Horizontal and Vertical Handheld Pointing Devices Comparison for Increasing Human Systems Integration at the Design Stage

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Abstract. In addition to postural and biomechanical aspects related to usage of handheld pointing devices it is also important to perform usability assessment. The paper reports on an experimental study comparing two computer pointing devices, a standard horizontal PC mouse and a vertical device (for neutral pronation of the forearm), both commercially available. The standardized tasks implemented by software and performed by 20 experienced computer mouse users included pointing, dragging and steering. The usability parameters of effectiveness and efficiency were calculated and the participants subjectively assessed their discomfort, effort and ease of use in relation to each device in each task. Efficiency and effectiveness were higher for the horizontal device. Assessments of discomfort, effort and ease of use across the different tasks also supported the consideration of preference for the horizontal device in detriment of the vertical model. The results suggest that designing hybrid configurations may configure a better compromise.

Keywords: Ergonomics · Human-systems Integration · Usability · Handheld Pointing Devices

Introduction

Computer usage can be associated with the development of neck and upper extremity pain, especially hand and forearm musculoskeletal pain induced by intensive mouse use [1]. About ten years ago, approximately 30% to 80% of computer work involved the mouse [2], depending on the type of work. The PC mouse has become an essential part of computer work, even today; actually, the more recent use of tablet PCs does not substitute all the types of work usually performed using a conventional PC, CAD (computer aided design) operations are part of this group. Furthermore, recent research has concluded that tablet PC users are exposed to extreme wrist postures that are less neutral than those assumed with other computing technologies [3] and may be at greater risk of developing musculoskeletal injuries, especially when these devices are intensively used for long periods of time. One important issue is that screen positioning and pointing area positioning get in conflict for best posturing. Hence, methods have been developed in an attempt to relieve these problems, such as palm rejection technology, although the results of research on the use of this technology show that it generally reduces discomfort but with increased wrist extension and with no benefit to shoulder unloading [4]. Extended use of computer pointing devices is bound to endure in present and future days, because in computer tasks such as pointing, dragging and steering, continuously needed, touch screens have so far not been able to replace the PC mouse, e.g. in 3D computer aided design [5]. The complexity of certain CAD operations and the time involved to produce this kind of computer work led some companies to invest in expensive pointing devices. In this field there are some types of pointing devices that can lead to occupy both hands, one standard device for use by one of the hands and one device for use by the other hand, called knob, intended for use with certain operational functions [6]. Computer usage and particularly computer pointing devices, such as PC mice, have been widely studied. The biggest concern reported in previous studies is related with musculoskeletal disorders. Therefore, research is conducted by collecting data from muscle activity and motion analysis [7, 14], often the same emphasis is not given to usability, even when it comes to developing a new pointing device. Evaluation of pointing devices from an ergonomics and usability perspective involves the assessment of postural and biomechanical aspects as well as the efficiency, effectiveness and satisfaction of the person in the activity of task completion. Hence, human systems integration is typically assessed in this application domain from both an objective and subjective standpoint.

The paper reports on an experimental study comparing two commercially available PC pointing devices, having a major difference between them in what concerns the orientation of the device and its shape, although with additional differences in size and weight. The mouse weight is thought to influence wrist motion and muscle activity of the forearm when using the device in high-speed operation, while such effect is reduced in low speed operation; moreover, a mouse with proper weight would promote improved movement efficiency and decreased muscular activity during fast operation [7]. A proper mouse weight could hence benefit the users in terms of increasing movement efficiency. Its dimensions and geometry should be based on anthropometry, hand gestures and comfortable hand postures [8]. Hand size of the subjects seems to make a difference during computer mouse usage, affecting grasp position and the level of muscle activity, suggesting that a computer mouse must be chosen according to the size of the hand of the subject [9]. Moreover, previous tests performed on a standard PC mouse (model A in the present study) revealed statistically significant association between hand width and effectiveness of dragging with the middle button of the mouse [10].

Figure 1 shows de devices under study, model A is a Microsoft® standard horizontal PC mouse, while model B is an Evoluent® vertical PC mouse (supporting the adoption of a neutral forearm pronation posture by the person in the pointing activity). Standard PC mouse model A (Figure 1) has a mass of 57 grams (taken from weighing the device on a precision scale with the cable horizontally supported; the total weight including cable and USB plug is 78 grams). Analogously, vertical PC mouse (model B) has a mass of 137 grams and the total weight including cable and USB plug is 170 grams.

The overall aim of this paper is to contribute to the body of knowledge supporting the design of handheld computer pointing devices for increased human systems compatibility at the design stage.

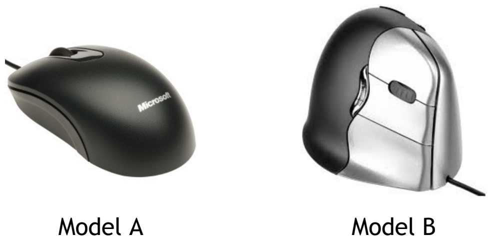

Fig. 1. Handheld pointing devices studied (model A and model B)

Methods

A set of tasks representative of a CAD operator's activity were standardized and recreated by a tailor made computer software application to support the experimental studies undertaken. The standardized tasks included pointing at different sized targets, dragging with different mouse buttons, as well as steering and scrolling. This set of task were collected and adapted from previous studies [11, 12]. All 20 subjects (10 female and 10 male) used each one of the devices performing the standard tasks in the following order: pointing at large targets (pointing large), pointing at medium targets (pointing medium) and pointing at small targets (pointing small) at first. Then, dragging targets with the left button (dragging left), dragging with the middle button (dragging middle), dragging with the right button (dragging right), and, finally, steering targets inside a tunnel. The devices were randomly sorted and the participants performed the tests using the same device across the tasks in the sequence described above, and they then repeated the same sequence of tasks with another device after a resting period. A comparative overview of the graphical setup of the tasks is shown in Figure 2. The pointing tasks consisted of alternately clicking on 18 equally distributed round targets arranged in a circle (Figure 2). Participants clicked on the center circle to start the task and then would move the cursor and click on the first active circle target (black-highlighted), if the click hit the target it would disappear, enabling the target on the diametrically opposite side of the circle, which when hit, would lead to the next target to randomly go active, and so on. The pointing task ran in pairs, one target was randomized and the next target stood opposite to it. The dragging tasks consisted of alternately dragging 8 equally distributed round targets arranged in a circle (Figure 2) and participants would click and drag the circle to the diametrically opposite side matching the targets with another click. The steering task partially resembled the dragging task, it was necessary to hit the black-highlighted circle, release the mouse button, and then drive the circle to the diametrically opposite side matching the targets and trying not to get outside of the tunnel.

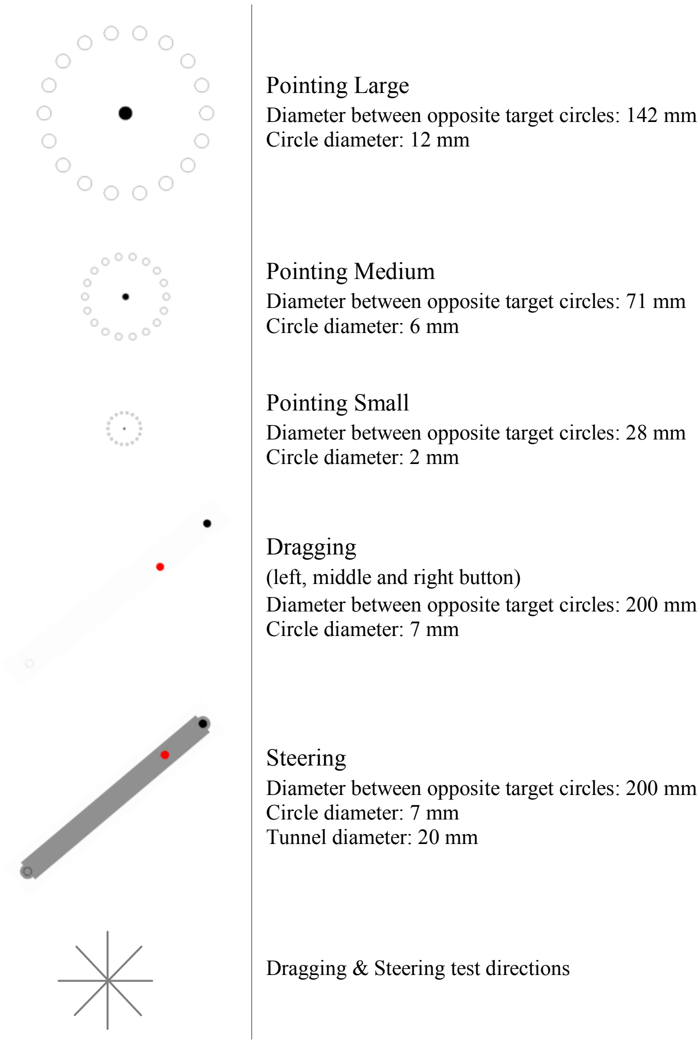

Fig. 2. Pointing, dragging and steering tasks (implemented by a tailor made computer software application); task sequence from top to bottom (pointing large to steering).

The purpose-built software collected several parameters of the trials including time to complete tasks and errors undergone, enabling calculation of effectiveness and efficiency usability parameters. The effectiveness for pointing and dragging tasks was calculated from equation (1) whereas for the steering task equation (2) was used. Efficiency was calculated from equation (3).

$$efa_{(point \wedge drag)} = 1 - \frac{No.FailedTargets}{No.TotalTargets} . \tag{1}$$

$$efa_{(steering)} = \frac{minimum\ mean\ deviation}{mean\ deviation(subject)} . \tag{2}$$

$$efi_{(point \wedge drag \wedge steering)} = efa \times \frac{minimum\ mean\ completion\ TIME}{mean\ completion\ TIME\ (subject)} . \tag{3}$$

Participants also assessed their discomfort and effort subjectively in the completion of the tasks using each one of the pointing devices, as well as rating the ease of use of each device in the course of the activity within the performance of the standardized tasks. Both subjective and objective evaluation parameters are compared across the sample between the two handheld devices under focus. Table 1 summarizes the comparative study performed. Subjects were given 3 scales (discomfort, ease of use and effort), each one composed of several items. Ratings were provided in 6-point Likert scales. Statistical analysis was carried out using IBM SPSS version 23.

Table 1. Comparative study – tasks and evaluation parameters (scrolling efficiency and effectiveness are not reported in this paper)

PC mouse	Tasks	Usability Evaluation		
		objective		subjective
		measures	calculations	(subjects ratings)
Model A (0º) vs. Model B (90º)	pointing (different size targets)	time (to completion)	efficiency	discomfort
	dragging (different mouse buttons)	errors (undergone)	effectiveness	effort
	steering			ease of use
	(scrolling)			

Each session lasted between 10 and 12 minutes per device. An additional set of several non-conventional pointing devices was evaluated in the same experiment, and the order of evaluation was randomized for each subject across the several devices evaluated. This paper focuses only on two devices, a commercially available standard PC mouse and a commercially available vertical PC mouse.

Results

Participants ranged in age from 20 to 38 years old (mean=25 years, SD=4.8 years) and all of them were right handed. Hand width (hand breath) and hand length were measured using a retractable steel tape measure, resulting, respectively on female hand width with a mean of 79.9mm (SD=4.06mm), female hand length with a mean of 177.3mm (SD=5.73mm), male hand width with a mean of 88.8mm (SD=4.02mm) and male hand length with a mean of 191.7mm (SD=4.67mm).

The non-parametric Mann-Whitney U test was applied to the distributions of the four subjective evaluation variables (shown in Figure 3 as mode bars, the mode is the value that appears most often in the data) across the two PC mouse models under study. As a result the null hypothesis stating that ‘the distributions are the same across the two categories of pointing devices’ was not rejected with statistical significance over the four variables under interest.

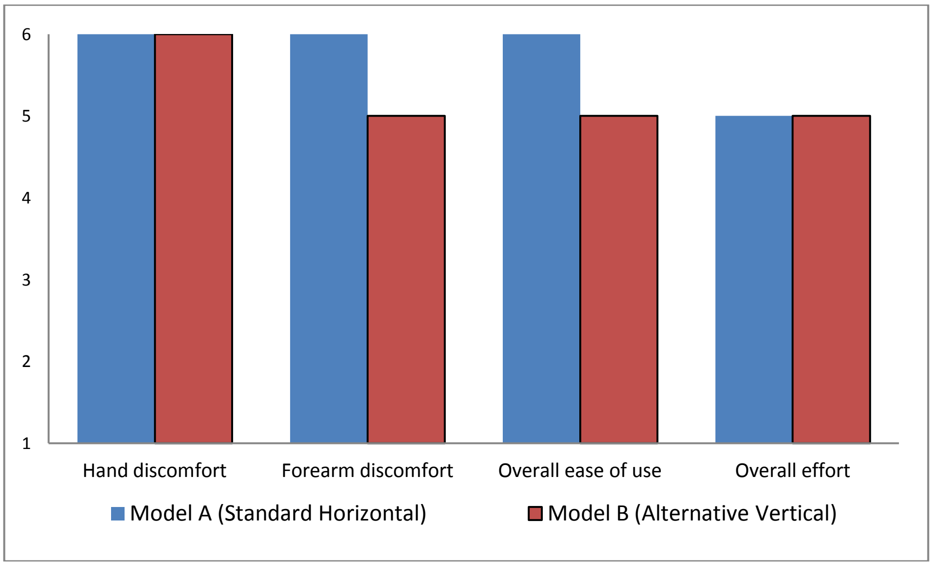

Fig. 3. Hand discomfort mode, forearm discomfort mode, overall ease of use mode and overall effort mode plotted against PC mouse models (All rated from ‘1’ to ‘6’; Discomfort: from ‘1’ – extreme discomfort to ‘6’ – no discomfort; Ease of Use: from ‘1’ – very difficult to ‘6’ – very easy; Effort: from ‘1’ – extreme effort to ‘6’ – no effort).

Figure 4 shows mean effectiveness of task completion using PC model A and PC model B and from these results it is observed, globally, that model A seems to be more effective than model B. The same applies in almost all the tasks performed by the subjects. The non-parametric Mann-Whitney U test returned rejection of the null hypothesis (equality of distributions across categories) considering a p-value lower than 0.05 for: effectiveness of pointing large (U= 290, p=0.014), effectiveness of pointing medium (U= 302.5, p=0.005), effectiveness of pointing small (U= 319.5, p=0.00) and effectiveness of dragging right (U=274, p=0.046).

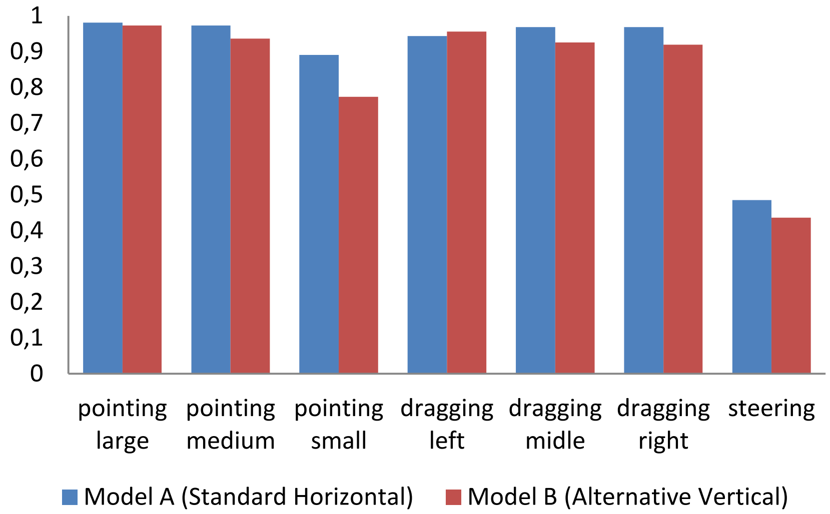

Fig. 4. Mean effectiveness of tasks plotted against the two PC mouse models considered in the study.

Likewise, the mean efficiency of task completion using PC mouse model A and model B is plotted in Figure 5. The graphic shows that the mean efficiency of tasks completion is comparably greater in model A. The non-parametric Mann-Whitney U test supports these assumptions, since it returned rejection of the null hypothesis (equality of distributions across categories) considering a p-value lower than 0.05 for efficiency of pointing medium (U= 356, p=0.00), efficiency of pointing small (U= 357, p=0.00), efficiency of dragging left (U= 278.5, p=0.033) and efficiency of dragging right (U= 323, p=0.00).

The variables under focus were analyzed using non-parametric statistics [13] to statistically prove or disprove the differences among subgroups, such as those exemplified in Figures 3, 4 and 5 giving good support relatively to objective evaluation parameters of usability. Particularly, the results of the Mann-Whitney U test did not support rejecting the null hypothesis (the populations are the same across the categories) with statistical significance over all the four focused variables from subjective evaluation, hand discomfort, forearm discomfort, overall ease of use and overall effort.

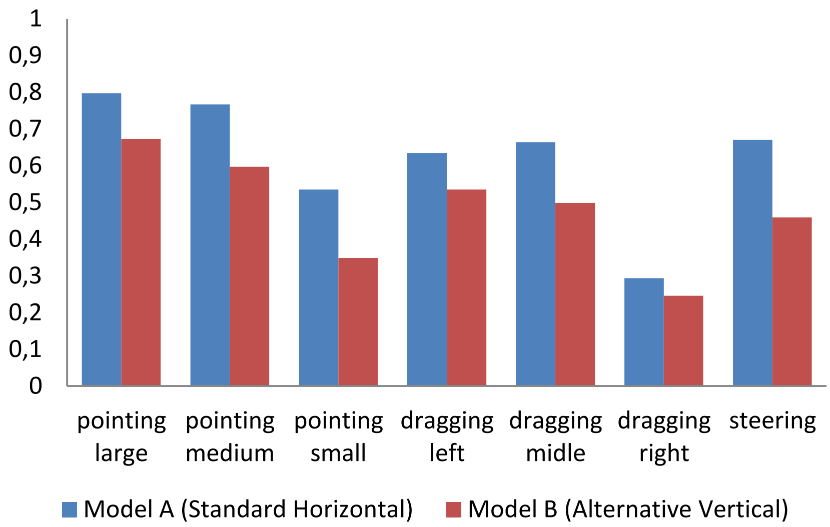

Fig. 5. Mean efficiency of tasks plotted against the two PC mouse models considered in the study.

Additionally, the subjective usability variables depicted in Figure 3 were correlated (Spearman rank order correlation, according to the approach described in [15]) with the objective variables depicted in Figures 4 and 5, across the two categories of pointing devices included in the study. No significant correlations with objective indicators of usability were found involving hand and forearm discomfort. In what concerns overall effort, a significant moderate correlation was found with efficiency of the pointing at medium targets task (rho=0.378, p=0.016). Finally, the subjective variable of overall ease of use was positively and moderately associated to the following four objective usability indicators: effectiveness of pointing at large targets (rho=0.42, p=0.07), effectiveness of pointing at medium targets (rho=0.386, p=0.014), efficiency of pointing at medium targets (rho=0.333, p=0.036) and efficiency of pointing at small targets (rho=0.343, p=0.030). These results indicate the very expressive importance of the pointing tasks in formulating the subjective impression of overall ease of use.

Conclusion

An experimental set up with 20 participants was the basis on which to perform usability evaluation of two handheld devices (PC mice) geometrically and paradigmatically quite distinct. The first one is a standard, classic, horizontal and symmetric PC mouse and the second device is an alternative vertical PC mouse (supporting the adoption of a neutral forearm pronation posture by the user in the pointing activity). The study included both subjective and objective evaluation parameters of usability.

The difference reached in efficiency between model A and model B for the most tasks under interest, is statistically supported, in spite of the small sample size and short session time that may have benefited the classic device, show clearly better performance results for model A. Especially the tasks pointing at medium size targets, pointing at small size targets and dragging with right button of the PC mouse, all were simultaneously supported by Mann-Whitney U tests for efficiency as well as effectiveness, all together agreeing with the assumption taken above. The reported tasks play a key role in several computer aided design software tools, hence the present study may help users to better choose their PC mice.

Association between subjective and objective variables suggests the prominent role of pointing tasks in the subjective formulation of the concept of overall ease of use. This notwithstanding, discomfort subjective variables were not significantly associated to any of the objective usability parameters considered.

The results suggest that the envisaged health benefits in what concerns a lowered risk of musculoskeletal disorders of the hand, wrist and forearm proposed in the adoption of the vertical mouse are opposed by reduced efficiency and may increase effort and discomfort (hand and forearm) in the short term leading to the perception of lower ease of use. Hence, the results of the comparison reported in the paper suggest designing hybrid configurations of handheld pointing devices, in order to achieve a compromise between the expected long term effects on health and the objective and subjective task completion usability parameters.

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