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Wrist and forearm postures and motions during typing

ELAINE R. SERINA†, RON TAL‡ and DAVID REMPEL‡*

†Piziali and Associates, Inc., 655 Skyway Road, Suite 202, San Carlos, CA 94070, USA

‡University of California Ergonomics Program, 1301 South 46th Street, Building 112, Richmond, CA 94804, USA

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Awkward upper extremity postures and repetitive wrist motions have been identified by some studies as risk factors for upper extremity musculoskeletal disorders during keyboard work. However, accurate body postures and joint motions of typists typing on standardized workstations are not known. A laboratory study was conducted to continuously measure wrist and forearm postures and motions of 25 subjects while they typed for 10–15 min at a standard computer workstation adjusted to the subjects' anthropometry. Electrogoniometers continuously recorded wrist and forearm angles. Joint angular velocities and accelerations were calculated from the postural data. The results indicate that wrist and forearm postures during typing were sustained at non-neutral angles; mean wrist extension angle was 23.4 ± 10.9° on the left and 19.9 ± 8.6° on the right. Mean ulnar deviation was 14.7 ± 10.1° on the left and 18.6 ± 5.8° on the right. More than 73% of subjects typed with the left or right wrist in greater than 15° extension and more than 20% typed with the left or right wrist in greater than 20° ulnar deviation. Joint angles and motions while typing on an adjusted computer workstation were not predictable based on anthropometry or typing speed and varied widely between subjects. Wrist motions are rapid and are similar in magnitude to wrist motions of industrial workers performing jobs having a high risk for developing cumulative trauma disorders. The magnitude of the dynamic components suggests that wrist joint motions may need to be evaluated as a risk factor for musculoskeletal disorders during typing.

1. Introduction

Upper extremity musculoskeletal disorders among office workers, such as lateral epicondylitis and wrist tendonitis, are major contributors to worker's compensation claims and lost work time. The annual number of new cases of musculoskeletal disorders among office workers has increased 10-fold in the past 5 years (Bureau of Labor Statistics 1993). Development of musculoskeletal disorders has been associated with prolonged computer use in many studies (Burt *et al.* 1990, Bernard *et al.* 1994, Faucett and Rempel 1994, Bergqvist *et al.* 1995) but not in others (De Krom *et al.* 1990). The increasing occurrence of these injuries in the office is probably due in part to the increasing use of computers.

Some studies have identified constrained and awkward wrist and forearm postures as contributors to hand and arm pain during keyboard-like activities. Duncan and Ferguson (1974), in their study of 135 male telegraphists during teleprinter operations, observed a greater percentage of symptomatic than asymptomatic

*Author for correspondence.

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subjects assuming wrist extension and wrist ulnar deviation angles further from the neutral position. Hunting *et al.* (1981) and Sauter *et al.* (1991) found wrist ulnar deviation to be a significant predictor of arm discomfort, based on questionnaires and static postural measurements of keyboard operators. Seligman *et al.* (1986) reported a relationship of increased wrist extension, not ulnar deviation, to hand pain in a comparative study of 10 police transcribers with and without wrist symptoms. However, the studies by Sauter *et al.* (1991) and Starr *et al.* (1985) did not find wrist extension to be associated with arm discomfort among VDT users and telephone operators. In the industrial workplace, high wrist angular velocities and accelerations have been identified as risk factors for cumulative trauma disorders (CTDs) independent of wrist postures (Marras and Schoenmarklin 1993). However, wrist motion has not been studied in the office setting.

Upper extremity postures and joint motions during typing are not accurately known. Postural data obtained to date have been captured with static measurement techniques, such as manual goniometers, photographs, or single frames from videos (Hunting *et al.* 1980, 1981, Nakaseko *et al.* 1985, Starr *et al.* 1985, Seligman *et al.* 1986, Sauter *et al.* 1991). Representing posture by single-point measurement values acquired while subjects perform keyboard-like activities or maintain a stationary typing posture may have led to posture misclassification. Limitations of static measurement techniques have resulted in a paucity of forearm rotation and bilateral data. Continuous measurement of the body postures during typing has not been performed. This laboratory study was conducted to continuously measure wrist and forearm joint postures and motions of typists while they typed at a computer workstation configured according to a common guideline (ANSI/HFS 1988).

2. Method

Twenty-five subjects typed for 10–15 min on a computer workstation adjusted to their body dimensions while electrogoniometers mounted on their upper extremities continuously measured wrist and forearm angles. Joint angular velocities and angular accelerations were calculated from the postural data. Joint angles, velocities, and accelerations were compared to anthropometry for each subject and summary statistics of postures and motions were calculated across all subjects.

2.1. *Goniometer system*

Four electrogoniometers of a compact and nonrestrictive design (Penny and Giles Blackwood Ltd, Gwent, UK) recorded wrist flexion/extension (F/E), wrist ulnar/radial deviation (U/R), and forearm pronation/supination (P/S) angles on the left and right sides. Wrist F/E and U/R were measured with a model M110 twin-axis goniometer mounted on the dorsal side of each hand and forearm. Forearm P/S was measured with a model Z-110 single axis torsiometer mounted on the dorsal ulnar side of each forearm.

Goniometer placement was conducted with the wrist neutral, forearm fully pronated, upper arm perpendicular to the floor, and elbow at approximately a right angle. Reference lines based on anatomical landmarks (Ryu *et al.* 1991) were drawn to permit consistent placement of the goniometers. The twin-axis goniometer was mounted on the radial side of a line drawn along the ulnar border of the third metacarpal extending through the centre of rotation of the wrist to the midpoint of the epicondyles. The distal endblock of the torsiometer was placed lateral to this reference line immediately proximal to the wrist, and the proximal endblock was aligned with a line connecting the styloid process of the ulna head with the lateral epicondyle. Goniometers were attached with double-sided adhesive tape and secured with adhesive medical tape. Placement of the goniometers did not interfere with joint motions.

To minimize errors associated with mounting, anthropometry and skin stretching, calibration curves in the U/R and P/S directions were generated for each subject. Calibration consisted of recording the goniometer output voltage at two joint angles in each direction of joint motion (F/E: 45° F, 0°, 45° E; U/R: 12° U, 0°, 12° R; P: 30°, 60°, 90°). The subject sat in a specially-designed calibration jig that firmly held the hands and forearms flat on a horizontal surface with the upper arms vertical. The jig isolated joint motions to minimize cross-talk during goniometer calibration and zeroing. Calibration curves were approximated by a piecewise function with two line segments. Owing to the high linearity in the F/E direction, goniometers were calibrated in F/E in another jig prior to mounting (Smutz *et al.* 1994).

Error analysis of the goniometer system was conducted prior to experimentation to quantify the effects of repeatability, linearity, and cross-talk errors (Taylor 1982). Statistical analysis of repeatability tests in which five subjects placed their hands repeatedly in a neutral wrist posture provided an upper bound estimate of the repeatability error (F/E: 3.6%, U/R: 1.8%, P/S: 3.7%). Errors resulting from the assumption of linearity in the F/E and U/R goniometer directions were estimated as per Smutz *et al.* (1994). For the P/S direction, errors were calculated by comparing goniometer output with values from an electronic inclinometer ($\pm 0.5°$) as three subjects pronated their forearm from 0 to 90° in 5° increments while rotations in other planes were constrained. Linearity errors did not exceed F/E: 4.4%, U/R: 1.8%, P/S: 4.0%. Cross-talk errors were low, especially during small F/E and U/R deviations, because forearm pronation varied little from the fully pronated position (Armstrong *et al.* 1993).

2.2. *Subjects*

Twenty-five typists (23 females; two males) were recruited from a temporary employment agency. A criterion for participation in the study was the ability to type at least 45 words per minute (wpm). The mean typing speed measured during the typing tasks was 49 ± 11 wpm (range: 36–74 wpm). Subjects were informed of a financial bonus, up to 50% of base pay, if their productivity during the experiment (typing speed minus errors) surpassed their baseline typing speed determined by the employment agency. An attempt was made to select subjects with broad demographic characteristics (age, gender, race) and skills (typing speed, experience with computers). Mean age was 39 ± 11 years (range: 18–54 years). Twenty-three subjects were right-handed. All subjects were pain-free at the time of testing, although nine subjects reported having hand and arm pain in the past 6 months; two were previously diagnosed by their physicians as having carpal tunnel syndrome or tendonitis, and two as having arthritis.

2.3. *Workstation*

The workstation was adjusted to the body dimensions of each subject. Seat height, seat pan angle, and back rest were set so that the subject's feet were flat on the floor, knees were approximately at a right angle, and torso was upright. Table height was adjusted so that the subject's forearms in the typing position were approximately parallel to the floor. The monitor was positioned with the first line of text level with the subject's horizontal line of sight. A standard flat alphanumeric QWERTY keyboard with slope of 8° was used (Apple Extended™, Cupertino, CA). No wrist or arm rests were provided and resting the wrists or arms was not permitted while typing. Lighting, temperature and noise were controlled.

Anthropometric data from each subject were measured with the subject seated at the adjusted workstation: popiteal height, shoulder width (acromion to acromion), seated elbow height, hand length (distal wrist crease to tip of the third digit), wrist width (between styloid processes of radius and ulna), and wrist thickness. The subject reported body height and weight on a questionnaire. Anthropometric data from all subjects are summarized in table 1.

2.4. *Experimental protocol*

Following goniometer mounting, goniometer calibration, and workstation set-up, a warm-up period was provided to familiarize the subject with the experimental setting. The subject typed lines of alphabetic text displayed on the monitor for 10–20 min while typing productivity was monitored (Smutz *et al.* 1994). When a constant productivity level was reached, after about 7 min, data acquisition was immediately initiated and continued for approximately 10–15 min. Moffet and Hagberg (1995) determined that forearm postures during typing are stable after a 10-min warm-up period. During data acquisition, the six channels of joint angle data were simultaneously sampled at 2000 Hz.

2.5. *Data analysis*

Joint angle data from each channel were averaged to 20 Hz then filtered with a low-pass 6th order Butterworth filter (5 Hz cut-off frequency). A pilot study comparing raw and averaged-filtered right F/E, U/R, and P/S angle data from four subjects confirmed that goniometer data treated with this filtering technique accurately represented the postures and motions of the wrist and forearm during typing. Mean raw and averaged-filtered angles differed by less than 1% over all joint postures.

Table 1. Summary statistics of anthropometry data ($n = 25$). Popliteal height, elbow height, hand length, and wrist dimensions were measured on the subject's right side.

	Mean	Standard deviation	Range
Weight (kg)	70.8	19.9	47.7–136.4
Height (cm)	163.8	6.1	152.4–180.3
Body mass index ($kg/m^{1.5}$)*	33.6	8.6	22.5–62.8
Elbow height (cm)**	67.8	1.9	62.5–70.5
Hand length (cm)†	18.0	1.0	16.5–19.5
Popliteal height (cm)**	43.5	2.3	38.0–48.0
Shoulder width (cm)‡	40.6	3.8	34.0–54.0
Wrist thickness (cm)	4.1	0.4	3.2–4.5
Wrist width (cm)§	5.9	0.5	5.0–6.7

*Body mass index = (weight)/(height)$^{1.5}$. See Bray (1985).
**Floor to olecranon height with the subject seated at the adjusted workstation.
†Distal wrist crease to tip of the third digit.
‡Acromion to acromion.
§Between styloid processes of radius and ulna.

Power spectra obtained using a fast Fourier transform technique on both the raw and averaged-filtered angle data were qualitatively identical; 97–99% of the power in the raw data was retained by the filtering process for all joint postures. This filtering method was also validated by Hansson *et al.* (1996) in their study of wrist angles and joint angular velocities in fish processing tasks.

Joint angular velocities and accelerations were calculated by twice differentiating the averaged-filtered angle data using a finite difference method. Conservative estimates of joint motions were obtained. From the pilot study described above, mean rectified velocities calculated from averaged-filtered raw signals were, on average, 10% lower in F/E, 14% lower in U/R, and 15% lower in P/S than velocities calculated from 5 Hz filtered raw data. Maximum velocities from the averaged-filtered data were also lower for F/E, U/R, and P/S by 18, 25 and 24%, respectively. Hansson *et al.* (1996) calculated wrist velocities in a similar manner.

For each subject, statistical summary values for joint positions (°), angular velocities (°/s) and angular accelerations ($°/s^2$) were calculated over the entire data acquisition period. Mean joint angles and within- and between-subject standard deviations were calculated. Angular velocity and acceleration data were rectified (data were observed to be symmetrical about the horizontal axis), and mean, standard deviation, and maximum values were calculated. Relationships of mean joint postures and motions with selected anthropometry measures were evaluated using Pearson correlation coefficients and tested for statistical significance. Postural differences between the left and right wrists and forearms were assessed with a Student *t*-test. Statistical significance was defined as $p < 0.05$. All statistical analyses were conducted on JMP (SAS Institute Inc., Cary, NC).

3. Results

3.1. *Joint posture*

Typical joint angle data over the 10–15 min typing period for one subject are plotted in figure 1. The relative stability of the mean postural angles over this period is typical of data collected from all subjects. Mean values of the within-subject standard deviations of joint angles are: left F/E: 5.5°; right F/E: 6.2°; left U/R: 3.7°; right U/R: 4.1° left P/S: 3.3°; right P/S: 4.5°.

Histograms of the mean joint angles for wrist extension and wrist ulnar deviation for the 25 subjects are presented in figure 2 with summary means and within- and between-subjects standard deviations listed in table 2. Sample mean values were normally distributed, as determined by a KSL test for normality ($p > 0.05$). Mean wrist extension angles were $23.4 \pm 10.9°$ (left) and $19.9 \pm 8.6°$ (right). Mean wrist ulnar deviation angles were 14.7 ± 10.1 (left) and $18.6 \pm 5.8°$ (right). Mean forearm pronation angles were $90.3 \pm 12.4°$ (left) and $83.2 \pm 10.9°$ (right). The observed difference between left and right sides for wrist extension and for ulnar deviation were not statistically significant ($p > 0.10$). A borderline significant difference between left and right forearm pronation ($p = 0.054$) was observed, with the left forearm pronated 6.4° more than the right.

3.2. *Joint motions*

Mean rectified joint angular velocities and accelerations and within- and between-standard deviations for all subjects for wrist F/E and U/R are listed in table 3. Histograms of mean rectified joint angular velocities are presented in figure 3. Highest velocities and accelerations occurred in F/E. Mean non-rectified angular

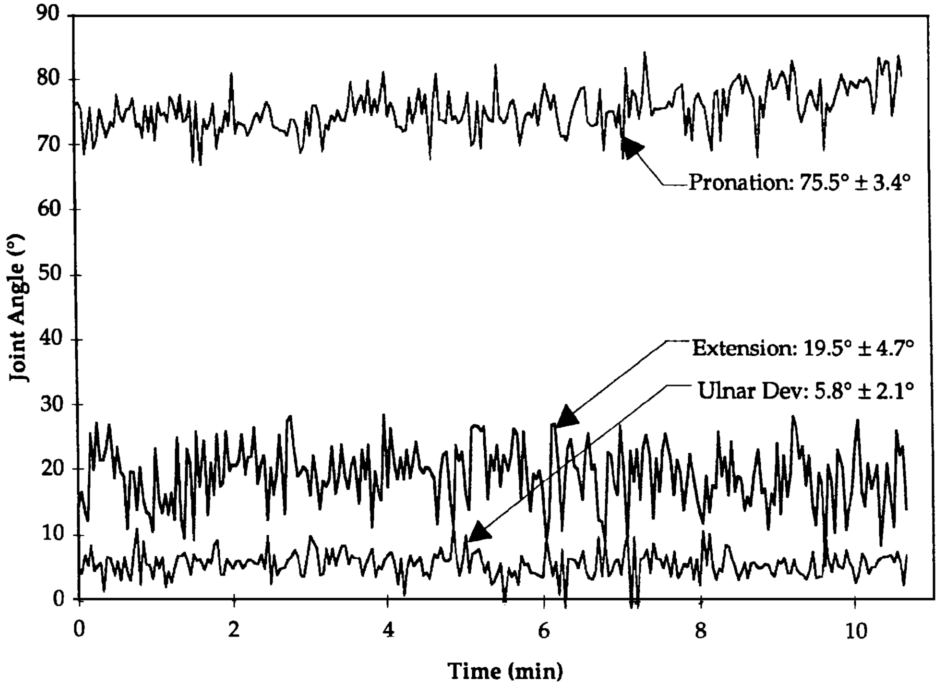

Figure 1. Variation of wrist and forearm angles with time over a 10–15 min typing period. Data is shown for the left side of subject 17 and is representative of data from all subjects ($n=25$). Every 50th point from the filtered dataset (5 Hz cut-off frequency) is plotted. Means and standard deviations for each joint angle are indicated.

Table 2. Mean joint angles (°) and within- and between-subject standard deviations (SD) for each joint direction ($n=25$).

Joint posture	Mean joint angle	Within-subject SD	Between-subject SD
Left extension	23.4	5.4	10.9
Right extension	19.9	6.0	8.6
Left ulnar deviation	14.7	3.7	10.1
Right ulnar deviation	18.6	4.1	5.8
Left pronation	90.3	3.3	12.4
Right pronation	83.2	4.5	10.9

velocities and accelerations were approximately zero for each subject and were not a consequence of the averaging process. Similar maximum and minimum values of the non-rectified data for each subject were observed.

3.3. *Correlations among postures, motions and anthropometry*

Few statistically significant relationships between joint postures, joint motions, and anthropometry measurements were found. The factors tested are listed with their corresponding Pearson correlation coefficients (r) in table 4. Statistically significant

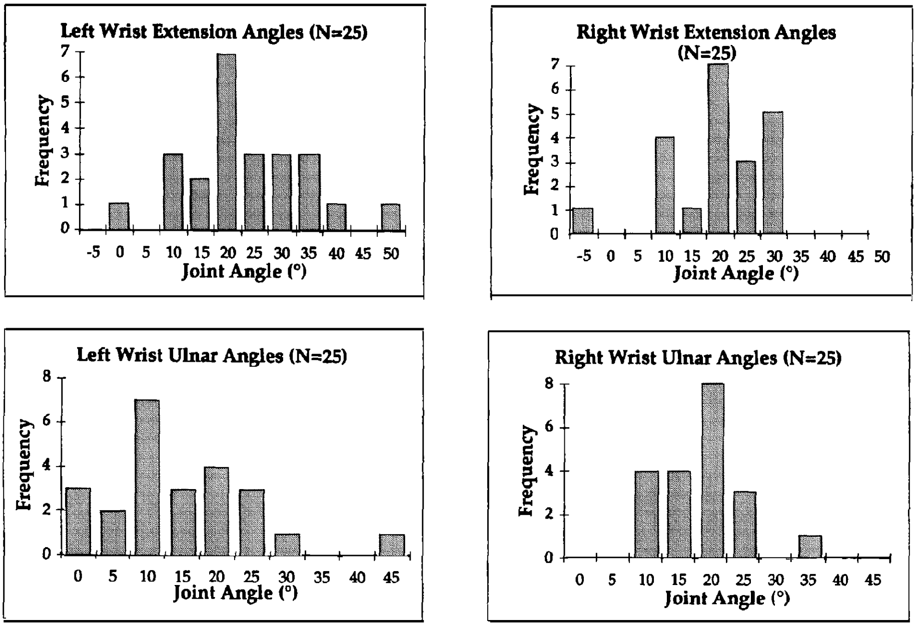

Figure 2. Histograms of subject mean wrist extension and ulnar deviation angles measured over a 10–15 min typing period ($n = 25$). Data from left and right wrists are shown separately.

Table 3. (a) Mean rectified, within- and between-subject standard deviations (SD), and mean maximum joint angular velocities (°/s) for each joint direction of motion and for each side ($n = 25$); (b) mean rectified, within- and between-subject standard deviations (SD), and mean maximum joint angular accelerations ($^{\circ}/s^2$) for each joint direction of motion and for each side ($n = 25$).

(a) Motion direction	Mean rectified velocity	Within-subject SD	Between-subject SD	Mean maximum velocity
Left flexion/extension	23	11	7	188
Right flexion/extension	25	12	8	164
Left ulnar/radial deviation	12	7	4	94
Right ulnar/radial deviation	11	7	4	82
Left pronation/supination	11	6	3	106
Right pronation/supination	14	8	4	120

(b) Motion direction	Mean rectified acceleration	Within-subject SD	Between-subject SD	Mean maximum acceleration
Left flexion/extension	295	105	103	2444
Right flexion/extension	317	152	128	2058
Left ulnar/radial deviation	141	78	62	966
Right ulnar/radial deviation	127	74	37	940
Left pronation/supination	145	79	47	1529
Right pronation/supination	191	102	49	1424

correlations ($p < 0.05$) were found between shoulder width and both right extension ($p = 0.03$; $r = -0.50$) and right pronation ($p = 0.02$; $r = -0.51$). The correlation between right extension and right pronation was also statistically significant ($p = 0.01$, $r = -0.58$). No other correlations among anthropometry and joint angles were statistically significant. Specifically, no relationship between shoulder width and wrist ulnar deviation was observed, as seen in figure 4.

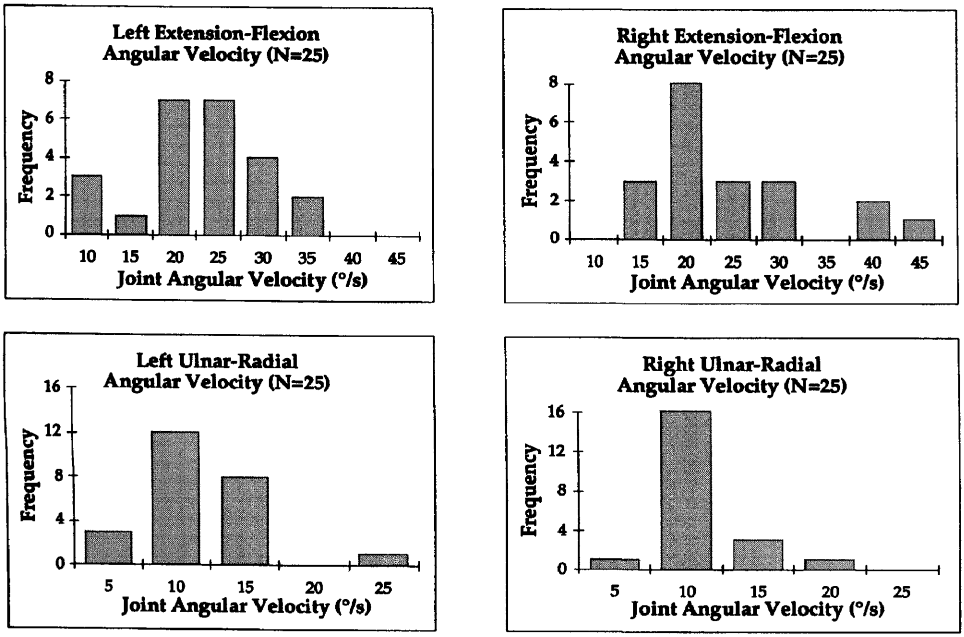

Figure 3. Histograms of subject mean wrist extension-flexion and ulnar-radial deviation angular velocities calculated from posture data over a 10–15 min typing period ($n = 25$). Data from left and right wrists are shown separately.

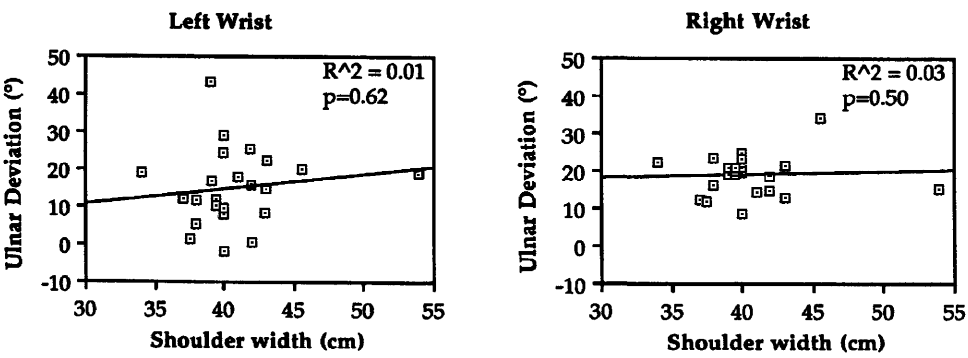

Figure 4. Scatter plot showing no relationship between mean left or right wrist ulnar deviation and shoulder width for all subjects ($n = 25$). Linear functions are fitted to the data and R^2 and p-values are shown.

Table 4. Pearson correlation coefficients (r) of mean joint angles with selected anthropometry data ($n = 25$). Statistically significant correlations ($p < 0.05$) are indicated with an asterisk (*). Cells corresponding to untested correlations are left blank.

Factors	Left extension	Right extension	Left ulnar	Right ulnar	Left pronation	Right pronation
Body mass index*	0.23	0.21	0.04	0.23	−0.17	−0.36
Elbow height**	−0.11	−0.06	−0.07	0.23	0.41	−0.27
Hand length†	−0.24	−0.43	0.26	0.03	−0.02	0.38
Shoulder width‡	0.19	0.50*	−0.11	0.17	−0.29	−0.51*
Wrist thickness	0.01	0.25	—	—	—	—
Wrist width§	—	—	0.15	0.01	—	—
F/E	—	—	Left ext: −0.23	Right ext: −0.18	Left ext: −0.31	Right ext: −0.58*
U/R	—	—	—	—	Left uln: −0.01	Right uln: −0.05

*Body mass index = (Weight)/(Height)$^{1.5}$ (Bray 1985).
**Floor to olecranon height with the subject seated at the adjusted workstation.
†Distal wrist crease to tip of the third digit.
‡Acromion to acromion.
§Between styloid processes of radius and ulna.

To determine whether typing speed modified wrist motions, relationships of typing speed to within-subject standard deviations of joint angles, angular velocities, and angular accelerations were investigated. No statistically significant correlations were found between typing speed and these parameters.

4. Discussion

Subjects typing on an 'ideal' computer workstation assumed wrist extension angles that are much larger than the keyboard slope. Current workstation guidelines for keyboard slope are based on the assumption that wrist angles during typing coincide with keyboard slope. The ANSI/HFS Standard No. 100-1988: 37 states that:

> wrist extension beyond 15 degrees can increase histological pressure inside the carpal tunnel of the wrist, which is associated with carpal tunnel syndrome. Accordingly, it is recommended that keyboard slopes be minimized and limited to the range 0 to 15 degrees.

In this study, mean left and right wrist extension were 23.4° and 19.9°, respectively, well beyond the 8° slope of the keyboard that was used.

The finding that a majority of subjects typed with their left, 76% (19/25), or right, 73% (16/22), wrists in greater than 15° extension, respectively, raises concern about the 'ideal' workstation set-up for people who use computers for long periods of time. Of greater concern is that 28% (7/25) and 9% (2/22) of subjects in this study typed with a mean left or right wrist extension greater than 30°, respectively. Seligman *et al.* (1986) found that mean wrist extension angles of transcribers complaining of musculoskeletal symptoms (24.0°) were significantly greater than those without symptoms (16.6°), indicating a possible increased risk of injury with increasing wrist extension. Sustained wrist extension causes elevated fluid pressure within the carpal tunnel (Weiss *et al.* 1995), elevated muscle activity of wrist and finger extensors (Rose 1991), and has been associated with musculoskeletal disorders in epidemiologic studies (Duncan and Ferguson 1974, De Krom *et al.* 1990, Faucett and Rempel 1994). The current recommendations for workstation and input device design (ANSI/HFS 1988) will need to be reconsidered if a neutral wrist posture is desired.

An association between increasing wrist ulnar deviation and musculoskeletal pain and discomfort in the upper extremity during keyboard-like activities has been identified by previous studies (Ferguson and Duncan 1974, Hunting *et al.* 1981, Sauter *et al.* 1991). In particular, Hunting *et al.* (1981) found a marked increase in complaints of forearm muscle pain among typists assuming wrist ulnar deviation angles greater than 20°. In the present study, 20% (5/25) of subjects typed with a mean left wrist ulnar deviation greater than 20° while 41% (9/22) of the subjects typed with a mean right wrist ulnar deviation greater than 20°. Subjects with sustained large wrist deviation are probably at greater risk for wrist and forearm musculoskeletal disorders.

Mean wrist postures and between-subject standard deviations while typing on an 'ideal' computer workstation in the laboratory environment were similar to those measured by others in field studies (Hunting *et al.* 1980, 1981, Nakaseko *et al.* 1985, Seligman *et al.* 1986, Sauter *et al.* 1991). Summary values of the wrist postures from these studies are tabulated in table 5. Only the wrist extension angles reported by Starr *et al.* (1985) differ greatly from the wrist extension angles measured in this study. Starr *et al.* (1985: 270) attempted to determine the typical typing posture of

Table 5. Summary of mean wrist postures measured during keyboard-like activities. Job description and measurement technique are described. All previous methods used static measurement techniques. Wrist angles obtained from this study are listed in the bottom row.

Study	Job description	Measurement technique	Mean wrist extension (SD)	Mean wrist ulnar deviation (SD)
Hunting *et al.* (1980)	57 accounting machine operators	Manual goniometer	Right: 20.5° (7.4°)	Right: 14.0° (8.7°)
Hunting *et al.* (1981)	295 typists	Manual goniometer	Right: 10–16°	Left: 13–21°; Right: 12–17°
Nakaseko *et al.* (1985)	51 typists	Manual goniometer	—	Right: 20° (approximate)
Starr *et al.* (1985)	100 telephone operators	Photographs	1° (Range:- 35–54°)	—
Seligman *et al.* (1986)	10 police transcribers	Videotaping	24.0° cases; 16.6° noncases	Left: 22.4° cases; 20.0° noncases Right: 19.4° cases; 19.0° noncases
Sauter *et al.* (1991)	40 VDT users	Manual goniometer	Left: 24.9° (14.9°) Right: 26.0° (15.3°)	Left: 15.5° (9.1°) Right: 11.7° (8.6°)
Serina *et al.* (1995)	25 typists	Electrogoniometers	Left: 23.4° (10.9°) Right: 19.9° (8.6°)	Left: 14.7° (10.1°) Right: 18.6° (5.8°)

directory assistance operators from a single flash photograph taken while the operator was 'viewing the screen with hands on or slightly above the keyboard'. Whether this resting posture is the same as the posture assumed while typing continuously for long periods of time is not known. Errors associated with estimating a three-dimensional posture with a single two-dimensional image, such as not aligning the camera perpendicular to the F/E and not accounting for forearm rotation, could have contributed to the large range of angles measured (37° flexion to 54° extension) by Starr *et al.* (1985). The similarity of wrist postures provides some confidence for the use of some static measurement techniques, such as manual goniometers or videotaping, for obtaining measures of wrist postures during typing in the field. However, wrist postures on an 'ideal' workstation were not closer to a neutral position than on a workstation in the field, raising the question of whether current recommendations for workstation set-up decrease the risk of wrist and forearm musculoskeletal injury.

Subject anthropometry did not predict wrist and forearm postures while typing on a standardized computer workstation. The lack of correlations in the present study between joint angles and anthropometric measurements does not support relationships observed or postulated by others. Duncan and Ferguson (1974) observed a significant association between wrist extension and wrist ulnar deviation among teleprinter operators with symptoms of occupational cramp and myalgia ($p < 0.05$). The present authors observed no associations between extension and ulnar deviation in either the left or right wrists. Zipp *et al.* (1983), Seligman *et al.* (1986), and Rose (1991) suggested that the degree of wrist ulnar deviation was influenced by the anthropometry of the typist. They postulated that the elbows of a smaller-sized individual would be closer to the centre of the body, due to narrower shoulder widths, leading to less ulnar deviation. On the other hand larger persons, they postulated, would have their elbows further apart, increasing wrist ulnar deviation. The present authors observed no relationship between wrist ulnar deviation and either shoulder width or body mass index (figure 4). They did observe a correlation between increasing shoulder widths and increasing right wrist extension angles and between increasing shoulder widths and decreasing right forearm pronation angles. However, these two correlations would not be statistically significant if a correction factor for multiple comparisons was applied. Wrist postures were not predictable based on subjects' size, shoulder width, hand length or wrist dimensions at an adjusted workstation.

Although wrist and forearm postures appeared to be stationary during typing, in reality, motions of these joints during typing were rapid. Peak wrist angular velocities and accelerations were similar to wrist motions of industrial workers (table 6). Mean maximum F/E angular velocities during typing were similar to velocities from industrial workers performing tasks associated with high-CTD risk. Mean maximum U/R angular velocities during typing fell between velocities reported for low- and high-CTD risk industrial tasks. Mean maximum F/E angular accelerations were only 13% less than those measured from the industrial low-CTD risk group. Comparing angular accelerations from different studies should be done with caution. Some differences resulted from the differing treatment of the raw data. Angular accelerations calculated from angle data are very sensitive to measurement methods and filtering techniques. The angular accelerations reported in this study are somewhat lower than actual wrist and forearm angular accelerations experienced during typing because they were derived from conservative estimates of angular

Table 6. Mean maximum wrist and forearm joint angular velocities (°/s) and joint angular accelerations (°/s^2) during different tasks ($n = 25$). Standard deviations are shown in parenthesis. Joint angular velocities and accelerations during typing are compared to joint angular velocities and accelerations during industrial tasks with low- and high-risk of developing CTDs.

Joint direction	Typing*	Low-risk industrial task**	High-risk industrial task**
Joint angular velocities (°/s)			
Flexion/extension	176 (100)	120 (38)	174 (58)
Ulnar/radial	88 (48)	77 (31)	116 (40)
Pronation/supination	113 (107)	300 (129)	449 (256)
Joint angular accelerations (°/s^2)			
Flexion/extension	2251 (1486)	2588 (802)	4471 (1527)
Ulnar/radial	953 (402)	1759 (834)	3077 (1313)
Pronation/supination	1477 (1578)	7169 (2980)	11291 (4954)

*This study.
**Marras and Schoenmarklin (1993).

velocities based on the filtering technique used. Marras and Schoenmarklin (1993) have shown an increased incidence of lost-time injuries in industrial jobs with high wrist velocities and accelerations. The dynamic components of the wrist and forearm during typing, especially in F/E, possessed sufficiently high magnitudes to recommend their evaluation in future studies as possible risk factors for musculoskeletal disorders.

This study demonstrated that the typing posture is characterized by sustained wrist extension, wrist ulnar deviation, and forearm pronation throughout the keyboard operating period. On an 'ideal' workstation set-up, a majority of subjects typed with a mean wrist extension angle greater than 15° with more than one-quarter of subjects typing with a mean wrist extension greater than 30°. Several subjects (41%) typed with a mean wrist ulnar deviation angle greater than 20°. The current approach to workstation and input device design and training needs further study if a neutral wrist posture is desired. In general, wrist postures and motions were not predictable based on body size, elbow height, hand length, shoulder width, or wrist dimensions. Wrist angular velocities and accelerations were rapid during typing and F/E velocities were comparable to wrist motions of industrial workers in jobs with high-CTD risk. Wrist and forearm motions should be evaluated as possible risk factors for musculoskeletal disorders during typing.

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