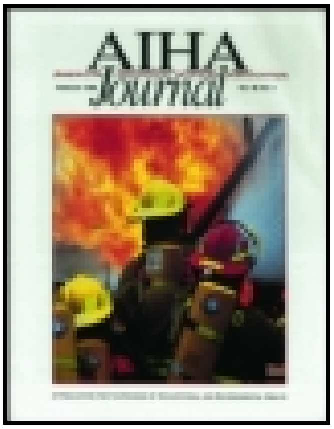

AIHAJ - American Industrial Hygiene Association
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/uaah20

Computer Users' Postures and Associations with Workstation Characteristics

Fredric Gerr [a], Michele Marcus [e c], Daniel Ortiz [b], Beth White [b], Wendy Jones [b], Susan Cohen [e], Eileen Gentry [d], Alicia Edwards [e] & Emily Bauer [e]

[a] Department of Environmental and Occupational Health, Rollins School of Public Health, Emory University, 1518 Clifton Road, Atlanta, GA 30322 e-mail: fgerr@sph.emory.edu

[b] Safety, Health, and Environmental Technology Division, Georgia Tech Research Institute, Georgia Institute of Technology, Atlanta, GA

[c] Department of Epidemiology, Rollins School of Public Health, Emory University, Atlanta, GA

[d] EMaGine Consulting, St. Augustine, FL

[e] Department of Environmental and Occupational Health, Rollins School of Public Health, Emory University, 1518 Clifton Road, Atlanta, GA 30322

Published online: 04 Jun 2010.

To cite this article: Fredric Gerr , Michele Marcus , Daniel Ortiz , Beth White , Wendy Jones , Susan Cohen , Eileen Gentry , Alicia Edwards & Emily Bauer (2000) Computer Users' Postures and Associations with Workstation Characteristics, AIHAJ - American Industrial Hygiene Association, 61:2, 223-230, DOI: 10.1080/15298660008984531

To link to this article: http://dx.doi.org/10.1080/15298660008984531

Computer Users' Postures and Associations with Workstation Characteristics

AUTHORS
Fredric Gerr[a]
Michele Marcus[a,c]
Daniel Ortiz[b]
Beth White[b]
Wendy Jones[b]
Susan Cohen[a]
Eileen Gentry[d]
Alicia Edwards[a]
Emily Bauer[a]

[a]Department of Environmental and Occupational Health, Rollins School of Public Health, Emory University, 1518 Clifton Road, Atlanta, GA 30322; e-mail: fgerr@sph.emory.edu; [b]Safety, Health, and Environmental Technology Division, Georgia Tech Research Institute, Georgia Institute of Technology, Atlanta, GA; [c]Department of Epidemiology, Rollins School of Public Health, Emory University, Atlanta, GA [d]EMaGine Consulting, St. Augustine, FL

This project was supported by a grant from the National Institute for Occupational Safety and Health (R01-OH03160).

APPLIED STUDIES

This investigation tested the hypotheses that (1) physical workstation dimensions are important determinants of operator posture, (2) specific workstation characteristics systematically affect worker posture, and (3) computer operators assume "neutral" upper limb postures while keying. Operator head, neck, and upper extremity posture and selected workstation dimensions and characteristics were measured among 379 computer users. Operator postures were measured with manual goniometers, workstation characteristics were evaluated by observation, and workstation dimensions by direct measurement. Considerably greater variability in all postures was observed than was expected from application of basic geometric principles to measured workstation dimensions. Few strong correlations were observed between worker posture and workstation physical dimensions; findings suggest that preference is given to keyboard placement with respect to the eyes ($r = 0.60$ for association between keyboard height and seated elbow height) compared with monitor placement with respect to the eyes ($r = 0.18$ for association between monitor height and seated eye height). Wrist extension was weakly correlated with keyboard height ($r = -0.24$) and virtually not at all with keyboard thickness ($r = 0.07$). Use of a wrist rest was associated with decreased wrist flexion (21.9 versus 25.1°, $p < 0.01$). Participants who had easily adjustable chairs had essentially the same neck and upper limb postures as did those with nonadjustable chairs. Sixty-one percent of computer operators were observed in nonneutral shoulder postures and 41% in nonneutral wrist postures. Findings suggest that (1) workstation dimensions are not strong determinants of at least several neck and upper extremity postures among computer operators, (2) only some workstation characteristics affect posture, and (3) contrary to common recommendations, a large proportion of computer users do not work in so-called neutral postures.

Keywords: ergonomics, field study, posture, video display terminals

Despite the wide dissemination of recommendations for specific computer operator posture from industry and government sources,[1,2] very little data on actual operator posture among computer users in business and industry is available in the literature. Furthermore, aside from studies performed under controlled laboratory conditions, virtually no information is available in the literature on the relationships between either workstation dimensions or use of specific office equipment (e.g., computer mouse, keyboard wrist rest, or adjustable chairs) and operator posture. Even the relationships of joint angles of the upper extremities to each other among computer users are not well described.

To address these gaps, a field-based survey of computer workstation dimensions, workstation equipment, and operator posture was performed. The goals of this investigation were to test the hypotheses that (1) physical workstation dimensions are important determinants of operator posture, (2) specific workstation characteristics (e.g., presence of adjustable chair, wrist rests) systematically affect worker posture, and (3) the majority of computer operators assume "neutral" postures consistent with those recommended by industry and government sources.

METHODS

Participants

Participants were recruited from among eight large employers in the metropolitan Atlanta, Ga., area. Participating organizations included insurance and financial companies, telecommunications companies, food product producers, hospitals, and universities. At each of the participating organizations, all newly hired workers who anticipated using a computer keyboard for 15 hours or more per week and who were free of upper extremity musculoskeletal disorders at the time of enrollment were eligible to participate. Among eligible participants, only those who had completed questionnaire forms documenting demographic and job characteristics and had ergonomic evaluation of their workstations performed were included in the analyses. All participants described in the current article were recruited to participate in a prospective epidemiologic study of the association between musculoskeletal disorders and work with computers. The purpose of the study was explained to all interested participants and written informed consent was obtained.

Between October 1, 1995, and January 1, 1998, three hundred seventy-nine participants were enrolled. The demographic characteristics of the participants are provided in Table I. The population was relatively young and well educated, with only 21.4% greater than 40 years of age and about 12% having less education than an associate degree. There was wide variation in household income, with about one-fourth of the population below $25,000 and about one-third at or above $50,000. The single largest job category was secretarial. On average, participants reported spending about 28 hours per week at their computer workstations and 20 hours per week keying.

Ergonomic Evaluation

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

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

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

TABLE I. Demographic Characteristics of Study Population (N = 379)

Characteristic	Number	Percentage
Age		
<20	3	0.8
20–29	156	41.3
30–39	138	36.5
40–49	68	18.0
50–59	13	3.4
Unknown	1	
Sex		
Proportion female	278	73.4
Ethnicity		
White, non-Hispanic	228	60.2
Black, non-Hispanic	124	32.7
Hispanic	7	1.8
Native American	1	0.3
Asian/Pacific Islander	15	4.0
Other	4	1.1
Education		
High school	29	7.7
Technical school	18	4.7
Associate degree	86	22.7
College	224	59.1
Other	22	5.8
Annual household income		
<$15,000	21	5.8
$15,000–24,999	80	22.0
$25,000–34,999	81	22.3
$35,000–49,999	64	17.6
$50,000–74,999	71	19.5
≥$75,000	47	12.9
Unknown	15	
Handedness		
Proportion right-handed	343	90.7
Unknown	1	
Job description		
Executive	8	2.1
Professional	98	26.2
Technical	18	4.8
Sales	32	8.6
Secretarial	218	58.3
Unknown	5	

Note: Number of unknowns shown but not included in percentages.

TABLE II. Upper Limb Postural Angles Measured for Keyboard, Keypad, and Mouse

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

TABLE III. Placement of Goniometer Pivot and Arms for Each Postural Measurement

Postural angle measured in degrees

Wrist ulnar/radial deviation

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

Wrist flexion/extension

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

Elbow angle

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

Shoulder flexion/extension

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

Shoulder abduction/adduction

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

Gaze angle

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

Head tilt angle

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

Head rotation angle

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

head rotation angle were measured after the participant was instructed to look at the center of the monitor and again after the participant was instructed to look at a source document, in its usual location, if one was used during typing.

A 6-inch goniometer (North Coast Medical, Inc., San Jose, Calif.) was used to measure wrist angles, and a modified 12-inch goniometer (North Coast Medical, Inc.) was used to measure shoulder, elbow, and head and neck angles. The modified goniometer had two carpenter's levels attached to one of the arms, one in a perpendicular orientation and one in a parallel orientation, so that measurements could be made relative to true vertical and horizontal. All postural angles were recorded to the nearest degree. Goniometer pivot and arm placements for each of the postural measurements are provided in Table III. The locations of pivot and arm placements were based on those published in occupational ergonomic[3,4] and physical rehabilitation literature.[5] The postural measurement methods used were tested by the investigators prior to use in this study and found to have minimal interrater variability and good reliability regardless of time-of-day or day-of-week in a test-retest validation study.[6] In addition, on repeated measures, within-participant variability was significantly smaller than between participant variability, demonstrating that changes over time for individual participants were significantly smaller than differences in posture between participants. Specifically, the ratio of the variability between subjects to the variability within subjects ranged from nearly 8-fold for ulnar deviation to 77-fold for gaze angle.[6]

TABLE IV. VDT Workstation Physical Attributes (N = 379)

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

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

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

Data Analysis

Student's t-test and analysis of variance were used to determine the statistical significance of relationships between categorical and continuous variables, and Pearson's correlation coefficient was used to characterize associations between pairs of continuous variables. Since right-side and left-side postural measures were highly correlated, only results for the right side are reported.

RESULTS

Workstation Physical Attributes

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

TABLE V. VDT Workstation Dimensions (N = 379)

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

[A]N = 372.

workstations and below the surface at 26% of workstations. A document holder was present at 39% of workstations.

Workstation Dimensions

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

Linear Measures and Head/Neck Postures

Linear measures and head and neck postures of computer operators obtained while they keyed are presented in Table VI. Seated elbow height from floor (73.9 cm, SD = 4.2 cm) was very similar to keyboard height from floor (74.1 cm, SD = 4.3 cm, Table V). Seated eye height from floor (116.8 cm, SD = 4.4 cm) was, on average, 10.6 cm greater than monitor height from floor (106.2 cm, SD = 8.3 cm, Table V). The head rotation angle while viewing the monitor varied from −43.0 to 41.0° (SD = 11.6) and was centered around 0° (mean = 1.4° right of midline). The head rotation angle for viewing a document (for those who used documents) ranged from −64.0 to 72.0° (SD = 27.9) and was centered 9° to the left of midline. Both mean gaze angle and mean head tilt angle were more downward (i.e., became more negative) with shifting visual attention from monitor to document. However, the change in mean gaze angle when shifting between these two visual targets (25.2°) was considerably larger than the change in mean head tilt (9.2°) when shifting between these two visual targets, suggesting that changes in visual gaze were preferred over changes in head tilt.

Upper Limb Posture

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

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

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

TABLE VI. VDT Workstation/Worker Linear Measures and Head and Neck Postures (N = 379)

Measure	Mean	Median	SD	Range
Linear measures (cm)				
Elbow height from floor	73.9	74.0	4.2	59.0–84.0
Eye height from floor	116.8	117.0	4.4	105.0–127.0
Eye to midpoint of monitor	64.7	63.5	11.5	38.0–117.5
Eye to midpoint of document[A]	60.6	60.0	9.6	31.0–99.5
Head and neck posture (degrees)[B]				
Head rotation angle, monitor	−1.4	0.0	11.6	−43.0–41.0
Head rotation angle, document[A]	8.8	18.0	27.9	−64.0–72.0
Gaze angle, monitor	−11.5	−12.0	8.8	−43.0–25.0
Gaze angle, document[A]	−36.7	−40.0	13.5	−72.0–28.0
Head tilt angle, monitor	9.5	10.0	7.0	−19.0–26.0
Head tilt angle, document[A]	0.3	3.0	12.1	−50.0–30.0

[A]N = 372 (excludes individuals who do not use a document).
[B]Head rotation left = +; head rotation right = −; gaze angle above horizontal = +; gaze angle below horizontal = −.

TABLE VII. Upper Limb Posture as a Function of Input Device, Right Side (All Values in Degrees)

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

the table surface (27.3 versus 23.3°, $p < 0.05$), and shoulder flexion was significantly smaller when the keyboard was located below the table surface than when it was on the table surface (23.7 versus 30.6°, $p < 0.05$). No systematic differences were observed for wrist ulnar deviation or shoulder abduction across the keyboard location conditions.

Correlation Analyses

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

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

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

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

Additional Analyses

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

Mean values for head postures while viewing a document (gaze angle, head tilt angle, and head rotation angle) were calculated for the 115 participants who used a document holder and the 257 participants who did not use a document holder (34 of the 149 participants who had a document holder at their workstations did not use it and were therefore not included in this analysis). The mean gaze angle was −24.3° (SD = 12.1°) for participants who used a document holder and −42.2° (SD = 9.9°) for participants who did not use a document holder ($p < 0.01$). The mean head tilt angle was 7.6° (SD = 8.6°) for participants who used a document holder and −2.9° (SD = 12.0°) for participants who did not ($p < 0.01$). Finally, the mean head rotation angle was 11.1° (SD = 28.4°) for participants who did not use a document holder and 3.7° (SD = 26.2°) for participants who did ($p < 0.02$).

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

DISCUSSION

Relationships Between Workstation Dimensions and Operator Posture

It was hypothesized that workstation dimensions were important determinants of operator posture among computer users. Although some of the results of the correlation analyses were consistent with this hypothesis, others were not. For example, the relatively strong associations observed between gaze angle and monitor height and between shoulder flexion and inner elbow angle were consistent with this hypotheses. Other associations expected on the basis of geometric principles were not observed, however. For example, no association was observed between wrist extension and keyboard thickness (before and after stratifying by use of wrist rests) and only a modest association was observed between inner elbow angle and the height of the elbow above the keyboard. Similarly, shoulder flexion was only modestly associated with keyboard height.

A much stronger correlation was observed between elbow height and keyboard height than between eye height and monitor height. These results suggest that current office furniture design and/or adjustment practice preferentially locates the height of the elbow at or near keyboard height without similar attention to the height of the eyes with respect to the monitor height. This apparent inattention to monitor placement has been described by others[7] and may result in preventable neck disorders if head tilt

TABLE VIII. Correlation Matrix for Selected Postural Angles and Linear Measures (Right Side)

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

Note: Kybd = keyboard, mon = monitor, doc = document.

angle is a determinant of these conditions. As expected, use of a document holder was associated with large differences in all three neck postures measured, with significantly reduced downward gaze angle, head tilt angle, and head rotation angle among those with document holders in comparison with those without them.

Applying basic geometric principles, it is possible to estimate the "expected" range of postures for some joints from the range of observed workstation dimensions. For example, it is possible to predict the expected range of elbow angles from (1) the observed range of "J"-key heights (62.0 cm to 81.7 cm) and (2) the length of the operators' arms. Using a mean elbow-to-finger distance of 49.6 cm for a 5th percentile female,[8] the predicted range of elbow angles (i.e., maximum minus minimum) is 28°. Use of 50th and 95th percentile values predict even smaller ranges. The actual range of elbow angles observed in the current study was 72°, indicating that factors other than keyboard height contribute to the range of observed elbow angles. When this technique is applied to other joints, the observed range of posture is consistently greater than the expected range of posture. This empirical observation is consistent with the relatively modest correlation coefficients observed between posture and workstation dimensions (Table VIII). It also demonstrates that, contrary to the authors' hypothesis, workstation dimensions are major determinants of only a few of the postures measured; most postures measured were modestly or poorly associated with workstation dimensions.

Relationship Between Workstation Characteristics and Operator Posture

It was hypothesized that having an easily adjustable chair would affect operator posture. However, having an easily adjustable chair (one equipped with a pneumatic/hydraulic mechanism that could be operated from a seated position) had no observable association with the postures measured. The authors did not collect information about actual use of the chair adjustment. It is possible that the subset of participants who actually used the chair adjustment had different postures than those who did not. Regardless, the absence of differences in postural measures as a function of chair adjustability indicates that, at least, among participants in the current study, the simple provision of an adjustable chair was not sufficient to influence working posture. Additional investigation is needed to determine whether proper instruction in chair use would result in changes in working posture.

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

Inspection of the results of postural measures for the upper limb as a function of input device shows that reaching with the upper limb occurred while participants operated the mouse. Specifically, when compared with the posture at the keyboard, the inner elbow, shoulder abduction, and shoulder flexion angles were increased. Wrist ulnar deviation was decreased only slightly and wrist extension was essentially unchanged with mouse use. Only one other article was identified in the peer-reviewed literature in which postural measures were obtained among mouse users.[9] In that study, similar changes were observed in the elbow and shoulder angles between mouse and keyboard use.

Comparison of Observed Postures to Recommended Postures

Recommendations for posture and workstation design often center around placement of furniture and computer hardware to maintain a neutral hand posture with elbows close to the body and elbow angle around 90°.[1,2] In the current study, a large proportion of participants were observed to be keying in nonneutral postures of the wrist, elbow, and shoulder. For example, over 40% of participants were observed to key with wrist extension of $>25°$ or $<-25°$, and over 60% of participants were observe to key with shoulder flexion $>25°$.

The range of wrist postures observed in the current study represents a large portion of the total range of movement of the wrist. For example, wrist extension was observed to be as great as 60° in the current study. This represents a considerable proportion of the female 95th percentile wrist extension of 87.5.°[8] Mean wrist extension, however, and the wrist extension observed for the majority of operators in the current study was well within the established range of wrist extension. Likewise, wrist ulnar deviation was observed to be as great as 30° in the current study, a considerable proportion of the female 95th percentile wrist ulnar deviation of 37°. However, like wrist extension, the mean wrist ulnar deviation and the majority of operators in the current study were well within the established range of wrist ulnar deviation.

TABLE VIII. Extended

Gaze angle (doc)	Head tilt angle (doc)	Key height from surface	Key height from floor	Monitor height from floor	Elbow height	Elbow height–key height	Eye height
1.00							
0.51	1.00						
0.16	0.12	1.00					
−0.17	−0.18	0.00	1.00				
0.15	0.10	−0.03	0.16	1.00			
−0.25	−0.23	−0.06	0.60	0.14	1.00		
−0.09	−0.05	−0.06	−0.47	−0.03	0.43	1.00	
−0.14	−0.12	−0.05	0.22	0.18	0.46	−0.26	1.00

In contrast to the wrist, the range of elbow and shoulder postures observed in the current study were not near the reported extremes of posture for these joints.[8]

Comparison with Other Studies

The postures observed among participants in the current study are generally consistent with those reported by other investigators. Comparisons between this and other studies in which similar ergonomic measures are provided appear in Table IX. In particular, remarkable similarity between the current study and that of Hales et al.[10] was observed, with no major differences on any of the ergonomic measures. Several small differences were observed between the current results and those of Grandjean et al.[11] Specifically, the inner elbow, shoulder abduction, and shoulder flexion angles appear to differ slightly between the two populations. One possible explanation for the differences in results observed between these two studies is that participants in the study by Grandjean et al.[11] were working in their "preferred body posture," whereas those in the current study were not necessarily so positioned. Preferred body postures were achieved by Grandjean et al.[11] by providing fully adjustable workstations to all study participants and by providing intensive training and personal assistance to study participants wishing to change their workstations. In contrast, participants in the current study were observed as they worked in their usual jobs with workstations provided by their employers. Differences in posture between these two conditions are not unexpected.

In comparison with results observed by Sauter et al.,[4] the mean shoulder abduction angle was greater and the mean shoulder flexion angle smaller among participants in the current study. These discrepancies appear to be due to differences in the methods used to perform the measurements. The numerical difference between seated elbow height and keyboard height (i.e., elbow height from floor − keyboard height from floor) was about 9 cm larger in the study by Sauter et al.[4] than in either the current study or that of Hales et al.[10] This may reflect actual differences in populations or workstations across these studies or may be due to dissimilar methods.

TABLE IX. Comparison of Current Study with Previous Studies

Ergonomic Variable	Current Study (n = 379)	Hales(18) (n = 340)	Grandjean (31) (n = 59)	Sauter(16) (n = 40)
Angular measures (degrees)				
Wrist ulnar deviation	5.0	6	9	12
Wrist extension	24.3	28	—	267
Inner elbow angle	112.7	109	99	101
Shoulder abduction	14.0	—	22	1.5
Shoulder flexion	28.6	29	23	19
Gaze angle, monitor	−11.5	−12	−9	−10
Head tilt angle, monitor	9.5	6	—	A
Linear measures (centimeters)				
Table surface height				
Keyboard height	70.7	71.1	—	—
Monitor height	74.1	73.4	79	—
Elbow height	106.2	102.6	103	—
Keyboard height –	73.9	68.1	—	—
elbow height	0.3	<0.3	—	8.9
Eye height	116.8	113.3	115	—
Eye to screen distance	64.8	68.1	76	—

AMethods not comparable with current study.

Shortcomings of the Current Study

The subjects enrolled in the current study do not represent a randomly selected sample of all computer users. To recruit such a sample would require enumeration of all computer users and use of a sampling strategy in which each computer user had an equal probability of being included in the study sample. Such a sampling strategy is rarely, if ever, feasible in studies of working populations. The sampling strategy employed in the current study had well-defined entry criteria and all persons who met the criteria were invited to participate. The results are generalizable to computer users who meet the entry criteria and have similar demographic characteristics.

In the current study, manual goniometry was the method used to measure posture, and measurements were performed at a single point in time. Manual goniometry was used to measure posture in the current study because of its rapidity, reliability, low cost, and high acceptability to study participants and their employers. The complete assessment of the workstation and the worker's posture was accomplished in about 20 min. Other, more equipment-intensive methods, such as video analysis, are more costly and require more time for setup, data collection, and analyses of raw data collected. 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.[3–6] Among computer users, it has been shown to have good agreement with more costly, time-consuming, and complex video analyses of posture.[12] Furthermore, the use of goniometers also allows for comparison of the results obtained in the current study with those found by other investigators who also used this method.[4,10,11,13]

The specific postural measurement methods used in this study were tested by the investigators prior to their use and found to have minimal interrater variability and good reliability regardless of time-of-day or day-of-week in a test-retest validation study.[6] In addition, on repeated measures, within-participant variability was significantly smaller than between-participant variability, demonstrating that changes over time for individual participants were substantially smaller than differences in posture between participants. These findings suggest that single time point measures are adequately representative of operator posture over time. The stability of postural measures among keyboard users also has been reported by others.[14] In addition, to account for some of the dynamic elements of posture during computer use, upper extremity postures were measured while operators used the numeric keypad and the mouse as well as the alphabetic keyboard, and head postures were measured while operators viewed a document, if present, as well as the computer monitor.

Finally, it is possible that postures assumed while under observation may be systematically different from those assumed without observation. Ultimately, this is difficult to determine. All methods used to measure elements of human behavior, regardless of sophistication, can produce changes in the phenomena observed. The consistency of the current results with those reported by others suggests that should this effect have occurred, it must have occurred consistently across several studies performed by different investigators in different settings at different times. Furthermore, in the test-retest study performed by Ortiz et al.,[6] no systematic change in posture was observed between the first and the sixth measures. If observation of posture resulted in posture changes among operators, some attenuation over time as a result of repeated measures (accommodation) might have been anticipated.

CONCLUSIONS

Workstation and postural data for nearly 400 VDT users are presented in this article. This represents the largest series of field observations of computer users available in the peer-reviewed literature. From the results of this investigation, it is concluded that:

- workstation dimensions were only partly responsible for some operator postures;
- considerable variability in posture could not be accounted for by workstation dimensions alone;
- observed variability in posture was greater than expected when basic geometric principles were applied to observed workstation dimensions;
- the correlation between elbow height and keyboard height was stronger than the correlation between eye height and monitor height, suggesting preferential location of the elbow/keyboard in comparison to the eye/monitor;
- reaching for and using the mouse resulted in increased shoulder flexion, shoulder abduction, and inner elbow angle; and
- a large proportion of computer users do not work in neutral postures.

REFERENCES

1. **Occupational Safety and Health Administration (OSHA):** *Working Safely with Video Display Terminals.* Washington, DC: OSHA, 1996.
2. **Dell Computer Corp.:** *Reference and Troubleshooting Guide.* Austin, TX: Dell Computer Corp., 1998.
3. **Maeda, K., W. Hunting, and E. Grandjean:** Factor analysis of localized fatigue complaints of accounting machine operators. *J. Human Ergol. 11*:37–43 (1982).
4. **Sauter, S.L., L.M. Schleifer, and S.J. Knutson:** Work posture, workstation design, and musculoskeletal discomfort in a VDT data entry task. *Human Factors 33*:151–167 (1991).
5. **Lastayo, P.C., and D.L. Wheeler:** Reliability of passive wrist flexion and extension goniometric measurements: A multicenter study. *Phys. Therapy 74*:162–176 (1994).
6. **Ortiz, D.J., M. Marcus, F. Gerr, W. Jones, and S. Cohen:** Measurement variability in upper extremity posture among VDT users. *Appl. Ergonom. 28*:139–143 (1997).
7. **Arndt, R.:** Working posture and musculoskeletal problems of video display terminal operators—review and reappraisal. *Am. Ind. Hyg. Assoc. J. 44*:437–446 (1983).
8. **Kroemer, K., H. Kroemer, and K. Kroemer-Elbert:** *Ergonomics: How to Design for Ease and Efficiency.* Englewood Cliffs, NJ: Prentice Hall, 1994.
9. **Karlqvist, L., M. Hagberg, and K. Selin:** Variation in upper limb posture and movement during word processing with and without mouse use. *Ergonomics 37*:1261–1267 (1994).
10. **Hales, T., S. Sauter, M. Petersen, V. Putz-Anderson, L. Fine, T. Ochs, L. Schleifer, and B. Bernard:** *Health Hazard Evaluation Report* (US West Communications, HETA 89–299–2230). (1992). pp. 1–34.
11. **Grandjean, E., W. Hünting, and M. Pidermann:** VDT workstation design: Preferred settings and their effects. *Human Factors 25*:161–175 (1983).
12. **Wrigley, T.V., R.A. Green, and C.A. Briggs:** Microcomputer video image processing technology in working posture analysis. *Appl. Ergonom. 22*:2–8; 1991.
13. **Faucett, J., and D. Rempel:** VDT-related musculoskeletal symptoms: Interactions between work posture and psychosocial work factors. *Am. J. Ind. Med. 26*:597–612 (1994).
14. **Hunting, W., E. Grandjean, and K. Maeda:** Constrained postures in accounting machine operators. *Appl. Ergonom. 11*:145–149 (1980).