

Effects of Delboeuf Illusion on Pointing Performance

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ABSTRACT

It is not widely known that visual illusions that cause misrecognition with regard to the perception of length or width of figures affect human behavior. Thus, we investigate the influence of the Delboeuf illusion on pointing performance in this study. If the control circle of the Delboeuf illusion, which is the central circle of the Delboeuf illusion figure, is surrounded by a slightly larger circle, it is perceived to be larger than its actual size. On the contrary, if the control circle is surrounded by a much larger circle, it is perceived to be smaller than its actual size. Therefore, the Delboeuf illusion figure affects the perception of circle sizes and can also affect the movement time of pointing movements. The result indicates that there is no significant difference in the movement time and the error rate among three tasks—two tasks with the Delboeuf illusion and the other task without the Delboeuf illusion. Moreover, Fitts' law showed sufficient fits for all conditions. From these results, it can be said that the participants conducted the trials with the Delboeuf illusion as same as the trial without the Delboeuf illusion. This is because the participants saw the circles of the Delboeuf illusion at once in the questionnaire, but they saw the circles one by one during the trials so the illusion magnitude was difference between trials and a questionnaire.

CCS CONCEPTS

• **Human-centered computing** → **Human computer interaction (HCI)**.

KEYWORDS

Delboeuf illusion, visual illusion, Fitts' law, pointing movements

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1 INTRODUCTION

There are several visual illusions that cause misrecognition with regard to the perception of length or width of figures, and such

illusions have been investigated for a long time. However, it is not widely understood whether visual illusions affect human behavior and how strong their effects are in case they do. There are several human behavior models. Among these models, Fitts' law can predict the movement time of pointing tasks by means of the target width and the distance.

In this study, we focus on the effects of the Delboeuf illusion. The Delboeuf illusion is a visual illusion that causes misrecognition in terms of the perception of its control circle, which is the central circle of the Delboeuf illusion figure. If the control circle is surrounded by a slightly larger circle, the control circle is perceived to be larger than its actual size. On the contrary, if the control circle is surrounded by a much larger circle, the control circle is perceived to be smaller than its actual size.

If we can reveal the effect of visual illusion on pointing performance, we can apply them to graphical user interfaces (GUIs) in order to enhance usability and accuracy of human performance in pointing. For example, if a user perceives the target size to be larger than its actual size, he or she would operate the cursor faster so the movement time would be shorter. As another example, if a user perceives the target size to be smaller than its actual size, he or she would operate the cursor more carefully, thereby decreasing the error rate.

Our goal is to reveal the relations between the Delboeuf illusion and pointing movements.

First, we analyzed whether the participants perceived the Delboeuf illusion's effects. As a result, we found that the participants perceived the effect, so we investigated the effects of the Delboeuf illusion on pointing performance. We revealed that the Delboeuf illusion did not affect the pointing performance in the conditions of this study, though the participants perceived visual illusion. Thus, we wondered whether the movement time of pointing movements using the Delboeuf illusion demonstrated a good fit of Fitts' law because it seemed that the participants undertook pointing tasks using the Delboeuf illusion as same as the normal one, which are pointing tasks without the Delboeuf illusion. Consequently, we observed that the movement time showed a good fit of Fitts' law.

2 RELATED WORK

2.1 Pointing movements using visual illusion

There have been studies of relations between visual illusions and pointing movements. Knol et al. investigated the elements that affected the illusion magnitude of the Ebbinghaus illusion by using Fitts' law task [6]. In their study, they found that the size of the context circles affect the illusion magnitude of the Ebbinghaus illusion, but their results did not demonstrate a good fit of Fitts' law. In addition, Donkelaar found that visual illusions affect the

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movement time, but they did not affect the error rate of pointing movements [10].

2.2 Effects of visual illusions

Ittersum et al. observed that a plate filled with food has the same effect as the Delboeuf illusion, causing underserving and overserving of food [11]. Moreover, they found that high color-contrast condition, attention, and not having prior knowledge make these effects stronger. In contrast, low color-contrast condition, less attention, and having prior knowledge make these effects weaker.

Hara et al. investigated effects of the Müller–Lyer illusion [5]. They found that the Müller–Lyer illusion affects the planning phase of movements, thereby verifying the effects of visual illusions on behavior.

2.3 Differences in plasticity

Girgus et al. investigated the differences in plasticity, focusing on the Delboeuf, Ebbinghaus, and Ponzo illusions [4]. They divided these visual illusions into two groups—contrast and assimilation. A visual illusion that causes overestimation is classified as the assimilation illusion, and the one that causes underestimation is classified as the contrast illusion. They found that the more times participants see contrast illusions, the less effects they acquire. In contrast, no matter how many times participants observe assimilation illusions, their effects do not get smaller.

3 EXPERIMENT

3.1 Apparatus

Figure 1 shows experimental apparatuses: we used an HP Spectre 13-ac000 x360 (Intel Core i7, 2.7 Gz) and a Logicoool MX Anywhere 2S Wireless Mobile Mouse (1000 dpi). The display resolution was 1920×1080 pixels (the actual size was 13.3 inches). The cursor speed was Windows 10's default settings. The experimental system was developed by using Processing and displayed in full screen.

3.2 Participants

Twelve volunteers participated in this experiment (4 females, *mean age* = 21.1, *SD* = 1.50). All participants operated the mouse with their right hand.

3.3 Task

The task included two black circles; depending on conditions, the two circles were surrounded by larger circles (Figure 2). The participants need to click the left circle and then click the right circle (target) as quickly and accurately as possible. When the participants clicked the black area of the start circle, a start sound was played and a trial began. If the click was within the black area of the end circle, a success sound was played. Otherwise (i.e., when the participants clicked the margin between the black area and the outer circle), a failure sound was played and the trial was regarded as an error. The participants were instructed not to perform *clutching* (raise up the mouse and then reposition it) because it is known that the performance of pointing operations changes depending on the number of the clutching [2].

3.4 Design and Procedure

The width of the black circles W was 20, 40, 70, 100 pixels (3.06, 6.12, 10.7, or 15.3 mm, respectively). The distance D between the centers of two circles was either 600 or 800 pixels (91.8 or 122.4 mm, respectively). In addition, there were three target types T : *Normal*, *Assimilation*, and *Contrast*. In $T = \textit{Normal}$, the outer circles did not exist; thus, this is a normal pointing task. When $T = \textit{Assimilation}$ or $T = \textit{Contrast}$, the two black circles were surrounded by larger circles. In $T = \textit{Assimilation}$, the left circle was surrounded by a circle with width of $4.071 \times W$ and the right circle was surrounded by a circle with width of $1.357 \times W$. $T = \textit{Contrast}$ was the opposite of $T = \textit{Assimilation}$; the left circle was surrounded by a circle with width of $1.357 \times W$ and the right circle was surrounded by a circle with width of $4.071 \times W$. In $T = \textit{Assimilation}$, we presume that because the target looked larger than its actual size, the movement time is smaller than that of the same W and D condition for $T = \textit{Normal}$. On the contrary, in $T = \textit{Contrast}$, we presume that the target looked smaller than its actual size; the movement time is larger than that of the same W and the D condition for $T = \textit{Normal}$. In these conditions, we believe that the participants conducted the pointing task under the Delboeuf illusion.

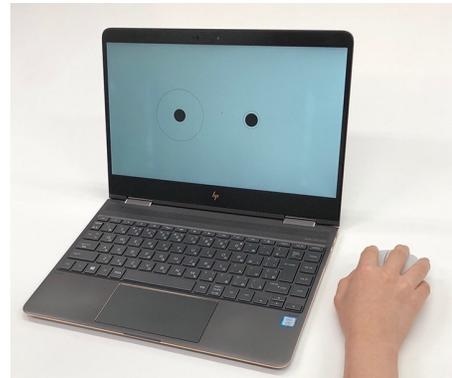


Figure 1: Apparatus

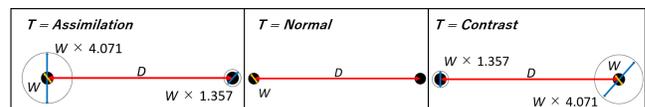


Figure 2: Experimental task outline

One *set* comprised $4W \times 2D = 8$ trials for a fixed T condition in random order. The participants conducted one set as practice and then ten sets to produce experimental data. The order of T was balanced by Latin square law among the participants. A total of 2,880 (i.e., $4W \times 2D \times 3T \times 10 \text{ sets} \times 12 \text{ participants}$) trials were performed, and the entire time was approximately 20 min per participant. Before starting the experiment, each participant received a brief explanation.

After each experiment, we conducted a questionnaire. In a questionnaire, like the experimental task, two circles were displayed. We

asked whether the right circle looks larger, smaller or equal to the left circle by each condition (i.e., $4W \times 2D \times 3T$). The participants chose a score (7-point Likert scale; -3: very small, 0: neutral, 3: very large) depending on their perception.

4 RESULT

Among the 2,841 trials (excluding 39 outliers¹), 64 errors occurred (2.25%). We analyzed the data by using repeated-measures analysis of variations (ANOVA) with Bonferroni correction as the p -value adjustment method. The independent variables were D , W , and T , and the dependent variables were the movement time (MT : the time from clicking the start circle to clicking the end area, excluding the erroneous trials), subjective evaluation (how large the right circle is compared to the left circle; 7-point Likert scale; -3: very small, 0: neutral, 3: very large), and the error rate. In our graphs of the results, the error bars represent the standard error, and ***, **, and * indicate $p < 0.001$, $p < 0.01$, and $p < 0.05$, respectively.

4.1 Subjective Evaluation

We checked whether the Delboeuf illusion occurred to the participants via a subjective evaluation. We observed the main effect T ($F_{2,22} = 14.78, p < 0.001, \eta_p = 0.57$) not D ($F_{1,11} = 0.028, p = 0.87, \eta_p = 0.0025$) and W ($F_{3,33} = 0.36, p = 0.78, \eta_p = 0.032$). As shown in Figure 3 left, in $T = \text{Assimilation}$, the participants believed that the right circle is larger than the left circle, and, $T = \text{Contrast}$ had the opposite effect of $T = \text{Assimilation}$. We also observed the interaction for $W \times T$ ($F_{6,66} = 5.41, p < 0.001, \eta_p = 0.33$). On increasing W , the participants were more affected by the Delboeuf illusion (Figure 3 right). From this result, we observed that the participants were affected by the Delboeuf illusion during the task.

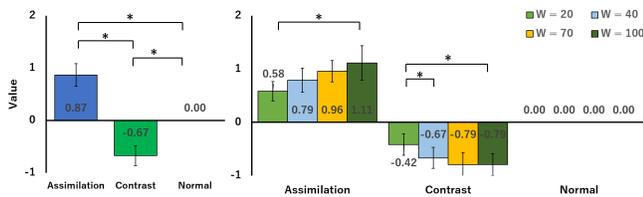


Figure 3: (left) Relation between the target type and the Likert-scale rating. (right) Relationship between the target type and the Likert-scale rating in terms of each target width.

4.2 Movement Time

We observed the main effects for D ($F_{1,11} = 6.20, p < 0.05, \eta_p = 0.36$) and W ($F_{3,33} = 10.43, p < 0.001, \eta_p = 0.49$) not T ($F_{2,22} = 0.91, p = 0.42, \eta_p = 0.076$). Figure 4 shows the results of the post-hoc test. No interactions were observed.

¹We used the criteria of [1, 9]. When the movement distances were less than $D/2$, the trial was regarded as an outlier. In addition, we did not use a trial where the click position is more than $2W$ away from the target center.

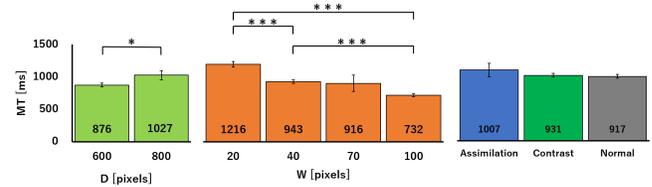


Figure 4: Relation of movement time to distance, target width, and target type.

4.3 Error Rate

We observed the main effect for W ($F_{3,33} = 4.12, p < 0.05, \eta_p = 0.27$) not D ($F_{1,11} = 1.02, p = 0.34, \eta_p = 0.085$) and T ($F_{2,22} = 0.60, p = 0.56, \eta_p = 0.052$). Figure 5 shows the results of the post-hoc test. No interactions were observed.

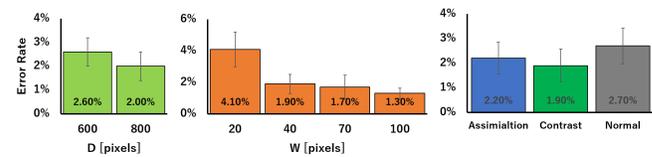


Figure 5: Relation of error rate to distance, the target width, and target type

4.4 Model Fitting

Fitts' law (Equation 1) can predict the movement time (MT_f) of pointing the target with a certain width (W_f) and distance (D_f) [3, 7].

$$MT_f = a + b \log_2 \left(\frac{D_f}{W_f} + 1 \right) \quad (1)$$

where a and b are the regression constants. The logarithm term is called ID (index of difficulty), and high ID indicates that it is difficult for users to perform pointing operations and the operations take time; the predicted MT become large. Basically, Fitts' law is suitable for one-dimensional pointing tasks; the target has certain width and infinite height, however, later, it is revealed that the model can be applied to circular targets [8].

We found that the target type (T) does not affect the movement time (MT); the participants conducted the pointing task depending on the inner circle width (W), not the outer circle width (T). Thus, we verified the model fitness for Fitts' law that uses the inner circle width (W) by each T . As shown in Figure 6, Fitts' law showed sufficient fits ($R^2 > 0.89$) for all T conditions.

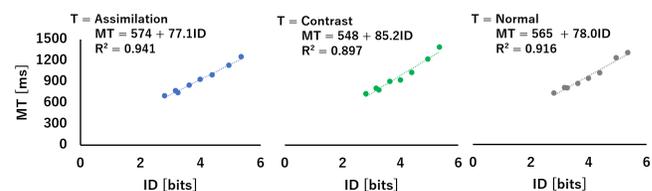


Figure 6: Relation between MT and ID .

5 DISCUSSION

We found that the movement time depends on the target width W and the target distance D but not on the target type T , and it showed a good fit of Fitts' law.

From these results, it can be said that the participants conducted the task in $T = Assimilation$ and $T = Contrast$ as same as that in $T = Normal$. In other words, the Delboeuf illusion did not affect the movement time and the error rate in trials, though the participants perceived visual illusion in the questionnaire.

There are several reasons that caused the results. First, the participants saw two circles at once in the questionnaire. However, the participants did not see the two circles at once during the trials; they saw the circles one by one. The participants see the figures on display in different ways depending on the situation and this resulted in the illusion magnitude being different between trials and a questionnaire. Second, it is known that the longer the participants concentrate on the Delboeuf illusion, the stronger effects they get [11]. When the participants see the Delboeuf illusion with focused attention, the participants obtain a stronger effect than when they see it without focused attention. However, the participants were instructed to aim for the target as quickly as possible so they did not see the circles with focused attention. Finally, it is known that the Delboeuf illusion do not affect the person strongly who knows about the Delboeuf illusion [11]. However, all participants knew about the Delboeuf illusion and its effect and this could cause to weaken the illusion effect. Therefore, the Delboeuf illusion effect was different between trials and a questionnaire and was not strong enough to affect the pointing performance.

6 LIMITATION AND FUTURE WORK

In this study, we found that the Delboeuf illusion did not affect pointing performance. However, this can be said only for the conditions of this study. Furthermore, there is no significant difference between $T = Assimilation$ and $T = Contrast$, so it can be said this result was caused no matter what size the outer circle was. In other words, this could be caused not by the Delboeuf illusion but by outer circles themselves. Therefore, in future studies, we would investigate the effect of outer circles; for this, we will require a task that comprises two circles with outer circles of the same size.

Moreover, the Delboeuf illusion gains its illusion magnitude owing to high color contrast [11]; therefore, we would redesign the experiment to gain its color contrast. If the illusion magnitude increases, the participants will obtain a more strong influence by the figures on display. For example, the participants will operate the cursor more faster in $T = Assimilation$. In this study, all participants knew the Delboeuf illusion and its effect; therefore, we need participants who do not know about the Delboeuf illusion in order to strengthen the illusion's effect.

Furthermore, it is known that visual illusions affect the planning phase of human performance [5], so if they see the figures entirely at the beginning of each trial, the visual illusion could affect pointing performance. However, we did not instruct the participants to observe the circles on the whole at the beginning of each trial. To investigate the effect of visual illusion in detail, we would instruct the participants to observe the figures on the whole when they start each trial in future studies.

All these future works will be conducted for clarifying whether we should ignore the effect of the Delboeuf illusion and for making the most of its effect if people are influenced by the effect.

Besides, Knol et al. investigated the effects of the Ebbinghaus illusion on pointing performance [6]. In their study, they focused on the Ebbinghaus illusion, and we focused on the Delboeuf illusion. The control circle of the Ebbinghaus illusion is surrounded by several larger or smaller circles. The visual illusions are different, but both cause misrecognition in the perception of its control circle; thus, they are similar to each other. However, the results are completely different, so we would like to investigate whether their experiment design was correct and the reasons for this difference.

7 CONCLUSION

In this paper, we investigated the effects of the Delboeuf illusion on pointing performance. We found that although the participants perceived visual illusion via a questionnaire, there is no significant difference in the movement time and the error rate among the three different conditions. We concluded that the participants did not perceive as strong an illusion as they did in a questionnaire. This could be caused by that the participants did not see the circles with focused attention and knew about the Delboeuf illusion and its effect beforehand.

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