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Does elevating and tilting the input device support surface affect typing force and postural exposures of the wrist?

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Abstract. *Objective*: Compare wrist kinematics and typing force during computer work across two workstations, one configured according to recommended guidelines with the keyboard support surface flat and near resting elbow height, the other according to users' actual setup and preference, with an elevated, and positively tilted support surface.
Participants: Twenty participants completed a standard computer task at the two workstation configurations.
Methods: A thin profile force plate, placed under the keyboard recorded keyboard reaction forces. Twin axis electro-goniometers (SG65 Biometrics Ltd, London, UK) affixed to the back of the right and left hand of each subject continuously measured wrist extension/flexion and ulnar/radial deviation.
Results: Typing force and wrist kinematics were similar between the two configurations with only 10^{th} percentile ulnar deviation for the right hand showing a borderline significant difference of 1° between the two configurations.
Conclusion: Elevating and tilting the input device support surface does not necessarily affect typing force and kinematics of the wrist. The combination of the input device support surface and user upper extremities form a complex kinematic system with several degrees of freedom. Wrist postures during computer use are a function of multiple factors other than simply keyboard tilt.

Keywords: Computer workstation, physical risk factors, musculoskeletal disorders

1. Introduction

According to the Bureau of Labour Statistics, nearly 77 million persons used a computer at work in 2003 (BLS, 2005) representing over 50% of all workers in the US. Several cross sectional studies have reported an association between computer use and musculoskeletal disorders of the upper extremities [1] while a longitudinal study found more than 50% of the participants reported being symptomatic within the first year of starting a new computer-using job [2]. Several other longitudinal studies have reported associations between computer use and musculoskeletal symptoms and complaints [1,3].

One of the factors of computer work which has been associated with increased risk of upper extremity musculoskeletal symptoms is workstation configuration [4]. In a cross sectional study, Sauter et al. [5] reported leg discomfort increased with low, soft seat pans and arm discomfort increased with increases in keyboard height above elbow level. Marcus et al. [6] conducted a prospective study following six hundred and thirty-two newly hired computer users. They reported an increase in risk of neck and shoulder symptoms and

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Table 1
Mean anthropometric measures

Measure	Mean (SD)
Age (years)	33.0 (11.0)
Height (cm)	168.5 (10.3)
Weight (kgs)	68.1 (13.5)
Shoulder Breadth (cm)	34.6 (2.5)
Right Arm Length (cm)	30.0 (2.8)
Right Forearm Length (cm)	24.6 (1.9)
Right Hand Length (cm)	17.6 (1.4)
Right Hand Width (cm)	7.8 (0.6)

disorders when working with the keyboard above elbow height. Wu and Yang [7], evaluated the effect of keyboard height and inclination on discomfort for wheelchair users. Their results indicated the optimum keyboard height was at or 5 cm below elbow-level with the keyboard inclination horizontal to the seat of the wheelchair. These studies support using a workstation where keyboard is flat and set at or below elbow height.

As part of a separate field based study within an office environment with systems furniture, we observed a large number of participants and others within the environment had their keyboard and mouse support surface adjusted above resting elbow level with a positive tilt. Many of these employees had taken on-line ergonomics training that promoted elbow height and flat keyboard configurations; however, their workstations were not configured following these recommendations. We noticed that by tilting the support surface while elevating it at the same time, users can keep the keyboard in line with the forearms and wrists and their shoulders relaxed. One benefit of this configuration is the positive tilt which provides better visual access to the keyboard. Even though many of the individuals were touch typist, computing often involves several non-traditional key activations such as chording keys like the control, escape and function keys. This configuration also elevated the support surface, increasing the space under the support surface for the legs.

In this study, our goal was to determine if specific differences in biomechanical exposures exist between the user defined configuration and the recommended flat keyboard and lower support surface configuration. We conducted a small repeated measures laboratory study with the observed workers. We measured typing force and wrist kinematics (joint posture, velocity and acceleration) as these biomechanical factors have been associated with injury [4,8–11]. Specifically, we tested two null hypotheses:

1) Typing force and wrist kinematics during computer work will not differ between a user configured workstation with an elevated and positively sloped support surface and a standardized workstation with a flat and lower support surface near elbow height. Testing this hypothesis will determine whether lowering the keyboard height and flattening the keyboard to best comply with recommended guidelines would affect these biomechanical exposures.
2) No correlation exists between user defined support surface height and tilt with typing force and wrist kinematics. Testing this hypothesis will determine how these specific workstation configuration parameters affect these biomechanical factors.

2. Methods

2.1. Participants

Eight men and twelve women (ranging in age from 23 to 66 (mean = 33.4, sd = 11.0) recruited from a single worksite agreed to participate in this study. All participants indicated they completed computer work for more than 4 hours per day. The mean anthropometric measures for the subjects were typical of the northern American population (Table 1). All participants read and gave signed consent before participating in the study. The Harvard School of Public Health Office of Human Research Administration approved all protocols and participant consent forms.

Once recruited, measurements of the user's current desk were taken. These measures included chair height, seat pan depth, keyboard height (defined as the height from the floor to the "J" key), keyboard distance (defined as the distance of the "J" key to the edge of the support surface), keyboard tilt, monitor height and monitor distance (defined as the distance of the screen to the edge of the support surface).

2.2. Experimental protocol

Participants completed a standardized task at a workstation under two configurations. The order in which the configurations were presented was counterbalanced across subjects. For one configuration, (USER), the workstation parameters listed above were adjusted to emulate the participants' actual workstation dimensions. For the other configuration, (STD), the same parameters were set up according to recommended guidelines (ANSI-HFES-100, Table 2).

Table 2
Mean (SD) anthropometric and workstations measures in ANSI and USER configurations

Measure	Standardized (STD) adjustment	USER	STD	p-value*
Chair Height (cm)	Set to match subject popliteal height	46.8 (3.5)	45.3 (2.9)	0.10
Arm Rest Height (cm)	Remove arm rests	68.6 (4.3)	NA	NA
Keyboard Height (cm)	"J" key set to elbow height (set to 5 cm) above elbow height for 16 subjects	76.3 (2.9)	69.1 (3.4)	$<$ **0.01**
Keyboard Distance (cm)	"J" key set to 12 cm from edge of desk+	13.6 (3.9)	12.0 (0.0)	0.08
Keyboard Tilt (°)	Set to 0° tilt	12.5 (5.2)	0.0 (0.0)	$<$ **0.01**
Monitor Height (cm)	Set to match subject eye height	117.9 (5.3)	116.9 (6.7)	0.62
Monitor Distance (cm)	Adjusted according to subject preference	48.8 (9.3)	46.7 (5.4)	0.24

*__Bold__ highlights p-values < 0.05.
+12 cm selected based on Marcus et al. 2002.

Due to the thickness of the support surface (3 cm), keyboard height in the standardized configuration was adjusted to 5 cm above elbow height (instead of at elbow height as recommended) for 16 participants in order to allow enough space for their thighs to fit under the support surface. We selected a thick support surface for the laboratory workstation as it was similar to the support surfaces used by most participants at their own workstation, which was part of systems furniture (ANSWER, Steelcase, Grand Rapids, USA).

The standardized task involved a combination of typing text, pointing and clicking on icons, selecting-dragging-and-dropping of icons, and comprehensive reading exercise. The task was designed to require relatively equal amounts of keyboard and mouse use as well as periods of not using the input devices (e.g. reading text from the screen). Completing the task took approximately 10 minutes.

2.3. Apparatus

A thin profile force plate under the keyboard recorded keyboard reaction forces. The force plate consisted of 3 uniaxial load cells secured to a thin, rigid plate measuring 480 mm wide, 180 mm deep and 6 mm thick. Data were digitally recorded continuously onto a personal computer at 200 Hz and then low pass filtered with a 20 Hz cutoff. The signals of all three force sensors were then converted to units of force and summed. The resulting signal was then processed for inertia artifacts and down sampled to 40 Hz. Further details are described in Asundi et al. [12].

Twin axis electro-goniometers (SG65 Biometrics Ltd, London, UK) affixed to the back of the right and left hand of each subject continuously measured extension/flexion and ulnar/radial deviation. The system had a resolution of $< 0.1°$ and an accuracy of $\pm$ 2° measured over a range of $\pm$ 90°. Postures were digitally recorded at 250 Hz to a datalogger (ME 6000, Mega Electronics, Finland), low pass filtered with a 10 Hz cutoff and down sampled to 40 Hz. Zero radial/ulnar deviation was defined when the third metacarpal, the capitate and the lateral epicondyle were aligned, while zero flexion/extension was defined when the lateral side of the 5th metacarpal, the ulnar styloid and the lateral epicondyle were aligned. Data were digital differentiated and double differentiated to obtain wrist joint velocities and accelerations, respectively. Due to instrumentation issues, wrist kinematics data was not collected for 3 subjects.

Computer interactions were monitored using a custom written program [13]. The program, written in LabView (National Instruments, Austin, TX, USA), recorded the start time and duration of each discrete key-strike and mousing activity (moving the mouse, clicking any of the buttons or scrolling the wheel). Force, wrist kinematics and computer interaction signals were synchronized by having the subject flex at the wrist and press down on the spacebar for 5 seconds, three times. This produced a recognizable pattern in each signal that could be matched up. The force datawere then parsed according to key-strikes (i.e. only data during periods of key-strikes were selected from the continuous signal). Wrist kinematics data were parsed according to computer episodes (periods of keyboard use, mouse use and short idles less than 30 seconds [12,14].

2.4. Data analysis

Statistical analyses were adjusted accordingly. All statistical analysis was done with JMP software (Version 7.0; SAS Institute, Cary, NC, USA). Summary measures were calculated from the parsed data. These included 50th and 90th percentile force values and 10th, 50th, 90th percentile and range of motion (95th–5th percentile) wrist postures values. Root mean square (RMS) of joint velocity and acceleration were also calculated.

Table 3
Mean (SD) wrist kinematics and typing force during computer work at each workstation

Wrist extension	Left wrist			Right wrist		
	USER	STD	p-value*	USER	STD	p-value*
10^{th} percentile (°)	20 (19)	22 (12)	0.47	24 (10)	24 (7)	0.90
50^{th} percentile (°)	35 (9)	35 (9)	0.86	37 (7)	36 (6)	0.50
90^{th} percentile (°)	43 (8)	42 (9)	0.71	45 (6)	45 (6)	0.74
Range of Motion (°)	27 (17)	24 (11)	0.11	26 (6)	26 (6)	0.34
RMS Velocity (°/s)	25 (8)	23 (7)	0.06	36 (12)	36 (10)	0.85
RMS Acceleration (°/s^2)	384 (122)	414 (146)	0.07	652 (222)	669 (242)	0.28
Wrist deviation$^+$	Left wrist			Right wrist		
	USER	STD	p-value*	USER	STD	p-value*
10^{th} percentile (°)	−3 (11)	−2 (12)	0.12	4 (10)	5 (10)	**0.05**
50^{th} percentile (°)	7 (11)	6 (11)	0.22	13 (10)	12 (10)	0.27
90^{th} percentile (°)	17 (10)	15 (8)	0.80	20 (10)	18 (10)	0.91
Range of Motion (°)	24 (10)	20 (9)	0.06	20 (4)	18 (3)	0.09
RMS Velocity (°/s)	16 (4)	16 (4)	0.43	19 (7)	20 (6)	0.34
RMS Acceleration (°/s^2)	243 (60)	251 (69)	0.13	329 (110)	323 (128)	0.46

Typing force	Both hands		
	USER	STD	p-value*
50^{th} percentile (N)	0.8 (0.3)	0.9 (0.4)	0.49
90^{th} percentile (N)	2.1 (0.4)	2.2 (0.5)	0.64

$^+$Negative values indicate radial deviation.
*p-value from ANOVA.
Bold highlights p-values < 0.05.

Repeated measures analysis of variance (ANOVA) was used to compare workstation dimensions and summary statistic means between USER and STD workstation configurations.

For measures collected in the USER workstation configuration, we evaluated the effects of keyboard tilt and keyboard height above resting elbow height on wrist kinematics and typing forces using linear regression.

3. Results

The participants had set their own adjustable support surface to an average height of 76.3 cm, which was, on average, 10.6 cm higher than their seated elbow height (Table 2). They also positively tilted the surface an average of 12.5° (distal side higher than the proximal side). Only 2 of the 20 had a flat support surface. Individuals had adjusted the height of their chairs to values close to the recommended height. In addition, all user configurations included arm rests, set to an average height of 68.6 cm (4.3 std.dev.).

Typing force, wrist kinematics were very similar between configurations with no statistically significant ($p > 0.05$) differences (Table 3). Differences in average median and peak typing forces between configurations were less than 0.03 N while differences in wrist postures were less than 2°. Differences in wrist joint velocity and accelerations between configurations were less than 8%. Borderline significant ($0.05 < p < 0.06$) differences were observed for right 10^{th} percentile ulnar deviation and left ulnar range of motion.

For measures collected in the USER workstation configuration, significant ($p < 0.05$) but weak ($R^2 < 0.3$) correlations were seen between the distance from keyboard to seated elbow height and left ulnar deviation 10^{th} percentile postures, range of motion and velocity (Fig. 1 and Table 4). No significant correlations ($p > 0.05$) were seen between keyboard tilt and wrist kinematics or typing force (Table 5).

4. Discussion

In this study we measured typing force and wrist kinematics of participants completing simulated work under two workstation configurations; the first matched their personal workstation (USER) where the keyboard and mouse support surface was adjusted above resting elbow level with a positive tilt while the second was configured with a flat support surface near elbow height (STD). Consistent with our first hypothesis, no significant changes in wrist kinematics or typing forces were seen between workstations. Consistent with our second hypothesis, keyboard tilt did not correlate with

Table 4
Correlations between keyboard height above elbow height and wrist kinematics and typing force

Wrist extension	Left wrist			Right wrist		
	Slope	R2	p-value*	Slope	R2	p-value*
10^{th} percentile (°)	−1.7	0.14	0.13	−0.5	0.06	0.35
50^{th} percentile (°)	−0.1	0.00	0.81	−0.4	0.07	0.30
90^{th} percentile (°)	0.0	0.00	0.93	−0.1	0.01	0.73
Range of Motion (°)	1.5	0.14	0.14	0.5	0.13	0.15
RMS Velocity (°/s)	0.7	0.15	0.12	1.1	0.16	0.11
RMS Acceleration (°/s^2)	11.1	0.11	0.20	14.5	0.07	0.32
Wrist deviation	**Left wrist**			**Right wrist**		
	Slope	R2	p-value*	Slope	R2	p-value*
10^{th} percentile (°)	−1.4	0.28	**0.03**	−0.4	0.03	0.51
50^{th} percentile (°)s	−0.5	0.03	0.49	−0.5	0.04	0.41
90^{th} percentile (°)	−0.1	0.00	0.85	−0.4	0.02	0.57
Range of Motion (°)	1.2	0.27	**0.03**	0.3	0.08	0.28
RMS Velocity (°/s)	0.5	0.25	**0.04**	0.4	0.07	0.30
RMS Acceleration (°/s^2)	6.6	0.17	0.10	5.1	0.03	0.51

Typing force	Both hands		
	Slope	R2	p-value*
50^{th} percentile (N)	0.0	0.02	0.56
90^{th} percentile (N)	0.0	0.03	0.44

*p-values from ANOVA.
Bold highlights values < 0.05.

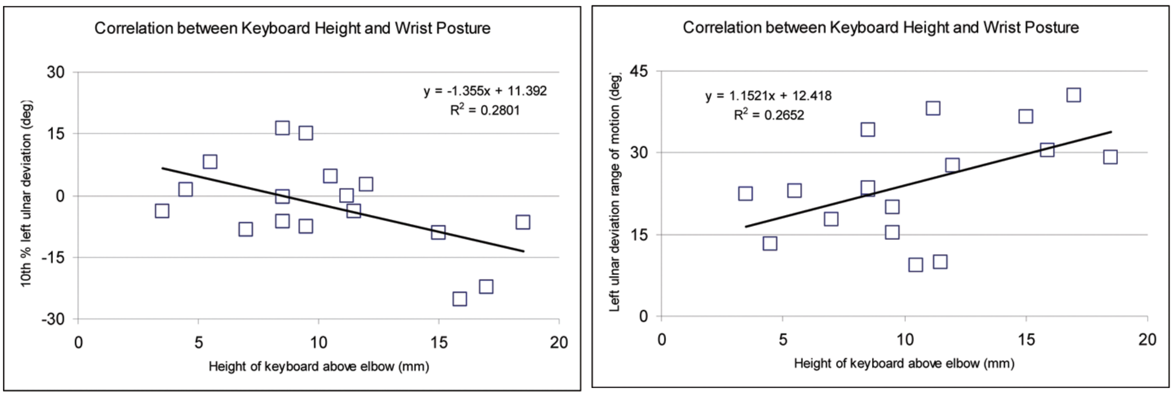

Fig. 1. Greater keyboard height above elbow height correlated with lower 10^{th} percentile left wrist ulnar deviations (left) and greater left ulnar deviation range of motion (right). The correlations were weak ($R^2 < 0.3$) but significant ($p < 0.05$).

wrist kinematics or typing forces. Keyboard height above resting elbow height did correlate, weakly, with a few measures of left ulnar deviation. These results indicate computer use at a workstation configured with an elevated and positively tilted support surface does not significantly alter wrist kinematics or typing forces compared to a workstation with a flat keyboard, near elbow height.

Our findings support statements within the current 2007 HFES-ANSI-100 standard [15] suggesting that keyboard tilt and height requirements interact. To accommodate the large range in size and working posture of computer users, adjustments in both parameters may be used to satisfy the recommendations for postures of the upper extremity and provisions of clearance space for workers legs.

A laboratory study by Simoneau and Marklin [16] also looked at the effects of keyboard height and tilt on wrist postures. They had participants type on a keyboard whose slope was adjusted to +15°, +7.5°, 0°, −7.5°, and −15°. The height of the keyboard was adjusted such that participants' wrists were at the same height as their elbows, 5 cm above their elbows, and 4 cm below their elbows. For all conditions, a wrist rest was provided. They reported a significant effect of both keyboard height and keyboard tilt with greater

Table 5
Correlations between keyboard tilt and wrist kinematics and typing force

Wrist extension	Left wrist			Right wrist		
	Slope	R2	p-value*	Slope	R2	p-value*
10^{th} percentile (°)	0.9	0.06	0.33	0.4	0.04	0.43
50^{th} percentile (°)	0.5	0.09	0.25	0.4	0.10	0.22
90^{th} percentile (°)	0.4	0.10	0.22	0.3	0.07	0.29
Range of Motion (°)	−0.5	0.02	0.56	−0.1	0.00	0.85
RMS Velocity (°/s)	−0.4	0.07	0.29	−0.6	0.07	0.29
RMS Acceleration (°/s^2)	−9.3	0.12	0.16	−12.9	0.09	0.25
Wrist Deviation	Left wrist			Right wrist		
	Slope	R2	p-value*	Slope	R2	p-value*
10^{th} percentile (°)	−0.1	0.00	0.85	0.3	0.03	0.43
50^{th} percentile (°	−0.4	0.04	0.42	0.6	0.08	0.22
90^{th} percentile (°)	−0.4	0.05	0.40	0.6	0.08	0.22
Range of Motion (°)	−0.6	0.11	0.20	0.2	0.05	0.39
RMS Velocity (°/s)	−0.1	0.03	0.53	−0.2	0.04	0.44
RMS Acceleration (°/s^2)	−3.5	0.08	0.28	−4.3	0.03	0.47

Typing force	Both hands		
	Slope	R2	p-value*
50^{th} percentile (N)	0.0	0.02	0.60
90^{th} percentile (N)	0.0	0.03	0.50

*p-values from ANOVA.

height and negative tilt leading to smaller wrist extension values. Comparable to our findings, subjects who typed on a positively sloped keyboard above elbow height had similar left wrist extension angels and lower right extension angles than subjects who typed on a flat keyboard at elbow height. A distinction between their study and ours is that our participants completed multiple computer tasks in addition to typing which included mouse use and passive interactions. The distribution of these interactions has been shown to affect wrist postures [13].

A limitation of this study was that keyboard height was set slightly above elbow level for several participants and therefore, wrist kinematics and typing forces measured for the standardized workstation configuration may not match with those measured at a workstation with the support surface at or below elbow level. The adjustment was necessary in order to allow clearance for the participants' thighs, stemming from the fact that the support surface was not a thin keyboard tray, but a substantial part of the work surface with a thickness of 3 cm. This support surface was similar to the support surfaces used by the participants at their own workstation. Even with the adjustment, however, keyboard height in the USER configuration was significantly higher than keyboard height in theSTD configuration.

A second limitation was the short duration of the simulated computer task. During longer sessions users may alter their posture which may be constrained by the configuration they are working in. An additional limitation is the small sample size. A larger sample size may allow us to identify significant correlations between workstation configurations and postures, particularly those that are borderline significant. Finally, this study only evaluated wrist kinematics and typing forces. Workstation configuration has a significant impact on all upper extremity postures as well as muscle activity [17–19] and these must be evaluated before recommending an alternative to the standardized configuration. Similarly, we did not measure any symptomatic outcomes and hence cannot comment on the specific associations with comfort and pain.

In conclusion, this pilot studyidentified an alternative workstation configuration which leads to similar wrist kinematics and typing forces observed in users working at the standardized configured workstation. The alternative workstation allows greater space under the keyboard support surface for leg clearance as well as improved visual access to the keyboard. Further studies should be conducted to evaluate the effects of this alternative configuration on muscle loads and additional upper extremity postures, particularly the shoulder.

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