Where Does the Mouse Go? An Investigation into the Placement of a Body-Attached TouchPad Mouse for Wearable Computers

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Abstract: We investigated the effects of placement of a TouchPad input device on a user's body for the control of a wearable computer. This study involved 25 subjects performing selection tasks with a TouchPad mouse while wearing a wearable computer on their back and using a head-mounted display. Each subject performed the tasks in 27 different combinations of four postures (sitting, kneeling, standing and prone) and seven different placements of the TouchPad mouse on the subject's body (forearm, thigh by 2, torso by 2, and upper arm by 2). We measured the time and error rate to complete the selection of a circular target. The results for the effects due to posture showed that there were similar time effects for sitting, standing and kneeling. When examining the effects resulting from mouse position, the front of the thigh was shown to be the best position of the mouse. When the posturing and mouse position conditions were combined, the results indicated that the thigh front mouse position would be most appropriate for sitting, kneeling and standing postures, and the forearm mouse position would be best for the prone position.

Keywords: Evaluation; TouchPad mouse; Wearable computers

1. Introduction

A *wearable computer* is a new physical form of a portable computer [1,2]. Instead of the computer being hand-held, it is attached to the user by a backpack or belt, so leaving the hands free when it is in use while the user views data in the privacy of a head mounted display (HMD). The application areas for this form of computer range from factory monitoring, stocktaking, and field data collection, to soldiers in the field. We believe the notion of hands-free operation is critical to the successful use of wearable computer systems and, as such, this study investigated possible placements of an input device on different portions of the user's body while the user assumed different postures (sitting, standing, kneeling and prone).

The placement of wearable computer devices on the user's body is critical to the usability of that computer system. Issues of weight, size and position of these devices are essential for the overall comfort and ease of use. In particular, the positioning of input devices is of concern for the operation of a wearable computer in applications that require the user to assume a varied set of postures. Maintenance tasks are a good example of such an application. As noted with the VuMan project, users were required to assume a wide array of postures and still be able to manipulate the computer. For example, while a user is repairing a large piece of machinery, they must be able to operate the computer while lying on their back and stomach, standing, kneeling and sitting. Many other areas, such as biology field observation, construction or military, require users to assume postures other than standing. This study is an investigation into how well users perform a selection task with a 2 degree of freedom pointing device while varying the their posture and the placement of the pointing device.

We were inspired by the paper "Design for Wearability" [3], where Gemperle et al. produced 13 design guidelines to help map the design space for developing wearable systems. We wish to apply six of Gemperle's guidelines to the use of input devices for a wearable computer in outdoor situations, as follows: placement, form, human movement, sizing, attachment and accessibility. Current workstation input devices (such as mouse, joystick and keyboard)

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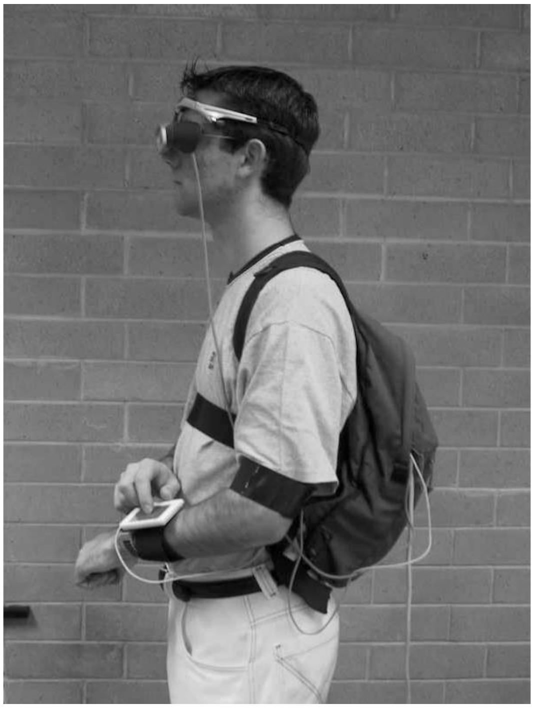

Fig. 1 The wearable computer used in the study.

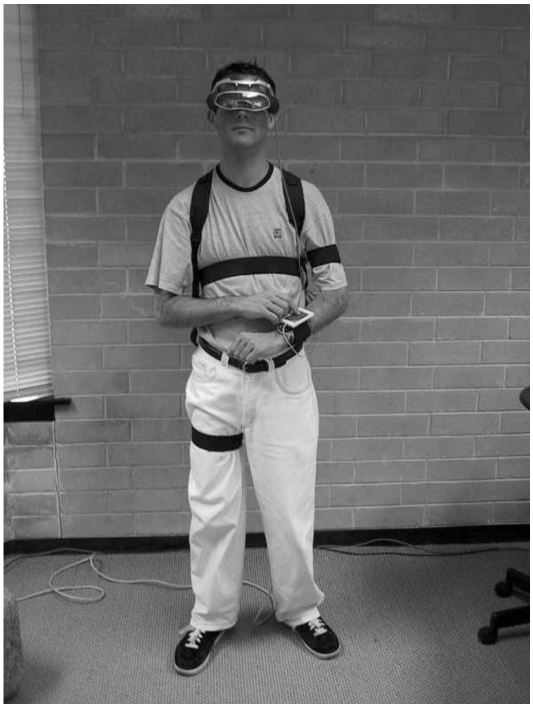

Fig. 2 Standing posture with the mouse on the forearm.

would not be practical for users standing in an outdoor environment, as such devices require a level flat surface to operate. A new form of input device is required, but how would users interact with this new kind of input device? For example, how does one point or select objects displayed on a head mounted display (HMD)? And how does one enter text or commands without a desktop keyboard?

One solution to the first question is to place a pointing device on the user's body. A suitable device is the TouchPad mouse, commonly found on Apple laptop computers. An example of a TouchPad mouse is shown in Fig. 1. Where on one's body should such a device be placed? This study evaluates the effect of the placement of a TouchPad mouse on a user's body.

2. Aims

We *aimed* to determine whether there was any measurable difference to a user operating a wearable computer (Fig. 1) with a TouchPad mouse when the following factors are varied: first, the position of the TouchPad mouse on the user's body (forearm, upper arm, torso, thigh front or thigh outer side); second, the posture of the user (standing (Fig. 2), sitting (Fig. 3), kneeling (Fig. 4), or in the prone position, lying down with the user propped up on their forearms (Fig. 5)). The study measured differences in time to complete selection tasks and the number of errors that occurred.

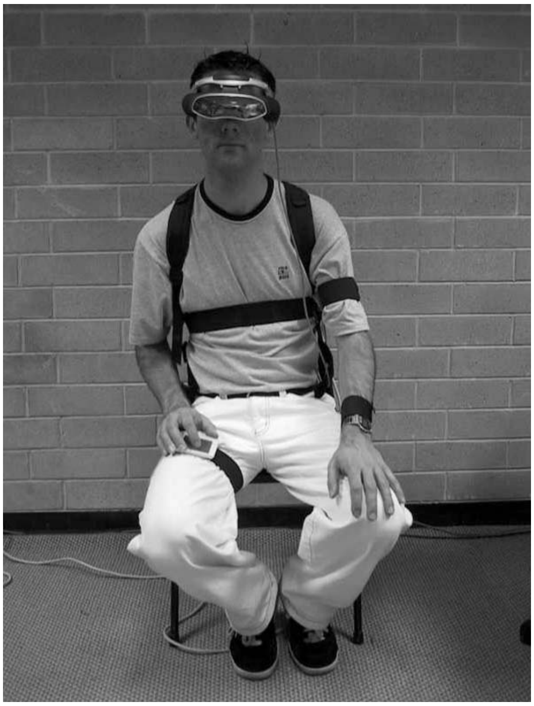

Fig. 3 Sitting posture with the mouse on the thigh.

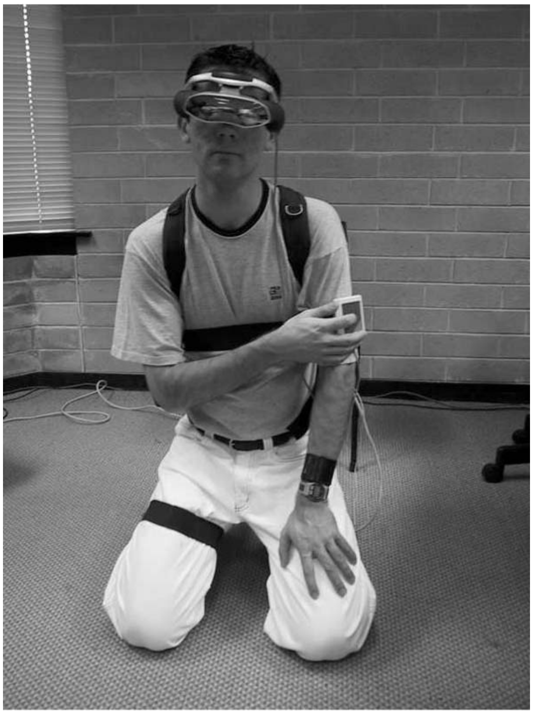

Fig. 4 Kneeling posture with the mouse on the upper arm.

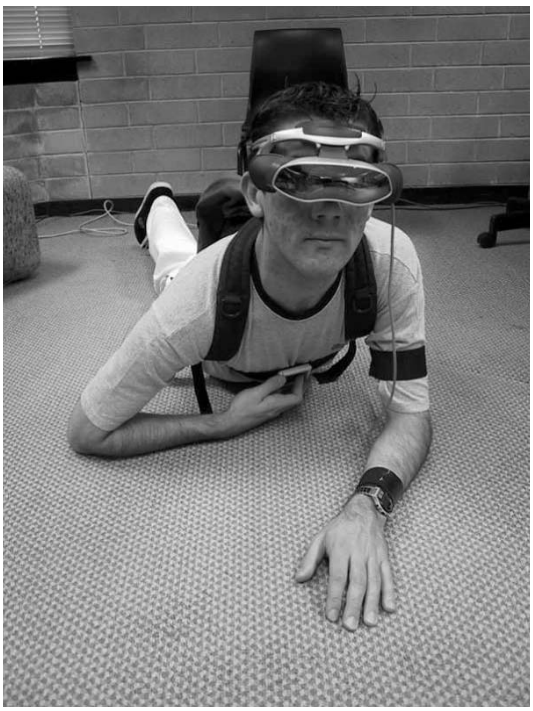

Fig. 5 Prone posture with mouse on the torso.

The study's *objectives* were twofold.

1. To determine the speed and error rate at which a subject can position the mouse cursor starting at a given target and selecting a final target for each of the above conditions. An error is defined as missing the target while attempting to select it.
2. To determine if there is a difference between the different positions on the user's body to which the TouchPad mouse is attached, and if there is a difference, to establish a ranking of effectiveness based on completion time and error rate.

Our hypothesis was that there was an optimal position for the TouchPad mouse in terms of operator performance and reported comfort levels.

3. Evaluating Computer User Input Devices

The traditional method for evaluating computer user input devices is based on the following measures: the time it takes to finish a given task; the number of errors recorded during the given task; and ratio of errors to time taken. These three dependent measures have been defined in the proposed standard, *ISO 9241 Ergonomic Requirements for Office Work with Visual Display Terminals, Part 9 Non-keyboard Input Devices Requirements* [4]. A number of tasks for the evaluation of user input devices may be modelled by Fitt's Law [5], which can predict time required for a person to move a part of their body from a home position to a stationary target. Fitt's Law can be expressed by the following equation:

$$MT = a + b \log_2 \left[\frac{2A}{W} \right]$$

where MT is movement time (the mean time it takes to finish the given task), A is the distance from the home position to the target centre, and W is the target width. The constants a and b are regression coefficients. The value of $b \log_2 (2A/W)$ is called the "index of difficulty"; the movement time is predicted to increase if either the movement distance A increases or the target width W decreases.

As mentioned above, Fitt's Law is a commonly-used tool in the evaluation of user interfaces [6]. In the case of evaluating an input device or technique, a customary task is to point and select a graphical object on a monitor. An example is the study by Kabbash et al. [7], which examined the performance of preferred and non-preferred hands while using three different devices: a mouse, a trackball, and a tablet-with-stylus. Subjects moved a cross-haired cursor back and forth between rectangular targets and selected each target by pressing and releasing a button on the mouse or trackball, or by applying and releasing pressure on the stylus. A similar procedure was utilised in a study investigating different selection techniques while using a TouchPad mouse (a similar device used in this study) [8]. Not all targets used in studies are rectangles; Campell et al. [9] used a semi-circular curved track to investigate a subject's ability to navigate a cursor along a non-linear path.

There are few empirical studies investigating the usability of input devices for wearable computers. Our study "Evaluation of text input mechanisms for wearable computers" is one of these investigations [10]. We compared three different input devices for text entry while a user wore a wearable computer in a standing posture. The devices were as follows: a forearm-mounted QWERTY keyboard, a five-button cording device, and an isometric mounted button that controlled a virtual keyboard displayed on the HMD. The forearm-mounted keyboard was found to be superior. A second study by Goldstein et al. [11] investigated two new wearable one-handed input paradigms, the finger-joint-gesture palm-keypad glove and the invisible phone clock. These were benchmarked against a traditional one-handed cellular phone keypad input device. No significant difference in error-corrected text entry speed was found between the different devices. Goldstein et al. [11] felt that these new input paradigms could be suitable candidates for new fragmentised interfaces where wearability is the key issue.

There have been a number of investigations into the overall usability of wearable computers for specific application domains. We present an overview of the types of investigations as a background into this field of study. A preliminary investigation by Ockerman and Pritchett [12] examined how the capabilities of wearable computers may be used to provide task guidance in mobile environments to aid a user in an inspection task. This study used as a case study the procedural task of pre-flight inspection of a general aviation aircraft. A second usability evaluation by Siegel and Bauer [13] was aimed at collecting accurate, detailed information for use in the evolutionary design and development of wearable systems for vehicle maintenance workers. Siegel and Bauer reported that all participants were able to complete their tasks using the wearable prototype and expressed willingness to use such a system in the future. Stein et al. [14] describe a commercially successful wearable data collection system. Their system is wrist mounted and specially designed for use in a package handling environment. Issues of long-term use and operation in rugged circumstances are examined. A second investigation into building an industrial wearable computer by Siewiorek et al. describes the importance of industrial design for the overall usability of a wearable computer [15]. Bauer et al. [16] conducted an empirical study aimed at evaluating the utility of a reality-augmenting telepointer in a wearable videoconference system. The results from their study show how, using the telepointer, a remote expert can effectively guide and direct a field worker's manual activities. They analysed verbal communication behaviour and pointing (via telepointing) gestures and were able to determine that experts overwhelmingly preferred pointing for guiding workers through physical tasks.

4. Where Does One Place the TouchPad Mouse?

Some conventional locations for the placement of input devices for a wearable computer system have been on the forearm, belt mounted and attached to the user's hands. The Phoenix 2 Belt Mounted Computer [17] includes a forearm keyboard and an isometric mouse mounted on top of the battery pack, positioned slightly in front of the right hip. The TwiddlerTM [18] input device attaches to the user's hand by straps, and combines the functions of a pointing device and a keyboard.

A key feature to wearable computing is its portable hands-free operation. The above placements pose a number of difficulties for the user. By placing an input device on the user's forearm, both arms are required to be in a constrained position during input operations. This would, for example, make it impractical for a user to hold another object or to steady themself. Having an input device attached to the user's hand restricts that hand; the user has to either lay the device down or reattach it to a different portion of their body.

In addition to ensuring that the use of the input device does not adversely affect function by impinging on the performance of secondary tasks, the biomechanical demands on the musculoskeletal system require consideration [19]. Placement of the input device in an area that requires the wearer to assume an awkward or sustained posture would adversely affect the *user friendliness* of the wearable computer. Ideally the position of the input device should allow the user to activate the device whilst maintaining the joints involved in a relatively neutral posture.

As an overview of the possible placements, the general areas Gemperle et al. found to be the most unobtrusive for wearable objects are: the collar area; rear of upper arm; forearm; rear, side, front of rib cage; waist and hips; thigh; shin; and top of foot. We deemed as *inconvenient* the placement of a TouchPad mouse in the following positions: rear of upper arm; rear rib cage; shin; and top of foot. In a previous study [10], subjects reported using an isometric mouse on their waist/hip uncomfortable, which leaves the collar area, forearm, side of rib cage, front of rib cage, and thigh as options.

Initially we chose to place the TouchPad mouse on the upper arm (similar relative position for the user's hand as the side of the rib cage), forearm, chest (front of rib cage or collar), stomach, front of the thigh, and side of the thigh. Through informal testing, we found that there was very little difference between placing the TouchPad mouse on the stomach and on the chest. We settled on what we refer to as the *torso*, a placement on the bottom of the subject's sternum.

4.1. Pilot Study

A pilot study was carried out to determine the desired orientation (four possible choices) of the TouchPad mouse for each mouse position. The four orientations relative to the orientation of the subject standing are:

1. 0° up;
2. rotated 90° towards the subject's hand;
3. rotated 180° down; and
4. rotated 90° away from the subject's hand.

To adjust for left and right handedness when the mouse is rotated 90°, we refer to the direction of the mouse buttons. In a normal desktop operation, the mouse is on a desk with the mouse buttons towards the user's hands.

The first part of the pilot study entailed five subjects performing the Chase game in the four different TouchPad mouse orientations, at the five different positions of the body, while standing and using the 800 by 600 resolution HMD. The Chase application is a "chase the dots" game. A game consists of selecting 20 white filled circles one at a time as quickly and accurately as possible. A second target appears with a random combination of the following conditions: *angle* (at an offset in one of eight directions, 45 degrees of arc apart); *distance* (at one of two lengths, 75 pixels or 150 pixels); *size* (having one of two diameters, 25 pixels or 50 pixels). Once each game is over, the subjects are presented with a result summarising how well they performed in terms of total completion time, total number of mouse presses, average completion time per target, and average number of mouse presses per target.

For all five positions, the orientation of the mouse in the directions down or away from the user's hand were not the subjects' preferred

Table 1. Seven combinations of preferred orientations by position.

Position	Orientation	Figure
forearm	towards	6
upper arm	up	7
upper arm	towards	8
torso	up	9
torso	towards	10
front of the thigh	up	11
side of the thigh	up	12

Fig. 6 Mouse position forearm – towards.

Fig.7 Mouse position upperarm – up.

Fig. 8 Mouse position upperarm – towards.

Fig. 9 Mouse position torso – up.

Fig. 10 Mouse position torso – towards.

Fig. 11 Mouse position front of the thigh – up.

Fig. 12 Mouse position side of the thigh – up.

orientations. Table 1 shows the seven combinations of preferred orientations by position and indicates the figure that depicts the use of TouchPad mouse in that orientation and position.

Velcro attaches the TouchPad mouse to one of these positions. The subject wears four custom-made rubberised straps wrapped around their forearm, upper arm, torso and upper thigh. The strap on the subject's thigh is rotated to provide the front and side positions for the TouchPad mouse.

5. Experimental Design

This section describes the design of the experiment, including the wearable computer system, and the training and experimentation sessions. All sessions were performed in the Wearable Computer Laboratory at the University of South Australia.

5.1. Wearable computer system

The hardware portion of the computer system consists of the following components: *Toshiba Portable Personal Computer 320 Series* laptop computer, *Sony Glasstron* see-through 800 x 600 SVGA display, and *Easy Cat*™ TouchPad mouse[1]. The computer and power converters are stored in a small backpack. Although the display and computer can be operated with battery power, the experiment was performed using mains power. The battery life (about two hours) and time to recharge (about one hour) made the use of mains power the preferred option. Figure 1 shows someone wearing the computer system.

Two custom-built applications, *Chase* and *Wheel*, were written using the X-Windows XLib library. These programs are instrumented to record information about where mouse press events occur and time intervals between mouse presses. We used the Linux operating system for the development and operation of these two applications.

5.2. Training session

Before subjects were enrolled into the experiment, they were interviewed so that the scope and requirements of the experiment could be explained, and they signed a consent form. The subjects then underwent a training session to use the TouchPad mouse attached to the top of a desk, using the Sony Glasstron display in the opaque non-see-through mode. During the training task the subjects did not wear the computer in a backpack, but rather sat in a chair next to the desk. This training involved the subjects operating the previously-described Chase application five times in order to optimise the time required to hit the targets.

[1]CIRQUE Corporation, 433 W. Lawndale Dr., Salt Lake City, UT, USA.

5.3. Experimental session

A second experimental session with a duration of about 1.5 hours was performed individually with a supervisor. The supervisor, reading from a script, explained to each subject what was expected of them during the session.

The task the subjects performed during the experiment was to use the TouchPad mouse to select a target place in the centre of the screen, the Wheel application. Once the target had been selected, that target was removed from the screen. A second target was placed with an offset of 183 pixels in one of eight directions, equally spaced around the centre of the screen, shown in Fig. 13. The targets are circles of 40 pixels in diameter. For each trial, the subjects performed 40 tasks in random order; the eight target positions were presented five separate times.

The subjects performed the first trial sitting at a desk using the Glasstron display but without wearing the computer and with the TouchPad mouse attached to top of the desk. Once this trial had been completed, the subjects donned the computer and wore it while performing the remaining tasks.

The subjects then performed a random order of 27 trials with a different combination of posture (four possible postures) and mouse placement (seven possible mouse positions). The four postures were standing, sitting on a chair, kneeling and prone. The TouchPad mouse was placed in one of seven different positions on the subject's body, as described above. (We refer to the combination of mouse position and orientation as *mouse position*.) For obvious reasons, the mouse position on the front of the

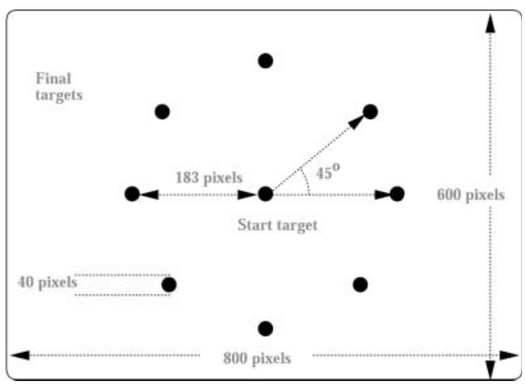

Fig. 13 Eight final positions of the target.

Table 2. Sample set of trials.

Test	Posture	Position
1	preliminary	on desk/up
2	prone	torso/towards
3	standing	thigh front/up
4	kneeling	thigh front/up
5	standing	upper arm/towards
6	sitting	thigh front/up
7	standing	upper arm/up
8	standing	thigh side/up
9	sitting	forearm/towards
10	sitting	upper arm/towards
=	60 sec break	=
11	kneeling	forearm/towards
12	prone	upper arm/up
13	prone	upper arm/towards
14	sitting	torso/towards
15	kneeling	upper arm/towards
16	prone	forearm/towards
17	kneeling	torso/towards
18	kneeling	upper arm/up
19	sitting	torso/up
=	60 sec break	=
20	prone	thigh side/up
21	standing	forearm/towards
22	sitting	thigh side/up
23	prone	torso/up
24	kneeling	torso/up
25	standing	torso/up
26	standing	torso/towards
27	sitting	upper arm/up
28	kneeling	thigh side/up

thigh could not be utilised in the prone posture. Table 2 illustrates a set of trials for a subject.

The data recorded for each trial include the times in milliseconds at which the user selects the start target and each selection until and including the final target. Post-processing of the data is performed to determine the number of errors and total time between the first selection and the final selection of each target.

6. Statistical Analysis

6.1 Subject population

We gathered results from 25 subjects who performed the experiment. Of these, there were 10 males and 15 females, 20 right handed and 5 left handed, and the mean age of the subjects was 27.6 years (min=20, max=38, SD=6.06). The subjects were volunteers from a pool of computer-literate people from the undergraduate and postgraduate students of the School of Computer and Information Science. The level of computer literacy of the subjects was the following: a mean of 12.1 (SD=5.5) years of computer experience; a mean of 9.0 (SD=3.8) years using a desktop mouse; a mean of 24.2 (SD=13.8) hours per weeks using window based applications; and a mean of 1.4 (SD=3.7) hours per week using a TouchPad mouse. Subjects had to be able to walk and have the full use of both arms.

6.2. Experimental data

The data allowed investigation of the independent and interactive effects of subjects' posture, the location of the mouse on the body, the orientation of the mouse when it was located on the torso and on the upper arm, the time subjects took to hit the target, and the number of attempts (clicks) subjects made to hit the target. Longer periods of time indicated increasing difficulty in visual estimation, and more than one click indicated errors in accuracy.

System difficulties during the experiment were reported, particularly influencing the time data by several aberrant (extremely large) values. These errors were dealt with by truncating the data at the 99th percentile, providing a working time range of 721–8371 milliseconds. There was minimal variability in the number of clicks taken to hit the target (93.6% of trials hit the target in one attempt, 5.2% of trials hit it in two attempts, 0.9% of trials hit it in three attempts, 0.2% of trials hit it in four attempts and 0.1% of trials hit it in five or more attempts). Analysis of the data was thus restricted to the most variable and therefore most useful outcome measure: time taken to hit the target.

The effect of the independent variables on time was estimated using analysis of variance models, which took into account the random allocation of subjects into test conditions. A combination variable was developed to integrate the mouse position and orientation – mouse position on torso (button up, button down), mouse position on upper arm (button up, button down), then one orientation of the button for all other mouse positions.

Two models were tested: an "all in" model with all postures, target angles, mouse positions and mouse orientations taken into account; and a "restricted" working model with the baseline posture (preliminary at desk) and mouse position (on desk) eliminated. Similar effects were found for the experimental conditions in both models, and thus the "restricted" model is reported in this paper, as the primary purpose of "sitting at the desk" acted as a refresher (training) aspect of the study.

7. Results and Discussion

We wanted to determine if there was a difference in time taken to complete the task between different positions of the TouchPad mouse attached on different positions of the user's body. If there was a difference, we wanted to rank the experimental conditions with regard to the completion time and error rate. As noted, the error rate was quite low for all conditions and, as such, we concentrated our analysis on the completion time as a measure of performance.

7.1. Experimental data

Significant effects on time taken to hit the target were found for all independent variables and interaction terms, except for the three way interaction term posture*mouse*angle. Table 3 shows the F values, and associated p values and degrees of freedom from the analysis of variance models that tested the independent and interaction effects of the elements for the experimental conditions. Post hoc analysis was undertaken of each of the independent condition effects in order to explore the impact of each condition on time taken to complete testing.

Table 3. Results from ANOVA.

Source	df	F value	P value
subject	24	267.3	<0.01
angle	7	15.5	<0.01
posture	3	113.4	<0.01
mouse	6	400.4	<0.01
subject*angle	168	1.9	<0.01
subject*posture	72	5.3	<0.01
subject*mouse	144	12.6	<0.01
angle*posture	21	1.7	<0.05
angle*mouse	42	3	<0.01
posture*mouse	17	12.2	<0.01
angle*posture*mouse	119	1.1	0.15

7.2. Effect of the target angles

The design of the subject's task was to emulate a user selecting an icon from a random direction. This emulation was performed by having different angles for the second target. Despite its significance in the analysis of variance model, the effect of the target angles on the time taken to complete the task appeared to be similar for all but two angles, as evidenced in the graph shown in Fig. 14, comparing mean values and

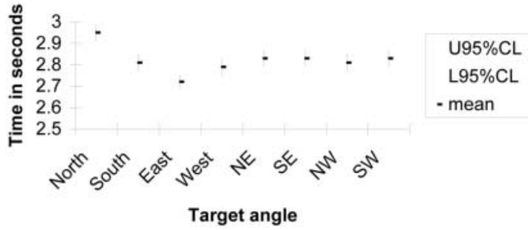

Fig. 14 Mean time for each target angle.

95% confidence limits. The strong effect of these two angles would have produced the significant overall effect of the target angle in both the independent and interaction terms. The north angle incurred a significantly longer mean performance time, while the east-facing angle incurred a significantly shorter performance time, than any of the other angles. Significant differences are observed in these two conditions, as the confidence limits surrounding the mean value of the angle fall outside the confidence limits of the other angles. From these findings, we suggest investigating screen designs that require users to predominantly move the cursor in the "east" direction relative to the screen and avoid the "north" direction.

7.3. Effect of posture

The significant independent and interactive effect of posture was derived from the effect of the prone posture, which incurred a significantly longer effect on time than the other postures. The average time values, standard errors and p values from serially paired t-tests are illustrated in Table 4. Serially paired t-tests comprised sitting and standing, standing and kneeling, kneeling and prone. There was no chance effect incurred by the serial *post hoc* testing (Bonferoni effect).

The results of data show there is a time penalty if we force the user to assume the prone posture while using a wearable computer with TouchPad input devices at these given positions. The difference between the sitting posture and prone posture is in the order of 10%. The total

Table 4. Analysis of posture effect.

Posture	Mean time	SE	p value
sitting	2.73	0.01	
standing	2.81	0.02	> 0.05
kneeling	2.79	0.01	> 0.05
prone	3.02	0.01	< 0.01

time difference over 100 operations is approximately 29 seconds; this size of penalty may be realised for tasks requiring large quantities of button selections, such as browsing a web base manual or using a calculator. Different mouse positions for the prone posture need to be investigated to improve the user's performance.

7.4. Effect of the mouse position and orientation

The effect of the mouse position and orientation on time taken for the task was evident by clustering of sets of experimental conditions, as presented in Fig. 15. The most efficient (shortest mean time) position/orientation appeared to be on the front of the thigh. The position/orientation on the side of the thigh, on the forearm and on the upper arm (orientation towards the body) had similar but less efficient effects on time taken to complete the tasks, and the least efficient mouse positions and orientations were the positions on the torso (orientation up or towards) and on the upper arm (orientation up).

The torso proved to be a poor position for the TouchPad mouse device. This was due to the awkward and uncomfortable position the mouse was placed in. Subjects commented a position of one's "hand over the their heart" (similar to the location of the Star Trek communicator's badge) would be a better position on the torso. This position would be closer to the collar area recommended by Gemperle et al. [3]. The upper arm (orientation up) poor performance was to due to orientation only; the upper arm (orientation up) position was chosen by only one of the subjects in the pilot study, and is not deemed an intuitive position.

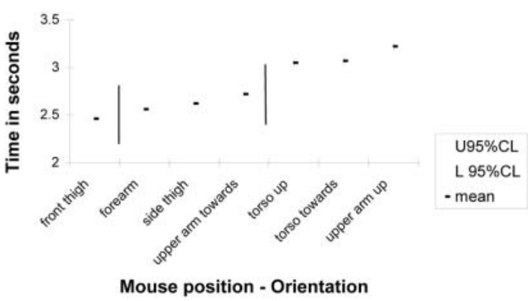

Fig. 15 Mean time for each mouse position.

7.5. Comparing postures, mouse positions and orientations

There were three groupings of postures, mouse positions and orientations that appeared to reflect distinct changes in efficiency, as illustrated in Fig. 16, which depicts the ranking of the mean time in seconds for completing the tasks for each combination. For all experimental groupings, the standard errors were in the order of 0.015–0.025. The three groupings of results were observed from the data; vertical lines highlight these groupings. The first of the three groupings, involving four combinations (sitting and kneeling), incurred the lowest time cost. The break between the first grouping and the second grouping is based on the mean time of task 4 (sitting/forearm) and is less than the lower 95% confidence limit of task 5 (standing/thigh front). The next eight combinations incurred a higher, but similar, time cost, involving a range of conditions and postures (standing, kneeling, prone and sitting). The final break was determined by the upper 95% confidence limit value of task 12, being less than the lower 95% confidence limit of task 13, providing a clear break. These remaining postures and mouse positions incurred increasing time costs.

From these results, the choice of mouse position is dependent on the posture assumed by the user. The use of the thigh front position is quite good for the sitting, kneeling and standing postures. If the application domain required a user to work within a enclosed space which would limit the access to certain portions of their body at different times, input devices may be placed in a number of preferred mouse positions, thigh front, forearm, thigh side, and upper arm towards. These results show there are a number of good position options for these three postures.The best position for the prone position is the forearm; this was the only position within the first two groupings for the prone posture.

8. Subjective Results

Results of the survey given to the subjects at the end of the experiment are presented in this section. The section is partitioned into five subsections corresponding to different information gained from the survey. The first section presents the subjects' reactions to the overall system and the TouchPad mouse itself. The next

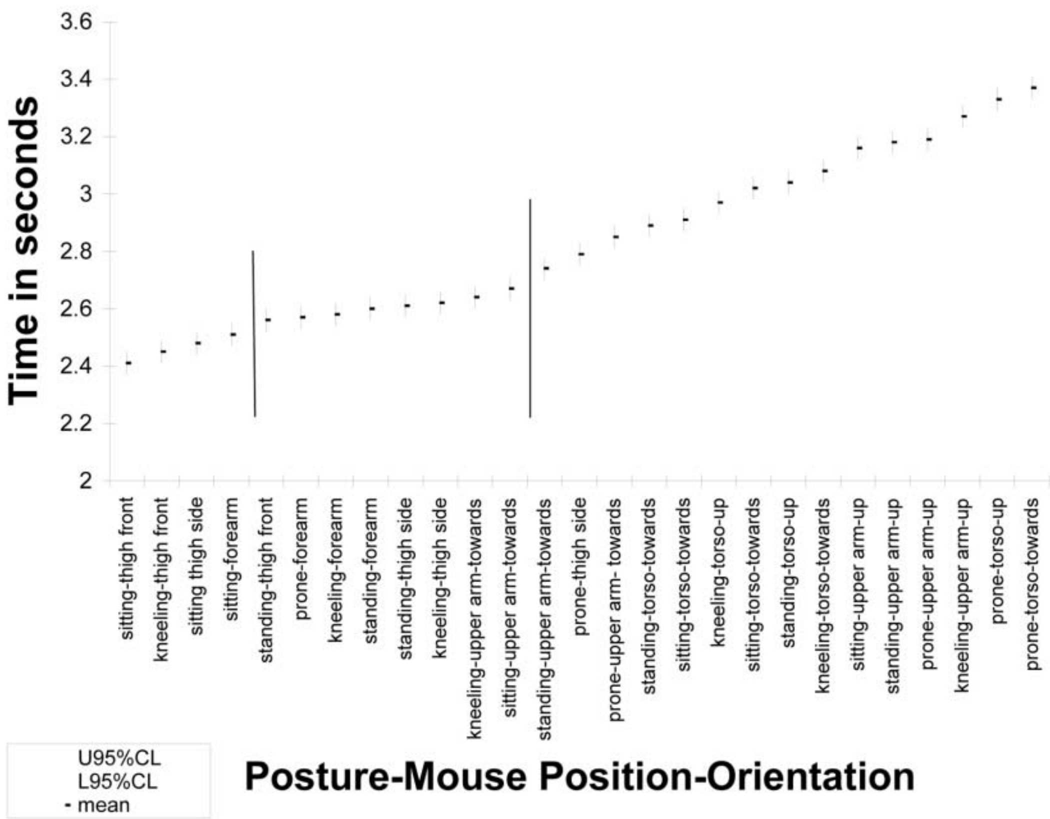

Fig. 16 Ranking by mean time in seconds for the 27 tasks.

section describes the subjects' impressions to the different positions in which the TouchPad mouse was placed. The third section describes the responses to the four different postures the subjects were asked to assume. The fourth section reports on the discomfort the subjects noted during the experiment. Finally, the last section presents in a summary free form comments provided by subjects at the end of the survey.

8.1. Overall reaction to the system and the TouchPad mouse

The first set of questions was about subjects' attitudes towards the overall experimental system and TouchPad mouse. The subjects were asked to quantify these reactions on a 7-point scale by the following four qualities: terrible to wonderful, frustrating to satisfying, dull to stimulating, and difficult to easy. Table 5

Table 5. Overall reaction to the system and the TouchPad mouse.

Question number	Scale	Mean	SD	SE	% below 3.5 (median score) i.e. a negative response
Overall reaction to the system					
5	terrible (1) to wonderful (7)	4.9	1.2	0.5	16
6	frustrating (1) to satisfying (7)	4.4	1.3	0.5	16
7	dull (1) to stimulating (7)	4.3	1.5	0.6	28
8	difficult (1) to easy (7)	5.0	1.4	0.5	20
Overall reaction to TouchPad mouse					
9	terrible (1) to wonderful (7)	4.5	1.4	0.6	24
10	frustrating (1) to satisfying (7)	4.0	1.3	0.5	36
11	dull (1) to stimulating (7)	4.5	1.1	0.4	16
12	difficult (1) to easy (7)	4.4	1.5	0.6	28

shows the results from the survey. The results show that the majority of the subjects were positive or neutral on issues for the overall system and the TouchPad mouse.

8.2. Favoured mouse position

In the survey, subjects were asked their overall reaction to the TouchPad mouse being placed on the forearm, upper arm, chest, front thigh, and thigh outer side. The subjects were asked to quantify these reactions on a 7-point scale by the following four qualities: terrible to wonderful, frustrating to satisfying, wrong location to perfect location, and difficult to easy. Table 6 shows the results from the survey, and Fig. 17 depicts a graph of the mean scores. Comparing the different positions, there is a grouping of most favoured within 1 standard deviation of the mean time for the forearm, upper arm, front thigh, and thigh outer side. As shown with large percentage of mean scores above the median 3.5 score for these four positions. With the chest position the only one clearly less favoured. This was indicated by high percentage of mean scores below the median score of 3.5.

Table 6. Subjects' reactions to TouchPad position.

Question number	Scale	**Mean**	SD	SE	% below 3.5 (median score) i.e. a negative response
Overall reaction to TouchPad mouse placed on forearm					
13	terrible (1) to wonderful (7)	5.4	0.8	0.3	0
14	frustrating (1) to satisfying (7)	5.3	0.8	0.3	0
15	wrong location (1) to perfect location (7)	5.5	1.0	0.4	4
16	difficult (1) to easy (7)	5.6	0.9	0.4	0
Overall reaction to TouchPad mouse placed on upper arm					
17	terrible (1) to wonderful (7)	4.4	1.1	0.4	24
18	frustrating (1) to satisfying (7)	4.4	1.1	0.4	20
19	wrong location (1) to perfect location (7)	4.2	1.4	0.5	32
20	difficult (1) to easy (7)	4.6	1.2	0.5	20
Overall reaction to TouchPad mouse placed on the torso					
21	terrible (1) to wonderful (7)	2.8	1.0	0.4	76
22	frustrating (1) to satisfying (7)	2.7	1.0	0.4	76
23	wrong location (1) to perfect location (7)	2.2	1.0	0.4	84
24	difficult (1) to easy (7)	2.9	0.9	0.4	68
Overall reaction to TouchPad mouse placed on front thigh					
25	terrible (1) to wonderful (7)	5.1	1.4	0.5	12
26	frustrating (1) to satisfying (7)	4.9	1.2	0.5	16
27	wrong location (1) to perfect location (7)	4.9	1.3	0.5	16
28	difficult (1) to easy (7)	5.2	1.4	0.6	16
Overall reaction to TouchPad mouse placed on thigh outer side					
29	terrible (1) to wonderful (7)	5.2	1.1	0.4	4
30	frustrating (1) to satisfying (7)	4.9	1.4	0.5	12
31	wrong location (1) to perfect location (7)	5.2	1.1	0.4	4
32	difficult (1) to easy (7)	5.5	1.3	0.5	4

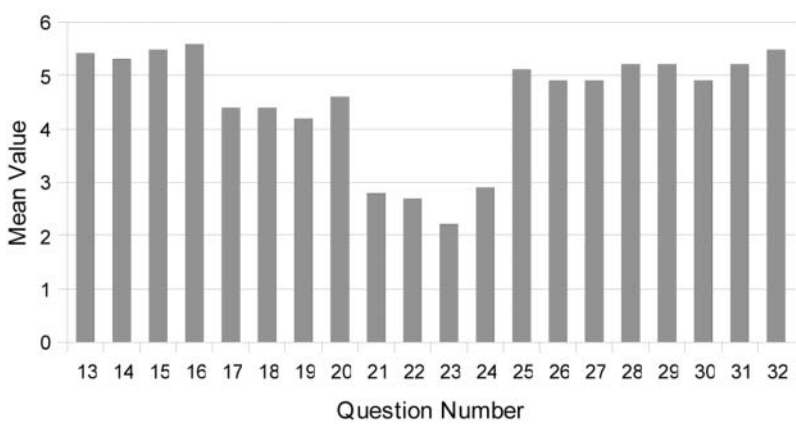

Fig. 17 Graph of subjects' reactions to TouchPad position.

The upper arm position showed a slight disfavour. This may be due to the two different orientations of the upper arm. The objective results showed the upper arm with an orientation towards the user's hand configuration was superior to the orientation of up. A final point is that subjects' show a slight preference (but not statistical significant) for the forearm position. This was shown in both the percent below 3.5 (median score), i.e. a negative response, and the slightly higher mean scores. The subjective finding relates quite well with objective findings describe in the previous section.

8.3. Favoured posture

As with the TouchPad position, subjects were asked their overall reaction to the four postures they were asked to assume: standing, sitting, kneeling and prone. The subjects were also asked to quantify these reactions on a 7 point scale by the following three qualities: terrible to wonderful, frustrating to satisfying, and difficult to easy. Table 7 shows the results from the survey, and Fig. 18 depicts a graph of the mean scores. Comparing the different positions, there is a grouping of within standard deviations of the standing, sitting and kneeling postures. This is also indicated by the high percentage of scores above the median score value. The prone posture stood out as least preferred, with 85% of the subjects having a below median response to it being a "difficult" posture and 76% of the subjects having a below median response to it being a "frustrating" posture.

Table 7. Subjects' reactions to assumed posture.

Question number	Scale	mean	SD	SE	% below 3.5 (median score) i.e. a negative response
Overall reaction to TouchPad mouse in standing					
33	terrible (1) to wonderful (7)	5.3	0.9	0.4	0
34	frustrating (1) to satisfying (7)	5.4	0.8	0.3	0
35	difficult (1) to easy (7)	5.6	1.0	0.4	4
Overall reaction to TouchPad mouse in sitting					
36	terrible (1) to wonderful (7)	5.8	0.8	0.3	0
37	frustrating (1) to satisfying (7)	5.5	1.0	0.4	0
38	difficult (1) to easy (7)	5.8	1.1	0.4	4
Overall reaction to TouchPad mouse while kneeling					
39	terrible (1) to wonderful (7)	4.5	1.2	0.5	12
40	frustrating (1) to satisfying (7)	4.5	1.1	0.4	8
41	difficult (1) to easy (7)	4.8	1.4	0.6	12
Overall reaction to TouchPad mouse while lying down					
42	terrible (1) to wonderful (7)	2.5	1.4	0.6	20
43	frustrating (1) to satisfying (7)	2.6	1.4	0.6	76
44	difficult (1) to easy (7)	2.3	1.4	0.6	84

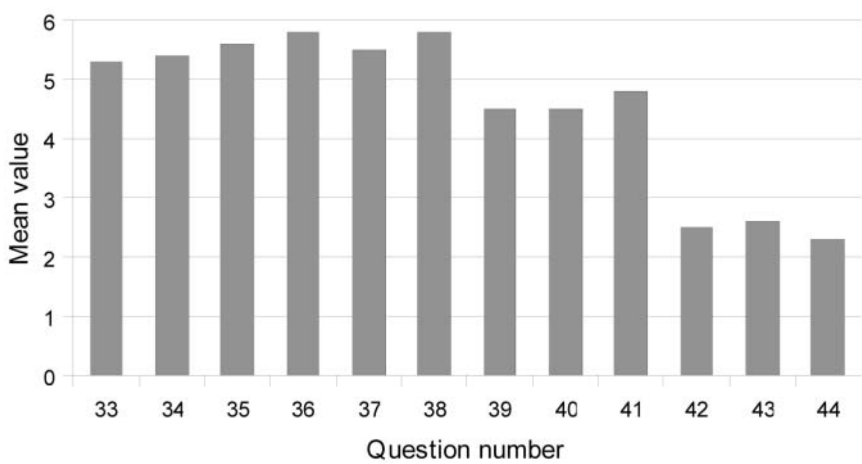

Fig. 18 Graph of subjects' reaction to assumed position.

Table 8. Subjects' reported level of discomfort.

Body location	mean	SD	SE	% response above 3.5 (more pain responses)
eyes	2.8	1.4	0.6	28
hands	2.1	1.3	0.5	24
arms	2.3	1.3	0.5	24
back	2.5	1.5	0.6	36
neck	2.4	1.3	0.5	28
head	2.0	1.4	0.5	20
legs	2.0	1.4	0.5	20

8.4. Discomfort while using the system

Subjects were asked to report the level of discomfort they felt during the task session for the locations on their bodies: eyes, hands, arms, back, neck, head, and legs. The subjects were asked to quantify these reactions on a 7 point scale by assigning a value of 1 for "no pain" and value of 7 for "very painful". Table 8 shows the reported levels of discomfort for the seven different locations. Each location was reported with at least one in five surveys having a level of pain above the 3.5 median value of scale. One cause of this was that the laptop computer became quite warm during the task session. A second reason is that the backpack itself was not designed to hold a computer of this size; therefore, better wearable computer configurations need to be investigated.

8.5. Summary of comments

To gain further insight into what the subjects thought of using the TouchPad mouse under the conditions presented in this investigation, the last two questions of the survey were as follows:

- Please comment on what you felt was positive about using the TouchPad mouse.
- Please comment on what you felt was negative about using the TouchPad mouse.

There were 27 responses to the first question and the second question elicited 32 responses, as some subjects made no responses and some made multiple responses. The subjects highlighted a number of issues. First, the subjects made positive comments about the physical size and weight of the TouchPad. A number of people liked the "feel" of the device. This was offset by subjects who reported trouble "clicking" on the target and problems with cursor movement. We perceive a number of factors that contribute these comments, as follows:

1. The attachment of the TouchPad device to the subject's body was not as rigid as it would be on a desktop. The back of the TouchPad mouse was not flush with the body surface. This in part caused the TouchPad to move while the subjects were interacting with the device. Custom attachment devices should be investigated.
2. The TouchPad device required a certain amount of training. In particular, the act of mouse clicking by tapping the TouchPad surface required a minimum amount of expertise.
3. Subtle control of the mouse required different mechanical actions to those of a standard desktop mouse. For example one technique subjects used was to roll their finger to obtain fine grain movement.

8.6. Positive responses to using the TouchPad mouse

The subjects made a number of positive comments about the use of the TouchPad mouse under the experimental conditions. The TouchPad mouse on the leg was the most comfortable. The subjects noted that the particular orientation of the mouse buttons made a large difference in performance. The subjects thought the size of the device was light, easy to use, portable, mobile, and of a good size. The subjects liked the "feel" of the cursor – nice, direct control of pointer gives the feeling of control over the machine. Subjects approved that using the device required minimal wrist motion, and the cursor moved the "right" amount as the finger moved. The overall comments from the subjects were that the TouchPad mouse was easy to use once one had learned how to operate the device.

8.7. Negative responses to using the TouchPad mouse

A number of negative responses from the subjects concerned problems while attempting to "click" or "mouse press" with the device. Tapping the surface of the TouchPad mouse could initiate a mouse press, and this caused some reported problems. Some of these problems included: no positive feedback to the click, accidental double clicking, accidental touching of the mouse registering as a click, and sometimes taps to the surface did not register as a click. Subjects believed that a possible cause of this problem was due to the TouchPad not being attached to a rigid surface, such as a desk. Better methods of attaching the device to the person might overcome some of these problems. Two major issues were raised concerning the cursor movement: 1) accuracy when moving the cursor small distances was sometimes difficult; and 2) the usable area a little too small for the screen dimensions. The difficulty with using the TouchPad mouse while lying down was commented on a number of times.

9. Conclusion

In conclusion, our study investigated where to place a TouchPad input device on a user's body for the control of a wearable computer. We observed a number of effects concerning the user's posture, position/orientation of the mouse device, and a combination of the posture and position/orientation.

For posture, there are similar time effects for sitting, standing and kneeling. These results indicate that the prone position is a posture that reduces the user's performance significantly. Further study is required to determine the cause of this poorer performance.

The effect of mouse position and orientation shows three groupings of the results for the seven different mouse positions. The front of the thigh is the best position for the mouse. The forearm, side of the thigh and upper arm towards the user's hand are the next grouping. The least favourable mouse positions are torso (with both mouse orientations) and the upper arm with mouse buttons in the up direction.

It is of note that the orientation of the mouse on the upper arm had a large effect on the user's performance, but the orientation of the mouse on the user's torso had a very small effect. The orientation of the mouse buttons on the torso and upper arm provides two different mental mappings. When the mouse buttons are towards the user's hand, the movement of the finger maps the movement the user's finger would make when the mouse is placed on a desktop, but the finger movement is 90° to the movement of the cursor on the display. In the second orientation of mouse buttons up, the finger movement is mapped to the cursor movement on the display, but not of that learned from the desktop examples.

When the posturing and mouse position conditions are combined, the results would indicate the thigh front mouse position would be most appropriate for sitting, kneeling and standing postures, and the forearm mouse position would be best for the prone position. If only one mouse position is to be used for all four postures, the forearm position would be the best choice.

However, in standing and kneeling postures the need to maintain the forearm mounted mouse in a position to allow adequate access with the inputting hand requires sustained muscle activity in the upper arm. This may affect the ability of the input device to be used for prolonged periods of time. The forearm mounted position may also affect the ability of this arm to perform gross secondary tasks. In the prone and sitting postures this would be less of an issue as the forearm could rest on the floor surface or thigh respectively. The front thigh position would require the least muscle activity to maintain function in the sitting, standing and kneeling postures, and would allow gross secondary tasks to be performed by the non-inputting hand. The ideal position of the input device would therefore depend on the function required, both in terms of postures assumed and duration of inputting.

This study has found functional performance is possible from a range of postures and mouse positions, with the mean difference in time of less than one second across all 27 experimental conditions. The most efficient performance was obtained in sitting and kneeling mouse positions ergonomically positioned on the thigh or forearm. We identified the need for proper orientation of the mouse to facilitate the mental mapping of hand movement with cursor movement. The functional application of our findings requires further testing to determine efficiencies for users in the field.

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