

Wrist and Forearm Postures of Users of Conventional Computer Keyboards

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The aim of this study was to perform a comprehensive investigation to document wrist and forearm postures of users of conventional computer keyboards. We instrumented 90 healthy, experienced clerical workers with electromechanical goniometers to measure wrist and forearm position and range of motion for both upper extremities while typing. For an alphabetic typing task, the left wrist showed significantly greater ($p < .01$) mean ulnar deviation ($15.0^\circ \pm 7.7^\circ$) and extension ($21.2^\circ \pm 8.8^\circ$) than the right wrist ($10.1^\circ \pm 7.2^\circ$ and $17.0^\circ \pm 7.4^\circ$ for ulnar deviation and extension, respectively). Conversely, the right forearm had greater mean pronation ($65.6^\circ \pm 8.3^\circ$) than the left forearm ($62.2^\circ \pm 10.6^\circ$). We noted minimal functional differences in the postures of the wrists and forearms between alphabetic and alphanumeric typing tasks. Ergonomists should consider the statistically significant and probable practical difference in wrist and forearm posture between the left and right hand in ergonomic interventions in the office and in the design of computer keyboards. Actual or potential applications of this research include guiding the design of new computer keyboards.

INTRODUCTION

The computer keyboard is currently the primary input device for computers and telecommunication. The conventional QWERTY keyboard is a flat keyboard that has a two-dimensional matrix of alphanumeric keys. To rest fingers on the home keys, operators of a conventional keyboard have a tendency to hold their hands and forearms in a biomechanically awkward position. Both forearms are substantially pronated, and both wrists may be deviated in the ulnar direction. In addition, most computer keyboard users hold their wrists in some degree of extension in response to the typical upward slope of the keyboard.

To better understand the mechanical and physiological stresses applied at the wrists and forearms during typing, a thorough understanding of wrist and forearm posture and movement patterns during various typing tasks must be achieved. Prior literature provides some infor-

mation in that regard. The average position of the wrist in ulnar deviation during typing has been reported to be between 11° and 25° (Chen et al., 1994; Honan, Serina, Tal, & Rempel, 1995; Nakaseko, Grandjean, Hunting, & Gierer, 1985; Smith & Cronin, 1993; Sommerich & Marras, 1994; Sommerich, Marras, & Parnianpour, 1996); some authors have reported that the amount of ulnar deviation on the left wrist was a few degrees greater than on the right (Hedge & Powers, 1995; Honan, Jacobson, Tal, & Rempel, 1996). Similarly for wrist extension, the average position of the wrist has been reported as between 13° and 33° (Hedge & Powers, 1995; Honan et al., 1995; Honan et al., 1996; Sommerich & Marras, 1994). Limited data exist on forearm pronation, which was reported to range from 69° to 79° (Honan et al., 1995; Honan et al., 1996).

After an extensive review of the literature on conventional computer keyboards, we identified the following research limitations: (a) Generally,

only a small number of participants have been included in studies that measured physical metrics, such as wrist and forearm posture and range of movement; (b) various methods of measuring wrist motion (including visual observation, videos, and electrogoniometers) may have led to a wide range of values on wrist and forearm position; (c) there is an overall lack of information on pronation/supination of the forearm; (d) authors commonly have only reported mean wrist position, whereas the dynamic aspect of typing has been, for the most part, ignored; and (e) wrist and forearm position was often measured only over a short time (from a few video frames to 60 s).

The objective of this research was to perform a comprehensive analysis of the wrist and forearm postures of a large sample of experienced clerical workers during typing on a conventional computer keyboard. We hypothesized that differences in wrist position and range of movement would exist between the right and left hand. We also hypothesized that wrist and forearm postures when typing text consisting of mostly alphabetic characters would be different than postures assumed when typing alphabetic text that included a large number of numeric characters. We also hypothesized that a positive relationship would exist between the participants' anthropometric dimensions and the amount of ulnar deviation of their wrists while typing.

METHODS

Participants

The participants consisted of 90 professional touch typists (88 women and 2 men). The mean age of participants was 37.8 ± 9.3 years (ranging from 21 to 58 years). All participants had a minimum of 2 and as much as 45 years of experience as touch typists. They typed on a conventional computer keyboard for a minimum of 2 h per day as part of their regular work duties and were able to type at least 40 words/min. Based on medical history and a combination of sensory, strength, and provocative tests (Tinel's and Phalen's tests), we determined that none of the participants had current or prior signs or symptoms of upper extremity pain, including carpal tunnel syn-

drome. Of the 90 participants, 77 were right-handed. The participants were recruited from a variety of government offices, corporations, and businesses. After agreeing to participate, the participants made an appointment for a half day of testing in the laboratory, where they were asked to sign a human subject consent form approved by the University's Human Subjects Committee.

Demographic and physical characteristics.

The participants' height and weight were measured with a medical balance beam scale. Anthropometric measurements, including elbow-to-elbow width (defined as the distance between the olecranon processes with the elbows held gently against the trunk), biacromial width, and olecranon-to-wrist length, were made using a set of calipers. Descriptive data were collected for hand and pinch strength using a Jamar hand dynamometer (TEC, Clifton, NJ) and a pinch dynamometer. Range of motion of the wrists and forearms was measured using a mechanical goniometer.

Computer Keyboard

The conventional computer keyboard used in this study was a flat keyboard that had a positive slope angle of 5°. The spacing between adjacent keys was 1.905 cm.

Work Station

The participant was seated at a computer workstation that was adjusted so that his or her posture met the criteria for video display terminal (VDT) operators in the American National Standards Institute standard (ANSI-HFS 100-1988, Human Factors and Ergonomics Society, 1988). Chair height was set so that the participant had both feet on the floor (or on a footrest) with a knee angle slightly less than 90°. The table supporting the monitor was adjusted such that the center of the VDT screen was approximately at a 20° angle below a horizontal line passing through the participant's eye level. The shelf supporting the keyboard was adjusted such that the participant's elbow angle was approximately 90° and the forearm was horizontal.

Electrogoniometers

A set of wrist and forearm electrogoniometers was attached to both upper extremities.

The wrist electrogoniometers were used to measure wrist position in the radial/ulnar and flexion/extension planes. These electrogoniometers were designed to collect on-line data in both planes simultaneously and independent of each other (Marras & Schoenmarklin, 1993; Schoenmarklin & Marras, 1993; Figure 1). Pronation/supination angles of both forearms were recorded with specially designed electrogoniometers (Schoenmarklin & Marras, 1993; Figure 2).

Once the participant was fully instrumented, each electrogoniometer was calibrated following a standardized procedure. The two sets of wrist monitors were individually calibrated in a neutral wrist position. Each pronation/supination device was individually calibrated using several predetermined angles of pronation of the forearm. Immediately following data collection, posttesting calibration of the electrogoniometers was repeated in order to verify proper equipment function and consistency of calibration throughout the testing session.

Typing Tasks

Testing began after a 3-min practice session to familiarize the participant with the testing procedure. Three typing tasks of 8 min each were performed. The first two typing tasks (called alphabetic typing tasks) consisted of typing almost exclusively letter characters with few numeric and symbolic (special function keys) characters. The texts, which were displayed on the VDT, were selected at random from a list of eight possible standard texts. The participant typed a different text during each of the two 8-min typing periods. The third typing task (called the alphanumeric typing task) consisted of typing text that included a large number of numeric and symbolic keys. All alphabetic, numeric, and symbolic keys were typed from the main section of the keyboard (the numeric keypad was not used). A short text sample for each typing task is shown in the Appendix. A rest period of approximately 2 min was provided between each typing task.

WRIST MONITOR

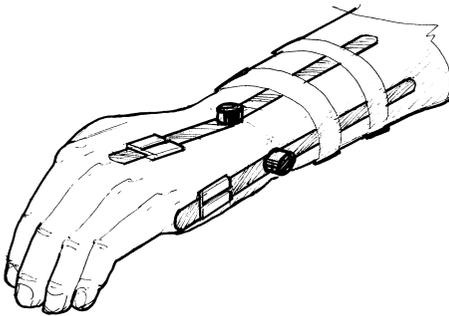


Figure 1. Illustration of the electrogoniometers used to measure wrist flexion/extension and wrist ulnar/radial deviation. The wrist monitors are composed of two segments of thin metal feeler stock joined by a rotary potentiometer. The wrist monitor is lightweight (approximately 0.05 kg) and small enough to be unobtrusive to the typist. The neutral position for wrist radial/ulnar deviation was defined as a line formed by the middle finger metacarpophalangeal joint, the lunate, and the dorsal bisection of the forearm. Neutral wrist flexion/extension position was defined as a line formed by the ulnar aspect of the little finger metacarpal, the ulnar styloid process, and the ulnar bisection of the forearm.

PRONATION/SUPINATION DEVICE

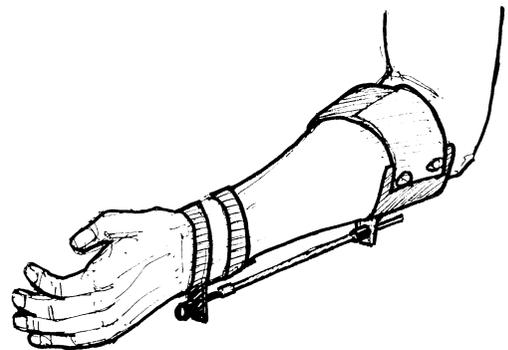


Figure 2. The pronation/supination device used to record the pronation/supination angle of both forearms. These electrogoniometers consist of a rod that remains parallel to the forearm during rotation. The rod is attached to a bracket affixed to the proximal end of the forearm with a velcro cuff. On the distal end of the forearm, the rod is connected to a potentiometer attached to a bracket. Neutral forearm pronation/supination position was defined as the hand in the vertical plane with the elbow at the side of the trunk.

Kinematic Data Collection

Wrist and forearm kinematic data were collected for 5 periods of 30 s during each of the three 8-min typing tasks. These 5 periods started at the following times: 1 min, 2.5 min, 4 min, 5.5 min, and 7 min after the start of the typing task. Testing did not interrupt the participant's typing, and the participant was not aware of the periods when kinematic data were collected. This data collection protocol generated data for a total of 5 min for the alphabetic task and 2.5 min for the alphanumeric task. Shorter samples of data collection (several files of 30 s as opposed to one file of 5-min) were preferred based on ease of file handling and data processing.

During the 30-s data collection trials, data from each of the electrogoniometers were collected at 300 Hz by a 12-bit analog-to-digital system and then stored on a personal computer. The position data were subsequently filtered by a 7-Hz, fourth-order, zero-phase-shift, low-pass Butterworth filter to remove noise and smooth the signal. Customized software was used to analyze all kinematic data, which included wrist radial/ulnar deviation, wrist flexion/extension, and forearm pronation/supination for both upper extremities. For each signal, the four variables of interest were mean angular position, minimum angular position, maximum angular position, and the variance of angular position.

The wrists' and forearms' mean angular position, maximum angular position, minimum angular position, and position variance were calculated for each of the 30-s sampling periods. For the alphabetic typing task, the values for the ten 30-s duration samples were averaged for each variable. For the alphanumeric typing task, the values for the five 30-s duration samples were averaged. The variance of the joint angular position (which is the square of the standard deviation about the mean joint angular position) was used as an index of the dynamic nature of typing. A smaller position variance value indicates that the joint is held in a relatively more static position while typing. A statistical procedure described in Glass and Hopkins (1984) was used to average the position variance for the 10 samples of data for the

alphabetic task and the five samples of data for the alphanumeric task.

Typing Performance Data

Typing performance data were collected using the commercially available Typing Tutor 6.0 program (Kriya Systems, Inc., Sterling, VA). The software generated performance data for typing speed in words/min (a word is defined as five typed characters including spaces between words) and accuracy percentage (accuracy is defined as the difference between the total number of characters typed and the total number of errors left in the document, divided by the total number of characters).

Statistical Analysis

Demographic, anthropometric, and typing performance data were analyzed with descriptive statistics. Analysis of the kinematic data included both descriptive and inferential statistics. A separate two-way analysis of variance (ANOVA) for repeated measures was performed on each dependent variable. The two independent variables for the two-way ANOVA were hand (two levels – right vs. left) and typing task (two levels – alphabetic vs. alphanumeric). For each ANOVA, main effects as well as interactions were tested statistically. Statistical significance was set a priori at $p < .01$. Post hoc analysis was performed on individual cell means by Tukey Honest Significant Difference Tests. Correlation analyses were used to investigate the level of association between selected measurements of anthropometry and wrist mean ulnar deviation.

RESULTS

Participants

Descriptive data for selected measurements of anthropometry, range of motion, and strength of the participants are presented in Tables 1 and 2.

Typing Performance

Average typing speed for all 90 participants was 61 ± 12 words/min and 45 ± 12 words/min for the alphabetic and alphanumeric typing tasks, respectively. Average typing accuracy was $99.6\% \pm 1.0\%$ for the alphabetic task

TABLE 1: Participant Characteristics (*n* = 90)

Variables	Mean ± SD	Range
Age (years)	37.8 ± 9.3	(21–58)
Years of experience	14.4 ± 8.8	(2–45)
Height (m)	1.64 ± 0.07	(1.47–1.93)
Weight (kg)	69.4 ± 16.7	(38.6–127.0)
Biacromial distance (cm)	38.4 ± 2.2	(33.5–45.2)
Elbow-to-elbow width (cm) ^a	42.4 ± 6.5	(30.6–57.2)
Elbow-to-wrist length (cm) ^b	25.8 ± 1.4	(22.6–30.5)

^aDistance between the olecranon processes with the elbows gently held against the trunk. ^bAverage of both upper extremities.

and 99.6% ± 1.0% for the alphanumeric task. The extremely high level of accuracy is attributable to the participants' high level of typing skill and their option (often an automatic response) to correct their errors while they were typing.

Kinematic Data: Radial/Ulnar Plane

The mean, minimum, maximum, and variance for the positions of both wrists in the radial/ulnar plane for the alphabetic and alphanumeric typing tasks are presented in Table 3. A significant main effect difference existed, $F(1, 89) = 41.57, p < .01$, between

the mean positions of the left and right wrists. On average the participants tended to place their left wrists in a mean position that was approximately 5° more ulnarly deviated than the position of their right wrists (15.9° and 10.5° of ulnar deviation for their left and right wrists, respectively). Similarly, a significant difference between the right and left wrists was found for minimum wrist position and position variance. The minimum wrist position was 5.9° of ulnar deviation on the left, compared with 2.1° on the right, $F(1, 89) = 16.63, p < .01$. The average wrist position

TABLE 2: Range of Motion and Strength of All Participants (*n* = 90)

Variables	Mean ± SD	Range
Right Side		
Wrist extension (°)	63 ± 9	(35–86)
Wrist flexion (°)	67 ± 8	(42–90)
Wrist radial deviation (°)	23 ± 6	(5–38)
Wrist ulnar deviation (°)	35 ± 6	(16–48)
Grip strength (kg)	28 ± 6	(14–42)
Palmar pinch (kg)	3.2 ± 0.8	(1.3–5.3)
Lateral pinch (kg)	6.6 ± 1.6	(2.0–10.0)
3-jaw chuck pinch (kg)	5.2 ± 1.4	(1.5–8.8)
Left Side		
Wrist extension (°)	64 ± 8	(40–86)
Wrist flexion (°)	65 ± 8	(42–86)
Wrist radial deviation (°)	25 ± 7	(14–50)
Wrist ulnar deviation (°)	36 ± 6	(20–52)
Grip strength (kg)	26 ± 6	(10–43)
Palmar pinch (kg)	2.7 ± 0.8	(1.3–4.8)
Lateral pinch (kg)	6.3 ± 1.4	(2.0–10.3)
3-jaw chuck pinch (kg)	4.8 ± 1.3	(2.3–8.3)

TABLE 3: Wrist Ulnar Deviation During a Typing Task ($n = 90$, Means \pm SDs in Degrees)

Variables	Typing Tasks		Hand Main Effect ^a
	Alphabetic	Alphanumeric	
Left			
Mean	15.0 \pm 7.7 ⁱ	16.8 \pm 8.0 ⁱ	15.9 ^b
Maximum	23.5 \pm 7.0 ^{j,k}	26.2 \pm 6.8 ^{j,k}	24.9
Minimum	5.3 \pm 9.0 ^{l,m}	6.5 \pm 9.5 ^{l,m}	5.9 ^c
Variance	14.1 \pm 7.5	19.2 \pm 10.9	16.7 ^d
Right			
Mean	10.1 \pm 7.2 ⁱ	10.8 \pm 7.2 ⁱ	10.5 ^b
Maximum	24.7 \pm 6.0 ^j	25.2 \pm 6.2 ^k	25.0
Minimum	2.3 \pm 7.6 ^l	1.9 \pm 7.9 ^m	2.1 ^c
Variance	20.5 \pm 9.3	23.8 \pm 15.6	22.2 ^d
Typing task main effect^e			
Mean	12.6 ^f	13.8 ^f	
Maximum	24.1 ^g	25.7 ^g	
Minimum	3.8	4.2	
Variance	17.3 ^h	21.5 ^h	

^aAverage for the left and right wrists when combining the two typing tasks. ^{b,c,d}Indicate a significant main effect between hands for mean joint position, minimum joint position, and joint position variance, respectively ($p < .01$). ^eAverage for the typing tasks when combining the two wrists. ^{f,g,h}Indicate a significant main effect between typing tasks for mean joint position, maximum joint position, and joint position variance, respectively ($p < .01$). ^{i,j,k,l,m}Indicate a significant difference between each pair of values labeled by these respective letters ($p < .01$).

variance was 16.7° on the left, compared with 22.2° on the right, $F(1, 89) = 19.65$, $p < .01$. No statistically significant difference was found between the left and right wrists for maximum ulnar deviations, which were 24.9° and 25.0°, respectively.

A comparison of wrist positions between typing tasks (alphabetic vs. alphanumeric) indicates a significant main effect difference for the mean positions of the wrists, the maximum ulnar deviation positions of the wrists, and the position variances of the wrists. During alphabetic task typing, the wrists had a mean ulnar deviation of 12.6°, compared with 13.8° during alphanumeric task typing, $F(1, 89) = 63.25$, $p < .01$. The maximum wrist ulnar deviations for the alphabetic and alphanumeric tasks were 24.1° and 25.7°, respectively, $F(1, 89) = 60.17$, $p < .01$. Finally, the wrist position variance around the mean during alphabetic task typing was 17.3°, compared with 21.5° during alphanumeric task typing, $F(1, 89) = 37.24$, $p < .01$.

A number of statistically significant Hand \times Typing Task interactions ($p < .01$) were found for three of the four dependent variables. For

mean wrist ulnar deviation, each of the four conditions (right-hand alphabetic task, right-hand alphanumeric task, left-hand alphabetic task, and left-hand alphanumeric task) was found to be significantly different from its respective counterparts, $F(1, 89) = 13.95$, $p < .01$. The significant interactions for maximum and minimum wrist ulnar deviation were identical, $F(1, 89) = 36.05$, $p < .01$, and $F(1, 89) = 22.87$, $p < .01$, respectively. For both of these dependent variables, the angle for the right hand in the alphabetic task was different from that for the left hand under both typing tasks, the angle for the right hand in the alphanumeric task was different from that for the left hand under both typing tasks, and the angle for the left hand in the alphabetic task was different from that for the left hand in the alphanumeric task. No statistically significant interactions existed for position variance.

Kinematic Data: Flexion/Extension Plane

The mean, minimum, maximum, and variance for the positions of both wrists in the flexion/extension plane for both typing tasks

TABLE 4: Wrist Extension During a Typing Task ($n = 90$, Means \pm SDs in Degrees)

Variables	Typing Tasks		Hand Main Effect ^a
	Alphabetic	Alphanumeric	
Left			
Mean	21.2 \pm 8.8 ^{i,k,m}	20.8 \pm 8.4 ^{j,l,m}	21.0 ^b
Maximum	26.1 \pm 8.8	26.6 \pm 8.6	26.4
Minimum	14.9 \pm 9.0	13.3 \pm 8.9	14.1 ^c
Variance	6.4 \pm 5.4	9.8 \pm 7.9	8.1 ^d
Right			
Mean	17.0 \pm 7.4 ^{ij}	17.4 \pm 7.6 ^{kl}	17.2 ^b
Maximum	25.2 \pm 7.9	26.2 \pm 8.3	25.7
Minimum	7.5 \pm 8.0	6.5 \pm 8.4	7.0 ^c
Variance	11.8 \pm 6.6	15.7 \pm 11.1	13.8 ^d
Typing task main effect^e			
Mean	19.1	19.1	
Maximum	25.7 ^f	26.4 ^f	
Minimum	11.2 ^g	9.9 ^g	
Variance	9.1 ^h	12.8 ^h	

^aAverage for the left and right wrists when combining the two typing tasks. ^{b,c,d}Indicate a significant main effect between hands for mean joint position, minimum joint position, and joint position variance, respectively ($p < .01$). ^eAverage for the typing tasks when combining the two wrists. ^{f,g,h}Indicate a significant main effect between typing tasks for maximum joint position, minimum joint position, and joint position variance, respectively ($p < .01$). ^{i,j,k,l,m}Indicate a significant difference between each pair of values labeled by these respective letters ($p < .01$).

are presented in Table 4. A significant main effect difference existed, $F(1, 89) = 23.24, p < .01$, between the mean wrist position of the left and right wrists. On average the participants tended to place their left wrists in a mean position that was approximately 4° more extended than the position of their right wrists (21.0° and 17.2° of extension for the left and right wrists, respectively). Similarly, a significant difference between the right and left wrists was found for minimum wrist position and wrist position variance. The average minimum wrist extension position was 14.1° on the left, compared with 7.0° on the right, $F(1, 89) = 60.51, p < .01$. The average wrist position variance around the mean was 8.1° on the left, compared with 13.8° on the right, $F(1, 89) = 55.17, p < .01$.

A comparison of wrist positions between typing tasks (alphabetic vs. alphanumeric) indicates a significant main effect difference for the maximum and minimum extension positions of the wrists and the position variances of the wrists. During alphabetic task typing, the wrist position reached a maximum angle

of 25.7°, compared with 26.4° during alphanumeric task typing, $F(1, 89) = 9.03, p < .01$. The minimum wrist extensions for the alphabetic and alphanumeric tasks were 11.2° and 9.9°, respectively, $F(1, 89) = 18.95, p < .01$. Finally, the variance around the mean for the wrist during alphabetic task typing was 9.1°, compared with 12.8° during alphanumeric task typing, $F(1, 89) = 39.81, p < .01$.

A significant Hand \times Typing Task interaction was found for wrist mean position only, $F(1, 89) = 7.13, p < .01$. The mean wrist angle for the right hand in the alphabetic task condition was different from the angles for the left hand in both typing tasks. Similarly, the mean wrist angle for the right hand in the alphanumeric task was different from the angles for the left hand in both typing tasks. The mean wrist angle for the left hand in the alphabetic task was different from the angle for the left hand in the alphanumeric task.

Kinematic Data: Pronation/Supination Plane

The mean, minimum, maximum, and variance for the pronation positions of both forearms for

TABLE 5: Forearm Pronation During a Typing Task (Participants for the Left Side, $n = 73$, and Participants for the Right Side, $n = 81$; Means \pm SDs in Degrees).

Variables	Typing Tasks		Hand Main Effect ^a
	Alphabetic	Alphanumeric	
Left			
Mean	62.2 \pm 10.6	62.3 \pm 10.1	62.3 ^b
Maximum	70.2 \pm 10.3	71.3 \pm 10.2	70.8
Minimum	54.6 \pm 11.7	53.3 \pm 11.4	54.0
Variance	11.9 \pm 9.2	17.5 \pm 14.8	14.7
Right			
Mean	65.6 \pm 8.3	66.3 \pm 8.4	66.0 ^b
Maximum	72.1 \pm 9.1	73.4 \pm 9.4	72.8
Minimum	57.0 \pm 10.7	56.8 \pm 11.3	56.9
Variance	15.1 \pm 16.5	12.9 \pm 18.0	14.0
Typing task main effect^c			
Mean	63.9	64.3	
Maximum	71.2 ^d	72.4 ^d	
Minimum	55.8	55.1	
Variance	13.5 ^e	15.2 ^e	

^aAverage for the left and right forearms when combining the two typing tasks. ^bIndicates a significant main effect between forearms for mean joint position ($p < .01$). ^cAverage for the typing tasks when combining the two forearms. ^{d,e}Indicate a significant main effect between typing tasks for maximum joint position and joint position variance, respectively ($p < .01$).

both typing tasks are presented in Table 5. Data from 17 participants for the left forearm and 9 participants for the right forearm were discarded because of a lack of consistency between pre- and posttesting calibration data on these participants. Therefore, the number of participants whose pronation/supination calibration data were consistent was 73 and 81 for the left and right forearms, respectively. The data lost in this manner were not problematic in this study because we had a large number of participants.

A significant main effect difference existed, $F(1, 68) = 12.28$, $p < .01$, between the mean positions of the left and right forearms. On average the participants tended to place their left forearms in a mean position that was approximately 3.7° less pronated than the position of their right forearms (62.3° and 66.0° of pronation for the left and right forearms, respectively). No statistically significant differences were found between forearms for the minimum position, maximum position, and position variance. The average maximum forearm pronation for all participants was about 72° . The average minimum pronation of the forearm was approximately 55° .

A comparison of forearm positions between typing tasks (alphabetic vs. alphanumeric) indicates a significant main effect difference for the maximum positions and the position variances of the forearms. During alphabetic task typing, the forearm position reached a maximum angle of 71.2° , compared with 72.4° during alphanumeric task typing, $F(1, 68) = 10.40$, $p < .01$. The variance around the mean for the forearm during alphabetic task typing was 13.5° , compared with 15.2° during alphanumeric task typing, $F(1, 68) = 12.27$, $p < .01$. No statistically significant Hand \times Typing Task interactions were found.

Anthropometry and Wrist Ulnar Deviation

The level of association between mean wrist ulnar deviation and shoulder width was low and not statistically significant ($r = .24$, $p = .06$). This association increased only slightly when mean wrist ulnar deviation was correlated with elbow width ($r = .29$, $p = .08$). When relating the measured mean wrist ulnar deviation to an anthropometrically predicted wrist ulnar deviation (calculated from the geometry of the width of the shoulders and the length of

the forearms), the level of association was $r = .22$ ($p = .05$). A similar geometric calculation using elbow width instead of shoulder width led to a correlation of $r = .23$ ($p = .06$).

DISCUSSION

This study, which included 90 experienced clerical workers, provides a unique and comprehensive data set that includes means, maximum and minimum joint positions, and position variances of both wrists and forearms during typing. Providing the range of joint position (minimum and maximum values) as well as the variability of postures about the mean (the position variance) provides quantitative evidence for the dynamic aspect of the typing task.

In our study the 90 participants typing on a conventional computer keyboard placed their right and left wrists at mean ulnar deviation angles of approximately 10° and 15° , respectively. Measurements of ulnar deviation from participants typing on conventional keyboards as reported in earlier studies ranged from 11° to 25° , with most reports in the 11° – 15° range (Chen et al., 1994; Smith & Cronin, 1993; Smutz, Serina, Bloom, & Rempel, 1994; Sommerich & Marras, 1994; Sommerich et al., 1996). The greater mean ulnar deviation of the left wrist (a 5° difference in our participants) generally agrees with the results of Hedge and Powers (1995), who found that participants ulnarly deviated their left wrists 2° more than their right wrists (15° – 13° ulnar deviation for left and right wrists, respectively) when they typed on conventional keyboards. Honan et al. (1996) also reported a 3° difference between the left (15°) and right (12°) wrists.

The participants in this study placed their right and left wrists at mean wrist extension angles of 17° and 21° , respectively. Previous literature reported a range of mean wrist extension from 13° to 33° , with most reports in the 20° – 25° range (Chen et al., 1994; Hedge & Powers, 1995; Honan et al., 1996; Smutz et al., 1994). In our study, the 4° difference between the left and right wrists is believed noteworthy and may be of significance in the etiology of wrist-related disorders associated

with computer keyboard use. Honan et al. (1995, 1996) previously reported the mean extension of the left wrist as approximately 10° more than that of the right. Although our results agree as to the left wrist having more extension than the right, the difference found in this study is less than half the magnitude reported by Honan et al.

Our recording of 62° and 66° of mean pronation for the left and right forearms, respectively, is slightly less than the 69° – 79° values reported by Honan et al. (1995, 1996). Our results indicated that the right forearm was pronated approximately 4° more than the left forearm. Given the range of motion of the forearm, this difference is unlikely to be of great clinical or functional significance. Interestingly, whereas it was the left wrist that showed greater ulnar deviation and extension when typing, it was the right forearm that was more pronated.

The reasons for the differences in wrist ulnar deviation and wrist extension between the two upper extremities are not fully understood. In theory, these differences in positioning could be explained kinesiotically. Typists are taught to keep their hands parallel to the surface of the keyboard, which requires a combination of wrist ulnar deviation and forearm pronation. One way to decrease forearm pronation is to slightly abduct the shoulders by moving the elbows away from the trunk. This abduction produces a greater angle between the forearm and the keyboard that needs to be compensated by an increase in the ulnar deviation of the wrist (Duncan & Ferguson, 1974). This theory would agree with our findings of lesser forearm pronation associated with greater wrist ulnar deviation on the left wrist compared with the right wrist. However, given that shoulder position and the geometric relationship between the keyboard surface and the hand were not measured in this study, we can only speculate on whether shoulder abduction caused the difference between the left and right wrist positions.

In addition to a difference in shoulder and elbow postures, it is also possible that the difference in kinematics between the right and left wrists is related to the distribution and frequency of use of alphabetic, numeric, or special

function keys. For example, greater use of the little finger on the left versus the right hand could favor reduced pronation and increased ulnar deviation on the left side.

According to physiological studies, the difference in wrist and forearm positions between the left and right upper extremities could have implications for the development of work-related musculoskeletal disorders. Wrist position has been shown to affect the pressure in the carpal tunnel (Weiss, Gordon, Bloon, So, & Rempel, 1995; Werner, Armstrong, Bir, & Aylard, 1997). Weiss et al. (1995) determined that the lowest carpal tunnel pressure of about 8 mm Hg was found when the wrist was deviated approximately 2° ulnarly and 2° in extension. In this same study, the carpal tunnel pressure increased to approximately 20 mm Hg and 50 mm Hg when the wrist was deviated 10° and 20° ulnarly, respectively. Based on the work reported by Dahlin and Lundborg (1990), pressures even as low as 20 mm Hg could substantially reduce axonal transport in the neuron, and a pressure of 30 mm Hg would result in marked detrimental morphological changes. Finally, the critical threshold for capillary integrity has been measured to be 30–40 mm Hg (Werner et al., 1997). Both ulnar deviation and extension of the wrist increase carpal tunnel pressure (Weiss et al., 1995; Werner et al., 1997). Therefore, less ulnar deviation and extension of the right wrist would result in lower carpal tunnel pressure and, theoretically, a lower incidence of carpal tunnel syndrome (Weiss et al., 1995; Werner et al., 1997).

A less deviated right wrist would also theoretically reduce normal and friction forces between the tendons crossing the wrist and the carpal bones and ligaments in the wrist. A reduction in these mechanical forces should theoretically decrease chronic tendon irritation, which is hypothesized to lead to tendinitis and tenosynovitis (Tichauer, 1978). Similarly, reduced pronation could be advantageous to the health of the operator by decreasing musculoskeletal stresses and reducing carpal tunnel pressure (Werner et al., 1997; Zipp, Haider, Halpern, & Rohmert, 1983). However, whether the small difference of only about 4° of forearm pronation would result in an appreciable difference in health outcomes is unknown.

The range of wrist position (the difference between the minimum and maximum values) demonstrates the extremes of postures that take place at the wrist during a typing task. Typists move their wrists through a range of approximately 20° of ulnar deviation while typing. This range of motion (from approximately 4° to 25° of ulnar deviation) covers nearly two-thirds of the available range of motion for ulnar deviation (36°, from Table 2). For extension, the range of motion on the left wrist is approximately 12° (from approximately 14° to 26° of extension), whereas the range of movement on the right wrist is 18° (from 7° to 25°). The range of motion in pronation is between 55° and 71°, a 16° range. These movements may need to be considered when trying to elucidate the pathomechanics possibly leading to work-related musculoskeletal disorders.

Although minimum and maximum joint positions are informative as to the extremes of motion required to perform a task, they are poor indicators of the continuous amount of motion that actually takes place. Position variance was used as an index of dynamic motion of the wrists and forearms while typing. A higher variance indicates that the joint deviates from its mean position with greater frequency. The variance data show that wrist ulnar deviation, wrist extension, and forearm pronation of the right upper extremity varied significantly and appreciably more than for the left side. The reason why the right wrist and forearm move more than the left wrist and forearm is not fully understood, especially considering that the left hand is used at a greater frequency (approximately 58% of letters typed in English text are typed with the left hand) than the right hand while typing (Dvorak, Merrick, Dealey, & Ford, 1936; Mayzner & Tresselt, 1965). Perhaps one major cause of the disparity in position variance is the location of frequently used keys such as the “Enter” key and the “Backspace” key, which are located on the right side of the keyboard, thereby requiring the right hand to deviate more than the left hand from the home row. Additional analysis, including an analysis of frequency and sequence of keys used, is needed to determine the exact cause or causes of the disparity in position variance between the right and left hands.

A number of statistically significant differences were found in wrist and forearm postures between participants for alphabetic and alphanumeric typing tasks. However, most of these differences (with the exception of the position variance for ulnar deviation) were less than 3° and are not likely of any clinical or functional significance. There were also a number of statistically significant two-way interactions for wrist ulnar deviation and wrist extension. Because in most cases the differences between groups were less than 2°, none of these interactions is believed to be of functional or clinical significance.

A positive but rather weak relationship was found between simple anthropometric measurements of shoulder width, elbow width, and forearm length with wrist ulnar deviation. The positive relationship indicates that the wider the person, the more ulnarly deviated the wrists are while typing. But the fact that this relationship was low (approximately, $r = .2$) demonstrates that typing style as well as position of the elbows probably have a more significant effect on wrist posture than the width of the person. For example, during testing we noted that a number of wider individuals would move their elbows anteriorly in order to rest them on their abdomen, effectively reducing the elbow-to-elbow distance and ulnar deviation of the wrists. This finding indicates a need for the individualization of alternative keyboard designs based on the particular typing position of each user and not based exclusively on his or her size.

CONCLUSION

In summary, there are statistically significant as well as potentially functionally significant differences between the posture of the right and left wrists and forearms when one is typing on a conventional computer keyboard. Compared with the right wrist, the left wrist was held in a more ulnarly deviated and extended position. Whereas the left wrist was held in a more deviated posture, the right wrist had a more dynamic function as evinced by its greater position variance. Typing an alphanumeric task compared with an alphabetic task led to greater dynamic function of the

wrist and forearm, but no practical difference in mean joint position existed between tasks. Surprisingly, a weak level of association was found between the amount of wrist ulnar deviation during typing and anthropometric dimensions of the participants.

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APPENDIX

Sample of Alphabetic Typing Task

The giant panda has a white round face, black eye patches, and black ears. It has a black collar, a white body, a short white tail, and black feet. Its thick fur, measuring two or more inches in places, keeps it warm in winter. The panda's black and white coat gives it color camouflage. In its shady forest homeland the panda is almost invisible to the hunter at a distance of thirty yards. Pandas are about five or six feet in length.

Sample of Alphanumeric Typing Task

15 assemblies are put on accelerated test without replacement. If the first 4 failures occurred at 16.5, 19.2, 20.8 and 37.3 hours find a 90% confidence interval. Test the null hypothesis that the failure rate is 0.004 failure per hour using the 0.01 level of significance. 7 welded pieces were subjected to specified frequencies and their ties to failure were 211, 350, 384, 510, 539, 620, and 715 thousand cycles.

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