1995

Comparison of integrated pointing devices

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COMPARISON OF INTEGRATED POINTING DEVICES

A Thesis

Presented to

the Faculty of the Department of Psychology

San Jose State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

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December, 1995

UMI Number: 1377270

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ABSTRACT

A COMPARISON OF INTEGRATED POINTING DEVICES

by Vasudha Sabada

The penetration of the Windows and similar interfaces in both the desktop and portable environments produced the need for a range of input devices to use in conjunction with the keyboard. For the past decade, pointing devices for the desktop environment such as the mouse, trackball, joystick, tablet, and other input devices have been evaluated for user performance with interactive systems. This study evaluated the performance of three integrated pointing devices- stick, trackball, and touchpad implemented in notebook computers. Twenty seven subjects performed a target acquisition task and a typing task which was included to simulate the actual word processing environment on all three devices for a total of 105 trials per device. Dependent measures, reaction time and errors were measured using analysis of variance for time to target. Independent measures included device, trial blocks, target size, and target distance. The results concluded that the subjects performed better with the trackball. Results on error showed no significant difference between the stick and the trackball. The error rate on the touchpad was significantly higher than that of the trackball or the stick.

ACKNOWLEDGMENTS

I would like to thank Patrick Nicolet for providing me with invaluable assistance in the completion of this study. I also want to thank Jack Chen for giving me the opportunity to do my internship at Logitech and making this thesis possible. I am grateful for his patience and understanding throughout my internship. I also want to thank the many people at Logitech, especially, Alain Wegmann, for their support.

I am grateful to Dr. Howard Tokunaga for accepting me into the program. His advice and guidance were invaluable. I am especially indebted to Dr. Kevin Jordan for his help and guidance over the years; for his comments, constructive critiques, and meticulous proofreading. I also want to thank everyone in the Psychology Department, SJSU, for their assistance.

My greatest debt is to my husband, Prasad, without whose support, patience, and encouragement, none of this would have happened.

This study was supported by Logitech Inc., Fremont, CA.

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ABSTRACT

The penetration of the Windows and similar interfaces in both the desktop and portable environments produced the need for a range of input devices to use in conjunction with the keyboard. For the past decade, pointing devices for the desktop environment such as the mouse, trackball, joystick, tablet, and other input devices have been evaluated for user performance with interactive systems. This study evaluated the performance of three integrated pointing devices- stick, trackball, and touchpad implemented in notebook computers. Twenty seven subjects performed a target acquisition task and a typing task which was included to simulate the actual word processing environment on all three devices for a total of 105 trials per device. Dependent measures, reaction time and errors were measured using analysis of variance for time to target. Independent measures included device, trial blocks, target size, and target distance. The results concluded that the subjects performed better with the trackball. Results on error showed no significant difference between the stick and the trackball. The error rate on the touchpad was significantly higher than that of the trackball or the stick.

Comparison of integrated pointing devices

The pervasive presence of computers in all aspects of everyday life has led to the development of human-computer interaction. The interaction between the human and the computer, in the form of commands and queries to the computer and the associated response and message from the computer, has led to the emergence of interactive application software such as database queries, graphical user interface, and other sophisticated applications.

The penetration of Windows and similar interfaces in both the desktop and portable environments fosters the need for a range of input devices to use in conjunction with the keyboard. In the design of many graphical interfaces, the manner in which the user points to the computer for the selection of some component on the graphical display is important (Maguire, 1985). As Bewley et al. (1983) put it, "Seeing something and pointing to it is easier for people than remembering a name and typing it" (p. 72). This has added an impetus to the development of a number of pointing devices such as the mouse, trackball, joystick, touch panel, light pen, and digitizing tablet now available to consumers. Many of these devices have been integrated in notebook computers.

Integrated pointing devices are built-in input devices like the trackball, touchpad, and the stick in the keyboard. Today, with continuous changes in the pointing device market, especially when it comes to integration of the devices, it is not an uncommon sight to see the pointing devices integrated in various locations in the notebook. For example, the integrated devices can be found in distinct locations such as in front of the keyboard, on the right corner of the keyboard or on the right corner of the screen. The trackball was the first pointing device to be integrated in a notebook computer.

A myriad of studies has been conducted comparing different input devices for desk top systems in the past decade (Albert, 1982; Epps, 1986; Whitfield et al., 1983). Pointing devices for the desktop environment such as the mouse, trackball, joystick, tablet, and other input devices have been evaluated for user performance on interactive systems with varied results. Several relevant studies are reviewed in the following section.

Review of Desktop Pointing Device Research

Albert (1982) compared a wide range of input devices, touch screen, light pen, data tablet with puck, trackball, force joystick, position joystick, and a keyboard on performance in a cursor positioning task. Each of the eight subjects were measured on a target acquisition task. Three criteria were used to measure the subjects performance: accuracy, speed, and subjective evaluation. The subjective measures included measures on ease of learning, fatigue, and general comfort of each device. Albert found that the trackball was the most accurate device in terms of speed and accuracy of target acquisition and the touch screen was the least accurate. Subjective analysis indicated that the light pen, touch screen, and touchpad were more comfortable, had shorter learning curve, and were the least fatiguing.

Haller, Mutschler, and Voss (1984) compared light pen, graphic tablet, mouse, trackball, cursor keys, and a voice recognition device. The subjects were required to correct a faulty one-page-letter which consisted of 18 one-character-replacement errors on the top, in the middle, and at the bottom of the prepared document. The subjects were given training prior to the the experiment and were allowed to choose the speed for the graphic tablet, mouse, and the trackball. Dependent measures were time to target and errors in replacement. Results showed that the mean error on positioning time was the lowest for light pen; and the voice input had the longest positioning time. No significant difference was found among the mouse, trackball, cursor keys, and the graphic tablet. On the positioning errors, the trackball had the highest error rate followed by the mouse. The light pen and cursor keys had the fewest errors. The high error rate on the trackball was attributed to the "touch sensitivity" of the ball. Subjective evaluations showed that the light pen was ranked high followed by the mouse.

Epps (1987) compared the performance of an absolute touchpad, mouse, trackball, relative touchpad, force joystick, and displacement joystick on a target acquisition task, text editing, and graphics tasks. The text editing and graphics tasks are not discussed here.

Twelve subjects performed a target acquisition task. Five levels of target sizes (4, 8, 16, 32, and 64 pixels), four levels of target distances (2, 4, 8, and 16 cm) and five levels of trial blocks were included. Performance measures were based on time to target and subjective evaluation on 10 bipolar scales and ranking on 6 criteria. Performance was analyzed across trial blocks prior to the comparison of devices across target size and target distance. Since the target positioning performance was found to be asymptotic after block one, subsequent comparisons across target size and target distance were performed from blocks two to five.

Results indicated that for the smallest, medium, and largest target sizes, the mouse and the trackball produced better performance. When compared across target distance, again the mouse and the trackball performed better and the rate-controlled joysticks were the worst performers. Analysis on the six ranking criteria (preference, positioning accuracy, positioning speed, perceived quality, comfort, and fatigue) showed that the mouse and the trackball were ranked best. On the bipolar scales, the subjects rated the mouse and the trackball best across all ten criteria.

MacKenzie, Sellen, and Buxton (1991) compared a mouse, trackball, and a stylus with tablet in the performance of pointing and dragging tasks. Subjects used their preferred hand to perform the pointing and dragging tasks across four target amplitudes (8, 16, 32, or 64 units) and four target sizes (1, 2, 4, or 8 units). All subjects completed five sessions of each task (pointing or dragging) on each device. A session included 16 randomized blocks.

Results showed that the mean movement time during pointing and dragging was faster for the tablet followed by the mouse. Analysis of the errors in the pointing task did not yield any difference across devices. However, in the dragging task, the mouse had the fewest numbers of errors and the trackball had the highest error rate. The poor performance of the trackball was attributed to the extent of muscle and limb interaction required to complete transitions.

In general, the mouse and the trackball have been the instruments of choice among users. But the main drawback of these desk top input devices is that they are not suited for the portable environment. One of the main issues is that the mouse requires large desk space to operate. There are also concerns regarding the 1.5 seconds (Card, Moran, & Newell, 1983) necessary to move from the keyboard to the mouse and a loss of time and the distraction of reaching for a mouse or other pointing device (Selker & Rutledge, 1993). Research has been done to find alternate solutions to the problems inherent in the desk top input devices and the emerging trend is to integrate pointing devices in the keyboard. A few studies on integrated pointing devices are reviewed in the following section.

Review of Notebook Pointing Device Research

Rutledge and Selker (1990) investigated an in-keyboard pointing device, the pointing stick. A miniature joystick was placed between the G and H keys so that it did not interfere with the typing. The operating buttons were placed below the space bar. Six subjects participated in two experimental procedures in random order. The subjects performed a simple pointing task and a "maze running" task using either the pointing stick or the mouse. The mouse was located adjacent to the keyboard on the preferred side, on a foam pad.

The pointing task required the subject to press the J key if the person was right handed or the F key if the person was left handed for the target, position the stick within the target, and press the mouse button or the pointing stick button. If they were successful in selecting the target, the subject pressed the J or the F key for the next target. If they missed, the screen blanked for the next attempt. Performance measures were time from the initial key press to first pointer movement, time to successfully hit a target, and time taken to return to the keyboard. Misses were excluded from the data analysis. Each subject completed ten trials.

The maze running task required the subject to sequentially point in varying directions and distances. Each subject selected numerals in numerical order. An event began with the successful selection of a numeral. Dependent measures were time to complete each event, total time elapsed, and the number of errors.

Results indicated that in the target acquisition experiment, the time from the keyboard to reach the pointing stick was higher than expected. The return time was longer for the mouse than for the pointing stick. In the maze running experiment, for most subjects there was a significant difference between the pointing stick and the mouse both in selecting the target and the first move toward the target.

Gill, Gordon, Dean, and McGehee (1991) developed and tested an integrated cursor control and clicking device called a KeyMouse for various tasks in three software applications. The software applications included Microsoft (MS) Word 5.0, MS Windows 3.0 and MS Excel for Windows 2.1. Gill et al. compared four KeyMouse configurations: (1) Single Hand (2) Left Cursor Control (3) Toggle and (4) Right Cursor Control. However, they did not test the last configuration due to equipment malfunction.

Each subject was given a task notebook which included specific tasks the subjects were required to perform. A Rating Checklist was included and the subjects were asked to check "No Problems" if they were able to complete the task without difficulty, and "Problems" if there were errors or if they had difficulty completing the mouse task. Eleven tasks were included in the MS Word, 12 tasks in MS Excel, and, 16 or 18 tasks were included in MS Windows 3.0.

The subjects were required to start the task with a traditional mouse attached to three computers. After completion of task using the traditional mouse, the subjects were given a 30 minute break before they started on their next task using the KeyMouse. After the completion of the tasks on all three software programs, the subjects were required to complete an Absolute Rating Evaluation for the KeyMouse design they had just used. All subjects performed one block of tasks with the traditional mouse, and six blocks with the KeyMouse. At the end of the test, the subjects were asked to complete a Final Comparative Evaluation and participate in the focus group.

Results indicated that the KeyMouse designs were relatively easy to learn. There was no difference between the traditional mouse and the KeyMouse. For the tasks the subjects completed with No Problems, the traditional mouse was found to be superior. The traditional mouse was comparable to Left Cursor Control and Toggle designs. But it was found to be superior to Single Hand. On error tasks, more errors were committed with the Single Hand KeyMouse than with the traditional mouse. No difference was found between the Left Cursor Control and Toggle design KeyMouse from that of the traditional mouse. In general, the subjects preferred the Toggle design and the Single Hand KeyMouse was the least preferred.

In another study, Selker and Rutledge (1993) found that Trackpoint ll, a pointing stick, integrated in IBM's Thinkpad notebook computers, increased task speed by 25% in tasks compared to other pointing devices. They also reported Trackpoint ll saved 0.9 seconds in making a single selection while typing. They did not discuss their experimental setup or the test parameters.

Bisset and Nicolet (1994) investigated the tracking speeds and acceleration curves for three Logitech trackballs integrated in notebook computers in three different locations. A 19 mm trackball was located in the middle of the keyboard below the spacebar, a 12.7 mm trackball was located to the lower right of the keyboard, and a 12.7 mm trackball was mounted on the display screen on the lower right.

Sixteen subjects were tested in two sessions. In each session, the subjects performed a target acquisition task. Three levels of target sizes (1, 2, and 4 mm), three levels of target distances (2, 8, and 14 cm), and four levels of trial blocks were manipulated. The acceleration curves and tracking speeds for the first session were Low, Medium, High, and 30%, 50%, and 70%. In the second session for the 19 mm and 12.7 mm trackball mounted on the screen, speeds were 10%, 20%, 30%, 40%, and 50%. For the trackball located on the keyboard, the speeds were 30%, 40%, 50%, 60%, and 70%. The acceleration curve for all the three trackballs were Low.

The results indicated that for the first session, the best acceleration curve and speed was Low 30% for all three trackballs. The results for the second session showed that the best curve and speed for the 19 mm trackball and 12.7 mm trackball located on keyboard was Low 40%. Subjective analyses showed that the settings used in the second session was most preferred. Overall, the 19 mm trackball was the most preferred and the 12.7 mm trackball located on the display screen was the least preferred.

Since a number of alternate devices like the touchpad, trackball, and stick exist that are now integrated in the notebook computer, it is fitting to evaluate the performance of the current technology. As notebooks are invading the market, the type of pointing device, quality, comfort , and position of the integrated pointing devices will influence the buying trend.

<u>Summary</u>

Research on desk-top pointing devices has, in general, shown that the mouse and the trackball as the best performers. But these results cannot be taken at face value. The varied methodologies, procedures, and analyses coupled with biased performances and the location of the pointing devices itself may have given confounding results.

Based on the information provided by the integrated pointing device research, its very hard to come to a conclusion. Further research needs to be done in this area before the results can be generalized to real world situations.

Objectives

The aim of this study is twofold: to evaluate the objective performance of three integrated input devices stick, trackball, and a touchpad and to determine the best integrated pointing device for computer tasks in the portable computer environment.

Method

Subjects

Twenty seven subjects recruited by an outside temporary services agency served as paid volunteers. All except one subject had at least two years experience using a mouse. The experience reported using a stick, trackball, and touchpad ranged from none to 24 months. The age group of the subjects ranged from 20 to 45 years.

Materials

Three notebook computers were used: an IBM Thinkpad with an integrated stick, a Compaq Contura 400 with an integrated optical trackball (19 mm) from Logitech Inc., and a GlidePoint portable touchpad from Cirque Corporation attached to a Toshiba T4700CS. The trackball and the touchpad were mounted below the spacebar on the keyboard. The IBM stick was placed between the G and H keys and above the B key within the keyboard.

The test was performed using the Logitech Windows driver (6.50) and the settings were optimized for each pointing device before the experiment. The Windows driver acceleration curves for the trackball and touchpad were set at Low. The acceleration curve for the stick was set to off, so that the IBM stick built-in acceleration curve could be used. The speed setting for all three pointing devices was set at 30%. Figure 1 shows the ideal acceleration curve for the three devices.

Procedure

All subjects were given an informed consent form to read and sign before the experiment. Subjects were then given oral instructions on how to perform the task and on how to operate the pointing device. The subjects were told that to activate the touchpad, they can either single tap on the pad or click the button once or they can alternate between tapping and clicking. Each subject was provided the time to use the device until they understood its proper operation and to acquaint themselves with the feel of the input device prior to doing an artificial target acquisition task.

Each subject participated in 105 target acquisition trials for each of the three pointing devices. A set of 105 trials is composed of seven blocks of 15 trials. The 15 trials result from the factorial combination of five levels of target size and three levels of target distance. The five levels of target size are 1 mm, 2 mm, 4 mm, 8 mm, and 16 mm; the three levels of target distance are 20 mm, 40 mm, and 80 mm. Order of presentation of target size and distance was randomized within a block of 15 trials. The task and device factors were within-subjects. A typing task was included to simulate the actual word processing environment. All subjects used their preferred hand.

In the target acquisition task, the subject moved the cursor into a square target and clicked the button once. If the subject was successful in selecting the target, the word 'foreign' appeared on the screen. The subject then typed the word and pressed the

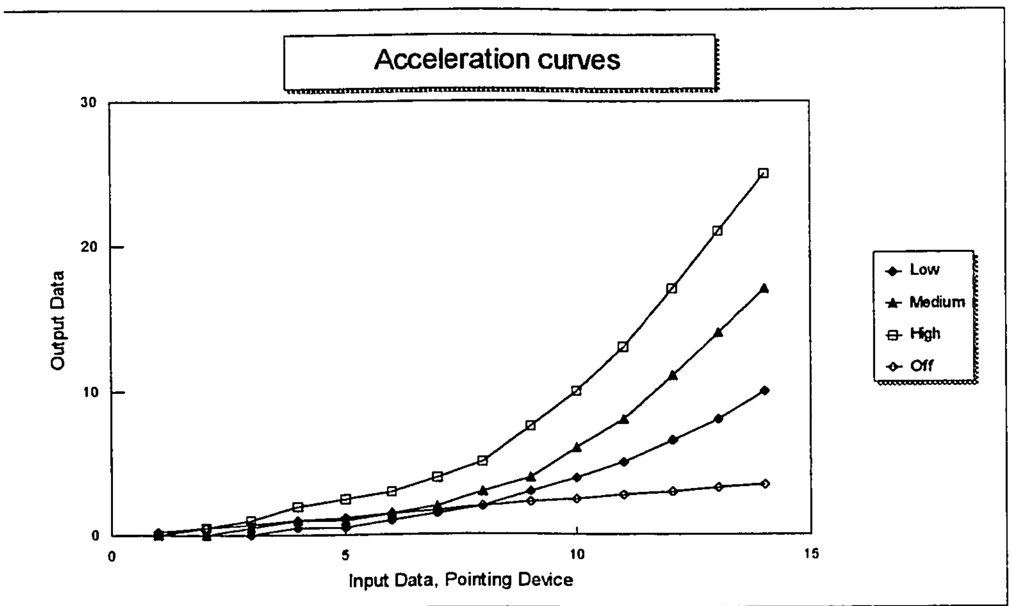
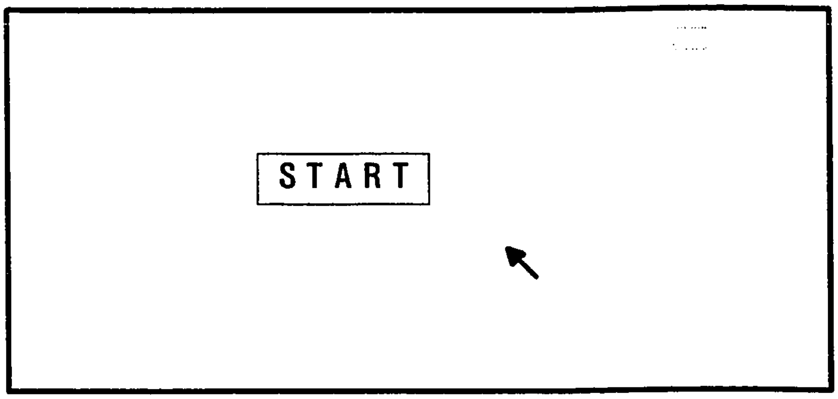


Figure 1. Idealized acceleration curves for the three devices

Enter Key for the next target (Figure 2). If unsuccessful in selecting the target, the subject repositioned the cursor inside the target, For all three devices, the cursor always started in the center of the screen. The subject then performed 105 trials with the device, and rested for 20 minutes before starting the trials for the next pointing device. The sequence was repeated for all the three pointing devices. Order of presentation of the devices were counterbalanced across subjects. Seven blocks with five levels of randomly presented sizes 1 mm, 2 mm, 4 mm, 8 mm, and 16 mm; three levels of randomly presented distances 20 mm, 40 mm, and 80 mm were used.

The dependent variables were Time to Target and Error Rate. Time to Target was based on the time for the subject to move their hand from the keyboard to the device, position the cursor within the target and click the button. Error Rate was defined as the number of targets missed.



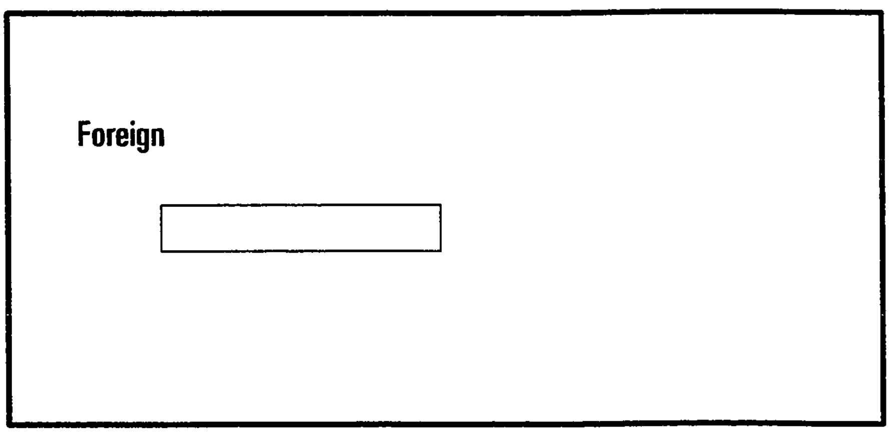


Figure 2. Experimental setup for the Target Acquisition Task

Results

Separate 3(devices) x 7(trial blocks) x 5(target sizes) x 3(target distances) within-subjects analyses of variance were performed for the dependent variables of time to target and error.

Time to Target

Results show that across all target sizes and target distances, the time to target was significantly faster for the trackball. Subjects performed better with the trackball than they did with the stick and the touchpad. The mean time taken was 3256.50 seconds. The mean response time for the stick and the touchpad were 3631.13 and 5027.67 respectively. The mean response time for the three devices are shown in Table 1.

An analysis was performed on the Device x Trial blocks to determine the learning effects associated with each device . The main effect for Trial Block $F(6, 156) = 15.18$, $p = <.001$ was significant. The Device x Trial Block interaction $F(12, 312) = 1.19$, $p = .30$ was not significant (Table 5). The effect of Trial Block is consistent for each Device. This is to be expected since the type of input device would presumably have the greatest impact on executing the function.

The mean and the standard deviation for each block are shown in Tables 2, 3, and 4. As seen in Figure 3, the time taken to target decreased steadily across trial blocks for the trackball and the stick. For the trackball and the touchpad, the performance was asymptotic after the second trial block whereas for the stick, it was after the first trial block. One of the reason for this result might be that the stick is not as sensitive as the trackball and the touchpad.

Analysis for the Device x Target Size x Target Distance for time to target is shown in Table 6 and is represented graphically in Figure 4. The main effects for the Device ($F(2, 52) = 17.86$, $p = <.001$), Target Distance ($F(2, 52) = 50.106$, $p = <.001$), and Target Size ($F(4, 104) = 174.46$, $p = <.001$) were significant. The Device x Target Size x Target Distance interaction ($F(16, 416) = 1.136$, $p = .318$) was not significant.

An analysis of variance by levels of Target Size showed a significant interaction with Device $F(8, 208) = 27.30$, $p = <.001$. However, no significant interaction was found by levels of Target Distances $F(4, 104) = 2.43$, $p = .052$, or was there any significant interaction between Target Size x Target Distance $F(8, 208) = 0.273$, $p = .974$.

In general, as the target size increased, the response time to target decreased. As can be seen in Figure 5, the time taken to target a 1 mm stimulus is much greater for all the three devices than the time taken to target a 16 mm stimulus. Overall, the time taken to target the 2 mm, 4 mm, 8 mm and 16 mm target sizes is consistently better for the trackball than for the stick or the touchpad. Although, the time taken to target the 1 mm stimulus is better for the stick (5787.88 seconds), the difference is not significant between the stick and the trackball (5923.93 seconds). This shows the trackball is on par with the stick for precision tasks. However, the time taken to target the 8 mm stimulus was better for the touchpad (2125.79 seconds) compared to the stick (2768.90seconds) (Tables 7, 8, and 9).

TABLE 1

Mean Response Time for the Three Devices

Device	Mean RT (Secs)	SD	Cases
Stick	3631.13	3296.77	2835
Trackball	3256.50	2732.77	2835
Touchpad	5027.67	7482.37	2835

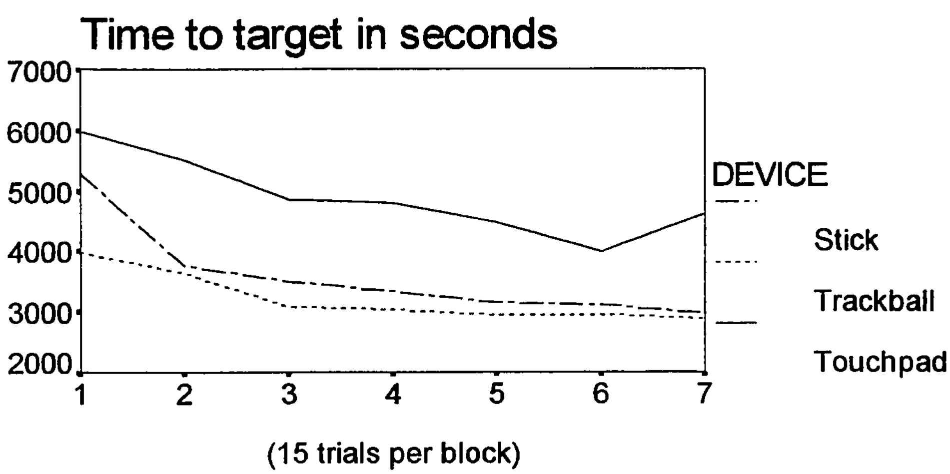


Figure 3. Comparison of pointing devices across Trial Blocks

TABLE 2

Mean and Standard Deviation for the Seven Blocks for the Stick

Blocks	Mean	SD	Cases
Block 1	5374.27	6640.04	405
Block 2	3790.38	2670.70	405
Block 3	3561.85	2403.39	405
Block 4	3339.15	2048.87	405
Block 5	3197.59	2150.76	405
Block 6	3157.44	1876.15	405
Block 7	2997.27	1709.32	405

TABLE 3

Mean and Standard Deviation for the Seven Blocks for the Trackball

Blocks	Mean	SD	Cases
Block 1	4009.11	3596.52	405
Block 2	3685.79	3281.75	405
Block 3	3117.56	2208.73	405
Block 4	3083.53	2378.90	405
Block 5	2962.59	2576.33	405
Block 6	3016.54	2438.65	405
Block 7	2920.35	2121.49	405

TABLE 4

Mean and Standard Deviation for the Seven Blocks for the Touchpad

Blocks	Mean	SD	Cases
Block 1	6383.62	10978.24	405
Block 2	5653.34	7875.02	405
Block 3	5007.50	7221.05	405
Block 4	4902.30	7180.44	405
Block 5	4535.18	5708.68	405
Block 6	4037.42	4529.99	405
Block 7	4674.35	7055.44	405

TABLE 5

ANOVA results for the Trial Block analysis based on Time to Target

Source	df	MS	F	p
<u>Within-Subjects</u>				
Device (dev)	2	2470099389	17.86	<.001
Subjects(S) * dev	52	138328605		
Trial Block (blk)	6	514198877	15.184	<.001
S * Blk	156	33864176		
Dev * Blk	12	33796205	1.185	.293
S * Dev * Blk	312	28529667		
Total	540			

As expected there were differences between the three target distances (Table 6) for time to acquire the target. The mean response time to target for all the three devices across Target Distances is shown in Figure 6 (Tables 10, 11, 12). Compared individually, the time taken to target across 20 mm, 40 mm and 80 mm target distances was again consistently better for trackball followed by stick. The mean time taken to target across the three target distances for the touchpad was significantly greater compared to the trackball or the stick as seen in Figure 6.

Error

Analysis on the error yielded a mean error of .09 on the stick, .12 on the trackball and .37 on the touchpad as can be seen in Table 13. As can be seen in Figure 7 and Tables 14, 15, and 16, there is a gradual decrease in the mean errors committed until Block 6 but errors go up for Block 7.

Compared across devices, the error rate decreases steadily after Block 2. For the trackball although the mean number of errors committed is less than that for the stick in the first block, the error rate is slightly higher than the stick. For the touchpad, the error rate fluctuates between going up and down after the fourth block. This could be due to fatigue.

Table 17 shows the main effect and interaction for the Device x Trial Block. The main effect for Trial Block $\underline{F}(6, 156) = 5.50$, $\underline{p} = <.001$ was significant. The Device x Trial Block interaction $\underline{F}(12, 312) = 0.69$, $\underline{p} =.76$ was not significant

TABLE 6

ANOVA Table for Device x Target Size x Target Distance Based on Time To Target

Source	df	MS	F	p
<u>Within-Subjects</u>				
Device (dev)	2	247009389	17.857	<.001
Subject (S) * Dev	52	138328605		
Target Distance (TD)	2	625871539	50.106	<.001
S * TD	52	12490897		
Target Size (TS)	4	8829120344	174.459	<.001
S * TS	104	50608489		
Dev * TD	4	28894702	2.432	.052
S * Dev * TD	104	11879233		
Dev * TS	8	980678508	27.302	<.001
S * Dev * TS	208	35919603		
TS * TD	8	3541106	0.273	.974
S * TS * TD	208	12951812		
Dev * TS * TD	16	11622580	1.136	.318
S * Dev * TS * TD	416	10227008		
Total	1188			

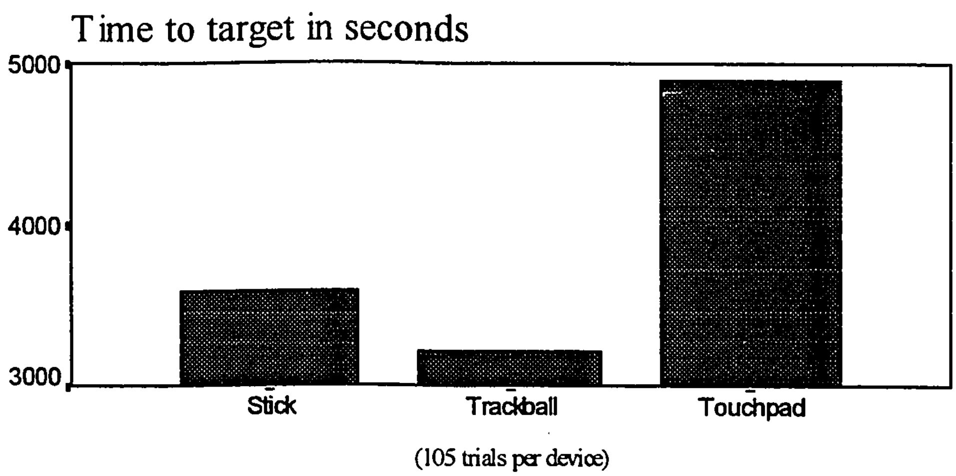
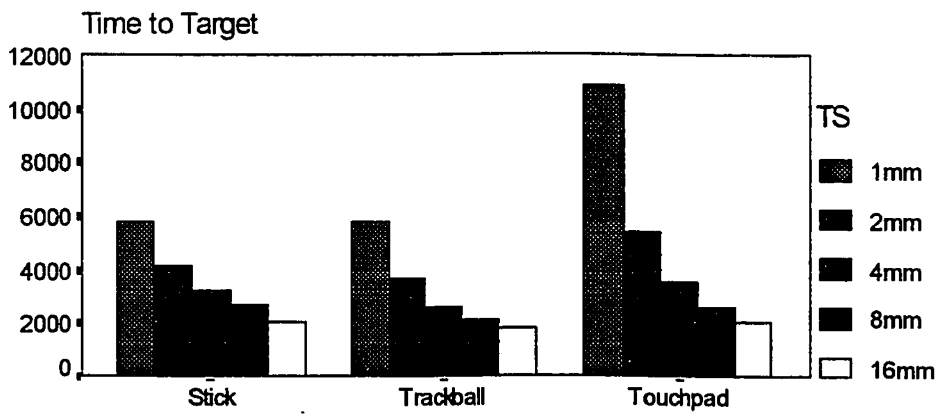


Figure 4. Comparison of pointing devices averaged across target size and target distance



(105 trials per device)

Figure 5. Comparison of pointing devices averaged across target sizes (TS)

TABLE 7

Mean Time Taken to Target for the Stick across Target Sizes (TS)

TS	MEAN	SD	SE	CASES
1 mm	5787.88	4842.14	203.35	567
2 mm	4211.51	3214.92	135.01	567
4 mm	3269.65	1842.81	77.39	567
8 mm	2768.90	2704.80	113.59	567
16 mm	2117.74	1326.32	55.70	567

TABLE 8

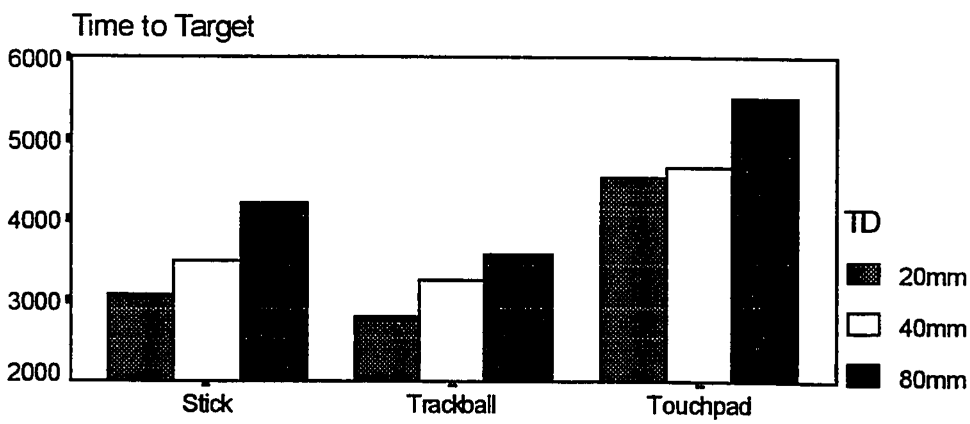
Mean Time Taken to Target for the Trackball across Target Sizes (TS)

TS	MEAN	SD	SE	CASES
1 mm	5923.93	4282.67	179.86	567
2 mm	3757.37	2078.69	87.30	567
4 mm	2663.53	1267.13	53.21	567
8 mm	2125.79	1107.99	46.53	567
16 mm	1811.86	891.49	37.44	567

TABLE 9

Mean Time Taken to Target for the Touchpad across Target Sizes (TS)

TS	MEAN	SD	SE	CASES
1 mm	11360.46	13509.54	567.35	567
2 mm	5485.92	4770.45	200.34	567
4 mm	3603.72	3275.94	137.58	567
8 mm	2611.19	2238.00	93.99	567
16 mm	2077.07	1527.00	64.13	567



(105 trials per device)

Figure 6. Comparison of pointing devices averaged across target distances (TD)

TABLE 10

Mean Time Taken to Target for the Stick across Target Distances (TD)

TD	MEAN	SD	SE	CASES
20 mm	3117.98	3645.03	118.57	945
40 mm	3548.76	3237.60	105.32	945
80 mm	4226.66	2869.73	93.35	945

TABLE 11

Mean Time Taken to Target for the Trackball across Target Distances (TD)

TD	MEAN	SD	SE	CASES
20 mm	2842.91	2446.89	79.60	945
40 mm	3319.91	3060.73	99.57	945
80 mm	3606.67	2601.27	84.62	945

TABLE 12

Mean Time Taken to Target for the Touchpad across Target Distances (TD)

TD	MEAN	SD	SE	CASES
20 mm	4721.85	8113.99	263.95	945
40 mm	4742.32	6696.48	217.84	945
80 mm	5618.85	7541.31	245.32	945

Analysis for the device x target size x target distance for time to target is shown in Table 18 and is represented graphically in Figure 8.

The device x target sizes x target distances mean errors are presented in Table 18 and are graphically represented in Figure 8. The main effect for device $F(2, 68.88) = 27.736$, $p = <.001$ and the main effect for target size $F(4, 120.21) = 227.85$, $p = .0005$ were significant. But the main effect for target distance $F(2, 0.116) = 0.188$, $p = .83$ and the device x target size x target distance interaction $F(16, 0.747) = 1.98$, $p = .013$ were non-significant.

Analysis was also done by levels of target sizes to see if the main effect and device x target size interaction were significant (Fig 9, Table 18). The main effect of target size ($F(4, 104) = 90.29$, $p = .000$) and interaction with Device ($F(8, 208) = 22.29$, $p = .000$) were significant. As can be seen in Figure 9, overall across devices, the error rate for 1 mm target size was higher compared to 16 mm target size. The mean errors committed on 1 mm target for stick were less than for the trackball. Compared to the stick and the trackball, the touchpad had a very high error rate on 1 mm target size. On 2 mm, 4 mm, 8 mm and 16 mm target sizes, again the error rate for touchpad was high compared to stick and trackball (Fig 10).

Compared across target distances, the main effect for Target Distance $F(2, 52) = 0.116$, $p = 0.83$ and the Device x Target Distance interaction $F(4, 104) = .30$, $p = .88$ were non-significant. Tables 22, 23, and 24 show the mean errors across Target Distances.

TABLE 13

Mean Errors for the three devices

Device	Mean	SD	Cases
Stick	0.09	0.51	2835
Trackball	0.12	0.49	2835
Touchpad	0.37	1.19	2835

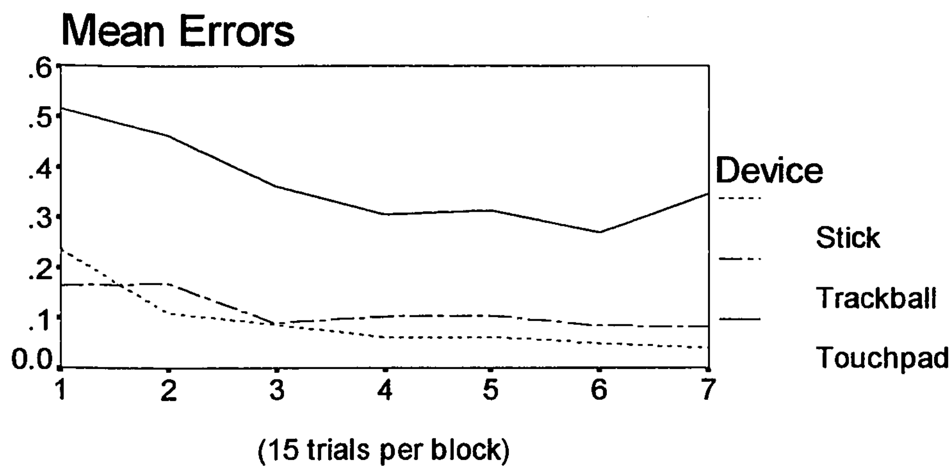


Figure 7. Comparison of pointing devices averaged across Trial Blocks

TABLE 14

Mean and Standard Deviation for the Seven Blocks for the Stick

Blocks	Mean	SD	Cases
Block 1	0.2494	1.0988	405
Block 2	0.0988	0.3919	405
Block 3	0.0840	0.4255	405
Block 4	0.0642	0.2740	405
Block 5	0.0593	0.2466	405
Block 6	0.0494	0.2488	405
Block 7	0.0395	0.2073	405

TABLE 15

Mean and Standard Deviation for the Seven Blocks for the Trackball

Blocks	Mean	SD	Cases
Block 1	0.1704	0.7434	405
Block 2	0.1679	0.6460	405
Block 3	0.0938	0.3931	405
Block 4	0.1111	0.4103	405
Block 5	0.1037	0.4092	405
Block 6	0.0914	0.3643	405
Block 7	0.0790	0.3046	405

TABLE 16

Mean and Standard Deviation for the Seven Blocks for the Touchpad

Blocks	Mean	SD	Cases
Block 1	0.5506	1.7019	405
Block 2	0.4444	1.0900	405
Block 3	0.3679	1.1369	405
Block 4	0.3062	1.1982	405
Block 5	0.3136	0.9840	405
Block 6	0.2741	0.7876	405
Block 7	0.3580	1.2137	405

TABLE 17

ANOVA results for the Trial Block analysis based on Errors

Source	df	MS	F	p
<u>Within-Subjects</u>				
Device (dev)	2	68.88	27.736	<.001
Subjects(S) * dev	52	2.48		
Trial Block (blk)	6	5.16	5.495	<.001
S * Blk	156	0.94		
Dev * Blk	12	0.60	0.687	.764
S * Dev * Blk	312	0.88		
Total	540			

TABLE 18

ANOVA Table for Device x Target Size x Target Distance Based on Error

Source	df	MS	F	p
Within-Subjects				
Device (dev)	2	68.88	27.736	<.001
Subject (S) * Dev	52	02.48		
Target Distance (TD)	2	00.12	00.188	0.829
S * TD	52	00.62		
Target Size (TS)	4	120.21	90.290	<.001
S * TS	104	1.33		
Dev * TD	4	0.16	0.299	0.878
S * Dev * TD	104	0.52		
Dev * TS	8	23.20	22.290	0.000
S * Dev * TS	208	1.04		
TS * TD	8	0.54	1.126	0.347
S * TS * TD	208	0.48		
Dev * TS * TD	16	0.74	1.983	0.013
S * Dev * TS * TD	416	0.37		
Total	1188			

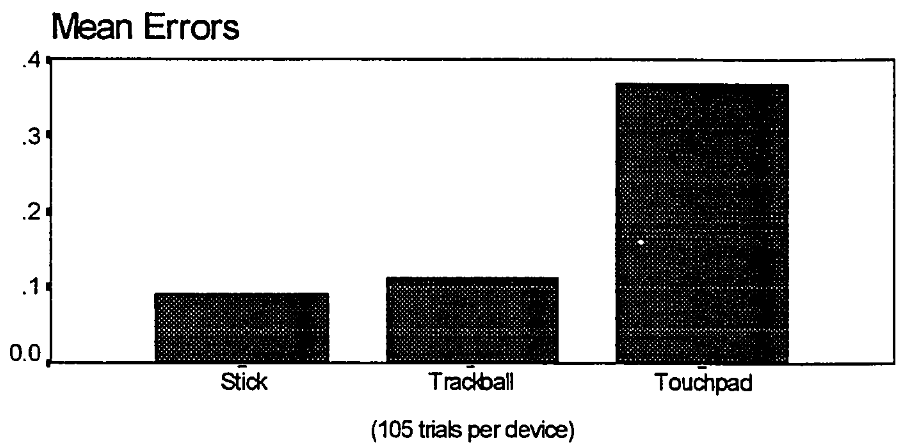


Figure 8. Comparison of pointing devices averaged across target size and target distance

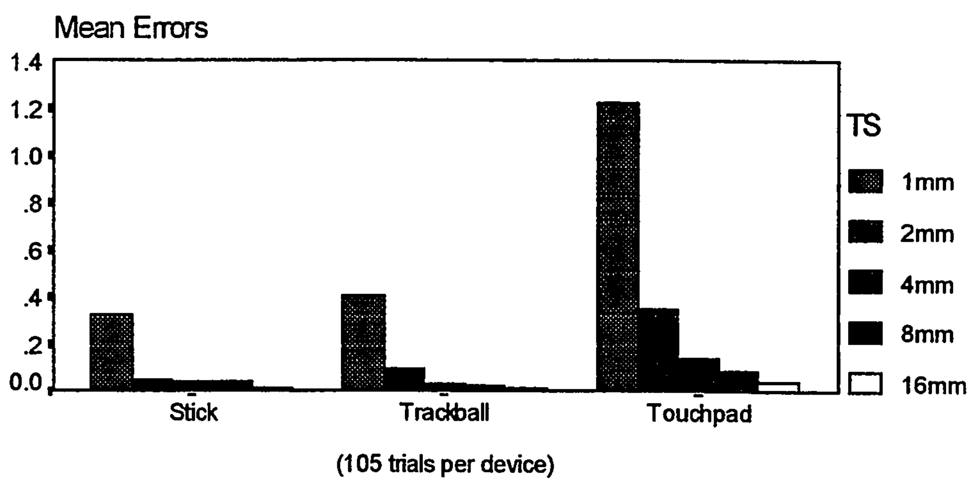


Figure 9. Comparison of pointing devices averaged across target sizes (TS)

TABLE 19

Mean Errors for the Stick across Target Sizes (TS)

TS	MEAN	SD	SE	CASES
1 mm	0.3263	0.9773	0.0410	567
2 mm	0.0494	0.2401	0.0101	567
4 mm	0.0353	0.2425	0.0102	567
8 mm	0.0423	0.3829	0.0161	567
16 mm	0.0071	0.0838	0.0035	567

TABLE 20

Mean Errors for the Trackball across Target Sizes (TS)

TS	MEAN	SD	SE	CASES
1 mm	0.4145	0.9301	0.0391	567
2 mm	0.0970	0.3558	0.0149	567
4 mm	0.0335	0.2158	0.0091	567
8 mm	0.0265	0.1998	0.0084	567
16 mm	0.0123	0.1255	0.0053	567

TABLE 21

Mean Errors for the Touchpad across Target Sizes (TS)

TS	MEAN	SD	SE	CASES
1 mm	1.2382	2.1925	0.0921	567
2 mm	0.3545	0.8934	0.0375	567
4 mm	0.1411	0.5619	0.0236	567
8 mm	0.0899	0.3425	0.0144	567
16 mm	0.0441	0.2374	0.0100	567

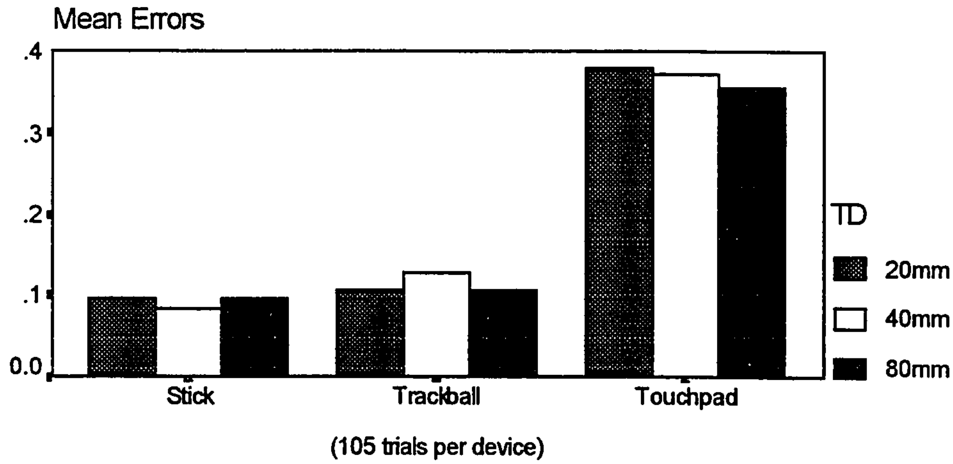


Figure 10. Comparison of pointing devices averaged across target distances (TD)

TABLE 22

Mean Errors for the Stick across Target Distances (TD)

TD	MEAN	SD	SE	CASES
20 mm	0.0942	0.5548	0.0180	945
40 mm	0.0878	0.5521	0.0180	945
80 mm	0.0942	0.4047	0.0132	945

TABLE 23

Mean Errors for the Trackball across Target Distances (TD)

TD	MEAN	SD	SE	CASES
20 mm	0.1079	0.3999	0.0130	945
40 mm	0.1354	0.6283	0.0204	945
80 mm	0.1069	0.4120	0.0134	945

TABLE 24

Mean Errors for the Touchpad across Target Distances (TD)

TD	MEAN	SD	SE	CASES
20 mm	0.3862	1.2656	0.0412	945
40 mm	0.3746	1.2510	0.0407	945
80 mm	0.3598	1.0403	0.0338	945

Discussion and Conclusion

There were two major findings in this study: (1) The trackball had the fastest reaction time and (2) there was no significant difference between the stick and the trackball on the error rate. These findings are discussed in detail in the following sections.

Time to Target

The target acquisition results show that the subjects performed the task best with the trackball. Subjects performed worst with the touchpad (Figure 4). When the three devices are compared across target sizes, there are no significant differences between the stick and the trackball at the smallest target size (1 mm). This shows that the trackball is as good as the stick for precision tasks. In addition, the trackball was better for the target sizes 4 mm, 8 mm and 16 mm. The performance with the touchpad improves on all these target sizes. There was no significant difference between the stick and the touchpad for these target sizes, showing that the performance level for the touchpad was comparable to the stick. For the largest target size (16 mm), the differences among the three devices are less pronounced and are not significant at this size (Figure 5).

Epps (1987) found similar results in desktop input devices. Of the six devices that were compared, the mouse and the trackball were significantly better at the smallest size. There were no significant differences among the six devices at the largest target size. In general, the results of this study confirmed that the integrated trackball is better for input tasks.

Compared across target distances, again the trackball was better followed by the stick. In short, for small as well as large displacements, the trackball has very good acceleration curve. In other words, the movement of the cursor across the screen is smooth and fast. However, for the touchpad, the results show that the users tended to overshoot the target at both small and large displacements (Figure 6). Bisset and Nicolet (1994), in their study of three integrated trackballs, found that the best curve and speed was Low 30%. The acceleration for the trackball in this study was set at Low 30% speed.

Learning Effects

Response time and errors were computed for each of the three devices for each of the seven Blocks (Tables 2, 3, 4, 14, 15, and 16). Based on the learning curve, the rate of learning was slightly higher for the trackball than for the stick and the touchpad. For the trackball and the stick, the target acquiring performance was asymptotic after block 1. However, for the touchpad, the performance was asymptotic after block 2 (Figure 3). For all three devices there was a steady decrease in response time over trial blocks. But for the touchpad, the response time increased slightly for the seventh block. This may be attributed to fatigue in using the touchpad. Epps (1987) found that the target acquisition performance was asymptotic after block 1 and found no significant improvement in performance from blocks two through five.

Errors

The mean number of errors committed using the stick was .09 and those of the trackball and touchpad were .12 and .37, respectively. The difference between the stick and trackball was not significant. Across target size, again there were no significant differences between the stick and the trackball compared to the touchpad (Figure 9). On all target sizes, the touchpad had a high error rate. This can be attributed to the sensitivity of the touchpad and the tendency of the cursor to overshoot. Again across target distance, the trackball and the stick produced better displacement than the touchpad (Figure 10).

The trackball produced fewer errors than the stick and the touchpad for the first block. Although the stick had a slightly lower error rate from blocks two through seven, the error rate for both the stick and the trackball remained fairly constant. However, for the touchpad, the error did not decrease with performance except for the seventh Block (Figure 8).

The results of this study are consistent with the past research with one exception. Albert (1982) found the trackball for the desk top system to be the most accurate device. But Haller et al. (1984) and Mackenzie et al. (1991) found that the trackball had a relatively high error rate compared to the other devices for desk top systems. The error rate of the trackball was attributed to the "touch sensitivity" and the extent of muscle and limb interaction needed to complete transitions. This was echoed by many subjects in this study (Appendix A).

The trackball, being a ball, is sensitive and the novice users may have had difficulty holding the ball and clicking the button at the same time thereby missing the target or overshooting. However, stick movement is not affected if the fingers are positioned on the stick while activating the clicking buttons. This makes it very easy to acquire targets. The high error rate of users of the touchpad can also be attributed to sensitivity. Slight finger movements tends to overshoot targets. Another reason is that the users tend to use the touchpad in different ways. In this study, some subjects tapped the touchpad with their nails, some tapped it with their finger buds while some with the ridge of their thumbs. This may have contributed to the high error rate and reaction time. Finally, the speed and the acceleration curve set for the trackball and the touchpad might have been too fast for the novice users compared to the stick. The default acceleration curve (Off) for the stick was used for this study.

Recommendations

This study concluded that the trackball was better overall as a pointing device. This study evaluated the three devices mainly on a pointing task and did not include the dragging tasks. Considering this limitation, it would be interesting to see if the subjects perform differently on dragging tasks. An effort was made to simulate the text editing task by including the typing task. But it was limited to one word. Editing a full scale text would be a good follow up study. Finally, to further validate the results, performance could be evaluated based on one hand versus using both hands to operate the device.

References

Albert, A. E. (1982). The effect of graphic input devices on performance in a cursor positioning task. Proceedings of the Human Factors Society - 26th Annual Meeting, October, 54-58.

Bewley, W.L., Robert, D. S., & Verplank, W.L. (1983). Human Factors testing in the design of Xerox's 8010 "Star" office workstation. Human Factors in Computer Systems (CHI'83) Proceedings, 72-77.

Bisset, S., & Nicolet, P. (1994). Trackball user study test report. Logitech Inc. Fremont, California.

Card, S.K., Moran, T.P., & Newell, A. (1983). Psychology of Human Computer Interaction. Lawerence Erlbaum Associates.

Epps,B. W. (1987). A comparison of cursor control devices on target acquisition, text editing, and graphics tasks. Unpublished dissertation, Virginia Polytechnic Institute and State University.

Gill, R., Gordan, S., Dean, S., & McGehee, D. (1991). Integrating cursor control into the computer keyboard. Proceedings of the Human Factors Society 35th Annual Meeting, 256-260.

Haller, R., Mutschler, H., & Voss, M. (1984). Comparison of input devices for correction of typing errors in office systems. Proceedings of the Interact '84 Conference, 2, 218-223.

Maguire, M.C. (1985). A review of human Factors guidelines and techniques for the design of Graphical Human-Computer Interfaces. Communication and Graphics, 2(3), 221-235.

Rutledge, J.D., & Selker, T. (1990). Force-to-motion functions for pointing. Human-Computer Interaction - INTERACT '90, 701-706.

Selker, T. & Rutledge, J.D. (1993). Trackpoint II: The in-keyboard pointing device. Personal Systems (January), 16-17.

APPENDIX A

User's Comments

Trackball:

" Ball rolls too easily to be accurate"

"Very easy to use"

"Very smooth, very fast".

"Liked the location and the response is excellent".

"Ball is very sensitive. Otherwise easy to use".

"A little bit too sensitive. Regardless it works great".

"(I) can use either hand".

"(I) frequently had to lift my finger and replace it on the ball to move the curso across the screen.".

Stick:

"The size of the stick made it difficult to use with (my) large hands".

"Was difficult to use on small targets"

"Clicker too far from the stick".

"Easier and more accurate than what (I) have used before ".

"Liked the position".

"Stick and button might be easier to operate if they were closer together"

"Liked the steadiness of it".

"Easy to control".

"It takes getting used to pushing the stick around".

Touchpad:

"Hard to keep fingers on keys while using thumb to control cursor".

"Was difficult positioning the cursor in small targets".

"It was the least fatiguing".

"Difficult to hold position"

"Would have liked it more if it was more accurate in tiny frames".

"Have to really get used to it before (I) can say (I) like it".

"Easy because (you) know exactly where (you) are pointing".

"Too sensitive".

APPENDIX B

Signed Proposal Approval Forms

APPROVED BY THE MASTER'S THESIS COMMITTEE

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