Pointing to Targets with Difference between Motor and Visual Widths

Hiroki Usuba
Meiji University
Tokyo
Japan
cs172047@meiji.ac.jp

Shota Yamanaka
Yahoo Japan Coporation
Tokyo
Japan
syamanak@yahoo-corp.jp

Homei Miyashita
Meiji University
Tokyo
Japan
homei@homei.com

ABSTRACT

In GUIs, there are clickable objects that have a difference between the motor and visual widths. For example, when looking at an item on a navigation bar, users think that the text length (the visual width) means the motor width. However, when a cursor hovers over the item, the cursor shape changes or the item is highlighted, and then users understand that the actual motor width differs from the visual width. In this study, we focus on the difference between the motor and visual widths and investigate how the difference affects user performance. Experimental results showed that 1) users aim at the motor width, 2) the reaction time is a U-shaped function whose optimal point is located where the motor and visual widths are the same, and 3) the movement time depends on the motor width. We also analyze existing GUIs and discuss the implications.

CCS CONCEPTS

• Human-centered computing → Graphical user interfaces

KEYWORDS

Different motor and visual target widths, target acquisition, human performance, graphical user interfaces

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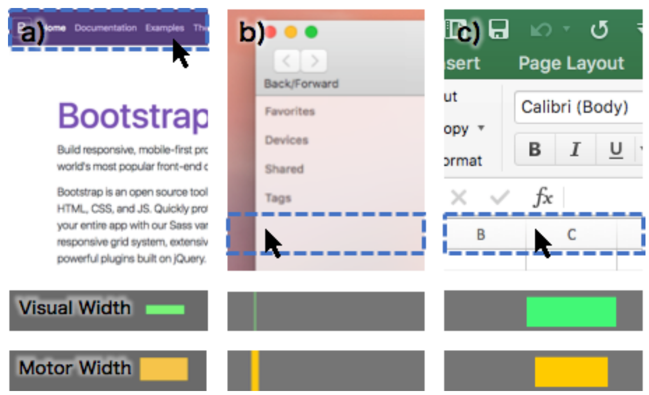

Figure 1: Examples of target with difference between visual and motor widths (top row). Visualizing visual width (middle row) and motor width (bottom row).

1 INTRODUCTION

In graphical user interfaces (GUIs), there are clickable objects with various sizes. Users select these objects for resizing a window, switching a tab, selecting an option from a menu, or opening a page. According to Johnson's design implications [20], designers should make objects large enough that users can easily click them, and should make the actual objects at least as large as the visual objects. Note that, in this paper, we define *motor target width* as the width at which users can fire a click event and *visual target width* as the width that is displayed on the screen. As Johnson pointed out, there are objects in GUIs that have a difference between the motor and visual widths (Figure 1). For example, when looking at an item on a navigation bar, users think that the text length (the visual width) equals the motor width, and

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thus they aim at the text. When the cursor hovers over the item, the cursor shape changes or the item is highlighted, and then users understand that the actual motor width differs from the visual width. As shown in Figure 1, there are many situations where visual and motor widths are different: not only when clicking an item on the navigation bar (a) but also when resizing a window (b) or selecting a column (c).

In this study, we focus on the difference between the visual and motor widths and investigate how the difference affects users' pointing performance. Usuba et al. [23] also investigated the difference [23], but they focused only on pointing to visually small targets (e.g., Figure 1b). In addition, in their study, there are the only two conditions where the motor and visual widths are the same and where the motor width is larger than the visual width. However, in GUIs, there is also a condition where the motor width is smaller than the visual width (Figure 1c). Therefore, as an extension of Usuba et al.'s study, in our experiments, we test larger targets and include conditions where the motor width is equal to, larger than, and smaller than the visual width.

2 RELATED WORK

In this section, first, we introduce Fitts' law, which is well-known as a pointing model. Fitts' law has been modified in various studies according to the conditions set. In our experimental conditions, unlike the original Fitts' law task, we include the difference between the motor and visual widths. Therefore, in this paper, we verify the applications of Fitts' law and the modified model to our experimental condition. To the best of our knowledge, the only other study that investigated the difference between the motor and visual widths is Usuba et al.'s [23]. Therefore, because we cannot discuss many studies that are similar to ours, we describe 1) dynamically expanding and shrinking the target and 2) the difference between the visual size and the control-display (C-D) gain. In the former studies, the motor and visual width changes dynamically, and in our study, the change is static. In the latter studies, the focus is the difference between the motor and visual size, similar to our study.

2.1 Fitts' law

Fitts' law [11] (Equation 1) can predict the movement time of pointing by using the regression components (a and b), the distance D, and the width W of a target. ID in Equation 1 indicates the index of difficulty.

$$MT = a + bID, where\ ID = \log_2\left(\frac{D}{W} + 1\right) \qquad (1)$$

In a Fitts' law task, the error rate is ideally 4%. When the error rate is higher or lower than 4%, the model can be modified by adjusting the target width. The adjusted target width is the effective width W_e [10, 25] (Equation 2), and the effective index of difficulty ID_e is calculated from W_e instead of W. σ in Equation 2 indicates the standard deviation of the hit distribution of the x-coordinate.

$$W_e = \sqrt{2\pi e}\sigma, ID_e = \log_2\left(\frac{D}{W_e} + 1\right) \qquad (2)$$

Similar to the above effective width, in Fitts' law, there are many modified models. For example, regarding touch input, there is FFitts' law [3], and regarding the dimension of pointing, there are the models of 2D pointing [2, 27] and 3D pointing [15]. Fitts' law is also applicable to dragging an object [13, 26], text selection [6], and several input techniques [6, 25, 26].

2.2 Dynamically expanding and shrinking target

There have been several studies on expanding the target [9, 22, 32], where the target becomes dynamically larger when a cursor approaches, such as Dock in macOS. It is known that visually expanding a target without increasing the motor width accelerate users' movement the same as expanding the motor width when the task is difficult [9]. In addition, Zhai et al. found that expanding the target accelerates the movement time even if users cannot predict whether the target is expanded [32]. There have also been several studies on shrinking the target [17, 18, 21, 32], where the target width dynamically decreases. Hoffmann found that the movement time and the error rate depend on the ID and the ratio of target shrinkage [17]. As with expanding the target, shrinking the target affects users' movement even if there is no prediction [32]. The fitness of Fitts' law in shrinking the target is the same as using the initial target width as W and as using the target width at capture as W [17]. Although changing the size of the area cursor (e.g., the bubble cursor [16], DynaSpot [8]) also changes the target width dynamically, in this paper we do not deal with the difference between motor and visual widths of the cursor.

2.3 Difference between visual size and C-D gain

The C-D gain is the relationship between a physical mouse movement and the cursor movement on a display. Increasing the C-D gain allows users to operate a cursor faster with little physical movement. In Semantic Pointing [4], when a cursor is close to a target, the gain decreases, and then the speed of the cursor slows down. In this way, Semantic Pointing can facilitate pointing without changing the visual shape of the target. The sticky icons approach [31] is the same in terms of controlling the C-D gain. Chapuis and Dragicevic investigated the effects of the visual scale and the *motor* scale on a small target [7]. In their study, note that they define visual scale as visual width but motor scale as not motor width but rather the C-D gain. Regarding a small target, they found that the motor and visual scale affects users' pointing performance even if the ID of Fitts' law is the same [7].

3 EXPERIMENT 1

Usuba et al. conducted an experiment with conditions where the motor and visual widths are equal or where the visual width is always one pixel [23]. Their results showed that the visual width does not affect users' performance even if the visual width is one pixel. However, their investigation was only with a small target. We therefore conducted an experiment with various combinations of motor and visual widths and investigated how the different widths affect users' movement.

3.1 Apparatus

We used an Apple MacBook Pro laptop (Intel Core i5, 2.4 GHz, 2 cores, Intel Iris 1536 MB, 8 GB RAM, macOS Sierra). The display scaling resolution was 1680 × 1050 pixels (the actual size was 13.3 inches, 286.47 × 179.04 mm, 0.17 mm/pixel resolution). The input device was an optical mouse, Logitech M100R (1000 dpi). The cursor speed was the macOS default. The full-screen experimental system was developed using JavaScript.

3.2 Participants

Fourteen volunteers participated in this study (3 females, *mean age* = 22.83, *SD* = 1.70 years). All participants were right-handed and operated the mouse with the right hand. Two participants usually used a mouse, and the others usually used a trackpad.

3.3 Task

An outline of the experimental tasks is given in Figure 2. We conducted 1D pointing tasks featuring several motor and visual widths. First, the motor target width was highlighted over the visual target width, which allowed the participants to know where they should click. This simulates a condition where users manipulate familiar applications and remember the motor width of the applications, as in Usuba et al.'s study [23]. Four hundred milliseconds after the motor width appeared, the motor width was hidden, and then the participants could start the trial. When they clicked any position, the cursor automatically moved to the middle of the start area (blue). When they clicked the start area, a sound was played to inform them of the trial beginning, and measurements began. Participants had to aim for the end area (green) as fast and accurately as possible. If the click was within the motor width, a success sound was played. However, if it was outside the motor width, a failure sound was played, and the trial was regarded as an error. The cursor color was changed from black to yellow when the cursor was within the motor width (as shown in Figure 3) so that participants could determine whether they should click. During the measurements, participants were not allowed to clutch the mouse, but they could perform this operation before starting the trial.

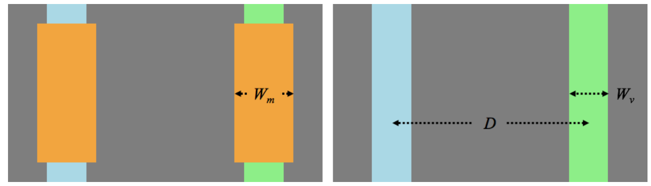

Figure 2: Experimental task outline. First, motor target width was highlighted (left). After 400 ms, the motor target width was hidden and the participants could start the trial (right).

3.4 Design and Procedure

Distance to the target D was 600 or 800 pixels (102.31 or 136.41 mm, respectively). Both the motor target width W_m and visual target width W_v were 20, 40, 70, or 120 pixels (3.41, 6.82, 11.94, or 20.46 mm, respectively). These correspond to conditions where the motor width was smaller than, equal to, and larger than the visual width. Motor and visual index of difficulty ID_m and ID_v were 2.58–5.36 bits. In pointing, it is known that user movement is ballistic if ID is less than 3.00 [12]. However, this has not been verified under the difference between motor and visual widths. One *set* consisted of D (2) × W_m (4) × W_v (4) = 32 trials in random order. Before starting the experiment, each participant received a brief explanation. After an introductory exercise set, each participant completed ten sets to produce experimental data. After completing all the sets, we asked each participant about the strategy they were using to try to complete the task under each condition. A total of 4,480 trials (i.e., D (2) × W_m (4) × W_v (4) × 10 sets × 14 participants) were carried out, and the whole time needed was approximately 15 min per participant.

3.5 Measurements

The cursor coordinates were recorded at approximately 100 Hz. The dependent variables were the reaction time RT (the time from the cursor color change to the trial end, excluding the error trials), the movement time MT (the time from clicking the start area to clicking the target, excluding the error trials), the pointing time PT (the value obtained by subtracting RT from MT), the spread of hits on the x-axis SD_x (the standard deviation of the x-coordinate of the cursor position, including the error trials), and the error rate.

3.6 Results

In 4,475 trials (excluding five outliers[2]), 144 pointing errors occurred (3.21%). This error rate is standard because it is approximately 4% [25, 28]. We analyzed the data using

[2] When the movement distances were less than $D/2$, the trial was regarded as an outlier [28]. We did not use a criterion that "the clicked position is far from $2W$ from the target center" because of the large difference of W_m and W_v).

repeated-measures ANOVA and the Bonferroni post hoc test. The independent variables were D, W_m, and W_v. The dependent variables were the same as described in the previous subsection. In graphs hereafter, the error bars represent standard error, and ***, **, and * indicate $p < 0.001$, $p < 0.01$, and $p < 0.05$, respectively.

Figure 3: Change of cursor color. If the cursor is within the motor target width, it turns yellow.

3.6.1 Reaction Time. We observed the main effects for W_v ($F_{3, 39} = 4.79$, $p < 0.01$, $\eta_p^2 = 0.53$) and W_m ($F_{3, 39} = 10.97$, $p < 0.001$, $\eta_p^2 = 0.76$). The results of the post hoc are shown in Figure 4. The interaction was found for $W_v \times W_m$ ($F_{9, 117} = 23.53$, $p < 0.001$, $\eta_p^2 = 0.93$, Figure 5). As shown in Figure 5, under each W_m, the fastest RT was when $W_m = W_v$. When $W_m = 40$ and $W_m = 70$ pixels, the shapes were U-shaped [1, 5]. In addition, we found that D did not affect RT. In the pointing task, it is known that error rate [30] and the duration of movement after peak velocity [24, 29] depend only on target size. Therefore, we assume that D did not affect the adjustment movement performed at the end of pointing, and thus D did not affect RT.

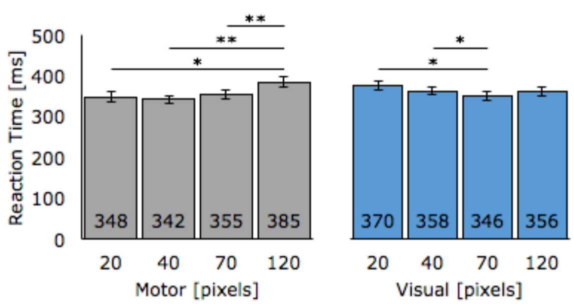

Figure 4: W_m versus RT and W_v versus RT.

3.6.2 Movement Time. We observed the main effects for D ($F_{1, 13} = 104.25$, $p < 0.001$, $\eta_p^2 = 0.89$) and W_m ($F_{3, 39} = 152.37$, $p < 0.001$, $\eta_p^2 = 0.76$). The post hoc test showed that increasing D and/or reducing W_m slowed down MT (Figure 6). Regarding W_v, there were no significant differences ($F_{3, 39} = 2.25$, $p = 0.098$, Figure 6). An interaction was found for $W_v \times W_m$ ($F_{9, 117} = 15.41$, $p < 0.001$, $\eta_p^2 = 0.44$, Figure 7). As shown in Figure 7, increasing W_v widened the gap between each W_m. In addition, for each W_m, the movement time was fastest when $W_m = W_v$. Similar to the reaction time, when $W_m = 40$ and $W_m = 70$ pixels, MT was U-shaped.

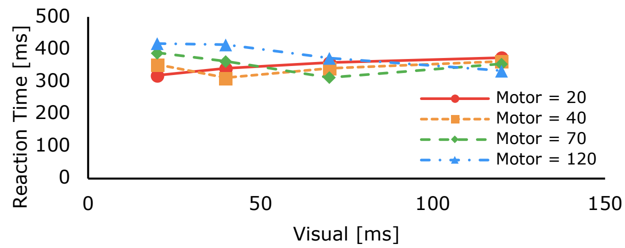

Figure 5: W_v versus RT for each W_m.

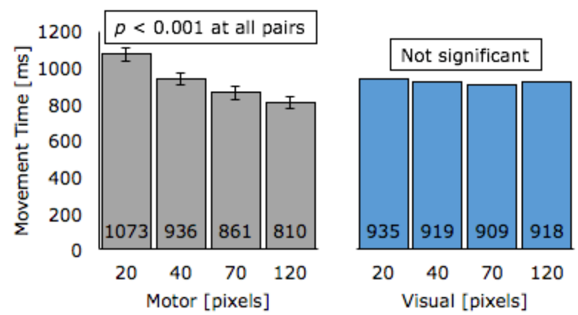

Figure 6: W_m versus MT and W_v versus MT.

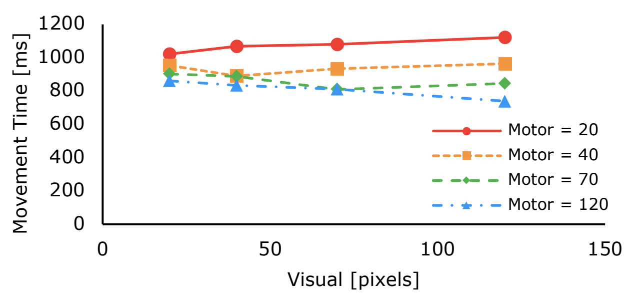

Figure 7: W_v versus MT for each W_m.

3.6.3 Pointing Time. We observed the main effects for D ($F_{1, 13} = 74.93$, $p < 0.001$, $\eta_p^2 = 0.85$) and W_m ($F_{3, 39} = 373.46$, $p < 0.001$, $\eta_p^2 = 0.98$). The post hoc test showed that increasing D and/or reducing W_m slowed down PT (Figure 8). Regarding W_v, there were no significant differences ($F_{3, 39} = 0.061$, $p = 0.98$, $\eta_p^2 = 0.021$, Figure 8).

3.6.4 Standard Deviation of X-coordinate. We observed the main effects for W_v ($F_{3, 39} = 4.22$, $p < 0.05$, $\eta_p^2 = 0.45$) and W_m ($F_{3, 39} = 113.65$, $p < 0.001$, $\eta_p^2 = 0.98$). The post hoc test showed that increasing W_m increased SD_x (Figure 9). An interaction was found for $W_v \times W_m$ ($F_{9, 117} = 3.90$, $p < 0.001$, $\eta_p^2 = 0.89$, Figure 10). As shown in Figure 10, when W_m was 70 pixels or more, increasing W_v increased SD_x.

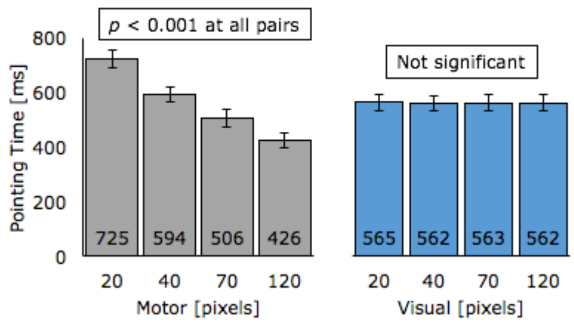

Figure 8: W_m versus PT and W_v versus PT.

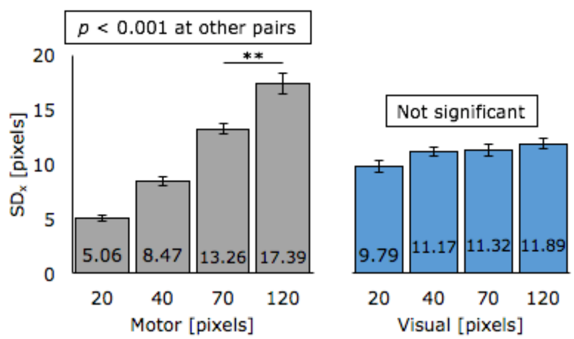

Figure 9: W_m versus SD_x and W_v versus SD_x.

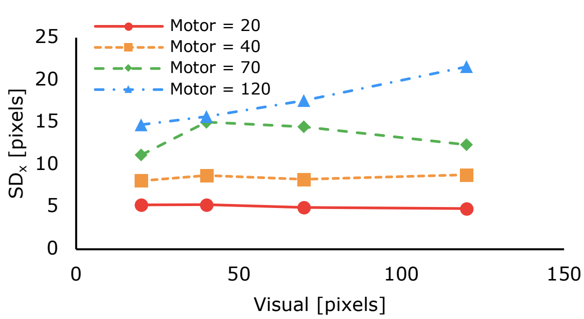

Figure 10: W_v versus SD_x for each W_m.

3.6.5 Error Rate. We observed the main effect for W_m ($F_{3, 39} = 15.04$, $p < 0.001$, $\eta_p^2 = 0.67$). The post hoc test showed that reducing W_m increased the error rate (Figure 11). Regarding W_v, there were no significant differences ($F_{3, 39} = 2.24$, $p = 0.099$, $\eta_p^2 = 0.15$, Figure 11). When W_m was 40 pixels or more, the error rate was approximately 4% or less.

3.6.6 Model Fitting. Figure 12 shows the fitness of Fitts' law for the 32 data points ($2D \times 4W_v \times 4W_m$). Considering that the typical threshold of coefficients of correlation is $R^2 > 0.90$ [14, 28], using ID_m and using ID_v is not a good fit ($R^2 = 0.86$ and $R^2 = 0.01$, respectively).

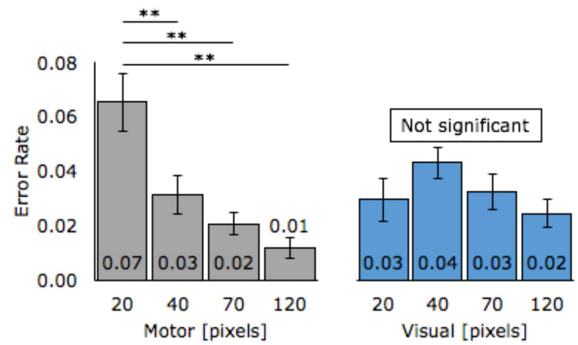

Figure 11: W_m versus error rate and W_v versus error rate.

3.7 Discussion

Compared with Usuba et al.'s results [23], we believe that the participants' movement here shows the same tendency. For example, Usuba et al. found that the reaction time when the motor and visual widths are the same was faster than when the visual width is always one pixel. Our experimental results also showed that the reaction time was the fastest when the motor and visual widths are the same. In addition, Usuba et al. found that users' movement depends on not the visual width but on the motor width. According to the pointing time in our experimental results, we believe that the participants' movement also depends on the motor width.

We found that the reaction time was U-shaped with the lowest point where $W_m = W_v$. According to the results in Figure 5, although $W_m = 20$ and $W_m = 120$ pixels did not show the U-shaped function, it was simply because those W_m values were the smallest and largest in the tested conditions, respectively. Therefore, we believe that these would have been U-shaped if there were smaller/larger targets. In addition, we found that the participants delayed the reaction when the visual and motor widths are different. Specifically, several participants aimed at the visual target when the visual and motor widths are equal but only actually performed pointing while watching the change of the cursor color when not equal. We believe that these different strategies affected the reaction time. According to the results in Figure 7, the fastest movement time was when W_m and W_v were equal, and the movement time was also U-shaped. However, analysis of the pointing time showed that the pointing time was not U-shaped (Figure 8). We therefore conclude that the shape of the movement time was due to what the reaction time was U-shaped. According to Figure 8, the pointing time depends not on W_v but on W_m. Several participants performed pointing by relying on their memory of the motor width (W_m), not on the displayed visual width (W_v) when W_m and W_v are different. Basically, the x spread was widened by not W_v but W_m (Figure 9 and Figure 10), which shows that the participants aimed at the motor width (W_m).

Regarding the error rate, it was approximately 4% or less when W_m was 40 pixels or more. As mentioned above, because the participants aimed at the motor width, i.e., they performed pointing by putting the cursor on the motor width, we believe that this error rate is standard. In addition, because the overall error rate is lower than 4%, we re-analyzed the fitness with the effective width (Equation 2). Figure 12 shows that using the effective width resulted in a better fit ($R^2 = 0.91$). We believe that this also shows that the participants aimed at the motor width.

To summarize experiment 1, we found that 1) the participants' movement depends on the target's motor width, as participants aimed at the motor width rather than the visual width, and 2) the reaction time was shortest when W_m and W_v are equal.

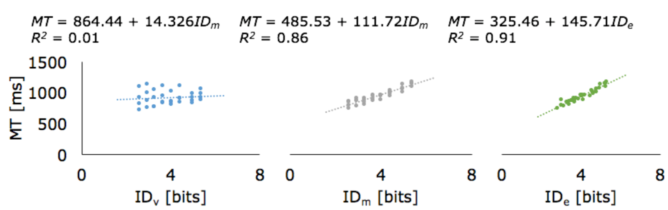

Figure 12: Model fitting with ID_v, ID_m, and ID_e.

4 EXPERIMENT 2

In this section, we describe the second experiment, where the motor width is controlled by the ratio. If the ratio is 0.80, the motor width is the visual width multiplied by 0.80. In several studies [e.g., 9, 22] where target width is changed dynamically, the final target width is doubled as the target widths, and thus it is controlled by the ratio. Considering the results of experiment 1, we believe that the reaction time is U-shaped with the origin as the point at which the ratio is 1.00. In other words, the difference between the motor and visual widths increases would negatively affect the reaction time. In experiment 1, for example, when W_m = 120 pixels, W_m was consistently W_v or more. Therefore, in experiment 2, with the ratio controlling the motor width, we set up the experiment such that the motor width is larger than, equal to, and smaller than the visual width in all conditions. Note that experiment 2 was conducted after experiment 1 on the same day. We used the same apparatus, participants, task, and measurements for both experiments; only the task parameters were different, as described below.

4.1 Design and Procedure

The distance to target D and visual target width W_v were the same as experiment 1. Instead of motor target width W_m, there was ratio $R_{m/v}$. $R_{m/v}$ was 0.60, 0.80, 1.00, 1.20, or 1.40. Again, if $R_{m/v}$ = 0.80 and W_v = 40 pixels, W_m = 32 pixels (= 0.80 × 40). Table 1 lists all W_m generated by W_v and $R_{m/v}$. The visual index of difficulty ID_v was the same as experiment 1, and motor index of difficulty ID_m was 2.19–6.08 bits. The order of D, W_v, and $R_{m/v}$ was randomized. One *set* consisted of D (2) × W_v (4) × $R_{m/v}$ (5) = 40 trials. The participants completed ten sets and then answered questions about which strategy they were using to try to complete the task under each condition. A total of 5,600 trials (i.e., D (2) × W_v (4) × $R_{m/v}$ (5) × 10 sets × 14 participants) were carried out, and the whole time needed was approximately 20 min per participant.

Table 1: All W_m generated by W_v and $R_{m/v}$.

W_v	$R_{m/v}$				
	0.60	0.80	1.00	1.20	1.40
20	12	16	20	24	28
40	24	32	40	48	56
70	42	56	70	84	98
120	72	96	120	144	168

4.2 Results

In 5,595 trials (excluding five outliers), 172 pointing errors occurred (3.07 %). We analyzed the data using repeated-measures ANOVA and the Bonferroni post hoc test. The independent variables were D, W_v, and $R_{m/v}$. The dependent variables were the same measurements described in the previous section.

4.2.1 Reaction Time. We observed the main effect for $R_{m/v}$ ($F_{5,52} = 12.06$, $p < 0.01$, $\eta_p^2 = 0.91$). The post hoc test showed that RT has a U-shaped function with $R_{m/v}$ = 1.00 as the origin (Figure 13). This indicates that RT is slowed down when W_m is larger/smaller than W_v.

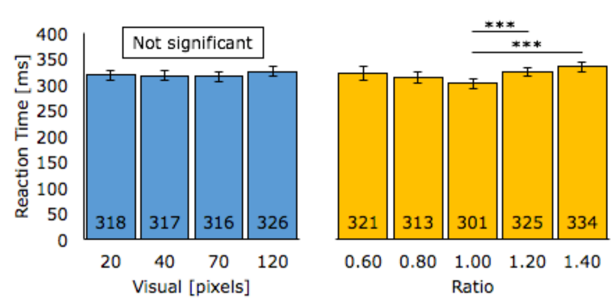

Figure 13: W_v versus RT and $R_{m/v}$ versus RT.

4.2.2 Movement Time. We observed the main effects for D ($F_{1,13} = 56.54$, $p < 0.001$, $\eta_p^2 = 0.81$), W_v ($F_{3,39} = 423.71$, $p <$

0.001, η_p^2 = 0.98), and $R_{m/v}$ ($F_{4, 52}$ = 55.25, p < 0.001, η_p^2 = 0.90). The post hoc test showed that increasing D, reducing W_m, and/or reducing $R_{m/v}$ slowed down MT (Figure 14).

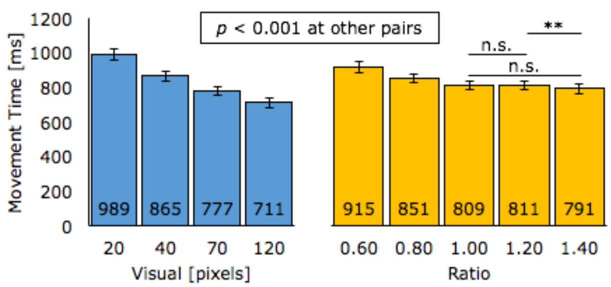

Figure 14: W_v versus MT and $R_{m/v}$ versus MT.

4.2.3 Pointing Time. We observed the main effects for D ($F_{1, 13}$ = 50.27, p < 0.001, η_p^2 = 0.79), W_v ($F_{3, 39}$ = 1151.88, p < 0.001, η_p^2 = 0.99), and $R_{m/v}$ ($F_{4, 52}$ = 282.32, p < 0.001, η_p^2 = 0.98). The post hoc test showed that increasing D, decreasing W_v, and/or decreasing $R_{m/v}$ increased PT (Figure 15).

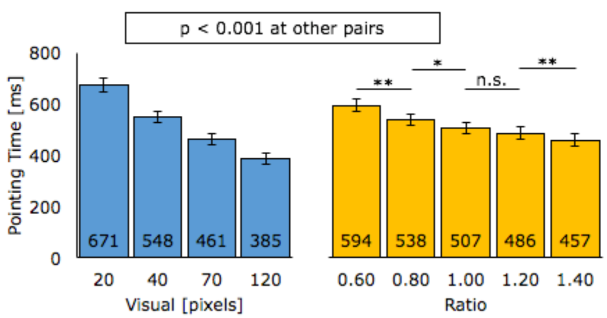

Figure 15: W_v versus PT and $R_{m/v}$ versus PT.

4.2.4 Standard Deviation of X-coordinate. We observed the main effects for W_v ($F_{3, 39}$ = 245.59, p < 0.001, η_p^2 = 0.98) and $R_{m/v}$ ($F_{4, 52}$ = 45.01, p < 0.001, η_p^2 = 0.94). The post hoc test showed that increasing W_v and/or $R_{m/v}$ increased SD_x (Figure 16). An interaction was found for $W_v \times R_{m/v}$ ($F_{12, 156}$ = 8.76, p < 0.001, η_p^2 = 0.97, Figure 17). As shown in Figure 17, increasing W_v widened the gap between each $R_{m/v}$.
4.2.5 Error Rate. We observed the main effects for W_v ($F_{3, 39}$ = 12.06, p < 0.001, η_p^2 = 0.48) and $R_{m/v}$ ($F_{4, 52}$ = 5.84, p < 0.01, η_p^2 = 0.31). The post hoc test showed that reducing W_v and/or reducing $R_{m/v}$ increased the error rate (Figure 18).
4.2.6 Model Fitting. Figure 19 shows the fitness of Fitts' law for the 40 data points (2D × 4W_v × 5$R_{m/v}$). Considering that the typical threshold of coefficients of correlation is R^2 > 0.90 [14, 28], using ID_m was a good fit (R^2 = 0.97); however, using ID_v is not good (R^2 = 0.83).

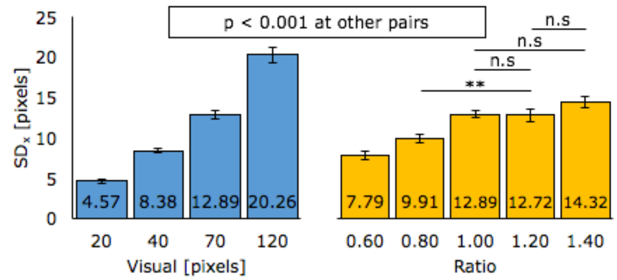

Figure 16: W_v versus SD_x and $R_{m/v}$ versus SD_x.

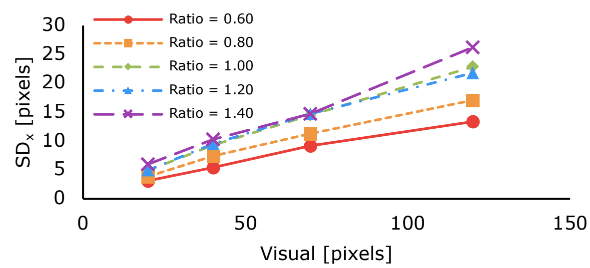

Figure 17: W_v versus SD_x for each $R_{m/v}$.

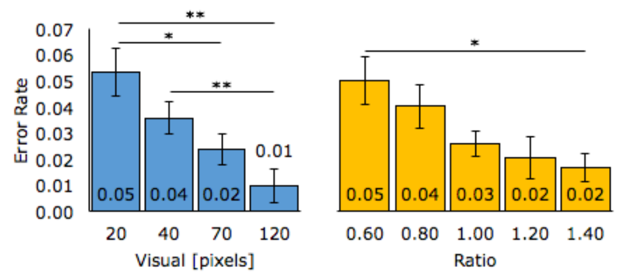

Figure 18: W_v versus error rate and $R_{m/v}$ versus error rate.

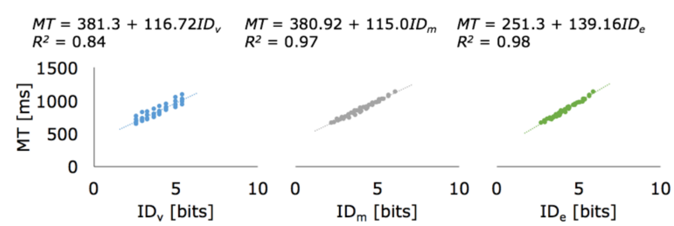

Figure 19: Model fitting with ID_v, ID_m, and ID_e.

4.3 Discussion

Similar to experiment 1, we found that the reaction time was U-shaped with the optimal point located where W_v = W_m (Figure 13), i.e. $R_{m/v}$ = 1.00. This suggests that the delay of the reaction time is caused by the difference between the motor and visual widths. In experiment 2, regarding the movement time and the pointing time, decreasing W_v and/or $R_{m/v}$ slowed them down. In experiment 1, in contrast to experiment 2, W_v did not affect the movement time or the pointing time. Again, Table 1 shows that the range of W_m that each W_v has was different. Therefore, we believe that the effect stems not from W_v itself but rather the condition of experiment 2. In experiment 1, as shown in Figure 7, the movement time was U-shaped. As shown in Figure 13, the difference between the maximum and minimum values was 13 ms, and the reaction time had little effect on the movement time; thus, in experiment 2, we believe that the movement time (Figure 14) was not U-shaped.

In addition, as in experiment 1, the results showed that the error rate was approximately 4% or less when W_m is 40 pixels or more.

Regarding the model fitting, it is the same as experiment 1, i.e., using ID_m was a better fit than ID_v. However, both R^2 were higher than in experiment 1. Regarding ID_v, because W_m is controlled by $R_{m/v}$, as Table 1 shows, the range of W_m that each W_v has was different. In addition, the average of W_m each W_v has equals W_v, so the small W_v had a small average of W_m and the large W_v had a large average. Therefore, because W_v and W_m were correlated, the movement time of ID_v was affected by W_m, and thus we assume that the R^2 was higher than in experiment 1. Regarding ID_m, although the movement time was affected by the difference between W_m and W_v (Figure 7), the difference between W_m and W_v in experiment 2 was smaller than in experiment 1, and the effect of the difference was also smaller, so we assume that the R^2 was higher. Additionally, using ID_e (Equation 2) was a good fit in both experiments 1 and 2. The effective width allows users to predict the movement time of pointing under the difference between the motor and visual widths.

5 GENERAL DISSCUSION

This study can be summarized as follows.

1) Users perform pointing while aiming at motor target width, not visual target width.
2) The reaction time is a downward U-shaped function with the origin at a point where the motor and visual widths are equal.
3) The movement time is affected only by the motor width.
4) The error rate was approximately 4% or less when the motor width is 40 or more.
5) Fitts' law with the effective width can predict the movement time under the difference between the motor and visual widths ($R^2 > 0.90$).

5.1 Implications

A Web site[3] cited by Johnson as an example [20] contains buttons with a difference between the motor and visual widths. The visual width is approximately 220 pixels and the motor width is approximately 40–190 pixels. We believe that users delay clicking buttons because of this difference. Regarding the error rate, users would not be frustrated with clicking buttons because the motor width is larger than 40 pixels. Regarding Figure 1a, although users can click items with almost no error because the motor width is larger than 40 pixels, they still delay clicking because of the difference. These results suggest that designers should make the motor width 40 or more in order not to frustrate users and should make the motor width as close as possible to the visual width if they would like users to operate faster. Because we found that larger motor sizes decreased the movement time, we recommend using large items both in terms of visual and motor sizes. In addition, users' performance is predictable by Fitts' law using the motor width (ID_m) and the effective width (ID_e), so we suggest that designers use these models, rather than ID_v, for adjusting interfaces.

5.2 Limitations and Future Work

There are several conditions that we have not verified. First, Usuba et al. investigated the condition where users do not know the motor width [23]. In this study, the participants always saw the motor width before starting a trial. We also gave the participants visual feedback by means of color change when the cursor hovered over the motor width. Therefore, if the visual feedback were shape change (e.g., changing from the default cursor to the resize cursor), we are not certain how that feedback would affect user performance. Although the condition where visual widths with extremely larger motor widths may not exist in GUIs, we have not investigated such conditions. If we experimented using this condition, we would be able to determine, for example, the thresholds of the visual and motor widths where the reaction time is U-shaped. In addition, we did not experiment under the condition where the visual width is controlled by the ratio. If we did, we could clarify how the visual width affects users' movement.

In the navigation bar on GUIs, there are objects similar to a target button. Figure 20 shows an example of this as a 1D pointing task. The objects line up at an interval I and the middle of the objects is the target. In this task, we believe that peripheral objects and the interval allow users to predict motor target width, and thus the users may perform pointing faster and more accurately than under our experimental conditions. We also feel that the users aim at the middle of the target so as to avoid clicking on peripheral objects.

[3] 2011 Aging in America Conference: https://web.archive.org/web/20110308051632/http://www.asaging.org/aia11/

Pointing by touch input is a major theme in research on pointing, and there have been several studies on clarifying touch input [e.g., 3, 19]. We also have an interest in how the difference between the motor and visual widths affects pointing by touch input. In touch input, users cannot perform pointing while also watching the changes of cursor color (in short, exploring the motor width) because they point at a target directly. In situations such as Figure 1a, we assume that users aim at the text (the visual width) because they think the text length equals motor width. Therefore, in pointing by touch input, we believe that the visual width would affect the movement time, the spread of the x-coordinate, and the error rate.

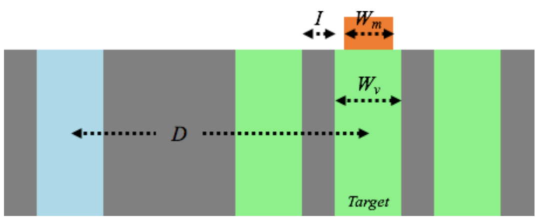

Figure 20: False objects around a target.

6 CONCULUSION

In this paper, we conducted two pointing experiments to examine the difference between motor and visual widths. Results showed that user performance depends on the motor width because this is the one that users aim at. These results should help designers to improve pointing interfaces.

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