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Effects of forearm and palm supports on the upper extremity during computer mouse use

Lynn C. Onyebeke [a], Justin G. Young [b], Matthieu B. Trudeau [a], Jack T. Dennerlein [a,c,*]

[a] Department of Environmental Health, Harvard School of Public Health, 677 Huntington Avenue, Boston, MA 02115, USA
[b] Kettering University, 1700 University Ave., Flint, MI 48504, USA
[c] Department of Physical Therapy, Bouvé College of Health Sciences, Northeastern University, 6 Robinson Hall, 360 Huntington Ave., Boston, MA 02115, USA

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ABSTRACT

The use of forearm and palm supports has been associated with lower neck and shoulder muscle activity as well as reduced musculoskeletal discomfort during keyboard use, however, few studies have investigated their effect during computer mouse use. Eight men and eight women completed several computer mousing tasks in six arm support conditions: Forearm Support, Flat Palm Support, Raised Palm Support, Forearm + Flat Palm Support, Forearm + Raised Palm Support, and No Support. Concurrently, an infrared three-dimensional motion analysis system measured postures, six-degree-of-freedom force-torque sensors measured applied forces & torques, and surface electromyography measured muscle activity. The use of forearm support compared to the no support condition was significantly associated with less shoulder muscle activity & torque, and the raised palm support was associated with less wrist extension. Forearm supports reduced shoulder flexion torque by 90% compared to no support. The use of either support also resulted in lower applied forces to the mouse pad. Participants reported less musculoskeletal discomfort when using a support. These results provide recommendations for office workstation setup and inform ergonomists of effective ways to reduce musculoskeletal exposures.

1. Introduction

Computer ownership and Internet use have increased substantially in the United States over the past decade (US Census Bureau, 2009) and it has been well documented that computer use is associated with the development of upper extremity musculoskeletal disorders (MSD) (Blatter and Bongers, 2002; Hernandez et al., 2003; Gerr et al., 2004). Approximately two-thirds of typical computer operation time is attributed to mouse use (Karlqvist et al., 1994), a proportion which can be much greater in some professions such as radiology (Goyal et al., 2009). Mouse use has been associated with high levels of static muscle activity and extreme postures (including shoulder abduction, wrist extension and ulnar deviation) (Karlqvist et al., 1994; Dennerlein and Johnson, 2006; Burgess-Limerick et al., 1999), which are risk factors for development of MSDs (Valachi and Valachi, 2003; Hales and Bernard, 1996). Consequently, evaluations of simple computer workstation interventions are needed in order to characterize biomechanical loads required for mousing tasks.

During mouse use, the upper extremity can be considered as a kinematic chain where a variety of factors affect the loads applied to joints and muscles. The use of workstation or chair arm supports can provide a mechanical ground to the arm kinematic chain and may change the biomechanical loads. A moderate level of evidence suggests that forearm supports can reduce the risk of developing neck and back musculoskeletal disorders (Conlon et al., 2008; Cook et al., 2004). The use of arm supports during keyboard use has been shown to reduce neck and shoulder muscle activity and reduce musculoskeletal discomfort in the neck, shoulders, wrist, and arms (Conlon et al., 2008; Aaras et al., 1997; Lintula et al., 2001; Delisle et al., 2006; Rempel et al., 2011). Forearm support use has been associated with a decrease in wrist extension and ulnar deviation (Cook et al., 2003; Lintula et al., 2001; Cook et al., 2004), though the use of wrist rests has been associated with increased carpal tunnel pressure and less postural variability (Cook et al., 2003).

Most previous research has been conducted for arm support use during keyboarding rather than mousing. Furthermore, to our knowledge, no studies have evaluated joint torques or grip forces during computer use in conjunction with the use of arm supports.

* Corresponding author. Department of Physical Therapy, Bouvé College of Health Sciences, Northeastern University, 6 Robinson Hall, 360 Huntington Ave., Boston, MA 02115, USA. Tel.: +1 617 373 5428; fax: +1 617 373 3161.
E-mail address: j.dennerlein@neu.edu (J.T. Dennerlein).

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Therefore, the objective of this study was to measure the biomechanical demands of the upper extremity while using forearm supports and palm supports during computer mouse use and examine the effects of these supports on biomechanical load and musculoskeletal discomfort. Specifically, we examined the effect of several arm support types on resulting biomechanical load, as measured by upper extremity forces, joint torques, posture, grip force, and muscle activity during computer mouse use.

We hypothesized that forearm supports and palm supports during computer mouse use will lower biomechanical load and result in reduced musculoskeletal discomfort compared to the no support condition. These results will provide insight on the effects of forearm and palm supports that can guide recommendations for office workstation setup and inform ergonomists of effective ways to reduce musculoskeletal loads on the upper extremity during mouse use.

2. Methods

A repeated measures laboratory experiment was performed in which participants completed a set of computer mousing tasks across six support conditions. Sixteen healthy right-handed participants (8 men, 8 women, 25.7 ± 3.1 yr) participated in this study. The mean anthropometric measurements for participants were typical of the average United States population (Table 1). The Harvard School of Public Health Office of Human Research Administration approved all protocols and informed consent forms.

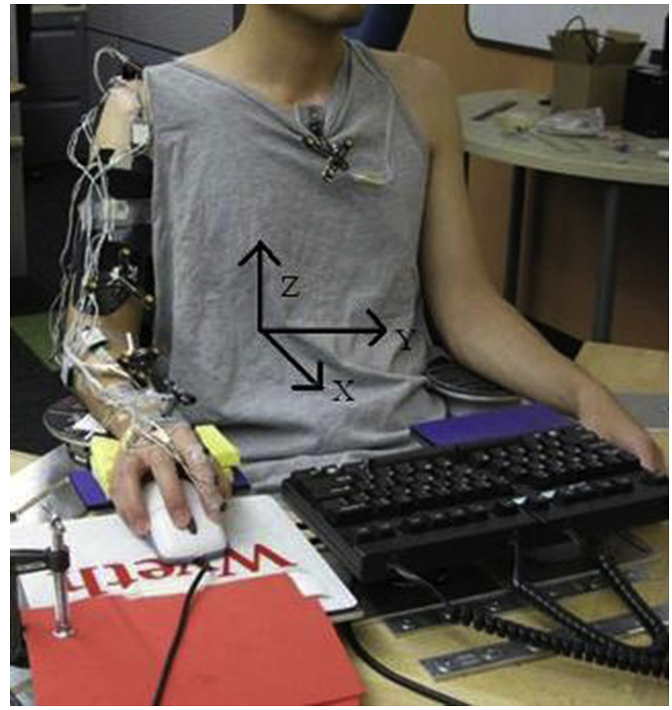

Fig. 1. Experimental Setup for the forearm and raised palm condition.

2.1. Experimental setup and support conditions

Participants sat in an armless chair at a workstation which consisted of a computer monitor, mouse and mouse pad (Fig. 1). The height of the chair and desk were adjusted so that the participant's feet were on the floor and the thighs were parallel with the floor, and all devices and support surfaces were at elbow height. The 20 × 24 cm mouse pad was fixed to the right of a keyboard (though the keyboard was not used in this study), with the center of the mouse pad approximately 30 cm to the right of the centerline of the workstation and monitor. The location of the participant's chair was adjusted so that the body's mid–sagittal plane was in line with the centerline of the workstation and as close to the table and comfortable as possible.

There were three support surfaces for the right arm that were positioned according to the participant's comfort: a forearm support, a flat palm support, and a raised palm support. The forearm support was a flat, 13 cm diameter circular support and was placed 18 cm from the front edge of the mouse pad, a distance which is approximately two thirds of the average American population forearm length from the wrist (Winter, 2005). This placement allowed for support of the forearm but not the elbow. When participants were using the forearm support, they rested their left arm on an identical left forearm support to maintain symmetry. The flat palm support was a 7.2 cm (length) × 15 cm (width) rectangular support placed in front of the mouse pad separated by only a slight space. For the raised palm support, 2.5 cm of soft foam was placed on top of the flat palm support. When using either of the palm supports, participants were asked to rest the scaphoid bone on the supports, rather than their wrist or distal forearms. The surface of the forearm support, palm support, and mouse pad were all the same material (fabric covered rubber material common to most mouse pads). Six total support conditions that were evaluated for each participant: Forearm Support, Flat Palm Support, Raised Palm Support, Forearm + Flat Palm Support, Forearm + Raised Palm Support, and No Support (Fig. 2). The order of the support conditions presented to participants was randomized.

For each support condition, participants were asked to complete a nine-minute simulated computer mousing task. The task was designed to incorporate the static, dynamic, and passive interactions involved during computer mouse usage that involved a combination of clicking, dragging, pointing and clicking on icons, and reading onscreen text. For the first three minutes, participants played a game of Solitaire and thus had to move the cursor, by dragging and clicking playing cards, to various areas of the computer screen. For the next three minutes, participants completed a custom web browsing task in which they had to read a few lines of text and click on answers to simple multiple-choice questions regarding that text after viewing pictures or clicking and scrolling through web pages to find information. For the next three minutes, the participants read an online news passage and clicked "Yes" at the bottom of the screen when asked if they had finished reading. The order of these mousing tasks (Solitaire, Web Browsing, and then Reading) was fixed for all subjects.

Table 1
Mean (SD) anthropometric measures.

	Males ($N = 8$)	Females ($N = 8$)	All
Age (yrs)	26.9 (3.5)	24.5(2.0)	25.7 (3.1)
Height (cm)	176.5 (7.2)	166.9 (6.9)	67.6 (3.3)
Weight (kg)	83.9 (18.1)	62.5 (12.5)	73.2 (18.7)
Shoulder width (cm)	46.9 (4.5)	38.4 (3.0)	42.7 (5.8)
Shoulder to wrist (cm)	58.4 (3.1)	56.7 (3.3)	57.6 (3.2)
Hand length (cm)	18.9 (1.2)	17.8 (1.3)	18.4 (1.4)
Hand breadth (cm)	8.3 (0.4)	7.4 (0.6)	7.8 (0.7)

2.2. Measurements

Posture, forces, and muscle activity applied to each support were recorded during each trial. An infrared three-dimensional (3D) motion analysis system (Optotrak Certus, Northern Digital, Ontario, Canada) measured upper extremity posture. Clusters of

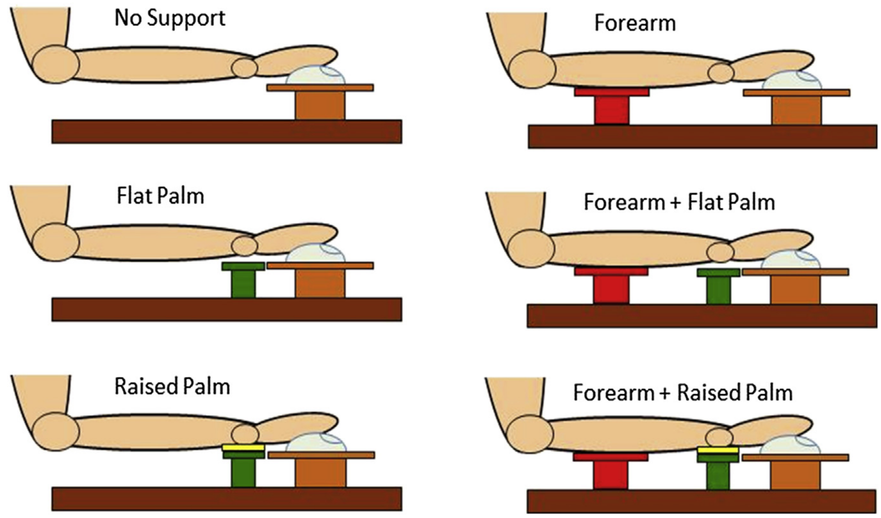

Fig. 2. Six support configurations.

three infrared light-emitting diodes (IREDs) were placed on the torso, upper arm, forearm, and hand of the right upper extremity. Each body segment was modeled as a rigid body (Winter, 2005), and several bony landmarks (including right and left acromion, lateral and medial epicondyle of the right humerus, radial and ulnar styloid of the right wrist, and metacarpal heads of the hand) were digitized and tracked relative to their corresponding IRED cluster. The locations of the arm supports and mouse pad were also digitized. The 0° reference postures for the head, neck, shoulder and wrist and 90° reference postures for the elbow and forearm were collected by aligning the local coordinate system of each segment with the global reference frame. IRED trajectories were collected at 100 Hz and subsequently low-pass filtered using a fourth order Butterworth filter with a 10 Hz cutoff frequency and zero phase shift. Local coordinate systems were defined for each body segment. The local coordinate system of each segment was also referenced to the global coordinate system, where orthogonal axes X (forward away from the participant) and Y (to the left from the participant) were aligned with the desk workstation and axis Z (vertical up from the participant) was parallel to gravity (Fig. 1). Joint angles were calculated from the Euler angles defined by the rotation matrices describing the orientation of the distal segment relative to the proximal segment with respect to the anatomical position and the vertical (Winter, 2005).

Six-degree-of-freedom force-torque sensors (ATI, Apex, NC, USA) were attached rigidly to each arm support plate & mouse pad and measured applied forces and torques. A standard optical computer mouse with scroll-wheel (Microsoft, Redmond, WA, USA) was modified so that three single axis load cells (ATI) measured squeezing forces applied by the thumb and fingers to either side of the mouse. All force and torque data were collected at 100 Hz via analog to digital hardware and custom Labview® software interface (National Instruments, Austin, TX, USA), and force and motion data were synchronized.

An inverse dynamics model calculated resultant joint torques. Velocities and accelerations of the center of mass for the hand, forearm, and upper arm were calculated through digital differentiation using a five-point differentiator. The angular velocities and accelerations were obtained from segment orientation matrices according to Berme et al. (1990). Analysis was performed via a custom Matlab® software program (Mathworks, Boston, MA).

Electromyography (EMG) of two right shoulder muscles (anterior deltoid and medial deltoid), two muscles of the right forearm (extensor carpi radialis (ECR) and extensor carpi ulnaris (ECU)), and one muscle of the upper back and neck (upper trapezius) were measured using surface electrodes (DE 2.1 Single Differential Electrode, Delsys, Boston, MA, USA). The electrodes were placed in standard locations as defined by Perotto (1994). Specifically, the electrodes of the extensor carpi ulnaris (ECU) and extensor carpi radialis (ECR) were placed on the superior-ulnar side of the forearm approximately 6 cm distal to the lateral epicondyle and the superior-radial side of the forearm 20 cm proximal to the radial styloid, respectively. The electrode for the trapezius was placed at approximately 5 cm vertical distance from the midpoint between the spine and acromion. The electrodes for the anterior deltoid and medial deltoid were placed on the ventral side approximately 5 cm from the acromion and on the lateral side approximately 5 cm from the acromion, respectively. Placement of the electrode on the muscles was validated through palpation and signal response to muscle contractions. After amplification, EMG signals were recorded at a frequency of 1000 samples per second, rectified, and smoothed using a 3 Hz low pass filter via the same interface as force and torque data. To normalize results across subjects, three 3-s maximum voluntary contractions (MVC) were collected for each muscle. Participants rested for 2 min between muscle contractions and the maximum signal obtained during the contractions was used as the MVC reference.

In addition to direct measures, participants completed a short survey at the end of each support condition. Participants marked a 10-cm visual analogue scale to indicate overall discomfort in the right upper extremity. Discomfort ratings were on a continuous scale from 0 to 10, with 0 being the lowest level of discomfort and 10 being the highest level of discomfort. Tick mark distances from the left side of the 10 cm line were measured and recorded as the discomfort rating for that condition.

2.3. Data and statistical analysis

For all dependent variables, means and standard deviations were calculated and used as the outcome measure for each trial. Statistical analysis was performed in SPSS® v. 17 (Chicago, IL, USA) linear mixed model module, with participant as the random effect. Variation for each outcome measure across the six support conditions was tested using a one-way repeated measures analysis of variance (RM-ANOVA), with an alpha value of 0.05 as the level of significance. When a significant effect was found, a post-hoc

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Table 2
Joint postural angle (°) ANOVA results and across subject means (SD).

Mean angle (°)	*F*	*p*	No support	Flat palm	Raised palm	Forearm	Forearm+ Flat palm	Forearm+ Raised palm
Shoulder abduction	**11.92**	**<0.001**	11 (6)^{BC}	11 (6)^{BC}	10 (4)^{C}	15 (5)^{A}	15 (5)^{A}	13 (5)^{AB}
Shoulder flexion	0.34	0.88	30 (10)	29 (13)	29 (10)	30 (13)	29 (7)	32 (13)
Shoulder internal rotation	**9.68**	**<0.001**	−3 (6)^{AB}	−5 (8)^{A}	−6 (7)^{A}	3 (8)^{BC}	3 (6)^{C}	3 (6)^{BC}
Elbow extension	0.50	0.77	−66 (16)	−67 (14)	−71 (10)	−67 (9)	−68 (11)	−68 (6)
Forearm pronation	**15.33**	**<0.001**	162 (11)^{AB}	161 (8)^{A}	160 (8)^{AB}	155 (11)^{C}	156 (10)^{C}	158 (10)^{BC}
Wrist adduction	0.99	0.45	11 (8)	12 (5)	13 (4)	12 (6)	12 (4)	14 (6)
Wrist extension	**20.85**	**<0.001**	15 (9)^{A}	8 (8)^{B}	−1 (8)^{C}	10 (7)^{AB}	9 (7)^{AB}	−3 (5)^{C}

Bolded *p*-values indicate statistically significant results. The superscript letter attached to the values reports the results from the Bonferroni post-hoc analysis across conditions. Values with the same letter denote groups without significant differences. Values with different letters are ranked such that A > B > C.

analysis with Bonferroni correction was conducted across the six support conditions.

3. Results

3.1. Arm posture

Shoulder abduction, shoulder internal rotation, forearm pronation and wrist extension postures significantly differed across support condition (Table 2). Shoulder abduction and internal rotation were significantly greater by approximately 8° and 5°, respectively for conditions with forearm support compared to those without support. Wrist extension was significantly highest in the no support condition of 15° on average and lowest for the conditions with palm support. The raised palm support resulted in the lowest wrist extension with the wrists slightly flexed at 2°. Wrist adduction was similar across support conditions.

3.2. Forces applied to supports and mouse

Mean vertical forces (Z) applied to the mouse pad significantly differed across the conditions with the largest force of 7.4 N for the no support condition and smallest force of 0.5 N with the raised palm support (Table 3, Fig. 3).

The mouse pinch forces were significantly lower by 27–36% in all support conditions compared to the no support condition (Table 3). Across the support conditions, the pinch forces were similar.

3.3. Resultant joint torques

Mean joint torques at the shoulder, elbow, and wrist significantly differed across support conditions (Table 4). Required shoulder abduction torque and shoulder flexion torque were

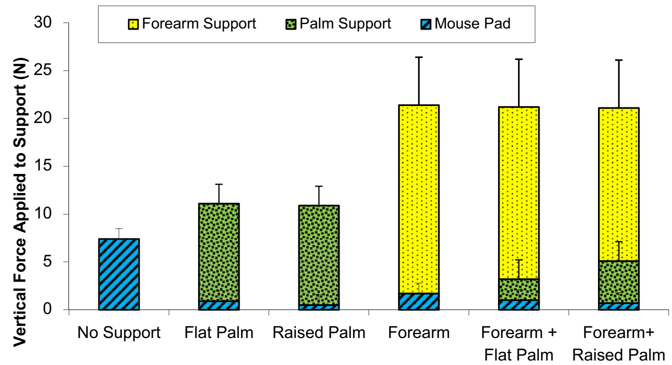

Fig. 3. Vertical Z forces applied to support across conditions. Support forces are larger in the support conditions; however, participants significant support forces from the mouse pad suggesting users utilize some support through the mouse.

significantly smaller when the forearm support was present by 50% and 90%, respectively compared to the no support condition. Elbow extension torque also varied significantly across support condition, though post hoc tests did not reveal differences between conditions after Bonferroni adjustment. For the wrist, extension and rotation torque differed significantly across support conditions with the wrist requiring a flexion torque of 0.2 N*m in the no support condition only, and all conditions with at least one arm support resulted in wrist extension torques that were not significantly different from one another. Similar to wrist adduction posture, wrist adduction torque was not affected by support condition.

3.4. Muscle activity

Muscle activity significantly differed across support conditions (Table 5). When the participant used either a forearm support, palm support or both during the mouse task, mean muscle activity of the

Table 3
Mean applied forces (N) ANOVA results and across subject means (SD).

Mean force (N)	*F*	*p*	No support	Flat palm	Raised palm	Forearm	Forearm + flat palm	Forearm + raised palm
Mouse pad X	1.03	0.433	−0.3 (1)	−0.1 (0.2)	−0.3 (0.9)	−0.1 (0.3)	−0.2 (0.9)	0.0 (0.2)
Mouse pad Y	2.07	0.127	1.0 (1)	0.3 (0.2)	0.2 (0.3)	0.2 (0.3)	0.2 (0.2)	0.2 (0.2)
Mouse pad Z	**16.00**	**<0.001**	7.4 (4.5)^{A}	0.9 (0.5)^{C}	0.5 (0.4)^{D}	1.7 (0.5)^{B}	1.0 (0.8)^{BC}	0.7 (0.4)^{CD}
Palm support X	**4.10**	**0.014**		1.4(1.7)^{AB}	−1.7 (2.2)^{A}		0 (0.6)^{B}	−0.9(0.9)^{AB}
Palm support Y	**6.10**	**0.002**		0.6 (0.6)^{A}	0.8 (0.4)^{A}		0.2 (0.3)^{B}	0.5 (0.6)^{AB}
Palm support Z	**33.36**	**<0.001**		10.2 (5.1)^{A}	10.4(4.4)^{A}		2.2 (1.4)^{B}	4.4 (2.2)^{B}
Forearm support X	0.90	0.422				0.3 (1)	−0.1 (1.3)	0.5 (1.4)
Forearm support Y	2.35	0.119				1.4 (1.1)	1.3 (1.7)	0.8 (1.3)
Forearm support Z	**4.84**	**0.018**				20 (11)^{A}	18 (8)^{A}	16 (8)^{B}
Mouse pinch	**8.916**	**<0.001**	1.1(0.4)^{A}	0.7(0.2)^{B}	0.7(0.3)^{B}	0.7(0.2)^{B}	0.8(0.3)^{AB}	0.7(0.3)^{B}

Bolded *p*-values indicate statistically significant results. The superscript letter attached to the values reports the results from the Bonferroni post-hoc analysis across conditions. Values with the same letter denote groups without significant differences. Values with different letters are ranked such that A > B > C > D. X direction: forward, Y direction: lateral, Z direction: vertical up.

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Table 4
Joint torque (N*m) ANOVA results and across subject means (SD).

	F	p	No support	Flat palm	Raised palm	Forearm	Forearm + flat palm	Forearm + raised palm
Shoulder								
Abduction	**5.12**	**0.001**	1.2 (0.7)^{A}	0.8 (0.6)^{AB}	0.8 (0.5)^{AB}	0.6 (0.7)^{B}	0.6 (0.8)^{B}	0.6 (0.7)^{B}
Flexion	**5.78**	**<0.001**	1.5 (1.6)^{A}	0.9 (1.2)^{ABC}	1.2(1.5)^{AB}	0.1 (1.4)^{C}	0.1 (1.3)^{C}	0.3 (1.4)^{BC}
Internal Rotation	1.41	0.271	−0.6 (0.5)	−0.4 (0.3)	−0.4 (0.3)	−0.5 (0.4)	−0.5(0.5)	−0.5 (0.5)
Elbow								
Extension	**3.42**	**0.009**	0.2(1.2)^{A}	0.8(1.0)^{A}	0.6(0.9)^{A}	0.2(0.6)^{A}	0.3(0.8)^{A}	0.2(0.7)^{A}
Wrist								
Adduction	1.43	0.267	0.1 (0.1)	0.02 (0.04)	0.03 (0.12)	0.01 (0.03)	0.02 (0.02)	0.0 (0.04)
Extension	**15.65**	**<0.001**	−0.2(0.3)^{A}	0.1 (0.1)^{B}	0.2(0.1)^{B}	0.1(0.1)^{B}	0.1 (0.1)^{B}	0.2 (0.1)^{B}
Rotation	**5.27**	**0.001**	0.04 (0.07)^{AB}	−0.01(0.08)^{B}	0.08(0.05)^{A}	0.04 (0.02)^{AB}	0.04 (0.03)^{A}	0.08 (0.08)^{AB}

Bolded *p*-values indicate statistically significant results. The superscript letter attached to the values reports the results from the Bonferroni post-hoc analysis across conditions. Values with the same letter denote groups without significant differences. Values with different letters are ranked such that A > B > C.

anterior deltoid (1.5% MVC) was lower compared to the no support condition (3% MVC). Muscle activity of the right trapezius was also lower with use of the forearm and palm supports but was not statistically significant. For the wrist extensor muscles, muscle activity was significantly lower in the no support condition compared to the five possible forearm/palm support conditions.

3.5. Discomfort scores

When participants used at least one support, they reported significantly less discomfort (Fig. 4). Participants found the Forearm + Raised Palm condition to have the least discomfort and the No Support condition to have the most discomfort. A significant difference was observed only between these two conditions.

4. Discussion

The goal of this study was to determine if using forearm and/or palm supports reduces upper extremity joint torques, forces, and muscle activity during computer mouse use. We found that supported conditions compared to the no support condition had less extreme wrist posture, shoulder muscle activation, and joint torques in the shoulder and wrist, while having larger wrist extensor activity. The forearm support was associated with larger differences for shoulder muscle activity and joint torques compared to the palm support, while the palm support was associated with larger differences on wrist posture compared to the forearm support. These biomechanical measures were **corroborated** by lower reported discomfort for supported conditions.

Wrist extension posture was lower for the raised palm support. Lintula et al. (2001) suggest that the use of arm supports resulted in a 10° decrease in right wrist extension compared to the floating posture. In Kotani et al., (2007), wrist extension increased by 20° as the keyboard was placed farther away from the user, but when a palm support was added, the wrist extension values did not differ from the configuration in which the keyboard was at the closest distance to the user. Use of supports also did not affect wrist abduction posture or abduction torque in our study. This result is contrary to previous studies of forearm and wrist support during keyboarding (Cook et al., 2004).

Use of the forearm support reduced shoulder flexor muscle activity, the anterior deltoid and torque; which is consistent with previous studies (Lee and Huang, 2006; Aaras et al., 1997; Lintula et al., 2001). Forearm supports provide a mechanical ground to reduce the load from the weight of an extended arm on the shoulder muscles. Others reported that only wrist/palm supports affected trapezius and deltoid muscle activity (e.g. Cook et al., 2004; Lee and Huang, 2006); however, their protocol differed from our study in terms of placement and type of the support as well as the tasks completed. In our study, the mouse and mouse pad were placed approximately 18 cm from the edge of the table, thus this may require more anterior deltoid muscle activity in unsupported conditions.

When no support is provided, the participants appeared to utilize the mouse and the mouse pad as a support. We observed the highest forces on the mouse pad during the no support condition. In addition, the mouse grip force was significantly lower when the participant was using a support. Externally applied forces to the palm and fingertip have been associated with carpal tunnel syndrome (Cobb et al., 1995; Keir et al., 1998), so these findings may suggest that providing a support proximal to the hand may reduce the level of exposure for mousing activities.

The lowest wrist extensor muscle activity was observed in the no support condition. One explanation for this is that the mouse and mouse pad was used as the only external support for the arm and thus vertical forces applied to counteract gravity acted distal to the wrist. Therefore, an internal flexion torque at the wrist was required to balance the external extension torque at the wrist (Table 4). Though activity of the wrist flexors was not measured, it can be expected that their activation would result in the observed

Table 5
Normalized muscle EMG (%MVC) ANOVA results and across subject means (SD).

Muscle	p	No support	Flat palm	Raised palm	Forearm	Forearm + flat palm	Forearm + raised palm
Shoulder							
Trap	0.678	5 (2)	4 (3)	4 (3)	4 (3)	4 (2)	4 (3)
AD	**<0.001**	3 (1)^{A}	1 (1)^{B}	2 (1)^{B}	2 (1)^{B}	1 (1)^{B}	1 (1)^{B}
MD	0.761	6 (6)	10 (19)	8 (12)	8 (1)	10 (12)	6 (6)
Forearm							
ECR	**0.003**	5 (3)^{B}	7 (5)^{A}	7 (5)^{A}	7 (5)^{AB}	7 (6)^{A}	7 (5)^{A}
ECU	**0.043**	9 (7)^{B}	10 (6)^{AB}	10 (7)^{AB}	10 (8)^{AB}	11 (9)^{A}	10 (7)^{AB}

Bolded *p*-values indicate statistically significant results. The superscript letter attached to the values reports the results from the Bonferroni post-hoc analysis across conditions. Values with the same letter denote groups without significant differences. Values with different letters are ranked such that A > B > C. Trap = Trapezius; AD = Anterior Deltoid; MD = Medial Deltoid; ECR = Extensor Carpi Radialis; ECU = Extensor Carpi Ulnaris.

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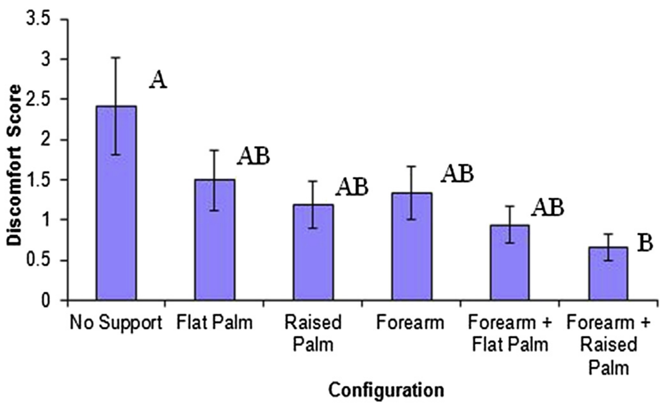

Fig. 4. Discomfort Scores. Participants reported their overall discomfort levels on a scale of 1–10, with 10 = highest discomfort level. The superscript letter attached to the values reports the results from the Bonferroni post-hoc analysis across conditions. Values with the same letter denote groups without significant differences. Values with different letters are ranked such that A > B > C. Error bars indicate one standard deviation.

reduction in wrist extensor activation. Similarly, since the shoulder was flexed 30°, the elbow had larger extension torques for the palm support conditions; however, these were not significantly different.

Reported discomfort scores were lower for the support conditions compared to the no support condition, also consistent with our hypothesis and results seen in previous literature. Cook et al. (2004) conducted a randomized controlled trial of call centre workers using forearm supports, and found lower levels of musculoskeletal discomfort were associated with the use of forearm supports. Conlon et al. (2008) wanted to determine the effects of an alternative mouse and/or forearm support on upper body discomfort in engineers and found that for engineers who worked on a computer for more than 20 h per week, the use of a forearm support was associated with less right upper extremity discomfort.

While we did observe significant differences between conditions, the values for muscle activity, non-neutral postures, and joint torques are small relative to the capabilities of the upper extremity. It is yet to be proven that such small differences will affect injury outcomes. This limitation plagues most biomechanical studies of computer workstations. However, almost all injury models (Sauter and Swanson, 1996; Wahlstrom, 2005) hypothesize that these biomechanical loads are related to injury outcomes. In addition, it is important to consider that these loads are often sustained for long durations and that the upper extremity is prone to MSD outcomes during computer use.

These findings must be taken into the context of the laboratory setting and the study design. This was a laboratory study instead of a field study, in which participants completed short simulated computer mousing tasks under controlled experimental conditions. As is the case with laboratory experiments, these findings may differ in the field setting. We would expect that the variability within and across participants would increase as many other factors are present, including workstation design and set up, the specific task, many of which are controlled for in a laboratory study. This increased variability would bias towards the null. However, these within subject findings may still hold true in the field similar to what we have observed in field studies (Bruno Garza et al., 2012) exploring the same question examined in the laboratory study (Dennerlein and Johnson, 2006). Although we were not able to observe the participants use the supports over an extended period of time, the controlled laboratory conditions allow for more exposure comparability across subjects. Also, our sample population consisted of young adults, so we may be unable to generalize these results to other populations. This was a study in which participants completed a repeated series of mouse tasks totaling for an hour. The mouse tasks consisted of a comprehensive set of pointing device activities that included a large range of static, dynamic, and passive interactions. However, since this study examined only mouse use, we are uncertain about whether these results can be generalized to using both the mouse and keyboard.

5. Conclusion

The forearm support reduced shoulder muscle activity and torque, and the palm support lowered wrist extension and applied forces to the mouse pad. These results were consistent with our hypothesis that the use of an upper extremity support is associated with lower biomechanical load during computer mouse use. These findings show that a complex relationship exists between workstation configuration and biomechanical load, thus future studies are needed to further evaluate factors for longer computer mousing exposures to gain more insight into how upper extremity supports affect biomechanical load.

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