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Analysis of cursor movements with a mouse

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Abstract

With a mouse input device, 32 experienced computer users moved a cursor from a starting position to a target, both of which were displayed simultaneously on the computer's screen. Cursor movements occurred under conditions of variations in the angle of approach to the target, the target size and shape, the distance to the target, and the nature of the task, drag-drop or point-click. In a fully crossed within-subjects design, all variables studied significantly affected movement time. Fitts' law accounted for 44% or 97% of the variance in movement time, depending on the method of analysis. Fitts' law was not equally effective under all combinations of the variables studied. An analysis of residuals showed that residuals were smaller for a point-click task in comparison to a drag-drop task, and residuals were lowest for the largest target displayed at the shortest distance from the starting position. The application of Fitts' law to cursor movements with a mouse should be qualified by noting the conditions under which the movements were observed.

Keywords: Icon selection; Fitts' law; Input devices; Human performance modeling

1. Introduction

Several studies have reported that Fitts' law (Fitts, 1954) may account for variances in movement time (MT) with a mouse under various conditions when a computer user moves a cursor from one location to another. Reported variances in MT range from 66% (Card, English, & Burr, 1978) to 97% (Boritz, Booth, & Cowan, 1991). More recently, Whisenand and Emurian (1996), in a study that investigated eight vertical, horizontal, and diagonal angles of approach to a target, reported that Fitts' law accounted for only 43% of the variance in MT. The latter study also

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showed that MT was faster along the vertical and horizontal directions, in comparison to the diagonals. Moreover, Fitts' law was a better predictor of MT for large targets close to the starting position, in comparison to small targets far from the starting position. The research literature, then, continues to support the value of Fitts' law when applied to movements of the mouse pointer to a target, and some studies suggest that the angle of approach is a factor affecting MT. The effectiveness of Fitts' law in accounting for MT, however, is influenced by target size and the distance to the target from a starting position.

More specifically, Fitts' law predicts the duration of a movement to a target based on the size of the target and the distance from a starting position to the target (Fitts, 1954). In its general form, based on Shannon's Theorem 17 (Shannon & Weaver, 1949), the law is stated as follows: $C = B\log_2(S+N)/N$, where C is the effective information capacity of a communication system (in bits/s), B is the band limit, S is the signal power, and N is the noise power. The law is expressed as a linear equation where MT is a function of target size and target distance, given in terms of a $\log_2$ calculation that yields an 'index of difficulty' (ID) for a task. Simply, the ID increases as target size decreases and target distance increases. Fitts' law has proven increasingly useful in human–computer interaction (HCI) research by providing a model to account for the speed of a user's successful movement to capture a target with a direct manipulation device, such as a mouse.

Under Windows 95, among many other operating systems, the default icons are approximately 10–15 mm on a side and generally square in shape. In comparison, targets presented in many studies were square (Epps, 1986; Jones, 1991; Kantowitz & Elvers, 1988) and/or rectangular (Card et al., 1978; Jones, 1991; MacKenzie, Sellen, & Buxton, 1991; Sears & Shneiderman, 1991), but they ranged in size from 0.4 to 32 mm in height and from 0.6 to 26 mm in width. Furthermore, there has been very little work reported in the literature on the effects of target shape on MT. The importance of considering target shape is related to its impact on the determination of the effective width of a target. Only a few studies, however, have presented circular targets (Carlton, 1980; Jagacinski & Monk, 1985; Radwin, Vanderheiden, & Lin, 1990), and until Sheikh and Hoffmann (1994) examined the effects of target shape on MT in a Fitts' task, the shape of a target had not been investigated as an independent variable. To produce findings that may better generalize to existing systems, the use of icon-like targets similar in size to existing operating system icons would be an alternative to actual icons, which could carry confounding semantic meanings, to test direct manipulation devices such as a mouse. Finally, the present study initiated a consideration of target shape as that variable may also affect MT with a mouse.

Selection tasks in a graphical user interface (GUI) environment are usually of two types: 'drag-and-drop' and 'point-and-click'. The drag-and-drop type task typically involves such actions as the selection of an option from a drop-down or pop-up menu, the selection of a block of text in word-processing, the selection of a block of data in a spreadsheet, or the placement of a graphic object within a presentation frame. The point-and-click type task typically involves a selection of an icon (representing an application to activate) or a button 'push' to invoke a function within an application. Both selection types may be available to the user as options. Few studies, however, have examined task type as an independent variable (Gillan, Holden, Adam, Rudisill, & Magee, 1992; MacKenzie et al., 1991). Since previous research has not yet investigated task type in relationship to Fitts' law or angle of approach, this study included a consideration of effects of a dragging task and a pointing task on MT.

Against that background, this study examines the effects on MT of the angle of approach, amplitude of movement, and target width for a mouse as the direct manipulation device performing discrete drag-drop and point-select tasks in the selection of square and circular objects displayed on a computer screen. There are four primary purposes of this study: (1) to investigate the effect of angle of approach on MT and accuracy, (2) to determine the effect of task (dragging and pointing) on MT and accuracy, (3) to determine which target shape, square or circle, has the greater effect on MT and accuracy for these tasks, and (4) to determine whether these factors impact Fitts' law predictions by undertaking an analysis of the residuals between observed and predicted movement time (PMT) in relationship to the variables under consideration.

2. Method

2.1. Participants

A total of 32 students in Information Systems and Computer Science volunteered and/or participated for course credit. The participants consisted of 19 males (age range, 21–36 years; mean age, 24.7 years) and 13 females (age range, 20–29 years; mean age, 23.6 years). All 32 participants used their preferred (right) hand to perform the tasks (26 right-handers, 6 left-handers). The left-handers all chose to use their right hand because that was the way they had learned to use a mouse, and it is the typical computer set-up. All participants reported over 30 days' experience with personal computers (PCs), and 28 participants reported over 6 months' experience with PCs. All but one reported over 30 days' experience with a mouse as an input device, and 24 reported over 6 months' experience with a mouse. The average weekly PC and mouse use reported was approximately 8 h/week. The median number of different computer systems that the participants had used was reported to be 4. The mean number of input devices that the participants had reportedly used was 4.6. None of the participants reported uncorrected visual problems or physical limitations that would inhibit their use of the mouse as an input device.

2.2. Apparatus

2.2.1. System configuration

This experiment used an Eclipse PC with a 486/33 Intel processor, 4MB of RAM, and an Orchid 280° F graphics board with 1MB RAM.

2.2.2. Software

The study was conducted using the Generalized Fitts' Law Model Builder (Soukoreff & MacKenzie, 1995), which generated the stimuli and recorded the MTs. The data analysis was performed using SAS.

2.2.3. Screen description

The visible screen on the CTX Proscan 17″ monitor was 31 × 23.5 cm (800 × 600 pixels). The background color of the screen was black, the starting box was purple, the cross-hair cursor was white, and the targets were outlined in white.

2.2.4. Mouse description

Cursor control and target selection were controlled by a Logitech two-button serial mouse.

2.3. Procedure

Participants were tested individually. Each participant was first interviewed to gather demographic data (age, gender, preferred hand, and visual and physical limitations) and experiential data (PC, mouse, and computer-system familiarity). The participant read a single page of written instructions. The experimenter (TGW) then demonstrated each task to familiarize the participant with the task and environment. The participant was instructed to perform each task as quickly and accurately as possible.

Amplitudes and angles were measured from the center of the starting box to the center of the target. The position of the square starting box (3 mm/side) varied to accommodate the angle and amplitude parameters of each trial. Each trial presented a square target or circle target (4, 8, or 16 mm/side or diameter) at an amplitude of 20, 40, 80, or 160 mm, and at an angle of 0°, 45°, 90°, 135°, 180°, 225°, 270°, or 315° for each of the two tasks, drag-drop and point-select. Fig. 1 presents a diagrammatic representation of several square and circle targets displayed at different amplitudes from the starting box.

Each participant completed a series of 4 trial blocks for each target shape (square or circle) for each task (drag-drop or point-select), for a total of 16 trial blocks. A trial block tested one shape for one task, and it consisted of 96 randomly presented, 'successful' individual trials, together representing each angle of approach, target width, and amplitude. The target shapes (square and circle) and the tasks (drag-drop and point-select) were randomly assigned and were balanced across the study. Each task/shape (series) combination was presented as the first, second, third, and last trial block eight times within the study. Each participant completed 1536 trials. A brief rest period between each of the four task/shape series allowed the participants an opportunity to comment on their interaction, comfort/discomfort, and fatigue, and to flex or stretch their arms and hands. The average duration between each task/shape series was approximately 1 min. The average duration of the study was 65.3 min.

For the point-select task, the starting box and the target were simultaneously displayed, with the target positioned at its angle and amplitude. When ready, the

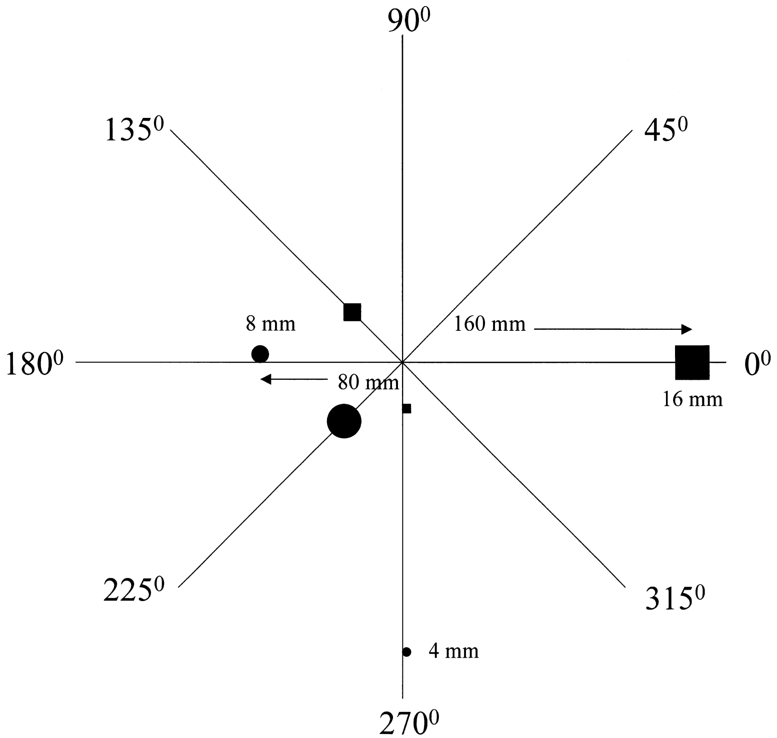

Fig. 1. A diagrammatic representation of several square and circle targets displayed at different amplitudes from the starting box.

participant depressed the mouse button (click—mouse down/up), and the starting box changed into a cross-hair cursor. The participant moved the cursor to the target as rapidly as possible and depressed the mouse button to complete the selection (mouse down). If the cross-hair was within the target, the trial was completed, and the participant proceeded to the next trial. If the cursor was not in the target, the computer 'beeped', an error was recorded, and that trial continued until the participant successfully selected the target. A trial block was not completed until all 96 targets were successfully captured. The drag-drop task required the participant to hold the mouse button down and to 'drag' the cursor to the target. The participant then released the mouse button (mouse up), 'dropping' the cursor within the target to complete the action.

The software automatically recorded the angle of approach, target width, amplitude, MT, and errors for every trial. The participant's identification code, trial block number, task/shape series number, along with task and target shape, were recorded as part of the data-file name. MT was measured in milliseconds from the time the starting box changed into a cross-hair cursor until successful target acquisition. Target width and movement amplitude were measured in millimeters, and angle of approach was measured in degrees. Error trials were recorded in the same data-file, but they were analyzed separately.

2.4. Design summary

A fully within-subjects repeated measures design was used. Independent variables were angle of approach (0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315°), target width (4, 8, and 16 mm), amplitude of movement (20, 40, 80, and 160 mm), target shape (square and circle), and task type (drag-drop and point-select). Dependent variables were MT and error frequency. All combinations of the independent variables were fully crossed and tested. The 96 angle by width by amplitude conditions were presented in random order until all were exhausted. This constituted one trial block. Four trial blocks were administered for each task/shape combination or series. The task/shape combinations were randomly assigned with shape randomly ordered within task. Sixteen trial blocks were administered for a total of 1536 trials per participant.

3. Results

The data analysis is based upon the MANOVA procedure recommended for within-subjects analyses (Maxwell & Delaney, 1990). This is a conservative test that does not require sphericity, which is required for the accurate interpretation of univariate tests. All contrasts reported were significant under Bonferroni critical value corrections ($p < 0.05$) for pairwise contrasts and Roy-Bose corrections ($p < 0.05$) for complex and interaction contrasts.

An error occurred when a participant registered a target acquisition while the cursor was outside the boundaries of the target. However, task MT measurement continued when such an error occurred, and it stopped only upon successful acquisition of the target. A total of 1480 errors occurred out of 49,152 total trials (3.01% error rate). The mean MT for all trials was 1155.0 ms, and the removal of the error trials reduced the mean MT to 1130.0 ms. The 'spurious' effects of errors were eliminated by removing the error trials from the data analysis.

3.1. Angle of approach

Fig. 2 presents means and standard deviations for MT across the eight angles of approach. The grand mean is presented to assist interpretation of the figure. Although the angle categories are discrete, the data-points are connected to clarify the graphical representation of the data. The adjusted data-set ($n = 47,672$, with errors removed) was reduced for multivariate analysis by averaging MTs over the four amplitudes of movement and the three target widths. MANOVA showed a significant effect of angle of approach on MT, $F(7,25) = 21.22$, $p < 0.001$. Pairwise contrasts showed significant differences among several pairs of angles as indicated in Table 1. Among other relationships, the table shows that MT at 180° was significantly different from all other angles except 0°. Fig. 2 shows that the angles of approach associated with the fastest MTs were along the horizontal axis (0° and 180°, and the angles of approach associated with the slowest MTs were along the

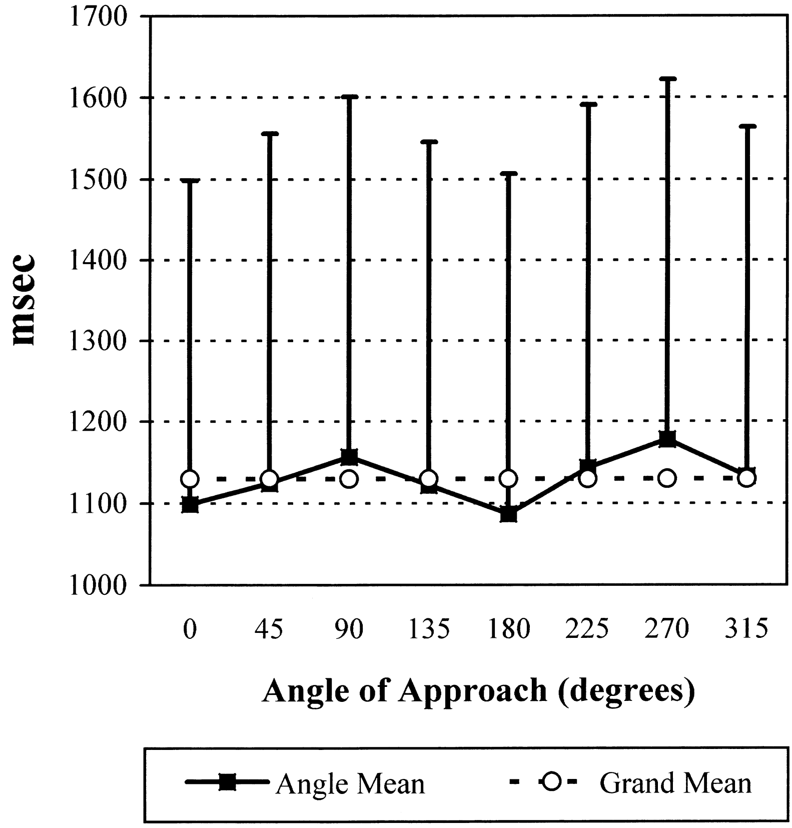

Fig. 2. Mean movement times and standard deviations across the eight angles of approach. The grand mean is presented to assist interpretation of the figure. Although the angle categories are discrete, the data-points are connected to clarify the graphical representation of the data.

Table 1
Pairwise contrasts

Angle	0°	45°	90°	135°	180°	225°	270°	315°
0°	–		Y			Y	Y	Y
45°		–	Y		Y		Y	
90°	Y	Y	–	Y	Y			
135°			Y	–	Y		Y	
180°		Y	Y	Y	–	Y	Y	Y
225°	Y				Y	–	Y	
270°	Y	Y		Y	Y	Y	–	Y
315°	Y				Y		Y	–

Y, significantly different ($p < 0.05$).

vertical axis (90° and 270°). A complex contrast between these two groupings was significant, $F(7, 505) = 391.9$, $p < 0.05$. The diagonal movements were closest to the grand mean.

3.2. Task

Fig. 3 presents means and standard deviations for MT for the dragging and pointing tasks. MANOVA showed a significant effect of task on MT, $F(1, 31) = 9.91$, $p < 0.004$. The dragging (drag-drop) task was significantly faster than the pointing (point-select) task.

3.3. Target shape and width

Fig. 4 presents mean MT for the circle and square targets across the three target widths. MANOVA showed significant main effects on MT of shape, $F(1, 31) = 14.80$, $p < 0.001$, and width, $F(2, 30) = 314.01$, $p < 0.001$. Pairwise contrasts showed significant differences between all pairs of the three target widths. For all target widths, MT was faster for the square target in comparison to the circle target, and for both shapes, MT progressively decreased as target width increased. The shape by width interaction was significant, $F(2, 30) = 8.92$, $p < 0.001$. Inspection of Fig. 4 suggests that the shape by width interaction is determined by the larger difference in MT observed at the 4 mm width in comparison to the differences at the 8 and 16 mm widths.

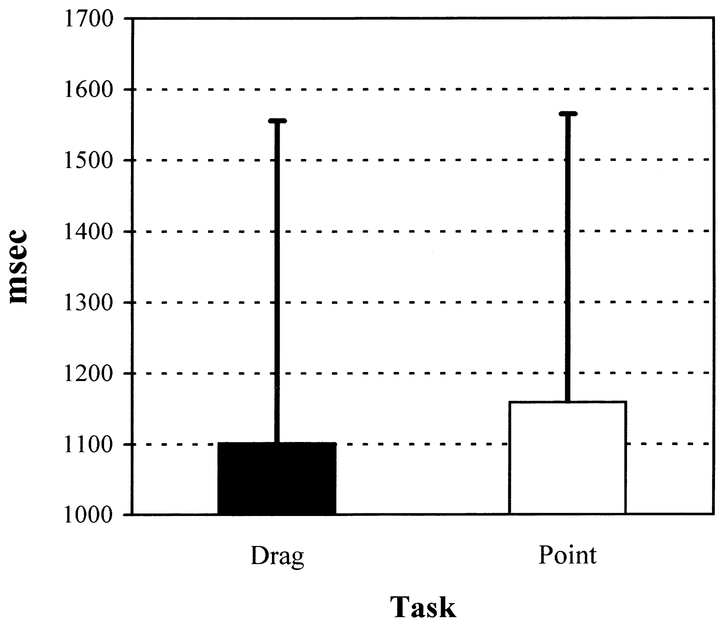

Fig. 3. Mean movement times and standard deviations for the dragging and pointing tasks.

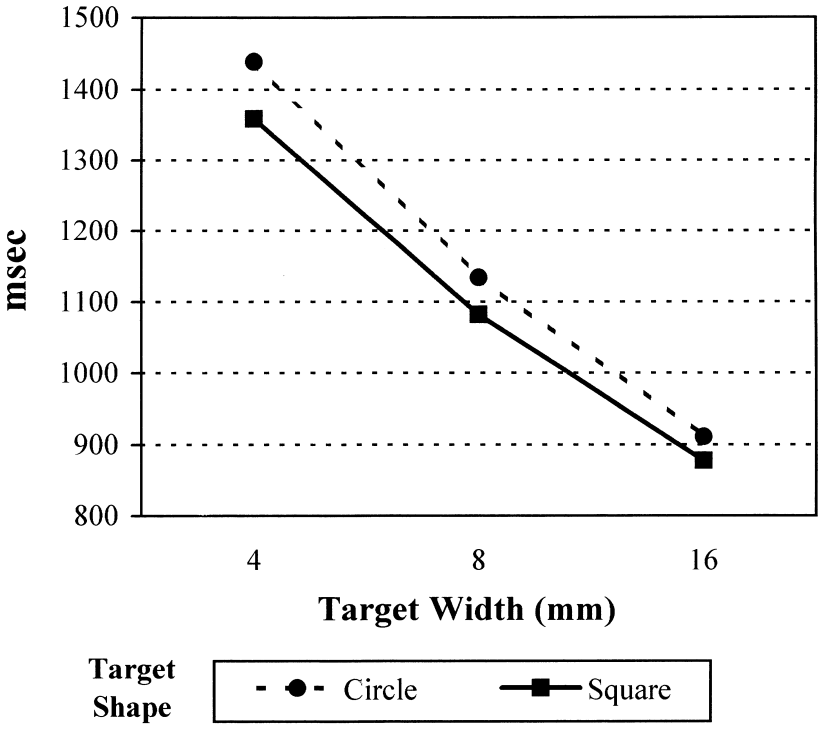

Fig. 4. Mean movement times for the circle and square targets across the three target widths.

3.4. Amplitude of movement

Fig. 5 presents means and standard deviations for MT across the four amplitudes. MANOVA showed a significant effect of amplitude on MT, $F(3, 29) = 397.27$, $p < 0.001$. Significant differences between all pairs of the four amplitudes were evident in pairwise contrasts. These data show that MT increased as the amplitude of movement increased.

3.5. Fitts' law

To determine the effectiveness of Fitts' law to account for MT in relationship to the independent variables presented in this study, a residuals analysis was undertaken. A residual is the difference between a PMT and the observed MT.

The PMT based on Fitts' law was calculated by the following equation:

$$\mathrm{PMT} = 208.0\ \mathrm{ID} + 338.6,$$

and these parameters were significant ($p < 0.001$). The regression of MTs onto IDs yielded an R^2 of 0.44 ($p < 0.001$).

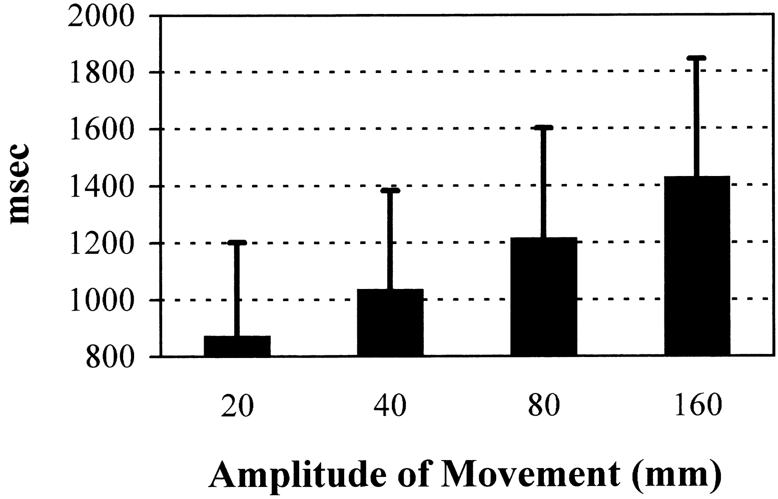

Fig. 5. Mean movement times and standard deviations across the four amplitudes of movement.

Since a univariate ANOVA revealed no effect of angle on residual, the data were averaged over angle to reduce the data-set size for the multivariate analysis. Fig. 6 presents means and standard deviations for residuals for the dragging and pointing tasks. The mean residual for the dragging task was greater than the corresponding mean residual for the pointing task. MANOVA showed a significant effect of task on residual, $F(1,31) = 4.60$, $p < 0.04$.

Fig. 7 presents mean residuals for each of the three target widths across the four amplitudes. MANOVA showed a significant effect of width on residual,

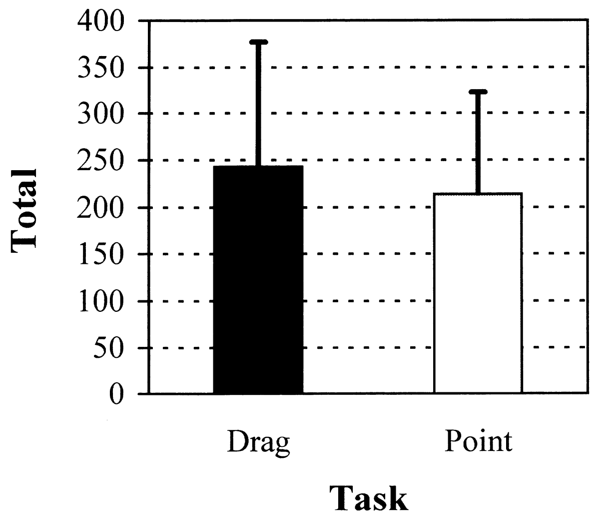

Fig. 6. Mean residuals and standard deviations for the dragging and pointing tasks.

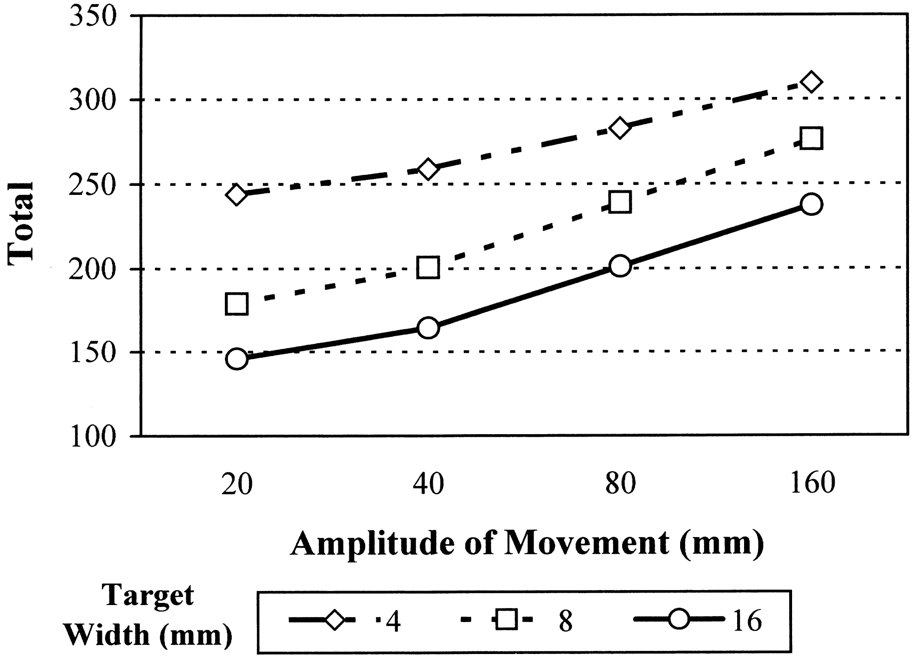

Fig. 7. Mean residuals for each of the three target widths across the four amplitudes of movement.

$F(2, 30) = 20.56$, $p < 0.001$. The greatest mean residual was associated with the 4-mm target, the smallest mean residual with the 16-mm target, and intermediate mean values with the 8-mm target.

MANOVA showed a significant effect of amplitude of movement on residuals, $F(3, 29) = 49.35$, $p < 0.001$. There was an orderly increase in the magnitudes of residuals across the four amplitudes. MANOVA showed a significant width by amplitude interaction on residuals, $F(6, 26) = 3.70$, $p < 0.01$. Inspection of Fig. 7 suggests that the width by amplitude interaction is determined by the larger difference in residuals observed between the 4- and 8-mm widths, at an amplitude of 20 mm, in comparison to all other widths and amplitudes.

3.6. Errors

An error occurred whenever the participant made a selection response with the mouse while the cross-hair cursor was not within the target. A total of 1480 errors out of 49,152 total trials (3.01% error rate) was committed. The 'error trials' had a significantly longer mean MT (t, unequal variances = 38.03, df = 1504.5, $p < 0.001$) than the 'no-error trials' (1944.0 ms and 1130.0 ms, respectively).

Fig. 8 presents total errors for the dragging and pointing tasks. The pointing task was associated with a higher frequency of errors in comparison to the dragging

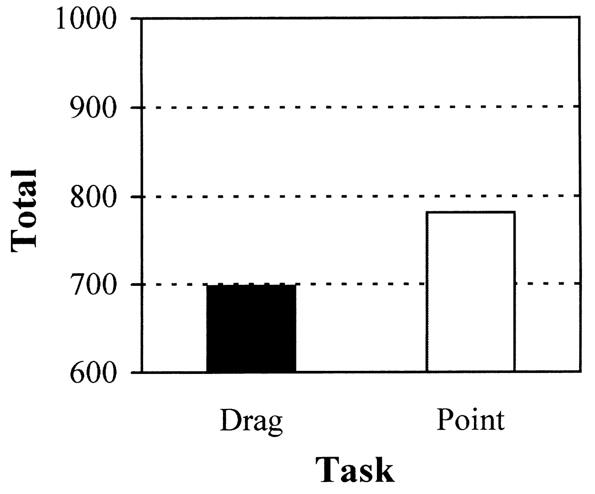

Fig. 8. Total errors for the dragging and pointing tasks.

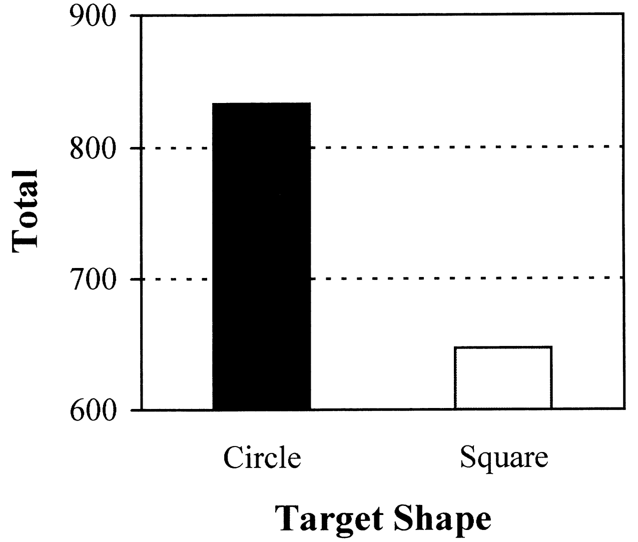

Fig. 9. Total errors for the circle and square targets.

task ($\chi^2 = 4.92$, $p < 0.03$). Fig. 9 presents total errors for the circle and square targets. The circle target was associated with a higher frequency of errors in comparison to the square target ($\chi^2 = 24.10$, $p < 0.01$). Fig. 10 presents total errors across the three target widths. Errors decreased as the target width increased ($\chi^2 = 472.72$, $p < 0.01$).

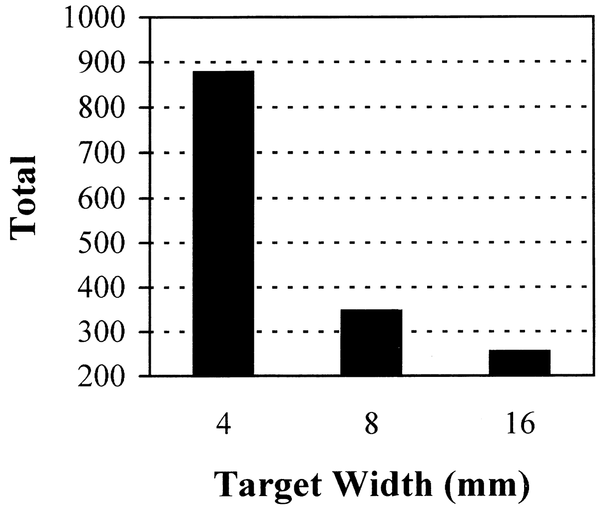

Fig. 10. Total errors across the three target widths.

4. Discussion

4.1. Angle of approach

The results of this study show that the angle of approach affects the time required to move a cursor with a mouse from one position on a computer screen to a target object located at another position. Movements were significantly faster along the horizontal directions in comparison to movements along the vertical directions. These results confirm and extend the findings of Boritz et al. (1991), who reported more rapid mouse-driven cursor movements at 0°, in comparison to 270°, for item selection in a 'pie-shaped menu' that consisted of icon-like square targets similar to those used here. The present results are also consistent with MacKenzie and Buxton (1992), who reported longer MT for targets at 45°, in comparison to targets at 0°; they contrast with the latter results, however, by finding that movements at 90° took longer than at 45°.

A notable outcome difference was observed, however, between the results of the previous study (Whisenand & Emurian, 1996) and the results of the present research. The data from the previous study supported the conclusion that movements at 270° were the briefest observed, whereas the data from the present study showed that movements at 270° were the longest observed. This conspicuous difference in outcome is attributable, perhaps, to the differences in the target presentation paradigms between the two experiments. In the present study, the target location was visible at the start of the trial, thereby eliminating the initial downward, anticipatory move from the starting box observed frequently in the previous study. Except for this one discrepancy, this research confirmed and extended the results of the previous study to include circular targets and the tasks of both dragging and pointing. Finally, the inclusion of several starting box positions in the present study broadened the scope of the impact of the variables under investigation, thereby contributing to the reliability of these more general results.

Accounting for similarities and differences in outcome among the ever-increasing number of studies in this research domain presents difficult interpretive challenges, since there are many obvious and subtle differences in the task and selection events across experiments. Taken together, however, the studies indicate that angle of approach is a reliable factor across several conditions affecting MT. Finally, with the accumulating knowledge base, it is clear that conclusions regarding effects of angle of approach must be qualified by noting the paradigm for target presentation and acquisition.

The findings of this study indicate that the effects of angle of approach are sensitive to categorical groupings (horizontal and vertical angles) that may mask the effects of discrete angles or logical associations that can be derived from the analysis of discrete angles. This may help to explain apparent conflicts across previous studies when examining the effects of angle of approach on MT when using a mouse. Card et al. (1978), using three *ranges* approximating horizontal (0°), diagonal (45°), and vertical (90°) moves, found no effect of angle, while MacKenzie and Buxton (1992), using the same *discrete* angles, found that diagonal moves took significantly longer than other directional moves. Investigative work requires the inclusion of movements throughout the 360° range to obtain comprehensive and reliable effects of angle of approach on MT.

4.2. Amplitude of movement

Distance to a target is included in studies of Fitts' law applications to models of MT with a mouse because amplitude (i.e. distance) is a component in the equation for the ID. Intuitively, targets 'far' from a starting point should take longer to select than targets 'near' the starting point. In the present study, MT increased as target distance increased, and decreased as target size increased. Many studies have reported this effect, including Whisenand and Emurian (1996). In examining pointing and dragging as sequential steps in a text-editing task, Gillan et al. (1992) reported that dragging time increased as distance increased and decreased as font size increased, while pointing time showed orderly increases in mouse MT to a text object as distance increased for eight different horizontal sizes of text objects. These effects are similar to those reported for mouse pointing time by Card et al. (1978). The similarity in process outcome for amplitude contributes to the reliability and generality of other similar results across these studies.

4.3. Target width

Target width is the second variable used to compute the ID for Fitts' law. Logically, smaller targets require more precise movements and should, therefore, take longer to select than larger targets, which is the finding in the present study. The residuals analysis, however, showed that Fitts' law was a better predictor of MT at the largest target sizes and shortest distances. This effect might be attributable, in part, to the manner in which participants moved the cursor in relationship to different amplitudes and target widths. It was observed that many participants made an initial movement in a direction opposite from the direction to the target, particularly when the target's width was similar to the starting box (3-mm square) and as the distance to the target increased, perhaps confusing the relative position of the starting box and the target. Some participants were observed to move the cursor in a 'looping' motion toward the displayed target, especially with long amplitude movements. Other participants, when moving to smaller, more distant targets, tended to move the cursor in two steps: one long rapid movement in the general direction of the target, then a smaller, more precise or corrective movement to the target.

These motions obviously complicate the application of a Fitts' law model (Fitts, 1954), which is intended to account for motions along a straight line in a horizontal plane, although ballistic movements of a stylus also contributed to the accuracy of the original model formulation (Gan & Hoffmann, 1988). Many investigators have proposed an analysis of the components of a movement to a target, such that anticipatory and other 'preparatory' movement sequences not be included in the model (Gillan et al., 1992). An 'optimized-submovement' model, proposed by Meyer, Abrams, Kornblum, Wright, and Smith (1988), may permit a more robust linear modeling of the user's behavior than revealed in the present analysis, and Baccino and Kennedy (1995) have published a method to determine the dispersion, direction, and distance of mouse movements that may be useful within such modeling. Yet it is the case that users of a mouse, moving a cursor from a starting box to a target, do not always behave in ways that would optimize the predictive effectiveness of linear models based on Fitts' law.

4.4. Task type

The discrete drag-drop and point-select tasks tested in this study are dominant in today's GUI environments. Most early direct manipulation devices (e.g. joystick, mouse, trackball, etc.) were labeled as 'pointing' devices, since that was their first and, until recently, their major function. Only recently have dragging tasks been expanding in use and familiarity. In a previous study comparing pointing and dragging tasks, MacKenzie et al. (1991) found that pointing was significantly faster than dragging for a mouse. However, the task scenario in that study was atypical of a HCI environment in that it modeled the Fitts' manual tapping task and targets. The tasks for the present study, in contrast, were consistent with today's GUI environments, and the targets emulated current and typical target objects in shape, size, and placement on a computer screen. This study found that, opposite to the MacKenzie et al. study, MT for the dragging task was significantly faster than for the pointing task. The previous study was conducted 8–10 years ago, and this apparent conflict in results may be a consequence of the expansion of use of GUI interfaces over that time and the increased use of dragging operations in commercial software packages, with the subsequent sophistication of users' interface skills.

4.5. Target shape

While various target shapes have been used across previous studies, shape has not been an experimental factor in HCI-related studies. As used within this study, target shape had a significant effect on MT for the tested tasks. MTs for square targets were significantly faster than for circle targets. This result contrasts sharply with the previous study by Sheikh and Hoffmann (1994), where the results showed no significant effects of shape on MT for square-, circular-, and diamond-shaped targets, and a significant width by shape interaction not found in the present study. As previously noted, the former study was a manual tapping task, and it may not be exactly comparable to movements investigated here. The present study, then, built upon the work by Sheikh and Hoffmann, and it initiated a consideration of the shape of a target as a factor potentially affecting performance in computer-related tasks.

4.6. Error frequency

The maximum error rate in Fitts' original reciprocal tapping task (Fitts, 1954) was 4.08% for the 1 LB stylus. Several studies (Crossman, 1960; Welford, 1960) have suggested the use of a corrected estimate of target width (W_e), which has the effect of normalizing the error rate at 4%. More recently, reported error rates for the mouse in target acquisition tasks have been between 3.5% (MacKenzie et al., 1991) and 5% (Card et al., 1978). In the present study, the error rate for all participants across all blocks was 3.01%, which is consistent with the previous study's 2.96% (Whisenand & Emurian, 1996).

4.7. Predictive effectiveness of Fitts' law

Although the 16-mm target showed the lowest residual magnitude across the four amplitudes, in comparison to all other target widths, the magnitude of R^2 (0.44) was small in comparison to other investigations. When Gillan et al. (1992) reanalyzed their data with revised hypotheses of the 'effective distance' to a text object, R^2 was 0.95 for a point-click mouse movement sequence. Further, Card et al. (1978) reported an R^2 of 0.83 for a point-click sequence, Epps (1986) reported an R^2 of 0.70, and MacKenzie and Buxton (1992) reported an R^2 of 0.95 for an 'adjusted' target width for a point-click sequence. With particular reference to angle of approach, more recent analyses, which used a stylus task, have also emphasized the contribution of both horizontal and vertical constraint dimensions in the determination of a maximum ID (Hoffmann & Sheikh, 1994) that might best predict discrete MT. Also considered is an 'effective shape' such that a square presented on an angle may have greater width of effectiveness across its diagonal (Sheikh & Hoffmann, 1994).

The range of conditions under which data are obtained and analyzed affects the magnitude of regressions of MTs onto IDs. While R^2 is useful for within-study comparisons, across-study comparisons are problematic unless all conditions are equivalent among the compared studies. More importantly, perhaps, in most Fitts' law studies, MTs are averaged over participants, and a single data-point (i.e. mean) is entered into the analysis for each amplitude–width (A–W) condition. In that regard, Epps (1986) did not average across participants, and by using 240 data-points (12 participants crossed with 20 A–W conditions) rather than 20 in the analysis, an $R^2 = 0.696$ was obtained for a mouse using the Fitts' model.

The variation introduced by the use of raw observations may be a source of the relatively low correlation obtained in this study. Based on the examination of Fitts-related studies, a reexamination of the present data using the MTs averaged across all participants (32) for the 12 A–W conditions was undertaken. Fig. 11 presents the ID, sorted in ascending order, for all participants plotted against mean MT at each A–W combination. The figure graphically shows that as the ID increases, mean MT increases. Based upon the new equation, PMT = 208.2ID + 338.3, R^2 was 0.97 with significant slope and intercept parameters ($p < 0.05$). With 12 pairs of numbers, R^2 was 0.97; with 47,652 pairs, R^2 was 0.44. Although inter-subject variability may obscure orderly relationships when all data are used, the resulting R^2 (0.44) is, perhaps, a 'better' representation of the behavior of the participants.

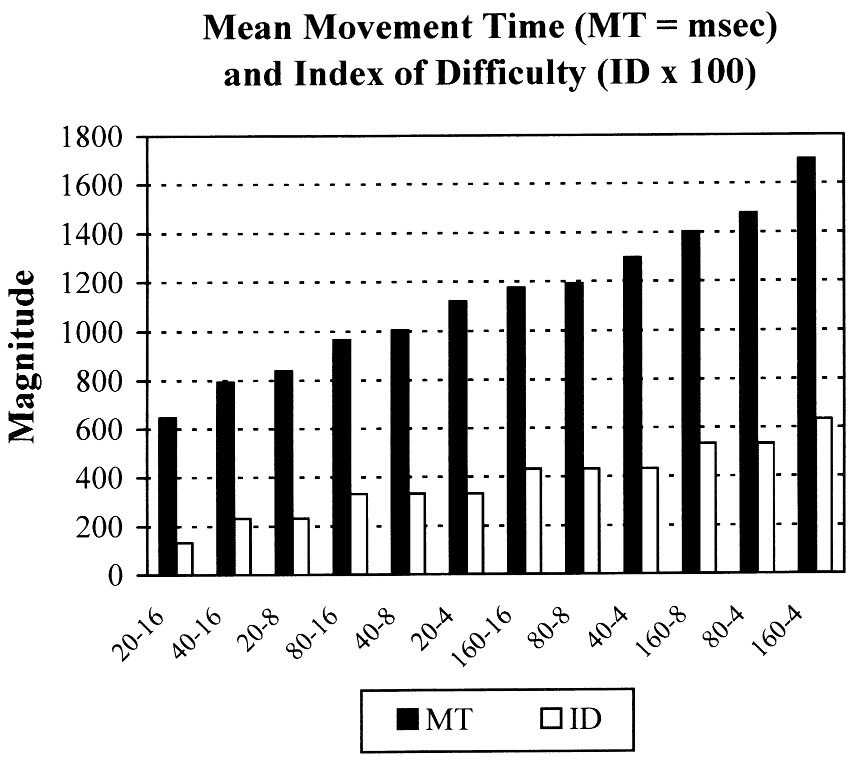

Fig. 11. The index of difficulty, sorted in ascending order, for all participants plotted against the mean movement time at each amplitude–width combination.

5. Conclusions and recommendations

Five basic findings emerged from this analysis. If speed and accuracy are matters of concern when using a mouse for the selection of target-type objects (e.g. icons, buttons, widgets, etc.) on a computer's screen, the interface designer should consider the following guidelines:

1. use square target objects;
2. size the target objects between 8 and 16 mm in width;
3. locate the target objects at a distance of 40 mm or less from the starting position;
4. use a discrete drag-drop selection task, or offer it as an alternative; and
5. approach the target objects from an angle of 0° or 180°.

These findings should improve the design of GUI systems, and they may be of value to researchers and practitioners interested in applying a Fitts' law model to target acquisition tasks in a two-dimensional plane, such as a computer's display screen. Further research into the effects of angle of approach, target shape, and task type on target selection may improve the understanding of their contributions to user performance as modeled by Fitts' law and may extend that understanding to other direct manipulation devices.

6. Implications and future directions

The continued advancements in the quality of HCI can be attributed, at least in part, to the improved interfaces developed through the use of the mouse as a primary input device and the use of bitmapped graphical output. There is an increasing need for the modeling and prediction of user activities at the boundary of the human–computer interface. As human–machine communication evolves into a 'cybernetic team' and becomes more direct, the processes and limitations underlying one's ability to execute rapid, precise movements emerge as performance determinants in interactive systems. Robust models such as Fitts' law can provide vital insights into interface design and evaluation strategies for maximizing human performance.

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