Effects of Target Shape and Display Location on Pointing Performance by Eye-Gaze Input System

Modeling of Pointing Time by Extended Fitts' Law

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Abstract. This study aimed at investigating the effects of the target shape, the movement distance, the target size, and the direction of target presentation on the pointing performance using an eye-gaze input system. The target shape, the target size, the movement distance, and the direction of target presentation were within-subject experimental variables. The target shape included: diamond, circle, rectangle, and square. The direction of target presentation included eight directions: upper, lower, left, right, upper left, upper right, lower left, and lower right. As a result, the pointing time of the rectangle tended to be longer. The upper directional movement also tended to prolong the pointing time. Such results would be effective for designing an eye-gaze-input HCI (Human-Computer Interaction). Moreover, as a result of modeling the pointing time by Fitts' modeling, it was suggested that the index of difficulty in Fitts' modeling for the rectangle should be defined separately from the circle, the diamond, and the square.

Keywords: Eye-gaze input · Target shape · Display location · HCI

1 Introduction

The opportunities to use PCs or internets daily and in workplaces are increasing more and more irrespective of sex, age, and educational level. In other words, PCs or internets are widespread universally. Although a mouse input is mostly widespread among PC and internet users, this device is not usable for older adults and disabled people. For such a user population, an eye-gaze input system is paid more and more attention as an alternative of a mouse input.

The technology for measuring a user's visual line of gaze in real time has been advancing. Appropriate human-computer interaction techniques that incorporate eye movements into a human-computer dialogue have been developed [1–9]. These studies have found the advantage of eye-gaze input system. However, few studies except Murata [8] have examined the effectiveness of such systems with older adults. Murata [8] discussed the usability of an eye-gaze input system to aid interactions with computers for older adults. Systematically manipulating experimental conditions such as

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the movement distance, target size, and direction of movement, an eye-gaze input system was found to lead to faster pointing time as compared with mouse input especially for older adults.

As eye-gaze input interfaces enable us to interact with PC by making use of eye movements, it is expected that even disables persons with deficiency on the upper limb can easily use it. A lot of studies [10–14] are reported on eye-gaze input interfaces as an alternative to a mouse. In these studies, an optimal click method, menu selection method, dragging method, and character input method have been discussed. However, there are still a lot of problems we must overcome so that such an input system can be put into practical use. For example, the shape of mouse cursor suitable for general human-computer interactions (HCI) except for eye-gaze interfaces is discussed, for example, by Pastel [15], Lecuier [16], and Phillips [17]. Like general HCI, we should use a proper cursor shape which enhances the usability of eye-gaze input system. As the eye-gaze input system differs from the mouse input in input mechanism, and has a lower resolution as compared with the mouse input, it is natural and reasonable to predict that the cursor shape proper for the mouse input does not necessarily lead to the high usability of eye-gaze interfaces. Although a conventional arrow-type cursor is used even in eye-gaze input interface, there seems to be no definite reason to use such a conventional cursor shape in eye-gaze input interfaces. It has been explored what type of cursor shape is suitable for eye-gaze input interfaces [13].

As compared with a lot of usability studies on mouse input, the usability of eye-gaze input system has not been systematically explored. More concretely, the effects of the target form (figure), the movement distance, the target size, and the direction of target presentation on the pointing performance by an eye-gaze input system has not been examined until now.

Therefore, this study aimed at investigating the effects of the target shape, the movement distance, the target size, and the direction of target presentation on the pointing performance by an eye-gaze input system. The target form (figure), the target size, the movement distance, and the direction of target presentation were within-subject experimental variables. The target shape included: diamond, circle, rectangle, and square. The direction of target presentation included eight directions: upper, lower, left, right, upper left, upper right, lower left, and lower right. On the basis of the experiment above, an attempt was made to model the pointing time in an eye-gaze input interface using Fitts' modeling.

2 Method

2.1 Participant

Ten healthy young adults aged from 21 to 24 years old took part in the experiment. All participants had an experience of personal computer with an average of 5.5 years (6-7 years). The visual acuity of the participants in both young and older groups was matched and more than 20/20. They had no orthopedic or neurological diseases.

2.2 Apparatus

Using EMR-AT VOXER (Nac Image Technology) (See Fig. 1), an eye-gaze input interface was developed. Visual C# (Microsift) was used as a programming language. This apparatus enables us to determine eye movements and fixation by measuring the reflection of low-level infrared light (800 nm), and also admits the head movements within a predetermined range. The eye-tracker was connected with a personal computer (HP, DX5150MT) with a 15-in. (303 mm x 231 mm) CRT. The resolution was 1024 × 768 pixel. Another personal computer was also connected to the eye-tracker via a RS232C port to develop an eye-gaze input system. The line of gaze, via a RS232C port, is output to this computer with a sampling frequency of 60 Hz. The illumination on the keyboard of a personal was about 200 lx, and the mean brightness of 5 points (four edges and a center) on CRT was about 100 cd/m^2. The viewing distance was about 70 cm. The experimental situation is shown in Fig. 1.

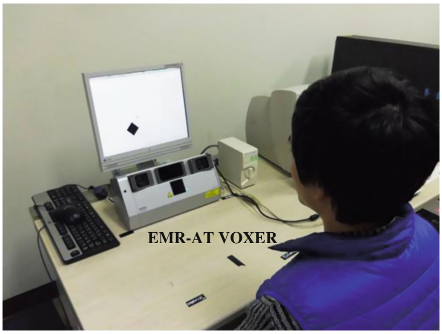

Fig. 1. Photo of experimental setting

2.3 Task, Design, and Procedure

The task was to point to a target presented either of eight directions in Fig. 2 by moving fixation from the initial fixation point to the target, and fixate it for 300 ms. The experimental conditions are summarized in Fig. 3. As well as the movement direction, the movement distance (210 pixel and 290 pixel), the target shape (square, diamond, circle, and rectangle), and the size of target (100 X 100 pixel^2, 75 X 75 pixel^2, and 50 X 50 pixel^2) were within-subject experimental factors. For each combinations of the movement distance, the target shape, and the size of target (there were a total of 24 conditions), the participant was required to carry out pointing task 10 times for each direction in Fig. 2. The eight kinds of directions were randomly presented to the participant. The order of performance of 24 conditions was also randomized across the participants.

After the calibration of eye camera and the practice session, the participants began the experimental session. First, the participants were ordered to fixate the center of the display. After the fixation to the center area, the target to be pointed to is presented on one of the eight directions in Fig. 2. The participants move their fixation from the central area to the target, and fixate there for the predetermined duration (in this study, 300 ms). This corresponds to one pointing trial.

The evaluation measure was the pointing time for the correct trial. The size of each form (square, diamond, circle, and rectangle) when the size corresponded to 100 X 100 pixel^2 is shown in Fig. 4.

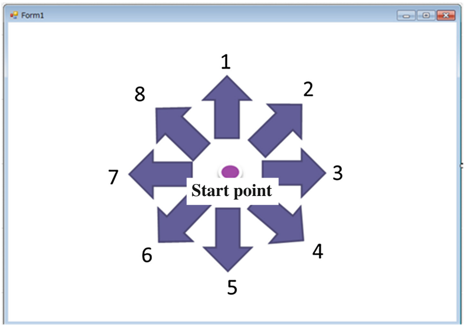

Fig. 2. Movement directions used in the experiment

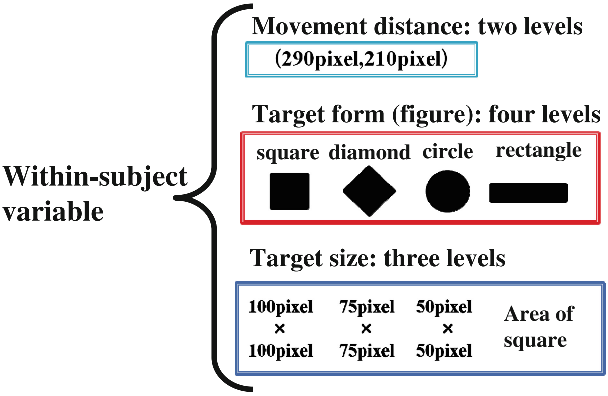

Fig. 3. Three factors other than movement direction used in the experiment

3 Results

In Fig. 5, the mean pointing time is compared between the two movement distance conditions (210 pixel and 290 pixel). The pointing time is compared among target shapes ((square, diamond, circle, and rectangle) in Fig. 6. In Fig. 7, the pointing time is compared among three levels of target size (100 X 100 pixel^2, 75 X 75 pixel^2, and 50 X 50 pixel^2). In Fig. 8, the pointing time is plotted as a function of target shape and target size. A three-way (size by shape by distance) ANOVA (Analysis of Variance) conducted on the pointing time revealed main effects of distance ($F(1,9)$ = 14.818,

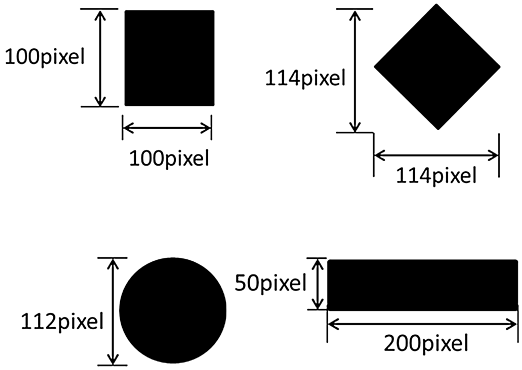

Fig. 4. Four shapes (100 X 100 pixel^2) used in the experiment

$p < 0.01$), size ($F(2,18) = 206.360$, $p < 0.01$), and shape ($F(3,27) = 538.883$, $p < 0.01$). A shape by size interaction was also significant ($F(6,54) = 12.712$, $p < 0.01$).

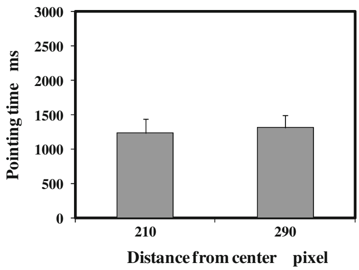

Fig. 5. Pointing time compared between two movement distances

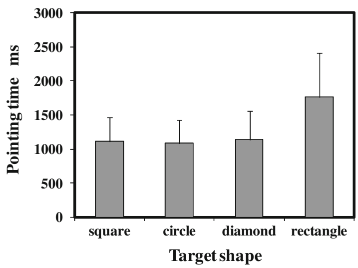

Fig. 6. Pointing time compared between four shape conditions

For each movement distance, a three-way (direction by shape by size) ANOVA was conducted on the pointing time. First, the result of movement distance of 210 pixels is mentioned. Significant main effects of size ($F(2,18) = 92.942$, $p < 0.01$), shape ($F(3,27) = 294.368$, $p < 0.01$), and direction ($F(7,63) = 12.996$, $p < 0.01$) were detected.

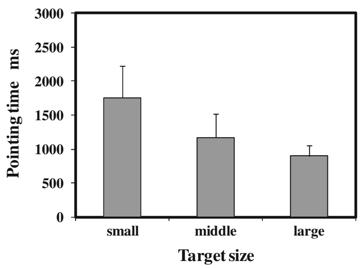

Fig. 7. Pointing time compared among three size conditions

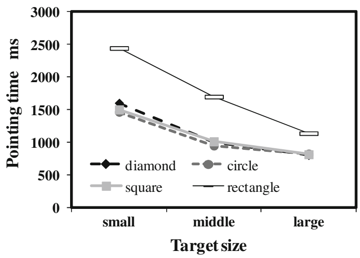

Fig. 8. Pointing time as a function of target shape and target size

A shape by size interaction ($\boldsymbol{F}(6{,}54) = 6.913$, $\boldsymbol{p} < 0.01$) and a size by direction interaction were also significant ($\boldsymbol{F}(14{,}126) = 3.182$, $\boldsymbol{p} < 0.01$). In Fig. 9, the pointing time is plotted as a function of target shape and target size. In Fig. 10, the pointing time is plotted as a function of movement direction and target size. Figure 11 compares the pointing time among three levels of target size (100 X 100 pixel^2, 75 X 75 pixel^2, and 50 X 50 pixel^2). In Fig. 12, the pointing time is shown as a function of target shape. In Fig. 13, the pointing time is compared among eight movement directions.

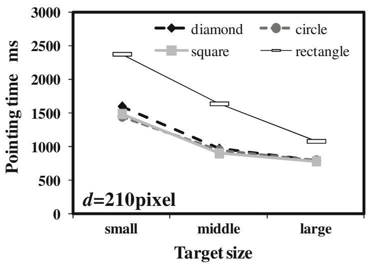

Fig. 9. Pointing time as a function of target size and target shape (d = 210 pixel)

Next, the results for the movement distance of 290 pixel are described. A three-way (direction by shape by size) ANOVA was conducted on the pointing time. Significant main effects of size ($\boldsymbol{F}(2{,}18) = 249.927$, $\boldsymbol{p} < 0.01$), shape ($\boldsymbol{F}(3{,}27) = 117.269$, $\boldsymbol{p} < 0.01$),

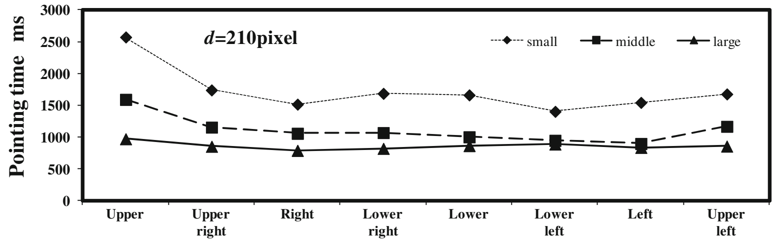

Fig. 10. Pointing time as a function of movement direction and target size (d = 210 pixel)

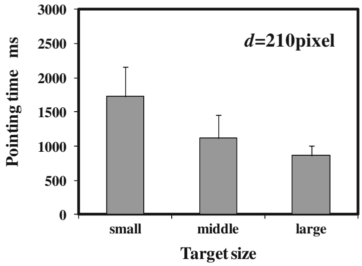

Fig. 11. Pointing time compared among target size conditions (d = 210 pixel)

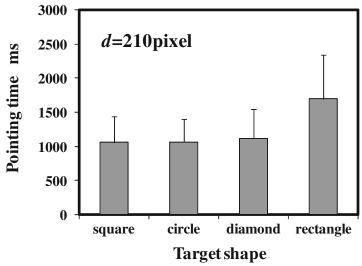

Fig. 12. Pointing time compared among target shape conditions (d = 210 pixel)

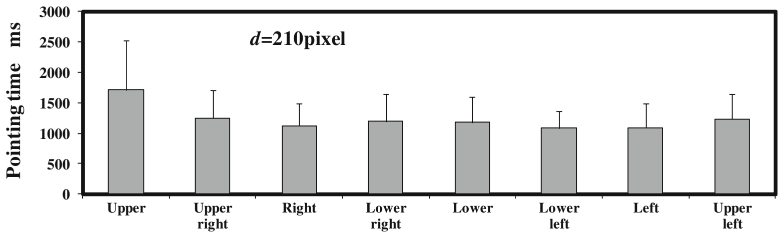

Fig. 13. Pointing time compared among movement direction conditions (d = 210 pixel)

and direction ($F(7,63) = 13.948$, $p < 0.01$) were detected. A shape by size interaction ($F(6,54) = 6.558$, $p < 0.01$) and a size by direction interaction were also significant ($F(14,126) = 4.088$, $p < 0.01$). In Fig. 14, the pointing time is plotted as a function of target size and target shape. In Fig. 15, the pointing time is plotted as a function of movement direction and target size. In Fig. 16, the pointing time is plotted as a function of movement direction and target shape. Figure 17 compares the pointing time among three levels of target size (100 X 100 $pixel^2$, 75 X 75 $pixel^2$, and 50 X 50 $pixel^2$). In Fig. 18, the pointing time is shown as a function of target shape. In Fig. 19, the pointing time is compared among eight movement directions.

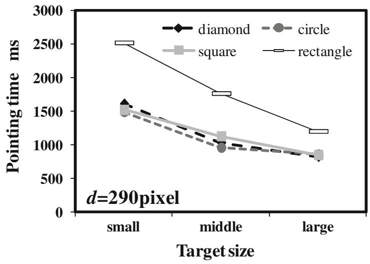

Fig. 14. Pointing time as a function of target size and target shape (d = 290 pixel)

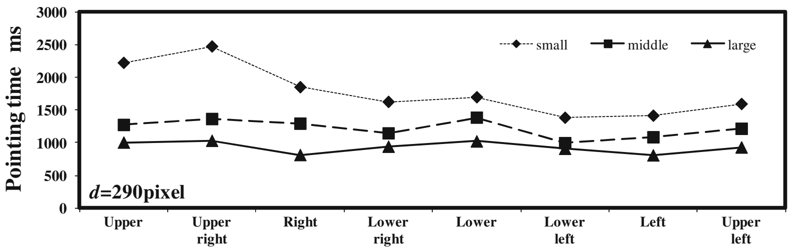

Fig. 15. Pointing time as a function of movement direction and target size (d = 290 pixel)

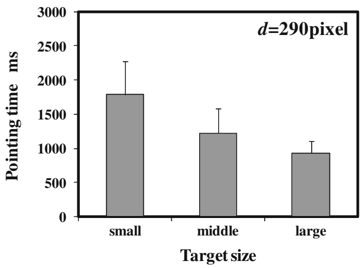

Fig. 16. Pointing time compared among target size conditions (d = 290 pixel)

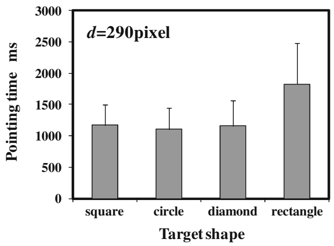

Fig. 17. Pointing time compared among target shape conditions (d = 290 pixel)

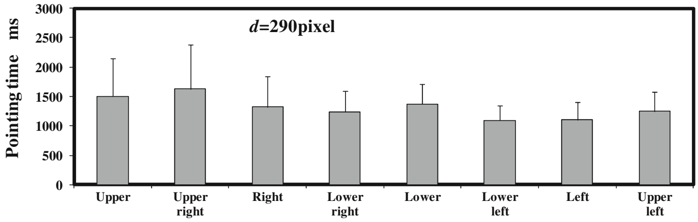

Fig. 18. Pointing time compared among movement direction conditions (d = 290 pixel)

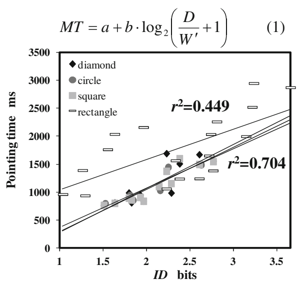

Fig. 19. Fitts' modeling (Eq. (1)) for the rectangle group and the diamond, circle, and square group

The results of modeling the relationship between the index of difficulty and the pointing time by means of Fitts' law are shown in Figs. 19 and 20. The indices of difficulty in Figs. 19 and 20 are given by Eqs. (1) and (2), respectively.

$$MT = a + b \cdot \log_2\left(\frac{D}{W'} + 1\right) \tag{1}$$

$$MT = a + b \cdot \log_2\left(\frac{D}{S} + 1\right) \tag{2}$$

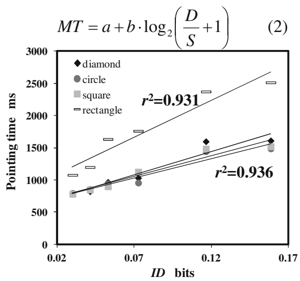

Fig. 20. Fitts' modeling (Eq. (2)) for the rectangle group and the diamond, circle, and square group

MT is the pointing time, *D* is the movement distance, *S* is the size of the target, and *W*' is the depth of the target along the movement direction. The parameters *a* and *b* are empirically determined.

4 Discussion

Figure 5 shows that the movement distance affected the pointing time as expected. As shown in Fig. 6, the target shape affected the pointing time, and the pointing time of the rectangle was by far longer than that of other target shapes. As expected, the target size affected the pointing time (see Fig. 7). As shown in Fig. 8, the size by shape interaction shows that the effects of target size on the pointing time are similar for circle, square, and diamond, although the effects of target size on the pointing time is not similar to those of circle, square, and diamond. As no interactions were detected between the movement distance and other factors, a three-way (shape by size by movement direction) ANOVA was carried out on the pointing time for each movement distance.

As shown in Figs. 9-13 and Figs. 14-18, similar results (effect of shape, size, and movement direction on pointing time) were observed for both movement distances. An attempt was made to model the pointing time using Fitts' model (Murata et al. [18]). The results are shown in Figs. 19 and 20. The fit to the data is better in Fig. 20 (Eq. (2)) than in Fig. 19 (Eq. (1)). This indicates that the area of the target should be used as the size parameter in Fitts' law modeling. Moreover, Fig. 20 indicates that the circle, the diamond, and the square can be modeled using the same equation, although the Fitts' equation for the rectangle is different from that for the circle, the diamond, and the square. This means that the index of difficulty ($\log_2(D/S + 1)$) does not apply to the rectangle. Therefore, the indices of difficulty for these two types of shapes (the circle, the diamond, and the square (Eq. (3)) and the rectangle (Eq. (4))) were defined as follows separately.

$$ID = \log_2\left\{\left(\frac{D}{S} + 1\right)\right\} \quad (3)$$

$$ID = \log_2\left\{\alpha\left(\frac{D}{S} + 1\right)\right\} \quad (4)$$

In Eq. (4), α is empirically determined parameter. When α is one, this coincides with Eq. (3). The results of separate definition of index of difficulty are shown in Figs. 21 and 22. As compared with Fig. 21, the separate definition of index of difficulty improved the fit to the data (Fig. 22), and made the contribution r^2 increase from 0.539 to 0.702. The difficulty of pointing to the rectangle target like a Web menu item can be well expressed by the model (Eq. (4)) proposed in this study.

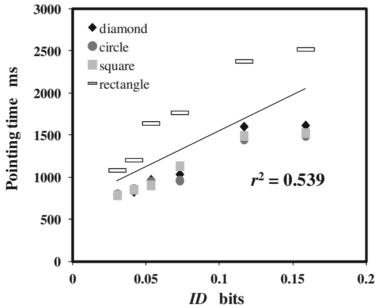

Fig. 21. Fitts' modeling (Eq. (3)) for all of the shape conditions

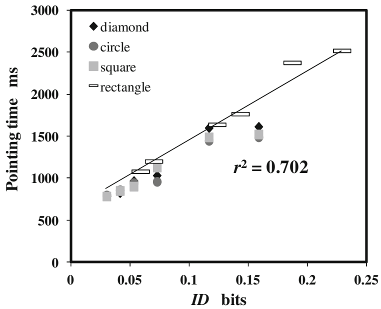

Fig. 22. Fitts' modeling (Eq. (4)) for all of the shape conditions

5 Conclusions

The pointing time of the rectangle tended to be longer than that of the square, the diamond, and the circle. The pointing time of the square, diamond, and the circle was similar even when the movement direction, the movement distance, and the target size changed. This property was not true for the rectangle. The upper directional movement also tended to prolong the pointing time. Moreover, as a result of modeling the pointing time by Fitts' modeling, it was suggested that the index of difficulty in Fitts' modeling for the rectangle should be defined separately from the circle, the diamond, and the square.Such results would be effective for designing an eye-gaze-input HCI (Human-Computer Interaction).

Future research should verify the effectiveness of this study under more realistic HCI such as a Web search.

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