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Different computer tasks affect the exposure of the upper extremity to biomechanical risk factors

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In order to determine differences in biomechanical risk factors across computer tasks, a repeated measures laboratory experiment was completed with 30 touch-typing adults (15 females and 15 males). The participants completed five different computer tasks: typing text, completing an html-based form with text fields, editing text within a document, sorting and resizing objects in a graphics task and browsing and navigating a series of intranet web pages. Electrogoniometers and inclinometers measured wrist and upper arm postures, surface electromyography measured muscle activity of four forearm muscles and three shoulder muscles and a force platform under the keyboard and force-sensing computer mouse measured applied forces. Keyboard-intensive tasks were associated with less neutral wrist postures, larger wrist velocities and accelerations and larger dynamic forearm muscle activity. Mouse-intensive tasks (graphics and intranet web page browsing) were associated with less neutral shoulder postures and less variability in forearm muscle activity. Tasks containing a mixture of mouse and keyboard use (form completion and text editing) were associated with higher shoulder muscle activity, larger range of motion and larger velocities and accelerations of the upper arm. Comparing different types of computer work demonstrates that mouse use is prevalent in most computer tasks and is associated with more constrained and non-neutral postures of the wrist and shoulder compared to keyboarding.

Keywords: Office; Task analysis; Upper extremity; Computer

1. Introduction

Computer work has long been associated with musculoskeletal disorders of the upper extremity (Faucett and Rempel 1994, Bergqvist *et al*. 1995) and in a recent study, half of

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all new employees working at a computer workstation experienced symptoms associated with musculoskeletal disorders within the first year of employment (Gerr *et al.* 2002). While the injury mechanisms of chronic musculoskeletal disorders are not fully understood, work-related physical or biomechanical risk factors include repetition, force, awkward posture, direct pressure and vibration (Armstrong and Silverstein 1987, Silverstein *et al.* 1987, Rempel *et al.* 1992). Work on computer workstations includes many of these risk factors.

While working on a computer is a ubiquitous task within the office environment, the specific tasks that workers complete on a computer vary and as a result so does the keyboard and pointing device use. For example, a graphical designer may spend hours using a computer mouse to manipulate graphical objects, whereas a data entry or call-in centre worker may exclusively utilize the keyboard. Both Hünting *et al.* (1981) and Onishi *et al.* (1982) observed that different types of musculoskeletal disorders existed across different job titles. However, these studies were conducted prior to the mouse being used as a mainstream input device and may not be representative of today's computers. In a more recent study, Anderson *et al.* (2003) reported that the prevalence of carpal tunnel was higher within individuals who self-reported using the mouse more than 20 h per week. However, in another study, Blatter and Bongers (2002) observed only a small non-significant increase in hand and arm complaints with increased mouse usage. These are some of the first studies to attempt to dissect difference in health outcomes based upon keyboard and mouse activity.

Laboratory and field studies have examined the effects of computer input device design (Swanson *et al.* 1997), workstation set-up (Hedge *et al.* 1999) and how the forces applied to the mouse (Wahlström *et al.* 2000) and keyboard (Sommerich *et al.* 1996) affect various biomechanical risk factors. For example, Gerard *et al.* (1999) examined the effects of key switch make force on the forces and muscle activity during touch-typing. Studies of split keyboards have examined the resulting postural effects (e.g. Marklin *et al.* 1999, Tittiranonda *et al.* 1999). Fernström and Ericson (1997) and Harvey and Peper (1997) have examined alternative pointing devices, such as track balls. Workstation set-up affects postural loading and several studies have examined workstation factors. Simoneau and Marklin (2001) demonstrated the effects of keyboard height and slope on the awkward postures of the wrist. For each of these studies the same tasks, such as typing, were completed across the different experimental conditions. Individual factors, such as typing style (Sommerich *et al.* 2001) and mouse usage (Karlqvist *et al.* 1994) are also associated with differences in posture and muscle activity. There have also been some studies of computer mice comparing applied forces (Johnson *et al.* 1994) and carpal tunnel pressure (Keir *et al.* 1999) between drag and point-and-click activities.

There is evidence that specific biomechanical factors differ between keyboard and mouse tasks. Sommerich *et al.* (2001) demonstrated that head posture and activity level of the trapezius along with other muscles of the neck vary across reading, mouse and keyboarding tasks. Cooper and Straker (1998) reported changes in activity of both the trapezius and the anterior deltoid trapezius muscles across mouse and keyboard tasks. For a notebook computer configured with an external keyboard and mouse, Sommerich *et al.* (2002) reported little difference in average shoulder and wrist postures or static activity of the muscle between keyboard and mouse tasks, contrary to Cooper and Straker (1998). However, no study to date has systematically examined how wrist, arm and shoulder biomechanical exposures (force, posture and muscle activity) are affected by different commonly engaged-in computer activities and/or how these biomechanical exposures differ between mouse and keyboard use.

The goal of the present study therefore was to simulate a continuum of computer tasks ranging from exclusive mouse use, mixed mouse and keyboard use to exclusive keyboard activity and compare the biomechanical exposures across these various tasks. This repeated measures laboratory design allowed direct comparisons of exposures across various tasks and between mouse and keyboard use. The study tested the hypothesis that differences in a comprehensive set of biomechanical exposure measures for the wrist, arm and shoulder exist across the different commonly engaged computer tasks and determined whether there are differences in biomechanical exposures when using the mouse and keyboard.

2. Methods

2.1. *Subjects and task*

Thirty subjects (15 males and 15 females) ranging in age from 21 to 39 years (mean 26.9 (SD 4.9) years), all of who touch-typed at 40 words per min or higher, were recruited through a temporary employment agency. The Harvard School of Public Health Human Subjects Committee approved all protocols and consent forms. For the experiment subjects completed a series of tasks described below whilst seated at an adjustable workstation. The workstation consisted of an adjustable chair without arms, an adjustable work surface for the keyboard and mouse and a flat-panel monitor on an adjustable monitor stand. The workstation was adjusted for each individual in accordance with guidelines put forth by ANSI-HFS (1988) and Occupational Safety and Health Administration (1997). The keyboard was placed near the edge of the workstation with the alphanumeric portion of the keyboard centred with the body's centreline. The mouse was positioned adjacent and just to the right of the keyboard. Forearm and wrist supports were not provided.

The five tasks were typing (TYPE), completing an HTML-based form (FORM), text editing (EDIT), sorting and resizing graphical objects (GRAPH), and intranet web page browsing (WEB). For the TYPE task subjects typed Poe's *The Raven* into a word processing program. Subjects viewed both the original and the typed text on the same monitor. For the FORM, subjects filled in a series of text fields on a local web page, which required the subjects to read the instruction of the field, select the field and then enter the text. The EDIT task required the participants to use the mouse and select highlighted text in a word processing document, delete the text with the delete key on the keyboard and then enter the corrected text consisting of one to six letters. For the GRAPH task, participants sorted objects on a page by geometric shape as well as resized objects to match the size of a second object in the field. Finally, in the WEB task participants viewed a series of photographs with a short descriptive text on a set of local intranet web pages (removing any delays associated with downloading from an actual site on the Internet). To navigate between the web pages, the subject used the mouse and clicked on the next page links, which were placed in random locations on the web page. The orders of these five tasks are randomized.

2.2. *Apparatus*

A computer usage software program written in LabView (National Instruments, Austin, TX, USA) recorded all activity on the keyboard and mouse during the tasks. For each discrete computer activity, the computer usage program recorded the duration of the activity and recorded the event into a file. The events recorded were keyboard activities, mouse activities and idle periods. Idle periods less than 2 s, which were between a keyboard and mouse event or vice versa, were denoted as transfer idles. This was because it typically took subjects 2 s or less to move their hand between the mouse and keyboard (Chemor-Ruiz *et al.* 2003). Idle events lasting longer than 2 s were called idle periods.

The participants wore a two-channel, glove-based electrogoniometry system (Wrist-system; Greenleaf Medical, Palo Alto, CA, USA) that measured wrist posture during the tasks from both the left and the right hand. The system measured wrist flexion and extension and ulnar and radial wrist deviation. The system had a resolution of 0.1°, an accuracy of 2° over a $\pm$ 90° range and was calibrated using a wrist jig in accordance with the methods described in Jonsson and Johnson (2001). Postures were recorded continuously by a data logger at 20 samples per second during the tasks. Digital differentiation of the data was used to calculate the wrist joint velocities and accelerations after the position data were digitally low-pass filtered at 8 Hz. Noise measured in a stable, non-moving postural signal created less than 0.2°/s and $1.5°/s^2$ root mean square (RMS) values for the velocity and acceleration calculations, respectively. Neutral posture was as defined using the wrist postures prescribed by the American Academy of Orthopaedic Surgeons (Greene and Heckman 1994).

For the first 15 participants, the right upper arm postural data were collected using a three-axis orientation sensor (Model 3DM; Microstrain, Inc., Winooski, VT, USA) placed on the lateral midpoint of the right humerus, defined as halfway between the lateral epicondyle and the acromiom process. The 3DM measured abduction ($\pm$70°) and flexion ($\pm$180°) using inclinometers and rotation ($\pm$180) using a magnetometer. For the remaining 15 participants, an electro-magnetic motion analysis system (MiniBird; Ascension Technology, Burlington, VT, USA) measured the orientation of the upper arm using two sensors, one placed on the forearm and one on the upper arm, midway on the humerus. For both systems, data were recorded through the serial port into a personal computer at 10 samples per second. The neutral position for the upper arm was defined as seated, shoulders relaxed with the elbows at their side and the palms of the hands resting on the subject's own thighs. No statistical differences were detected between the two measurement systems.

The electromyographic (EMG) activity from four muscles of the right forearm and three muscles of the right shoulder were recorded during the tasks. The forearm muscles monitored were the flexor carpi radialis (FCR), the flexor carpi ulnaris, the extensor carpi ulnaris and the extensor carpi radialis. The three shoulder muscles monitored were the anterior deltoid, the medial deltoid and the upper trapezius muscles. Surface electrodes (DE-2.1 Single Differential Electrode; Delsys, Boston, MA, USA) were placed on top of the muscle bellies in accordance with Perotto (1994). Placements were validated through palpation and signal response to isometric test contractions. After amplification (Bagnoli-eight amplifier; Delsys, with a bandwidth of 20 to 450 Hz), the EMG signals were recorded onto a personal computer at 1000 samples per second. The EMG amplitude was represented by a RMS value calculated over a 0.2 s moving window. To normalize the EMG results across subjects, three 5-s maximum voluntary isometric contractions (MVCs) were collected for each muscle. The experimenter manually restrained the movement of the joint at which the muscle of interest articulated. For the forearm muscles, the directions were those defined by Buchanan *et al.* (1993). With the upper arm near the neutral posture (that is, at rest and vertically aligned with the torso) for the anterior deltoid, the experimenter resisted shoulder flexion and for the medial deltoid shoulder abduction was resisted. For the trapezius muscle, subjects attempted to lift/shrug their shoulders with the direction of the resistance being applied vertically downward at the acromion. Participants rested for 1 min between contractions. The MVC EMG normalization value was the highest RMS amplitude averaged over a 1-s moving window from the three MVC contractions.

Strain gauge-based sensors located under the keyboard and within the mouse measured the applied forces to the input devices during the tasks. The keyboard force-sensing system consisted of a rectangular aluminium plate 3.18 mm thick with four 25-N load cells (model ELFS-B3 – 5L; Entran Devices Inc., Fairfield, NJ, USA) mounted to the underside of the plate. The platform had a force sensitivity of 0.03 N and could measure compressive forces up to 100 N. The mouse contained five miniature load cells (Model AIFP-PJ; Microstrain) with four load cells embedded between two stainless steel plates on the side of the mouse and one under the button, providing a measure of thumb grip and finger forces, respectively (Johnson *et al.* 2000). Calibration of the mouse indicated the miniature side force-sensing system had a sensitivity of 0.01 N, was linear ($r = 0.996$) and was accurate in measuring forces over the whole area of the side of the mouse. The side force-sensing system was also repeatable and had an average measurement error of 6.5% when 0.5 N was repeatedly applied 20 times. The button force-sensing system was linear ($r = 0.983$) and moderately accurate in measuring forces over a 1.5 cm $\times$ 1.5 cm area (average, absolute force measurement error over the area was 18.0%). Button force measurement was repeatable with an average error of 3.4% while applying 0.5-N force 20 times. The force signals were digitally recorded onto a personal computer at 200 samples per second and then digitally low-pass filtered at 20 Hz to remove high frequency noise and platform resonance ($\sim$100 Hz). To normalize force measurements subjects performed three 5-s MVCs for finger flexion and for grip. For the typing and mouse button force, subjects pressed with their fingertip on the keyboard force transducer and for the mouse grip force they squeezed a force transducer of the mouse between their thumb and fingers, as described by Johnson *et al.* (2000). Participants rested for 1 min between contractions. The force MVC normalization value was the highest amplitude averaged over a 1-s moving window from the three MVC contractions.

2.3. *Data and statistical analysis*

Summary statistics were calculated for the muscle activity and the upper extremity postural data. These statistics included the mean and standard deviation as well as the 10th, 50th and 90th percentiles of signal amplitude, which provide a description of the range of the parameter values during the experimental conditions. For EMG values the 10th percentile represents the static muscle load, whereas the 50th and 90th percentiles represent the more dynamic muscle activities associated with a task (Jonsson 1988). For the postural measures the difference between the 90th and the 10th percentile provides a measure of the range of motion and the 50th percentile provides a measure of the median posture by definition. For the velocity and acceleration the postural data were digitally differentiated and double differentiated, respectively, and then RMS values were calculated over the entire task.

The mouse and keyboard force data were parsed into grip and typing episodes respectively. Episodes were defined when the force applied to the side of the mouse or the keyboard exceeded minimum force and standard deviation thresholds. A grip episode on the mouse was defined as any period where force applied to the side of the mouse was above 0.08 N and a 100 ms moving window of the force standard deviation exceeded 0.025 N. For the keyboard force, the standard deviation of the force signal over a 0.15 s window had to be above a 0.45 N threshold, indicating a dynamic activity, and the maximum force for the episode had to be above the activation force for the keyboard (0.65 N) and have a duration of longer than 0.15 s. Once an episode was identified, the average force and peak force (95th percentile) as well as the duration of the episode were calculated. These force parameters were then averaged across episodes to provide the summary statistics for each task.

Differences in these summary statistics (that is, the dependent parameters of input device usage percentage, postural and EMG 10th, 50th and 90th values, and force parameters) between the five tasks (TYPE, FORM, EDIT, GRAPH and WEB) were tested individually (e.g. flexor carpi radialis 10th percentile EMG values across tasks) using a repeated measures ANOVA and Tukey's post-hoc analysis in JMP statistical software (version 4.0; SAS Institute, Cary, NC, USA). Significance was noted for probability of a false positive being less than 5% (i.e. $\alpha = 0.05$).

3. Results

The various tasks resulted in significant differences ($p < 0.001$) in input device usage patterns (figure 1). As expected the TYPE task was a keyboard-intensive task, whereas the GRAPH and the WEB tasks were mouse-intensive. Completing the FORM and the EDIT tasks was a mixture of keyboard and mouse usage. Within the mouse-intensive tasks, mouse use can be broken up into two general types of activities: 1) pointing and clicking; and 2) dragging. The GRAPH and EDIT tasks consisted of mostly drag events, 88% and 71% respectively, whereas the WEB task consisted of mostly point-and-click events (59%). On average the TYPE task was completed in 9 min 57 s, the FORM task in 3 min 34 s, the EDIT task in 4 min 49 sec, the GRAPH task in 4 min 31 s and the WEB task in 4 min 48 s. Idle periods for the TYPE, FORM, EDIT and GRAPH tasks were

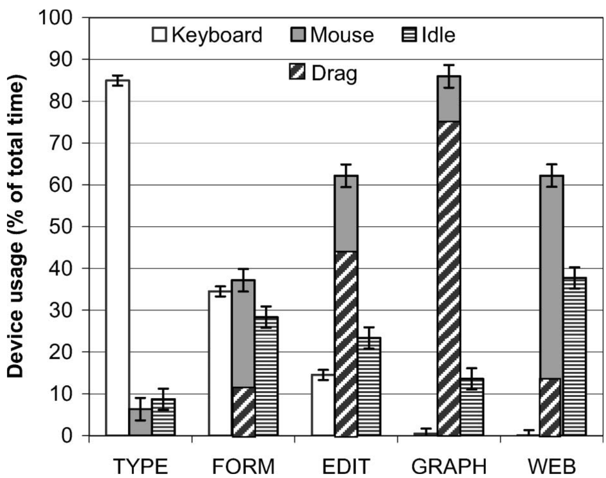

Figure 1. Differences in input device usage and idle activity across tasks. Error bars represent 1 SE. For the mouse task, the proportion devoted to drag activities is denoted by the cross-hatched bars. The typing (TYPE) task was predominantly a keyboard task, the sorting and resizing graphical objects (GRAPH) and intranet web page browsing (WEB) tasks were predominantly mouse and the HTML-based form (FORM) and text editing (EDIT) tasks used a mixture of the two devices.

over 75% transfer idles, whereas no transfer idles occurred during the WEB task, which was completed with the mouse only.

There were significant differences in postures between tasks ($p < 0.0001$); however, the pattern differed between the wrist and the upper arm postures (figures 2 and 3, table 1). For the wrist posture, mouse-intensive tasks (GRAPH and WEB) had more wrist extension with less overall movement of the wrist than the TYPE task. The keyboarding intensive task (TYPE) had more ulnar deviation and a wider range of wrist postures in extension. The task that incorporated an equal amount of both keyboard and mouse use (FORM) had the largest range of wrist motion. Wrist flexion/extension velocities and accelerations varied over an eight-fold range across the tasks with TYPE having the highest values (table 2).

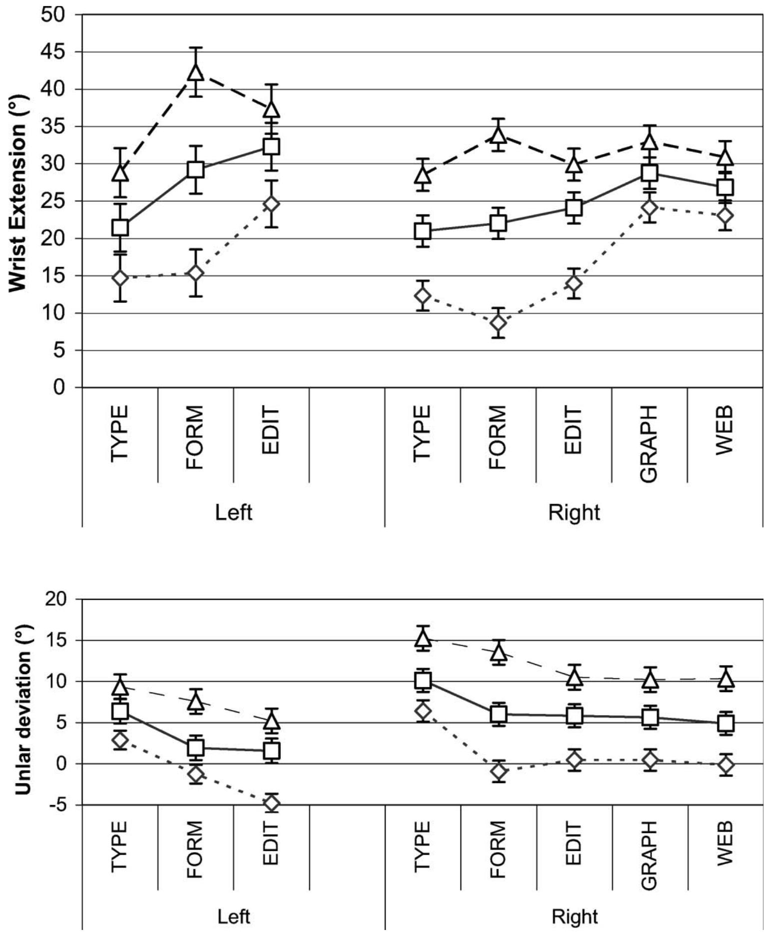

Figure 2. Wrist postures (10th (◇), 50th (□) and 90th (Δ) percentile) varied across the different tasks ($p < 0.0001$; see table 1 for statistical details). Error bars represent 1 SE. The tasks are presented with lines between conditions indicating the expected continuum of increasing mouse usage (from left to right). Since the graphic (GRAPH) and web browsing (WEB) tasks did not require the use of the left hand these were not included in the comparisons shown in the figure. TYPE = typing task; FORM = HTML-based form task; EDIT = text editing task.

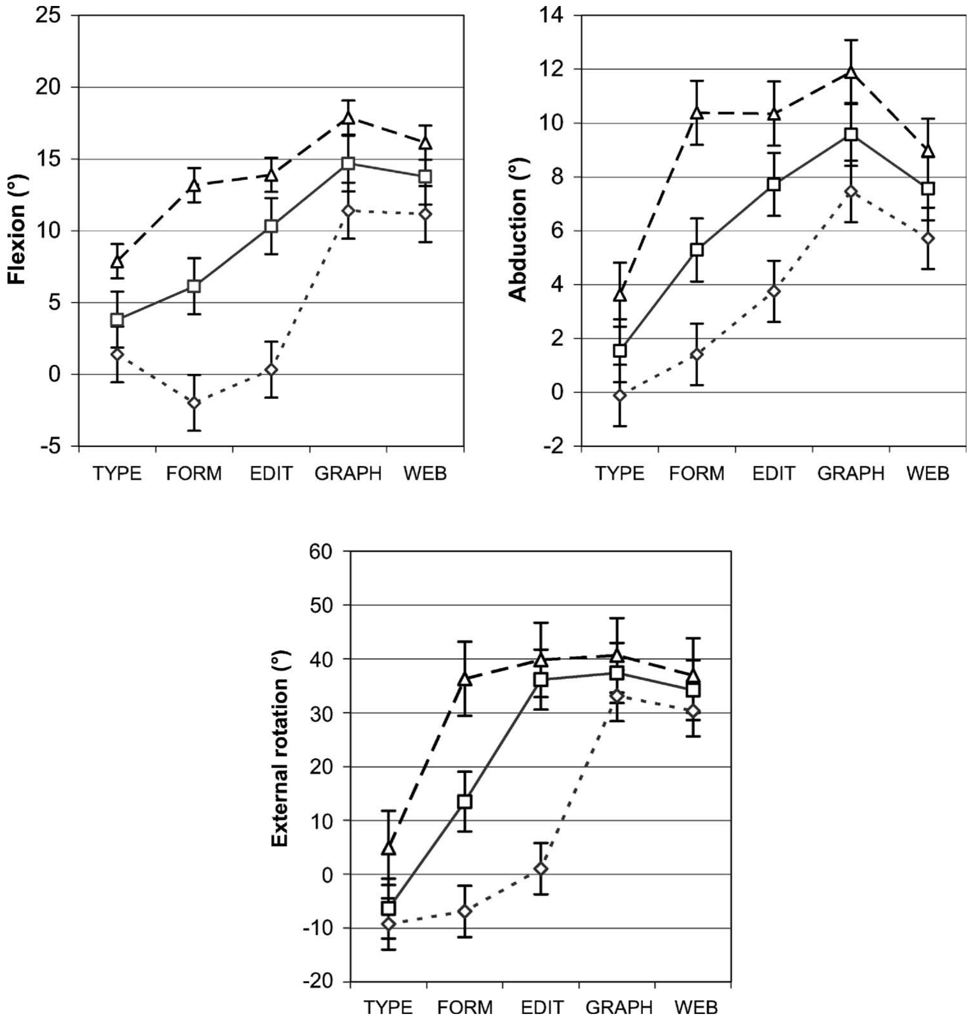

Figure 3. Upper arm postures (10th (◇), 50th (□) and 90th (Δ) percentile) varied across tasks ($p < 0.0001$; see table 1 for details). Positive values indicate flexion, abduction and external rotation. Error bars represent 1 SE. The tasks are presented with lines between conditions indicating the expected continuum of increasing mouse usage (from left to right). TYPE = typing task; FORM = HTML-based form task; EDIT = text editing task; GRAPH = sorting and resizing graphical objects task; WEB = intranet web page browsing task.

Unlike the wrist, the shoulder was in a neutral posture during the TYPE tasks with the shoulder only slightly flexed and abducted (figure 3). During mouse-intensive tasks, the shoulder was flexed, abducted and externally rotated compared to the TYPE tasks. When use of both the keyboard and the mouse was required (FORM and EDIT) the range of motion of the shoulder was the greatest (as shown in figure 3) along with the upper arm velocities and accelerations values (table 2).

There were significant differences in muscle activity ($p < 0.001$, table 3) across the tasks. Forearm muscles were the most active with keyboard tasks and decreased by as

Table 1. Results of the statistical analysis for the postural parameters illustrated in figures 2 and 3. Repeated measures of analyses were completed for each parameter across the five conditions with Tukey post-hoc analysis.

	Task	Percentile/range	p	TYPE	FORM	EDIT	GRAPH	WEB
Left Wrist	Flexion/Extension	10th	0.0053	A	A	B	–	–
		50th	0.0047	A	A,B	B	–	–
		90th	0.0007	A	B	B	–	–
		90th – 10th	<0.0001	A	A	B	–	–
	Radial/Ulnar deviation	10th	<0.0001	A	B	C	–	–
		50th	<0.0001	A	B	B	–	–
		90th	<0.0001	A	A	B	–	–
		90th – 10th	<0.0001	A	B	A	–	–
Right wrist	Flexion/Extension	10th	<0.0001	A,B	A	B	C	C
		50th	0.0004	A	A,B	A,C	C	B,C
		90th	0.0425	A	B	A,B	A,B	A,B
		90th – 10th	<0.0001	A	B	A	C	C
	Radial/Ulnar deviation	10th	<0.0001	A	B	C	B,C	B,C
		50th	<0.0001	A	B	B	B	B
		90th	<0.0001	A	A,B	B,C	C	C
		90th–10th	<0.0001	A	B	A	A	A
Right shoulder	Flexion	10th	<0.0001	A	A	A	B	B
		50th	<0.0001	A	A,B	B,C	C	C
		90th	<0.0001	A	B	B	B	B
		90th – 10th	<0.0001	A	B	B	A	A
	Abduction	10th	<0.0001	A	A,B	B,C	D	C,D
		50th	<0.0001	A	B	B,C	C	B,C
		90th	<0.0001	A	B	B	B	B
		90th–10th	<0.0001	A	B	C	A	A
	Internal/External rotation	10th	<0.0001	A	A,B	B	C	C
		50th	<0.0001	A	B	C	C	B,C
		90th	<0.0001	A	B	B	B	B
		90th – 10th	<0.0001	A	B	B	C	C

The same letters denote groups without significant differences. TYPE = typing task; FORM = HTML-based form task; EDIT = text editing task; GRAPH = sorting and resizing graphical objects task; WEB = intranet web page browsing task.

Table 2. Dynamic postural values (mean for position, and root mean square for velocity and acceleration data) for right wrist and shoulder. For wrist position data, positive values indicate extension and ulnar deviation. For shoulder position data, positive values indicate flexion, abduction and external rotation.

	Task	TYPE	FORM	EDIT	GRAPH	WEB
Right wrist						
Extension (Flexion)	Position (°)	21[a]	22[a]	23[a]	28[b]	27[b]
	Velocity (°/s)	22[a]	17[b]	13[c]	6[d]	3[d]
	Acceleration (°/s^2)	291[a]	185[b]	157[c]	67[d]	35[e]
Ulnar (Radial) deviation	Position (°)	10[a]	6[b]	6[b]	6[b]	0[b]
	Velocity (°/s)	10[a]	7[b]	6[c]	4[d]	3[e]
	Acceleration (°/s^2)	121[a]	83[b]	70[c]	43[d]	31[e]
Right shoulder						
Flexion (Extension)	Position (°)	4[a]	6[a,b]	9[b]	14[c]	14[c]
	Velocity (°/s)	6[a]	11[b]	12[c]	6[a]	3[d]
	Acceleration (°/s^2)	43[a]	69[b]	73[b]	33[c]	17[d]
Abduction (Adduction)	Position (°)	2[a]	6[b]	7[b]	10[c]	7[b]
	Velocity (°/s)	3[a]	5[b]	5[b]	3[a]	2[c]
	Acceleration (°/s^2)	20[a]	31[b]	32[b]	17[c]	10[d]
External (Internal) Rotation	Position (°)	−4[a]	15[b]	28[c]	36[d]	34[c]
	Velocity (°/s)	12[a]	25[b]	31[c]	12[a]	6[d]
	Acceleration (°/s^2)	64[a]	124[b]	147[c]	64[a]	32[d]

The same superscript letters denote groups without significant differences. TYPE = typing task; FORM = HTML-based form task; EDIT = text editing task; GRAPH = sorting and resizing graphical objects task; WEB = intranet web page browsing task.

much as 60% for the mouse-intensive tasks (figure 4). Mouse-intensive tasks had the least variability in forearm muscle activity, whereas keyboard tasks were associated with a larger range of activity. On average the extensors were twice as active as the flexors, reaching dynamic levels of 35% MVC compared to 18% MVC for the flexors. The median value for the flexor activity was also high for the GRAPH task. The relative level of shoulder activity was quite low compared to the activity of the forearm muscles (figure 4). The highest values for the shoulder were observed for the mixed input device usage tasks (FORM and EDIT).

While the average forces applied to the keyboard and mouse were relatively small (<4 %MVC), there were differences between tasks (table 4). Average absolute keyboard forces during the TYPE task were approximately 33% and 50% larger than during the FORM and EDIT tasks, respectively. Peak keyboard forces varied less than the average forces across the tasks with only the EDIT task having 15% less peak force than the TYPE and FORM tasks. The duration of typing episodes were, as expected, the smallest for the EDIT and FORM tasks. Average grip forces during mouse episodes were approximately 50% larger for the drag-intensive EDIT and GRAPH tasks compared to the TYPE, FORM and WEB tasks. Peak grip forces were approximately 100% larger for the GRAPH and 50% larger for the EDIT and WEB tasks compared to the TYPE and FORM tasks. Average button forces were 100% larger for the GRAPH and 50% larger for the EDIT task compared to the TYPE and WEB tasks. The durations of mouse grip episodes for the GRAPH and WEB tasks were ten times longer than the durations of the episodes for the TYPE, FORM and EDIT tasks.

Table 3. Results of the statistical analysis for the electromyographic distribution parameters illustrated in figure 4. Repeated measures of analyses were completed for each parameter across the five conditions with Tukey post-hoc analysis.

	Task	Percentile	p	TYPE	FORM	EDIT	GRAPH	WEB
Forearm	FCR	10th	0.001		A	B	B	A
		50th	< 0.0001	A	B,C	A,C	A,C	B
		90th	< 0.0001	A	C	C	C	B
	FCU	10th	< 0.0001	A,C	B	A	A	B,C
		50th	< 0.0001	A	B,C	A,C	A	B
		90th	< 0.0001	A	B	B	B	C
	ECU	10th	< 0.0001	A	B,C	B	A,B	C
		50th	< 0.0001	A	B	B	B	C
		90th	< 0.0001	A	B	B	B,C	C
	ECR	10th	< 0.0001	A	B	B	A,C	B
		50th	< 0.0001	A	B	B	B,C	C
		90th	< 0.0001	A	B	B	B,C	C
Shoulder	Trapezius	10th	0.0023	A	A	A	A,B	B
		50th	< 0.0001	A,B	A	A	B,C	C
		90th	< 0.0001	A,B	A	A	B,C	C
	Anterior deltoid	10th	0.0001	A	B	A,B	B	B
		50th	< 0.0001	A	A	A,B	B,C	C
		90th	< 0.0001	A	B	A,B	A	C
	Medial deltoid	10th	< 0.0001	A,B	A	C	C	B,C
		50th	< 0.0001	A	A,B	C	B,C	A,B
		90th	< 0.0001	A	B	B	B	A

The same letters denote groups without significant differences. TYPE = typing task; FORM = HTML-based form task; EDIT = text editing task; GRAPH = sorting and resizing graphical objects task; WEB = intranet web page browsing task; FCR = flexor carpi radialis; FCU = flexor carpi ulnaris; ECU = extensor carpi ulnaris; ECR = extensor carpi radialis.

4. Discussion

The results illustrate that differences in exposure to biomechanical risk factors of the wrist, forearm and the shoulder do exist across different computer tasks that require different amounts of mouse and keyboard usage. The results also indicate that tasks involving the keyboard were associated with greater exposure variability, whereas mouse-intensive tasks were associated with less variable and relatively constrained exposures (more postural fixity). As a result, field studies of computer workers should take into account such differences in input device usage to develop a better understanding between exposure and outcomes and the development of interventions. For example, greater wrist extension, less postural variability and the longer durations of the force episodes that occurred during mouse use might explain the association between use of a mouse device more than 20 h per week and the risk of possible carpal tunnel syndrome reported by Andersen *et al.* (2003). Such exposure information could be used to design administrative interventions and develop an exposure-based taxonomy based on the proportions of mouse and keyboard activity.

When comparing mouse- and keyboard-intensive tasks, mouse-intensive tasks were found to require shoulder postures that were more deviated from neutral; however, there were only small differences between static (10th percentile) and median EMG levels,

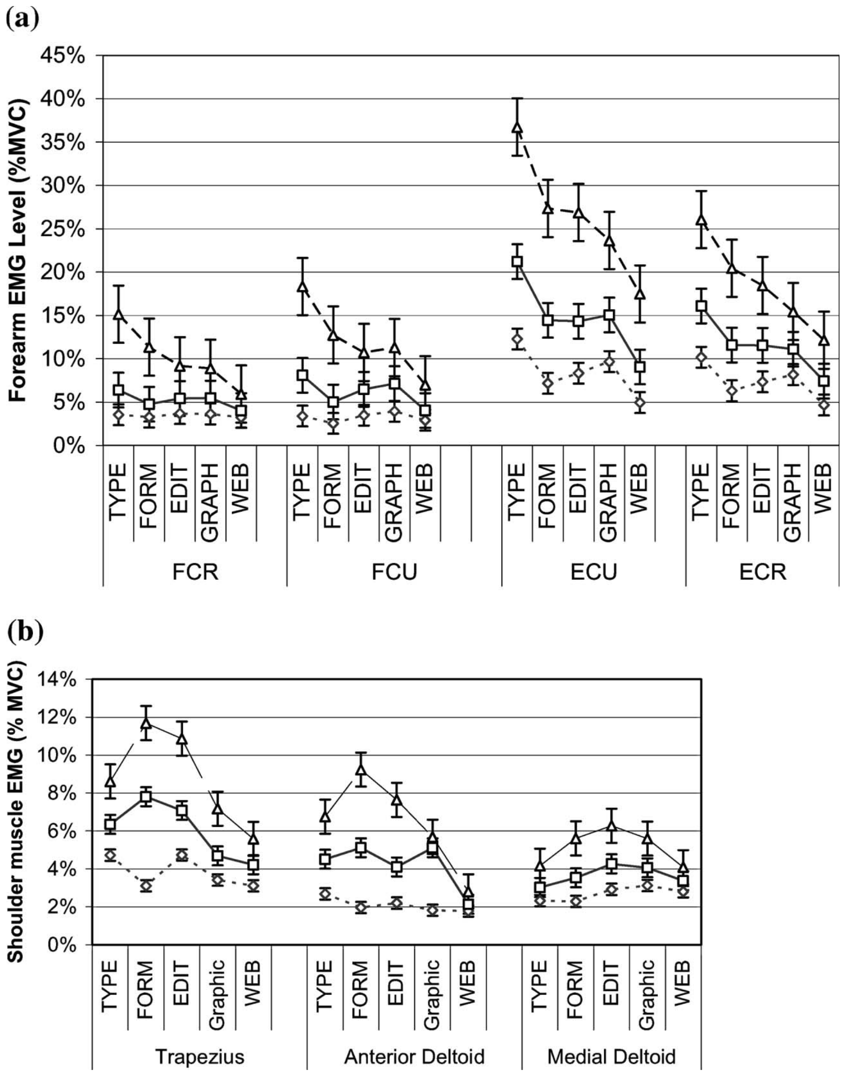

Figure 4. Electromyographic (EMG) amplitude distribution (10th (◇), 50th (□) and 90th (Δ) percentile) values varied across the tasks ($p < 0.0001$; see table 3 for statistical details) for the forearm (a) and shoulder (b) muscles. Error bars represent 1 SE. The tasks are presented with lines between conditions indicating the expected continuum of increasing mouse usage (from left to right). MVC = maximum voluntary isometric contraction; FCR = flexor carpi radialis; FCU = flexor carpi ulnaris; ECU = extensor carpi ulnaris; ECR = extensor carpi radialis. TYPE = typing task; FORM = HTML-based form task; EDIT = text editing task; GRAPH = sorting and resizing graphical objects task; WEB = intranet web page browsing task.

whilst keyboard-intensive tasks typically had higher peak (90th percentile) EMG levels. While a decrease was observed in the trapezius muscle activity similar to Cooper and Straker (1998), when moving from keyboard to mouse work little difference was observed in the anterior deltoid muscle activity between mouse and keyboard use, contrary to

Table 4. The average (and standard error) applied force parameters during keyboard and mouse episodes.

	Task	TYPE	FORM	EDIT	GRAPH	WEB
Keyboard	Mean force N	1.2[a] (0.1)	0.9[b] (0.1)	0.8[b] (0.1)	–	–
	Mean force %MVC	3.0[a] (0.3)	2.3[b] (0.3)	1.9[b] (0.3)		
	Peak force N	2.3[a] (0.1)	2.3[a] (0.1)	2.0[b] (0.1)	–	–
	Peak force %MVC	5.7[a] (0.4)	5.6[a] (0.4)	4.8[b] (0.4)		
	Mean episode duration (s)	6.4[a] (0.3)	2.0[b] (0.3)	1.2[b] (0.3)	–	–
Mouse	Mean grip force N	0.8[a] (0.1)	0.9[a] (0.1)	1.3[b] (0.1)	1.2[b] (0.1)	0.8[a] (0.1)
	Mean grip force %MVC	0.8[a] (0.1)	0.9[a] (0.1)	1.4[b] (0.1)	1.3[b] (0.1)	0.8[a] (0.1)
	Peak grip force N	1.4[a] (0.2)	1.6[a] (0.2)	2.2[b] (0.2)	2.8[c] (0.2)	2.3[b] (0.2)
	Peak grip force %MVC	1.4[a] (0.3)	1.7[a,b] (0.3)	2.4[b,c] (0.3)	2.9[c] (0.3)	2.4[b,c] (0.3)
	Mean button force N	0.7[a] (0.1)	0.9[a] (0.1)	1.1[b] (0.1)	1.4[c] (0.1)	0.7[a] (0.1)
	Mean button force %MVC	1.8[a] (0.3)	2.1[a,b] (0.3)	2.7[b] (0.3)	3.3[c] (0.3)	1.8[a] (0.3)
	Mean episode duration (s)	3.5[a] (4.2)	4.5[a] (5.2)	3.8[a] (5.2)	27.7[b] (5.1)	31.7[b] (5.4)

Mean values are averages for the episodes of activity, not the averages over the whole task. The same superscript letters denote groups without significant differences. TYPE = typing task; FORM = HTML-based form task; EDIT = text editing task; GRAPH = sorting and resizing graphical objects task; WEB = intranet web page browsing task; MVC = maximum voluntary isometric contractions.

Cooper and Straker's results. These differences may be related to postural demands due to the position of the mouse (Karlqvist *et al.* 1998). In the wrists and forearms, mouse-intensive tasks required greater extension, whilst keyboard-intensive tasks resulted in greater ulnar deviation. With regard to forearm EMG levels, keyboard-intensive tasks had slightly higher static levels with greater differences in median and peak levels.

In terms of the forces applied during typing, some differences were seen in the mean force levels across the three tasks; however, the peak force levels (95th percentile) were not very different. Comparing mean forces across these tasks may be problematic since the forces applied to the keyboard may be influenced by overlapping keystrokes, typing speed and the task (continuous typing compared to the short bursts of editing). A six-fold difference was observed in the durations of typing episodes across the different keyboard tasks. Due to the complex and redundant biomechanics of the musculoskeletal system, typing force alone may not be an accurate indicator of internal muscle loads and typing style (Dennerlein *et al.* 1999, Baker and Redfern 2003).

For the mouse, differences in force were observed across the different tasks. Higher mean grip and button forces were recorded during the drag-intensive GRAPH and EDIT tasks. Other researchers (Johnson *et al.* 1994, Keir *et al.* 1999) have observed that grip force and button force, as well as the internal pressure inside the carpal tunnel, increase for dragging activities compared to simple point-and-click activities for the mouse. In the present study an increase in the median wrist flexor EMG was also observed during the GRAPH task, which is most likely due to the increased force applied to the mouse during this task. Furthermore, the GRAPH task required some amount of precision motor control for the resizing of objects, whereas the WEB task did not, which also has increased muscle activity and force (Visser *et al.* 2004).

It is also quite clear from these data that typing is a very dynamic task for the wrist and the forearm muscles and to a lesser degree for the shoulder. Compared to the mouse-intensive tasks, velocities and accelerations of the wrist joint were higher during typing, similar to motions documented by others (Serina *et al.* 1999) and with accelerations as high as in other 'high risk' manual intensive jobs (Marras and Schoenmarklin 1993). However, the sampling rate for postural data was slower in the present study than in others and, as a result, there may be some underestimation of the velocities and accelerations.

The large changes in the 90th percentile value of the forearm EMG across the different tasks further supports that typing is quite a dynamic activity for the wrist and forearm muscles. Mouse activities, however, were less dynamic for the wrist and forearm, requiring more static loading of the muscles and less movement about the wrist joint. The range of motion of the wrist and the range between the 90th percentile and the static 10th percentile forearm EMG values were also the smallest for the mouse-intensive tasks (figures 2 and 4). Mouse activity was also associated with less neutral upper arm postures, especially in internal and external rotation. The range of motion of the upper arm as well as the differences between the more dynamic (90th percentile) and static (10th percentile) EMG parameters were more restricted for the mouse-intensive tasks, similar to the wrist (figure 4).

For the upper arm the largest dynamic activity occurred during the FORM and EDIT tasks, which involved both the keyboard and the mouse. In these tasks, the right arm had to move the hand between the keyboard and the computer keyboard frequently. Slightly higher values of EMG were observed for the trapezius muscle during typing compared to the purely mouse-intensive GRAPH and WEB tasks, even though the shoulder is in a more neutral posture. These higher activities may be related to factors that were not measured, such as elevation of the shoulder, or due to dynamic stabilization of the shoulder joint due to the higher dynamic activity at the wrist. It should be noted that a forearm support was not provided during these activities.

These conclusions do need to be taken within the context of these laboratory experiments and their associated limitations. First and foremost the interaction between workstation design and the exposure to these biomechanical risk factors was not examined, which may, and mostly likely does, exist in the field. The workstation was adjusted in accordance with existing guidelines, but other laboratory studies have examined such relationships (e.g. Simoneau and Marklin 2001) and more studies are needed to fully understand the effects of non-standard postures that have been illustrated as being protective in field studies (Marcus *et al.* 2002). The differences across tasks, while significant, are small in terms of the magnitude or size of the difference measured (e.g. a few % MVC, 0.1 N, etc). In terms of exposures, it is not known whether these small differences matter. However, the effect of these small differences may be magnified over the course of a day (even weeks or months) and/or have a greater impact when combined with concomitant increases in the other two primary determinants of exposure, duration and frequency.

The computer tasks here were designed to simulate real world tasks (typing, completing and editing forms, doing sophisticated graphical manipulations and simple surfing the web) where both the keyboard and the mouse are utilized either in isolation (e.g. TYPE and GRAPH) or in a mixed use (e.g. EDIT and FORM); however, mouse use occurred more than expected in many of the tasks, especially TYPE and FORM (figure 1). These data suggest that even when attempting to design keyboard tasks within a graphical user interface such as Windows, mouse use will be encountered. Exposure differences between the computer tasks tested in this study and real tasks completed in the field are unknown. Johnson *et al.* (2000) reported a difference in mouse grip force between a standardized task and actual work and therefore one can only speculate that such differences exist in the field.

The main limitations of this study are primarily the short duration of exposure and that the task simulations did not expose the subjects to the psychological pressures and demands associated with real world tasks in a paying job. In addition, a limited number of muscles and postures were monitored during these tasks. For example, the EMG of the trapezius was measured, but shoulder elevation (that is, raising of the acromion relative to the torso), which may be associated with activity of the trapezius, was not monitored. Also, arm support was not controlled during the tasks utilizing the mouse and therefore with the mouse-intensive tasks shoulder activity may be smaller (Visser *et al.* 2004). What these experiments do provide, however, is a basis for the description of exposure across specific computer tasks. Furthermore, there may have been limitations with the measurement techniques. The accuracy of the upper arm postural measurements may have been compromised by differences in soft tissue movement relative to the movement of the underlying bones. As the upper arm rotates externally, the bone may move further than the outer layers of muscle and skin tissues. Therefore, the absolute measures of internal and external rotation were most likely underestimated. However, this was a repeated measures design and differences were observed across the conditions, hence not changing the overall conclusions. Furthermore, the difference in rotation between keyboard and mouse use ($\sim 40^\circ$) is very similar to the difference of 37° reported by Sommerich *et al.* (2002).

In conclusion, this study demonstrates through a repeated measures design that exposure to various biomechanical risk factors differs across different computer tasks. The mouse-intensive tasks were associated with non-neutral static wrist and upper arm postures and the keyboard-intensive tasks were associated with more dynamic wrist postures and forearm muscle activity. Understanding these differences will help further the understanding between input device use and specific dose-response relationships associated with musculoskeletal disorders.

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