Ebbinghaus Illusion in the Tactile Modality

Mounia Ziat*, Erin Smith1, Cecilia Brown1, Carrie DeWolfe1, Vincent Hayward2
1Psychology Department, Northern Michigan University, Marquette, MI
2UPMC Univ Paris 06, Institut des Systèmes Intelligents et de Robotique, Paris, France

ABSTRACT

In this paper, we report the first evidence for the existence of the Ebbinghaus illusion in the tactile modality. Participants were asked to explore bimanually two sets of Ebbinghaus circles while blindfolded. The results show that the participants are more likely to be deceived when an illusion-induced stimulus is present than when a control stimulus (no illusion) is present. These results contribute to the perception-action debate. The existence of the tactile equivalent of the Ebbinghaus illusion weighs in favor of the two-stream hypothesis that assumes the existence of separated pathways for action and perception.

Keywords: Ebbinghaus illusion, Titchener illusion, Tactile modality, Tactile-Visual analogy, perception-action, visual pathways.

Index Terms: [Human-centered computing]: Human computer interaction (HCI) — Interaction paradigms; Empirical studies in HCI.

1 INTRODUCTION

Besides their mind-bending and impressive character, perceptual illusions are powerful paradigms used to investigate and study human perception. Visual illusions have been intensively studied and help to categorize the ones that occur in the early stages of the visual system, such as Hermann Grid [1] and those requiring top-down processing such as inattentive blindness where attentional mechanisms contribute to the perception of the illusion [2]

![Ebbinghaus illusion](image)

Figure 1: Ebbinghaus illusion: the inner circle surrounded by the larger outer circles looks smaller than the inner circle (of the same size) surrounded by smaller outer circles.

In this paper, we investigate the transposition of a well-known visual illusion in the touch modality. Specifically, we created a counterpart of stimuli that elicit the Ebbinghaus or Titchener illusion; Titchener being the first to report Ebbinghaus’ work in a Textbook [3]. The Ebbinghaus illusion is linked to the effects of visual context to change the apparent size of an object [4]. The illusion consists of seeing the inner circle surrounded by larger outer circles smaller than the inner circle surrounded by smaller outer circles. Although both inner circles are the same size, the size of the outer circles affects the perceptual outcome and creates the illusion of perceiving one inner circle larger than the other (Figure 1).

Only a few haptic illusions have visual counterparts. However, we will focus only on the visual-tactile analogy (see [5], [6], [7], and [8] for a full review of tactile and haptic illusions). Visual illusions that have comparable equivalents in touch are mainly geometrical or movement illusions such as Müller-Lyer, Penzo illusion, or Horizontal-Vertical Illusion. In the case of geometrical illusions, blindfolded or visual impaired participants are asked to tactiley explore the stimuli with either their finger or their hand. The illusion effects are often weaker in touch than in vision [6].

In the case of illusions related to movement, Ziat et al. described the phenomenon of tactile suppression of displacement [9] that is equivalent to the visual saccadic suppression of image displacement [10], where the participants failed to detect the change of a moving stimulus due to the brief interruption of sensations on the sensory receptors. In this case, the brain fails to detect the change because the stimuli appears too early than what the participants had expected. This putative predictive brain strategy (more details in [9]) has been supported by events-related potentials (ERPs) results [11].

2 EBBINGHAUS ILLUSION IN GRASPING

The first study that investigated Ebbinghaus illusion in motor action showed that grasping was not affected by the illusion suggesting that the conscious perception pathway and visually-guided action pathway are separated in the brain [12]. These results have been corroborated by the same team of researchers [13], [14] under different conditions, suggesting that motor systems resist optical illusions [15]. Obstacle avoidance (participants avoiding the outer circles) seems to affect the grip trajectory and thus, reduce the illusion in motor action. However, Pavani et al. obtained opposite results; that’s said the illusion affects grasping aperture and suggested that both visual pathways (perception and action) share similar functional properties [16]. Other studies [17], [18] suggested that there was no evidence that both pathways are separated in the visual system. For instance, Franz et al. [17] used a much larger sample than the original study [12] and only one stimulus was shown at the same time. Others suggested a planning/control model of the grip that contributed to the illusion [19]. Whether the Ebbinghaus illusion exists in grasping is still an open question, but this illusion has played an important role in the debate of the existence of perception-action streams in the visual system (one for conscious perception and one for visually-guided action) as suggested by Goodale and Milner [20]. A more recent study showed that the illusion is dependent on the context sensitivity, which is less present in children younger than 10 years old and thus were less sensitive to the illusion [4].

The motivation behind this study is to contribute to the debate of perception-action dissociation in the brain by having blindfolded participants tactiley explore Ebbinghaus circles to investigate whether the illusion exists in active touch. Blindfolding procedure to explore perception-action dissociations is not new as it has been extensively used in blind-walking experiments [21] and walkable illusions [22]. It is important to point out that not all actions are visually guided. For instance, when searching for a light-switch or
a cellphone on a nightstand in the dark, your action is guided by your previous visual experience. Although you do not have difficulty finding the object, you might guide your hand to the wrong object, or reach the wall instead of the switch. Even though your visual awareness allows you to recognize the object before you turned off the light-switch or put on the objects on the nightstand, your non-visually guided action relies more on a “memory” of your conscious visual awareness. Our hypothesis is that in the absence of vision, even for a brief second, the illusion would affect the performed action, such as a grip aperture or a haptic exploration, as it is the case in the present study. This statement could explain the divergence of results in Ebbinghaus grasping experiments. For instance, Franz et al. [17] showed that presenting one stimulus at the same time affects grasping. However, these results are not surprising, as the perception-action loop has been modified. Indeed, in the one-stimulus condition, the participants had to rely on their visual sensory memory. The illusion effect fades because it is more an “out of context” condition. Besides, the key of Ebbinghaus illusion is to show two sets of Ebbinghaus circles. If one removes one of the sets, there is no longer illusion. How could you judge that the inner circle surrounded by large circles is “smaller” if there is no other set to compare it to?

3 Preliminary Studies

It was important to determine the optimum diameter of the inner circle by itself during a blindfolded exploration for 1) a unimodal matching task; 2) a multimodal visual-tactile matching task. The purpose of the first experiment was to determine a relatively easy size distinction of a single circle stimulus. If participants were not able to differentiate the size of two circles, adding more context (outer circles) would have been a very difficult task to perform. The purpose of the second experiment was to identify whether a visual-tactile discrimination would affect performances under the same conditions.

3.1 Participants

All participants were NMU psychology students (11 males and 29 females) and received a course credit for their participation. Thirty of them participated in experiment 1, 10 others participated in experiment 2. Thirty-eight of them declared that they were right handed, and two that they were left handed. The participants’ mean age was 26 (range 18–56). The institutional ethics committee approved the experimental protocol, and participants gave their informed consent before participating.

3.2 Apparatus and Stimuli

A laser cutter was used to construct sticky foam circles of 3 mm thick. Experiment 1 allowed us to determine the size range of the inner circles used in the Ebbinghaus circles. The stimuli for experiment 1 consisted of 5 circles with a size range of 17.49-23.81 mm with a 1.58 mm step for group 1, 5 circles with a size range of 20-28 mm with a 2 mm step for group 2, and 5 circles with a size range of 24-35 mm with a 3 mm step for group 3. This experiment allowed us to determine the size for the following experiments, where four circles with a size range of 28-37 mm with a step of 3 mm were used.

3.3 Experiment 1: Procedure and Results

Participants, divided into three groups, had to explore 5 different sized circles. This experiment allowed us to determine the step threshold (i.e. the diameters of inner circles alone, without outer circles, which can be easily distinguished). The blindfolded participants were sitting comfortably in front of a table where the stimuli were presented. It consisted of circles; one on the left and one on the right. The circles were glued on letter size sheets attached to the table using Velcro to avoid movement during exploration. Participants were asked to explore the two sets simultaneously, one with each hand, and report whether the two circles were the same or different sizes, and when different, which circle was larger (or smaller). Each participant performed a total of 50 trials equally randomized (5 sizes x same vs. different).

![Figure 2: Percentage of correct answers per group of participants](image)

Results are displayed in Figure 2. The assumption of homogeneity of variance has been met (Levene’s test > 0.05) and the one-way ANOVA showed a significant effect of the group factor on the percentage of correct answers, F(2,29) = 6.46, p = 0.005. Tukey posthoc tests revealed a significant different between G1 and G3 (p=0.004), but not a significant difference between G2 and G3, and G1 and G2. Indeed, participants’ performances for group 3 are higher than the two other groups. Although, all the three groups perform above chance level, the purpose of this experiment was to ensure an easy level of recognition without the context (the outer circles) that will serve as a baseline comparison. Based on our results and previous literature in grasping (see above), a range of sizes from 28-37 mm with a step of 3 mm has been judged to be a comfortable level of recognition for the following experiments.

3.4 Experiment 2: Procedure and Results

The purpose of experiment 2 was to identify the cross-modal tactile-visual interaction vs. unimodal tactile-tactile interaction for size estimation. The participants were divided into two groups (G1: tactile-visual vs. G2: tactile-tactile). G1 was asked to touch a circle, hidden behind a screen, with their dominant hand and compare its size to three sets of circles shown visually during the exploration. G2 task was similar to experiment 1, i.e. touching and comparing the size of two circles while blindfolded.

![Figure 3: Percentage of correct answers for cross-modal (visual-tactile) and unimodal condition (tactile-tactile)](image)
Results of the experiment are shown in Figure 3. The assumption of homogeneity of variance has not been violated and the one-way ANOVA showed a significant difference between crossmodal and unimodal conditions, $F(1,9) = 15.47, p = 0.004$. Selective attention could be an explanation for these results, as suggested by Martino et al. [23]. Nonetheless, these results are quite surprising since our task is not as demanding as Martino’s experiment, where participants had to pay attention to one modality or the other. In addition, no conflict was introduced in the visual-tactile matching as in the case in Heller et al. [24]. However, these results are preliminary, and we plan to run a larger sample of participants per condition.

4 EBBINGHAUS EXPERIMENT

We used the unimodal condition from experiment 2 as the control experiment, and we added more participants to match the number of participants of the test experiment. This allowed us to identify whether the Ebbinghaus illusion exists in touch. The control experiment aimed to identify participants’ abilities to compare two diameters while blindfolded. The test experiment used the Ebbinghaus circles.

4.1 Participants

All participants were NMU psychology students (6 males and 9 females) and received a course credit for their participation. All were right handed and their mean age was 26 (range 18–54). The institutional ethics committee approved the experimental protocol, and participants gave their informed consent before participating. 15 participants participated in the test condition, and 10 participants has been added to the control condition (same procedure than the unimodal condition in experiment 2).

4.2 Apparatus and Stimuli

The sticky foam circles used were 3 mm thick (Fig. 2). The size range of the inner circles was 28-37 mm with a 3 mm step. The large and small outer circles were 50 mm and 10 mm in diameter respectively. The distance from the center of any outer large circle to the center of the central disc was 100 mm and the distance from any small circle to the center of the central disc was 50 mm. The inner circle had either an annulus of 11 small circles or 5 large circles. Each set of Ebbinghaus circles were glued on a letter size sheet on their sticky side where three possible layouts could be compared, as described in the following table:

<table>
<thead>
<tr>
<th>Outer circles</th>
<th>Inner circles sizes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large vs. large</td>
<td>Same or different</td>
</tr>
<tr>
<td>Small vs. small</td>
<td>Same or different</td>
</tr>
<tr>
<td>Small vs. large</td>
<td>Same or different</td>
</tr>
</tbody>
</table>

Table 1. Possible layouts of the Ebbinghaus circles

4.3 Procedure

The blindfolded participants were sitting comfortably in front of a table where the stimuli were presented. It consisted of two Ebbinghaus sets; one on the left and one on the right (small vs. large circles were equally randomized); that were presented to the participant. The sheets were attached to the table via Velcro to avoid movement during exploration. The participants were asked to explore the two sets simultaneously, one with each hand, and to report which one of the two inner circle was larger, or whether they are the same size. Participants were instructed to touch the stimuli as an ensemble, and to avoid ignoring the outer circles (Figure 4).

Each participant performed a total of 64 equally randomized trials (4 sizes x 4 layouts x same vs. different). The participants were faced with the following possibilities:

1. When both sets have the same size outer circles (either small or large), there is no possible illusion.

2. When the outer circles of both sets are different, the participants are faced with three possible situations:
   a. both inner circles have the same size which corresponds to the classical Ebbinghaus illusion;
   b. the illusion is reduced when the inner circle with the annulus of the large circles is smaller in size than the inner circle surrounded by small outer circles. Indeed, this configuration increases accuracy and therefore reduce the illusory effect;
   c. the illusion effect increases when the size of the inner circle with large outer circles is larger than the inner circle with an annulus of small circles.

4.4 Data analysis

Because we were interested in the responses related to the illusion in the tactile modality, we separated the participants’ answers by using the signal detection theory (SDT) that determines not only participants’ sensitivity, but also their decision-making under fuzzy conditions [25].

<table>
<thead>
<tr>
<th>Response “illusion”</th>
<th>Response “no illusion”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal present (illusion effect)</td>
<td>HIT</td>
</tr>
<tr>
<td>Signal absent (no illusion effect)</td>
<td>FA</td>
</tr>
</tbody>
</table>

Table 2. Signal detection theory: the matrix of the four categories. The HIT rate is the category that is relevant for this experiment (illusion effect perceived)

Signal detection theory is a powerful psychophysics method that is used for assessing participants’ perceptual judgments and decision criterion. It measures not only participants’ sensitivity to the stimulus, but also their decision making style. In a typical
experiment based on SDT, a signal is presented in some trials, and no signal (usually a noise) is presented in others. In our case, our presented signal is “the illusion effect”, while the noise is “the no illusion effect”, where the signal is not present (Table 2).

Within any given experiment, participants respond “yes” if they perceive the signal and “no” if they don’t. A participant’s response in each trial of a signal detection experiment can be classified as belonging to one of four categories:

1) Answering “yes” after a signal is presented is a hit
2) Answering “yes” after no signal is presented is a false alarm.
3) Answering “no” after a signal is presented is a miss.
4) Answering “no” after no signal is presented is a correct rejection.

Table 2 summarizes the trials sorted into four categories: when the illusion effect is present and the participant is deceived (the illusion is perceived) the trial is counted as a HIT, when the illusion is not detected the trial is weighted as a MISS. Conversely, when there is no possible illusion in the presented stimulus and the participant correctly identify the sizes, the trial is considered a correct rejection (CR). However, when an illusion is perceived and there is no illusion, the trial is counted as a false alarm (FA).

4.5 Results
First, we tested the participants’ sensitivity (d’) as showed by the ROC curve (Figure 5). The data of one participant has been removed due to low sensitivity to the stimulus (d’ prime value equal zero, which is equivalent to random responses). The percentage of correct answers has been compared to the participants’ answers in the control conditions. A one-way ANOVA has been performed after verifying that the assumption of homogeneity of variance has been met. The analysis of variance showed significant difference between the test and control experiments, F (1, 25) = 25.24, p < 0.001. Indeed, the results show that the performance for circles in context (with outer circles) is lower than when the circles are alone (Figure 6). This suggests that the participants were sensitive to the context, and therefore based their answers by taking into consideration the outer circles.

Comparisons showed a significant difference between CR and all the three categories MISS, FA, and HIT. This suggests that when no illusion was present, the participants were able to determine the correct size of the inner circles despite the presence of the outer circles. There is no difference between the number of MISS (correct rejection of the illusion) and the number of HIT (illusion is perceived). This suggests that when the illusion was present, the participants made more errors (number of MISS none significantly different) and the illusory stimulus indeed deceived the participants. This is corroborated by the significant difference between HIT and FA, which states that there are more errors when an illusory stimulus is presented comparing to when the no-illusory stimulus is presented.

5 General Discussion and Conclusion
These preliminary results show that the participants made less mistakes when there was no illusion (number of FA) than when the illusion was presented (number of HIT). This supports the idea that the Ebbinghaus illusion could exist in the tactile domain when vision is not present. This could be a possible explanation for the divergence of results obtained in the grasping experiments. A brief interruption of visual inputs, such as change blindness or tactile inputs such in tactile suppression of displacement, could affect the way we perceive the world, and therefore causes the perceptual illusion. If the stimuli are constantly present in vision, the illusion does not affect grasping, because one constantly adjusts ones’ successive actions and ones’ successive perceptions, which support the idea of the two perception-action stream hypothesis.
used to perceive the circle, while vision would be used to give the answer. We are also planning to investigate different exploratory procedures to determine their role in the illusion. Indeed, exploratory procedures have been described in 3D haptic exploration [26], haptic search [27], and sensory substitution [28]. These studies showed that tactile and/or haptic perception is dependent on these perceptual strategies and the way we interact with 2D or 3D objects. It is possible that some strategies reduce or increase the illusion effect.

REFERENCES