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Cursor Positioning Performance as a Function of Delay Between Trackmarble Movement and Cursor Motion

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Preface

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13. ABSTRACT *(Maximum 200 words)*

The amount of delay between activation of a cursor control device and the actual cursor movement on a display device can affect an operator's performance of cursor positioning tasks. An experiment was performed to investigate time-to-target performance under various processing delays from 75 to 400 ms and several cursor-to-target directions and distances. Subjective assessments by the subjects of the delay's characteristics were also recorded. Results showed large and highly significant effects of both delay and distance. There were smaller effects due to direction. Optimum performance was found to be less than or equal to 75 ms. A Delay Perceptibility Threshold, the point at which half of the subjects perceived the delay, was found at 120 ms, and a Threshold of Annoyance, at which half of the subjects were annoyed by the delay, was found at 212 ms. Keywords,

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

CURSOR POSITIONING PERFORMANCE AS A FUNCTION OF DELAY BETWEEN TRACKMARBLE MOVEMENT AND CURSOR MOTION

INTRODUCTION

For an interactive computing system to be effective, it is critical that when a user moves a trackmarble or joystick or when he completes a command by pressing an Enter key, the system should immediately provide some form of confirmation that the user's action has been received. The confirmation for a trackmarble or joystick movement need only be the accompanying motion of the controlled cursor on the display screen. As workstation architectures become more complex, the potential to depart from a quick and comfortable trackmarble-cursor feedback loop also increases. If the delay between the user's trackmarble movement and the trackmarble motion becomes too large, the user may have to guess the amount of trackmarble movement needed to place the cursor in a new location. He may feel "disconnected" from the cursor he is supposed to be controlling. When determining specifications for system response time, it is important, from a human factors standpoint, that the effect of system delay on cursor positioning performance be understood and properly accounted for in the operational response time budget.

The trackmarble has been shown to be a highly effective cursor control device[1], and preliminary work has produced an effective algorithm for mapping the trackmarble movement to the cursor motion. The purpose of the present experiment was to investigate the effect of trackmarble-cursor delay time on operator performance. The subjects performed a series of simple target acquisition trials in which a cursor was moved to a target. The system delay within the trackmarble-cursor feedback loop was under experimental control and was constant for a given trial. Also, in order to examine the effect of cursor-to-target distance and direction on performance, the initial location of the cursor and the location of the target were under experimental control and were varied for each trial.

OBJECTIVE

The primary intent of the experiment was to examine the effect of cursor processing delay time, that is, the time between trackmarble motion and resultant cursor displacement on the timed performance of a simple cursor movement task. Six delay times were selected: 75 ms, 100 ms, 150 ms, 200 ms, 300 ms, and 400 ms. A baseline delay of 75 ms was chosen during preliminary work that suggested this delay could not be perceived

[1]Epps, B.W., Snyder, H.L., and Muto, W.H. (1986) Comparison of Six Cursor Devices on a Target Acquisition Task, SID 86 Digest, 302-304.

by an operator. Delays of up to 400 ms were selected since they were representative of modeling results for several projects.

Subjective qualities of the effects of cursor delay, such as perceptibility, annoyance, and reliability, were investigated through subject interviews in order that thresholds for these attributes could be determined. The purpose of combining both objective timed performance and the subjective perceptions of the subjects was to determine an upper limit of acceptability in cursor delay. A secondary goal was the examination of the effect of both direction and distance, from initial cursor location to target location, on performance.

METHOD

SUBJECTS

Twelve individuals, 10 men and two women, with modest experience using trackmarbles, served as subjects. There was one left-handed subject.

APPARATUS

The test was performed in the Acoustic Display Research Facility at the Naval Underwater System Center, New London, CT. The test console housed four Measurement Systems Inc. (MSI) 1.5-in. diameter trackmarbles, four Enter switches (one approximately 3 in. above and behind each trackmarble), and two 19 in. CRT monitors. The monitors had a resolution of 1024 lines x 1280 pixels. For this experiment, only the rightmost and leftmost trackmarbles with their Enter switches, and the lower CRT, at eye level to the seated subject, were used. The trackmarble inputs were sent to a MicroVAX II which drove a Ramtek 9400 display generator, which in turn drove the CRT monitor. One trackmarble, either the far right or the far left, as determined by the handedness of the subject, was used per session.

Reports containing the amount of trackmarble rotation were sent by the trackmarble to the MicroVAX II every 50 ms during trackmarble activity. No reports were sent when the trackmarble was idle. The report contained the amount of trackmarble rotation, along both the x and y axes, which had occurred since the last report. The amount of rotation was given in pulses per axis and the trackmarble had a resolution of 180 pulses per revolution per axis. Pressing the trackmarble's Enter switch would also cause a report to be sent. The software generated a delay between the creation of the trackmarble report and the corresponding movement of the cursor on the display. This delay of up to 400 milliseconds between a trackmarble report and the corresponding cursor movement did not interfere with the reception of new trackmarble reports at the 50 ms rate. It was therefore possible to time shift the entire resulting cursor motion by up to 400 ms while maintaining the smoothness of a 50 ms period between consecutive cursor updates on the display.

The algorithm used to determine pixel displacement of the cursor based on the trackmarble report implements rate-aiding to provide greater cursor displacement for high rates of trackmarble movement.

The algorithm can be described as follows:

$$D = P \qquad :\text{for } P < 10$$
$$D = 2P \qquad :\text{for } P \geq 10,$$

where P = Pulses for a given axis within a report, and
D = Resultant cursor displacement in pixels for that axis.

DESIGN

A 6x3x8x2 repeated measures experimental design was used. Six delays, three cursor-to-target distances, eight directions, and two sessions per subject constituted the four different factors.

The experiment consisted of simple target acquisition trials. A trial began with a blank dark display upon which the green 0.4-in. crosshair cursor was presented in a random location. Shortly after the cursor appeared, the target appeared. The target consisted of a green 0.4-in. square with a center point. To discourage anticipatory movement by the subject, the time between the appearance of the cursor and the target varied between 1 and 3 seconds. The appearance of the target on the display surface was momentarily postponed if anticipatory trackmarble movements were detected. Figure 1 shows the cursor and target as they appeared on the display surface. Only the cursor and target actually appeared on the display surface. The subject's task was to place the center of the cursor on the target center point as quickly and accurately as possible and to press the Enter switch with the hand which moved the trackmarble. When the Enter switch was pressed, an accurate cursor placement (within 2 pixels of the target center on both the x and y axis) was confirmed by a red X drawn within the target box. Nothing was drawn if the cursor was inaccurately placed. After the Enter switch was hit, the cursor, target, and X (if the placement was accurate) remained on the screen for approximately 0.5 seconds; this time was provided for the subject to determine the success of the trial by noting the presence or absence of the confirmation X. The screen was then cleared in preparation for the next trial. Figure 2 shows the event sequence time line for one trial.

Each subject was tested in two sessions separated by at least one day, resulting in a total of 24 test sessions. Each session was comprised of six Delay blocks, one block per cursor delay tested (75 ms, 100 ms, 150 ms, 200 ms, 300 ms, and 400 ms). A Latin square test schedule was used to determine the order of the Delay blocks within each session to eliminate learning or other progressive effects as performance bias factors.

Additional independent variables within each Delay block were Direction and Distance. Figure 1 shows the Direction and Distance components of the initial cursor and target locations. Direction is defined as the angle between the cursor start point and the target. Eight directions were tested: 0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315°. Distance was defined as the number of pixels between the cursor start location and the target. The three selected Distance values were 46, 274 and 823 pixels (approximately 0.5 in., 2.75 in., and 8.25 in., respectively). There was one trial per Distance/Direction combination per Delay block. However, if a trial was inaccurate (not within 2 pixels), the trial was discarded and the combination was repeated sometime before the completion of that Delay block. Thus, there were 24 accurate trials per Delay block, a total of 144 trials per session.

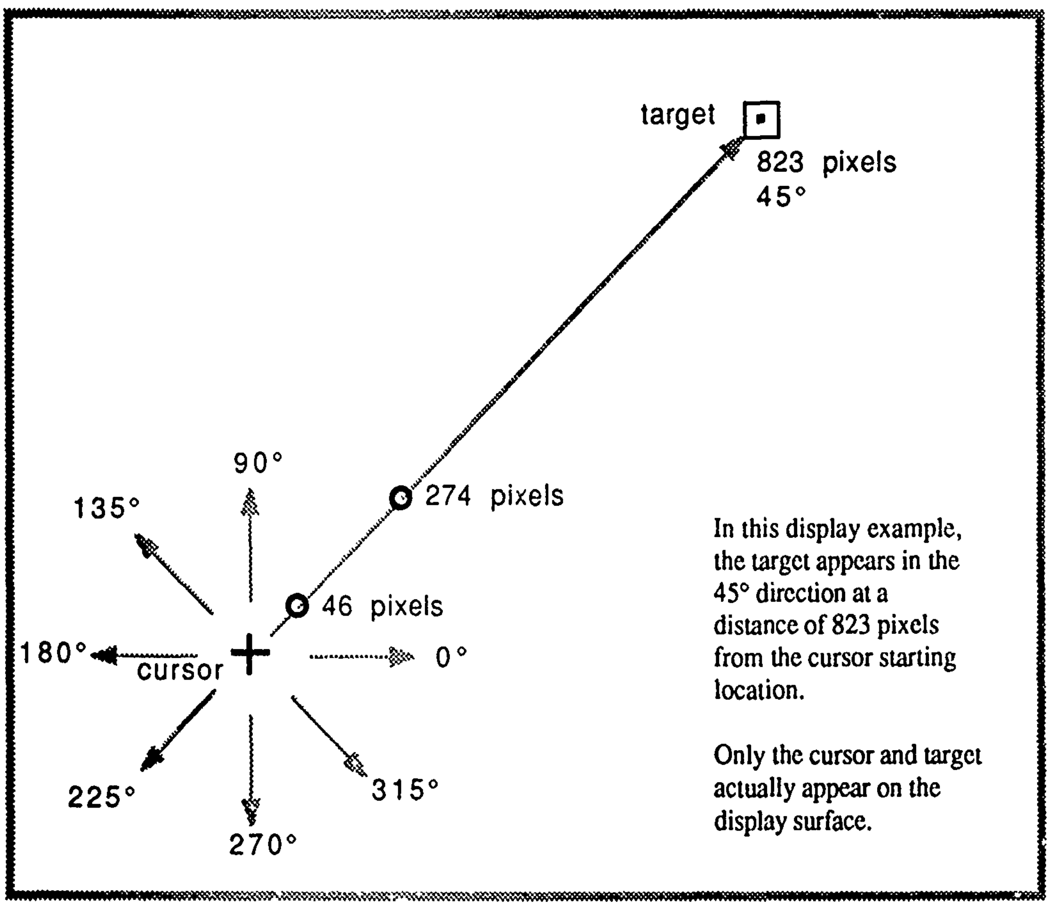

Figure 1. Cursor and Target with Selected Distance and Direction

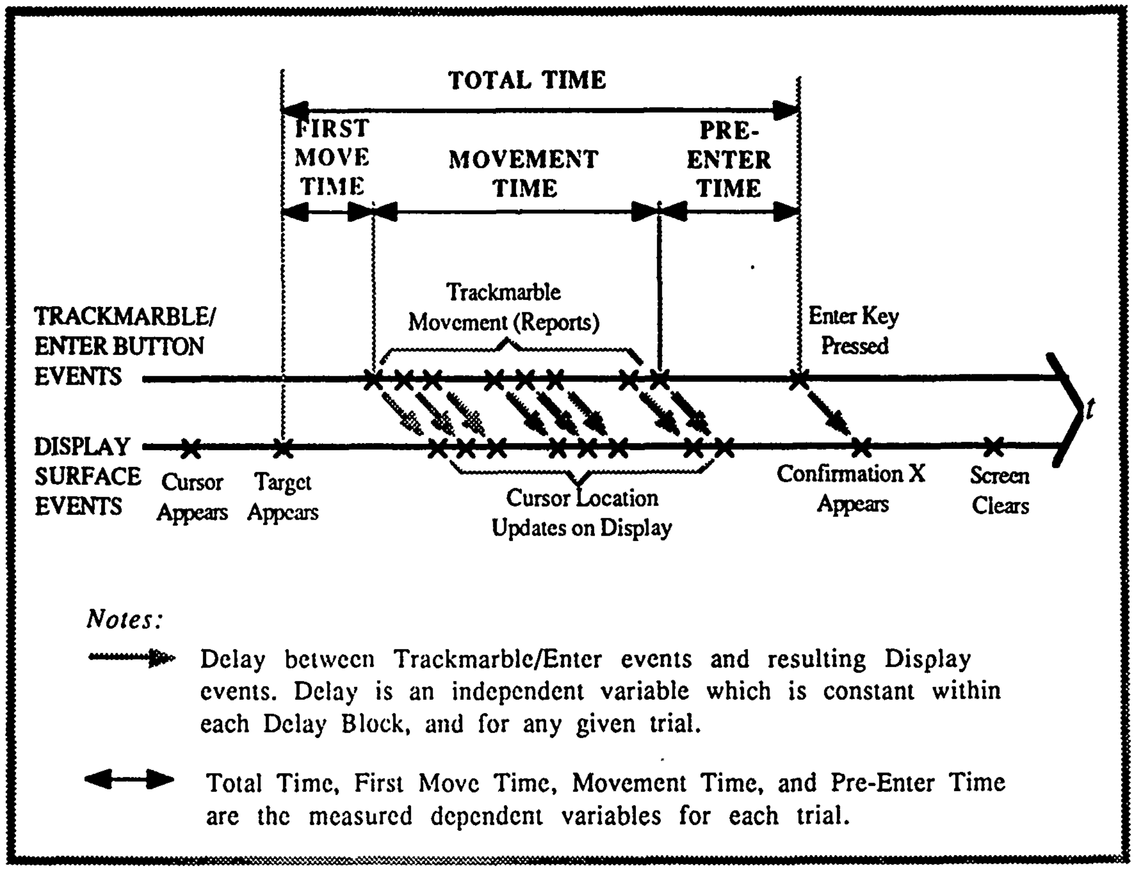

Figure 2. Trial Time Line

The cursor and target start locations and the time and magnitude of every trackmarble movement were recorded. From these data, four dependent variables (see figure 2) were derived for each trial:

1) Total Time, defined as the time between the appearance of the target and the pressing of the Enter switch by the subject.

2) First Move Time, defined as the time between appearance of the target and the first trackmarble movement.

3) Movement Time, defined as the time between the first trackmarble movement and the last trackmarble movement during the trial.

4) Pre-Enter Time, defined as the time between the last trackmarble movement and the pressing of the Enter switch.

PROCEDURE

At the beginning of each session, the subjects were given written instructions explaining the trial task and structure of the session. The subjects were not told which delays were being tested. The session consisted of six Delay blocks.

Each Delay block began with five untimed practice trials. The purpose of the practice trials was to familiarize the subjects with the feel of each delay. Directly following the practice trials, the subjects were notified that timed trials would begin. The subjects then performed the timed trials. Within the set of timed trials, the subject was presented with every Direction and Distance combination. If the subject inaccurately placed the cursor on the target for a trial, the trial was repeated later within that set of timed trials, using the same Direction and Distance combination. Upon completion of the timed trials for each Delay block, the subjects were asked to comment on their performance for that Delay by answering three "yes/no" questions:

1) Was the cursor delay perceptible?
2) Was the cursor delay annoying?
3) Was the cursor delay unreliable?

A fourth question was asked during the second session only:

4) Did you feel the cursor delay impacted your performance?

Upon completing the yes/no questions which concluded the delay block, the subject began the next Delay block by performing the test trials for the new Delay value and continuing with the timed trials and the yes/no questions. This cycle was repeated for each of the six Delay blocks.

RESULTS

TIMED PERFORMANCE

During the test sittings, less than 3 percent of the target trials did not meet the accuracy criteria, which required the cursor to be no more than two pixels on either axis from the center of the target, and those trials were repeated.

This experiment produced several significant effects by the independent variables of Delay, Distance and Direction, on the dependent variables of Total Time, Movement Time, First Move Time, and Pre-Enter Time. The most important and numerous effects were by variations in the Delay and Distance variables and their interactions. Also, small effects due to the Direction variable were observed.

Effects of Delay and Distance

Total Time. Figure 3 shows the Total Time averages of all trials at a given Delay. This function of Delay appears to be relatively linear over the range tested. As Delay increased from 75 ms to 400 ms, Total Time increased from 3.462 seconds to 5.864 seconds, a 69% increase.

Using a logarithmic scale for the Distance axis, figure 4 plots Total Time averages of all trials at a given Distance. Varying Distance produced Total Times ranging from 3.382 seconds at 46 pixels, to 5.224 seconds at 823 pixels, a 54% increase.

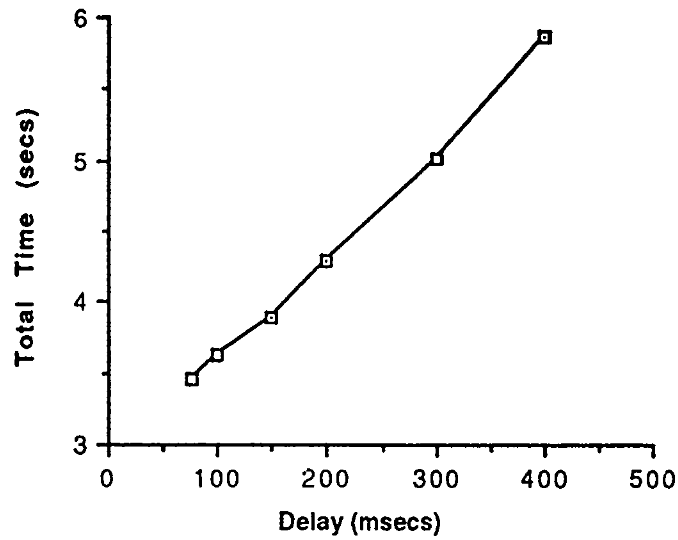

Figure 3. Total Time as a function of Delay.

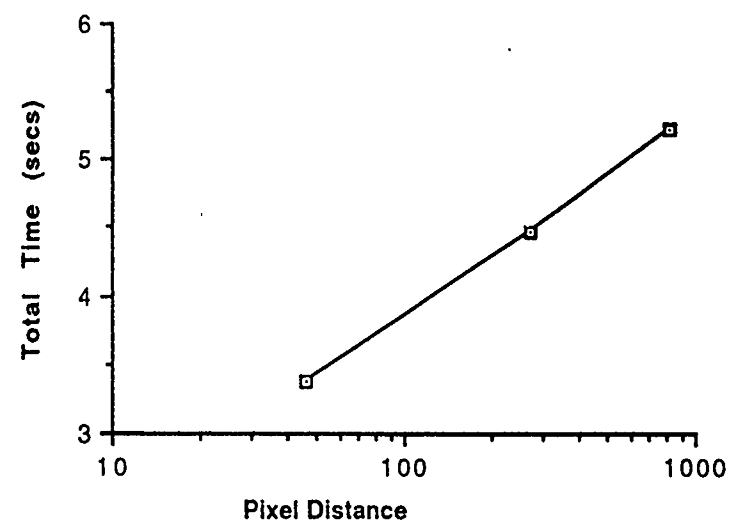

Figure 4. Total Time as a function of Distance.

Figure 5 depicts the Total Time for each combination of Distance and Delay. Total Time clearly increases as a function of both Delay and Distance. The combination of Distance and Delay produced quite large changes in Total Time. At the smallest Distance and shortest Delay (46 pixels, 75 ms) the Total Time for target acquisition was 2.775 seconds, while the largest Distance and longest Delay (823 pixels, 400 ms) produced a Total Time of 7.089 seconds, an increase of 155%.

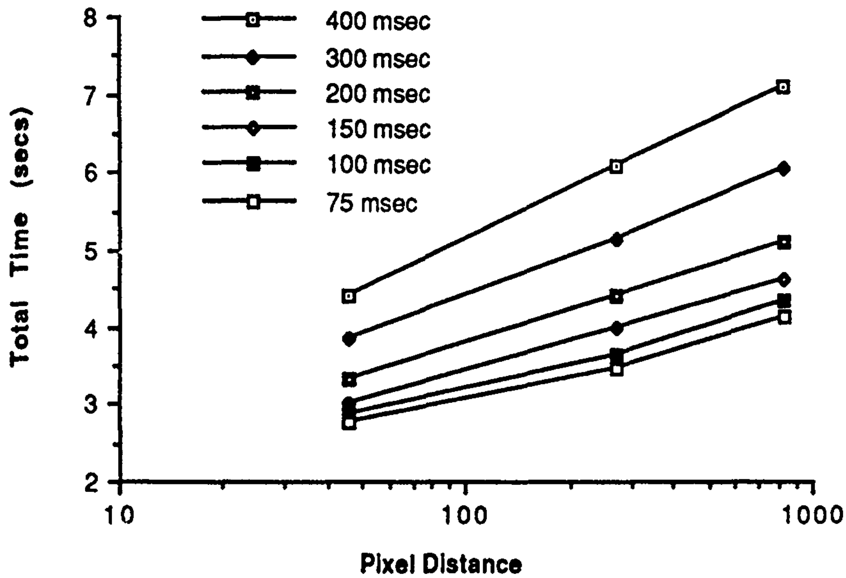

Figure 5. Total Time vs. Distance for each Tested Delay.

Because the same subjects appeared in all experimental conditions, a Distance x Delay x Subjects Analysis of Variance (ANOVA) was performed. The ANOVA revealed a statistically significant main effect for Delay ($F[5/55] = 135.33$, $p < 0.001$), and for Distance ($F[2/22] = 245.08$, $p < 0.001$), as well as a Distance-by-Delay interaction ($F[10/110] = 17.523$, $p < 0.001$).

Movement Time. Figures 6 and 7 show the Total Times across Delay and Distance, respectively, and divide Total Time into the three time segments defined above: First Move Time, Movement Time, and Pre-Enter Time. In both figures, the largest and most dynamic component is the Movement Time. First Move Time and Pre-Enter Time are fairly constant (although small effects on First Move Time and Pre-Enter Time are discussed below). When these relatively constant values are subtracted from the Total Time to determine the trackmarble Movement Time, we see an enhancement of the effects of Delay and Distance.

As shown in figure 6, Movement Time increases from 2.157 seconds, at 75 ms delay, to 4.223 seconds, at 400 ms delay, an increase of 96%.

As shown in figure 7, when the distance increases from 46 pixels to 823 pixels, Movement Time increases from 1.920 seconds to 3.776 seconds, an increase of 97%.

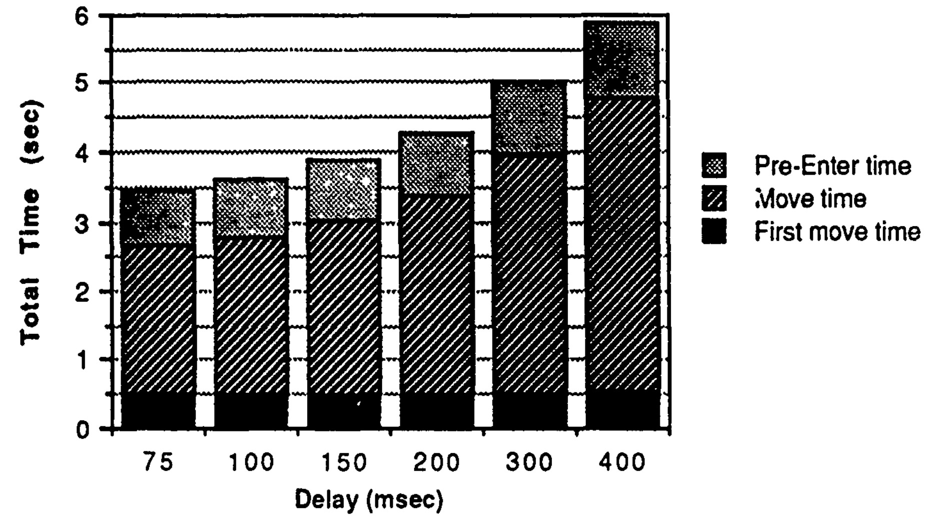

Figure 6. Total T'me Breakdown by Delay

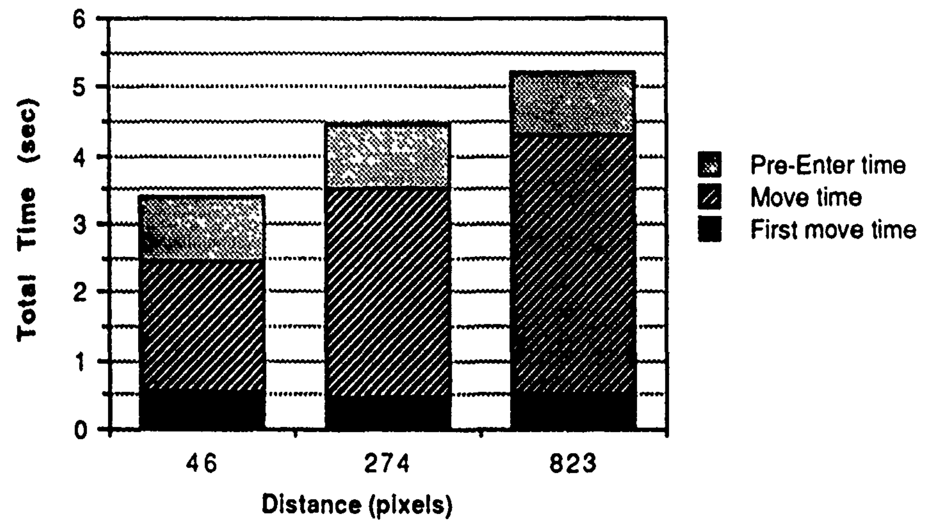

Figure 7. Total Time Breakdown by Distance

Please note the Delay values in figure 6 are simply plotted in sequential order and are not spaced proportionately to the Delay value, therefore the reader should not conclude from the graph that Total Time increases exponentially. Total Time as a function of Delay is more accurately described as linear as previously shown in figure 3.

As with Total Time, the combined effect of Delay and Distance produced a large range of Movement Times. At the smallest distance and shortest delay (46 pixels, 75 ms), the Movement Time was 1.444 seconds; the largest distance and longest delay (823 pixels, 400 ms) produced a Movement Time of 5.457 seconds, an increase of 278%.

First Move Time. Figure 8 depicts the First Move Time for each Distance and Delay combination. There was a small but statistically significant effect on First Move Time by Delay ($F[5/55] = 6.836$, $p < 0.001$), especially at the longer delays of 300 ms and 400 ms. There was also an effect on First Move Time by Distance ($F[2/22] = 23.324$, $p < 0.001$). Surprisingly, the First Move Time was largest at the shortest distance tested.

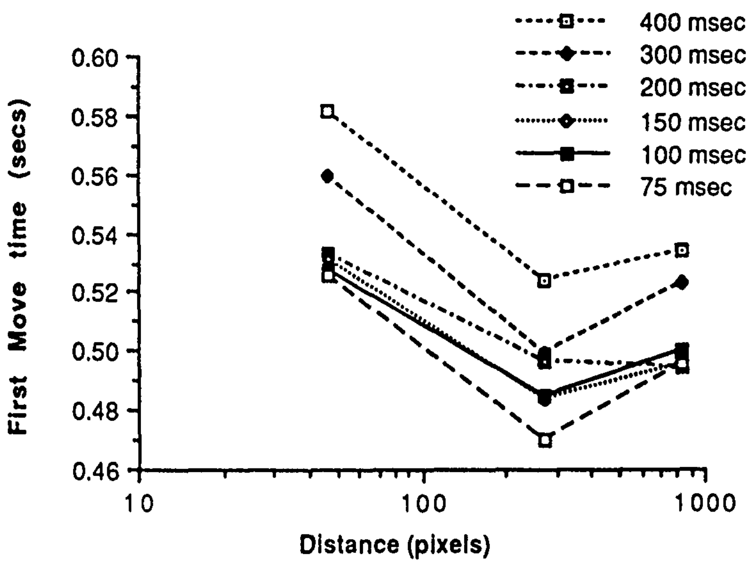

Figure 8. First Move Time as a function of Distance and Delay.

Pre-Enter Time. The only significant effect was the main effect of Delay ($F(5/55) = 37.718$, $p < 0.001$). Pre-Enter Times varied over Delay from 0.808 seconds at 75 ms delay to 1.094 seconds at 400 ms delay. However, note that Pre-Enter Time, as shown in figure 2, includes the time between the last trackmarble movement and the display of the final cursor position (equal to the Delay being tested) as well as the time between the settling of the cursor and the pressing of the Enter switch.

It was hypothesized that Pre-Enter Times were larger at the longer Delays because the subject had to wait a longer time after his final trackmarble movement to see if the cursor settled in the desired location before he moved his hand to press the Enter Key.

After Pre-Enter Times were adjusted for Delay, by subtracting the Delay from the Pre-Enter Time, an ANOVA was performed which showed Delay to have no effect on the resultant data ($F(5/55) = 1.176$ NS).

Effects of Direction

Total Time. A statistically significant effect for Direction on Total Time was found ($F[7/77] = 14.203$, $p < 0.001$). Figure 9 depicts the Total Time for each Direction, sorted by ascending Total Time. The first group, with smaller times, is comprised of those directions requiring movement along just the x or y axis, that is, 0°, 90°, 180°, and 270°. The second group contains the directions requiring movement along both the x and y axis.

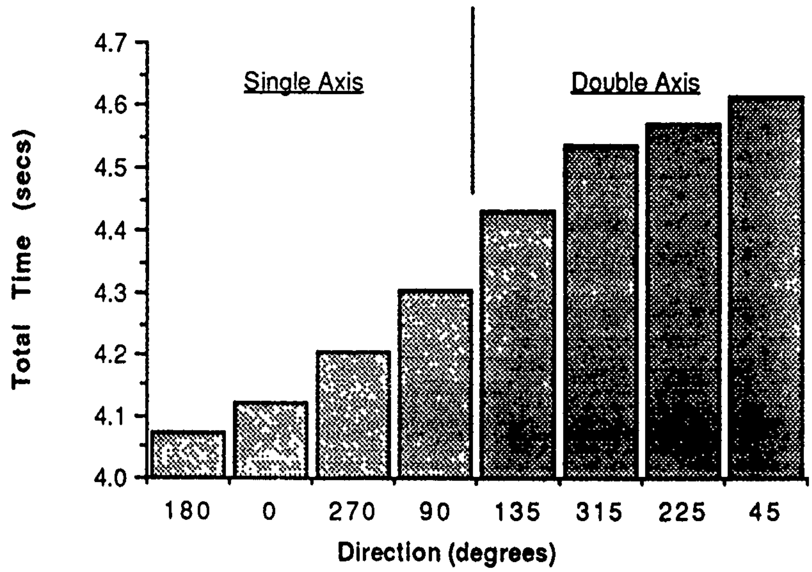

Figure 9. Total Time as a function of Direction

First Move Time. Figure 10 depicts mean First Move Times for Direction. The graph shows slightly larger but statistically significant ($F[7/77] = 12.521$, $p < 0.001$) times for trials requiring an initial upward movement (45°, 135°, and 90°).

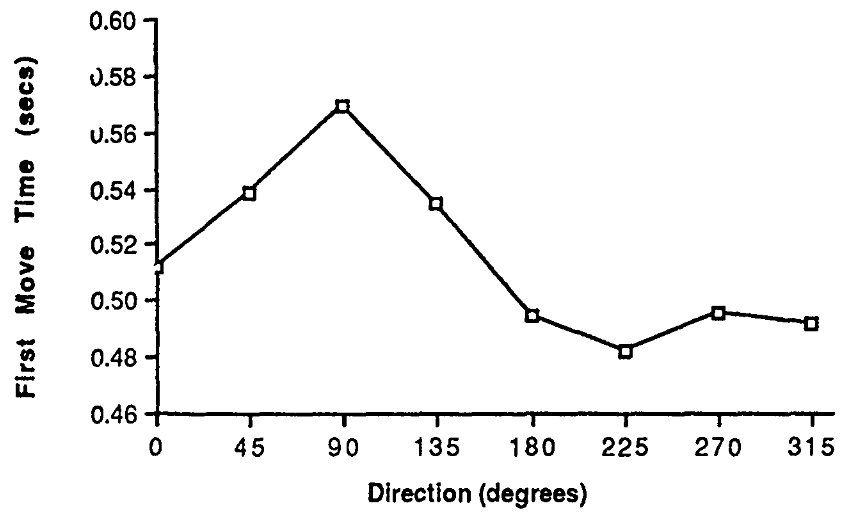

Figure 10. First Move Time as a function of Direction

SUBJECTIVE EVALUATIONS

The subjects were asked for comments regarding each cursor delay at the completion of each Delay block. The subjects were asked the following questions: 1) Was the delay perceptible? 2) Was the delay annoying? 3) Was the delay unreliable? This provided 24 responses per delay per question. Due to subjects' comments in the first session, a fourth question was introduced for the second session: 4) Do you think that the cursor delay impacted your performance? (12 responses per delay). Figure 11 shows the percentage of yes responses to the four questions for each of the 6 delays.

Only 8% of responses described the 75 ms delay as being perceptible. At a delay of 100 ms, only 33% of responses indicated perceptibility. There was an increase to 75% of responses indicating perceptibility at a delay of 150 ms. Interpolation to determine a 50% Perceptibility Threshold produces a value of 120 ms.

The percent of responses indicating the delay was annoying increased more gradually. At 200 ms delay, almost half (46%) of responses described the delay as annoying. Interpolating, a Threshold of Annoyance can be set at 212 ms.

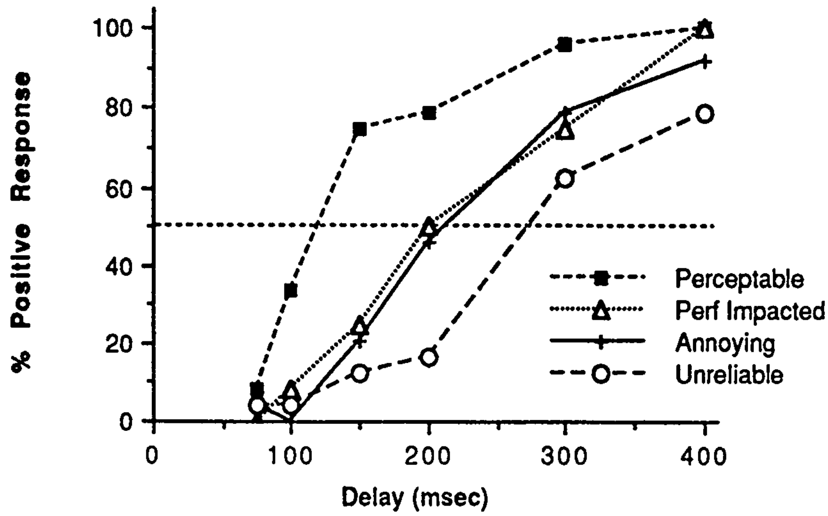

Figure 11. Subject Responses by Delay

Related to the values of annoyance are the values for perceived performance impact. Typically, a delay which was considered annoying by the subject was also perceived to have a negative impact on the timed performance. For 92% of second session Delay blocks, the response to the question of delay annoyance matched that of performance impact. The percentage of responses indicating annoyance were slightly lower than the percentage indicating a perceived performance impact, 50% of responses indicated that the 200 ms delay had a negative impact on their performance.

At 200 ms, only 17% of responses indicated the delay was unreliable. Responses that the delay was unreliable increased to 63% for the 300 ms delay. Interpolation produces a Threshold of Reliability at 270 ms.

DISCUSSION

DELAY AND DISTANCE

Both cursor processing delay and the cursor-to-target distance have marked effects on the performance of a simple task. Extrapolating the rather linear Total Time values across Delay, it is expected that further performance improvements could be gained at delays shorter than 75 ms. When averaged for each tested Delay value, the mean Total Time for target acquisition varied by 2.4 seconds or 69%. Averaged for each Distance value, the Total Time varied by 1.8 seconds or 54%. The combined effect of Delay and Distance were even greater; the mean Total Times over Distance and Delay combinations varied by 4.3 seconds or 155%.

While the Total Time as a function of Delay was nearly linear, Total Time as a function of Distance was not. Total Time did not increase proportionately to the increase in Distance. This suggests two classes of trackmarble movement: fine and course. At close distances, the subject needed only to use fine trackmarble movements. At larger Distances, the subject first uses course trackmarble movements followed by a series of fine trackmarble movements in order to place the cursor directly on the target. That course movements are less sensitive to changes in Distance may account for the shape of the Distance vs. Total time curve.

The effects of Distance and Delay on Movement Time, the time actually spent moving the cursor excluding the initial reaction time and the time to press the Enter switch, were very large. The mean Movement Time over Distance and Delay combinations varied by a factor of 3.8. This suggests that delay may have even greater impact on tasks which involve constant adjustments of the cursor, such as following a moving target, than on the simple target acquisition task studied in this experiment.

The Distance parameter had a small effect on First Move Time. Surprisingly, the mean First Move Time was slightly longer (approximately 43 ms) for the shortest distance tested than for the two longer distances. This may be due to subjects slowing down their first move in order to prevent the cursor from overshooting the target.

There was a significant effect on Pre-Enter Times by Delay. However, Pre-Enter Time includes the time between the last trackmarble movement and the display of the final cursor position (equal to the Delay being tested), plus the time between the settling of the cursor and the pressing of the Enter switch. When the Pre-Enter Times are adjusted for Delay (Pre-Enter Time minus Delay) there was no significant effect on adjusted Pre-Enter

Time by Delay. This suggests that the Pre-Enter Time effect is due simply to the time necessary for the cursor to settle after the last trackmarble movement.

The subject's responses to questions concerning the delays suggests a Threshold of Perceptibility at 120 ms of cursor processing delay. At delays of 200 ms or more, at least half of the subject responses indicated that the subject was annoyed by the delay and felt that the delay adversely impacted his performance. When comparing the subjects responses to the questions regarding annoyance and perceived performance impact, it appears that a delay was annoying if, in the subjects view, the delay impacted his performance.

At delays of 300 ms and 400 ms, the subjects felt the delay produced an unreliable response; interpolation produced a Threshold of Unreliability at 270 ms. Most subjects commented that these delays were unacceptably long and that the cursor seemed to float independently. A small percentage of subjects, who described the 300 ms and 400 ms delays as reliable, also stated that although the system performed badly, it was consistent, and therefore described the behavior of the system as reliable.

DIRECTION

The Direction variable produced effects both on Total Time and First Move Times. This section will first address the simpler and smaller effect on First Move Time by Direction; the remainder of this section will be an analysis of the Direction variable's effects on Total Time.

First Move Times were slightly longer for trials requiring an initial upward movement (45°, 135°, and particularly 90°, which is straight up). Most likely, prior to the appearance of the target, the subjects' fingers were positioned slightly past the center of the trackmarble, such that an initial movement upward would require that the fingers first be moved in front of the trackmarble.

The effect on Total Time by the Direction parameter can be seen in figure 9. For this discussion, the Single Axis Group is defined as the vertical or horizontal directions (0°, 90°, 180°, and 270°), and the Double Axis Group is defined as the off-axis directions (45°, 135°, 225°, and 315°). Total Times for the Single Axis Group were, in all cases, shorter than the Total Times for the Double Axis Group. The shorter times for the Single Axis Group might have been due to the subject needing to make gross and fine movements with subsequent correctional movements along primarily one axis instead of two axes.

Further ordering can be found within the Single Axis Group. The horizontal directions produced shorter Total Times than the vertical directions. Further, the left direction (180°) had a smaller mean Total Time than the right direction (0°) and the up direction (90°) had a smaller Total Time than the down direction (270°).

Shorter Total Times for horizontal vs. vertical, right vs. left, and up vs. down are echoed within the Double Axis Group. If the mean Total Times for the Single Axis Group are put in ascending order and the directions are labeled 1 through 4, and the mean Total Times for the Double Axis Group are put in ascending order and the directions are labeled 1' through 4', a similarity between the groups emerges (see figure 12). Although the Single Axis Group (1 through 4) all produced shorter Total Times than the Double Axis Group (1' through 4'), the within-group order is identical except for a shift of 45° clockwise.

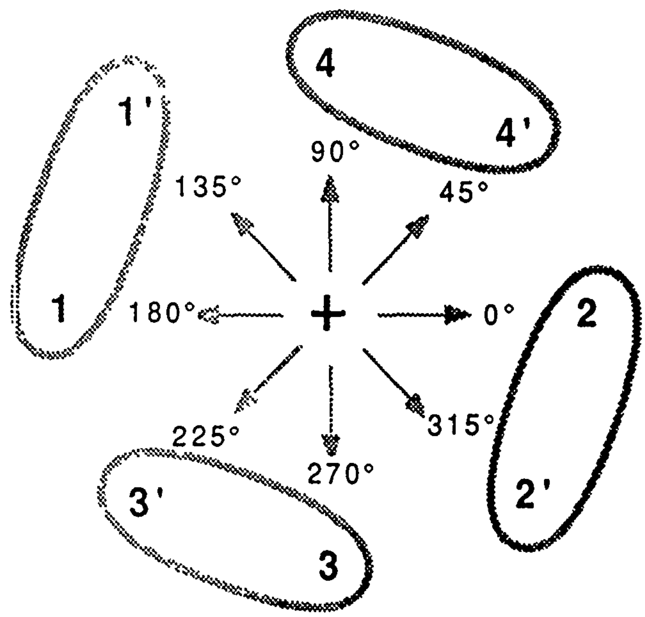

Figure 12. Direction Effects on Total Time. The Single Axis Group, marked 1-4, all produced shorter mean Total Times than the Double Axis Group, marked 1'-4'. Within each group, the directions are sorted by ascending mean Total Times.

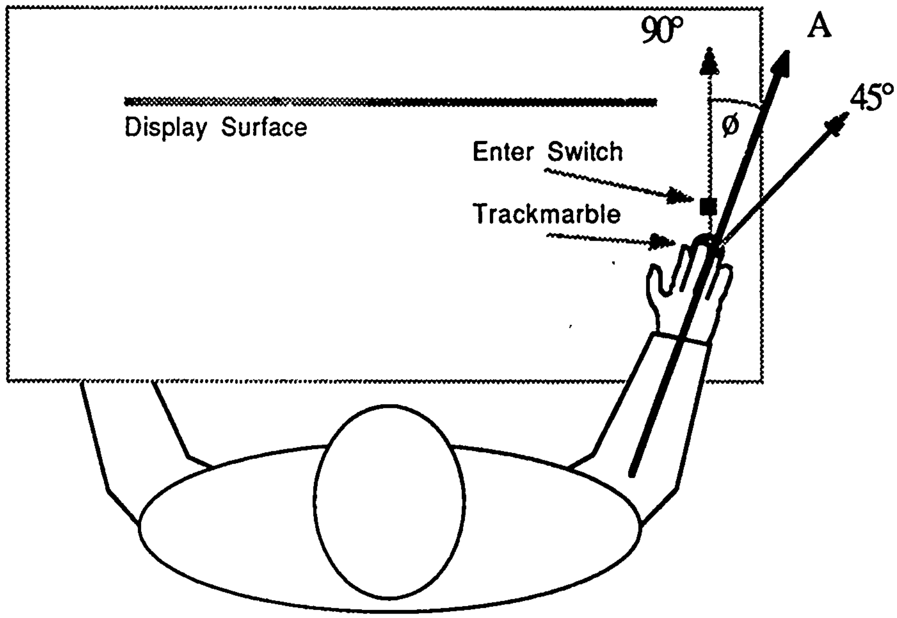

Figure 13. Possible Resting Angle of Arm and Hand. A stylized layout of the test console showing the subjects arm and hand pointing at some angle ø away from 90°.

The shift clockwise, instead of counterclockwise, of the within-group ordering, may be due to the relative position of the subjects right hand and the location of the right trackmarble, which was used by the majority of subjects (11 of 12 subjects were right-handed). The right trackmarble was located on the test console to the right of the subject, probably causing the majority of subjects to position their right arm angled to the right. As seen in figure 13, the subject's right arm and hand probably pointed in direction A, at some angle Ø away from the 90° direction, towards the 45° direction. In this situation, it is expected that movements for the 90° direction should be more similar to those of the 45° direction than those of the 135° direction. Thus, the expected similarity of movements for the grouped directions (1 and 1' or 2 and 2', etc.) may have caused the similarity of ordering of Total Times within both the Single and Double Axis Groups.

Summarizing, the most important aspect of Direction on Total Time concerns the number of axes involved; the directions along one axis all produced shorter Total Times than those directions along two axes. Second, within the Single and Double Axis groups, horizontal directions produced smaller times than vertical directions. Third, within the Single and Double Axis groups, the right direction was faster than the left direction and the down direction was faster than the up direction. These results also suggest that trackmarble placement relative to the operator can have a directional effect on performance.

RECOMMENDATIONS.

Due to the combined impact of performance by cursor processing delay and cursor-to-target distance, it is important that both of these factors be kept to a minimum. Display layout designers should minimize the distance between objects to which the cursor is likely to be driven.

Within the range of delays tested, performance decreased linearly as Delay increased. Extrapolation suggests that further increases in operator performance could be achieved at delays below 75 ms. Thus, for optimal performance, the upper limit of acceptability in cursor delay should be no larger than 75 ms.

Although the Threshold of Perceptibility was determined to be 120 ms, there was a difference in mean performance even between the shorter delays of 75 ms and 100 ms. Delays of 200 ms or more can be expected to create frustrated operators.

It should be remembered that the delays tested in this experiment were constant. On real systems the delay may be variable due to fluctuations in system processing loads. Such irregular delays would most likely impede operator performance to a greater extent than in this experiment and would most likely lower the Thresholds of Perceptibility, Annoyance, and Unreliability compared to those produced by this experiment.

Future work is recommended to investigate cursor task performance on systems with delays that vary within a particular trial. While this experiment was concerned with a simple target acquisition task, more complex tasks, such as following a moving target with the cursor, should be studied. Other future studies could investigate system delays less than 75 ms, varying target sizes, varying input devices, cursors which move along only one dimension, and cursors which jump between screen regions (hysteresis).

SUMMARY AND CONCLUSIONS

The present experiment was carried out to determine the effects of system delay and cursor-to-target distance and direction on cursor manipulation by a trackmarble. Subjects were given a series of simple target acquisition tasks and were asked to evaluate the cursor delays.

Results may be summarized as follows:

• Cursor processing delay and the cursor-to-target distance have marked effects on the performance of a simple cursor task. It is important that both of these factors be kept to a minimum. The linear nature of Total Time performance as a function of Delay suggests that the optimum upper limit of acceptability is less than or equal to 75 ms.

• A Threshold of Perceptibility was found at 120 ms. A Threshold of Annoyance was set at 212 ms. This was also the threshold at which subjects felt the delay negatively impacted their performance of the tasks. A Threshold of Unreliability was set at 270 ms.

• The effects of Delay and Distance on the time spent actually moving the trackmarble were very large; the mean Movement Time over Distance and Delay combinations varied by a factor of 3.8. This suggests that system delay is a very important performance parameter for tasks involving continuous target tracking.

• There were minor effects on performance by the test Direction parameters. Simultaneous movement along both axes (that is, 45°, 135°, 225°, and 315°) produced longer mean Total Times. Right-left hand movements are quicker than up-down movements.

From these findings, it is recommended that cursor task performance continue to be investigated. Suggestions were made for system parameters and tasks appropriate for future work.