A Comparison of Three Cursor Control Devices on a Cursor Control Benchmark Task

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Technical Report

Prepared For

Institute for Information Technology
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Human-Computer Interface Laboratory

Industrial and Systems Engineering
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TABLE OF CONTENTS

ABSTRACT

A number of past studies have compared performance of various cursor control devices. Overall conclusions regarding the "best" cursor control device for a particular application are difficult to draw because the exact tasks used in previous comparisons have differed greatly from one another and have not necessarily included all of the factors affecting performance with the input devices. The present study used a target acquisition task whose components were derived from analyzing the cursor control device movements of several users while performing actual benchmark work processing and graphics tasks. The components of the task were: target size, target distance, direction, and mode (i.e. point and click vs. drag).

Three cursor control devices, the cursor keys, mouse, and trackball, were each used by 12 subjects to perform the target acquisition task. Results indicate the mouse and trackball perform similarly in nearly all cases. The cursor keys nearly always performed more poorly than the other two devices. In addition, the cursor keys were more sensitive to changes in target size, target distance, and direction. Hence, the mouse and trackball are preferable to the cursor keys based strictly on objective measure of user performance. In conditions where cursor keys are necessary, careful attention should be paid to aspects of the interface such as target size, target distance, and direction in order to attain the highest levels of performance possible.

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

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INTRODUCTION

A relatively large body of literature exists on the topic of computer input devices, most of which simply reviews the technology and discusses the advantages and disadvantages of various devices. Comparatively, only a small portion is research oriented, comparing the performance of various cursor control devices (e.g. mouse, trackball, joystick, cursor keys, touch pad, light pen, etc.) on different types of tasks. Much of this research is summarized in Epps (1986) and Greenstein and Arnaut (1989). In both cases, the authors agree that overall conclusions are difficult to make regarding the "best" cursor control device in terms of positioning accuracy, positioning speed, or subjective satisfaction.

One reason why results from past studies differ from one another so greatly is the differences in the experimental tasks used. For example, English, Engelbart, and Berman (1967) used a target acquisition task within a word processing environment. The subject would use the cursor device to move a cursor within a target and then press a select key. The targets consisted of both one character targets in a nine character field as well as a one word target in a nine word field. Mehr and Mehr (1972) used a simple target acquisition task in which the subject placed the cursor inside a 1.38 mm diameter circular target located at different places on the screen. Similarly, Albert (1982) used a simple target acquisition task with a 3.18 cm square target. Card, English, and Burr (1978) also used a simple target acquisition task, but both target size and target distances were varied. The target consisted of a character or word in inverse lettering. Karat, McDonald, and Anderson (1984) used a menu-type target acquisition task imbedded within two applications (1) a computer-based telephone aid and (2) an appointment calendar.

Although many past studies have used target acquisition tasks, the exact nature of the tasks vary greatly. In addition, the ability of an artificial target acquisition task to predict device performance on other tasks, such as word-processing, graphics, menu selection, etc. is questionable. Epps (1986) investigated the degree to which performance on a target acquisition task could be generalized to other tasks by having subjects perform both a text editing and a graphics task in addition to the target acquisition task. He hypothesized that performance on the target acquisition task at specific target sizes may be predictive of actual performance on tasks which require the acquisition of targets of those sizes. For example, his target sizes of 0.27 and 0.54 cm square is representative of character sizes found in text editing tasks, while his target size of 0.13 represents the level of accuracy often needed in many graphics tasks. He found, however, that the target acquisition results do not fully predict the performance results of the devices for either graphics or word processing tasks. Using the Pearson's Product Moment Correlations, the association between time to acquire a 0.27 target and the time to complete the word processing task with the six cursor control devices used was quite low ($r=0.24$, $p=0.65$). For the graphics task, the association between the target acquisition time for the 0.13 cm target and the task completion time for the graphics task was higher ($r=0.80$, $p=0.057$).

However, there are obviously elements missing in the target acquisition task which are present in actual applications which affect cursor control device performance.

In order to determine these "missing elements", Chase (1990) videotaped users performing actual benchmark word processing and graphics tasks. He decomposed the actions of the users into a primitive task set representative of all of the movements required in all user tasks. In addition to the elements of target size and target distance, he also noted that direction and button mode (where a simultaneous button down and move represents a "drag") may be critical components. He hypothesized that by analyzing an actual task and breaking it down into elementary parts and their respective frequencies, it would then be possible to predict a user's performance on the composite task with a particular input device by simply measuring their ability to perform the low level elementary tasks with that device. He tested this hypothesis by having subjects perform a cursor movement benchmark task (i.e. an extended target acquisition task) as well as a benchmark graphics task. For results of this comparison, the reader is referred to Chase (1990). This report will concentrate on describing the cursor movement benchmark task and describing the comparison of three cursor control devices on that task.

METHOD

Subjects

Twelve subjects (three male and nine female) from the university community participated and were compensated for their time. Subjects ranged in age from 18 to 55 years. Eleven of the subjects were dominantly right-handed and used their right hand to operate each of the three input devices. One subject described himself as ambidextrous and used his left hand to operate one device (the mouse) and his right hand to operate the other devices.

Experimental Apparatus

A Macintosh SE was used to present the computer-based task and record task completion time data. A specially developed program running under Hypercard was developed and used to present the task. The cursor control devices used were 1) a standard single button Macintosh mouse; and 2) a Kensington Turbo Mouse (a trackball with mouse button and mouse hold (i.e. toggle) button; and 3) the Macintosh SE expanded keyboard directional cursor keys as defined by the Apple Macintosh system utility Easy Access (as illustrated in Figure 1). The control/display ratio setting for each device was chosen based strictly on the manufacturer's recommendations. With respect to the Macintosh control panel, the cursor keys were set at the slowest possible speed (i.e. tablet speed), the turbo mouse was set at the second slowest speed, while the mouse was set at the second fastest speed.

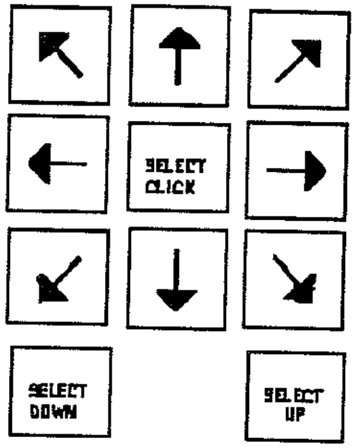

Figure 1. Cursor keys as defined by Easy Access.

Experimental Design

The target acquisition task required the subject to move the cursor from one target area labeled "start" to a second target area using the cursor control device, and then "select" the second target. The experimental design consisted of a full factorial 3 x 4 x 3 x 2 x 8 within subject design. Device had three levels: cursor keys, turbo mouse, and mouse. Each target was a square shape. Target size had four levels: 0.27, 0.54, 1.07, and 2.14 cm side. Target distance had three levels: 2, 4, and 8 cm. These target sizes and distances are representative of the range typically encountered in graphics and word processing task environments (Epps, 1986). Button Mode (or select Mode) had two levels: button up and button down. (Note, a simultaneous button down and move is often referred to as a "drag"). Finally, Direction had eight levels corresponding to the four primary directions (N, S, E, and W), and diagonals at 45 degrees off axis (NW, NE, SW, and SE). Hence, for each device, the subject completed 192 (4 sizes x 3 distances x 2 button modes x 8 directions) target acquisitions. All button up trials with a particular device either preceded or followed all button down trials. The presentation order of the two modes was randomized. The 96 trials for each Mode were presented in random order.

Dependent Measure

The dependent measure was acquisition time (measured in hundredths of a second) for each target. In the case of a button up move, timing began when the subject first crossed the starting target boundary and ended when the subject correctly "clicked" within the second target area. (Note, the subject was required to "mouse down" and "mouse up", but only the mouse up action was measured and was required to be within the target boundaries). Feedback was provided to the user by having the start target become highlighted when the cursor entered the start target area, and the final target became highlighted when the user correctly "moused up" inside the final target. For a button down move, timing began when the subject "moused down" inside the starting target and ended when the subject crossed the boundary of the second target. Feedback was provided by having the start target becoming highlighted when the user correctly "moused down" inside the start target area, and the final target became highlighted when the cursor crossed the final target boundary.

Protocol

Each subject was tested over a three day period, using each device on a separate day. Presentation order of the three devices was completely balanced across subjects. The first session began by having the subject read and sign an informed consent form, read a task description, and receive instructions on the operation of the first device. S/he then received 60 practice trials for the button up Mode, randomly chosen from the 96 possible Target Size x Target Distance x Direction combinations. S/he then completed the 96 target trials in the button up Mode, followed by practice on and then testing with the 96 trials in the button down Mode. This procedure was repeated for the second and third days of testing with the remaining devices. Following completion of the task with the last device, the subject was debriefed and compensated for his/her time.

RESULTS

An analysis of variance was performed on the target acquisition time data using Device, Target Size, Target Distance, Direction, and Mode as the main effects and all possible interactions thereof. A complete ANOVA summary table is shown in Table 1. Because of the large number of data points (576 observations per subject, for a total of 6912 data points) and hence large number of degrees of freedom for the treatment and error terms, alpha was set equal to 0.005 to compensate for the resulting overly sensitive F-test. A post hoc Student Newman-Keuls test ($p < 0.05$) was performed for pairwise means comparisons within each significant main effect and interaction.

Main Effects

All five main effects were found to be significant. Table 2 shows the results of the post hoc tests performed on these main effects. These tests reveal the keys to be different from the trackball and mouse, but the mouse and trackball perform equally well. All four levels of Target Size were shown to be significantly different from one another with respect to target acquisition time. The three levels of Target Distance were also shown to be significantly different from one another. Examining the rank ordering of the eight directions (as shown in Table 2) shows the four off-axis directions to require a longer time to acquire than the four primary axis directions. The northwest direction is significantly poorer than all other directions except the northeast direction. None of the axial directions differ significantly from one another, and

Table 1. Complete Anova Summary Table.

Source	Deg. Freedom	SS	F Value	P Value	Significance
D	2	5746.91	94.05	0.0001	*
D*S	22	672.13			
D*TS	6	830.13	50.95	0.0001	*
D*TS*S	66	179.21			
D*TD	4	4	18.02	0.0001	*
D*TD*S	44	41.2			
D*DIR	14	14	4.07	0.0001	*
D*DIR*S	154	275.5			
D*B	2	2	5.96	0.0086	
D*B*S	22	69.48			
D*TS*TD	12	9.32	0.81	0.6393	
D*TS*TD*S	132	126.55			
D*TS*DIR	42	42	3.58	0.0001	*
D*TS*DIR*S	462	346.21			
D*TS*B	6	6	4.4	0.0008	*
D*TS*B*S	66	69.18			
D*TD*DIR	28	28	2.46	0.0001	*
D*TD*DIR*S	308	249.42			
D*DIR*B	14	14	2.32	0.0063	
D*DIR*B*S	154	127.4			
D*TD*B	4	2.96	0.78	0.542	
D*TD*B*S	44	41.64			
D*TS*TD*DIR	84	76.89	1.19	0.1289	
D*TS*TD*DIR*S	924	712.74			
D*TS*TD*B	12	7.93	0.53	0.8894	
D*TS*TD*B*S	132	163.41			
D*TS*DIR*B	42	33.98	0.89	0.6703	
D*TS*DIR*B*S	462	420.2			
D*TD*DIR*B	28	22.18	0.99	0.4884	
D*TD*DIR*B*S	308	247.4			
D*TS*TD*DIR*B	84	102.92	1.38	0.0159	
D*TS*TD*DIR*B*S	924	818.68			
TS	3	3	133.33	0.0001	*
TS*S	33	114.3			
TS*DIR	21	21	5.03	0.0001	*
TS*DIR*S	231	170.2			
TS*B	3	3	10.52	0.0001	*
TS*B*S	33	19.89			
TS*TD	6	10.15	1.36	0.2419	
TS*TD*S	66	81.86			

TS*TD*B	6	4.4	0.63	0.707	
TS*TD*B*S	66	77.03			
TS*DIR*B	21	20.35	1.15	0.3011	
TS*DIR*B*S	231	195.19			
TS*TD*DIR	42	42.82	1.23	0.1603	
TS*TD*DIR*S	462	383.23			
TS*TD*DIR*B	42	54.2	1.34	0.0796	
TS*TD*DIR*B*S	462	444.03			
TD	2	2	43	0.0001	*
TD*S	22	36.57			
TD*DIR	14	14	2.83	0.0008	*
TD*DIR*S	154	143.08			
TD*B	2	0.97	0.37	0.6966	
TD*B*S	22	29.16			
TD*DIR*B	14	11.51	1.01	0.4492	
TD*DIR*B*S	154	125.78			
DIR	7	7	9.22	0.0001	*
DIR*S	77	133.64			
DIR*B	7	7	2.73	0.0139	
DIR*B*S	77	59.27			
B	1	1	27.62	0.0003	*
B*S	11	21.89			

most do not differ significantly from the southwest and southeast directions.

<u>Two-way Interactions</u>

Post hoc tests were also performed on the significant two-way interactions of Device x Target Size, Device x Target Distance, Device x Direction, Device x Mode, Target Size x Direction, Target Size x Mode, Target Distance x Direction, and Direction x Mode.

Figure 2 and Table 3 illustrate the Device x Target Size interaction. As shown, all four levels of Target Size are significantly different from one another for the cursor keys. For both the mouse and the trackball, the smallest size does not significantly differ from the second smallest, but does require significantly

Table 2. Student-Newman-Keuls Test for the Main Effects.

Device				
Cursor Keys	A			
Trackball		B		
Mouse		B		
Target Size (cm)				
27	A			
54		B		
107			C	
214				D
Target Distance (cm)				
8	A			
4		B		
2			C	
Direction				
NW	A			
NE	A	B		
SW		B	C	
SE		B	C	
W			C	D
S			C	D
N			C	D
E				D

*Means with the same letter are not significantly different across the main effect at $p<0.05$.

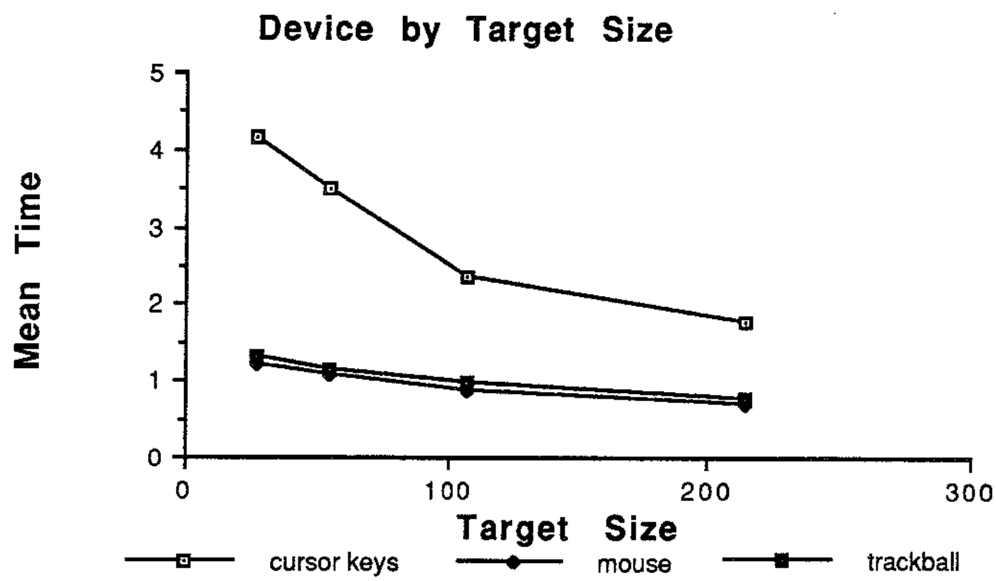

Figure 2. Device x Target Size interaction.

Table 3. Student-Newman-Keuls Test for the Device x Target Size Interaction.

Device	Target Size								
KEYS	27	A							
KEYS	54		B						
KEYS	107			C					
KEYS	214				D				
TBALL	27					E			
MSE	27					E			
TBALL	54					E	F		
MSE	54					E	F	G	
TBALL	107						F	G	H
MSE	107							G	H
TBALL	214								H
MSE	214								H

*Means with the same letter are not significantly different across the interaction at $p<0.05$.

more time than the largest two sizes. Similarly, the largest target is not significantly different than the second largest, but is different from the two smaller target sizes. Clearly, the cursor keys are much more sensitive to changes in Target Size than either the mouse or the trackball. Additionally, at none of the four target sizes do the mouse and trackball differ from one another, but both always results in faster performance than the cursor keys.

The Device x Target Distance interaction is illustrated in Figure 3 and Table 4. Immediately apparent is the fact that the cursor keys result in poorer performance than either the mouse or trackball irrespective of Target Distance; and at no Target Distance do the mouse and trackball differ from one another in performance. In addition, the cursor keys appear to be slightly more sensitive to changes in Target Distance than the mouse or trackball. Although all three levels of Target Distance are significantly different from one

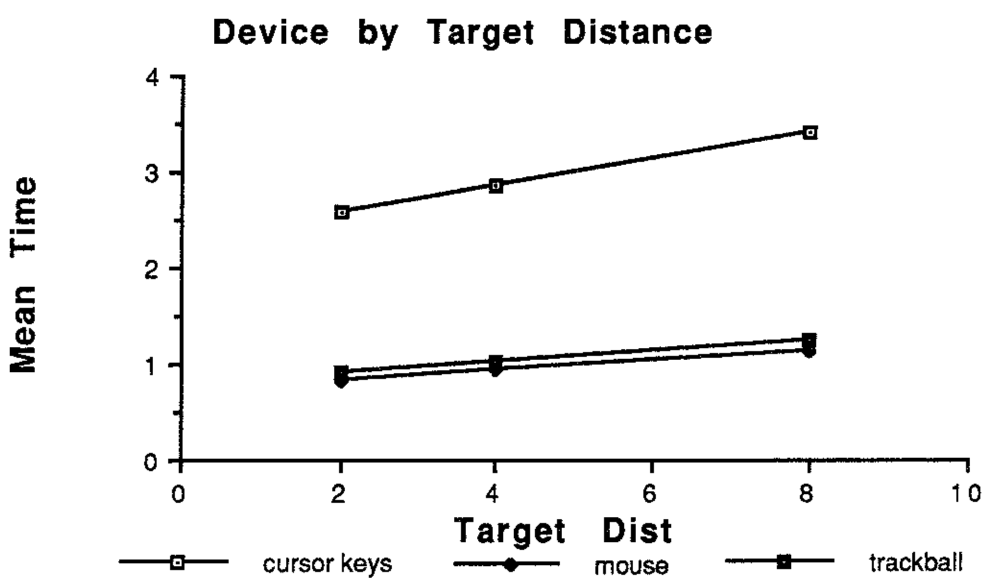

Figure 3. Device x Target Distance interaction.

Table 4. Student-Newman-Keuls Test for the Device x Target Distance Interaction.

Device	Target Distance						
KEYS	8	A					
KEYS	4		B				
KEYS	2			C			
TBALL	8				D		
MSE	8				D		
TBALL	4					E	
MSE	4					E	
TBALL	2					E	F
MSE	2						F

*Means with the same letter are not significantly different across the interaction at $p<0.05$.

another for each Device (with the exception of the smalller two target distances for the trackball), the increase in target acquisition time as a function of increasing Target Distance is notably greater for the cursor keys than for the mouse and trackball.

Shown in Table 5 and Figure 4 is the Device x Direction interaction. Clearly, the significance of the Direction main effect lies strictly with the cursor keys. For both the mouse and the trackball, subjects performed equally well in all eight directions. However, performance with the cursor keys varied as a function of Direction. The northwest direction proved to be slower than all other directions. The other three off-axis directions were not significantly different from one another, but were poorer than the axial directions. The east direction resulted in better performance than the other three axial directions.

Table 5. Student-Newman-Keuls Test for the Device x Direction Interaction.

Device	Direction	
KEYS	NW	A
KEYS	NE	B
KEYS	SW	B
KEYS	SE	B
KEYS	N	C
KEYS	W	C
KEYS	S	C
KEYS	E	D
TBALL	NW	E
TBALL	NE	E
TBALL	SW	E
TBALL	SE	E
TBALL	W	E
MSE	NW	E
TBALL	S	E
MSE	NE	E
MSE	SE	E
TBALL	N	E
MSE	SW	E
MSE	N	E
TBALL	E	E
MSE	W	E
MSE	E	E
MSE	S	E

*Means with the same letter are not significantly different across the interaction at $p<0.05$.

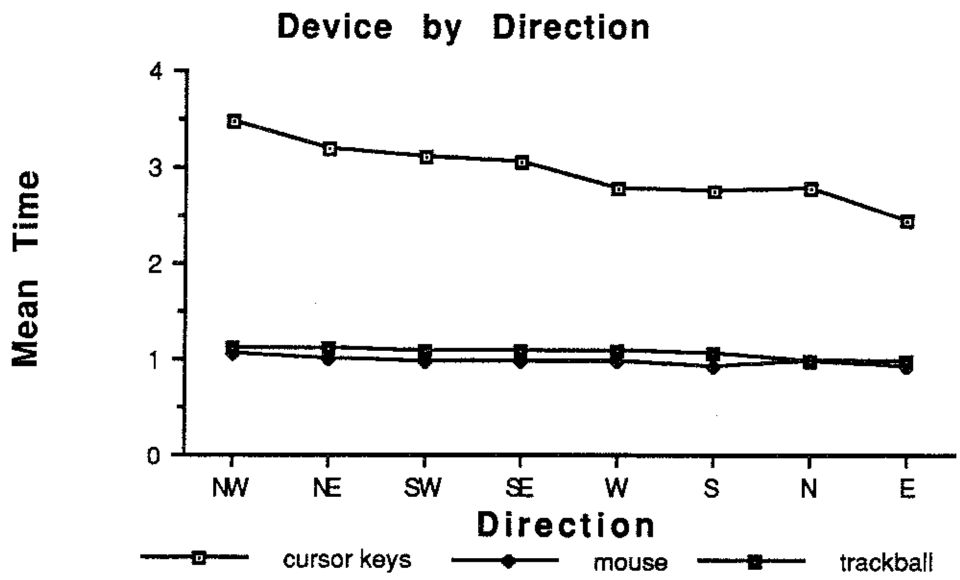

Figure 4. Device x Direction interaction.

The Device x Mode interaction is depicted in Table 6 and Figure 5. Both the trackball and mouse proved to operate more quickly during button down moves than button up moves, however performance with the cursor keys was not affected by the mode of operation.

The Target Size x Mode interaction is illustrated in Figure 6 and Table 7. For the three smaller target sizes, the button down Mode resulted in better performance than the button up Mode. However, at the largest level of Target Size, both modes of operation resulted in similar performance.

Table 6. Student-Newman-Keuls Test for the Device x Mode Interaction.

Device	Mode			
KEYS	DN	A		
KEYS	UP	A		
TBALL	UP		B	
MSE	UP		B	
TBALL	DN			C
MSE	DN			C

*Means with the same letter are not significantly different across the interaction at p<0.05.

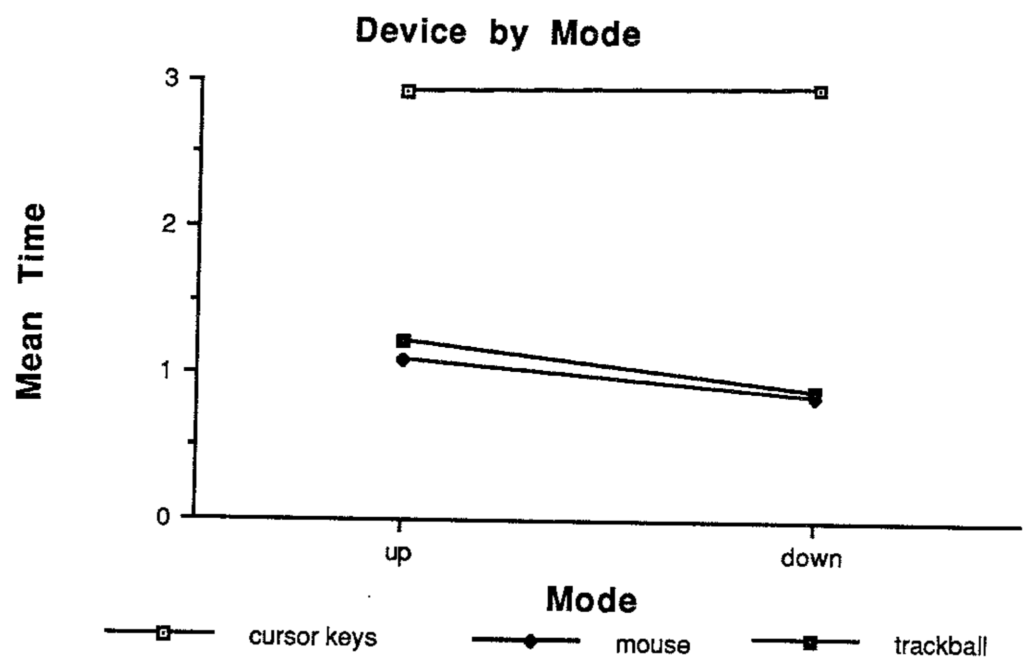

Figure 5. Device x Mode interaction.

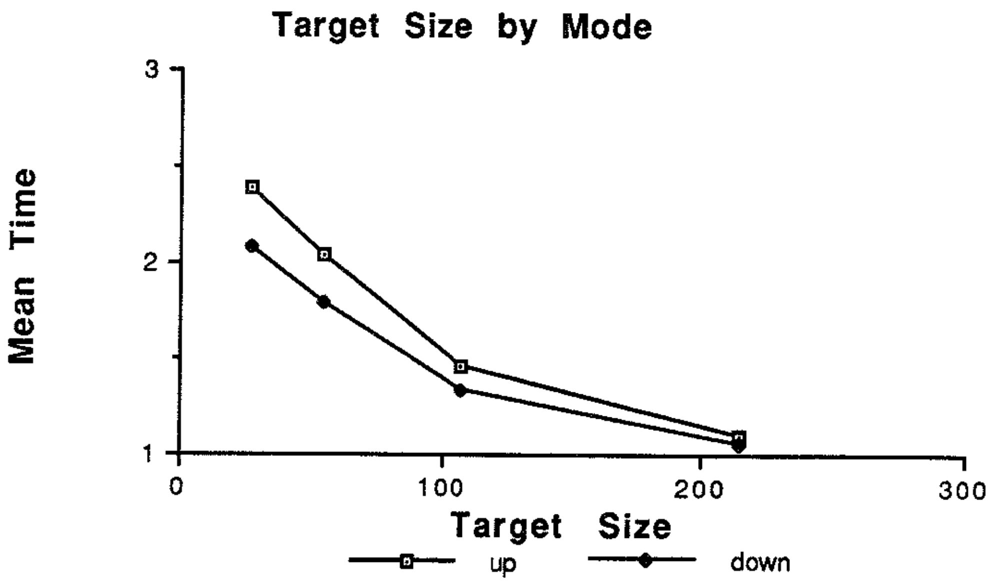

Figure 6. Target size x Mode interaction.

Table 7. Student-Newman-Keuls Test for the Target Size x Mode interaction.

Target Size	Mode						
27	UP	A					
27	DN		B				
54	UP		B				
54	DN			C			
107	UP				D		
107	DN					E	
214	UP						F
214	DN						F

*Means with the same letter are not significantly different across the interaction at $p<0.05$.

Figure 7 and Table 8 describe the Target Size x Direction interaction. Though difficult to interpret because of the complexity of the graph, the affect of Direction appears to increase slightly as Target Size decreases. No significant differences in performance between the eight directions exists at the largest level of Target Size. For both of the intermediate sizes, performance differs slightly as a function of Direction (e.g. in both cases, the "best" and "worst" direction are significantly different from one another). At the smallest level of Target Size, the northwest direction is significantly poorer than all other directions except the southwest direction, and the two better directions are significantly different than the poorer four directions.

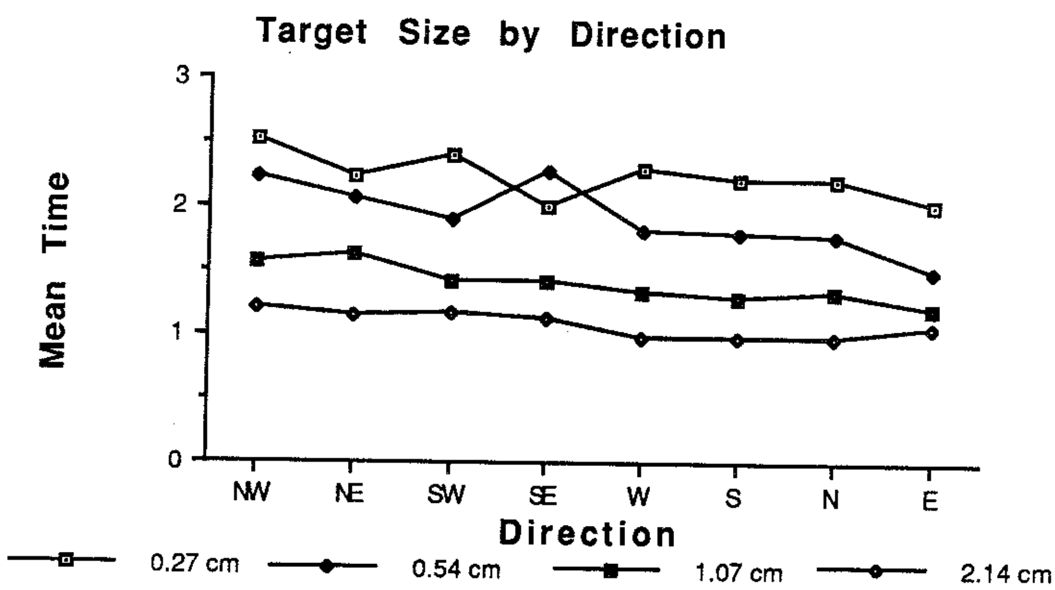

Figure 7. Target size by Direction interaction.

Table 8. Student-Newman-Keuls Test for the Target Size x Direction Interaction.

Target Size	Direction														
27	NW	A													
27	SW	A	B												
27	W		B	C											
54	SE		B	C											
27	NE		B	C	D										
54	NW		B	C	D										
27	S		B	C	D										
27	N		B	C	D										
54	NE			C	D	E									
27	E				D	E	F								
27	SE				D	E	F	G							
54	SW					E	F	G							
54	W						F	G	H						
54	S						F	G	H						
54	N							G	H						
107	NE								H	I					
107	NW									I					
54	E									I	J				
107	SW									I	J	K			
107	SE									I	J	K			
107	W										J	K	L		
107	N										J	K	L		
107	S										J	K	L	M	
107	E											K	L	M	
214	NW											K	L	M	N
214	SW												L	M	N
214	NE												L	M	N
214	SE												L	M	N
214	E													M	N
214	S														N
214	N														N
214	W														N

*Means with the same letter are not significantly different across the interaction at $p<0.05$.

Figure 8 and Table 9 show the Target Distance x Direction interaction. Again, because of the complexity of the graph, the interaction is difficult to identify. Interesting to note, nevertheless, is that the combination of the largest level of Target Distance and the poorest level of Direction (NW) results in performance that is significantly different than all of the other combinations of Target Distance and Direction.

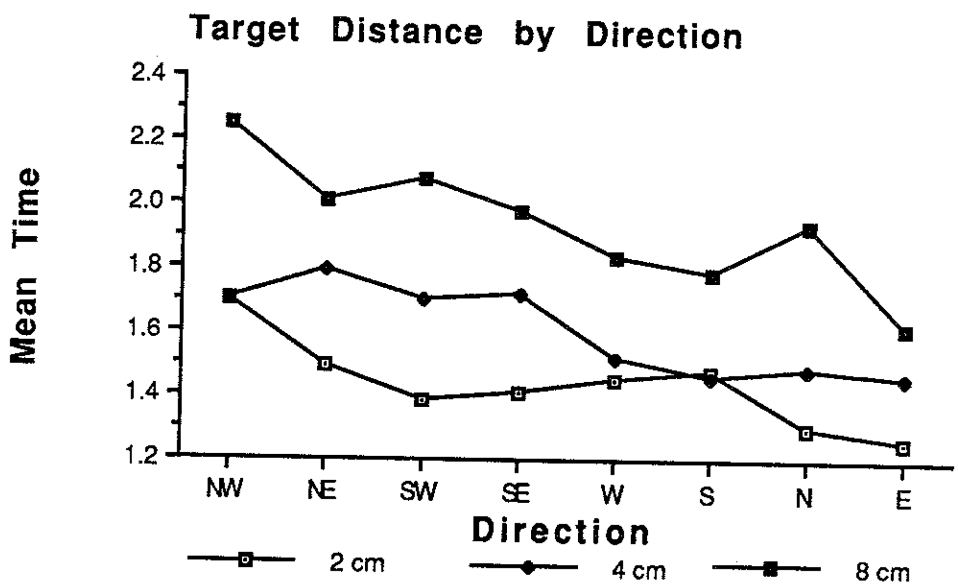

Figure 8. Target distance x Direction interaction.

Table 9. Student-Newman-Keuls Test for the Target Distance x Direction Interaction.

Target Distance	Direction								
8	NW	A							
8	SW		B						
8	NE		B	C					
8	SE		B	C					
8	N		B	C	D				
8	W			C	D	E			
4	NE			C	D	E			
8	S			C	D	E			
4	SE				D	E	F		
2	NW				D	E	F		
4	SW				D	E	F		
4	NW				D	E	F		
8	E					E	F	G	
4	W						F	G	H
2	NE						F	G	H
4	N						F	G	H
2	S						F	G	H
4	E						F	G	H
4	S						F	G	H
2	W						F	G	H
2	SE							G	H
2	SW							G	H
2	N								H
2	E								H

*Means with the same letter are not significantly different across the interaction at $p<0.05$.

Finally, the Direction x Mode interaction is represented in Table 10 and Figure 9. Again, the poorest level of Direction (NW) combined with the poorer Mode (button up) resulted in performance that was inferior to all other conditions.

Table 10. Student-Newman-Keuls Test for the Direction X Mode Interaction.

Direction	Mode								
NW	UP	A							
NE	UP		B						
SE	UP		B	C					
SW	UP		B	C	D				
NW	DOWN		B	C	D				
W	UP		B	C	D	E			
SW	DOWN		B	C	D	E			
S	UP		B	C	D	E			
NE	DOWN			C	D	E	F		
N	UP				D	E	F	G	
SE	DOWN				D	E	F	G	
N	DOWN					E	F	G	H
W	DOWN						F	G	H
E	UP						F	G	H
S	DOWN								H
E	DOWN								H

*Means with the same letter are not significantly different across the interaction at $p<0.05$.

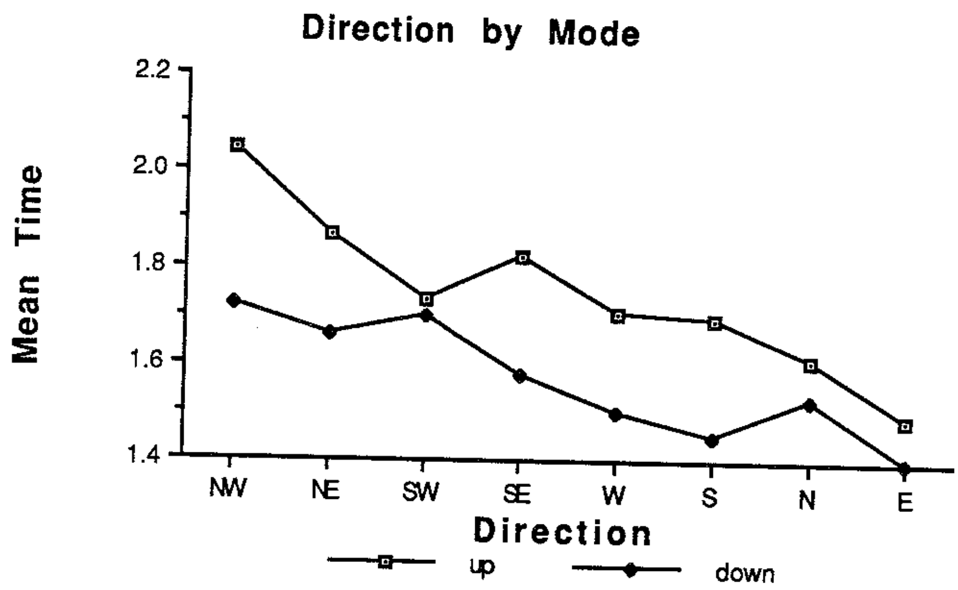

Figure 9. Direction x Mode interaction.

Three-way Interactions

In addition, three of the three-way interactions were significant at the alpha=0.005 level: Device x Target Size x Mode, Device x Target Size x Direction, and Device x Target Distance x Direction.

Examining the results of the post hoc tests on the Device x Target Size x Mode (Table 11) indicate that most of the significance of the interaction is due to the performance of the cursor keys. For the keys, at both of the smaller two targets, button up moves required significantly more time than the button down moves, while at the larger two target sizes the opposite occurs: the button up mode is quicker than the button down mode. No such reversal in performance is found for the other two devices. For both the mouse

Table 11. Student-Newman-Keuls Test for the Device x Target Size x Mode Interaction.

Device	Target Size	Button Mode	A	B	C	D	E	F	G	H	I	J	K
KEYS	27	UP	A										
KEYS	27	DN		B									
KEYS	54	UP			C								
KEYS	54	DN				D							
KEYS	107	DN					E						
KEYS	107	UP					E						
KEYS	214	DN						F					
KEYS	214	UP							G				
TBALL	27	UP							G				
MSE	27	UP							G	H			
TBALL	54	UP							G	H			
MSE	54	UP								H	I		
TBALL	27	DN								H	I		
TBALL	107	UP									I		
MSE	27	DN									I		
TBALL	54	DN									I	J	
MSE	107	UP									I	J	
MSE	54	DN									I	J	
TBALL	214	UP									I	J	
TBALL	107	DN										J	K
MSE	214	UP										J	K
MSE	107	DN										J	K
MSE	214	DN											K
TBALL	214	DN											K

*Means with the same letter are not significantly different across the interaction at $p<0.05$.

and trackball, the button up mode always results in slower performance than the button down mode for the same target size.

The results of the post hoc tests on the Device x Target Size x Direction interaction show that much of the Target Size x Direction interaction can again be explained by the performance of the cursor keys. Performance with the cursor keys varies as a function of Target Size and Direction, with small sizes, particularly in conjunction with the off-axis directions resulting in the poorest performance. Although performance with the mouse and cursor keys varies as a function of Target Size and Direction, the differences in performance are much smaller.

Clearly, the significant Target Distance x Direction interaction can be attributed to the performance of the cursor keys alone. As shown by the results of the Device x Target Distance x Direction interaction (Table 12), no significant differences were found between any of the combinations of Target Distance and Direction for either the trackball or the mouse. The cursor keys, however, differ widely across the resulting 24 combinations of Target Distance and Direction. As expected, the combination of the largest distance and poorest Direction (NW) resulted in significantly poorer performance for the keys than all other conditions.

Table 12. Student-Newman-Keuls Test for Device x Target Distance x Direction Interaction.

Device	Target Distance	Direction								
KEYS	8	NW	A							
KEYS	8	SW		B						
KEYS	8	NE		B	C					
KEYS	8	SW		B	C					
KEYS	8	N			C	D				
KEYS	4	NE			C	D	E			
KEYS	8	W			C	D	E			
KEYS	2	NW			C	D	E			
KEYS	4	SW			C	D	E			
KEYS	4	SW			C	D	E			
KEYS	8	S				D	E			
KEYS	4	NW					E			
KEYS	2	NE						F		
KEYS	2	S						F	G	
KEYS	8	E						F	G	H
KEYS	4	N						F	G	H
KEYS	4	W						F	G	H
KEYS	4	E						F	G	H
KEYS	4	S						F	G	H
KEYS	2	SE						F	G	H
KEYS	2	SW						F	G	H
KEYS	2	N							G	H
KEYS	2	E								H

(All combinations of:
mouse x td x Direction
trackball x td x Direction)

*Means with the same letter are not significantly different across the interaction at $p<0.05$.

DISCUSSION AND CONCLUSIONS

As noted before, all five main effects were found to be significant. The Device main effect result is similar to the results of Epps (1986) and others who have found the mouse and trackball to perform similarly. The poorer performance of the cursor keys was also expected. This is perhaps due to the indirect nature of the cursor keys as a pointing device as compared to the mouse and trackball.

All levels of both Target Size and Target Distance were found to be significantly different from one another, with smaller target sizes and larger distances requiring longer acquisition times. These results are in agreement with previous work (e.g. Epps, 1986), and support the application of Fitts' law, which states that movement time is inversely proportional to Target Size and proportional to Target Distance, to cursor control devices.

Most previous research in the area of comparing cursor control devices has not considered Direction as a separate independent variable, but has either randomized Direction, or neglected it's consideration entirely. The significant Direction main effect suggests that Direction does play a significant role in cursor positioning performance.

The final independent variable considered, Mode, has received little attention in previous studies as well. The results in the current study show button down moves to be quicker than button up moves. This finding conflicts both with intuition, as well as with the results of Gillan, Holden, Adam, Rudisill, and Magee (1990).

The conflict can, however, likely be accounted for by considering the method in which the target acquisition time was measured in the current study. For the up move, timing began when the cursor crossed the start target boundary moving from inside the target to outside the target. Timing ended when the user selected down and then up (or clicked) correctly inside the final target boundaries. For the down mode, timing began when the user selected down inside the starting target and ended when the cursor crossed the boundary into the final target. Note that in button down moves, timing stopped when the cursor crossed the target boundary, <u>not</u> when the user correctly "buttoned up" within the target boundaries. Thus, the user was not required the hold the cursor inside the target and release the button. So, in fact, the user could overshoot the final target, but as long as the cursor crossed into the target, the move would be accepted as correct and timed, regardless of whether the user was able to hold the cursor on the target.

In actual applications, the mouse down move would almost always require the user to hold the cursor on the final target and mouse up. Additionally, the start target was always larger than the 214 cm target. The final target, however, was varied in size. This means a mouse up move would require the user to simply cross into this large target, but then locate as well as mouse down inside the final target, which may be as small as 27 cm. The mouse down moves, on the other hand, require the user to locate and mouse down inside this large target, but merely cross the boundary into the smaller final target. As shown by the Target Size main effect, it is more difficult to locate and select smaller targets. Naturally, as measured in this study, the mouse down moves should be quicker than the mouse up moves. However, because the moves are not necessarily representative of "mouse up" and "mouse down" moves found in most applications, generalizations from these results must be made with care, making careful note of the way in which the moves were timed in this study.

The analyses of the two-way interactions offer even more interesting information and, of course, qualify the conclusions drawn from the main effects. The Device x Target Size interaction shows that while all three devices are affected by the size of the target, the cursor keys are move sensitive to changes in Target Size than either the mouse or the trackball. Previous work (Epps, 1986) has also shown the mouse and trackball to be less sensitive to Target Size than other pointing devices (e.g. touch tables and joysticks), but the larger sensitivity of the cursor keys to changes in Target Size had not been well demonstrated.

Similarly, the cursor keys appear to be much more sensitive to changes in Target Distance than either the mouse or the trackball. Clearly, the superiority of the trackball and/or mouse over the cursor keys as a pointing device holds regardless of Target Size or Target Distance, but when cursor keys are necessary, better performance will result when the Target Size is large and Target Distance is small.

The Device x Direction interaction shows immediately that the significance of the Direction main effect lies entirely with the cursor keys. Neither the mouse or trackball are affected by the direction of the move. Although this result does support the lack of inclusion of Direction in these types of studies, it is not necessarily easily explainable. As shown in Figure 1, the directional arrow keys were provided for all four axial directions as well as the four 45 degree off-axis directions. In all cases, the start target and final target were positioned such that a move from the start to final target requires either an axial or 45 degree off-axis move. As such, the movement required to perform the on-axis target acquisitions (pressing a single directional key) was the same as that required to reach the diagonal targets. However, approximately fifty percent of the subjects chose to only use the four axial cursor keys, even for diagonal moves. To move diagonally with just the on-axis keys requires the use of at least two keys, and requires the user to either alternate rapidly between the two keys or plan carefully the distance needed in each direction. While this would explain the fact that off-axis moves as a whole were slower than on-axis moves, it does not explain why the east direction was faster than the other on-axis directions, nor why the northwest direction was slower than the other off-axis directions. If the cultural bias of left to right moves (as in reading or writing) was responsible, it would seem that the mouse and trackball would be more, rather than less, suseptable to effects of Direction than the cursor keys since they require actual movement of the hand and arm. Further research would be necessary to further isolate the cause of this significance.

The Device x Mode interaction shows that the significance of the Mode main effect lies with the mouse and trackball, and not with the cursor keys. Much of this is explainable by recalling the method in which the button up and button down moves were timed. The button up moves were slower than buttondown moves for both the mouse and the trackball. Recall that the button up moves require the user to "click" (or mouse down and immediately mouse up) inside the final target. In many cases, this final target is quite small. Therefore, the user must hold the cursor inside a small target area while s/he clicks the select button. For each of these two devices, the user is likely to inadvertently move the cursor off the small target while trying to press the button down and release it. When this happens, timing continues until the user successfully presses the button down and releases it inside the target area. The button down moves do not require the user to hold the cursor inside a small area and click, but merely to cross into the target area. Hence, button down moves are more difficult than button up moves for these two devices. The cursor keys, on the other hand, do not suffer from roll-off. Once the cursor is placed inside the target, pressing the select button will not cause the cursor to inadvertently move from the target area. Hence, button down moves are no more difficult than button up moves for the cursor keys.

The Target Size x Mode interaction also supports the previous explanation. For the largest Target Size, the button down and button up moves are not significantly different from one another. However, for the smaller target sizes, where roll-off with the mouse and trackball is more likely, the button down moves are quicker than the button up moves. Somewhat supporting this explanationn as well is the Device x Target Size x Mode interaction (shown in Table 6). For both the mouse and trackball, at every Target Size the button down moves are faster than the button up moves. For the keys, on the other hand, the button down moves are faster than the button up moves for the two smaller target sizes, but the button up moves are faster for the two larger target sizes. Perhaps because the button down moves did not require the user to hold the cursor inside the target, these moves were faster than the button up moves at small target sizes: the user could merely move the cursor over top of the target without really having to try to stop it over the target. At larger target sizes, however, it was much easier to stop the cursor within the final target boundaries. Again, it must be remembered that these results are very much a function of the way in which the two modes were measured, and generalizations to other applications must be made with caution.

The Target Size x Direction interaction suggests that the affect of Direction increases as Target Size decreases. The three-way Device x Target Size x Direction interaction, as well as the two-way Device x Target Size and Device x Direction interactions, show that the majority of this interaction is due to the cursor keys. The cursor keys are particularly poor on smaller target sizes, and on the off-axis directions. As would thus be expected, when small target sizes and off-axis directions are combined, performance with the keys is especially poor. Just as the finding that cursor keys were sensitive to Direction is difficult to explain, this interaction is also difficult to explain.

Similarly, the Target Distance x Direction interaction suggests that as Target Distance increases, the affect of changes in Direction is more pronounced. The three-way interaction of Device x Target Distance x Direction (Table 7) suggests that this interaction is also due entirely to the performance of the cursor keys. Although an explanation is not readily apparant, these results suggest that when cursor keys are to be used, off-axis moves at large distances should be expected to be particularly troublesome.

Finally, the Direction x Mode interaction indicates that while both modes were affected by changes in Direction, the button up mode appears to be slightly more sensitve. Again, an explanation is difficult to construct.

In summary, the mouse and trackball appear to perform nearly identically, irrespective of Target Size, Target Distance, Direction, or button Mode. In no case were these two devices found to perform significantly differently from one another. In addition, the mouse and trackball performed better than the cursor keys in all cases. Where a choice exists, the mouse and trackball would apparently always be a better choice than cursor keys on tasks similar to that represented here.

Though performance with the mouse and trackball was affected by changes in Target Size and Target Direction, it was only affected to a relatively small extent. The cursor keys were much more sensitive to performance decrements due to small target sizes and large target distances. In situations where cursor keys are to be used as a pointing device, efforts should be made to maintain large targets and short distances.

Similarly, neither the mouse or trackball was affected by the variable Direction. Though it is not readily apparent why Direction affects performance with the cursor keys, off-axis moves with the cursor keys should be avoided where possible. In addition, further research would help to understand the nature of this finding.

Any conclusions regarding button Mode (pointing vs. dragging moves) from this study should be made with caution. The method used to measure beginning and ending times for button down moves in particular, are different than in most applications and therefore may not generalize well to other applications. Future research should take into account the manner in which button down moves actually occur in applications and time the moves accordingly. The results of any future study could then be compared with the previous findings to gain a full understanding of the differences between button up and button down moves.

Finally, many of the results found in the present study do not lend themselves to easy explanation. Further research would be necessary to determine whether the results are due to spurious occurances in the data or to actual influence and interactions of the variables considered. If the latter appears to be the case, the additional findings should aid in proposing suitable explanations.

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