Investigating effect of keyboard distance on the posture and 3D moments of wrist and elbow joints using OpenSim

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Abstract

Background

Musculoskeletal disorders (MSDs) of the upper extremities and computer use are common in modern societies, and both show a growing trend. This study was conducted to determine the posture and 3D moments of wrist and elbow joints at different keyboard distances on a desk.

Methods

Twelve healthy right-handed male volunteers attended the motion analysis laboratory. A keyboard was placed at three different distances from the participants' bodies while performing a standard computer task. The workstation was adjusted according to ANSI/HFES-100-2007 standard for each participant to maintain comfortable ergonomic posture for controlling confounding variables. Qualisys motion capture system, OpenSim software (Ver. 4.1), and visual analog scale (VAS) were used to collect and analyze the data. Also, SPSS (Ver.16) was used to descriptive, Friedman and Wilcoxon tests.

Results

The highest levels of wrist flexion and radial deviation as well as elbow flexion and pronation were observed when the keyboard was at the edge of the desk. When the keyboard was 8 cm away from the edge of the desk, the wrist flexion, deviation, and pronation had the least values. With increasing the distance of the keyboard from the edge of the desk, the range of motion (ROM) of the wrist flexion and deviation as well as elbow flexion, supination and pronation decreased. The joint moments were not significantly different for the different studied keyboard positions ($P\text{-value} > 0.05$).

Conclusions

However, a cut-off point has to be specified because large keyboard distances cause high extension and flexion of the limbs. The position of the keyboard relative to the body is an important parameter in computer work and has a significant impact on the posture of the upper extremities. A keyboard should be located at a distance that allows the upper extremities to remain in a neutral position so that the risk of MSDs is reduced.

Background

Musculoskeletal disorders (MSDs) of the upper extremities and computer use are common in modern societies, and both show a growing trend. Many studies have discussed a possible relationship between computer work and musculoskeletal problems in the upper extremities (1–3). Workstation factors that may increase the risk of upper extremity symptoms and disorders include lack of armrests and

inappropriate keyboard location (4, 5). These problems usually occur when operators have poor postures and have to work in this situation for a long time (6).

Existing guidelines for computer workstation designs are based on anthropometric measurements, while biomechanics and computer user behavior patterns are also important variables in developing musculoskeletal disorders (7). Evidence suggests that workstation parameters are associated with the development of MSDs (8, 9).

Marcus et al. showed the association of various workstation and postural factors with musculoskeletal symptoms in a large longitudinal epidemiological study. Most recommendations highlight modification of the body posture as the mainstay of risk reduction in computer users (10). Sauter et al., for example, reported that arm discomfort increased with keyboard height above elbow level (11).

Risk factors linked to computer use include physical ergonomic factors such as desk, chair, monitor height, and postures, as well as the use of input devices such as computer keyboard and mouse (12). Upper extremity musculoskeletal disorders (UEMSDs) are associated with the use of keyboard and visual display unit (VDU) (13). According to statistics, a significant contribution of all workplace injuries in the United States and Europe are related to MSDs (14). The prevalence of these disorders among Iranian office workers is 56.6% in the neck, 38.2% in the shoulder, 15% in the elbow, and 46.7% in the wrist (15). The prevalence of these disorders and the costs imposed on Iranian society have also been extremely high.

Computer workstation design is the main goal in ergonomics for preventing or minimizing work-related MSDs (16). An essential factor in workstations that increases the risk of shoulder and hand disorders is the placement of the keyboard and the lack of forearm support (10, 17). The keyboard location and its distance from the edge of the desk affect the posture and moments of hands, wrists, elbows, and arms (18). Repetitive movements and awkward postures in the computer keyboard typing are computer-related MSDs risk factors (19). The wrist flexion-extension and ulnar-radial deviation, as well as elbow rotation (supination-pronation), are important factors in causing MSDs. Higher values of these variables increase the risk of MSDs. Additionally, high values of joint moment are directly related to MSDs and affect the incidence of these disorders. If these parameters are not considered in the design and placement of keyboards, the risk of upper extremity injuries increases (11).

However, very few studies have been done on the effect of the horizontal distance of keyboard in the design of computer workstations. There are limited findings on the impact of these parameters and their relationship with MSDs in the upper extremities (20). Many studies have been conducted on variables such as slope, shape, and palm rest of the keyboard, and few studies indirectly have measured posture and muscle forces to recognize the effect of the horizontal distance of the keyboard from the edge of the desk on the posture and muscle forces (12, 20, 21).

Studying and controlling MSDs through software methods developed in neuromuscular biomechanics can significantly reduce the costs compared to treatment and rehabilitation approaches (22). Many

studies have used computers and input devices, such as keyboard and keyboard tray, while the use of keyboard tray is not yet common in Iran. Therefore, using modern biomechanical evaluation methods, this study aims to determine the effect of keyboard distance on the posture and 3D moments of wrist and elbow joints. It is believed that the findings can be used in product design and the development of standards for computer use.

Methods

Methods

An experimental study was conducted on twelve randomly selected healthy males aged from 25 to 30 years with no history of any MSDs. To prevent the probable dominant hand confounding effect, all participants were selected among right-handed individuals. Individuals who entered the study were familiar with computer use, and their mean (SD) of typing speed was 45.37 (11.67) words per minute (ranged from 25 to 87 words per minute). All participants signed informed consent before participating in the study. The inclusion criteria were: having a height of 165–185 cm, working with computer for 3–4 hours a day, and being right-handed. Exclusion criteria included the history of any MSDs in any body region.

This study used Qualisys motion capture system, OpenSim software (version 4.1), and VAS to collect and analyze data.

1. Qualisys motion capture system

Qualisys motion analysis system was calibrated and used with eight high-speed cameras at a frequency of 120 Hz. The magnitude error of the motion analysis system for each camera was less than 1 millimeter. The data obtained in this section was first defined based on anatomical points (labeling) and was stored in C3D format and then converted into TRC format using Mokka software (version 0.6) to be compatible with the OpenSim software for further biomechanical analysis.

2. OpenSim

OpenSim software calculated the joint kinematics and kinetics using inverse kinematics and inverse dynamics. Wrist flexion-extension, ulnar-radial deviation, elbow flexion-extension, and supination-pronation movements of both hands were evaluated using OpenSim. After entering the motion analysis data into OpenSim and using the Rajagopal model to perform scaling, the angles of the joints and their range of motion (ROM) were calculated. In this section, the wrist and elbow joints were selected to calculate their angles and moments separately.

Parameters such as minimum, maximum, mean, standard deviation (SD), and ROM of the kinematic and kinetic variables were also calculated. Before the test, the markers were placed on the participant's body and they were asked to maintain a standard anatomical posture with the torso straight, the arms in vertical position, and the forearms in horizontal position (90-degree elbow angle). The information

obtained from the position of the markers was used as static test to scale the model. Scaling the model was completed with an error of less than 2 cm. Inverse kinematic and dynamic calculation methods were used to determine ROM and 3D joint moments.

3. Visual analog scale

Participants completed a subjective discomfort assessment for each limb before and immediately after completing the task. This was done by placing a tick mark on a 10 cm continuous visual analog scale (23).

Experimental conditions

A QWERTY keyboard was randomly placed at three horizontal distances between the monitor and the user on the desk surface. These distances were set up as: the edge of the desk (T1), 8 cm away (T2), and 15 cm away (T3) from the edge of the desk. The conditions of the study were the same for all participants. The participants' age and anthropometric variables, including weight, body mass index, elbow, hip, knee, popliteal, eye height, and arm length, were recorded, and workstation dimensions were adjusted according to ANSI/HFES-100-2007 standard for each participant (24). A 17-inch flat monitor was positioned at eye height and arm length of the participants. The chair and the desk height were adjusted to knee height and elbow height of individuals, and the keyboard was aligned to the center of their bodies. The mouse was always located on the right side of the keyboard. Environmental conditions were the same in all trials for all participants, and a standard office chair was used.

Figure 2 demonstrates the experimental setup in which participants had to complete writing and reading comprehension for about 10 minutes (2 intervals of 5 minutes). A specific text was provided to the participants to type; the font size and document zoom level in Microsoft word were adjusted, respectively, to 14 and 120%, in all trials. After completing each trial, the participant rested for 5 minutes.

Reflective markers were placed, according to the standard protocol described in (25), on the participants' 7th cervical vertebrae, acromion process, arm, forearm, anterior superior iliac spine, posterior superior iliac spine, sternum, the base of metacarpal 1, 2, and 5, hand, medial-lateral elbow joints, and medial-lateral styloid processes of the wrist on both the right and left sides. Figure 3 shows markers placement for the motion capture system.

Data analysis

The statistics of mean and standard deviation were used to describe the quantitative variables. The normal distribution of the variables was determined by Kolmogorov–Smirnov test. Friedman test was used for comparing the differences between ROM, mean values of the moments, and subjective scores of VAS at the three keyboard distances. Wilcoxon test was used for two-by-two comparisons at different distances. SPSS (version 16) was used for statistical analysis, and all analyses were performed at a significance level of 0.05.

Results

The mean Participants' age, weight, and height were 27 (2.8) years, 73 (5.6) kg, and 178 (3.9) cm, respectively.

The local coordinate system of joints was defined in the OpenSim software so that the flexion, radial deviation, and pronation were positive, and extension, ulnar deviation, and supination were negative. Table 1 shows the mean ROM of flexion-extension and deviation of the right and left wrists.

Table 1
Mean ROM $\pm$ SD value of flexion-extension and deviation of the wrists in three distances of the keyboard (°)

Variable		Keyboard distances			P-value*
		T1	T2	T3	
Right Wrist	Flexion-Extension (°)	24.51 $\pm$ 18.51	2.96 $\pm$ 1.03	14.86 $\pm$ 9.15	0.012
	Ulnar-radial deviation (°)	18.61 $\pm$ 14.74	1.46 $\pm$ 0.74	11.32 $\pm$ 9.74	0.041
Left Wrist	Flexion-Extension (°)	22.61 $\pm$ 17.74	1.12 $\pm$ 0.12	17.55 $\pm$ 11.04	0.026
	Ulnar-radial deviation (°)	18.57 $\pm$ 13.23	1.13 $\pm$ 0.01	19.14 $\pm$ 16.02	0.035
* Friedman test. Bolded values indicate statistically significant results.					

T1: Trial 1, T2: Trial 2 and T3: Trial 3

The Friedman test showed that the ROM of flexion-extension and ulnar-radial deviation in both wrists differed significantly at the three different keyboard distances (P-value < 0.05). Two-by-two comparisons of the right wrist showed significant difference at all three distances.

In contrast, for the left wrist, only a difference was observed between T1 or T3 and T2 (P-value < 0.05), and no significant difference was seen between T1 and T3 distances (P-value > 0.05). Table 2 shows the mean ROM measured for the left and the right elbows at different keyboard distances. Flexion-extension, supination, and pronation of the elbows are presented in this Table.

Table 2
Mean ROM $\pm$ SD values of the elbows flexion-extension and pronation-supination in three distances of the keyboard (°)

Variable		Keyboard distances			P-value*
		T1	T2	T3	
Right Elbow	Flexion-Extension (°)	26.00 $\pm$ 18.49	0.99 $\pm$ 0.01	17.42 $\pm$ 11.29	0.001
	Pronation-Supination (°)	13.00 $\pm$ 8.87	2.40 $\pm$ 0.94	8.84 $\pm$ 6.02	0.043
Left Elbow	Flexion-Extension (°)	10.31 $\pm$ 7.79	1.15 $\pm$ 0.18	6.85 $\pm$ 2.93	0.039
	Pronation-Supination (°)	11.06 $\pm$ 5.92	3.01 $\pm$ 0.82	8.30 $\pm$ 3.01	0.063
* Friedman test. Bolded values indicate statistically significant results.					

T1: Trial 1, T2: Trial 2 and T3: Trial 3

The Friedman test results showed a significant difference between the elbow flexion and extension at different keyboard distances. Moreover, the ROM of supination and pronation of the right elbow at three different keyboard distances showed statistically significant differences (P-value < 0.05). There were no significant differences between the left elbow supination and pronation at three keyboard distances (P-value = 0.063).

Wilcoxon test for two-by-two comparison in both elbow flexion and extension showed a significant difference at the T1, T2, and T3 positions. However, in the supination and pronation movements of the right and left elbows, a significant difference was observed only between T1 or T3 and T2 (P-value < 0.05), and no significant difference was seen between T1 and T3 (P-value > 0.05).

Figure 4 shows the comparison of mean values of the moments of left and right wrist flexion-extension. The results of these variables are presented separately for different keyboard distances. The calculated moments were normalized based on the participant's weight. The Friedman test was used to differentiate distances shown in each figure by comparing different keyboard distances. The mean values of wrist flexion and extension moments were different at the three keyboard distances, but the difference between these values was not statistically significant (P-value > 0.05).

Figure 5 shows the mean values of the wrist ulnar-radial deviation moments at the three keyboard distances, T1, T2, and T3, respectively. As can be seen, at distances T2 and T3, the values for the right and left hands are equal (0.01 and 0.03 N.m/kg, respectively). Based on the results, the difference among the three distances is not statistically significant (P-value > 0.05).

Figure 6 shows the mean values of elbow flexion and extension moments at three keyboard distances (N.m/kg). The mean values of elbow flexion and extension are presented separately for different

keyboard distances. Despite the difference in the mean values of elbow flexion and extension at three keyboard distances, no significant difference was observed between these values (P-value > 0.05).

Figure 7 shows the mean values of elbow supination-pronation moments at the three distances of keyboard. The mean values for the right and left hands are presented separately for different keyboard distances based on the results. The statistical test did not show significant differences among the three keyboard distances (P-value > 0.05).

Table 3 shows the results of the participants' subjective assessment of discomfort at different keyboard distances after 10 minutes of predefined computer tasks. According to these results, the highest discomfort was reported when the keyboard was at distance T1.

Table 3				
Mean (SD) scores of subjective discomfort assessment (n = 12)				
Region	T1	T2	T3	P-value*
Right Wrist	3.12 (0.23)	2.01 (0.41)	1.27 (0.15)	0.012
Left Wrist	2.96 (0.8)	1.88 (0.3)	1.49 (0.2)	0.037
Right Elbow	2.78 (0.12)	2.16 (0.41)	1.93 (0.33)	0.962
Left Elbow	1.76 (0.04)	1.48 (0.08)	1.23 (0.13)	0.124
* Friedman test. Bolded values indicate statistically significant results.				

Zero meant no discomfort, and 10 represented the highest discomfort.

As shown in Table 3, the mean discomfort scores at the three keyboard distances are significantly different for wrists but not for elbows.

Discussion

The aim of the present study is to investigate the effects of different keyboard positions on the posture and 3D moments of wrist and elbow joints. Accordingly, the participants were asked to perform standard predefined computer tasks in three keyboard positions. The results showed that the keyboard distance affected the posture and the upper extremity joint moments.

The highest wrist flexion and radial deviation occurred at T1, and with increasing the distance of the keyboard from the body, these values decreased, and the lowest flexion and radial deviation occurred at T2. In this study, wrist flexion decreased by increasing the keyboard distance to 8 cm (T2). This is similar to the results of the study carried out by Kotani et al., in which by increasing the distance, the wrist flexion decreased (17).

In our study, the radial deviation decreased by increasing the distance of the keyboard from the body, as reported by Cook et al. (12). It can be concluded that at T2, the risk of MSDs in wrists and elbows is lower than at the other two distances.

By increasing the keyboard distance from T1 to T2, the ROM of left wrist flexion decreased (P-value < 0.05). In general, the ROM of left wrist flexion decreased as the distance increased (from T1 to T2 and T3), similar to the results of Kotani et al.

When the position of keyboard changed from T1 to T2, the ROM of the left wrist radial deviation decreased significantly (P-value < 0.05), similar to the results of Kotani et al. However, at distance T3, this value slightly increased compared to distance T1 (P-value > 0.05), which was not in agreement with the results of Kotani et al. (17).

By increasing the distance to T2, the left wrist radial deviation decreased significantly (P-value < 0.05). This was consistent with the results of previous studies (12, 17). However, at T3, the radial deviation increased. This part of our results was not in the same line with those of Ketone et al. (17). The study by Lindberg and Qing showed that wrist flexion and extension, even in a short time, can lead to wrist MSDs in prolonged working time (26, 27). As the keyboard distance increased, the ROM decreased, and the lowest value occurred at T2. At the other two distances, the ROM increased.

According to the study carried out by Waersted et al., elbow extension and flexion could contribute to elbow MSDs (3). In the left elbow, the ROM of flexion-extension showed a significant difference at the three keyboard distances (P-value < 0.05). Supination and pronation decreased by increasing the distance of the keyboard from T1 to T2 and from T3 to T2. Still, no significant difference was observed (P-value > 0.05), which was similar to the results of the studies by Marcus et al., Kotani et al., and Cook et al. (10, 12, 17). This can be explained by the fact that all participants were right-handed, and the left arm was passive (28).

There are differences in the wrist and elbow kinematics at the three distances as shown in Tables 1 and 2. These differences might be due to the fact that when the keyboard was moved away from the edge of the desk, the subjects placed their distal forearms on the desk to support their upper arms and shoulders, so wrist flexion, radial deviation, and pronation decreased.

When the keyboard was moved further away, the proximal forearms and the elbows were placed on the desk to support the upper arms and shoulders, so wrist extension, ulnar deviation, and supination increased (12).

The subjective assessment of discomfort showed that when the keyboard was placed on the edge of the desk, the wrists were mostly discomfort, which seemed to be due to excessive flexion of the wrists at this distance. The results of this assessment are similar to those of Marcus et al. (10).

The changes were more significant in kinematic than in kinetic variables. Therefore, the wrist and elbow moments did not show a statistically significant difference at the three distances of keyboard. This is

because the active muscles are fixed (static activity) during computer tasks. In other words, by changing the horizontal distance of the keyboard from the edge of the desk, the working muscles have static activity at the beginning and end of the task cycle.

The changes in the angles of the joints, no matter how small, affect the muscles. For more changes in the angles of the joints, and for a longer duration of joint involvement, the muscles are more involved, and the risk of injuries increases. This is because no muscles were deactivated but they acted as constant mover or stabilizer. The results of this part are similar to those of the study by Kotani et al. (17).

In this study, the Opensim software was used to evaluate the joints moments in three dimensions (3D) for making it possible to calculate the moments around the coordinate axes x, y, and z. This study had some limitations, such as testing only right-handed male participants in the age range of 25–30 years, and not considering other workstation elements, e.g., monitor, desk, and chair. Moreover, due to the short duration of the tests, the results may differ in studies with more extended test duration. These limitations should be considered in future studies.

Conclusions

According to the results of this study, changes in the horizontal distance of the keyboard can affect the upper extremity kinematics and moments. This may cause MSDs in the upper extremities in the long term. The keyboard distance has a significant impact on the posture of the upper limbs. However, when the joints are close to their neutral position, the risk of MSDs decreases. In general, when the keyboard is placed on the edge of the desk, it is expected that the flexion, radial deviation, and pronation are at high levels, as the most likely cause of the disorders. By increasing the keyboard distance to 8 cm from the edge of the desk, the values of these variables decrease significantly. However, increasing the distance to 15 cm, slightly increases these values. Accordingly, appropriate postures of wrists and elbows can be maintained when the keyboard is at a distance of 8 cm from the edge of the desk. This reduces the risk of MSDs in the upper extremities. Therefore, based on the results of this study, the keyboard distance should be neither on the edge of the desk nor at a large distance from the individual's body. Further studies on various other distances and on female subjects can provide more detailed information in this area.

Abbreviations

MSDs: Musculoskeletal Disorders; VAS: Visual Analogue Scale; ROM: Range of Motion; UEMSDs: Upper Extremity Musculoskeletal Disorders; VDU: Video Display Unit.

Declarations

Ethics approval and consent to participate

This study was performed according to the Helsinki declaration. Ethics approval and consent to participate has been approved by the ethics committee of Shiraz University of Medical Sciences and all

participants provided written informed consent.

Consent for publication

Consent for publication was obtained from all participants.

Availability of data and materials

The datasets analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

MG designed, data collection and analyzed, and was a major contributor in writing the manuscript. AC and MA designed and was a major contributor in writing the manuscript. AD performed the data analyze and was a major contributor in writing the manuscript. MK designed, data analyzed and was a major contributor in writing the manuscript.

All authors read and approved the final manuscript.

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Figures

Figure 1

The three distances of the keyboard. T1: keyboard positioned at the edge of the desk, T2: 8 cm away from the edge of the desk and T3: keyboard positioned at 15 cm away from the edge of the desk.

Figure 2

Experimental setup in the motion capture laboratory

Figure 3
 Placement of markers for optical motion capture system. A: Anterior, B: Posterior and C: Lateral view

Figure 4
 Mean values of flexion-extension of the wrists moments in three distances of the keyboard (N.m/kg)

Figure 5

Mean values of ulnar-radial deviation of the wrists moments in three distances of the keyboard (N.m/kg)

Figure 6

Mean values of flexion-extension of the elbows moments in three distances of the keyboard (N.m/kg)

Figure 7

Mean values of supination-pronation of the elbows moments in three distances of the keyboard (N.m/kg)