Evaluation of Mouse, Rate-Controlled Isometric Joystick, Step Keys, and Text Keys for Text Selection on a CRT

By Stuart K. Card, William K. English, and Betty Burr

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EVALUATION OF MOUSE, RATE-CONTROLLED ISOMETRIC JOYSTICK, STEP KEYS, AND TEXT KEYS FOR TEXT SELECTION ON A CRT

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ABSTRACT

Four devices are evaluated with respect to how rapidily they can be used to select text on a CRT display. The mouse is found to be fastest on all counts and also to have the lowest error rates. It is shown that variations in positioning time with the mouse and joystick are accounted for by Fitts's Law. In the case of the mouse, the measured Fitts's Law slope constant is close to that found in other eye-hand tasks leading to the conclusion that positioning time with this device is almost the minimal achievable. Positioning time for the key devices is shown to be proportional to the number of keystrokes which must be typed.

KEY WORDS AND PHRASES

pointing device, target aquisition, step tracking, mouse, joystick, step keys, text keys, text-editing, Fitts's Law

CR CATEGORIES

3.36, 8.1

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An important element in the design of the man-computer interface is the method of pointing by which the user indicates to the computer his selection of some element on the computer display. This is especially important for computer-based text-editing where the user may repeatedly use a pointing device to select the text he wishes to modify, or to invoke a command from a menu displayed on the screen. The choice of pointing device may have a significant impact on the ease with which the selections may be made, and hence, since pointing typically occurs with high frequency, on the success of the entire system.

English, Englebart, and Berman (1967) measured mean pointing times and error rates for the mouse, lightpen, grafacon tablet, and position and rate joysticks. They found the mouse to be the fastest of the devices, but did not investigate the effect of distance to target. They also gave no indication of the variability of their measures. Goodwin (1975) measured pointing times for the lightpen, lightgun, and Saunders 720 step keys. She found the light pen and lightgun equally fast and much superior to the Saunders 720 step keys. However she used only one target size and also did not investigate distance. In addition, her results also show large learning effects which are confounded with the device comparisons. Both studies were more concerned with the evaluation of devices than with the development of models from which performance could be predicted. In another line of development Fitts and others (Fitts, 1954; Fitts & Peterson, 1964; Fitts & Radford, 1968; Knight & Dagnal, 1967; Welford, 1968) developed and tested a relation between distance, size of target, and hand movement time. Such a relation might potentially be used to predict pointing times for devices involving continuous hand movements; however this has not been tested directly. In particular it is not known whether Fitts's Law would hold for targets of the shape and character of text strings.

The present report examines performance on four devices: the mouse, a rate-controlled isometric joystick, step keys, and text keys for a text selection task. The study differs from the English et al. and Goodwin studies in that distance, target size, and learning are all simultaneously controlled and a different set of devices is measured. Also, unlike these studies an attempt is made to give a theoretical account of the results. In particular performance on the continuous movement devices is tested against the predictions of Fitts's Law.

METHOD

Subjects.

Three men and two women, all undergraduates at Stanford University, served as subjects in the experiment. None had ever used any of the devices previously and all had little or no experience with computers. Subjects were paid $3.00 per hour with a $20.00 bonus for completing the experiments. One of the five subjects was very much slower than the others and was eliminated from the experiment.

Pointing Devices

Four pointing devices were tested (see Figure 1). Two were continuous devices: the mouse and a rate-controlled isometric joystick. Two were key operated: the step keys and the text keys. The devices had previously been optimized informally by testing them on local users, adjusting the device parameters so as to maximize performance. The mouse, a version of the device described in English et al. (1967), was a small device which sat on the table to the right of the keyboard, connected by a thin wire. On the under carriage were two small wheels, mounted at right angles to each other. As the mouse moved over the table one wheel coded the amount of movement in the X direction, the other the movement in the Y direction. As the mouse moved, a cursor moved simultaneously on the CRT, two units of screen movement for each unit of mouse movement.

The joystick used was a small strain gauge on which had been mounted a rubber knob 1.25 cm in diameter. Applying force to the joystick in any direction did not produce noticeable movement in the joystick itself, but caused the cursor to move in the appropriate direction at a rate $= .0178\ (\text{force})^2$ in cm/sec, where force is measured in Newtons. For forces less than about 4 Newtons, the cursor did not move at all, and the equation ceased to hold in the neighborhood of 45 Newtons as the rate approached a ceiling of about 40 cm/sec.

The step keys were the familiar five key cluster found on many CRT terminals. Surrounding a central HOME key were keys to move the cursor in each of four directions. Pressing the HOME key caused the cursor to go to the upper left corner of the text. Pressing one of the horizontal keys moved the cursor 1 character (.25 cm on the average) along the line. Pressing a vertical key moved the cursor one line (.46 cm) up or down. Holding down one of the keys for more than 100 msec caused it to go into a repeating mode, producing one step in the vertical direction each 133 msec or one step in the horizontal direction each 67 msec (3.54 cm/sec vertical movement, 3.67 cm/sec horizontal movement).

The text keys were similar to keys appearing on several commercial "word processing" terminals. Depressing the PARAGRAPH key caused the cursor to move to the beginning of the next paragraph. Depressing the LINE key caused the cursor to move downward to the same position in the next line. The text keys could also be used in a repeating mode. Holding the LINE, WORD, or CHARACTER keys down for longer than 100 msec caused that key to repeat at 133 msec per repeat for the LINE key, 100 msec per repeat for the WORD key, or 67 msec per repeat for the CHARACTER key. Since there were about .46 cm/line, 1.34 cm/word, and .25 cm/character movement rates were of 3.54 cm/sec for the LINE key, 13.10 cm/sec for the

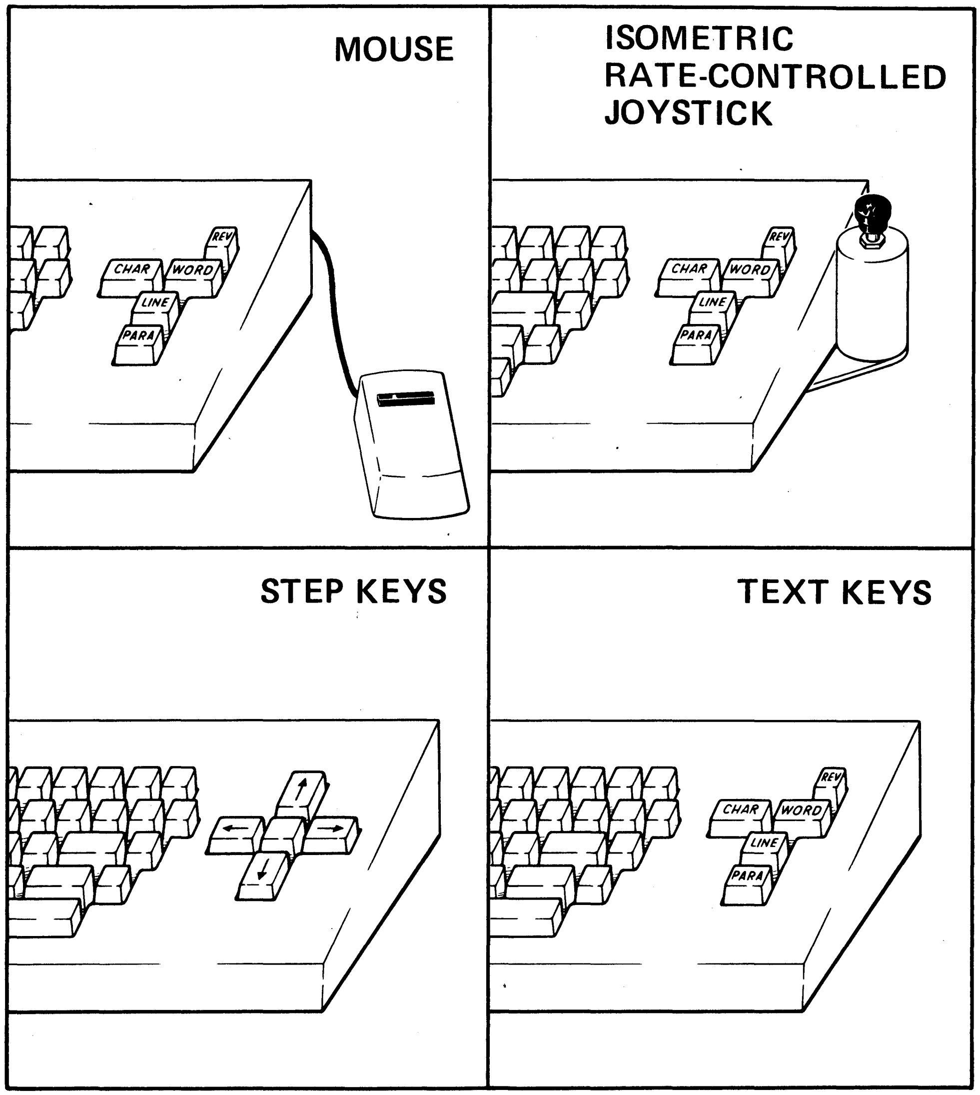

Figure 1. Pointing devices tested.

WORD key, and 3.67 cm/se for the CHARACTER key.

Procedure

Subjects were seated in front of a computer terminal with a CRT for output, a keyboard for input, and one of the devices for pointing at targets on the screen. On each trial a page of text was displayed on the screen. Within the text a single word or phrase, the target, was highlighted by inverting the black/white values of the text and background in a rectangle surrounding the target. S struck the space bar of the keyboard with his right hand, then, with the same hand reached for the pointing device and directed the cursor to the target. The cursor thus positioned, the subject pressed a button "selecting" the target as he would were he using the device in a text editor. For the mouse, the button was located on the device itself. For the other devices, the subject pressed a special key with his left hand.

Design

Text selections and targets were so arranged that there were five different distances from starting position to target, 1, 2, 4, 8, or 16 cm, and four different target sizes, 1, 2, 4, or 10 characters. All targets had word boundaries. Ten different instances of each distance x target size pair were created, varying the location of the target on the display and the angle of hand movement to give a total of 200, randomly ordered, unique stimuli.

Each subject repeated the experiment with each device. The order in which subjects used the devices was randomized. At the start of each day, the subjects were given approximately twenty warmup trials to refresh their memory of the procedure. All other trials were recorded as data. At the end of each twenty trials they were given feedback on the average positioning time and average number of errors for those trials. This feedback was found to be important in maintaining subjects' motivations. At the end of each 200 trials they were given a rest break of about fifteen minutes. Subjects normally accomplished 600 trials/day involving about two to three hours of work. They each used a particular device until the positioning time was no longer decreasing significantly with practice (operationally defined as when the first and last thirds of a block of the last 600 trials excluding the first 200 trials of a day did not differ significantly in positioning time at the $p < .05$ level using a t-test). An approximation to this criteria was reached in from 1200 to 1800 trials (four to six hours) on each device. Of the 20 subject x device pairs, 15 reached this criterion, 3 performed worse in their last trials (largely because some time elapsed between sessions), and only 2 were continuing (slightly) to improve.

RESULTS

Improvement of Performance with Practice

The learning curve which gives positioning time as a function of the amount of practice can be approximated (De Jong, 1957) by

$$T_N = T_1 N^{-\alpha} \qquad (1)$$

where

T_1 = estimated positioning time on the first block of trials
T_N = estimated positioning time on the Nth block of trials
N = trial number
α = an empirically determined constant

This form is convenient since taking the log of both sides produces an equation linear in log N

$$\log T_N = \log T_1 - \alpha (\log N) \qquad (2)$$

Thus the ease of learning for each device can be described by two numbers T_1 and α, which numbers may be conveniently determined empirically by regressing log N on log T_N. Figure 2 shows the results of plotting the data from error-free trials according to Equation 2. Each point on the graph is the average of a block N of twenty contiguous trials from, which error trials have been excluded. Only the first 60 trial blocks are shown. Since some subjects reached criterion at this point, not all continued on to further trials. The values predicted by the equation are given as the straight line drawn through the points. The average target size in each block was 4.23 cm (the range of the average target sizes for different trial blocks was 3.95 to 4.50 cm); the average distance to the target was 6.13 cm (range 5.90 to 6.42 cm).

The parameters T_1 and α, as determined by the regressions, are given in Table 1. Practice causes more improvement in the mouse and text keys than on the other two devices. The step keys, in particular, show very little improvement with practice. Equation 2 explains 37% of the variance in the average positioning time for a block of trials for the step keys, 57% to 68% of the variance for the other devices. The fit, at least for the mouse and the joystick, is actually better than these numbers suggest. Since subjects did 30 blocks of

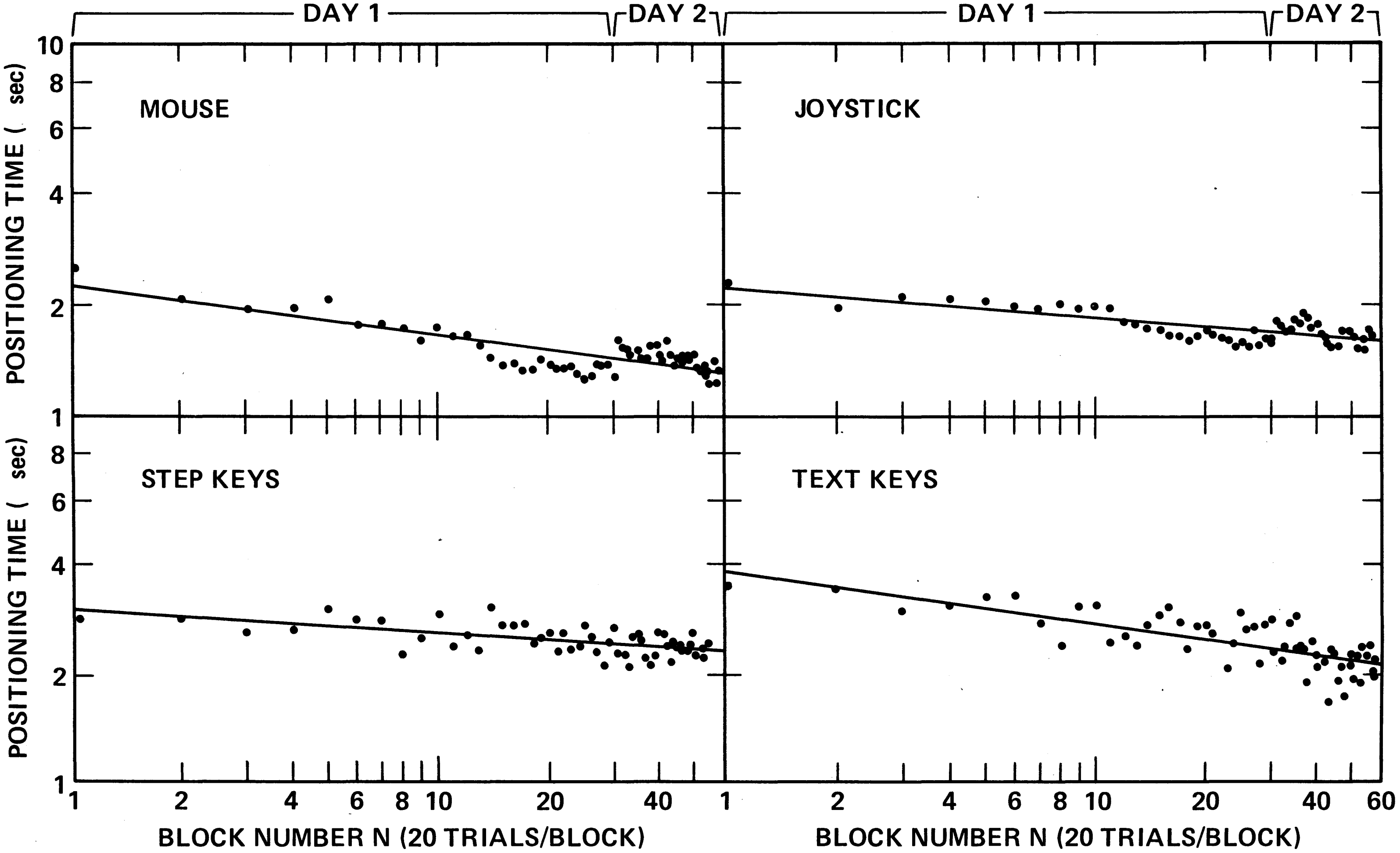

Figure 2. Learning curves for pointing devices.

TABLE 1
Learning Curve Parameters

DEVICE	T_1 (sec)	α	Learning Curve Equation[a]	s_e (sec)	R^2
Mouse	2.20	.13	$T_N = 2.20\ N^{-.13}$	.12	.66
Joystick	2.19	.08	$T_N = 2.19\ N^{-.08}$	.08	.62
Step Keys	3.03	.07	$T_N = 3.03\ N^{-.07}$	.11	.39
Text Keys	3.86	.15	$T_N = 3.86\ N^{-.15}$	.16	.61

[a] N is number of trial blocks. There are 20 trials in each block.

trials on a day typically followed by a pause of a day or two before they could be rescheduled, a break in the learning curve is expected at that point and indeed such a break is quite evident for the mouse and the joystick between the 30th and 31st blocks. Fitting Equation 2 to only the first day increases the percentage of variance explained to 91% for the mouse and 83% for the joystick. In the case of the step keys and text keys there is no such obvious day effect.

Overall Speed

In order to compare the devices after learning has nearly reached assymptote (as would be the case for office workers using them daily) a sample of each subject's performance on each device was examined consisting of the last 600 trials excluding the first 200 trials of a day (in order to diminish warmup effects). The remaining analyses will be based on this subset of the data, excluding those trials on which errors occurred. Table 2 gives the homing time, positioning time, and total time for each device averaging over all the distances and target sizes. *Homing time* was measured from the time the subject's right hand left the space bar until the cursor had begun to move. *Positioning time* was measured from when the cursor began to move until the selection button had been pressed. From the table, it can be seen that homing time increases slightly with the distance the device is from the keyboard. The longest time required is to reach the mouse, the shortest to reach the step keys. The text keys are an exception, taking almost as long to reach as the mouse. Either it is more difficult to position the hands on the text keys or, as seems likely, subjects often spent some time planning the strategy for their move in the time between hitting the space bar to start the clock and the time when they begin pressing the keys. Further evidence for this hypothesis comes from the relatively high standard deviations observed for the homing time of the text keys. While the differences between the homing times among all device pairs except the mouse vs. the text keys are reliable statistically (at $p < .05$ or better using a t-test) the differences are actually quite small. For example, while it takes 150 msec longer to reach the mouse than to reach the joystick, it takes 1020 msec longer to position the joystick than the mouse. Thus the differences in the homing times are insignificant compared to the differences between the positioning times.

The mouse is easily the fastest device, the step keys the slowest. As a group the continuous devices, the mouse and the joystick, are faster than the key operated

TABLE 2
Overall Times

DEVICE	Movement time for non-error trials (sec)						Error Rate	
	Homing Time		Positioning Time		Total Time			
	M	SD	M	SD	M	SD	M	SD
Mouse	.36	.13	1.29	.42	1.66	.48	5%	22%
Joystick	.26	.11	1.57	.54	1.83	.57	11%	31%
Step Keys	.21	.30	2.31	1.52	2.51	1.64	13%	33%
Text Keys	.32	.61	1.95	1.30	2.26	1.70	9%	28%

devices, the step keys and text keys. Differences between the devices are all reliable at $p << .001$ using *t*-tests.

Effect of Distance and Target Size

The effect of the distance from starting position to target on positioning time is given in Figure 3. At all distances greater than 1 cm, the continuous devices are faster. The positioning time for both continuous devices seems to increase approximately with the log of the distance. The time for the step keys increases rapidly as the distance increases, while the time for the text keys increases somewhat less than as the log of the distance, owing to the existence of keys for moving relatively large distances with a single stroke. Again the mouse is the fastest device and its advantage increases with larger distance.

Figure 4 gives the effect of target size on positioning time. The positioning time for both the mouse and the joystick decreases with the log of the target size. The time for the text keys is independent of target size and the positioning time for the step keys also decreases roughly with the log of the target size. Again the mouse is the fastest device and again the continuous devices as a group are faster for all target sizes.

Effect of Approach Angle

The targets in text editing are rectangles often quite a bit wider than they are high. Hence they might present a different problem when approached from different angles. In addition, the step keys and text keys work somewhat differently when moving horizontally than when moving vertically. To test if the direction of approach has an effect on positioning time, the target movements were classified according to whether they were vertical (0 to 22.5 degrees) diagonal (22.5 degrees to 67.5 degrees) or horizontal (67.5 degrees to 90 degrees). Analysis of variance shows the angle makes a significant difference in every case except for the mouse. The joystick takes slightly longer to position when the target is approached diagonally. The step keys take longer when approached horizontally than when approached vertically, a consequence probably deriving from the fact that a single keystroke would move the cursor almost twice as far vertically as horizontally. By contrast, the text keys take longer to position horizontally, reflecting the presence of the WORD key. The differences induced by direction are not of great

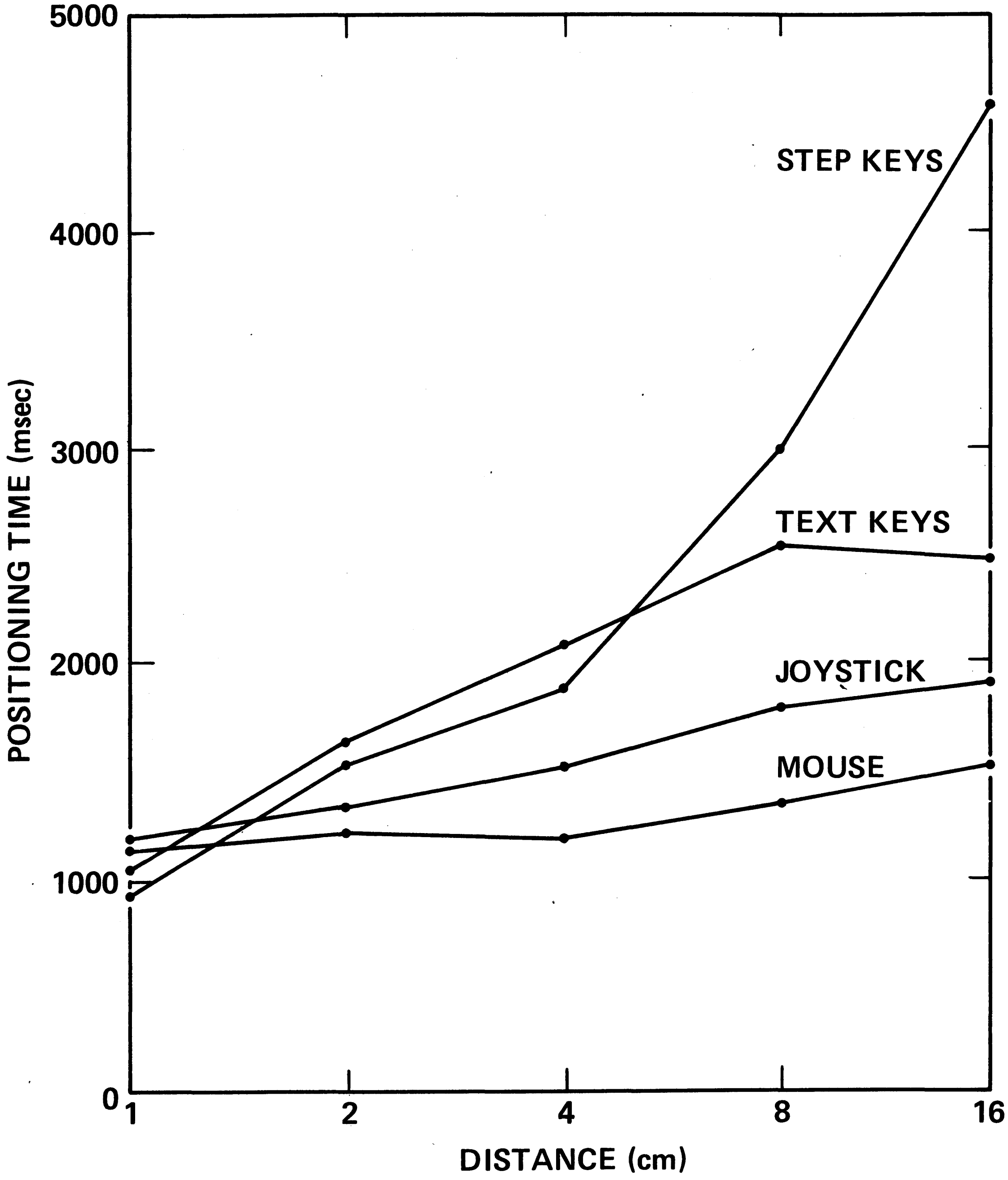

Figure 3. Effect of target distance on positioning time.

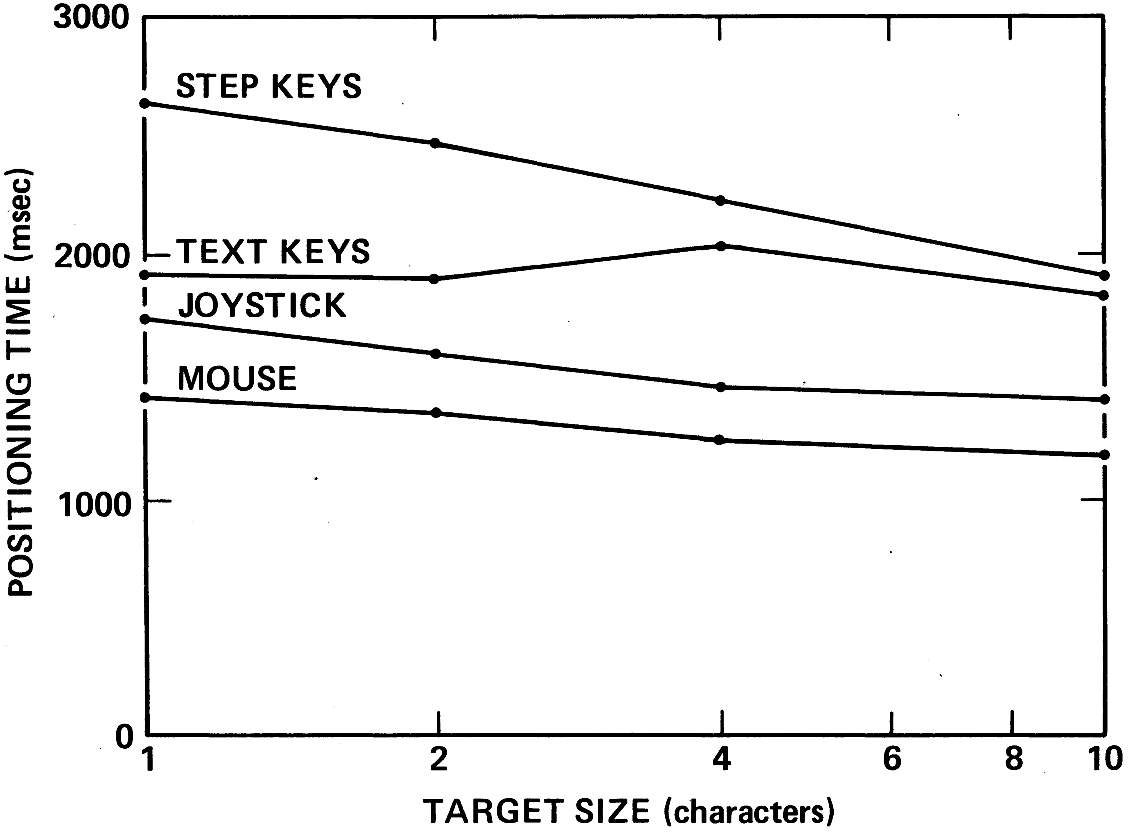

Figure 4. Effect of target size on positioning time.

consequence, however. For the joystick it amounts to 3% of the mean positioning time; for the step keys 9%; for the text keys 5% .

Errors

Of the four devices tested the mouse has the lowest overall error rate 5%, the step keys the highest at 13%. The differences are reliable at $p < .05$ or better using t-tests. There is only a very slight increase in error rate with distance. However, there is a decrease in error rate with target size for every device except the text keys (Figure 5). This finding replicates the result of Fitts & Radford (1966). In an investigation of self-initiated, discrete, pointing movements using a stylus, there was a similar marked reduction in errors as the target increased in size, but only a slight increase in error rate as the distance to the target increased.

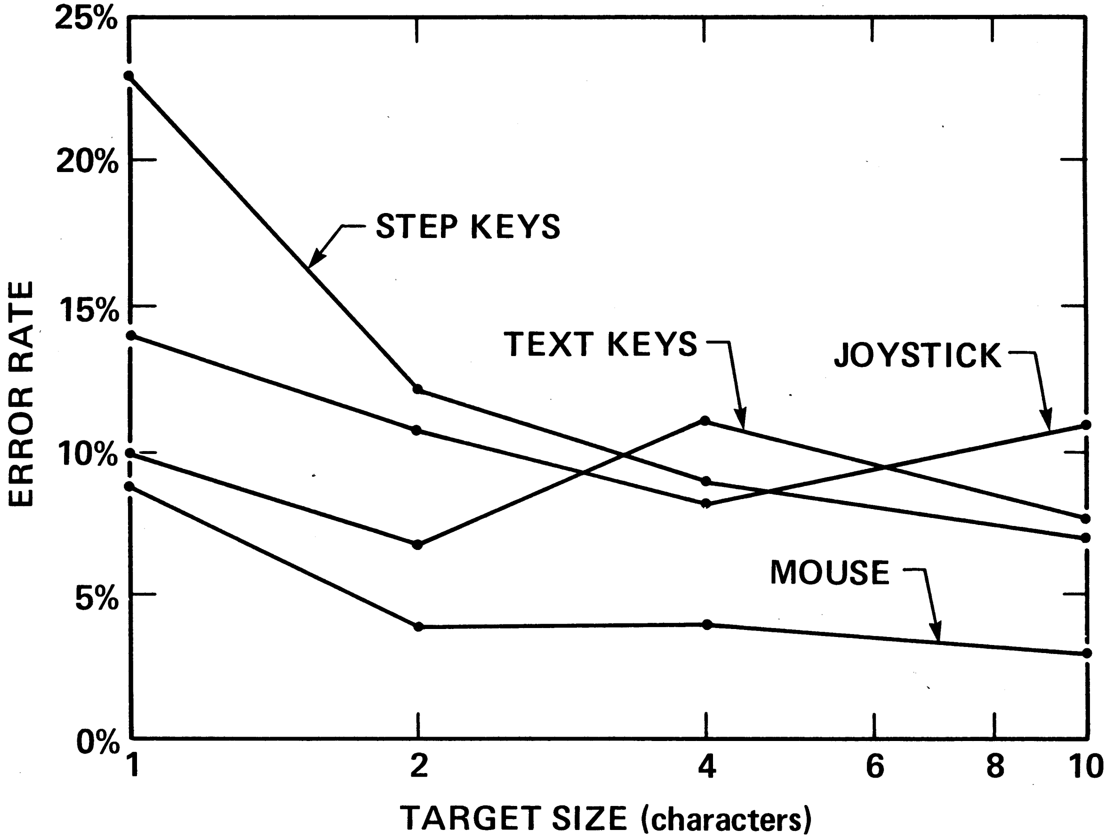

Figure 5. Effect of target size on error rate.

DISCUSSION

While these empirical results are of direct use in selecting a pointing device, it would obviously be of greater benefit if a theoretical account for these results could be made. For one thing, the need for some experiments might be obviated; for another, ways of improving pointing performance might be suggested. Fortunately, a first-order account for the devices of this experiment is not hard to give.

Mouse

The time to make a hand movement can be described by a version of Fitts's Law (Welford, 1968),

$$\text{Positioning time} = K_0 + K \log_2 (D/S + .5) \text{ msecs} \tag{3}$$

where

D = Distance to the target
S = Size of the target
K_0, K = Constants.

Here the constant K_0 includes within it the time for the hand initially to adjust its grasp on the mouse and the time to make the selection with the selection button. A constant of $K \simeq .1$ sec/bit (10 bits/sec) appears in a large number of studies on movement. This number is a measure of the information processing capacity of the eye-hand coordinate system. For single, discrete, subject-paced movements the constant is a little less than .1 sec/bit. Fitts & Radford (1966) get a value of 78 msec/bit or 12.8 bits/sec (recomputed from their Figure 1, Experiment I, for the experimental condition where accuracy is stressed). Pierce and Karlin (1957) get maximum rates of 85 msec/bit (11.7 bits/sec) in a pointing experiment. For continuous movement, repetitive, experimenter-paced tasks such as alternately touching two targets with a stylus or pursuit tracking, the constant is slightly above .1 sec/bit. Elkind and Sprague (1961) get maximum rates of 135 msec/bit (7.4 bits/sec) for a pursuit tracking task. Fitts's original dotting experiment as replotted by Welford (1968, p. 148) gives K of 120 msec/bit as does Welford's own study using the actual distance between the dots, the same measure of distance used in this study.

Fitts's Law predicts that plotting positioning time as a function of $\log_2 (D/S + .5)$ should give a straight line. As Figure 6 shows that prediction is confirmed. Furthermore the slope of the line K should be in the neighborhood of .1 sec/bit. Again the prediction is confirmed. The equation for the line in Figure 8 as determined by regression analysis is

$$\text{Positioning time} = 1033 + 96 \log_2 (D/S + .5) \text{ msec.} \tag{4}$$

The equation explains 83% of the variance of the means for each condition. This is roughly comparable to the percentage of variance explained by Fitts & Radford. The slope of 96 msec/bit is in the .1 sec/bit range found in other studies. Since the standard error of estimate for K is 8 msec/bit the mouse would seem to be close to, but slightly slower than, the optimal rate of around 80 msec/bit observed for the stylus and for finger pointing.

The values for positioning time obtained in this experiment are apparently in good agreement with those obtained by English et al. Making the assumption that their CRT characters were about the same width as ours and assuming an intermediate target distance of about 8 cm, Equation 4 (plus the addition of the .36 sec homing time from Table 2) predicts 1.87 sec for 1 character targets (English et al. got 1.93 sec) and 1.66 sec for "word" targets of 5 characters (they got 1.68 sec).

Joystick

Although it is a rate-controlled device instead of a position device we might wonder if the joystick follows Fitts's Law. Plotting the average time per positioning for each distance x size cell of the experiment according to Equation 3 (see Figure 6) shows that there is an approximate fit to

$$\text{Positioning time} = 1036 + 205 \log_2 (D/S + .5). \tag{5}$$

Equation 5 has a standard error of 132 msec and explains 89% of the variance of the means. The size of the slope K shows that information is being processed at only half the speed as with the mouse, and significantly below the maximum rate. Closer examination, gives some insight into the difficulty. The points for the joystick in Figure 6 actually form a series of parallel lines, one for each distance, each with a slope of around .1 sec/bit. Setting K to .1 sec/bit, we can therefore write as an alternative model

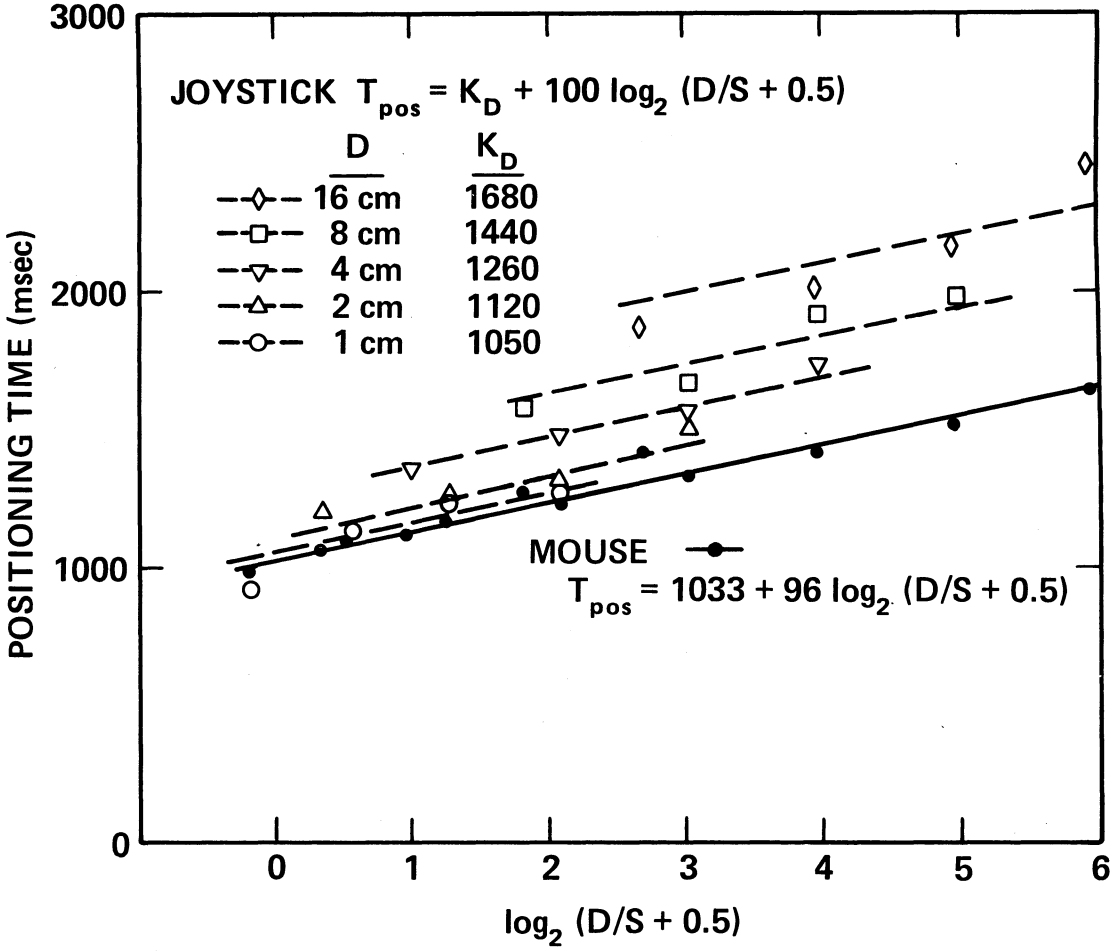

Figure 6. Positioning time for continuous devices as a function of Fitts's index of difficulty $\log_2$ (D/S + .5).

$$\text{Positioning time} = K_D + 100 \log_2 (D/S + .5).$$

K_D is the intercept for distance D. From the figure, K_D is about 1050 msec for $D = 1$ cm, 1120 for 2 cm, 1260 for 4 cm, 1440 for 8 cm, and 1680 for 16 cm. This equation has a standard error of 153 msec and explains 85% of the variance. Thus the tested joystick can be viewed as a Fitts's Law device with either a slope twice that for hand movements or with the expected slope but having an impediment which increases with distance. The problem with this joystick is likely related to the non-linearity in the control (cf. Poulton, 1974 and Craik & Vince, 1963). It should be noted that for the 1 cm distance (where the effect of non-linearity is slight) the Positioning time is virtually the same as for the mouse.

Step Keys

The time to use the step keys might, as a first approximation be expected to be governed by the number of keystrokes which must be used to move the cursor to the target. Since the keys can only move the cursor vertically or horizontally the number of keystrokes is $D_x/.46 + D_y/.25$ where D_x and D_y are the horizontal and vertical components of distance to the target; .46 is the size of a vertical step and .25 is the size of a horizontal step. Hence positioning time should be

$$\text{Positioning time} = K_0 + C\,(D_x/.46 + D_y/.25), \tag{6}$$

This equation with $K_0 = 1200$ sec and $C = 52$ msec/keystroke has a standard error of 541 msec and explains 84% of the variance of the means.

Since the tapping rate is around 150 msec/keystroke C is much too fast to be identified with the pressing of a key. It is also too fast to be identified with the 67 msec/keystroke automatic repetition mode. Figure 7 shows positioning time plotted against the predicted number of keystrokes. The dotted line is Equation 6 with the above parameters. The figure shows that positioning time is linear with the number of keystrokes until the predicted number of keystrokes becomes large (that is, the distance to the target is long). In these cases the user often has the opportunity to reduce positioning time by using the HOME key. Fitting Equation 6 to the first part of the graph $D_x/.46 + D_y/.25 < 40$) gives

$$\text{Positioning time} = 978 + 74\,(D_x/.46 + D_y/.25).$$

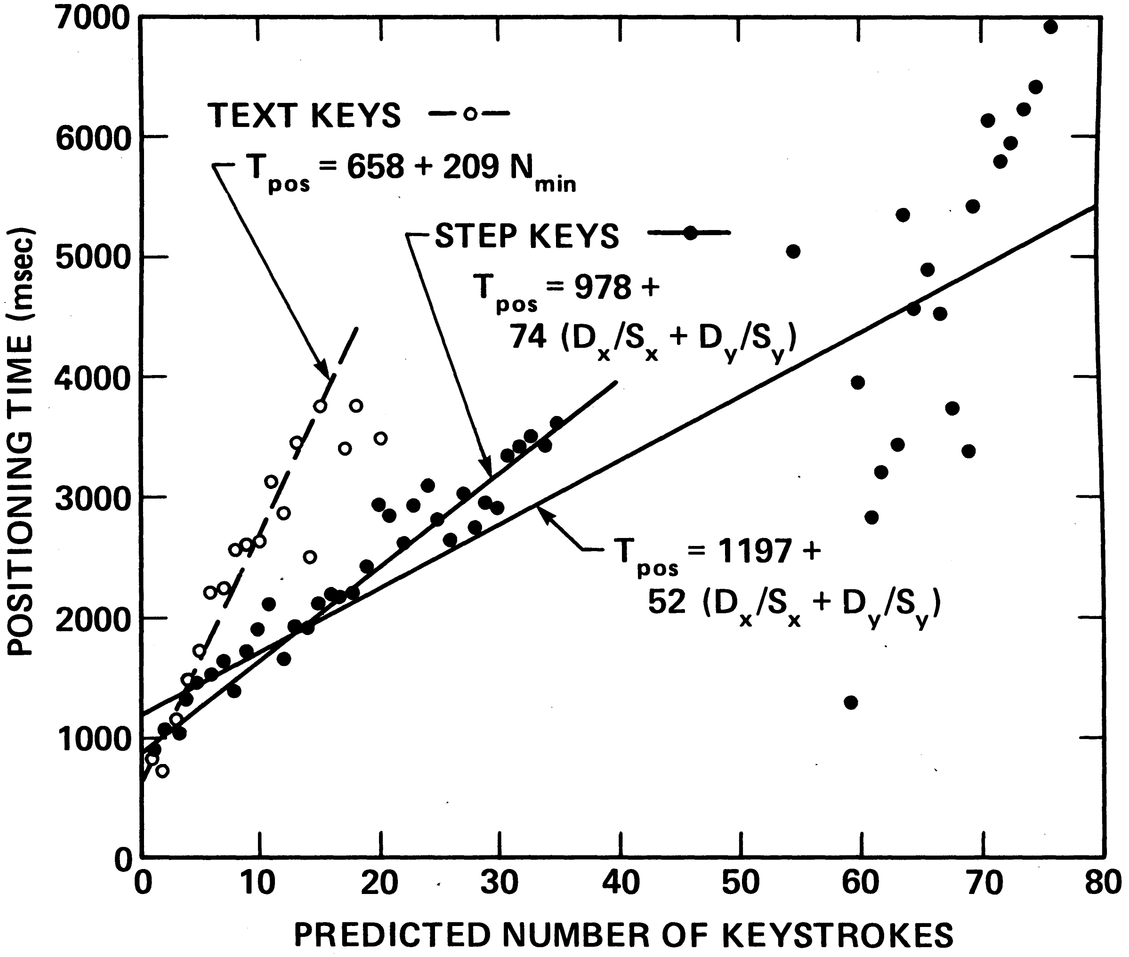

Figure 7. Positioning time for key devices as a function of predicted number of keystrokes.

This equation, indicated as a solid line on the figure, has a standard error of 177 msec and explains 95% of the variance in the means.

Text Keys

The text keys present the user on most trials with a choice of methods by which the target may be acquired. For example, he might press the PARAGRAPH key repeatedly until the cursor has moved to the paragraph containing the target paragraph. He could then press the LINE key repeatedly until it is on the target line, then use the WORD key to bring it over to the target. Or he might use the PARAGRAPH key to move to the paragraph after the target, then holding the REVERSE key down use the LINE key to back up to the line after the target line. And finally, using REVERSE and WORD, back up until he hits the target. In fact, there are 26 different methods for moving the cursor to the target, although only a subset will be possible in a given situation. The fastest method will depend on where the target is located relative to the starting position and the boundaries of surrounding lines and paragraphs.

A reasonable hypothesis would be that positioning time is proportional to the number of keystrokes and that for well practiced subjects the number of keystrokes will be the minimum necessary. To test this hypothesis each trial was analyzed to determine the minimum number of keystrokes N_{min} necessary to hit the target. The average positioning time as a function of N_{min} is plotted as the open circles in Figure 7. A least squares fit gives

$$\text{Positioning time} = 658 + 209\ N_{min}.$$

The standard error is 238 msecs and the equation explains 89% of the variance of the means. The keystroke rate of 209 msec/keystroke is very reasonable, being approximately equal to the typing rate for random words (Devoe, 1967). Evidently, the automatic repetition mode was little used. Examination of some statistics on the minimum numbers of keystrokes for each trial shows there was little need for it. For one thing, an average of only six keystrokes was necessary for the text keys to locate a target word. Ten or fewer keystrokes were sufficient for over 90% of the targets. For another, these keystrokes were distributed across several keys further limiting opportunities to use the repetition mode. The PARAGRAPH key was needed on 48% on the trials, the LINE key on 85%, the word key on 83%, and the REVERSE key on 81%.

All the models are summarized in Table 3. The column labelled "Cell Means" gives the standard error and proportion of variance explained, computed on the basis of one data point for each value of the model's independent variables (following Fitts). The column labelled "Trials" gives the same, computed on the basis of one data point per trial. These models allow prediction of pointing time in a number of different applications.

The match of the Fitts's Law slope to the roughly $K = .1$ sec/bit constant observed in other hand movement and manual control studies means that positioning time is apparently limited by central information processing capacities of the eye-hand guidance system (cf. Welford, 1968; Grosland, 1977). Taking $K = 80$ msec/bit as the most likely minimum value for a similar movement task, and $K_0 = 1000$ msec as a typical value observed in this experiment, it would seem unlikely that a continuous movement device could be developed whose positioning time is less than $1000 + 80 \log_2 (D/S + .5)$ msec (unless it can somehow reduce the information which must be centrally processed), although something might be done to reduce the value of K_0. If this is true then an optimal device would be expected to be no more than about 6% faster than the mouse in the extreme case of 1 character targets 16 cm distant ($1000 + 95 \log_2 [(16/1) + .5]$ msec vs $1000 + 80 \log_2 [(16/1) + .5]$ msec). Typical differences would be much less. By comparison in this same case the joystick is 83% slower than the optimal device, the text keys 107% slower and the step keys 239% slower. Even if K_0 were zero, the mouse would still be less than 23% slower than the minimum. While devices might be built which improve on the mouse's homing time, error rate, or ability for fine movement, it is unlikely their positioning time will be significantly faster.

This maximum information processing capacity probably explains the lack of any significant difference in positioning time between the lightpen and the lightgun in Goodwin's experiment. Both are probably Fitts's Law devices, both can be expected to have the same maximum .1 sec/bit rate as the mouse (if they are optimized with respect to control/display ratio and any other relevant variables).

Of the four devices, the mouse is clearly the most "compatible" for this task (cf. Poulton, 1974; Chapter 16), meaning less mental translation is needed to map intended motion of the cursor into motor movement of the hands than for the other devices. Thus it would be expected to be easier to use, put lower cognitive load on the user, and have lower error rates. There are, however, limits to its compatibility. Inexperienced users are often bewildered about

TABLE 3
Summary of Models for Positioning Time (T_{pos})

Device	Model (times in msec)	Cell Means s_e	Cell Means R^2	Trials s_e	Trials R^2
Mouse	$T_{pos} = 1033 + 96 \log_2 (D/S + .5)$	74	.83	280	.26
Joystick	$T_{pos} = 1036 + 205 \log_2 (D/S + .5)$	132	.89	392	.42
	$T_{pos} = K_d + 100 \log_2 (D/S + .5)$	153	.85	378	.46
Step Keys	$T_{pos} = 1197 + 52 (D_x/S_x + D_y/S_y)$	541	.84	1066	.57
	$T_{pos} = 978 + 74 (D_x/S_x + D_y/S_y)$	177	.95	714	.53
Text Keys	$T_{pos} = 658 + 209 N_{min}$	238	.89	940	.35

what to do when they run the mouse into the side of the keyboard trying to move the cursor across the screen. They need to be told that their mouse can simply be picked up and deposited at a more convenient place on the table without affecting the cursor. Even experienced users are surprised at the results when they hold their mice backward or sideways.

The greatest difficulty with the mouse for text-editing comes when it must be used with small targets. Punctuation marks such as a period are considerably smaller than an average character. The error rate for the mouse which was already up to 9% for one character targets would be even higher for these sorts of targets.

SUMMARY AND CONCLUSION

Of the four devices tested the mouse is clearly the superior device for text selection on a CRT.

1. Positioning time is significantly faster than for any of the other devices. This is true overall and at every distance and size combination save for single character targets.

2. The error rate is significantly lower than for other devices.

3. The movement of the mouse occurs at a rate which is apparently nearly maximal with respect to the information processing capabilities of the eye-hand guidance system.

4. The mouse is the most compatible with the pointing task of the four devices tested, although even more compatible devices can be imagined.

As a group the continuous movement devices are superior in both speed and error-rate. For the continuous movement devices, positioning time is given by Fitts's Law. For the key devices it is proportional to the number of keystrokes.

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