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# Multi-Stream Input:
# An Experimental Study of Document Scrolling Methods

**Shumin Zhai** **Barton A. Smith**

IBM Almaden Research Center

650 Harry Road, NWE-B2 , San Jose, California 95120, USA
{zhai, basmith}@almaden.ibm.com

**ABSTRACT** Navigating through online documents has become an increasingly common Human Computer Interaction (HCI) task. 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 on the dominant hand and a joystick on the other, both significantly improved users' performance. A human factors analysis on each of the three input methods is presented.

**KEYWORDS** Input Devices, Interaction Techniques, Web Browsing, Scrolling, Mouse, Isometric vs. Isotonic Devices, joystick, Wheel Mouse, IntelliMouse™, ScrollPoint Mouse™, Trackpoint™, Two-handed Input, Bimanual Interaction.

## 1. INTRODUCTION

The WIMP interaction style (windows, icons, menus and pointer) continues to gain an increasingly wide range of applications, despite its age and long history (Smith, Irby, Kimball, Verplank

& Harslem, 1982). 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. Buxton 1986), but they have been largely restricted to the research literature and isolated demonstrations. The unavailability of new commercial technology (hardware and software) and an incomplete understanding of human factors both 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 2 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 the users many advantages such as the ease of understanding and learning the interaction mechanism. The disadvantage, however, is the limited communication bandwidth (Buxton 1986) and the costs in time and effort of acquiring widgets and control points (Buxton and Myers 1986, Leganchuk, Zhai and Buxton 1996). A particular case in point 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 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 (Fitts 1954), 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 8 bits, which may take more than 2 seconds to complete (MacKenzie 1992).

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 with 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, requiring maintaining pressure on a button while moving the input device, is more difficult and takes more time than pointing over the same Fitts' index of difficulty (MacKenzie, Sellen and Buxton 1991). 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 the window jumps by, therefore loosing 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 in point 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.

## 2. THREE ALTERNATIVE METHODS FOR BROWSING

### 2.1. 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 (Rutledge and Selker 1990, Barret et al 1995). Each of the two devices can function as an independent normal 2 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.

Figure 1 The Joystick Mouse is a mouse with an miniature joystick mounted between the two buttons.

First, let us briefly review the two basic types of transfer functions in input: position and rate control (see Poulton 1974 for 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 (Zhai and Milgram 1993, Zhai 1995, 1998), 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 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. On the other hand, 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 either use 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. Due to the close proximity, the user can rely on kinesthetic memory to locate the stick without looking at it.

### 2.2. Mouse with finger wheel

The idea of adding an additional sensor onto a mouse is not new. As described in (Venolia 1993), a thumb wheel can be mounted onto a standard mouse for additional degree of freedom in 3D 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.

*Figure 2. ProAgio* by Mouse Systems

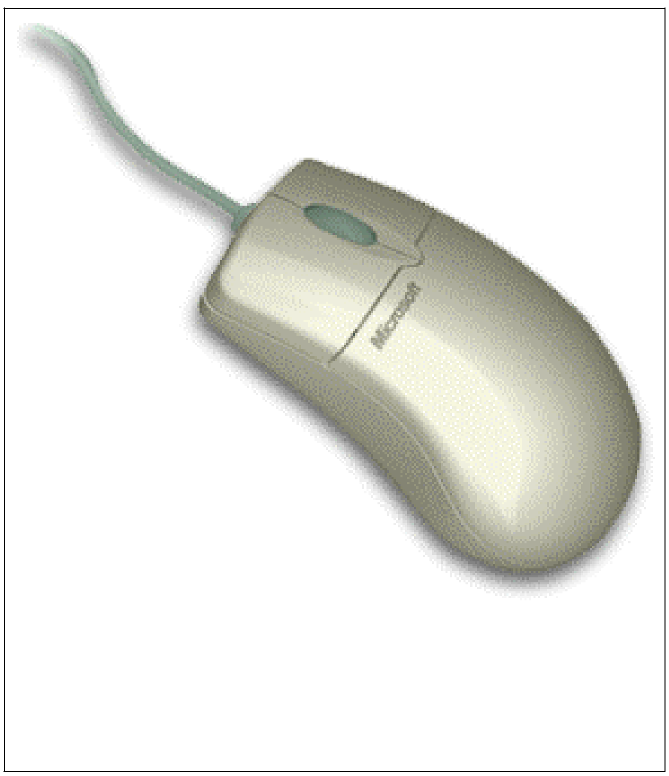



Figure 3. The Microsoft IntelliMouse™ used in the study.

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 to 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 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 down, 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 use either the index finger, or the middle finger to roll the finger wheel for scrolling. Pointing is done by normal mouse movement.

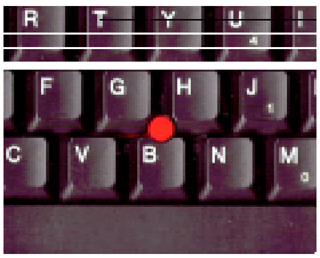
### 2.3. Two handed joystick and mouse

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 (Figure 4). The user operates the joystick with non-dominant hand to do scrolling and manipulates the mouse with the dominant hand to do pointing.

The idea of using the non-dominant hand for a scrolling task has been advocated by researchers such as Buxton (1986) 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' non-dominant hand with two strips of touch-sensitive tablet and their dominant hand with a puck on a graphics tablet, Buxton and Myers (1986) studied users' performance in a text document navigation (jump or scroll) and selection (pointing) task. In that experiment the participants used their non-dominant 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 set-up, 15% (for expert users) to 25% (for novice) performance improvement was measured.

The present two-handed system studied here differs from previous systems (Buxton and Myers 1986, Kabbash, Sellen and Buxton, 1994; Leganchuk, Zhai and Buxton, 1998), 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 device. 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 (Rutledge and Selker, 1990). Including an isometric joystick in the dual device system gives the user the choice when needed for a particular task.



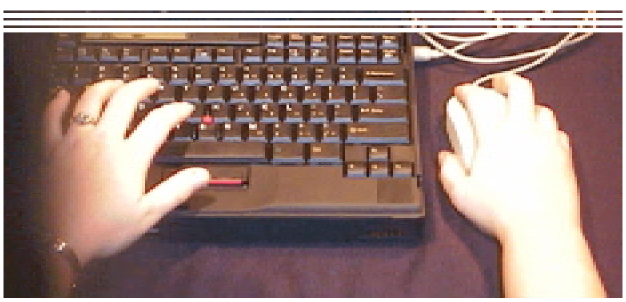



Figure 4 In-keyborad Isometric Joystick (top), operated by the non-dominant (left for this user) hand for scrolling while the dominant hand moves a mouse for pointing (bottom). Note that the system can be easily set for left-hand-dominant users.

Third, an isometric joystick requires less space, or footprint than any other device (mouse, touchpad or trackball). This 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-reengage 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 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.

We should briefly mention a human bimanual action theory: the Kinematic Chain (KC) model of bimanual action (Guiard 1987). The KC model strongly suggests that the two human hands work in a cooperative but asymmetric manner. The non-dominant 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 non-dominant 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 is also what we do in natural life: hold and move a document with our non-dominant hand and write within the page with our dominant hand.

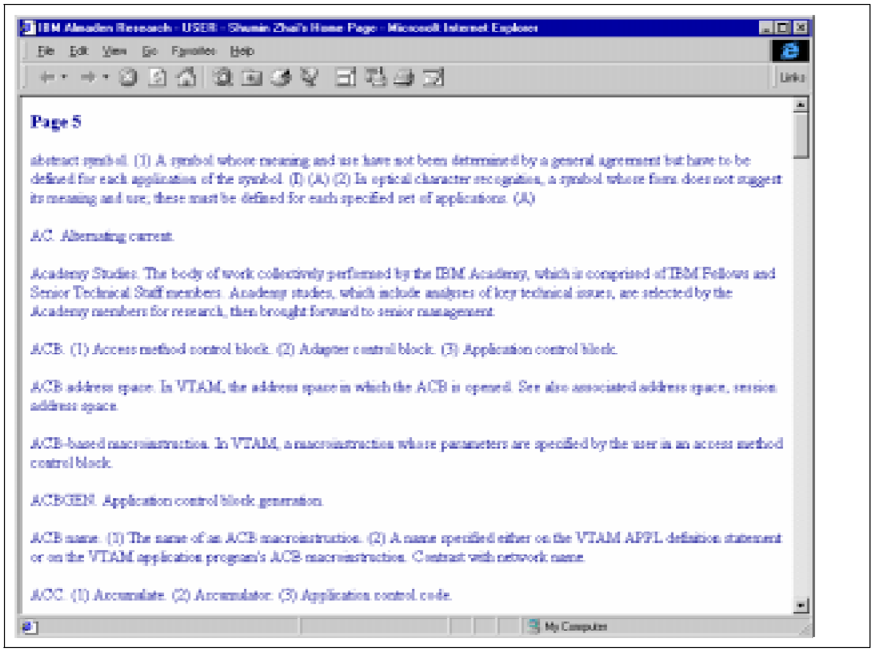
## 3. The Experiment

### 3.1. Experiment Design

We choose to model our experimental task after one of the most frequent interaction tasks 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 hyper link is embedded at an unpredictable location in each page. The user's task was to scroll the document until he/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 proceeded with string of asterisks so it can 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 as such 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 CRT 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 Hand). 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 explored all modes (in the cases of Mouse and Wheel Mouse) and strategies (aggressive or careful). Although encouraged to take as much time as they need, they all finished these 10 pages of practice in less than 10 minutes. The participants were then asked to performed 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 realized that these are 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.



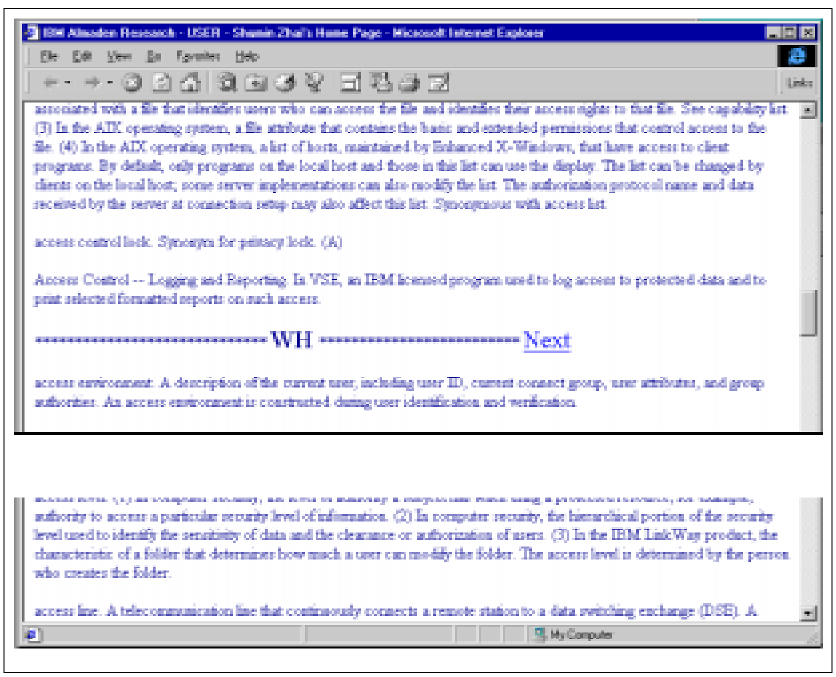




Figure 5 Web page browsing was used as the experimental task. The participants had to scroll and point at a hyperlink to proceed in the task. Shown here are the beginning (top picture) and the middle (bottom picture) of page 5.

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

Trade marks on the devices were covered and 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.

### 3.2. Results

Figure 6 shows the mean completion time and 95% 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: $F_{3, 11} = 1.1$, $p = .37$).

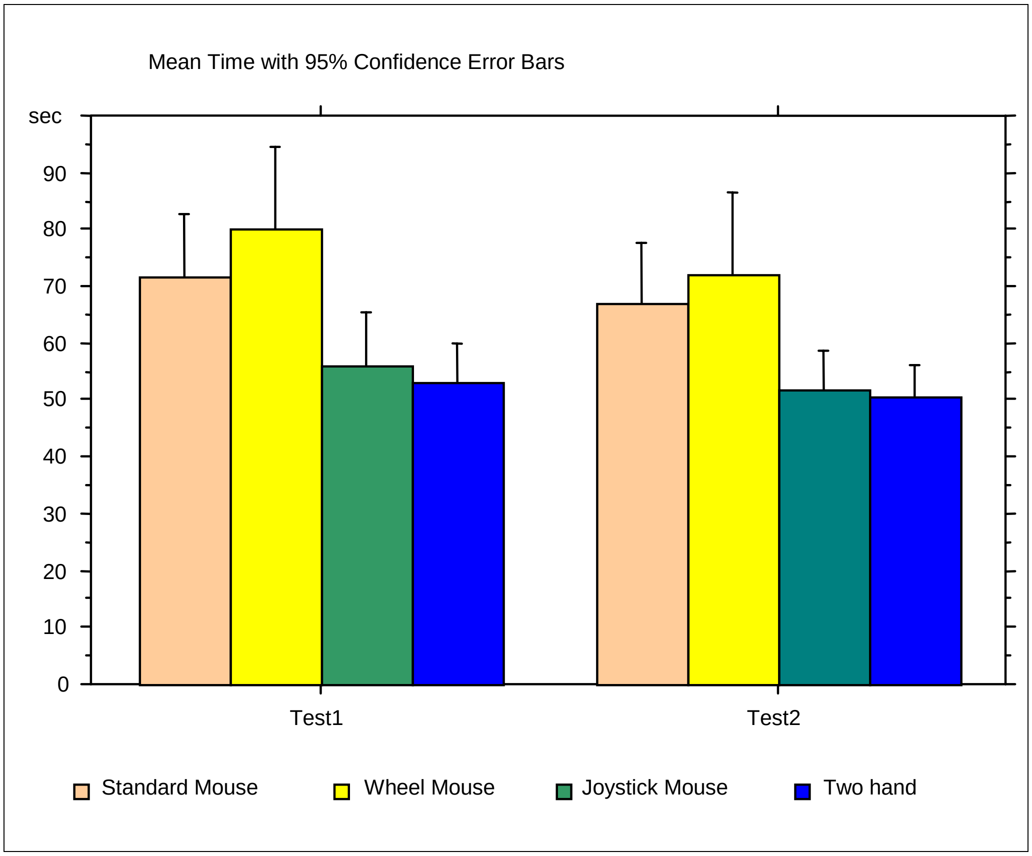



Figure 6 Completion time of web browsing task

Taking the Mouse condition as the reference, the Joystick Mouse and 2Hand 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 2Hand ($p = .57$) were not significant. All other pair wise comparisons were significant ($p < 0.0001$, t-Test).

Participants subjective rating based on their experience were similar to the performance measurements (Figure 6) 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 2Hand 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 ($p = .86$).

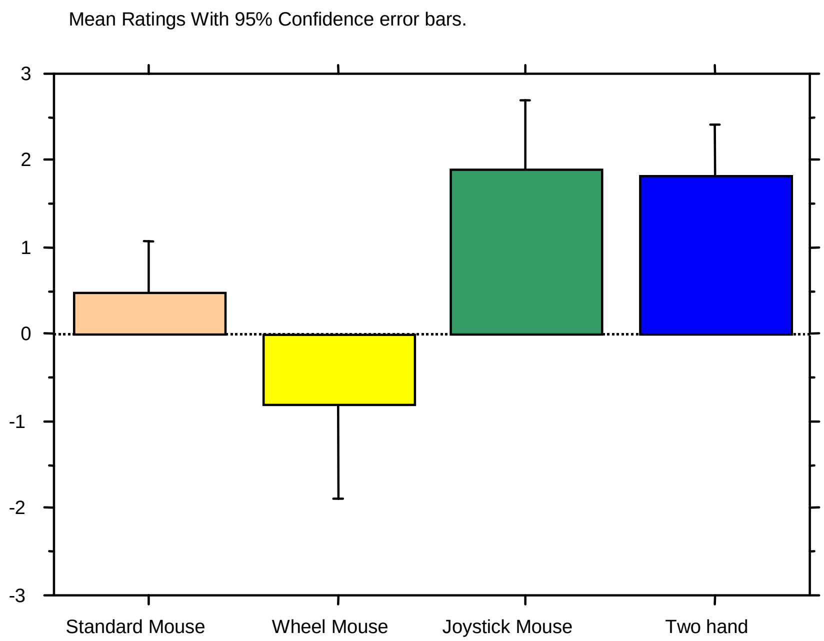



Figure 7  Mean subjective ratings, with 95% confidence error bars, on the four input methods: 3 = great, 2 = very good, 1 = good, 0 = OK, -1 = poor, -2 = very poor, -3 = terrible.

## 4. 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.  Three participants commented that it was tedious and tiring to repeatedly roll the wheel, although this was an intuitive mode. Although encouraged to explore all three modes in the practice phase, only 6 participants used the two additional 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 (Zhai and Milgram 1993, Zhai 1995, 1998). Alternatively, if the mouse functioned in position control mode when the button was pressed, user's 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 Hand. 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 if such a two handed system would work at all and if the user would confuse the functions of the two hands. Clearly this is 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 (1993) and graphical manipulation studied by Leganchuk, Zhai, and Buxton (1998). In fact it is extremely difficult, if not impossible, to use the one handed dual stream solutions in tasks that requires parallel actions, such as scaling, translating, and rotating a 2D geometry by controlling two vertices (Leganchuk, Zhai, Buxton, 1998).

For the scrolling - pointing task studied in this experiment, there could exist suitable techniques other than the ones investigated there. 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 case of all text document. There are two disadvantages to this solution. One arises in the case that 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 is less efficient. The second and more important disadvantage is that the Page Up and Page Down keys are located on the right hand 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 most user’s visual attention, since the page keys are too far from the “home row” (ASDFGHJKL) for touch-typing and yet not at the vary edge of the keyboard which can be more easily reached. A simple improvement 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 hand on these keys and their right hand on the mouse. Such an improvement will be complimentary to the advantages of dual stream mice studied in this experiment. When the users needs to move exactly one or multiple pages, they can simply press the page keys with their left hand. When they need to move at a non-fixed interval, they can use the dual stream mice. We recommend that keyboard manufacturers consider such modification.

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

## 5. 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 in one hand and joystick on the other, significantly outperformed the current standard single stream mouse input. However, the mouse with a wheel device did not performed 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 multi-stream input into mainstream commercial systems, although each step of a new design has to be guided by thorough human factors research to avoid mistakes.

**Acknowledgment**

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basis for a commercial product, the IBM ScrollPoint™ mouse using different hardware and software technologies.

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