Effects of Practice with Foot- and Hand-Operated Secondary Input Devices on Performance of a Word-Processing Task

Fredrick P. Garcia and Kim-Phuong L. Vu

Center for Usability in Design and Accessibility
Department of Psychology, California State University, Long Beach
1250 N. Bellflower Blvd. Long Beach, CA 90840, USA
garcia.fp@gmail.com, kvu8@csulb.edu

Abstract. This study compared the performance of users operating a foot controlled input device (foot mouse) with that of users operating a hand controlled input device (hand trackball). Four different tasks that required (1) direct manipulation of on-screen objects and menu command activation, (2) keyboard entry and direct manipulation, (3) keyboard entry and command activation, and (4) keyboard entry, direct manipulation, and command activation were assessed. Performance on each task was measured both before and after participants practiced computing tasks with one of the devices for 750 trials. For all 4 tasks, practice improved performance with the foot mouse but not the hand trackball. However, overall performance was better with the hand trackball.

Keywords: input device, foot input, hand input, practice, word processing.

1 Introduction

Graphical User Interfaces (GUIs) allow for a more efficient interaction with the computer environment than the command prompt interfaces that preceded them, but they still have costs associated with their use. One such cost relates to the fact that to be used to their greatest potential, GUIs require that a separate input device (e.g., a mouse) be operated in addition to the keyboard. Research has shown that a consequence of using the hand to control the secondary input device is increased musculoskeletal injuries [4], or at the very least, exposure to awkward angles identified as risk factors for musculoskeletal injuries [1, 3]. Also, a significant amount of time and accuracy are lost when the resources required by the secondary input device overlap with those that are already put to use from typing with the keyboard. These performance decrements come from physically switching back and forth between devices [2] and mentally preparing to execute the physical actions after attention has been switched from one task to the other [6]. However, there is a possibility that this lost time could be recovered if there were a way to prevent those resources required by the devices from overlapping. In attempting to prevent resource overlap, speech recognition software has been developed, but it is not advanced enough to handle keyboard responsibilities [9]. Furthermore, voice input cannot be used to perform all the

M.J. Smith and G. Salvendy (Eds.): Human Interface, Part I, HCII 2009, LNCS 5617, pp. 505–514, 2009.

activities that can be performed with a hand controlled input device (e.g., cursor positioning, dragging and dropping items, etc.) or take full advantage of the GUI interface (e.g., simple recognition of icons rather than recall of key combinations or voice commands). However, a foot controlled input device can perform these activities.

Previous research evaluating the appropriateness of using a foot controlled input device for working with computers has shown that people are consistently slower using their foot to control an input device than using their hand [7, 8, 10]. However, past research has failed to examine the role of practice in creating an efficient human-computer system involving a foot device. In past studies, while devices with which participants had worked before were operated with their hands, they were provided novel input devices to operate with their feet and allowed little practice. Another issue that may have led to slower foot input times in previous studies is the omission of foot specific input devices that are commercially available. Commercially available foot specific input devices would be expected to help users work as efficiently as possible. Previous studies have also limited the types of tasks used to test performance with foot controlled input devices. There have been no studies designed with tasks that take advantage of the unique ability of the foot controlled input device to be used in parallel with the keyboard, even though there are many multi-step computer tasks that require using both the keyboard and some other input device. Though simple tasks favor the hand operated input device, complex tasks may allow better overall performance with the foot operated input device.

The purpose of this study was to examine the effect of practice with a commercially available foot-specific secondary input device (a foot mouse) and a hand-controlled secondary input device that was not overpracticed like the hand mouse (a hand trackball) on word processing task performance. Typical word processing activities fall into three categories: textual input (typing), direct manipulation of on-screen objects (e.g., dragging and dropping objects or selecting text), and command activation (e.g., choosing to "Print" from a command menu) [5], so completion time was measured for 4 tasks requiring varying amounts of these activities. Participants used either the foot mouse or hand trackball with the keyboard (when needed) to complete the tasks before and after 750 trials of practice with one of the secondary input devices.

2 Method

2.1 Participants

Sixteen participants were recruited from the campus of California State University, Long Beach. Participants received $5.00 for each of the 10 sessions of the experiment they completed, except for sessions 1 and 10 for which they received $10.00 ($5.00 for each of 2 parts), and a $20.00 bonus for completing the entire experiment. Participants ranged from 21-32 years of age (*M* = 25 years). All participants had normal vision, were right handed and footed, and had full use of their hands and feet.

Participants reported being relatively experienced with computers (*M* = 1.27, with 1 being very familiar and 5 not at all familiar for this and subsequent questions), spending an average of 34 minutes a day using a Windows based computer, and being very familiar with the Microsoft Word word-processing program (M = 1.27). Participants also reported that they were very familiar with using the hand mouse (M = 1.27), not very familiar with using the hand trackball (M = 3.64), and not at all familiar with using a foot input device to interact with the computer (M = 4.93).

2.2 Apparatus

All parts of the experiment were programmed in Visual Basic (Microsoft Corporation). The program provided the workspace for the practice and word processing tasks and recorded task completion times. Both the practice trials and the word processing performance tests were run on a Pentium 4 based PC using a 19” color monitor. Text input was handled by a standard Dell QWERTY keyboard, while for command activation and direct manipulation activities the Logitec Trackman Wheel trackball was used as the hand-controlled input device and the NoHands Mouse by Hunter Digital was the foot-controlled input device.

2.3 Materials

The materials and task domain used to evaluate word-processing task performance were modified from four tasks developed for a previous experiment on word processing performance using multiple input devices [5]. For the first task, participants were given an unformatted document and told to reformat it to a predefined style (a preformatted version of the document served as the model and remained visible during the task, see Fig. 1) using six text formatting tools that were selected from a drop-down menu. This task was completed using only direct manipulation and commands executed with the secondary input device (i.e., keyboard was not used).

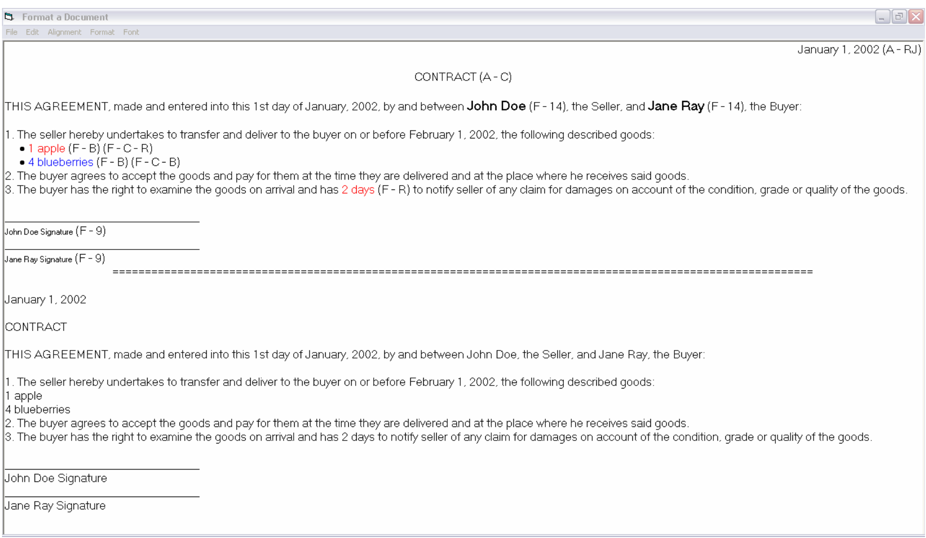

Fig. 1. Screenshot of Task 1 workspace

The second task required participants to type a short scientific formula (1) containing subscripted and superscripted text, and Greek symbols. To complete this task there was a minimum ratio of 1.48 required keystrokes to 1 required formatting command (approximately the same amount of keystrokes and commands were needed). Participants were asked to type the formula from left to right as they activated the necessary commands with the secondary input device. This task was completed using the keyboard and commands executed with the secondary input device.

$$d^2(r_v^1)/dt^2=-\mu^1(r_v^1/r_v^3)+\mu_m(-d_{mv}\, d_{mv}^3-r_m/r_m^3)\ . \tag{1}$$

The third task involved participants building a table consisting of the first 12 letters of the Greek alphabet and their English alphabet equivalents, using the copy and paste keyboard accelerator commands (Ctrl-C and Ctrl-V, respectively) while navigating the document by scrolling up and down. Scrolling was necessary because the list of letters and the table were not on the same page. To enter each letter in the table participants were asked to: 1) select the letter with the secondary input device, 2) copy it, 3) memorize the English alphabet equivalent corresponding to the letter, 4) scroll down to the table with the secondary input device, 5) paste the letter in the table, and 6) type in the English alphabet equivalent. If the participant did not remember the English equivalent, they needed to scroll back up to read it as many times as was necessary to correctly type it in the table. To create a keyboard to secondary input device dynamic that was similar to the previous task, there was a minimum ratio of 1 required keystroke to 1 required direct manipulation with the secondary input device.

The last word processing task required participants to type a short paragraph containing subscripted, superscripted, italicized, underlined, bolded text, and Greek symbols. All format changes were created using command activation (e.g., if a word was to be bolded, the Bold command was first selected from the Format drop down menu and then the word was typed). Greek symbols were created by selecting them from the Symbols command menu. Participants were required to type the text from left to right and activate the menu commands when needed. This task had a minimum keystroke to formatting command ratio of 16.31 to 1. However, this was the upper bound of the minimum keystroke to secondary input device activity ratio as the task also required that participants used the secondary input device to drag the scroll bar (direct manipulation) to compare what they were copying to what they were typing as the paragraphs were on separate pages. If participants wanted to see every line as they typed it, the minimum keystroke to secondary input device activity ratio was 10.02 to 1. This task incorporated all three word processing components: typing, command activation, and direct manipulation. The paragraph to be typed was:

> The teacher had the students turn to *Section 2* in their <u>Modern Mathematics</u>[1] textbook, which had replaced their previous text: <u>Old Math</u>[2]. The math lesson was on variables together with exponents, like x^5. The teacher was going to review the **Pythagorean Theorem**[3], where $a^2 + b^2 = c^2$, as an example. She also wanted to talk about finding the **area of a circle** using the formula $\pi\mathbf{r}^2$, where **r** stands for the radius of the circle. After Math, she was going to give a Chemistry lesson. She was going to begin by discussing H_2O, which she was *sure* everyone would know about.

2.4 Procedure

Upon arrival, each participant was asked to read and sign a consent form. Participants then filled out a demographic questionnaire and were reminded about the multiple session commitment required for the experiment. They were then asked to sit in front of a computer monitor at a comfortable viewing distance. Participants worked through each of the 4 word processing tasks using either the foot- or hand- operated secondary input device first (half of the participants used the device they had been assigned to practice on first, and half used the device they would not be practicing first).

Before beginning the 4 tasks with an input device, participants completed a block of practice trials to familiarize themselves with the device. This was the same activity that they later practiced for 750 trials in the practice sessions. Each trial consisted of the same 3 steps: 1) find and click the "1" button randomly located in the top 1/4 of the workspace, 2) scroll down to find and highlight the string of characters randomly located in the bottom 1/4 of the workspace, 3) scroll up to find and press button "2" randomly located in the top 1/4 of the workspace.

After participants performed 30 practice trials of this type they worked through the 4 word processing tasks described earlier (taking a 3-5 minute break between tasks). This completed part 1 of test session 1. After a 15 minute break, participants returned for part 2 of test session 1. During part 2, participants performed 30 practice trials with the other device and then worked through all 4 tasks with it as well. Participants always worked through the tasks in the following order: task 1, 2, 3 and then 4. Each task was explained to the participant just before they began. Participants took a break between tasks. Each part of test session 1 took less than an hour.

After initial testing with the 4 word processing tasks on the first day, participants returned for 8 practice sessions with the secondary input device with which they were assigned to receive practice. Which device each participant was assigned to practice with was determined randomly, but was counterbalanced across participants. Each of the practice sessions were no more than 1 hour long and contained between 50 and 150 practice trials of the sort previously described. More practice trials were able to be included in later practice sessions because performance improved with practice.

When participants finished all practice sessions, they returned for a final test session with the 4 word processing tasks. Participants used whatever input device they used first during the first test session. Again, each task was explained to the participant just before they began and any questions were answered. Participants took a 3 - 5 minute break between tasks and a 15 minute break when secondary input devices were switched. After completing all tasks using both the foot and hand, participants answered a post-experiment questionnaire and were then verbally debriefed as to the purpose of the experiment. The final testing session took 1 hour.

3 Results and Discussion

Separate 2 (practiced device: foot mouse or hand trackball) x 2 (operated device: foot mouse or hand trackball) x 2 (test session) mixed ANOVAs were performed on task completion times for each of the 4 word processing tasks. Practiced device is the between-subject factor, and operated device and test session are within-subject factors.

3.1 Task 1

There was a main effect for operated device such that participants were faster with the hand trackball (M = 121 s) than the foot mouse (M = 246 s), $F(1, 14) = 45.69$, p < .05. There was also a main effect of test session, where participants were faster at test session 2 (M = 160 s) than at test session 1 (M = 207 s), $F(1, 14) = 11.49$, $p < .05$. These main effects were qualified by a significant practiced device x operated device x test session 3-way interaction $F(1, 14) = 6.18$, $p < .05$, see Fig. 2.

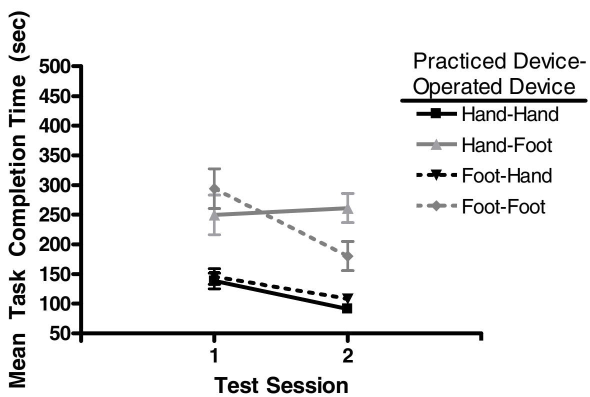

Fig. 2. Mean Task 1 Completion Time as a function of Practice Device, Operated Device, and Test Session

When this interaction was examined further, a significant interaction of practiced device x test session was found to be present when the foot mouse was the operated device, $p < .05$, but not when the hand trackball was the operated device, $F < 1.0$. When participants operated the foot mouse and had practiced with the foot mouse, their completion times improved from test session 1 to test session 2, $p < .05$. However, when they operated the foot mouse and had practiced with the hand trackball, completion times were not significantly different between test sessions, $p = .77$ (see Fig. 2). In sum, practice effects were evident with the foot operated secondary input device but not the hand operated one.

3.2 Task 2

There was a main effect for operated device such that participants were faster with the hand trackball (M = 151 s) than the foot mouse (M = 225 s), $F(1, 14) = 35.54$, $p < .05$. There was also a main effect of test session where participants were faster at test session 2 (M = 159 s) than at test session 1 (M = 217 s), $F(1, 14) = 50.20$, $p < .05$. These main effects were qualified by a significant practiced device x operated device x test session 3-way interaction, $F(1, 14) = 8.32$, $p < .05$, see Fig. 3.

When this interaction was examined further, a significant interaction of practiced device x test session was found to be present when the foot mouse was the operated device, $p < .05$, but not when the hand trackball was the operated device, $F < 1.0$. When participants operated the foot mouse and had practiced with either the foot mouse or hand trackball, their completion times improved from test session 1 to test session 2, *p*s < .05. However, greater improvement was observed between test session 1 and 2 when participants practiced with the foot mouse than when they practiced with the hand trackball, $p < .05$. Again, these results show that practice improved performance on the foot mouse but not the hand trackball.

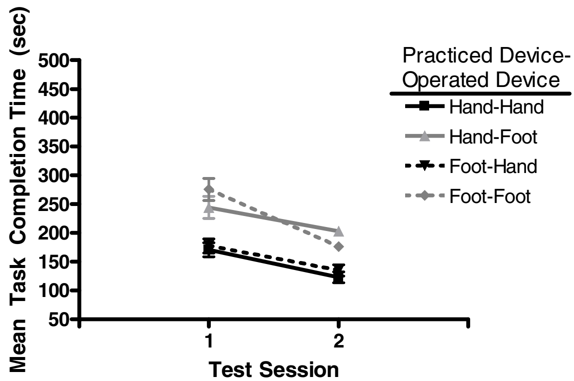

Fig. 3. Mean Task 2 Completion Time as a function of Practice Device, Operated Device, and Test Session

3.3 Task 3

The main effects for operated device and practice session were significant, Fs(1, 14) > 26.57, ps < .05. Participants were faster with the hand trackball (M = 204 s) than the foot mouse (M = 424 s), and at test session 2 (M = 272 s) than at session 1 (M = 356 s). These effects were qualified by a significant practiced device x operated device x test session interaction, F(1, 14) = 16.18, p < .05, see Fig. 4.

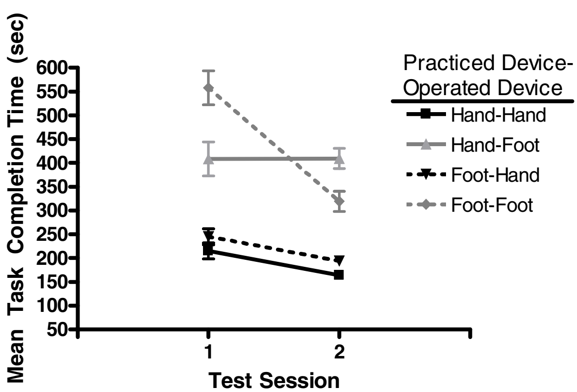

Fig. 4. Mean Task 3 Completion Time as a function of Practice Device, Operated Device, and Test Session

When this interaction was examined further, a significant interaction of practiced device x test session was found to be present when the foot mouse was the operated device, p < .05, but not when the hand trackball was the operated device, F < 1.0. When participants operated the foot mouse and had practiced with the foot mouse, their completion times improved from test session 1 to session 2, p < .05. However, when they operated the foot mouse and had practiced with the hand trackball, completion times were not significantly different between test sessions, p = .984. Again, practice improved performance on the foot mouse but not the hand trackball.

3.4 Task 4

There was a main effect for operated device such that participants were faster with the hand trackball (M = 494 s) than the foot mouse (M = 728 s), $F(1, 14) = 20.12$, $p < .05$. There was also a main effect of test session where participants were faster at test session 2 (M = 530 s) than at test session 1 (M = 693 s), $F(1, 14) = 39.78$, $p < .05$. These main effects were qualified by a significant practiced device x operated device x test session 3-way interaction, $F(1, 14) = 5.06$, $p < .05$, see Fig. 5.

When this interaction was examined further, a significant interaction of practiced device x test session was found to be present when the foot mouse was the operated device, $p < .05$, but not when the hand trackball was the operated device $F < 1.0$. When participants operated the foot mouse and had practiced with the foot mouse, their completion times improved from test session 1 to test session 2, $p < .05$. However, when they operated the foot mouse and had practiced with the hand trackball, completion times were not significantly different between test sessions, p = .345. Thus, similar to Tasks 1-3, practice improved performance on the foot mouse but not the hand trackball.

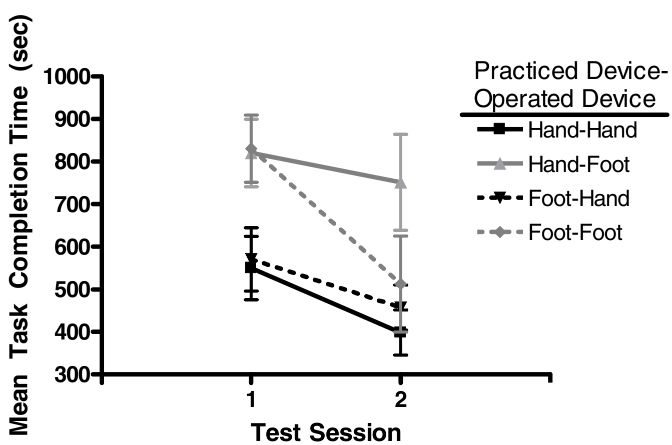

Fig. 5. Mean Task 4 Completion Time as a function of Practice Device, Operated Device, and Test Session

4 Conclusion

For all tasks, there was a significant main effect of operated device where participants were faster with the hand trackball than the foot mouse, and a significant main effect of test session such that participants were faster at test session 2 than test session 1. Also, for all tasks, these main effects were qualified by a 3-way interaction of practiced device x operated device x test session. Further analysis of these interactions showed that practice improved performance with the foot mouse but not with the hand trackball.

That practice did not improve performance when the hand trackball was the operated device suggests a ceiling effect for performance with the hand trackball. That is, participants may have already been so skilled with using their hand for activities similar to operating the trackball that 750 trials of practice could not further their hand trackball skills enough to show effects over the improvement that came from task repetition (i.e., improvement on each task from test session 1 to 2 regardless of device operated or practiced). A ceiling effect on performance with the trackball is somewhat surprising, as participants (on average) reported they were somewhat unfamiliar with the hand trackball. Moreover, finding a ceiling effect on a hand-controlled device, which was rated as being somewhat unfamiliar by users, calls into question all past research that compared performance with hand-controlled secondary input devices with foot-controlled secondary input devices.

Participants may be so skilled at using their hand to perform fine motor activities similar to operating a computer input device that using an unpracticed hand-operated input device may allow for a level of performance close to what could be expected if it were practiced. Even beyond general fine motor skills, it is possible that skills specific to using the hand to operate an indirect pointing device (where movement of an input device in the horizontal plane must be mapped to the vertical plane of the display and some gain is applied to the device where its velocity and acceleration are augmented in the display) to interact with a computer have been learned by the general population through repetitive hand mouse use. This previous experience with an indirect pointing device using the hand and not the foot could also contribute to unpracticed hand trackball performance resembling practiced performance and add to performance differences between the foot mouse and hand trackball.

The finding that practice significantly improves performance with a foot mouse, but not with a hand trackball, suggests that the foot mouse should be practiced many times before it is used in an experiment so that a more accurate determination can be made about the level of performance that can be expected with the device. It would be useful to look at the effect of different amounts of practice and whether further practice can continue to improve performance. It would also be beneficial to examine the effect of practicing the foot-controlled secondary input device with the keyboard rather than practicing it on component tasks separate from the keyboard.

One limitation of the current experiment concerns the foot-controlled secondary input device. During the experiment, the commercially available foot mouse progressively lost sensitivity until it could no longer be used. When a replacement was obtained it was more sensitive than the previous device had ever been. It would be expected that a commercially available foot controlled input device that is at least as reliable and consistent as commercially available hand controlled input devices would only increase performance improvements due to practice with the foot device.

References

1. Burgess-Limerick, R., Shemmell, J., Scadden, R., Plooy, A.: Wrist Posture During Computer Pointing Device Use. Clinical Biomechanics 14, 280–286 (1999)
2. Card, S.K., Moran, T.P., Newell, A.: The Keystroke-Level Model for User Performance Time with Interactive Systems. Communications of the ACM 23(7), 396–410 (1980)
3. Fagarasanu, M., Kumar, S.: Carpal Tunnel Syndrome Due to Keyboarding and Mouse Tasks: A Review. International Journal of Industrial Ergonomics 31, 119–136 (2003)
4. Jensen, C., Borg, V., Finsen, L., Hansen, K., Juul-Kristensen, B., Christensen, H.: Job Demands, Muscle Activity and Musculoskeletal Symptoms in Relation to Work with the Computer Mouse. Scandinavian Journal of Work and Environmental Health 24, 418–424 (1998)
5. Karl, L., Pettey, M., Shneiderman, B.: Speech-Activated Versus Mouse-Activated Commands for Word Processing Applications: An Empirical Evaluation. Technical Report No. CAR-TR-630. University of Maryland Center for Automation Research, College Park, MD (1992)
6. Monsell, S.: Task Switching. TRENDS in Cognitive Sciences 7(3), 134–140 (2003)
7. Pakkanen, T., Raisamo, R.: Appropriateness of Foot Interaction for Non-accurate Spatial Tasks. In: CHI 2004 Extended Abstracts on Human Factors in Computing Systems, pp. 1123–1126. ACM Press, New York (2004)
8. Pearson, G., Weiser, M.: Exploratory Evaluation of a Planar Foot-Operated Cursor-Positioning Device. In: O'Hare, J.J. (ed.) Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI 1988, pp. 13–18. ACM Press, New York (1988)
9. Schneiderman, B.: The Limits of Speech Recognition. Communications of the ACM 43(9), 63–65 (2000)
10. Springer, J., Siebes, C.: Position Controlled Input Device for Handicapped: Experimental Studies with a Footmouse. International Journal of Industrial Ergonomics 17, 135–152 (1996)