by job-strain quadrant. As the associations between job strain and neck–shoulder symptoms were consistent when job strain was expressed either as categories or as quadrants, it would seem that the observed associations were not the result of differential dropout.

Even though there was no statistically significant interaction for the experimental group status observed for either the neck–shoulder cohort or the hand–arm cohort, there was a suggestion that the effect of job strain in the neck–shoulder cohort was strongest among those not receiving any postural intervention (group C). However, the sample size for each stratum was small, and the interactions between the experimental group status and the job-strain variables were not statistically significant. In future studies of occupational psychosocial stress among participants who are also administered ergonomic intervention, researchers should be aware of potential interactions between stress and intervention status when they examine associations between the stress measures and musculoskeletal outcomes.

Although all of the participants were newly hired, most of them (87.3%) were employed in previous jobs that required ≥ 15 hours per week of computer use for at least 1 year in duration. Thus the sample may have been distorted by selective survival in that those who were the most predisposed to develop musculoskeletal symptoms may have already developed them and, in response, either limited their computer use or changed careers to avoid heavy computer use. Those included in the study with previous years of occupational computer use may have been those who have become physically accustomed to keying long hours or who were less susceptible to musculoskeletal symptoms. To the extent that it occurred, selective survival would have biased the observed associations between stress and musculoskeletal outcomes towards the null.

In addition to the effect of selective survival on the main effects observed in our study, it may also explain the effect modification that was observed. If those with

high past or high present computer usage were less susceptible to musculoskeletal symptoms, then an association with job strain among the participants in these exposure strata would be less likely to be observed. As previous epidemiologic studies have tended to show that daily and weekly hours of computer use were more consistently associated with work-related musculoskeletal disorders of the arm–hand than work-related musculoskeletal disorders of the neck–shoulder are (18), selective survival may have biased the results observed in the arm–hand cohort towards the null and may not have had such an effect on the neck–shoulder cohort.

Another limitation of our study is that we were not able to control for individual characteristics such as personality and behavior. It has been suggested that one's personality type, skill level, and experience may be risk factors for musculoskeletal symptoms and may also affect one's ability to cope with a poor psychosocial environment (19, 20). In addition, personality factors, such as negative affectivity, may influence the reporting of both psychosocial stress and musculoskeletal symptoms and thus create the appearance of an association between them.

Our study also has several methodological strengths. Nearly all of the earlier studies of associations between psychosocial stress and musculoskeletal outcomes among computer users have been cross-sectional in design, contributing to an uncertain temporal relationship between psychosocial measures and musculoskeletal symptoms. With our prospective study design, we obtained psychosocial measures prior to incident outcome ascertainment. This use renders the temporal relationship between the exposure and outcome unambiguous and precluded recall bias as well. Another strength was the instrument used to measure job strain. The Job Content Questionnaire is a standard measure that will allow for comparisons with past and future studies that also employ it. In addition, it has been shown to include reliable scales leading to precise parameter estimation (14). The two different methods of calculating job strain yielded similar associations with musculoskeletal symptoms, giving added credibility to the results. The potential for uncontrolled confounding was lessened by the availability of information on other potential risk factors, such as hours of keying per week and posture while keying.

Because the participants were not followed after reporting symptoms that met the case definition, no information about the natural history of the symptoms is available. Thus we do not know whether the symptoms were likely to be transient effects resulting from new employment or more permanent conditions likely to result in musculoskeletal impairment. We are also unaware of any other studies of newly hired computer workers that may provide insight into this issue. Future

research in which newly hired workers with new onset musculoskeletal symptoms are followed over time are needed to address this question.

Overall, job stress, as measured with the Job Content Questionnaire, appears to be a risk factor for neck-shoulder symptoms but not for arm-hand symptoms. Although we are aware of no well-controlled intervention studies, it is possible that reductions in job strain may lower the risk of neck and shoulder symptoms among computer users. Interventions designed to lower job stress should be developed and subsequently evaluated in well-controlled studies of their effect.

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