Movement Time for Different Input Devices

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Abstract. Fitts' law states that movement time can be predicted by knowing the size of a target to which a person is intending to move and the distance to be moved. The current study measured choice-movement time with three input devices commonly used in human-computer interaction tasks: response panel, computer mouse, and touch-screen. We also examined how direction of movement with the different input devices influences performance. Movement time was shorter when responses were made with the response panel than with the mouse and touch-screen. Furthermore, horizontal movement time was faster than vertical movement time, even when the size of the stimuli and distance to be moved were equal. Fitts' law was used to estimate the slope and intercepts of the functions for each input device and dimension to determine whether the devices and dimensions had greater influence on the starting time or the speed of execution.

Keywords: Fitts' law, input device, movement time, display-control compatibility.

1 Introduction

When a person interacts with his or her daily environment, it is likely that s/he will perform aimed movements. Examples of aimed movements include a) using a computer mouse to move a cursor to a menu item in order to select that item, b) moving a hand from the steering wheel of a vehicle to press a button on the control panel to change the radio station, and c) moving a hand from its current position to touch an icon on the screen of an iPhone to launch an application. Fitts' law states that movement time (*MT*) can be predicted by knowing the size the target and the distance from the target [1]. The shorter the distance and the larger the target, the faster the movement time will be.

Fitts' law refers to a mathematical relationship between movement speed and accuracy of movement. In 1954, Paul Fitts began exploring this relationship by having participants tap a metal, hand-held stylus onto two metal plates as many times as possible in a given period of time. During the experiment, Fitts also manipulated the size of the plates (target width, *W*) and the distance between them (amplitude, *A*), which allowed him to test performance across a variety of combinations of target sizes and distances. The participants were instructed to consider accuracy of movement as a higher priority than speed of movement. Performance was measured by the number of taps that could be completed in a given 15-second trial. Fitts and Peterson [2] continued to investigate this relationship, and concluded that movement

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time (*MT*) was a function of the difficulty of the movement, expressed as a logarithmic ratio of amplitude and width, known as the index of difficulty (*ID*). *Fitts' law* is expressed as $MT = a + b\ (ID)$, where a and b are empirically derived constants. Fitts' law is important to the field of HCI because many tasks involve aimed movements.

Fitts' law is robust, having been shown to hold for movements of the head [3] and feet [4], as well as for movements made underwater [5] and with remote manipulation [6]. Thus, many designers will benefit from using Fitts' law to estimate movement times. In particular, designers can benefit from using Fitts' law to determine how a device or movement direction affects performance. Because the constants in Fitts' law (a and b) represent properties of the device being tested, knowing these values can help designers diagnose where the cost in movement times with different devices originates. The constant, a (the intercept) is indicative of the time needed to start the movement with the device. Constant b, (the slope) is indicative of the inherent movement speed using the device.

Stimulus-response (S-R) compatibility, or how natural a response to a stimulus is, can also influence the slope of the Fitts' law function [7], where a higher degree of compatibility reduces the slope. There is also some evidence from the S-R compatibility literature suggesting that, in many situations, reaction time is faster for horizontal than vertical S-R relations, a phenomenon known as the right-left prevalence effect [8, 9, 10]. However, it is not known whether the advantage for the horizontal dimension would be evident in movement time. Thus, the goal of the current study was to examine whether the direction of movement in a choice reaction task has an effect on movement time with different input devices used in HCI tasks.

Three input devices were examined: response panel, computer mouse, and touch screen. All response devices were mapped compatibly to the stimulus display. The response devices differed with respect to their integration with the display. The touch screen was the most integrated input device because participants touched the target to make a response. The computer mouse was less integrated because participants moved the mouse to produce cursor movement to a target that was not on the same plane. Finally, the response panel was the least integrated because participants pressed a corresponding button on the response panel that was separate from the display.

2 Method

2.1 Participants

Forty-four undergraduate students (24 women, 20 men), ages 18-39 (*M* = 20.14 years), enrolled in an Introductory Psychology course at California State University, Long Beach participated the study. Participants were recruited from the Psychology Subject Pool and received credit toward their Introductory Psychology requirement. Each participant completed a demographic questionnaire after completing the experimental trials.

Participants reported using a computer an average of 20.5 hours per week. Participants were also asked to use a scale of 1 to 7, with 1 being no experience and 7 being very experienced, to rate their experience with different input devices. Participants rated their experience to be greatest for the computer mouse (*M* = 6.6) and a computer keyboard (*M* = 6.5), and least for a touch screen (*M* = 5.0).

2.2 Design

A 2 (distance: near and far) x 2 (dimension: horizontal and vertical) x 3 (device: mouse, touch screen, and response panel) within-subjects factorial design was used. The device variable was counterbalanced across participants prior to their arrival for the experiment.

2.3 Materials

The experimental apparatus consisted of an Asus Eee Top touch screen computer running Microsoft Windows XP Home Edition, a Microsoft IntelliMouse Explore 3.0, which was used during the mouse device condition. An Ergodex® DX1 Input System Panel was used in the response panel device condition. The response buttons were compatibly mapped with the stimuli that were presented on the screen. A custom program written using Microsoft Visual Basic 2008 Express Edition controlled the experiment and collected the data. The touch screen computer was located on a table that was 154 cm wide, 76 cm deep, with a height of 75 cm from the floor. The near edge of the table was 23 cm from the base of the computer.

2.4 Procedure

The experiment was conducted in a single session lasting approximately 45 minutes. Participants were seated at a table and given two copies of the informed consent form. All agreed to participate and signed the informed consent form, after which the experiment began.

For each condition, upon the press and release of the “Start Trial” button by the participant (located in the middle of the screen; see Figure 1), a target randomly appeared in one of four directions (above, below, left or right) and at one of two distances (near or far) from the “Start Trial” button. Participants were instructed to move to the stimulus once they had identified the target. The trial ended when the participant responded at the location of the target.

Movement time was measured from the time that the participant clicked on the “Start Trial” button until they selected the target. Ten practice trials with each device were given prior to beginning data collection. The experimental block consisted of 40 trials per stimulus location at the two distances (320 trials per device). The target consisted of a 1.27 cm by 1.27 cm black, square that appeared on a tan background. Participants were given rest periods between device conditions and were also told that they could rest at any time during data collection as long as there was no target on the screen. At the completion of the experimental trials, participants completed a demographic questionnaire. Finally, they were debriefed and thanked for their participation.

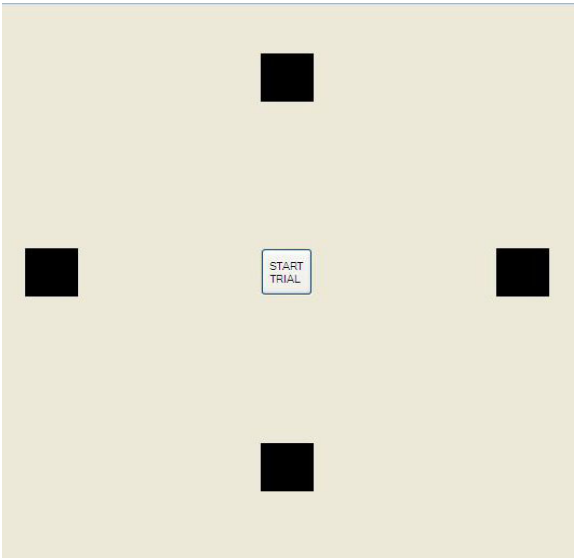

Fig. 1. Task Display. Participants clicked on the start trial button (or a response button located in the same spatial position on a response panel) to start the trial. Then, one target stimulus (depicted by the black squares) appeared, and participants were to respond by moving to the location of the target.

3 Results

A 2 (distance: near and far) x 2 (dimension: horizontal and vertical) x 3 (device: mouse, touch screen, and response panel) analysis of variance was conducted on mean movement time for each participant in each condition.

There was a significant main effect of distance, F (1,43) = 398, $p < .001$, $\eta^2 = .90$. Consistent with Fitts' law, movement time was longer for further distances than nearer distances (M = 520 ms, SE = 15.9; M = 400 ms, SE = 12.7). A significant main effect of dimension, F (1,43) = 20.4, $p < .001$, $\eta^2 = .32$, was also obtained in which movement time for the horizontal dimension was faster (M = 450 ms, SE = 13.52) than movement time for the vertical dimension (M = 472 ms, SE = 15.1).

The main of effects of distance and dimension were qualified by a significant distance x dimension interaction, F (1,43) = 4.4, $p < .05$, $\eta^2 = .09$, see Figure 2. Tests of simple effects were performed with the Bonferroni correction. Movement time was significantly different across both factors; the shortest movement time occurred when the target was near and in the horizontal direction (M = 393 ms, SE = 12.4), followed by when the target was near and in the vertical direction (M = 409 ms, SE = 13.3), followed by when the target was far and in the horizontal direction (M = 507 ms, SE = 15.4), and was longest when the target was far and in the vertical direction

(*M* = 535.64 ms, *SE* = 17.19), $p < .001$. In other words, this interaction reflects the fact that horizontal movement time was less affected by distance than vertical movement time.

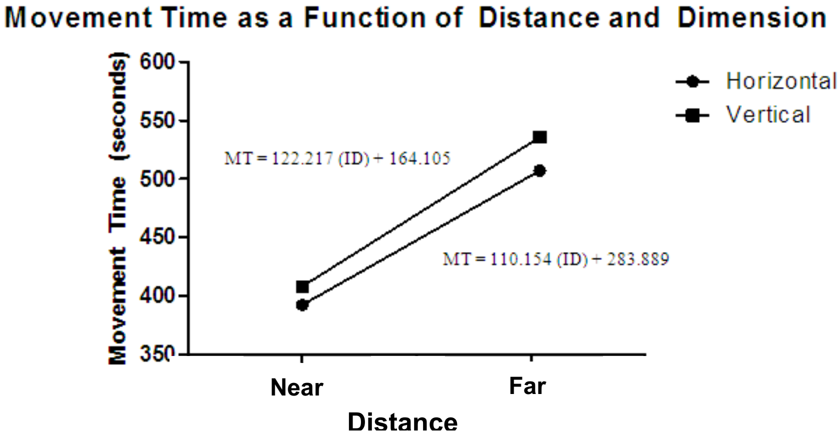

Fig. 2. Movement time as a function of distance and dimension

A significant main effect of input device was also found, *F* (2,42) = 112, $p < .001$, $\eta^2 = .84$, with movement time using the mouse being the longest (*M* = 569 ms, *SE* = 15.5), followed by movement time using the touch screen (*M* = 456 ms, *SE* = 18.4), and movement time using the response panel being the shortest (*M* = 358 ms, *SE* = 14.1). However, this main effect was qualified by a significant distance x device interaction, *F* (2,42) = 39, $p < .001$, $\eta^2 = .66$, see Figure 3. A post-hoc analysis using the Bonferroni correction was conducted to determine if there was a significant difference in the movement time with the different input devices when the target was near compared to when it was far. When the target was near, there was a significant difference in movement time across devices, where movement time was longest using the mouse (*M* = 492 ms, *SE* = 14.7), intermediate when using the touch screen (*M* = 393 ms, *SE* = 15.9), and shortest using the response panel (*M* = 317 ms, *SE* = 13.2). The same pattern held when the distance was far, where movement time for the mouse was still longest (*M* = 647 ms, *SE* = 17.4), followed by the touch screen (*M* = 518 ms, *SE* = 21.3), and response panel (*M* = 399 ms, *SE* = 15.7). However, the difference between devices was larger at the farther distance than at the nearer distance.

Because dimension did not interact with input device, Fitts' law was used to derive the constants *a* and *b* for each dimension (across device) and each input device (across dimension). The equations for estimating MT according to Fitts' law for each dimension and input device are presented in Figures 2 and 3, respectively.

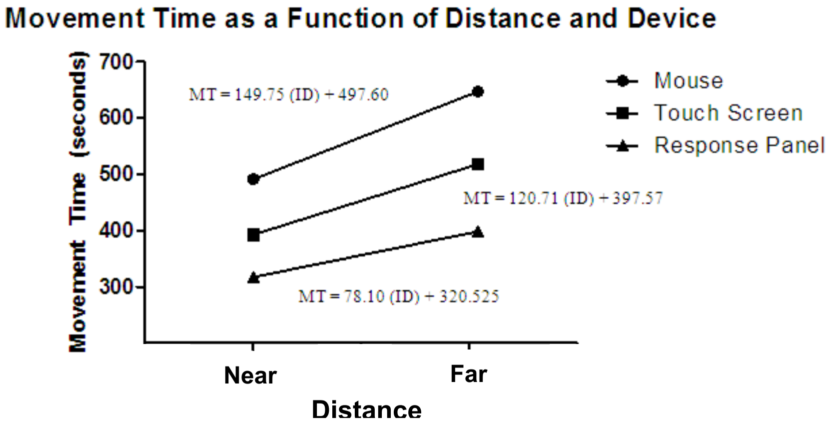

Fig. 3. Movement time as a function of distance and device

4 Discussion

The Fitts' law functions were different for each dimension and input device. For the dimension variable, movement time was found to be shorter for the horizontal than vertical dimension. Upon examining the slope of Fitts' law function, there was an 11% increase from the horizontal dimension to the vertical one. This difference may reflect easier motor control along the horizontal plane than vertical one. However, the increase in the slope of the functions was smaller than the increase observed in the intercept (73%), which is indicative of the time needed to start the movement along the horizontal and vertical dimensions. Because the experimental paradigm was a choice aimed-movement task, the difference may reflect that it takes longer to select responses along the vertical dimension than the horizontal one. This finding is consistent with other choice-reaction studies [11] that showed overall RT for horizontally arrayed S-R sets to be shorter than for vertically arrayed S-R sets.

For the input devices, the response panel yielded the shortest MT, followed by the touch screen, and then the computer mouse. When examining Fitts' law functions, there was a 55% increase in slope of the function when comparing the response panel to the touch screen, but only a 24% increase in the intercept of the functions. Although this finding may suggest that it is easier to move your finger from one key to another than to move your finger from one item on a touch screen to another, it may be the case that occlusion of the display by the hand on the touch screen accounts for part of the slowing. Comparison of the response panel with the mouse resulted in a 92% increase in the slope of the function and a 55% increase in the intercept. Because the two input devices require different types of movement, it is not surprising that most of the increase is in the slope. With the mouse movement, the input device is controlling a cursor on the display. Although the mouse is a zero-order control, in which changes in the position of the mouse correspond to changes in the position of the cursor, the mapping of distance is not direct (e.g., moving the mouse 1 inch to the left may result in the cursor moving 3 inches on the screen). Thus, mouse movement may be longer due to a need to slow the device to hone in on the target or to make corrections required for under- or over-shooting the target.

The implications of the present findings relating to the design of displays and controls are as follows:

- If the environment or situation in which the input will be made requires a short movement time, the design should use a discrete button push for the user to make the input. For example, if a person is driving and would like to change the radio station, it would probably take less time for the movement from the steering wheel to a button on the radio panel than to a button indicator on a touch screen display.
- When designing for a task that requires a short movement time along a single dimension, the design should involve movement along the horizontal dimension instead of the vertical dimension. For example, in a word processing program, such as Microsoft Word, the new ribbon design requiring selection of items from left to right may be more efficient than the old drop-down menu design.

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