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A Prospective Study of Computer Users: II. Postural Risk Factors for Musculoskeletal Symptoms and Disorders

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Background *Despite widespread recommendations regarding posture during computer use, associations between specific postures and musculoskeletal health are not well characterized.*
Methods *Six hundred and thirty-two newly hired computer users were followed prospectively to evaluate associations between posture and neck or shoulder (N/S) and hand or arm (H/A) musculoskeletal symptoms and musculoskeletal disorders. Participants' postures were measured at entry and they reported symptoms on weekly diaries. Participants reporting symptoms were examined for specific disorders. Multivariate Cox regression models were used to estimate associations between postural variables and risk of symptoms and disorders, controlling for confounding variables.*
Results *Keying with an inner elbow angle $> 121^{\circ}$, greater downward head tilt, and presence of armrests on the participants chair were associated with lower risk of N/S symptoms or N/S disorders. Keying with elbow height below the height of the "J" key and the presence of a telephone shoulder rest were associated with a greater risk of N/S symptoms or N/S disorders. Horizontal location of the "J" key > 12 cm from the edge of the desk was associated with a lower risk of H/A symptoms and H/A disorders. Use of a keyboard with the "J" key > 3.5 cm above the table surface, key activation force > 48 g, and radial wrist deviation of $> 5^{\circ}$ while using a mouse was associated with a greater risk of H/A symptoms or H/A disorders. The number of hours keying/week was associated with H/A symptoms and disorders.*
Conclusions *The results suggest that the risk of musculoskeletal symptoms and musculoskeletal disorders may be reduced by encouraging specific seated postures.* Am. J. Ind. Med. 41:236–249, 2002. *© 2002 Wiley-Liss, Inc.*

KEY WORDS: musculoskeletal disorders; computer; video display terminal; prospective study; ergonomics; posture

INTRODUCTION

The prevalence of work-related upper extremity musculoskeletal disorders (e.g., tendonitis, epicondylitis, and carpal tunnel syndrome) reported in the United States appears to have increased dramatically during the past 10 years [Mani and Gerr, 2000]. In 1999, they accounted for 66% of all work-related illness in the United States [US

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Department of Labor, 1999] compared to only 18% in 1982. Ergonomic exposures cited commonly as risk factors for musculoskeletal disorders (MSDs) include forceful and repetitive use of the hands and arms, and awkward or extreme postures. For computer users, most recommendations emphasize modification of posture as the mainstay of risk reduction.

Despite the ubiquity of recommendations for specific postures during computer use [OSHA, 1997], associations between posture and musculoskeletal health among computer users are not well characterized. Among the twenty or more field-based epidemiological studies that have explored the relationship between computer use and musculoskeletal health, only six examined the role of posture [Hunting et al., 1981; Starr et al., 1985; Sauter et al., 1991; Faucett and Rempel, 1994; Bergqvist et al., 1995a,b]. These studies were all cross-sectional in design and their results were inconsistent.

To more clearly characterize the effect of operator posture on musculoskeletal health, we conducted a prospective epidemiologic investigation among newly-hired computer users.

METHODS

Details of the study methods are provided in a companion paper [Gerr et al., 2002]. In brief, we recruited newly hired employees at eight large organizations in the metropolitan Atlanta area. Participants were eligible if they anticipated using computers for 15 or more hr/week and did not experience musculoskeletal symptoms in the week prior to beginning the new job. Measurements of worker posture and workstation configuration were made at entry and questionnaires were used to collect information on potentially confounding or effect-modifying variables. Participants kept weekly diaries documenting hours/week spent keying, hand-intensive activities other than keying, workstation changes, and the occurrence of symptoms. Those individuals who reported symptoms were examined by a clinician for signs of musculoskeletal disorders. The Emory University Human Investigations Committee approved the study protocol and written informed consent was obtained from all participants.

Postural Assessment

Measurements of workstation configuration and worker posture while typing were obtained within approximately two weeks of enrollment. These measures were repeated if the participant checked the box indicating workstation changes on the weekly diary. Variables representing workstation configuration and worker posture appear in Table I.

Using a standard checklist, study personnel examined each workstation for specific features such as presence of a document holder, a mouse or other pointing device, and a telephone headrest; then measurements of the workstation were made.

TABLE I. Groupings of Variables Representing Postural Exposures Included in Analyses

Postural exposures included in analyses of hand/arm symptoms and disorders
Keyboard use
Keyboard wrist extension (degrees)
Keyboard wrist ulnar deviation (degrees)
Presence of a wrist rest (absent vs. present)
Distance from table edge to "J" key (cm)
Mouse use
Mouse wrist ulnar deviation (degrees)
Mouse wrist extension (degrees)
Other
Height of the "J" key above the table (cm)
Presence of a sharp leading edge (absent vs. present)
Average key activation force (grams)
Postural exposures included in analyses of neck/shoulder symptoms and disorders
Keyboard use
Keyboard to elbow height difference (i.e., "J" key height from floor minus elbow height from floor) (cm)
Distance from table edge to "J" key (cm)
Keyboard inner elbow angle (degrees)
Keyboard shoulder flexion angle (degrees)
Keyboard shoulder abduction angle (degrees)
Mouse use
Mouse inner elbow angle (degrees)
Mouse shoulder flexion (degrees)
Mouse shoulder abduction (degrees)
Other
Presence of a chair armrest (absent vs. present)
Monitor head tilt angle[a] (degrees)
Monitor head rotation angle (degrees)
Presence of a telephone shoulder rest (absent vs. present)

[a]Persons with a horizontal monitor gaze angle (i.e., looking straight ahead) have a mean monitor head tilt angle of approximately 10°.

Each participant was asked to perform his/her usual key-entry task in his/her usual keying position. Upper extremity posture was measured, separately, while the participant used the alphanumeric portion of the keyboard and the mouse (or other pointing device). Gaze angle, head tilt angle, and head rotation angle were measured while the participant looked at the center of the monitor and again while the participant looked at a source document. Since virtually all participants indicated that they spent more time looking at the monitor than at a source document, we used the former measures in the analyses. Head tilt angle (rather than gaze angle) was selected *a priori* as the measure of head and neck posture for use in the analyses because it more directly represents the position of the head and neck. Goniometers (North Coast Medical, Inc., San Jose, CA) were used to measure wrist

angles (6-inch goniometer) and shoulder, elbow, head and neck angles (12-inch goniometer) [Maeda et al., 1982; Sauter et al., 1991; Lastayo and Wheeler, 1994; Ortiz et al., 1997; Gerr et al., 2000]. All postural angles were recorded to the nearest degree.

Health Outcomes Assessment

Participants responded to questions regarding discomfort of the neck/shoulder (N/S) region and hand/arm (H/A) region on a preprinted weekly diary. Symptom intensity was recorded on a 0–10 point visual analog scale (VAS) and any medication use for the control of the discomfort was noted. The study criterion for musculoskeletal symptoms was either the report of a symptom intensity of at least six on the VAS or the report of medication use for control of discomfort. Participants who met criteria for symptoms were examined by a certified hand therapist using a standard protocol to determine if they met the case definitions for specific disorders [Gerr et al., 2002].

Statistical Analyses

Four separate analyses were conducted. The purpose of each analysis was to identify postural factors that were associated with the incidence of each of the four primary outcomes: N/S symptoms, N/S disorders, H/A symptoms, and H/A disorders, while controlling for non-postural confounders. We also evaluated whether the number of hours keying/week modified associations between postural factors and musculoskeletal outcomes.

The postural measurements taken bilaterally were highly symmetric (except for mouse postural variables). Therefore, postural measurements made on the participants' right side were used in models of musculoskeletal outcomes occurring on either side. Less than 3% of participants used a mouse on the left side. For these participants, left-sided mouse postures were used in the main analyses. Additional analyses were performed excluding individuals with left-sided outcomes.

Screening potential confounders

Potential confounders were grouped and systematically screened prior to creation of the multivariate analytic models. Time-independent and time-dependent factors were grouped *a priori* by type (i.e., demographic, anthropometric, socioeconomic, past computer use, physical activity, and psychosocial) and screened for association with survival time to each of the four outcomes. Groups of potential confounders are provided in Table II.

Time-independent potential confounders. Time-independent factors such as age, race, and body mass index were categorized and screened first by examining the relationships between the variables and survival to each of the four outcomes using the SAS LIFETEST procedure [SAS, 1990; Kleinbaum, 1996]. Equality of survivorship across categories of each variable was assessed using Kaplan–Meier survival curves, log–log survival curves, and the log-rank test [Kleinbaum, 1996]. If the *P*-value for the log-rank test was ≤ 0.20, the variable was retained for inclusion in the multivariate analysis. If the log–log survival curves crossed, indicating that the relationship between a given factor and survival varied with time, then a variable representing this time-dependence was created and used in subsequent models [Kleinbaum, 1996]. All potential confounders remaining within each group after initial screening were entered simultaneously into a Cox regression model [SAS PHREG; SAS,

TABLE II. Groupings of Potential Confounders Included in Analyses

- Time-independent potential confounders
  - Demographic
    - Age
    - Gender
    - Smoking
    - Race/ethnicity
    - Children under age 6 in the home
  - Anthropometric
    - Height
    - Body mass index
  - Socioeconomic
    - Income index
    - Education
  - Past computer use
    - Total years keying 15 hr/week
    - Total years keying 20 hr/week
    - Total years keying 25 hr/week
- Time-dependent potential confounders
  - Activity
    - Weekly aerobic activity
    - Weekly hand-intensive activity
    - Weekly evaluation of job stress
    - Weekly proportion of days with five breaks $<$ 10 min
    - Weekly proportion of days with five breaks $\geq$ 10 min
  - Psychosocial
    - High information processing demands
    - Routine work lacking decision-making opportunities
    - Job future
    - Workplace hostility
    - Ability to step away from the workstation
    - Total support at work
    - Job variance
    - Job variety
    - Work pressure

1990]. Each variable was then eliminated from the model individually and the likelihood ratio test was used to compare the log likelihood of the full model to that of each reduced model. If the *P*-value for the likelihood ratio test was ≤ 0.15, then the variable was retained for inclusion in subsequent modeling steps. The exceptions were age, gender, and hours keying/week, which were forced into each model.

Time-dependent potential confounders. Non-psychosocial, time-dependent potential confounders were first examined in Cox regression models by comparing the log likelihood of the model containing the variable to the null model [Collett, 1994]. All variables that were associated with the hazard of the outcome with a *P*-value of ≤ 0.20 for the likelihood ratio test were then added simultaneously to the model containing the time-independent variables that met the screening criteria described above. The time-dependent variables were then individually eliminated from the model. If the *P*-value for the likelihood ratio test was ≤ 0.15, then the variable was retained for inclusion in subsequent modeling steps.

Because some participants experienced symptoms before the psychosocial questionnaire was administered during the fourth week of participation, prospective information on the psychosocial variables was not available for the entire study population. Therefore, potential psychosocial confounders were examined separately (using the same criteria as for other time-dependent variables) in smaller datasets that included information from only those participants who completed the psychosocial questionnaire prior to development of symptoms.

Models were then fit with all the potential confounders that met the screening criteria for each outcome. The results were the analytic models to which the postural exposures would be added.

Screening postural exposures

Because the postural exposure variables were numerous and some were biologically plausible risk factors for only one body region, separate lists of exposures for N/S outcomes and for H/A outcomes were created for screening. Continuous postural exposure variables were categorized to allow for assessment of non-linear relationships between exposures and survival time [Collett, 1994]. Most were categorized into quartiles. However, some postural variables more naturally were categorized by *a priori* concepts of ''neutrality''. For example, the referent group for monitor head rotation was composed of participants with neutral head position (-10 to 10°) rather than a particular range of degrees based on quartiles.

Unadjusted associations between the postural variables, all of which were time-varying (because participants were re-measured after a workstation change), and survival time to each outcome was examined individually with Cox regression models. These unadjusted associations are reported in Table III. For each variable, adjacent categories were collapsed if their hazard ratios were similar for a given outcome. The goal was to have the smallest number of categories necessary to represent adequately the relationship between the exposure and survival time to the outcome. Because the four main analyses were conducted separately, the categorization scheme of some variables was not the same across the four main outcomes.

Next, to explore relationships among postural variables that may be correlated with one another (e.g., shoulder abduction and inner elbow angle), they were grouped by type and by potential for collinearity *a priori*. Groupings for postural exposures are provided in Table I. To identify and minimize the effects of collinearity among postural risk factors within each group, Cox regression models were fit with all possible pairs of postural variables in the group for each outcome. If indications of collinearity were observed for a given pair (i.e., models did not converge or estimated hazard ratios or confidence intervals were exceptionally large [Kleinbaum, 1996]), then one member of the pair of postural risk factors (the variable with the weaker association with the outcome) was not included in subsequent models of associations with that outcome.

In the final screening step, for each outcome, remaining postural exposures were added separately to a model containing the non-postural potential confounders identified in the screening described above. If the likelihood ratio test comparing this model to the one containing only the non-postural variables had a *P*-value ≤ 0.30, then the postural exposure variable was retained for inclusion in the final models.

Interaction with hours keying/week

For each of the four outcomes, effect-measure modification by hours keying/week was examined by fitting separate Cox regression models with a postural exposure variable, a variable representing hours keying/week, and an interaction term. If the interaction term was statistically significant at the 0.05 level, then it was retained for inclusion in multivariable models which included that postural factor.

Adjusted effects of individual postural measures

For each outcome, we fit separate multivariable models with each one of the postural exposure variables that remained after the initial screening. In addition to the postural exposure variable, each model also included 1) the non-postural potential confounders that met the screening

TABLE III. Unadjusted and Covariate-Adjusted Hazard Ratios for Postural Risk Factors and Neck/Shoulder Symptoms (N = 436)

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

[a]Adjusted for age, gender, height, hours keying per week.
Hazard ratios in bold indicate $P < 0.05$ Wald test.

criteria, and, 2) if statistically significant, the interaction term between the postural risk factor and hours keying. Because each postural exposure variable was modeled separately, the hazard ratio represents the relationship between the postural exposure variable and the outcome, adjusted only for non-postural potential confounders.

Final models

We fit separate Cox regression models for each of the four primary health outcomes. The full models included the non-postural potential confounders that met the screening criteria, any statistically significant interaction terms between postural factors and hours keying, and all postural exposures that met the screening criteria.

The full models were reduced by first examining the statistical significance of the interaction term using the likelihood ratio test. If the interaction term was not significant at the 0.05 level, it was dropped from the analysis. To examine confounding, each non-postural factor was removed from the model individually and changes in the hazard ratio for all postural exposure variables were calculated. If the hazard ratio for any level of a postural exposure variable changed by $\geq 10\%$, then the variable that had been removed was considered a confounder of the relationship between that postural exposure and time to the outcome and it was included in all future models containing that postural exposure. With the exception of age, gender, and hours keying, which were included in all models, non-postural non-confounders were dropped sequentially from the final multivariable model. Then each postural factor was individually removed from the multivariable model. Following each removal, the likelihood ratio test was used to determine whether the variable was associated with survival ($P < 0.10$) to the outcome. Postural variables not associated with survival ($P \geq 0.10$) were dropped from the final multivariable model.

For each outcome, the final multivariable model contained variables representing 1) statistically significant ($P < 0.10$) postural predictors of survival to the health outcome, 2) statistically significant interactions between postural predictors and estimates of hours keying/week, 3) age, gender, and hours keying/week, and 4) non-postural confounders of associations between postural factors and survival to the outcome.

Psychosocial variables

In order to assess possible confounding by psychosocial variables, additional models were fitted for the smaller datasets from which participants who completed the psychosocial questionnaire *after* developing symptoms were excluded. Consequently, the analysis of survival to N/S symptoms included 368 of the 632 participants (58%) and to N/S disorders included data from 399 participants (63%). Survival to H/A symptoms included 419 of the 632 participants (66%) and to H/A disorders included 439 participants (70%). The psychosocial variables remaining after screening were added to the final models described above. The psychosocial variables were then removed sequentially from these models and changes in the hazard ratios for each of the postural exposures calculated. A psychosocial variable was considered a confounder of a postural exposure if its removal resulted in a change of 10% or more in the hazard ratio for any level of that postural variable.

RESULTS

Unadjusted and Covariate-Adjusted Associations Between Postural Exposures and Incident Symptoms and Incident Disorders

Neck/shoulder symptoms

Associations between postural risk factors and incident N/S symptoms are presented in Table III. Increases in the unadjusted hazard ratios were observed for participants with keyboard to elbow height difference > 0 cm (i.e., elbow below the keyboard), mouse shoulder flexion angle $> 25^\circ$, monitor head tilt angle $> 3^\circ$[1], and for those whose phone was equipped with a telephone shoulder rest. A lower risk was observed among those with inner elbow angle $> 121^\circ$. After adjustment for age, gender, height, and hours keying per week, no appreciable changes in the associations between postural factors and N/S symptoms were observed.

Neck/shoulder disorders

Associations between postural risk factors and incident N/S disorders are presented in Table IV. Hazard ratios adjusted for age, gender, height, and hours keying per week were not appreciably different from unadjusted hazard ratios. Increases in the hazard ratios were observed for participants with a keyboard to elbow height difference > 0–2.3 cm, monitor head tilt angle $> 3^\circ$, and presence of a telephone shoulder rest. A lower risk was observed among those with keyboard inner elbow angle $> 121^\circ$ and armrests on their chairs.

A statistically significant interaction between keyboard inner elbow angle and hours keying/week was observed. Those with a keyboard inner elbow angle $> 121^\circ$ were at

[1] Persons with a horizontal monitor gaze angle have a mean monitor head tilt angle of approximately 10°. Therefore, a head tilt angle of 3° is associated with gaze angle below the horizontal. Head tilt angles between 3 and 10° are associated with gaze angles below or at the horizontal and those greater than 10° degrees are associated with gaze angles above the horizontal. Increasing head tilt angle involves movement in the direction of neck extension.

TABLE IV. Unadjusted and Covariate-Adjusted Hazard Ratios for Postural Risk Factors and Neck/Shoulder Disorders (N = 472)

Postural risk factor	N	Unadjusted HR (95% CI)	Adjusted[a] HR (95% CI)
Keyboard to elbow height difference			
≤ 0	256	1.0	1.0
0–2.3	99	1.56 (0.90–2.70)	1.57 (0.90–2.73)
> 2.3	117	0.91 (0.48–1.69)	0.93 (0.50–1.75)
Keyboard inner elbow angle (degrees)			
≤ 121	360	1.0	1.0
> 121	112	0.64 (0.35–1.18)	**0.42 (0.18–0.98)**[b]
Keyboard shoulder abduction angle (degrees)			
≤ 10	127	1.0	1.0
11 to 14	147	1.23 (0.68–2.25)	1.11 (0.72–1.70)
15 to 17	86	0.66 (0.29–1.53)	1.08 (0.67–1.76)
> 17	112	1.01 (0.52–1.96)	0.87 (0.53–1.43)
Keyboard shoulder flexion angle (degrees)			
≤ 21	121	1.0	1.0
22 to 28	115	1.27 (0.65–2.45)	1.17 (0.74–1.85)
29 to 35	121	1.47 (0.78–2.77)	1.13 (0.73–1.76)
> 35	115	0.66 (0.31–1.43)	0.88 (0.54–1.41)
Distance from table edge to "J" key (cm)			
≤ 12.5	249	1.0	1.0
12.5	223	0.79 (0.49–1.27)	0.77 (0.47–1.25)
Mouse inner elbow angle (degrees)			
≤ 137	237	1.0	1.0
138–148	119	1.43 (0.84–2.44)	1.35 (0.79–2.32)
> 148	116	0.78 (0.41–1.51)	0.75 (0.39–1.44)
Mouse shoulder abduction angle (degrees)			
≤ 21	120	1.0	1.0
22 to 27	137	1.06 (0.56–1.98)	1.04 (0.55–1.95)
28 to 33	105	0.87 (0.42–1.78)	0.97 (0.47–2.01)
> 33	110	1.32 (0.69–2.51)	1.43 (0.74–2.76)
Mouse shoulder flexion angle (degrees)			
≤ 25	120	1.0	1.0
26 to 34	120	0.98 (0.51–1.88)	1.01 (0.53–1.95)
35 to 44	117	1.08 (0.55–2.13)	1.15 (0.58–2.28)
> 44	115	0.98 (0.50–1.92)	0.93 (0.47–1.84)
Monitor head tilt angle (degrees)			
≤ 3	119	1.0	1.0
> 3	353	1.76 (0.87–3.55)	1.63 (0.81–3.32)
Monitor head rotation angle (degrees)			
0 to 10	371	1.0	1.0
> 10	101	1.11 (0.64–1.96)	1.25 (0.71–2.21)
Presence of a chair armrest			
No	107	1.0	1.0
Yes	365	**0.60 (0.36–0.97)**	0.65 (0.39–1.08)
Presence of a telephone shoulder rest			
No	439	1.0	1.0
Yes	33	**2.78 (1.46–5.32)**	**2.54 (1.32–4.92)**

[a]Adjusted for age, gender, years keying greater than 20 hr/week, and hours per week keying.
[b]Also adjusted for the interaction term of keyboard inner elbow angle by hours keying per week. Hazard ratio calculated with hours keying per week set to its median value.
Hazard ratios in bold indicate $P < 0.05$ Wald test.

TABLE V. Unadjusted and Covariate-Adjusted Hazard Ratios for Postural Risk Factors and Hand/Arm Symptoms (N = 496)

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

[a]Adjusted for age, gender, smoking, education, years keying greater than 20 hr/week, and hours per week keying.
Hazard ratios in bold indicate $P < 0.05$ Wald test.

lower risk of N/S disorders. However, this protective effect diminished with increasing hours keying/week (data not shown).

Hand/arm symptoms

Associations between postural risk factors and incident H/A symptoms are presented in Table V. Hazard ratios adjusted for age, gender, smoking, education, years keying at least 20 hr/week, and current hours keying/week were not appreciably different from unadjusted hazard ratios. Participants with keyboards with the "J" key > 3.5 cm above the table surface were at greater risk of H/A symptoms and those whose keyboards were placed with the "J" key > 12 cm from the table edge were at lower risk of H/A symptoms.

TABLE VI. Unadjusted and Covariate-Adjusted Hazard Ratios for Postural Risk Factors and Hand/Arm Disorders (N = 520)

Postural risk factor	N	Unadjusted HR (95% CI)	Adjusted HR (95% CI)[a]
Keyboard wrist extension angle (degrees)			
−10 to 10	43	1.28 (0.49–3.34)	1.25 (0.47–3.28)
11 to 25 (referent group)	273	1.0	1.0
26 to 30	88	0.65 (0.27–1.57)	0.80 (0.32–1.97)
> 30	114	1.58 (0.87–2.88)	1.39 (0.74–2.64)
Keyboard wrist ulnar deviation angle (degrees)			
< − 5	34	1.08 (0.42–2.77)	0.92 (0.35–2.45)
−5 to 5 (referent group)	290	1.0	1.0
6 to10	123	0.80 (0.43–1.59)	0.86 (0.43–1.72)
> 10	73	0.85 (0.39–1.86)	0.83 (0.37–1.83)
Distance from table surface to "J" key (cm)			
≤ 3.5	442	1.0	1.0
> 3.5	78	1.61 (0.87–3.00)	1.54 (0.80–2.94)
Distance from table edge to "J" key (cm)			
≤ 12	258	1.0	1.0
> 12	262	**0.47 (0.27–0.83)**	**0.52 (0.29–0.93)**
Presence of a wrist rest			
No	362	1.0	1.0
Yes	158	1.37 (0.78–2.38)	1.36 (0.77–2.39)
Mouse wrist ulnar deviation angle (degrees)			
< −5	96	**1.99 (1.09–3.63)**	**2.03 (1.09–3.80)**
−5 to 5 (referent group)	301	1.0	1.0
> 5	123	1.22 (0.62–2.43)	1.35 (0.67–2.73)
Mouse wrist extension angle (degrees)			
≤ 17	137	1.0	1.0
18 to 23	125	0.64 (0.30–1.35)	0.66 (0.31–1.39)
24 to 30	166	0.78 (0.40–1.53)	0.80 (0.40–1.58)
> 30	92	0.77 (0.39–1.66)	0.72 (0.31–1.65)
Average key activation force (g)			
≤ 48	131	1.0	1.0
> 48	389	1.81 (0.89–3.70)	1.66 (0.81–3.41)
Presence of a sharp leading edge on table surface			
No	347	1.0	1.0
Yes	173	0.96 (0.55–1.66)	1.03 (0.59–1.82)

[a]Adjusted for age, gender, smoking, body mass index, and hours keying per week.
Hazard ratios in bold indicate $P < 0.05$ Wald test.

Hand/arm disorders

Associations between postural risk factors and incident H/A disorders are presented in Table VI. Hazard ratios adjusted for age, gender, smoking, body mass index, and hours keying/week were not appreciably different from unadjusted hazard ratios. Participants with keyboards with the "J" key > 3.5 cm above the table surface were at greater risk of H/A disorders and those whose keyboards were placed with the "J" key > 12 cm from the table edge were at lower risk of H/A disorders. Participants with > 5° of wrist radial deviation while using the mouse (i.e., < −5° wrist ulnar deviation) had greater risk of H/A disorders than those with neutral wrist posture (−5 to 5° ulnar deviation). Greater key activation force (i.e., > 48 g) also was associated with an increased risk of H/A disorders.

Final Models of Postural Exposures and Incident Symptoms and Incident Disorders

The final models of associations between multiple postural factors and N/S and H/A symptoms and disorders are presented in Tables VII and VIII, respectively.

TABLE VII. Adjusted Associations Between Postural Factors and Neck/Shoulder Symptoms and Neck/Shoulder Disorders

	Neck/shoulder symptoms			Neck/shoulder disorders		
Variable	**Hazard ratio**	**95% CI**	***P*-value[a]**	**Hazard ratio**	**95% CI**	***P*-value[a]**
Postural exposures						
Keyboard height > elbow height (vs. ≤ elbow height)	1.42	0.96–2.10	0.08	—	—	—
Keyboard inner elbow angle > 121° (vs. ≤ 121°)	0.16	0.04–0.62	0.01[b]	0.11	0.02–0.66	0.02[b]
Keyboard inner elbow angle by hrs keying/week interaction	1.05	1.00–1.10	0.04[b]	1.07	1.01–1.14	0.02[b]
Mouse inner elbow angle > 137°–148° (vs. ≤ 137°)	1.67	1.09–2.55	0.04	—	—	—
Mouse inner elbow angle > 148°(vs. ≤ 137°)	0.94	0.56–1.59		—	—	—
Monitor head tilt angle > 3° (vs. ≤ 3°)	1.58	0.94–2.65	0.09	—	—	—
Presence of telephone shoulder rest	2.05	1.14–3.71	0.02	2.71	1.40–5.23	0.008
Adjustment factors						
Age ≥ 30 years (vs. < 30 years)	1.79	1.19–2.70	0.01	1.75	1.04–2.93	0.04
Female gender (vs. male)	1.31	0.83–2.06	0.25	1.37	0.77–2.44	0.27
Hours keying per week (HR per hour)	1.01	0.99–1.03	0.24[b]	1.01	0.99–1.04	0.24[b]

Hazard ratios are adjusted for all variables in model. Dash indicates variable not included in model.
[a] *P*-value for the likelihood ratio chi-square except where indicated.
[b] *P*-value for the Wald chi-square.

Neck/shoulder symptoms

Elevated risks were observed for keyboard height from floor greater than elbow height from floor, mouse inner elbow angle > 137–148°, monitor head tilt angle > 3°, and the presence of a telephone shoulder rest (Table VII). A lower risk was observed for keyboard inner elbow angle > 121° but the effect was attenuated with increasing hours of keying/week. For example, those with angles > 121° had a nearly 75% lower risk of N/S symptoms at 10 hr of keying/week whereas at 20 and 30 hr keying/week, the relative hazards were only 55 and 30% lower (Table IX).

Neck/shoulder disorders

An elevated risk was observed for the presence of a telephone shoulder rest (Table VII). The interaction of keyboard inner elbow angle and weekly hours keying resulted in an attenuation of the protective effect of a larger inner elbow angle with increasing keying hours (Table IX).

Hand/arm symptoms

The risk of H/A symptoms was higher among those using a keyboard wrist rest and lower among those with

TABLE VIII. Adjusted Associations Between Postural Factors and Hand/Arm Symptoms and Hand/Arm Disorders

	Hand/arm symptoms			Hand/arm disorders		
	Hazard ratio	**95% CI**	***P*-value[a]**	**Hazard ratio**	**95% CI**	***P*-value[a]**
Postural exposures						
Presence of a keyboard wrist rest	1.66	1.03–2.67	0.04	1.96	1.05–3.65	0.04
Mouse wrist ulnar deviation < −5° (vs. > 5°)	—	—	—	1.82	1.03–3.22	0.05
Keyboard "J" key > 12 cm from table edge (vs. ≤ 12 cm)	0.50	0.32–0.80	0.003	0.38	0.20–0.71	0.002
Adjustment factors						
Age ≥ 40 years (vs. age < 40 years)	1.55	0.99–2.43	0.07	1.58	0.89–2.82	0.13
Female gender (vs. male)	1.63[b]	0.93–2.87	0.08	2.18	1.09–4.34	0.02
Hours keying per week (HR per hour)	1.04	1.02–1.06	< 0.001	1.04	1.02–1.06	< 0.001

Hazard ratios are adjusted for all variables in model. Dash indicates variable not included in model.
[a] *P*-value for the likelihood ratio chi-square.
[b] If survival time ≤ 8 weeks, coded as gender = 0. If survival time > 8 weeks, coded as female = 1, male = 0.

TABLE IX. Interaction of Keyboard Inner Elbow Angle and Hours Keying for Neck/Shoulder Symptoms and Neck/Shoulder Disorders

Hours keying/week	Hazard ratio[a] N/S symptoms	Hazard ratio[b] N/S disorder
10	0.27	0.23
20	0.44	0.48
30	0.72	0.97

[a]Upper quartile of inner elbow angle versus lower quartile.
[b]Upper quartile of inner elbow angle versus all other quartiles.

the keyboard "J" key ≥ 12 cm from the table or desk edge (Table VIII).

Hand/arm disorders

The risk of H/A disorders was lower among those with the keyboard "J" key ≥ 12 cm from the table edge (Table VIII). The risk of H/A disorders was higher among those using a keyboard wrist rest and among those with wrist radial deviation of $> 5^\circ$ (i.e., less than -5° of wrist ulnar deviation) when using a mouse.

Additional Analyses

No psychosocial variables met criteria for confounding and none were included in the four final models (data not shown). Further, when analyses were limited to health events occurring on the right side only, no meaningful change in any of the hazard ratios was observed (data not shown).

DISCUSSION

The results of the current study suggest that a seated posture with the keyboard low and some distance away from the operator is associated with a lower risk of musculoskeletal symptoms and musculoskeletal disorders than one with the keyboard at or above elbow height and close to the operator. Other elements of operator posture associated with lower risk of symptoms and disorders include supporting of the arms on either the desk surface or chair arm rests, downward head tilt, and absence of a telephone handset shoulder rest. Radial deviation while using the mouse was associated with an increased risk. Some of these results are contrary to the common conception of "good computer posture", often described as a position in which the arm is perpendicular to the floor, the elbow is at a right angle, the forearm is parallel to the floor, and the keyboard is located at or above elbow height and near the edge of the desk or drawer on which it is placed.

Individuals with inner elbow angles $> 121^\circ$ while using the keyboard were less likely to develop N/S symptoms and disorders. Because they were collinear, shoulder flexion angle was not included in any models that also included inner elbow angle. As a result, no estimation of the effect of shoulder flexion angle independent of inner elbow angle on symptoms or disorders was obtained. Study participants with inner elbow angles $> 121^\circ$ had a mean shoulder flexion angle of 38° (SD $= 8.6^\circ$). Individuals with inner elbow angles between 137 and 148° while using the mouse were at lower risk of developing N/S symptoms than were individuals with an inner elbow angle of $< 137^\circ$. However, those with an inner elbow angle $> 148^\circ$ were not at increased risk. This surprising finding was not altered or modified by the presence of armrests or other measures suggestive of forearm support (e.g., distance of the "J" key from the edge of the table). However, we did not collect information on other types of forearm support (e.g., table surface area to the right of the keyboard) that might be important while using the mouse. These unmeasured variables may explain the observed association.

Elbow height lower than "J" key height was a risk factor for N/S disorders. Presence of a telephone shoulder rest was associated with a twofold higher risk of both N/S symptoms and N/S disorders.

A weaker association was found between wrist extension and H/A symptoms and disorders than was observed for keyboards with the "J" key ≥ 3.5 cm above the table surface and H/A symptoms and disorders. It may be that the measure of wrist extension used in the current study was a more variable estimator of actual wrist extension than was the measure of "J" key height from the table surface. This possibility is supported somewhat by the observation that wrist extension was among the more widely varying of the postural measures used in this study [Ortiz et al., 1997]. It is possible that wrist extension is, in reality, more strongly associated with H/A symptoms and disorders than was actually observed in the current study but the relationship was attenuated because the single measure used did not adequately characterize an individual's wrist extension.

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

Hours/day of current keyboard activity was associated with an increased risk of H/A symptoms and disorders. If this association is linear, the risk of both H/A symptoms and disorders would increase 2.2-fold with an increase of 20 hr/week of keying. Further exploration of the nature of this association is a high priority.

Comparison to Prior Studies

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

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

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

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

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

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

Numerous methodological differences may account for the discrepancies in associations observed between the current study and those reported in the literature. Unlike the studies reviewed above, the current study was prospective in design with measures of posture obtained before the onset of symptoms. The sample sizes of the studies described above were often much smaller than that of the current study, resulting in diminished power to observe associations of modest magnitude. Less complete control of confounding in some previous studies also may account for differences in results. Finally, imprecise measures of postural variables may have affected results in previous studies as well as the current study.

Strengths and Weaknesses of the Current Study

The most important strength of the current study is its prospective design. Only individuals who did not meet criteria for musculoskeletal symptoms were recruited and measurements of posture were made prior to the development of symptoms. Previous studies of computer users measured workers' posture and discomfort at the same point in time. Associations observed in such studies may reflect alterations in posture as a consequence of discomfort rather than postures causing discomfort. However, in the current study we cannot rule out the possibility that subtle discomfort (severity less than 6 on the 10 point VAS and no use of medication) may have influenced some aspects of worker posture.

In the current study, manual goniometry was used to measure posture and measurements were performed at a single point in time (unless a change in the workplace was reported, in which case measures were repeated). Manual

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

The specific postural measurement methods used in this study were pilot tested by the investigators and found to have good reliability regardless of rater, time-of-day or day-of-week in a test-retest validation study [Ortiz et al., 1997]. In addition, on repeated measures, within-participant variability was significantly smaller than between-participant variability, demonstrating that changes in posture over time for individual participants were substantially smaller than differences in posture between participants. These findings suggest that single time point measures can distinguish individuals with different postures from one another. The stability of postural measures among keyboard users has also been reported by others [Hunting et al., 1981]. In addition, in order to account for some of the dynamic elements of posture during computer use, upper extremity postures were measured while operators used the mouse as well as the alphanumeric keyboard. However for some elements of posture (e.g., wrist extension), a single measure may have been inadequate for assessing risk.

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

Recommendations

In light of the results of the current study, the seated position traditionally recommended for computer users–upper arms perpendicular to the floor, elbows kept at a right angle, forearms parallel to the floor, and the keyboard at or above elbow height and near the edge of the desk or tray–may not be the lowest risk posture. Although promulgation of this posture is widespread, it appears to have gained its near universal acceptance without epidemiological evidence of its efficacy. Clinical trials of various seated postures should be performed to assess their effectiveness for reduction of risk of musculoskeletal symptoms and musculoskeletal disorders among computer users.

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