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Computer mouse and track-ball operation: Similarities and differences in posture, muscular load and perceived exertion

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Abstract

Posture (optoelectronic 3D motion analysis system), muscular load (EMG), perceived exertion (rating scales), preference and productivity were investigated in 20 healthy VDU-operators (10 male and 10 female) during text editing with two different data input devices, a mouse and a track-ball. Work with the track-ball entailed lower shoulder elevation and less neck/shoulder muscle activity than work with the mouse. Arm support reduced muscle activity in the neck/shoulder region irrespective of input device used. A table height lower than 3 cm above elbow height allowed arm and shoulder support without undue shoulder elevation. Work with the track-ball entailed more wrist extension than work with the mouse. Perceived exertion ratings were lower for the shoulder and higher for the hand with track-ball than with mouse operation. Thus, biomechanical demands differ between different input devices. The women elevated and rotated their right shoulder outwards more than the men during work with both input devices. The overall EMG results showed a higher activity among the women than among the men in two of the examined muscles. This may relate to anthropometric differences which also influence biomechanical load moments. Another reason could be the observed differences in working techniques between the men and the women.

Relevance to industry

The design of input devices affects levels of muscular load in neck/shoulder and hand/forearm muscles. Joint positions differ depending on the size and design of the input device and the operators' anthropometry. The design of input devices should be adapted to the differences in work tasks and variations of human dimensions in order to avoid injuries and to enhance the effectiveness of VDU work.

Keywords: Computer mouse; Muscular load; Perceived exertion; Posture; Track-ball; VDU

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1. Introduction

In recent years, the occurrence of work-related musculoskeletal disorders in the neck and upper limb, such as finger extensor and flexor tendalgies, carpal tunnel syndrome and neck-shoulder myofascial pain have increased dramatically and now account for over 60% of the reported occupational illnesses in the USA (Bureau of Labor Statistics, 1992). In Sweden, neck and upper limb disorders account for 41% and this is the most common separate reason for reporting occupational illnesses (The National Social Insurance Board, 1990). Neck and upper limb disorders are more common in women than in men (Bergqvist et al., 1995; Karlqvist et al., 1996). Previous studies of visual display unit (VDU) operators have indicated that workstation ergonomics contribute to chronic musculoskeletal symptoms (Burt et al., 1990; Hagberg et al., 1995; Bergqvist, 1993).

The computer mouse and other non-keyboard computer input devices supplement the keyboard in many visual display unit (VDU) workstations. The mouse technique changes working posture and movements, compared with keyboard use without the mouse (Karlqvist et al., 1994). Nowadays computerized work is mostly performed in so-called "window interface". New data programs make it possible to rework a text or other data freely, but make the users dependent on the non-keyboard computer input device. Although it is still possible to use the keyboard for data commands this is seldom done today in word processing work. Today the market is filled with different non-keyboard computer input devices, e.g. mouse, track-ball, track-point, pen, or touch-pad; the most common non-keyboard computer input device besides the mouse is the track-ball. Few studies have been reported so far evaluating the effects on the operators of using these input devices.

The aim of the present investigation was to study whether there were any differences in posture, muscular load, perceived exertion, preference and productivity during text editing with a mouse compared to a track-ball and if there was a gender difference in the above-mentioned work characteristics that could explain the higher prevalence of neck and upper limb disorders in women.

2. Subjects and methods

2.1. Subjects

Twenty healthy computer operators, 10 men and 10 women randomly selected from a department with about 40 volunteers, participated in the study. They were all professional computer users, working with the window technique and using a mouse or a track-ball beside the keyboard. Mean age among the men was 41 yr (range 29–49) and among the women 47 yr (range 30–56). The men were taller and heavier than the women. Median working hours/week were 40 h in both groups and both groups also reported similar experience of mouse and track-ball use, an average of six and five years respectively (Table 1). They mainly used software such as Word, Excel, Canvas and Delta Graph. All subjects used their right hand for the non-keyboard computer input device.

All subjects were informed of the aim of the study and the study design. Most of the subjects were

Table 1
Data about participating subjects

	Men	Women
Number (*n*)	10	10
Age, years (mean; range)	41 (29–49)	47 (30–56)
Body length, cm (mean; range)	182 (172–191)	166 (156–173)
Body weight, kg (mean; range)	81 (70–101)	60 (45–82)
Work hours/week (mean; range)	40.2 (32–50)	37.6 (30–42)
VDU work in % of working day (mean; range)	49 (30–84)	43 (20–70)
VDU work experience, month (mean; range)	114 (6–264)	100 (26–324)

familiar with both a mouse and a track-ball, and moreover all subjects practised for at least one week in their ordinary work with the two input devices used in the study. On the day of measurement, more detailed information of the study was given and everyone received a personal presentation of the procedure and the questionnaires to be filled in.

This study was approved by the Ethics Committee of the Karolinska Institute, Stockholm.

2.2. Methods

2.2.1. Experimental set-up

The study was performed in a laboratory with a modern, adjustable workstation. The desk and the chair were easy to modify for differences in anthropometric data among the subjects who adjusted the heights and working positions themselves. The chair had two ordinary, removable armrests and the subjects could choose to use them or not, according to their habits. There was adapted light and a manuscript holder.

All subjects corrected a given text during fifteen minutes, using a mouse (Apple® BusMouse II) or a track-ball (Kensington Tracball) in randomized order. The number of pages corrected and the number of errors with each input device were calculated.

The screen of the computer was in a fixed position at a distance of 0.50 m from the front edge of the work table, and the height from the work table surface to the mid-point of the screen was 0.30 m. After all subjects had adjusted the workstation, workstation dimensions were compared with anthropometric data (Table 2).

2.2.2. Postures

Postures of the neck, shoulder, elbow and wrist of the right hand side were registered with an optoelectronic three dimensional (3D) motion analysis system, the MacReflex system, version 3.0 (Qualisys, Gothenburg). This was done by using 4 cameras with video processors, a Macintosh computer and 11 markers attached to the subject (Fig. 1).

All eleven markers attached to the study subjects were recorded by at least two cameras at a time. Markers 1–4 (head, neck, shoulder, elbow, Fig. 1) were recorded by camera 1, 2 and 4 and markers

Table 2
Anthropometric data and workstation dimensions

	Men ($n = 10$) mean (range)		Women ($n = 10$) mean (range)	
Sitting height, cm	136 (126–144)		125 (120–135)	
Eye height, cm	125 (116–132)		116 (108–125)	
Shoulder height, cm	108 (101–114)		98 (92–108)	
Elbow height, cm	69 (66–73)		62 (58–72)	
Popliteal height, cm	48 (44–53)		43 (39–47)	
	Mouse work	Track-ball work	Mouse work	Track-ball work
Chair height, cm	54 (47–75)	52 (50–55)	49 (45–54)	49 (45–54)
Table, height, cm	74 (70–76)	74 (70–76)	71 (70–71)	71 (70–71)
Keyboard position, cm				
depth	21 (0–33)	22 (10–34)	16 (8–25)	16 (9–24)
width	8 (4–13)	7 (2–15)	7 (5–11)	7 (4–8)
Input device position, cm				
depth	26 (12–32)	27 (15–38)	16 (8–24)	20 (10–27)
width	35 (30–38)	32 (0–40)	35 (31–47)	38 (33–41)
Work surface below (−) or above (+) elbow height	0 (− 5–4)	0 (− 5–4)	3 (− 5–9)	3 (− 5–9)
Eye height, cm	125 (118–130)	125 (118–130)	118 (108–128)	118 (113–125)

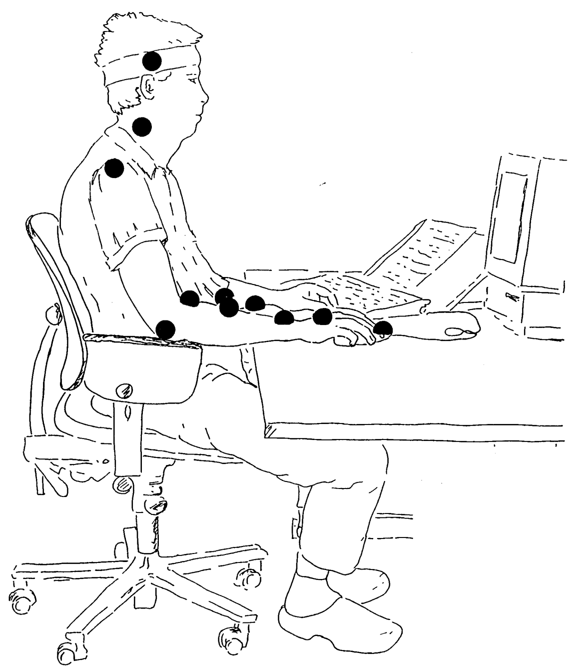

Fig. 1. Placement of eleven markers attached to the subject.

5–11 (forearm, reference coordinate system, wrist, hand surface, mouse, Fig. 1) were seen by camera 3 and at least one of the other three cameras.

The sampling frequency was set to 10 Hz and registrations were made during the last five minutes of the total 15-minute work period with each input device.

When the subject had adjusted his/her workstation the MacReflex measurement system was calibrated with a calibration reference frame. The frame had a size that covered the field of view for all cameras, had six markers, and was placed on the work table during the calibration procedure.

Just before the registrated work period, the subject's reference posture was collected in a starting position (upright sitting, looking straight ahead with an angle of 90° in elbows and palms on the edge of the table).

Flexion was calculated in the neck, the right shoulder, the right elbow and the right wrist. Abduction and rotation of the right shoulder and deviation of the right wrist were also calculated. Postures and joint motion were defined according to the American Academy of Orthopedic Surgeons (Greene and Heckman, 1994). Negative values were used for angles of extension and inward rotation of the shoulder and radial deviation and flexion of the wrist.

In addition, to document body postures during the whole work period of 15 min, video recordings in the sagittal plane were made.

2.2.3. *Muscular activity*

A digital telemetric ME4001 EMG Analysis System equipment (Mega Electronics Ltd, Finland) was used for measuring electromyographic (EMG) muscle activity. The raw EMG signal was root mean square (RMS) detected at a time constant of 100 ms. Data collection was made with BioPac, Qualisys Synchronized Unit, where EMG signals were collected synchronized with MacReflex measurements during the last five minutes of the total 15-min work period with each input device. EMG-data from BioPac were then transferred to a Macintosh computer for editing in the AcqKnowledge program.

Surface electrodes (Medicotest A-10-S) were placed in pairs with 30 mm centre distance, upon carefully prepared skin overlying the muscles studied (Delagi et al., 1981). All electrodes were placed by the same person (A.I.).

Muscle activity was studied from the following muscles:

- M. trapezius, pars descendens, sinister (midpoint between the two electrodes was 10 mm lateral of half the distance between C7 and acromion) (Jensen et al., 1993),
- M. trapezius, pars descendens, dexter (as above),
- M. deltoideus dexter (front part),
- M. extensor digitorum dexter (midpoint between the two electrodes was 1/3 of the distance between the lateral epicondyle and the lateral styloid process).

To set EMG baselines, the subject relaxed for 30 s before the registrations with each input device, and again after finishing the last test.

At the beginning of the recordings the subject performed standardized *maximal* contractions to obtain the Maximal Volontary Electrical activity (MVE) of all relevant muscles. This was done against manual resistance and performed by the same person every time (TR).

2.2.4. Subjective ratings

After finishing the work with each input device, the subjects made a personal rating of perceived exertion, ranging from 0 to 14, in eyes, neck, back, right and left shoulder/arm/hand (modified Borg scale, Borg, 1970). In addition they compared the last input device with the previous one (i.e. the one just tested). They compared (1) how easy it was to change between keys and input device, (2) usability of the input device, (3) exertion in the shoulder and (4) exertion in the hand/forearm. When comparing, the previous input device was always set to zero on a scale from -4, much worse/much less to $+4$, much better/much more. Ratings from each subject were normed from the mouse $=0$ when input devices were compared. The preferred input device was noted.

2.3. Statistics

As data was normally distributed all descriptive data is presented as means with SD or range. Data from the two input devices were analysed by two-way ANOVA for repeated measurements, with gender and input device as independent variables (SuperANOVA®). *P*-values less than 0.05 were considered as statistically significant and tendencies are marked non-significant (ns). When production (number of corrected pages and number of errors) and %MVE were compared, 95% confidence intervals for the differences between means were calculated with the *t*-distribution (Gardner and Altman, 1989).

The results of two male subjects were excluded in the analysis of postures and muscular load due to technical recording errors.

3. Results

3.1. Postures

There were only minor differences in postures between the two input devices (Table 3). Wrist extension was larger with track-ball than with mouse use. Work with the mouse led to a higher shoulder elevation than work with the track-ball, both among the men and the women. The women rotated their right shoulder outwards more than the men when using both the track-ball and the mouse. The women also lifted their right shoulder more than the men when working with both input devices (Table 3).

Postures of the neck, shoulder, elbow and the wrist showed large interindividual differences for

Table 3
Mean joint positions with mouse and track-ball operation. Measured in degrees with standard deviation within brackets

	Mouse		Track-ball	
	Men ($n=8$)	Women ($n=10$)	Men ($n=7$)	Women ($n=10$)
Neck flexion	31 (7.3)	24 (8.2)	31 (8.7)	23 (8.2)
Shoulder rotation	7 (6.0)	14 (6.0)	1 (16)	16 (4.6)
Shoulder abduction	21 (5.7)	22 (6.7)	22 (6.3)	24 (6.8)
Shoulder flexion	5 (6.7)	-2 (11)	8 (12)	-2 (7.6)
Wrist extension	24 (11)	21 (5.5)	28 (10)	28 (3.8)
Wrist deviation	11 (4.8)	9 (6.0)	10 (5.7)	9 (6.3)
Elbow flexion	95 (7.3)	87 (8.6)	94 (14)	87 (5.9)
	Mouse		Track-ball	
	Men ($n=8$)	Women ($n=10$)	Men ($n=7$)	Women ($n=10$)
	-11 (11)	0 (11)	-20 (7.2)	-4 (9.3)

Note: Shoulder elevation measured in millimeters, as difference between reference posture and input device: mean with standard deviation within brackets.

the same input device. The results from the analysis of variance showed main effects of gender and input device differences for shoulder elevation, but no interaction (i.e. the effects were the same for the men and the women with both input devices) (Table 4). The effect of input device differences for wrist extension was large and showed no interaction with gender (Table 4). There were differences in shoulder abduction (ns) for the two input devices, with more abduction when the track-ball was used (Tables 3 and 4). The men flexed their shoulder (ns) and bent their neck (ns) slightly more than the women (Tables 3 and 4).

Table 4
Analysis of variance for repeated measurements of joint positions in the neck and the arm, and input devices. Interactions between input device and gender. Two-way ANOVA for repeated measurements with degrees (or mm) as the dependent variable

Source	*df*	*F*-value	*P*-value
Neck flexion			
Gender	1	3.982	0.0633
Input device	1	2.073	0.1692
Input device * Gender	16	1.194	0.2908
Shoulder rotation			
Gender	1	9.358	0.0075
Input device	1	0.812	0.3809
Input device * Gender	16	3.098	0.0975
Shoulder abduction			
Gender	1	0.181	0.6759
Input device	1	4.266	0.0555
Input device * Gender	16	0.603	0.4489
Shoulder flexion			
Gender	1	4.155	0.0584
Input device	1	0.712	0.4113
Input device * Gender	16	1.022	0.3270
Shoulder elevation			
Gender	1	11.231	0.0041
Input device	1	8.554	0.0099
Input device * Gender	16	1.323	0.2670
Elbow flexion			
Gender	1	3.793	0.0692
Input device	1	0.049	0.8276
Input device * Gender	16	0.151	0.7027
Wrist extension			
Gender	1	0.253	0.6216
Input device	1	31.532	0.0001
Input device * Gender	16	3.510	0.0794
Wrist deviation			
Gender	1	0.277	0.6058
Input device	1	0.170	0.6853
Input device * Gender	16	0.642	0.4348

3.2. Muscular activity

The men and the women showed a lower activity in the right trapezius muscle when they used the track-ball than when they used the mouse (Table 5).

There were large interindividual differences in muscular activity for the same input device. The results from the analysis of variance for the four muscles showed differences between input devices in the right trapezius muscle, and between men and women in the right trapezius, the deltoid and the extensor digitorum muscles, but no interactions between input device and gender (Table 6).

Comparison between the two input devices showed a higher activity in left (ns) and right trapezius muscles and the right deltoid muscle (ns) with mouse operation than with track-ball operation (Fig. 2). Track-ball operation entailed a higher activity in the right extensor digitorum muscle (ns) (Fig. 2).

The video recordings showed that all the eight men supported parts of their right arm against the table or the armrest of the chair when using both the mouse and the track-ball. Five of the 10 women supported their right arm when using the mouse and nine when using the track-ball. Since all subjects were using the keyboard (most often without

Table 5
Mean muscular activity (%MVE) with mouse and track-ball operation

	Men ($n = 8$)		Women ($n = 10$)	
	Mouse	Track-ball	Mouse	Track-ball
M Trap sin	5.3 (3.5)	4.7 (3.6)	11.0 (9.3)	9.8 (7.9)
M Trap dx	3.3 (2.3)	2.8 (2.0)	10.3 (7.0)	8.1 (4.5)
M Delt dx	1.3 (0.9)	1.2 (0.7)	3.0 (2.0)	4.8 (3.2)
M Ext dig dx	6.4 (3.5)	6.8 (4.1)	9.1 (2.1)	10.4 (3.2)

Note: Standard deviation within brackets.

Table 6
Analysis of variance for repeated measurements of the four muscles with use of mouse and track-ball, and interactions between input device and gender. Two-way ANOVA for repeated measurements with %MVE as the dependent variable

Source	*df*	*F*-value	*P*-value
Left trapezius muscle			
Gender	1	2.863	0.1100
Input device	1	2.462	0.1362
Input device * Gender	16	0.282	0.6027
Right trapezius muscle			
Gender	1	8.112	0.0116
Input device	1	6.509	0.0213
Input device * Gender	16	2.606	0.1260
Right deltoid muscle			
Gender	1	9.827	0.0064
Input device	1	2.863	0.1100
Input device * Gender	16	3.660	0.0738
Right extensor digitorum muscle			
Gender	1	4.601	0.0476
Input device	1	2.896	0.1081
Input device * Gender	16	0.997	0.3329

arm support) as well as one of the input devices it is not possible to draw any conclusions from arm support and %MVE in the right trapezius muscle. If we compare the two input devices during the sessions when the right arm was fully supported, with %MVE, we find that out of a total of 10 work sessions (5 with the mouse and 5 with the track-ball) with fully supported right arm, all 5 with the track-ball also demonstrated the lowest %MVE in the right trapezius muscle.

The analysis of anthropometric data and workstation dimensions showed that 9 subjects (of the 18 from whom technical recordings were available) adjusted the work surface to be 30 to 90 mm above elbow height during work. The other 9 subjects chose the work surface to be less than 30 mm above their elbow height. The EMG results showed lower activity ($p < 0.05$) in both trapezius muscles and the deltoid muscle among the subjects who had chosen the work surface to be lower than 30 mm above their elbow height during work performance with both input devices.

The women showed a higher muscular activity in the right trapezius and deltoid muscles than the

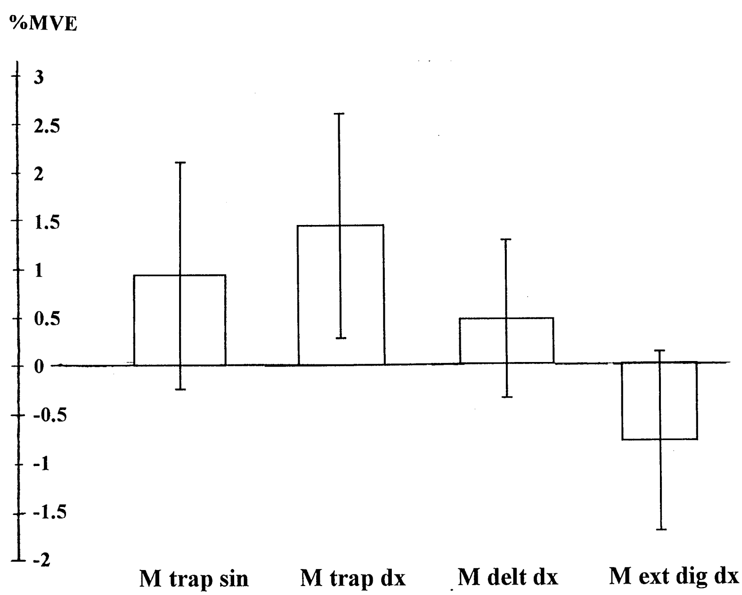

Fig. 2. Results of EMG-data presented as mean difference of %MVE for mouse/track-ball operation. Difference in means is given as 95% confidence intervals in left upper trapezius (M trap sin), right upper trapezius (M trap dx), right deltoid (M delt dx) and right extensor digitorum (M ext dig dx) muscles.

men for both input devices (Table 5). In the other two muscles the women also showed higher muscle activity for both input devices, but it was non-significant (Table 5).

On average the men used between 25% and 71%MVE of the women's. The largest difference was in the deltoid muscle and the least in the extensor digitorum muscle.

3.3. Subjective ratings

There were no main differences in perceived exertion ratings, on the Borg scale (0–14), between the two input devices. However, there were large interindividual differences for the same input device. The women showed a higher mean score in all 13 assessed body locations than the men, but it was non-significant (Table 7). However, the women showed, from the summation of the 13 body locations, a higher mean score of perceived exertion than the men. The mean difference for the mouse was: men–women −1.40 with 95% confidence intervals −2.53– −0.27. For the track-ball the corresponding values were −1.20 (−2.34– −0.06).

Comparison data between the two input devices (on the scale −4 to +4) showed only small differences. On the question of "how easy it was to change between keys and input device" both the men and the women rated a higher score for the mouse (ns). The men rated usability of the input device and exertion in the shoulder (on the scale −4 to +4) higher for the mouse than for the track-ball (ns). Both the men and the women rated exertion in the hand/forearm (on the same scale) higher for the track-ball than for the mouse (ns) (Table 8). Six of the male and 6 of the female operators preferred to work with the mouse while the other 8 operators preferred the track-ball.

3.4. Productivity

The women corrected more pages of the text (ns) when using the mouse than using the track-ball (Tables 9 and 10). The women made more errors than the men when working with the track-ball and the men made more errors with the mouse (ns) than with the track-ball (Tables 9 and 10).

4. Discussion

In this study the mouse and the track-ball were evaluated concerning physical and user preference aspects. A hypothesis was that an input device offering low physical load, high comfort and good subjective usability would be an efficient tool.

Table 7
Mean perceived exertion with mouse and track-ball operation. Measured in modified Borg scale (0–14) with range within brackets

	Mouse		Track-ball	
	Men ($n = 10$)	Women ($n = 10$)	Men ($n = 10$)	Women ($n = 10$)
Eyes	4.1 (0–7)	5.4 (1–9)	4.3 (0–7)	5.7 (1–9)
Left shoulder (scapular)	1.0 (0–3)	2.1 (0–6)	1.1 (0–3)	2.6 (0–6)
Left shoulder joint (upper arm)	1.0 (0–3)	2.2 (0–6)	0.9 (0–3)	2.5 (0–7)
Left elbow	0.9 (0–3)	2.1 (0–6)	0.9 (0–3)	2.3 (0–7)
Left wrist	0.9 (0–3)	1.3 (0–3)	1.1 (0–3)	2.1 (0–7)
Left hand/fingers	0.9 (0–3)	1.3 (0–3)	0.9 (0–3)	1.5 (0–3)
Neck	2.8 (0–7)	4.7 (1–9)	2.8 (0–7)	4.0 (0–10)
Right shoulder (scapular)	2.9 (0–6)	4.7 (0–11)	2.5 (0–7)	4.4 (0–9)
Right shoulder joint (upper arm)	2.1 (0–5)	4.7 (0–11)	2.1 (0–7)	4.5 (0–9)
Right elbow	1.8 (0–7)	4.1 (0–8)	2.9 (0–7)	3.9 (1–8)
Low back	2.3 (0–7)	3.0 (0–5)	1.9 (0–7)	3.1 (0–6)
Right wrist	1.9 (0–6)	3.7 (1–10)	3.7 (0–9)	4.7 (1–10)
Right hand/fingers	1.4 (0–5)	3.0 (1–7)	3.8 (0–9)	3.2 (1–7)

Table 8
Subjective ratings of the track-ball in relation to the mouse when normed for the mouse = 0 on a scale running from − 4 (much worse/much less) to + 4 (much better/much more). Mean values

	Men (n = 10)	Women (n = 10)
How easy it was to change between keys and input device	− 0.6	− 0.2
Usability of the input device	− 0.5	0.0
Perceived exertion:		
in the shoulder	− 0.2	0.0
in the hand/forearm	0.7	0.3

Table 9
Mean productivity, described as number of pages corrected and number of errors

	Mouse		Track-ball	
	Men	Women	Men	Women
Number of pages	2.8 (0.82)	3.1 (0.84)	2.7 (0.67)	2.6 (0.74)
Number of errors	8.9 (3.57)	9.4 (4.43)	5.8 (4.18)	10.8 (3.36)

Note: Standard deviation within brackets.

Table 10
The mean difference of productivity described as number of pages corrected and number of errors

	Mean difference	95% CI for difference in means
Number of pages		
Mouse (men/women)	− 0.3	− 1.08–0.48
Track-ball (men/women)	0.1	− 0.56–0.76
Men (mouse/track-ball)	0.1	− 0.60–0.80
Women (mouse/track-ball)	0.5	− 0.24–1.24
Number of errors		
Mouse (men/women)	− 0.5	− 4.28–3.28
Track-ball (men/women)	− 5.0	− 8.56– − 1.44
Men (mouse/track-ball)	3.1	− 0.55–6.75
Women (mouse/track-ball)	− 1.4	− 5.09–2.29

Note: The difference in means is given as 95% confidence intervals.

4.1. Comparison between the mouse and the track-ball

4.1.1. Posture

There were only minor differences in the subjects' postures between the two input devices. However, the analysis of work postures showed a lower shoulder elevation with track-ball than mouse use for both the men and the women. This may depend on differences in the subjects' working techniques between mouse and track-ball use. Whole arm movements that activated the shoulder muscles when using the mouse have earlier been indicated (Karlqvist et al., unpublished paper). It may be easier to relax the shoulder when using the track-ball, since only the fingers were moving the "ball". On the other hand, track-ball use entailed larger wrist extension, both among the men and the women, with an accompanying higher muscle activity in the extensor digitorum muscle (ns). The track-ball used in this study was a Kensington Tracball, which is designed with a big "ball" in the centre of a plate, which causes hand/finger activity about 50 mm above the surface of the table. No extra support (pad) was used in the study to lower the distance to the "ball" and that may be one reason for the large wrist extension.

4.1.2. Muscular load

Since our study concentrated on computer mouse and track-ball operation, the expectations were that shoulder muscle load would be similar for the two input devices due to the similar location of the two tools. However, track-ball use in our study, led to a lower activity in the right trapezius muscle than mouse use, both among the men and the women. This could depend on differences in the subjects' working techniques between the two input devices described above: a lower shoulder elevation and more relaxation of the arm during track-ball use. Similar results (decreased shoulder muscle activity) have been reported with track-point use (a track-point is an input device which is placed in the centre of the keyboard) compared with mouse use (Fernstrom and Ericson, in press).

The trapezius activity on the left side followed the same pattern as that of the right side, even though all subjects used their right hand for the non-keyboard computer input device. This may be an effect of contralateral muscular activity and/or neck flexion (Schüldt and Harms-Ringdahl, 1988).

4.1.3. Subjective ratings

There were no main differences in the subjects' perceived exertion ratings between the two input devices. The large wrist extension, when using the track-ball, may have influenced the subjective ratings, since 12 of the 20 subjects preferred to work with the mouse if they had to choose one of the two devices in the study.

4.1.4. Productivity

There were no differences in productivity between the two input devices.

4.2. Comparison between the men and the women

4.2.1. Posture

The analysis of work postures showed gender differences. The women rotated their right shoulder outwards more than the men when using both the mouse and the track-ball. The subjects adjusted the workstation themselves and could therefore locate the keyboard, mouse and track-ball where they wanted. The length of the keyboard seemed to determine the location of the other input devices (Karlqvist et al., 1994). Most subjects put the keyboard just in front of them and placed the mouse and the track-ball further away and laterally to the keyboard. Since this entailed more outward rotated shoulder for the women, it probably reflects anthropometric differences between males and females in our study group. Anthropometric studies have shown that men are more broad-shouldered than women (Pheasant, 1986). The women abducted their right shoulder more when using the track-ball, which was reflected in an increased activity in the deltoid muscle. Extreme outward rotation and abduction in the shoulder cause high biomechanical load in neck/shoulders (Harms-Ringdahl, 1986). Gender differences in neck and shoulder flexion were seen, but were similar for the two input devices. The men bent their neck slightly more than the women. The reason could be that the screen was placed at a fixed height and the men were taller than the women. No extremes were found in the neck flexion (Harms-Ringdahl and Ekholm, 1986), and the results were in accordance with findings in other studies among VDU-operators (Hünting et al., 1981; Grandjean, 1988; Sauter et al., 1991; Bergqvist et al., 1995).

4.2.2. Muscular activity

The analysis of variance showed gender differences in %MVE for the right trapezius, the deltoid and the extensor digitorum muscles. The women showed a higher activity than the men. This may relate to the lower muscle strength among the women, and to anthropometric differences which also influence biomechanical load moments. Another reason may be the observed differences in working techniques. Among the subjects who had adjusted their work surface to be lower than 30 mm above their elbow height (6 of the 8 men and only 3 of the 10 women) and supported their right arm against the table or the armrest the lower activity in both trapezius muscles and the deltoid muscle was obvious. This is in accordance with studies of musculoskeletal loads and biomechanical torques in neck/shoulders (Hagberg and Sundelin, 1986; Harms-Ringdahl, 1986; Schüldt et al., 1987; Sundelin and Hagberg, 1992).

4.2.3. Subjective raings

There were great interindividual differences in perceived exertion for the same input device. Although not significant in each assessed body localisation, the women rated a higher score than the men (Table 7). The mean score was highest for the eyes in both groups and then came the neck and the right side of the upper limb. This is in accordance with findings in other studies among VDU-operators (Bergqvist et al., 1995; Karlqvist et al., 1995). There was a higher mean score (ns) of perceived exertion in the right wrist and hand, both with the Borg scale and with the comparing scale (-4 to $+4$), when the track-ball was used, which mirrors the large wrist extention. Accordingly, there was a lower mean score (ns) of perceived exertion in the shoulder (both scales), when the track-ball was used, which mirrors the lower %MVE in the trapezius muscles. The men were more negative towards the usability of the track-ball than the women.

4.2.4. Productivity

Productivity should be a good measure of an efficient tool. Our study showed only minor differences in productivity between the mouse and the track-ball: more corrected pages with the mouse (ns) for the women, and fewer errors with the track-ball (ns) for the men. These results are contradictory and have to be analysed in a more detailed way.

All subjects have given comments on the two input devices and a summary showed: (1) the mouse was easier to control and better for precision; (2) the track-ball was (a) more comfortable for the arm ("easier to find a relaxed posture") and did not need big arm movements, (b) too uncomfortable for the wrist ("too high over the table") and the "ball" was too difficult to control ("too unstable and big for my hand" – comment from 4 women) which led to problems in placing the cursor and entailed more errors for the women.

Maybe the work period of 15 min was too short to fully discriminate between the two input devices. Nevertheless, an efficient tool has to take a lot of different factors into consideration: the operator's joint position, muscle activity, anthropometry and human-computer interaction.

4.3. Limitations of the study

The direct measurements in this study were collected during a time period of only five minutes for each input device, while the subjective ratings covered the whole work period of 15 min for each input device. When the MacReflex system is used, short sampling periods are necessary due to time-consuming data analysis. However, all subjects were experienced computer operators (familiar with both input devices) and should not have had any initial difficulties in performing the work.

Muscle activity was studied from only four muscles. The reason for choosing these four muscles was based on earlier reports on musculoskeletal symptoms and muscular loads during VDU work (Sundelin and Hagberg, 1992; Schüldt and Harms-Ringdahl, 1988; Harms-Ringdahl, 1986; Armstrong et al., 1995; Fernstrom and Ericson, 1997).

The work performed in this study was text editing and it was done in a laboratory setting and not in an ordinary work place. The results should be generalized with great care. There are many types of mice and track-balls on the market today and this study used only one of the standard mice and one of the standard track-balls. The software parameters were regulated for normal use and with the same mean velocity for all subjects.

4.4. Practical implications

Different input devices e.g. mouse, track-ball, track-point, pen, or touch-pad cause different levels of muscular load in neck/shoulder and hand/forearm muscles. Joint positions also seem to differ, depending on the size and design of the input device and the operators' anthropometric dimensions. Important generalizations are:

- an input device offering natural shoulder joint positions with supported arm and few arm movements causes a low shoulder muscle activity,
- an input device offering natural hand/wrist joint positions with supported forearm/wrist and a balanced pointer, designed for the size of the hand, gives a low forearm muscle activity.

The operators should be offered different input devices in order to reach local load variation.

5. Conclusions

- Work with the track-ball entailed lower shoulder elevation and less shoulder muscle activity than work with the mouse.
- Work with the track-ball entailed more wrist extension than work with the mouse.
- Arm support reduced muscle load in the neck/shoulder region.
- A table height lower than 0.03 m above elbow height allowed arm and shoulder support without undue shoulder elevation.
- Gender differences were observed in working technique.

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