ORIGINAL ARTICLE

Effect of *Tilt*-adjustable *Mouse Pad* on the Forearm Muscle Activity and Upper Limb Discomfort During a Computer Mouse *Task*

Hamid Salmani Nodooshan[1], MSc; Hadi Daneshmandi[2], PhD; Alireza Choobineh[2], PhD; Farzaneh Yazdani[3], PhD; Mohsen Razeghi[3], PhD; Taymaz Shahnazar Nezhad Khales[4], MSc

[1]Department of Ergonomics, School of Health, Shiraz University of Medical Sciences, Shiraz, Iran
[2]Research Center for Health Sciences, Institute of Health, Shiraz University of Medical Sciences, Shiraz, Iran
[3]Department of Physiotherapy, School of Rehabilitation Sciences, Shiraz University of Medical Sciences, Shiraz, Iran
[4]Institute of Mechanics, College of Technology and Engineering of Shiraz, Shiraz, Iran

Correspondence:
Alireza Choobineh, PhD;
Research Center for Health Sciences, Institute of Health, Shiraz University of Medical Sciences, Shiraz, Iran
Tel: +98 9171184450
Fax: +98 71 37250053
Email: alrchoobin@sums.ac.ir
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Abstract

Background: Musculoskeletal disorders in the upper extremities are common among computer users. This study aimed to assess the effect of mouse pad angle on the forearm muscles activity and upper limb discomfort.

Methods: This is an experimental research design. The mouse pad was set at 0, 10, 20, and 30 degrees of forearm supination. Ten subjects performed an identical text editing task with mouse in each pad position. Electrical activity of the selected forearm muscles was recorded with surface electrodes. 10-point rating scales were used for assessing perceived discomfort.

Results: Extensor Carpi Radialis had the lowest mean of Electromyography (EMG) values in the 0° slanted pad (5.94), and the highest values were associated with Pronator Quadratus in 0-degree slanted pad (22.29). The highest and the lowest mean (SD) of the users' upper limb discomfort were 3.70 (1.63) and 1.90 (1.28) in 30° and 10° slanted pads, respectively.

Conclusion: Using slanted mouse pads could be a helpful and practical tool for office workers to keep more neutral wrist/hand positions.

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Introduction

Using computer, as an integral part of modern society, is constantly rising.[1-7] Using mice, as the most common non-keyboard input devices in office works,[2, 5, 8, 9] constitutes 62% of the time working with a computer.[10-12] Previous studies have frequently reported a significant relationship between prolonged use of computer mouse and Musculoskeletal Disorders (MSDs).[13-16]

Office workers with intensive mouse use usually experience more severe hand/wrist symptoms compared to those working without a computer mouse.[17] Specifically, Carpal Tunnel Syndrome (CTS) or median nerve compression is a common condition among office works with prolonged use of the mouse. For example, in a cohort study, Anderson et al.[18] showed a higher risk of CTS in participants who were using the mouse for more than 20 hours per week. Similarly, Karlqvisit et al.[19] reported that using a computer mouse for more than 6 hours per week might cause carpal tunnel syndrome. Factors such as wrist flexion, force on the finger to get the mouse, and press on the keys can damage the median nerve.[2, 20, 21]

Negative effects of prolonged office works are not limited to the hand/wrist, and several studies also reported that individuals with more than 6 h per day of computer use were strongly susceptible to disorders in different parts of the upper body regions, e.g. the neck, shoulder, elbow, arm, and wrist/hand.[22] Specifically, prolonged mouse use has been shown as a significant ergonomic risk factor which contributes to sustained muscle load and non-neutral postures such as extreme ulnar deviation, wrist extension, and forearm pronation.[2, 5, 15, 23-25]

For better understanding of how prolonged use of the mouse contributes to MSDs, a closer look is needed at the mouse from a design perspective. In most of the current computer workstations, conventional mice are used on a flat surface, putting more pressure on the forearm muscles, wrist tendons, and nerves. The findings of previous studies have shown that non-slanted mice are always used with considerable forearm pronation and wrist deviation known as potential risk factors for musculoskeletal injuries in the elbow and the forearm.[3, 6, 15, 16, 26, 27] Over 60° pronation from the vertical plane would result in a notable increase in the forearm muscle activity.[19]

To mitigate these issues, Chen and Leung designed and evaluated a new design of a mouse in which one can grippe it with a less pronated forearm.[28] Their study showed that 25° or 30° slanted mice caused lower muscle activity and more neutral working postures for Extensor Carpi Ulnaris (ECU), Trapezius, and Pronator Tres (PT) muscles. According to this study and several other works[5, 29-33] compared to conventional design, inclined mouse relieves the load from the forearm muscles.

Aims and Hypotheses

Most of the previous studies have focused on mouse design and its outer surface slope to reduce pronation of the forearm and improve the upper extremities postures. Given the positive impact of a tilted mouse on MSDs, a proper slop of mouse pad may also improve the hand and wrist postures. Therefore, this study aimed to assess the effect of mouse pad slope on wrist and hand postures, forearm muscles activities, as well as user's musculoskeletal discomfort. We hypothesized that with a slanted mouse pad, users will experience fewer forearm muscles activities and less upper extremities discomfort while working.

Methods

Materials

We first designed an adjustable mouse pad and then investigate its effectiveness in an experiment with participants. Therefore, this study was designed in 2 phases. In the first phase, a computer desk was designed with adjustable angle of the mouse pad in the XY plane. We first designed a mouse pad based on the standard dimensions of available mouse pads in the market (26 *21 cm) and made it adjustable in four different slanted angles of 0, 10, 20, and 30 degrees.

The increase of mouse pad angle (from 0 to 30 degrees) was possible in a clockwise direction from the subject's viewing angle in the XY plane. This condition changes the rotation of the subject's forearm. To adjust the mouse pad angle, we used a three-way tilting device (Figure 1).

In Figure 1, the angle of the slanted surface is defined as the angle between a horizontal plane and the inclined surface of the mouse pads in the front view. To prevent the mouse from sliding in the higher angles (i.e., 10, 20 and 30 degrees) on the mouse pad, we made the surface pattern of the mouse pad of specific foam. It should be noted that this modification had no interference with the mousing task performance of the participants. We also designed an adjustable arm with the capability of motion toward the computer desk and vice versa (front and back of the person) to support the participants' right arm (Figure 2).

In the second phase, a computer desk with an adjustable mouse pad angle and a seat with height adjustable which is commonly used for computer works (Figure 1) were used in the experimental setups. Computer and peripheral devices included a monitor (18.5-inch, resolution of 768×1024 pixels, LG Co), a standard conventional-style (horizontal) mouse (Dell, Model: Mov 1800, Optical Mouse), and a keyboard (MEVA MAK 3400 model).

We used the 8 Channel Goniometer and EMG Systems (PS900 model, Biometrics Ltd, UK) to measure the electrical muscle activities. To measure the electrical activity of the selected forearm muscles, we connected the surface EMG electrodes to a portable data logger (SX230-1000 & DataLog MWX8, Biometrics Ltd, UK). Electrical activities of six muscles, including Extensor Digitorum Communis (EDC), Extensor Carpi Ulnaris (ECU), Extensor Carpi Radialis (ECR), Flexor Pullicis Longus (FPL), Flexor Digitorum Superficialis (FDS), and Pronator Quadratus (PQ) were recorded from the right hand of the subjects (Figure 2). These are the muscles that have the most involvement in working with a computer mouse.[20, 29]

We also used the 10-point Numeric Rating Scale (NRS) to assess perceived body discomfort (0=no

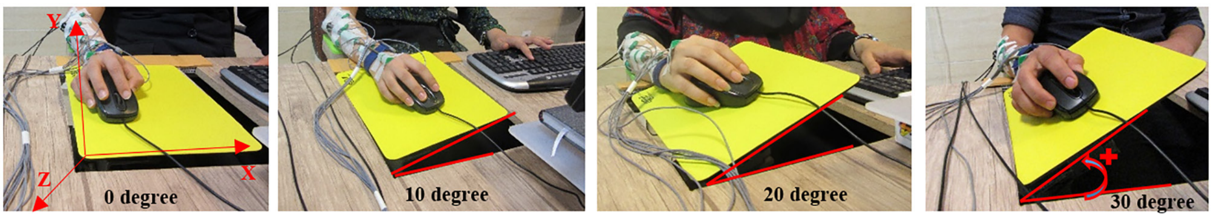

Figure 1: Mouse pad and slanted angles of 0, 10, 20, and 30 degrees

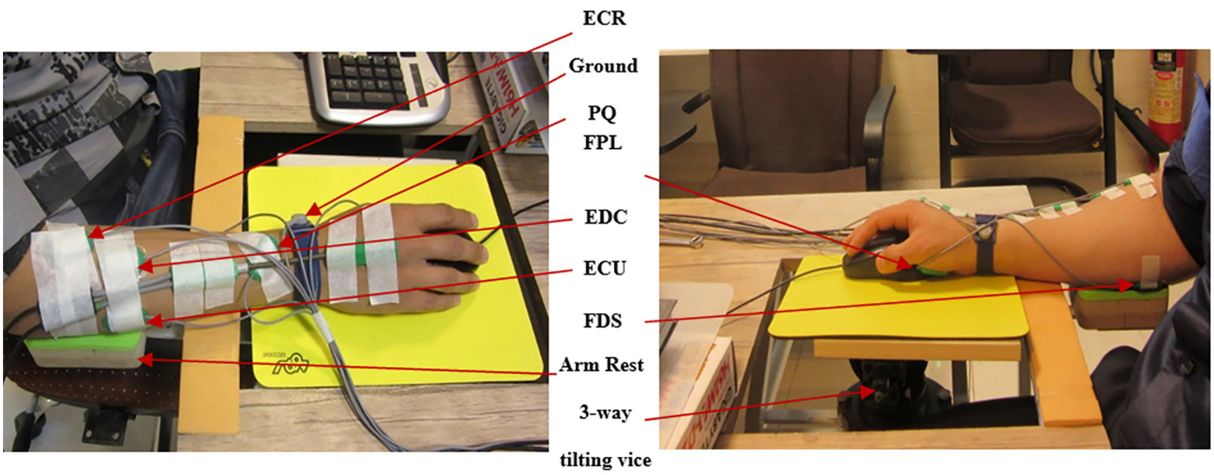

Figure 2: Sensors placement (EDC: Extensor Digitorum Communis, ECU: Extensor Carpi Ulnaris, ECR: Extensor Carpi Radialis, FPL: Flexor Pullicis Longus, FDS: Flexor Digitorum Superficialis, PQ: Pronator Quadratus)

discomfort, and 10=extremely discomfort). Moreover, the amount of time that the subject was involved in each condition was recorded using a timer. Temperature, relative humidity and lighting, as the environmental factors, were measured by a mercury thermometer, a sling psychrometer (Casella Co, England, PT C8303/2 Model), and a digital lux meter (Hagner Co, Sweden, EC1 model), respectively.

Methods

A repeated measures study was designed, and the participants performed a computer task (standardized text editing) with a traditional mouse in four different mouse pad angles. The study protocol was approved by the Ethics Committee of Shiraz University of Medical Sciences (approval ID: CT-P-9376-7456). Ten (5 female) right-handed volunteers who had a history of computer work for at least three hours a day (with the past 2 months) with no history of upper extremity musculoskeletal injuries participated in this experiment. The samples included casual computer users (non-skilled) who routinely used computers for daily tasks. The subjects signed an informed consent form to participate in the study. Table 1 shows the demographic characteristics of the participants.

The experimental conditions were kept the same throughout the experiments with an office temperature of 25.5°C, relative humidity of 42%, and lighting of 470 to 650 Lux. This study was conducted in the Ergonomics Department of Shiraz University of Medical Sciences from January 2016 to May 2016. To counterbalance the carry-over and order effects of testing, we randomly set the allocation of mouse pads for each subject.

Participants were asked to seat upright in a height-adjustable and without right armrest office chair, with feet placed flat on the floor, and rested both forearms on the desk. Before the test, the height of the seat was adjusted to accommodate a comfortable posture for each subject. The mouse was used on the right side of the keyboard (Figure 3).

The right side of the mouse pad was at the level of the desk, and the changes in the angles in the XY plane could change the forearm/wrist pronation and supination. Angles on other anatomical planes that caused flexion/extension and ulnar/radial deviations were controlled. The location of the studied muscles for electrode placement was identified based on Cram, Kasman and Holtz's study,[34] with the subjects' active motion and examiner palpation as the final determinant for the electrode placement. All electrodes were placed by the same experimenter. To minimize the skin resistance, we shaved the participant's hand hair and cleaned the skin with alcohol before the placement of each electrode.

Table 1: Personal characteristics of the participants in the study (n=10)

Variables		Mean	Standard deviation
Age (years)		27.30	[4.90]
Weight (kg)		65.40	[1.20]
Height (cm)		170.50	[7.80]
BMI* (kg/m^2)		22.30	[3.20]
Average working with mouse per day (hours)		5	[2.10]
Education	BSc and lower	2 (20%)	
	MSc and higher	8 (80%)	
Sex	Male	5 (50%)	
	Female	5 (50%)	

*Body Mass Index (kg/m^2)

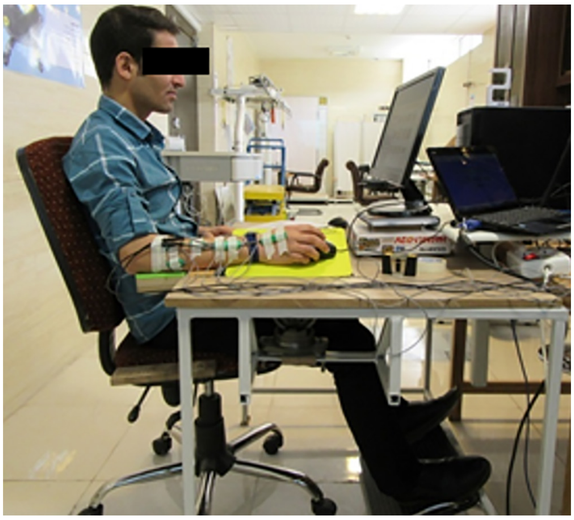

Figure 3: Simulated computer workstation

To normalize EMG data and capture a contraction baseline, we determined the Maximal Voluntary Contraction (MVC) for each muscle at the start of each session. For this purpose, each subject was asked to contract a certain muscle with extreme force against the resistance applied by the examiner and maintain the contraction for 5 seconds. The electrical activity of each muscle was within this time. Each MVC test was recorded three times for each muscle; the remaining interval between testing was set at one minute.[35]

EMG signals were gathered at a frequency of 1000 samples per second, rectified by an EMG system (8 Channel Goniometer & EMG Systems PS900). It should be noted that the electrodes were attached to the skin with adhesive tape to control the electrode movements and noises.

At the start of each session, the participant was asked to sit on the chair in an upright posture in which the angle of the trunk and thigh was about 90°. Moreover, to keep the consistency of all experimental sessions, we kept the angle of the knees at about 90°. We also used a footrest to adjust the thighs of the subject in a horizontal position. The top of the monitor was set at the eyes level, and the participant was asked to place his/her elbows on the armrests (newly designed armrest for the right hand, and chair armrest for the left hand).

Next, the steps were explained to the participants, and then they began to operate the instructed tasks. The experimental task was editing a text consisting of several paragraphs with highlighted words and letters.[20, 29] Participants were asked to select the highlighted characters (random location) with the mouse and then delete the characters by hitting the delete key on the keyboard with the left hand. After performing the task in each paragraph, the subjects were asked to copy the paragraph through right-clicking and then paste the text into the next blank box. The task was done by dragging in the next paragraph. Text editing was performed on the word processing document (Microsoft Office software, ver. 2003) on Windows XP operating system (ver. 2002). Each subject was asked to perform the task for 15 minutes (for practicing) in each four mouse pad positions randomly. Then, the subject was asked to perform the same task (like 15 minutes practicing) for 120 seconds, and EMG data was recorded for this time (120 seconds). In the next step, the data of 60 seconds (from the second 30 to the second 90 of 120 seconds) were selected for each trial and analysed through the related software. Four 17-min trials (15 minutes practicing plus 2 minutes EMG signal recording) were separated by 5-min breaks to eliminate the cumulative effect of the muscle fatigue.

Before and after each trial, the subjects were asked to indicate their upper extremity discomfort using a 10-point NRS. The 10-point NRS was also used to rate the duration the subjects could continue the task in each position. In addition, they were asked to prioritize the use of each mouse pad from one to four after ending four trials. All trials were carried out, and the data were collected from 8 am to 3 pm.

Data Analysis

EMG data Analysis: We used Root-Mean-Square (RMS) of raw EMG signals to normalize the means of maximum EMG values, and the data were analysed using Biometrics LTD, DATALOG software management & analysis (SW4901-11 V9.01). The muscular electrical activity was also analysed based on a percentage of MVC (%MVC) which was obtained for each muscle in each test. The signal is smoothed with a 20-point moving average.

Statistical Analysis

For all dependent variables, means and standard deviations were calculated. Statistical analyses were performed using SPSS software (version 21). Since the normality test (Kolmogorov- Smirnov) did meet normality assumptions in EMG data, the ANOVA was replaced by non-parametric analysis. The significant difference between each of the four trials was analysed using the Wilcoxon test, and the statistical significance was set at $P<0.05$.

Results

Muscular Activity

Table 2 presents all normalized means of maximum EMG values of the 10 subjects in terms of the six examined forearm muscles after using each of the four slanted mouse pads and common computer mouse for one min.

As it is shown, the lowest and highest EMG values

Table 2: The normalized mean of the maximum Electromyography (EMG) value by Maximal Voluntary Contraction (MVC) (n=10)

Tilt of mouse pad	EDC*		FPL†		PQ‡		ECU**		ECR††		FDS‡‡	
	M[a]	SD[b]	M[a]	SD[b]	M[a]	SD[b]	M[a]	SD[b]	M[a]	SD[b]	M[a]	SD[b]
0°	11.71	[7.30]	19.90	[1.17]	22.29	[1.04]	15.87	[5.97]	5.94	[3.81]	8.01	[4.56]
10°	11.44	[6.75]	18.06	[8.39]	20.83	[1.00]	15.90	[7.21]	6.38	[4.44]	7.50	[4.36]
20°	10.99	[7.53]	13.94	[7.42]	20.49	[1.10]	15.18	[9.02]	6.65	[4.85]	8.60	[6.28]
30°	11.48	[8.18]	13.17	[7.09]	18.90	[1.03]	13.58	[1.01]	6.54	[4.60]	8.47	[5.28]

*Extensor Digitorum Communis; †Flexor Pullicis Longus; ‡Pronator Quadratus; **Extensor Carpi Ulnaris; ††Extensor Carpi Radialis; ‡‡Flexor Digitorum Superficialis; [a]Mean; [b]Standard deviation

Table 3: The difference between normalized EMG of the selected forearm muscles in each slanted mouse pad position compared with non-slanted mouse pad

	P values[a] (each slanted mouse pad vs. the non-slanted)					
	EDC*	FPL†	PQ‡	ECU**	ECR††	FDS‡‡
10° vs. 0°	0.953	0.575	0.091	0.314	0.333	0.362
20° vs. 0°	0.066	0.008	0.203	0.441	0.204	0.575
30° vs. 0°	0.515	0.011	0.028	0.093	0.26	0.441

[a]Wilcoxon test; *Extensor Digitorum Communis; †Flexor Pullicis Longus; ‡Pronator Quadratus; **Extensor Carpi Ulnaris; ††Extensor Carpi Radialis; ‡‡Flexor Digitorum Superficialis

Table 4: Mean score of the upper limb discomfort and time of work duration ability with mouse in the four trials

	0°		10°		20°		30°	
	M*	SD†	M*	SD†	M*	SD†	M*	SD†
Upper limb discomfort	3.20	[1.75]	1.90	[1.28]	2.60	[1.50]	3.70	[1.63]
Work duration ability with mouse (hours)	2.55	[1.36]	3.20	[1.08]	3.00	[1.43]	2.00	[1.17]

*Mean, †Standard deviation

Table 5: Mean score of perceived discomfort in different upper extremity regions in the four trials (n=10)

Upper limb extremity	0°		10°		20°		30°	
	M*	SD†	M*	SD†	M*	SD†	M*	SD†
Shoulder/ Arm[a]	2.50	[1.50]	1.80	[1.22]	2.10	[1.96]	3.00	[1.76]
Elbow/ Forearm[a]	2.70	[1.82]	1.70	[1.70]	2.40	[1.71]	2.90	[1.19]
Wrist/ Hand[a]	4.30	[1.70]	2.10	[1.96]	2.80	[1.93]	3.90	[2.02]

[a]10-point scale: 0=without discomfort, 10=extremely discomfort; *Mean; †Standard deviation

were for the ECR and PQ muscles when using a non-slanted (zero degree) mouse pad, respectively. FDS and ECR muscles had the lowest mean EMG values compared to the other four muscles. In addition, ECR muscle had a minimum mean of muscle activity in all tests, and it was the lowest in zero-degree mouse pad.

Table 3 displays a comparison of the muscle contractions in different tilts of the mouse pad and the non-slanted mouse pad. For FPL muscle in 20° and 30° slanted mouse pad and PQ muscle in 30° slanted, the EMG values were significantly lower compared to the non-slanted mouse pad condition (Table 3).

Perceived Discomfort

Table 4 demonstrates the mean score of the subjects' upper limb discomfort and the time that they could keep working with the mouse in the four trials.

The lowest and highest level of the subjects' upper limb discomfort were reported in 10° and 30° slanted mouse pads, respectively. In addition, the subjects could keep working in 10° and 30° slanted mouse pads with the standard mouse for 3.20 and 2.00 hours, respectively.

The perceived discomfort in different upper limb regions is also shown in Table 5.

The highest perceived discomfort was reported in the wrist/hand region in the non-slanted mouse pad. On the contrary, the least perceived discomfort was reported while working with the 10°-slanted mouse pad. Moreover, the results showed that 60% of the subjects preferred to use the 10°-slanted pad as the priority, and 80% of them reported the 30°-slanted pad as the last choice.

Discussion

This study was conducted to assess the effect of mouse pad angle on the forearm muscles activity and upper limb discomfort during work with a standard computer mouse. The findings of the study showed that decreasing the forearm pronation resulted in a decrease in muscle activity in some forearm muscles while using a computer mouse. In addition, upper limb discomfort reduced when pronation of the forearm decreased. Over two-thirds of all occupational disorders recognized have been reported to be work-related musculoskeletal disorders of the upper limbs, mainly induced by biomechanical factors such as repetitive motion, strenuous effort, and extreme joint postures.[2, 5, 15, 23-25]

The results of the study revealed that the highest and lowest EMG values were PQ and ECR while using the 0° slanted mouse pad, respectively. PQ muscle activity value significantly decreased in 30° vs. 0° slanted pad. PQ is one of the muscles that pronates the forearm, and when using a common mouse, it keeps the forearm to full pronation. Thus, it is expected that when the forearm pronation decreases, PQ muscle activity declines. ECR muscle had the lowest mean EMG value when the subjects used the non-slanted mouse pad. Houwink et al.[31] and Hedge et al.[36] reported that the wrist extension was greater using the slanted and vertical mice compared to using the standard mouse. However, some other studies are not in line with these results.[28, 30] The differences may be related to the design of devices, the amount of training and familiarization provided, and experimental conditions.

The findings of the present study revealed that the mean EMG values of the FPL muscle in the 20° and the 30° slanted mouse pads were significantly lower as compared with those of the non-slanted mouse pad. Increasing the mouse pad angle results in the neutral wrist/hand and forearm postures and decreases the loads on some muscles.[5, 7, 20, 29-32, 37, 38] Also, to avoid the mouse from sliding at higher angles, the mouse pad was made from a specific foam. This also helped to lower the activity of the muscle for prevention of the mouse slipping downward the mouse pad which might be a reason for this; thus, muscle activity values will decrease. In a study with five mice with different slanted angles of 0°, 10°, 20°, 25°, and 30°, the mice with 25° and 30° slanted surfaces were reported to be better than the other ones because of causing neutral wrist and forearm working postures and low ECU, upper trapezius, and PT muscles activities.[28]

In general, the results of this study (Table 2) showed that when the angle of the mouse increased from 20 to 30, EMG values of all muscles, except EDC, decreased. However, these results are not significant. A similar pattern was also observed in all muscles except ECU when the angle of the mouse increased from 0 to 10. Interestingly, lower EMG values were recorded in ECU, PQ, FPL, and EDC as the result of increased mouse pad angle from 10 to 20, though again it was not statistically significant.

Labbafinejad et al. reported that the electrical activity of EDC, ECR, FDS, and FPL muscles is reduced when working with slanted mouse.[37] Gaudez et al. reported that Flexor FDS and ECR activities were greater using the standard mouse compared to the vertical or slanted mouse.[30]

The reported upper limb discomfort scores were lower for the 10- and 20-degree tilted positions compared to the non-slanted condition. This is also consistent with our hypothesis that using a standard computer mouse with a slanted pad resulted in lower discomfort. The lowest value was observed for the 10°-slanted pad. In previous studies, subjective methods such as rating scales were used to evaluate the computer interface devices. Although Visser[39] and Chen[28] have reported that rating scales are not generally applicable for the subject's judgment assessment when the level of stress and load of demand is low; these subjective assessment methods have been frequently used in previous studies.[3, 11, 20, 28, 29, 40]

The lowest upper limb discomfort value in the 10° slanted mouse pad can be attributed to the neutral hand/wrist and forearm postures. Chen et al.'s study[28] reported that 25° and 30° slanted mice were better than the other types because of lower muscle activity and more neutral working postures.

The results illustrated that the subjects could continue computer mouse activities for a longer duration when using 10° and 20° slanted pads. In this situation, neutral upper extremities postures and less muscle fatigue result in low discomfort. Based on the results of this study, the working posture of the wrist/hand was awkward while working with a 0° slanted mouse pad. Subjects reported that using the 10°-slanted pad helped them to keep better postures in all regions of the upper extremity.

In addition, the subjects reported a higher discomfort in shoulder/arm posture when using a 30°- slanted mouse pad, and lower discomfort when using the 10°-slanted pad. Although the 30° slanted mouse pad helped the subjects to keep a more neutral posture in the wrist and forearm, a higher level of discomfort was reported in the shoulder/arm posture by increasing the tilt.

The results of the present study also indicated that among different angles of the mouse pads, most of the users (60%) preferred 10°-slanted pad as the priority and a 30° slanted mouse as the last priority.

Limitations

Since the standardized task only included text editing, the results of this study may not be generalizable for all types of office works with computers. This study was also conductedin a lab condition, and participants were tested under controlled experimental conditions; the results may vary in real conditions. Moreover, our findings are associated with the short duration of computer mousing activities (17 min). Thus, long-term mousing activities may yield different results.

Conclusion

This study reported that hand posture while using a computer mouse could affect the muscle activity of the forearm and the users' discomfort. In general, the use of tilted mouse pads caused lower muscle activity than the common (non-slanted) pad. Mouse pads with different angles had diverse effects on the forearm muscle activity. In line with our hypothesis, lower EMG values were recorded in some muscles by increasing the tilt of the mouse pad. Moreover, working with a mouse in a higher slanted position helped the participants to keep better upper limb postures. However, they reported low discomfort when they used a 10° slanted mouse pad on the XY plane. These findings show that a relationship between workstation configuration and biomechanical loads can be complex; thus, more studies are needed to further evaluate these factors for a longer time. In general, using slanted mouse pads could be helpful for office workers to keep more neutral hand positions in hand as a useful and practical activity as compared to slanted and high-cost computer mice.

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Conflicts of Interest: None declared.

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