Multistream input: An experimental study of document scrolling methods

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Navigating through on-line documents has become an increasingly common task in human-computer interaction. This paper investigates alternative methods to improve user performance for browsing World Wide Web and other documents. In a task that involved both scrolling and pointing, we compared three input methods against the status quo. The results showed that a mouse with a finger wheel did not improve user's performance; two other methods, namely a mouse with an isometric rate-control joystick operated by the same hand and a two-handed system that put a mouse in the dominant hand and a joystick in the other, both significantly improved users' performance. A human factors analysis of each of the three input methods is presented.

The WIMP (windows, icons, menus, and pointer) interaction style continues to gain an increasingly wide range of applications, despite its age and long history.[1] The rapidly developing World Wide Web (WWW) makes the use of this style of interaction even more frequent and intense. As a result, the limitations of existing WIMP features also become more severe and obvious. There have been numerous interface inventions and studies since the basic WIMP style was developed (e.g., see Reference 2), but they have been largely restricted to the research literature and isolated demonstrations. Both the unavailability of new commercial technology (hardware and software) and an incomplete understanding of human factors have contributed to the lack of major improvements in the mainstream interfaces.

One basic feature of the existing mainstream WIMP interfaces is that the user communicates with the computer system via a single stream of input. Such input is physically driven by a two-degree-of-freedom input device, typically a mouse, and graphically displayed as a cursor. Depending on the cursor position, such as on a document, a window, a menu, a scroll bar, an icon, or a hyperlink, the function of the cursor switches from pointing, to selection, to drawing, to scrolling, to opening, and so on. Such a single-stream operation, needless to say, has offered users many advantages such as ease of understanding and learning the interaction mechanism. The disadvantage, however, is the limited communication bandwidth[2] and the costs in time and effort of acquiring widgets and control points.[3,4] A particular case is document browsing, which is one of the most frequent tasks in interacting with computers. A document, such as a text file, a spreadsheet, a folder, and most importantly, a WWW page, is often larger than the viewing window. Only a portion of the document can be displayed at a time. The user often has to move (scroll) the window to view other portions of the document. Scrolling is traditionally done by dragging the scroll bar handle on the side or the

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bottom of the viewing window. There are at least the following three limitations to such a method:

1. It takes a certain amount of time, T1, to acquire (point to and press on) the scroll bar. According to the well-studied Fitts' law,[5] T1 is logarithmically proportional to the ratio of A and W. A is the distance the cursor has to travel, and W is the size of the widget acquired. At the extreme case (travel across the entire screen to acquire the arrow widget at the end of a scroll bar), the Fitts index of difficulty can be up to eight bits, which may take more than two seconds to complete.[6]

2. There are three methods of using a scroll bar; each has some limitations. First, the user can acquire the moving handle and drag it. The advantage of this method is that the user can scroll the document at a controlled speed that is suitable for the particular task. The disadvantage is that the dragging function, which requires that pressure be maintained on a button while moving the input device, is more difficult and takes more time than pointing over the same Fitts' index of difficulty.[7] The second method is to use the cursor to press the arrow buttons at the ends of the scroll bar, causing the document to scroll at a speed that is not adjustable by the user. This is binary control: either move at a fixed (or accelerated speed) or stop. The speed could be too slow when the user wants to move very far, or too fast when the user wants to visually track the document. The third method is to click on the rest of the space on the scroll bar, causing the document to "jump." The user is often unaware of the increment by which the window jumps, therefore losing track of the target area.

3. Perhaps most importantly, when the user has to go to the scroll bar to move a document, even by just one line, it takes the perceptual, cognitive, and motor resources away from the target that the user focused attention on, hence breaking the work flow. One basic principle of good user interface design is to help the user to focus on the task, not the user interface. Graphical scroll is a case that violates this principle.

The above analysis shows that the standard, single-input stream WIMP interface is inadequate for browsing documents. This study looks into three alternative methods for browsing. We conducted a human factors analysis on each of the three techniques, which was followed by a formal experiment that compared these methods against the standard single-stream method.

Figure 1 The Joystick Mouse

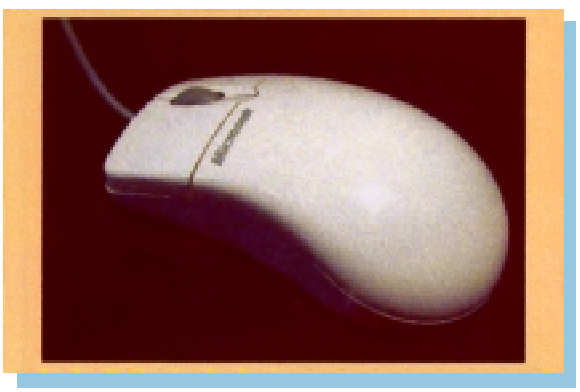
Three alternative methods for browsing

Mouse with isometric joystick. As shown in Figure 1, one alternative device we studied is the Joystick Mouse, a two-button mouse with a miniature joystick mounted between the two buttons. The mouse retains all usual functions of a standard mouse. The miniature isometric joystick, an IBM TrackPoint* pointing device, is a rate-controlled input device.[8,9] Each of the two devices can function as an independent normal two-degree-of-freedom input device. In the current study we assign the mouse for pointing and the miniature joystick for scrolling. We hypothesized that the isometric joystick is particularly suitable for scrolling tasks based on the following analyses.

First, let us briefly review the two basic types of transfer functions in input: position and rate control (see Poulton[10] for a detailed review). Position control, also called zero order control, maps the user input variable to the cursor displacement according to a constant or variable gain. Rate control, also called first order control, maps the user input variable to cursor velocity. As shown in recent six-degree-of-freedom input control studies,[11–13] position control is better conducted with isotonic, free-moving devices, such as the mouse, and rate control is better conducted with isometric or elastic devices. The key factor to this compatibility issue is the self-centering effect in isometric or elastic devices. With self-centering, rate control can be easily done. Without

Figure 2 ProAgio by Mouse Systems

Figure 3 The Microsoft IntelliMouse



it, rate control requires conscious effort. Either position control or rate control can give users the ability to control all aspects of movement, including displacement, movement speed, or higher-order derivatives, but each mode corresponds to only one aspect directly: displacement or speed.

Scrolling, or navigating through a document, requires the user not only to control the final displacement of the document to make the target appear in the viewing window, but also to control the speed of the movement so that the user can comfortably scan the document to look for the target. An isometric rate control device apparently meets these requirements. In contrast, if we use an isotonic position control device, such as the mouse, the user may not be able to control the speed of movement continuously. In particular, due to physical constraints (of either the human arm or the mouse pad), position control allows the user to move only within a certain distance at one stroke. The user has to release (by lifting the mouse) and re-engage the position control device repeatedly in order to scroll over a longer distance.

When using the Joystick Mouse, the user can use either the index finger or the middle finger to operate the joystick. In practice, most users use the index finger. When using the index finger, the user has to switch the same finger between the left button and the joystick. Because of its close proximity, the user can rely on kinesthetic memory to locate the stick without looking at it.

Mouse with finger wheel. The idea of adding an additional sensor to a mouse is not new. As described in Venolia,[14] a thumb wheel can be mounted onto a standard mouse for an additional degree of freedom in a three-dimensional interface. The first commercial mouse with scroll capability, the *ProAgio*** by Mouse Systems (Figure 2), dedicated a wheel to scrolling. We call this class of device Wheel Mouse and used a recent model, the Microsoft IntelliMouse** (Figure 3) in the current study.

The wheel in the IntelliMouse works in position control mode. It is largely free-moving (isotonic) but with a detent mechanism. The control gain from a detent step to the number of lines of scrolling is adjustable. To set the control gain high will make the scrolling faster. However, in order to be able to scroll documents at the resolution of a line of text, the detent step should be set to one line. The user may repeatedly stroke the wheel for long movement.

The IntelliMouse provides two additional modes of scrolling; both turn the mouse itself into a rate control device. As analyzed earlier, an isotonic device lacks the self-centering effect that is desirable in rate control. In one mode of the IntelliMouse, the user presses down on the wheel, which is also a button, to turn the mouse body movement to rate control scrolling: the further the mouse is moved from where the wheel is pressed, the faster the document scrolls. When the user releases the wheel, scrolling stops. In the second mode, the user presses and releases the wheel to start the rate control scrolling. Any following click, either on the wheel or on other buttons, stops the scrolling. In both cases, a visual anchor is displayed on the screen to indicate where the rate control scrolling starts. This may help the lack of centering effect in the mouse for rate control, but such a centering feedback comes from the visual channel, not the haptic feel.

As with the Joystick Mouse, the user can roll the finger wheel for scrolling with either the index finger or the middle finger. Pointing is done by normal mouse movement.

Two-handed joystick and mouse. The third method we studied was a two-handed input method. A keyboard with a TrackPoint (between the G, H, B keys, as in IBM ThinkPad* computers) and a standard mouse were used in this method as shown in Figure 4. The user operates the joystick with a nondominant hand to do scrolling and manipulates the mouse with the dominant hand to do pointing. Note that the system can be easily set for left-hand-dominant users.

The idea of using the nondominant hand for a scrolling task has been advocated by researchers such as Buxton[2] for over a decade. Scrolling was also one of the first scenarios in which two-handed input was experimentally demonstrated to be superior to the standard one-handed input. Equipping subjects' nondominant hands with two strips of touch-sensitive tablet and their dominant hands with a puck on a graphics tablet, Buxton and Myers[3] studied users' performance in a text document navigation (jump or scroll) and selection (pointing) task. In that experiment the participants used their nondominant hand to jump (one strip that was absolute position sensitive) or scroll (another strip that was relative movement sensitive) the document and used the dominant hand to select targets. With such a two-handed setup, a 15 percent (for expert users) to 25 percent (for novice users) performance improvement was measured.

The present two-handed system studied here differs from previous systems[3,4,15] in terms of the physical devices used in two-handed interaction. One of the two devices in the system is an isometric rate control joystick (Figure 4). There are four potential advantages to including an isometric joystick in a two-handed system.

First, there are individual preferences for different types of devices. Having one joystick and one mouse in the system gives the user a choice when they need only one device. Second, device performance is task-dependent. A unique advantage of in-keyboard isometric joysticks is that the user's fingers do not have to leave the keyboard, making mixed typing and pointing tasks much faster.[8] Including an isometric joystick in the dual-device system gives the user a choice when needed for a particular task.

Figure 4 In-keyboard isometric joystick (top), operated by the nondominant dand (left for this user) for scrolling while the dominant hand moves a mouse for pointing (bottom)

Third, an isometric joystick requires less space, or footprint, than any other device (mouse, touchpad, or trackball). This advantage is not only important for portable computing, but also important for a two-handed desktop environment where a keyboard with a mouse has already crowded the workspace. Fourth, as pointed out earlier, a rate control technique that is compatible with isometric devices can be particularly suitable for scrolling tasks; no repetitive release-re-engage problem exists as in position control techniques.

However, the joystick-mouse two-handed system also poses an unanswered theoretical question. With previous two-handed systems that have been demonstrated to be advantageous, both hands were engaged in the same isotonic position modes, which means consistent or similar motor actions across two hands. In the current system, the two hands are engaged in different motor control mechanisms: one in isotonic position control and the other in isometric rate control. Is such a combination still superior to the standard one-handed input system?

What is also conceptually interesting is the contrast between the two-handed system (Figure 4) and the

Joystick Mouse (Figure 1). Identical transducers were used in the two input methods. The only difference was the location of the joystick. In the case of the Joystick Mouse, the joystick was on the mouse and was manipulated by the same hand that operates the mouse. In the current case, the joystick was in the keyboard and was manipulated by a different hand. In other words, we are distributing two streams of input in two ways: one puts both streams into one hand and the other separates them to two hands. It is interesting to find out how user performance differs between the two methods.

Our experimental task modeled one of the most frequently used interactive computer tasks of today.

We should briefly mention a human bimanual action theory: the kinematic chain (KC) model of bimanual action.[16] The KC model strongly suggests that the two human hands work in a cooperative but asymmetric manner. The nondominant hand, like a base link in a chain, tends to take precedence (act first), work on a larger but coarse scale, and set the frame of reference. The dominant hand, like a terminal link in a chain, tends to act later, work in a smaller but finer scale, and operate within the frame of reference. The current two-handed system coincides with these characteristics very well: the nondominant side acts first (scroll first), sets the frame of reference, and moves at a larger distance (rate control). The dominant hand acts later and operates within that frame on a smaller scale. This model is also what we do in natural life: hold and move a document with our nondominant hand and write within the page with our dominant hand.

The experiment

Experiment design. We chose to model our experimental task after one of the most frequent interaction tasks that today's computer users do: Web browsing. A Web page, stored as a local file to avoid transmission delay, was presented to the participant. The document contains texts from an IBM computing terminology dictionary (Figure 5). A hyperlink is embedded at an unpredictable location in each page. The user's task was to scroll the document until he or she found the target hyperlink (Figure 5, bottom). Clicking on the target word "Next" would bring the participant to the beginning of the next Web page. The target word "Next" was displayed in a larger font and different color and was preceded with a string of asterisks so it could be easily recognized. Each test of the experiment consisted of 10 pages of browsing (scroll and point). The size of the Web pages was set so that the scroll handle width was 1.3 cm (so it was not too difficult to click and drag for the standard mouse condition; see Figure 5, bottom). The Web browser viewing area was 24 cm wide and 15 cm long on a cathode ray tube display. Participants were allowed to adjust the positions of mouse, keyboard, and display on the desk to suit their own preferences.

Four interaction methods were tested in the experiment: standard mouse (Mouse), mouse with a finger wheel (Wheel Mouse), mouse with joystick (Joystick Mouse), and mouse with in-keyboard joystick operated by different hands (Two Hands). Note that the pointing mechanism is the same with all four methods: mouse movement by the dominant hand. A total of 12 volunteers participated in the experiment. A within-subject design was used with a Latin square pattern for order balancing. Each of the four methods was presented as the first, second, third, or fourth technique tested to an equal number of participants. Each participant performed the tests with all four methods. With each method, the participants were first given one practice run, during which they were asked to explore all modes (in the cases of Mouse and Wheel Mouse) and strategies (aggressive or careful). Although encouraged to take as much time as they needed, they all finished the 10 pages of practice in less than 10 minutes. The participants were then asked to perform two consecutive tests (10 pages each test) as quickly as possible.

The same 10 Web pages were used for all tests to ensure the same task difficulty for all methods tested. None of the participants appeared to realize that these were the same pages. If some of them did remember the locations of the targets, they may have performed overall faster and hence reduced the differences among the four methods. We considered such an effect to be weak and hoped that we could still detect meaningful significant differences between the methods.

Figure 5 Web page browsing was used as the experimental task; shown are the beginning (top picture) and the middle (bottom picture) of page 5

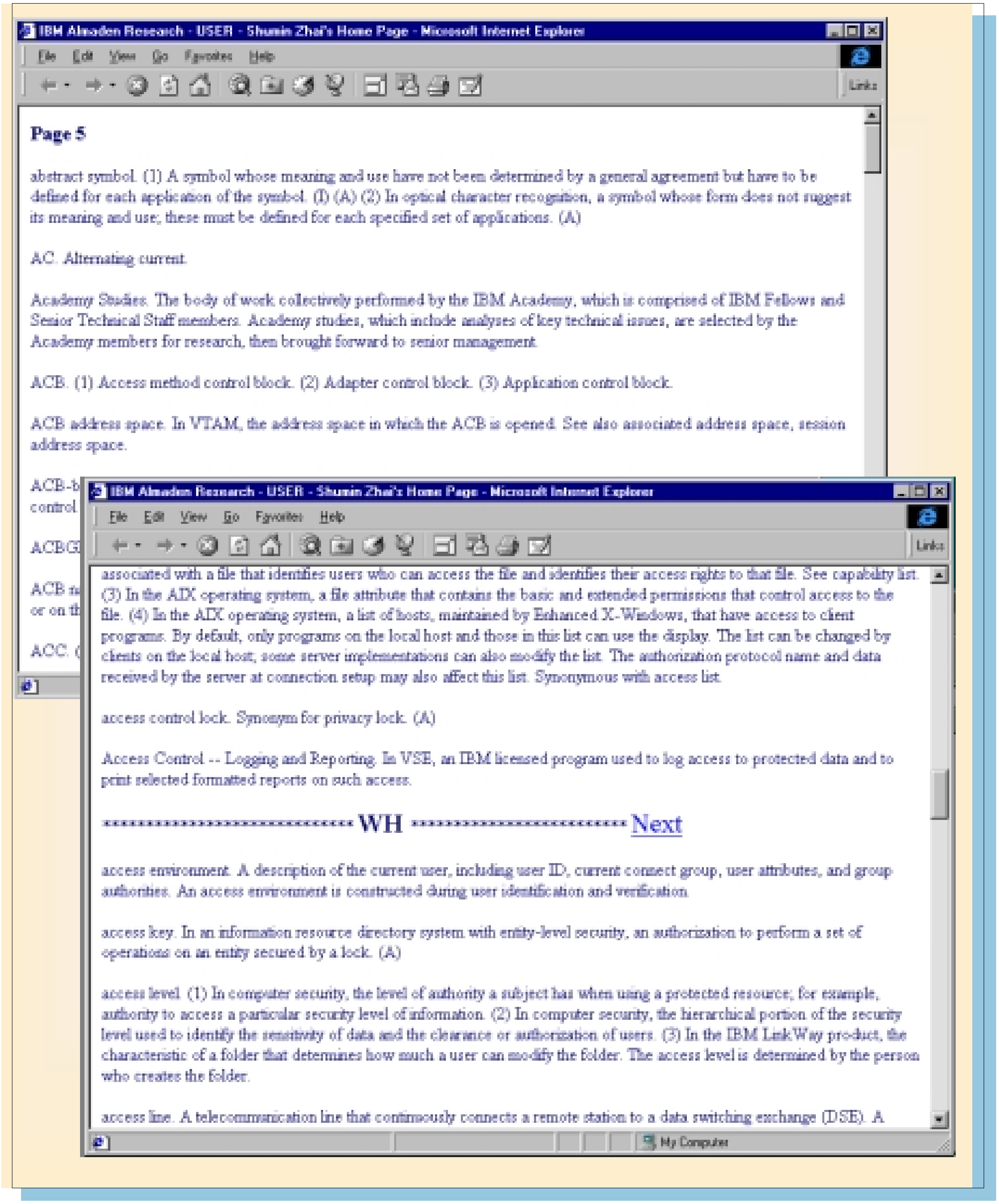
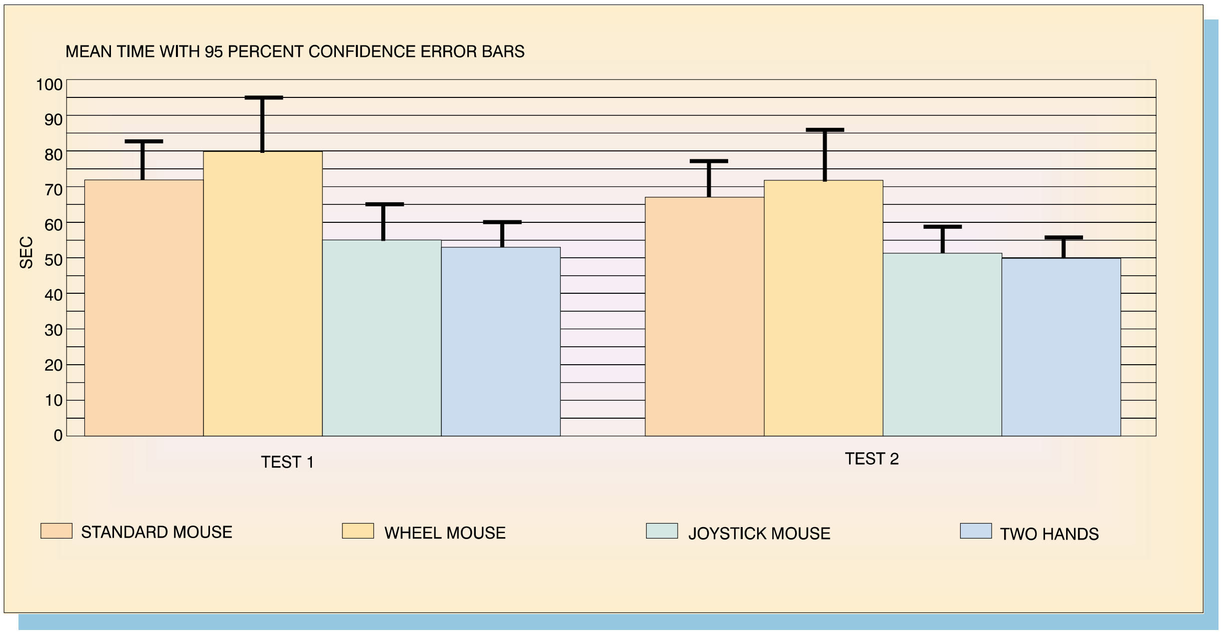


Figure 6 Completion time of Web browsing task



Of the 12 participants, all had daily experience with using a mouse; five had daily experience with using the in-keyboard isometric joystick; all but one had no experience with the three alternative methods; one participant had used the three alternative methods once before.

Trademarks on the devices were covered, and the devices were presented as research prototypes in order not to influence participants' opinions on each of the methods. After completing all four methods, participants were asked to rate each of the four methods on a −3 (terrible) to +3 (great) scale based on their experience.

Results. Figure 6 depicts the mean completion time and 95 percent confidence bars in each of the two consecutive tests. A repeated measure variance analysis showed that participants' completion time was significantly affected by input method ($F_{3,11} = 20.3$, $p < .0001$). Although Test 2 was significantly faster than Test 1 ($F_{1,11} = 12.4$, $p < .01$), such an improvement did not alter the relative performance pattern of the input methods (Method X Test insignificant: $F_{3,11} = 1.1$, $p = .37$).

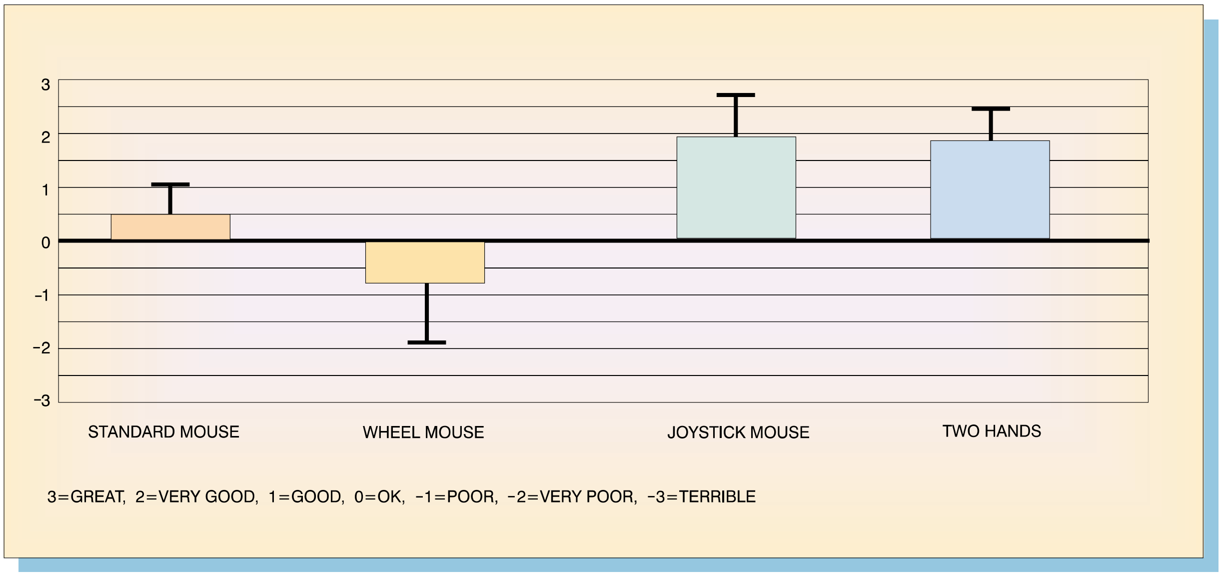
With the Mouse condition as the reference, the Joystick Mouse and two-hand conditions were 22.4 and 25.5 percent faster, and the Wheel Mouse condition was 8.7 percent slower than the standard mouse condition. Statistically, the difference between Mouse and Wheel Mouse conditions ($p = .086$) and the difference between Joystick Mouse and two-hand conditions ($p = .57$) were not significant. All other pairwise comparisons were significant ($p < 0.0001$, t-Test).

Participants' subjective ratings based on their experience were similar to the performance measurements (Figure 7) except for the difference between Mouse and Wheel Mouse. Participants gave the Wheel Mouse a significantly lower rating than the standard mouse ($p < .05$, t-Test). The Joystick Mouse and two-hand conditions were rated significantly higher than the other two methods (p value from .01 to .0001), but the difference between the two was not significant ($p = .86$).

Discussion

Wheel Mouse. Surprisingly, although it offered dual-stream input, the Wheel Mouse did not perform faster than the standard mouse, despite the fact that with a single-stream mouse one has to switch between target selection and manipulating the scroll bar.

Figure 7 Mean subjective ratings, with percent confidence error bars, on the four input methods



Three participants commented that it was tedious and tiring to repeatedly roll the wheel, although this mode was intuitive. Although encouraged to explore all three modes in the practice phase, only six participants used the two other rate control modes in addition to wheel rolling in the real tests. It was felt that the rate control mapping functions in the IntelliMouse could be improved. However, we believe the lack of self-centering in the isotonic device (mouse) places it at a fundamental disadvantage to do effective rate control.[11–13] Alternatively, if the mouse functioned in position control mode when the button was pressed, users' performance might have been better. The low performance of the Wheel Mouse in this task shows that a dual-stream solution is not guaranteed to outperform the status-quo single-stream input.

Joystick Mouse. Supporting our analyses in the introduction, this dual-stream input device outperformed the standard single-stream input significantly. Subjective ratings also verified its advantages. Comparatively, although both the Joystick Mouse and the Wheel Mouse used one hand to handle two streams of input (even with the same fingers), the Joystick Mouse significantly outperformed the Wheel Mouse, by a mean magnitude of 29 percent.

Two Hands. Interestingly, no significant performance or rating difference was found between the two-handed system and the Joystick Mouse, even though the two streams of input were assigned very differently and the two-handed system conforms to the KC theory. Nonetheless, the results showed that an asymmetric two-handed design, one hand with isometric rate control and the other hand with an isotonic position control, worked well, outperforming the status quo by 25 percent for the browsing task. Concerns were raised as to whether such a two-handed system would work at all and whether the user would confuse the functions of the two hands. Clearly this was not the case. Note that although the two-handed system did not prove to be superior to the one-handed, dual-stream input in the current scrolling-pointing task, the conclusion should not be applied to many other tasks, such as tool glass studied by Bier, Stone, Pier, Buxton, and DeRose[17] and graphical manipulation studied by Leganchuk, Zhai, and Buxton.[4] In fact it is extremely difficult, if not impossible, to use the one-handed dual-stream solutions in tasks that require parallel actions, such as scaling, translating, and rotating a two-dimensional geometry by controlling two vertices.[4]

For the scrolling-pointing task studied in this experiment, there could exist suitable techniques other than the ones investigated. One possible example is to use the page up and page down keys for scrolling and the mouse for pointing. The main advantage with the page keys is that they move the document by precisely one window, which is very desirable in the case of an all-text document. There are two disadvantages to this solution. One arises when the user needs to move less than a page in order to place a picture, a table, or a subroutine of a program in the center of the window. One page might move too far in this case. The arrow keys that move one line at a time are less efficient. The second and more important disadvantage is that the page up and page down keys are located on the right side, the same side as the mouse for all right-handed users and many left-handed users who use their right hand for mouse manipulation. This means that the users have to take their right hand off the mouse in order to reach the page keys and move back to the mouse afterwards. This process requires the visual attention of most users, since the page keys are too far from the "home row" (ASDFGHJKL) for touch-typing and yet not at the very edge of the keyboard, which can be more easily reached.

A simple improvement that can be made is to add another column of keys, such as page up, page down, copy, paste, and delete to the *left* edge of the keyboard. With such an arrangement, the majority of users will be able to keep their left hands on these keys and their right hands on the mouse. Such an improvement will be complimentary to the advantages of dual-stream mice studied in this experiment. When users need to move either exactly one or multiple pages, they can simply press the page keys with their left hands. When they need to move at a nonfixed interval, they can use the dual-stream mice. We recommend that keyboard manufacturers consider such a modification.

We would also like to point out that the task used in the experiment is intentionally an experimental abstraction of a real browsing task so that differences in performance of the input system could be measured. Real browsing behavior includes reading and other components, which may dilute the performance differences we found in this study.

Conclusions

Three dual-stream input systems, two single-handed and one two-handed, were analyzed and compared in a Web browsing task that required scrolling and pointing. Both performance measurement and subjective rating showed that a mouse with a joystick all controlled by one hand, or a mouse for one hand and a joystick for the other, significantly outperformed the current standard single-stream mouse input. However, the mouse with a wheel device did not perform any better than the standard mouse. In order to take advantage of additional input streams, the types of input devices must be appropriately matched to the tasks being performed. In addition to much evidence in the literature, this study indicates that it is time to add multistream input to mainstream commercial systems, although each step of a new design has to be guided by thorough human factors research to avoid mistakes.

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*Trademark or registered trademark of International Business Machines Corporation.

**Trademark or registered trademark of Mouse Systems or Microsoft Corporation.

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