



The Ebbinghaus illusion with small inducers appears larger on the right side

Ayako Saneyoshi¹

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Abstract

The effects of left and right alignment on the Ebbinghaus illusion were investigated in three experiments. In Experiment 1, the Ebbinghaus illusion was presented on the left or right side, and the points of subjective equality (PSE) were measured. Only the central disk of the figure with small inducers was perceived larger when it was positioned on the right side rather than on the left. In Experiments 2 and 3, left, right, and central placement were used to determine if the results of Experiment 1 were caused by a decrease of the illusion on the left side or an increase of the illusion on the right side. There was no difference in the illusion effect between the left and the center; however, the illusion effect increased when the figure was presented on the right side. These results suggest that a hemispheric asymmetry for global and local spatial attention influences the laterality of the Ebbinghaus illusion.

Keywords Ebbinghaus illusion · Laterality · Global/local · Spatial attention

Introduction

The Ebbinghaus illusion (Titchener illusion) is a perceptual phenomenon in which the apparent size of a central object (e.g., a circle or disk) is affected by the size of surrounding objects. In the illusion figure, the central object is referred to as a target and the surrounding objects are termed inducers. When the target is surrounded by large inducers (left side of Fig. 1) its perceived size is diminished; when the target is surrounded by small inducers, its perceived size is increased (right side of Fig. 1).

Many studies have investigated factors that affect the Ebbinghaus illusion. Massaro and Anderson (1971) have shown that increasing the disparity in size between the inducer and target circles, increasing the number of inducing circles, and decreasing the separation between small inducers and target circles all increase the Ebbinghaus illusion. Furthermore, Coren and Enns (1993) explored the effect of the semantic relationship between test and inducing stimuli on the magnitude of size contrast in an Ebbinghaus illusion. They manipulated the inducers and test stimuli for visually identical or

semantically identical items. When the inducing and test stimuli were visually and taxonomically identical, the illusion was greatest. On the other hand, when the inducing elements differed from the test element, the magnitude of the illusion was expected to depend on the semantic similarity between the test and inducing elements. The results of the four experiments suggested that the magnitude of the Ebbinghaus illusion was proportional to the semantic, conceptual similarity of the inducer and target object. Based on these findings, most researchers conclude that the illusion is produced by a comparison of the central circle with its context. On the other hand, some researchers claimed that the illusion could be dependent on sensory-level contour interactions, such as the Delboeuf illusion (Jaeger and Klahs 2015). Although a large amount of research has investigated the Ebbinghaus illusion, there is no unanimous agreement as to the cause of the illusion. Therefore, more research is needed.

The most compelling demonstration of the Ebbinghaus illusion requires that the two figures with small or large inducers be positioned side-by-side. To our knowledge, however, little is known about the effects of left and right alignment on the Ebbinghaus illusion. Several authors have proposed that the effects of some optical illusions operate differently within the left and right hemispheres. For example, Clem and Pollack (1975) found right hemispheric

✉ Ayako Saneyoshi
a-sane@main.teikyo-u.ac.jp

¹ Department of Psychology, Teikyo University, 359 Otsuka, Hachioji, Tokyo 192-0395, Japan

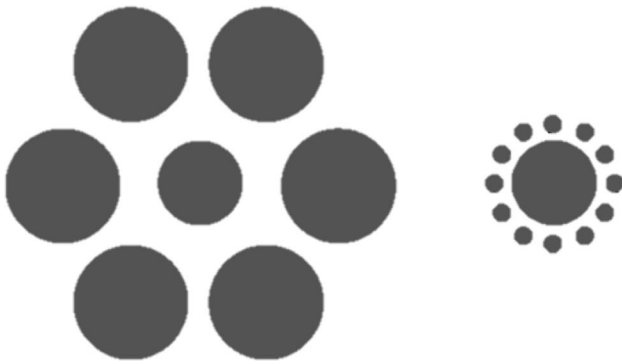


Fig. 1 Ebbinghaus illusion

dominance in the Müller-Lyer illusion. Rothwell and Zaidel (1990) examined an Oppel–Kundt illusion (i.e., a figure illusion that is filled with shading lines, resulting in the figure being overestimated). In this study, the strength of this illusion increased when it was presented to the left visual field/right hemisphere (LVF/RH). Rasmjou, Hausmann, and Güntürkün (1999) investigated the effects of handedness, gender, and laterality on a Hellingbone illusion. Their results suggested right hemisphere superiority for the illusion only in right-handed males. Josev, Forte, and Nicholls (2011) reported that the horizontal-vertical line illusion effect was stronger when the vertical line was on the left side. Furthermore, Gonzalez et al. (2006) investigated hemispheric specialization for the visual control of action in the Ebbinghaus illusion. The results of this study suggested that the illusion effect was diminished when grasping objects embedded in the Ebbinghaus illusion with the right hand, regardless of participants' handedness. Although some studies have found no visual field differences in visual illusions (e.g., Greist and Greier 1977, for a Poggendorff illusion; Bertelson and Morais 1983, for a Ponzo illusion), there have been many reports of greater right hemisphere involvement in visual illusions.

The question remains as to what mechanism produces the laterality effect of visual illusions. The dominant theory is that the laterality of illusions is caused by a right hemisphere advantage in operating visual spatial attention. Previous studies have shown that there are several spatial cognitive tasks that show asymmetries for the left and right sides (e.g., Jewell and McCourt 2000; Voyer et al. 2012). For example, individuals with lesions in the right parietal lobe show neglect for contralateral sides of space, while patients with lesions in the left parietal lobe do not show any obvious neglect. This clinical evidence suggests that the right hemisphere is more important in directing spatial attention than the left hemisphere (Dickinson and Intraub 2009). In individuals without lesions, evidence suggests that lateral biases for the right hemisphere (i.e., the left side of visual

field) exist in spatial cognitive tasks (pseudoneglect: Jewell and McCourt 2000; grayscale task:; Mattingley et al. 1994; Nicholls and Roberts 2002; Nicholls et al. 1999). These studies suggest that the right hemisphere is superior for the processing or directing of attention to the left visual field. If this allocation of attention triggers a mechanism for illusion production, an incremental increase of the illusion effect should be observed when the Ebbinghaus illusion is presented on the left side.

However, the Ebbinghaus illusion is composed of inducers and a center target. Hemispheric asymmetry has been shown for different types of spatial attention, specifically, in global and local processing (Van Kleeck 1989; Martinez et al. 1997; Hellige et al. 2010). Furthermore, the right hemisphere processes information in a global, holistic way, whereas the left hemisphere has an advantage for local, analytical, or sequential styles of information processing (Van Kleeck 1989; Martinez et al. 1997; Hellige et al. 2010). Shulman (1992) investigated the effect of visual attention on the Ebbinghaus illusion. He proposed that attention to the inducers produces the Ebbinghaus illusion effect. Therefore, if the Ebbinghaus illusion requires local attention to the inducers, and analytic processes enable comparison of figural elements, a left hemisphere/right visual field advantage for the illusion would be predicted.

Three studies were conducted to investigate the effect of left and right alignment on the Ebbinghaus illusion. In Experiment 1, the effect of left/right alignment on Ebbinghaus figures with small or large inducers was investigated. Experiments II and III aimed to clarify whether the alignment effect obtained in Experiment I was due to an increase in the illusion in the right field or a decrease in the illusion in the left field.

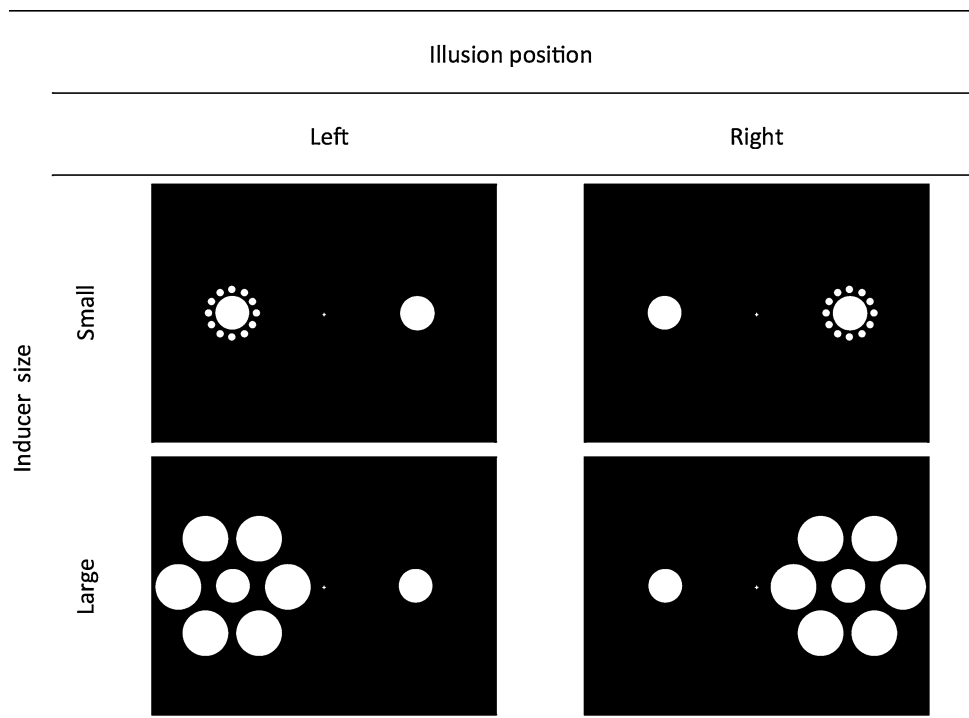
Experiment 1

Methods

Participants

Twelve right-handed undergraduate students (aged 18–22 years old) were recruited from Teikyo University to participate in Experiment 1. Handedness was assessed by self-report. They received course credit for their participation in the experiment. All participants claimed that they had normal or corrected-to-normal visual acuity. They were unaware of the hypothesis under investigation. Prior to participation, they provided informed written consent. All experimental procedures were approved by the Institutional Review Board of the Teikyo University Psychology Department (No. 227).

Fig. 2 Stimulus examples in Experiment 1. In the left panel, Ebbinghaus illusion figures were presented on the left side, and in the right panel, figures were presented on the right side. The upper panel shows the Small inducer condition and the lower panel shows the large inducer condition. The four center disks were the same size in all panels



Experimental design

The experimental design comprised an orthogonal combination of the size of inducer disk (Small, Large, and No inducer) and position (left or right). All variables were manipulated within participants. The dependent variable was the illusion magnitude calculated by the perceived size of the central disk of the Ebbinghaus figures, and these sizes were determined using an adaptive staircase method.

Apparatus

Stimuli were presented on a 21-inch Cathode-ray tube monitor, connected to an Apple MacBook Pro computer, running MATLAB R2012b (MathWorks Inc., Natick, MA) with Psychtoolbox 3 (Brainard 1997). A keyboard was connected to the computer, and served as a response console.

Stimulus

The stimulus and fixation were presented in white (27.5 cd/m^2) on a dark-gray background (1.9 cd/m^2). The Ebbinghaus stimulus or single target disk with no inducer and comparison disks were presented side-by-side. The target disks had the same diameter (2.52°) for both size conditions, while the size of the comparison disk varied. The sizes of the small and large inducer disks were 0.42° and 3.19° , respectively (see Fig. 2). The figure size, which included the inducers and target, was 3.78° for the small condition and 10.63° for

the large condition. The distance between the center fixation and center disk was 10.92° for both Position conditions. The distance between the center of the test disk and the center of the inducer was 1.60° for the small condition and 3.78° for the large condition. The number of inducers was 6 for the large condition and 12 for the small condition. The initial size of the comparison disk was 0.84° , or 4.20° , and the size changed depending on the response (see “Task and procedure”).

Task and procedure

Participants were seated in a dark room, approximately 57.4 cm away from the monitor. They were told to keep their chin on the chin rest, and to maintain their gaze toward the fixation cross as much as possible. Participants completed 16 practice trials prior to the experiment. Participants were instructed to judge whether the left or right disk was larger than the other disk, by pressing the “F” or “J” key, with their left or right index fingers. Participants received a short break after every 20 trials.

In each trial, a fixation cross appeared for 500 ms, followed by an Ebbinghaus illusion and a comparison disk. The target illusion and comparison disk were presented until the response was submitted. The fixation was presented throughout the trial to encourage appropriate differentiation between the left and right visual fields.

An adaptive staircase procedure, termed a “parameter estimation by sequential testing” (PEST: Taylor and

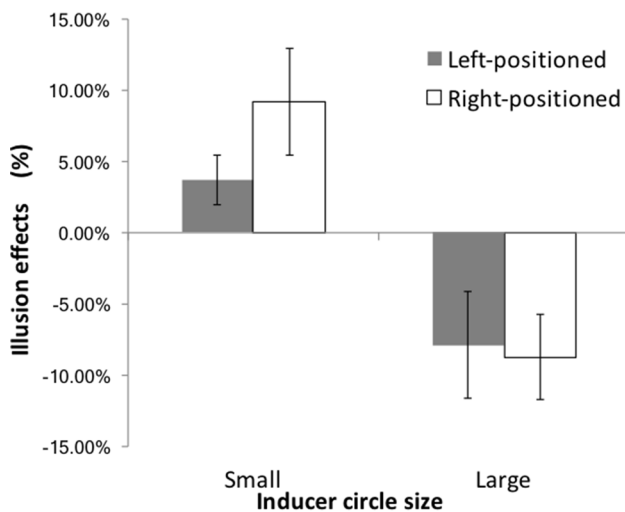


Fig. 3 Mean illusion effects from Experiment 1. Error bars show the 95% confidence interval of the mean (calculated by the method of Beguley 2012). Higher scores indicate a greater illusion. A positive value indicates that the target disks were perceived as larger than the actual size, and a negative value indicates that they were perceived as smaller

Creelman 1967), was used to estimate the PSE for each condition. Each condition had four randomly interleaved staircases. For each staircase, the initial size of the comparison disk was either clearly smaller or larger than the target (the center disk of the Ebbinghaus illusion). Depending on the participants' response, the size of the comparison disk was changed on a trial-by-trial basis, according to an adaptive algorithm. The future size of the comparison disk decreased by one step size after a "comparison disk was larger than the target disk" response and increased after a "comparison disk was smaller than the target disk". If participants provided the same response three times in a row, the step size was doubled, except in the case where the size had already increased to that point. After the response changed, the step size was halved. When the step size was smaller than 0.08° , the staircase was completed, and the size of the comparison disk was recorded. There was an ascending series and a descending series. Each staircase was interleaved, so that participants were unaware of the size change pattern. The mean number of trials was 345.2 (SD = 14.7).

Results and discussion

The last diameters of the comparison disk for the four trials were averaged and used as the PSE for each condition. To calculate the amount of the illusion, the difference of the PSE and actual target disk size was divided by the actual size of the target disk (see Fig. 3). These amounts were entered into a 2 (Inducer size: Small or Large) \times 2 (Position: left or right) repeated measures ANOVA, with participants as

the random factor. There was a main effect for Inducer size [$F(1,11) = 35.44$, $p < 0.001$, $\eta^2 = 0.763$]. This main effect revealed that participants perceived the target size of the Small inducer condition as larger than they did in the Large condition. The main effect of position, however, was not significant [$F(1,11) = 1.62$, $p = 0.229$, $\eta^2 = 0.128$]. Furthermore, there was an interaction of Inducer size and Position, [$F(1,11) = 6.05$, $p = 0.003$, $\eta^2 = 0.355$]. Post-hoc comparisons (multiple t test with Bonferroni correction) for this interaction revealed that the target on the right side ($M = 9.20\%$, $SE = 2.71\%$) was perceived as larger than the target on the left side ($M = 3.72\%$, $SE = 1.16\%$), but only in the Small inducer condition ($p = 0.025$).

Because the specific viewing conditions (e.g., the computer monitor properties) would make the disk look smaller or larger, there was a problem with using the actual size of the central disks as a baseline for illusion magnitude score calculation. These effects could be controlled using the subjectively perceived size of a single disk (with no inducers) as the baseline. Hence, the illusion magnitude score was re-calculated using the PSE of a single disk as baseline. The ANOVA results indicated that the interaction of Inducer size and Position was significant [$F(1,11) = 5.69$, $p = 0.036$, $\eta^2 = 0.341$]. Post-hoc comparisons revealed that the target on the right side ($M = 6.60\%$, $SE = 1.60\%$) was perceived as larger than the target on the left side ($M = 4.20\%$, $SE = 2.40\%$), but only in the Small inducer condition ($p = 0.030$). Furthermore, there was no significant difference between the PSEs of the disks in the No inducer condition presented on the left ($M = 2.51^\circ$, $SE = 0.02^\circ$) or right ($M = 2.57^\circ$, $SE = 0.02^\circ$), and actual size of the disk (2.52° ; $ps > 0.05$). Therefore, it was suggested that this alignment effect was not caused by the specific viewing condition.

In Experiment 1, the left and right position affected the Ebbinghaus illusion. The central disk in the small context figures on the right side were perceived as larger than they were on the left side. However, it was not clear whether this left–right difference was produced by a decreased illusion effect on the left side, or an increased illusion effect on the right side. In Experiment 2, by adding the center condition as a control, it was investigated whether the observed laterality was caused by a decrease of the effect in the left-positioned condition or an increase in the right-positioned condition. To reduce the burden on participants, the Small inducer condition and Large inducer condition were examined in a between-participants design in Experiment 2.

Experiment 2

Methods

Participants

Twenty-four right-handed undergraduate students (aged 18–22 years old) participated in Experiment 2. Twelve participated in the Small inducer condition, and 12 participated in the Large inducer condition. The criteria for participation were the same as in Experiment 1. The participants in Experiment 2 did not participate in Experiment 1. Because two participants showed response biases (one in the Small inducer condition, and the other in the Large inducer condition), their data were excluded from the analyses.

Experimental design

The experiment used a mixed design. Position [left, right, and center (above and below)] was manipulated within participants and Inducer size (small and large) was manipulated between participants. The dependent variable was the illusion magnitude calculated by the perceived size of the central disk of the Ebbinghaus figures, and these sizes were determined using a constant method.

Apparatus

The apparatus was the same as in Experiment 1.

Stimulus

In the left and right position conditions, the Ebbinghaus illusion figure and comparison disks were presented side-by-side, in the same manner as in Experiment 1. In the center-positioned conditions, the illusion figure and comparison disk were presented above and below the fixation (see Fig. 4). There was a visual resolution asymmetry in the vertical visual field. The effective visual area of the above visual field was 8° , while the effective visual area of the below visual field was 12° (Hatada 1993). Therefore, the distance between fixation and the center of the stimulus was manipulated to equal their visibility. In the above condition, the distance between the inducers and the center of the figure subtended a visual angle of 5.80° , while in the below condition, the distance between the fixation and the center of the figure subtended a visual angle of 8.53° .

The PSE was estimated by a constant method in Experiment 2, to calculate PSE more accurately (Kingdom and Prins 2016). The size of the target disk was 2.52° , both in the Small and Large inducer conditions. The sizes of the comparison disks in the Small inducer condition were 2.37°

(94%), 2.47° (98%), 2.57° (102%), 2.67° (106%), 2.77° (110%), 2.87° (114%), and 2.97° (118%). Conversely, the sizes of the comparison disks in the Large inducer condition were 2.17° (90%), 2.27° (92%), 2.37° (94%), 2.47° (98%), 2.57° (102%), 2.67° (106%), and 2.77° (110%).

Participants completed four practice trials prior to the experiment. They were instructed to judge whether the left or right (above or below) disk was larger than the other disk by pressing the “F” or “J” key with their left or right index fingers. The left–right condition and the above–below condition were performed in different sessions. There were 40 trials for each condition (4 position \times 7 comparison disk sizes); therefore, participants completed 1120 trials divided into 56 blocks. Participants received a short break after each block. Task order, block order, and trial order were counterbalanced across participants.

The procedure of a trial was the same as in Experiment 1. In each trial, a fixation cross appeared for 500 ms, followed by an Ebbinghaus illusion and a comparison disk. The fixation was presented throughout the inspection period and until the judgment was made.

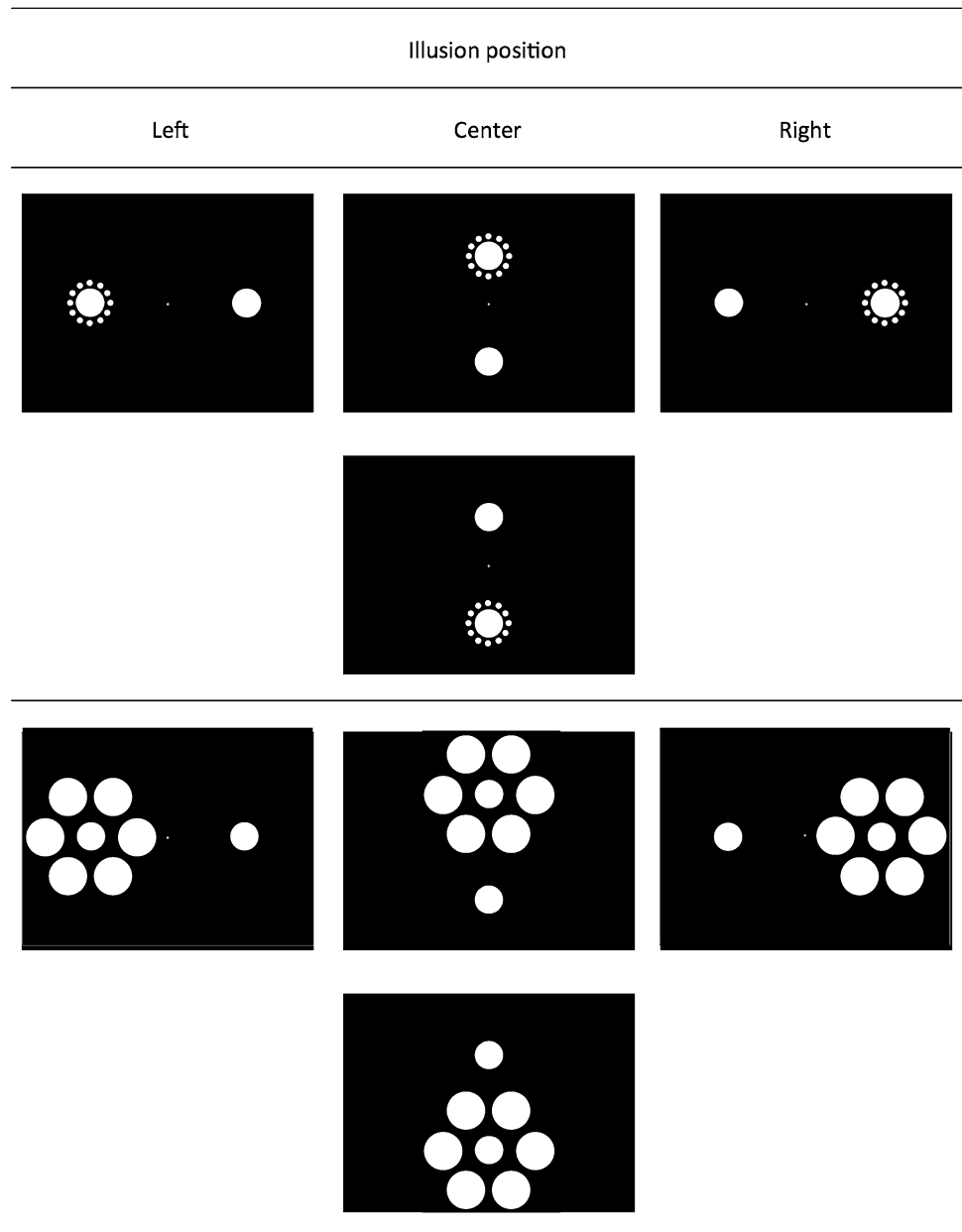
Results and discussion

The probability of the “large” response for each condition was estimated. The curves were fitted by probit transformations, using the maximum-likelihood method. Because there was no significant difference ($p=0.552$), the PSE data of the above and below conditions were averaged and used as data for the center condition. The illusion effect was calculated by the formula that the difference of the PSE and the actual target disk size was divided by the actual size of the target disk (see Fig. 5).¹

The illusion effect data were entered into a 2 (Inducer size (between participant factor): Small and Large) \times 3 (Position (within participants factor): left, right, and center) mixed-design ANOVA. There was a main effect of Position [$F(2,40)=18.86$, $p<0.001$, $\eta^2=0.485$], and an interaction of Inducer size and Position [$F(2,40)=6.18$, $p=0.022$, $\eta^2=0.236$]. Furthermore, there was a main effect of Inducer size [$F(1,20)=98.91$, $p<0.001$, $\eta^2=0.832$]. The perceived size of the central disk was smaller in the Large inducer condition than the Small inducer condition. For post-hoc

¹ In Experiments 2 and 3, a No-inducer single disk condition was not included. Thus, the magnitude of illusion was calculated with the actual size of the disk in these experiments. There was no difference between the results that were calculated with an actual size and those that were calculated with the perceived size of a No-inducer single disk in Experiment 1. Furthermore, there were no significant differences between the actual size and perceived size of the No-inducer single target disk. Because the apparatus (PC and monitor) did not change in these three experiments, the magnitude of illusion of Experiments 2 and 3 was calculated with the actual size of the disk.

Fig. 4 Stimulus examples in Experiment 2. In the left panel, Ebbinghaus illusion figures were presented on the left side, and in the right panel, figures were presented on the right side. The central panel shows the center condition, where the Ebbinghaus figure was positioned higher or lower relative to the center fixation point. The upper was the Small inducer condition and the lower was the Large inducer condition

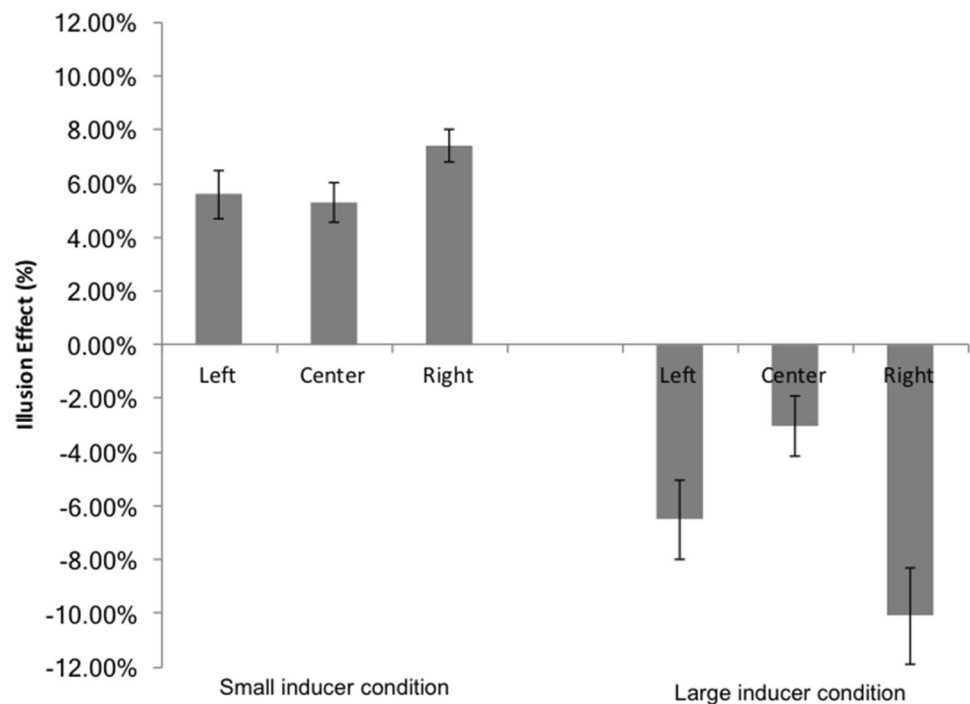


comparisons, a one-way ANOVA for Position was analyzed in the Small and Large conditions. There was a main effect for Position in the Large inducer condition [$F(2,20) = 13.81$, $p < 0.001$, $\eta^2 = 0.580$]. Post-hoc comparisons (multiple t test with Bonferroni correction) for this main effect revealed an elevated illusion effect for the right ($M = 10.1\%$, $SE = 1.4\%$) and left ($M = 6.5\%$, $SE = 1.1\%$) conditions compared to the center condition ($M = 3.1\%$, $SE = 0.9\%$; all $ps < 0.05$). There was no significant difference between the left and right conditions ($p = 0.149$). Furthermore, there was a main effect for Position in the Small condition [$F(2,20) = 5.78$, $p = 0.010$, $\eta^2 = 0.366$]. Post-hoc comparisons (multiple t test with Bonferroni correction) for this main effect revealed a higher illusion effect for the right ($M = 7.4\%$, $SE = 0.9\%$)

condition when compared to the center condition ($M = 5.3\%$, $SE = 1.1\%$; $p = 0.008$). There was also a difference between the left ($M = 5.6\%$, $SE = 1.1\%$) and right conditions ($p = 0.069$), but it did not reach significance. Finally, there was no significant difference between the left and center conditions ($p = 1.00$).

There were significant differences between the left, right, and center conditions in the large inducer condition. The illusion magnitude was very small in the center condition. Because the distance between the illusion figure and the comparison disk was very short in the center condition, the illusion effect would have decreased in the center condition. Although it was not significant, the illusion magnitude was larger when the figure was presented on the right than on the

Fig. 5 Mean illusion effects from Experiment 2. Error bars show the 95% confidence interval of the mean (calculated by the method of Beguley 2012). Higher scores indicate a greater illusion



left. The left hemisphere has an advantage for local analytical information processing. Attention to the “local” inducer disks would be encouraged in the right visual field (left hemisphere) not only in the Small inducer condition, but also in the Large inducer condition. However, the inducer disks were larger than the target disk, so it was difficult to entirely attend to the inducer disks in the Large inducer condition.

Consequently, it is possible that the laterality of the left–right array for the small context Ebbinghaus illusion was caused by an increased illusion effect in the right-position condition. However, the illusion figure and comparison disk were presented in the left and right visual fields side-by-side in Experiment 2; thus, the laterality effect was small in this result. Therefore, in Experiment 3, both the illusion figure and comparison disk were presented within the left or right visual field, vertically. By including the stimuli within one visual field, it could be determined whether the position effect was caused by hemispheric asymmetry for the different types of attentional processing.

Experiment 3

Methods

Participants

Twenty-one right-handed undergraduate students (aged 18–22 years old) participated in Experiment 3. Twelve participated in the Small inducer condition, while nine

participated in the Large inducer condition. The criteria for participation were the same as those in Experiments 1 and 2. The participants in Experiment 3 did not participate in Experiments 1 or 2.

Experimental design

The experiment employed a mixed design. Position [left, right, and center (above and below)] was manipulated within participants, and Inducer size (small and large) was manipulated between participants. The dependent variable was the illusion magnitude calculated by the perceived size of the central disk of the Ebbinghaus figures, and these sizes were determined using a constant method.

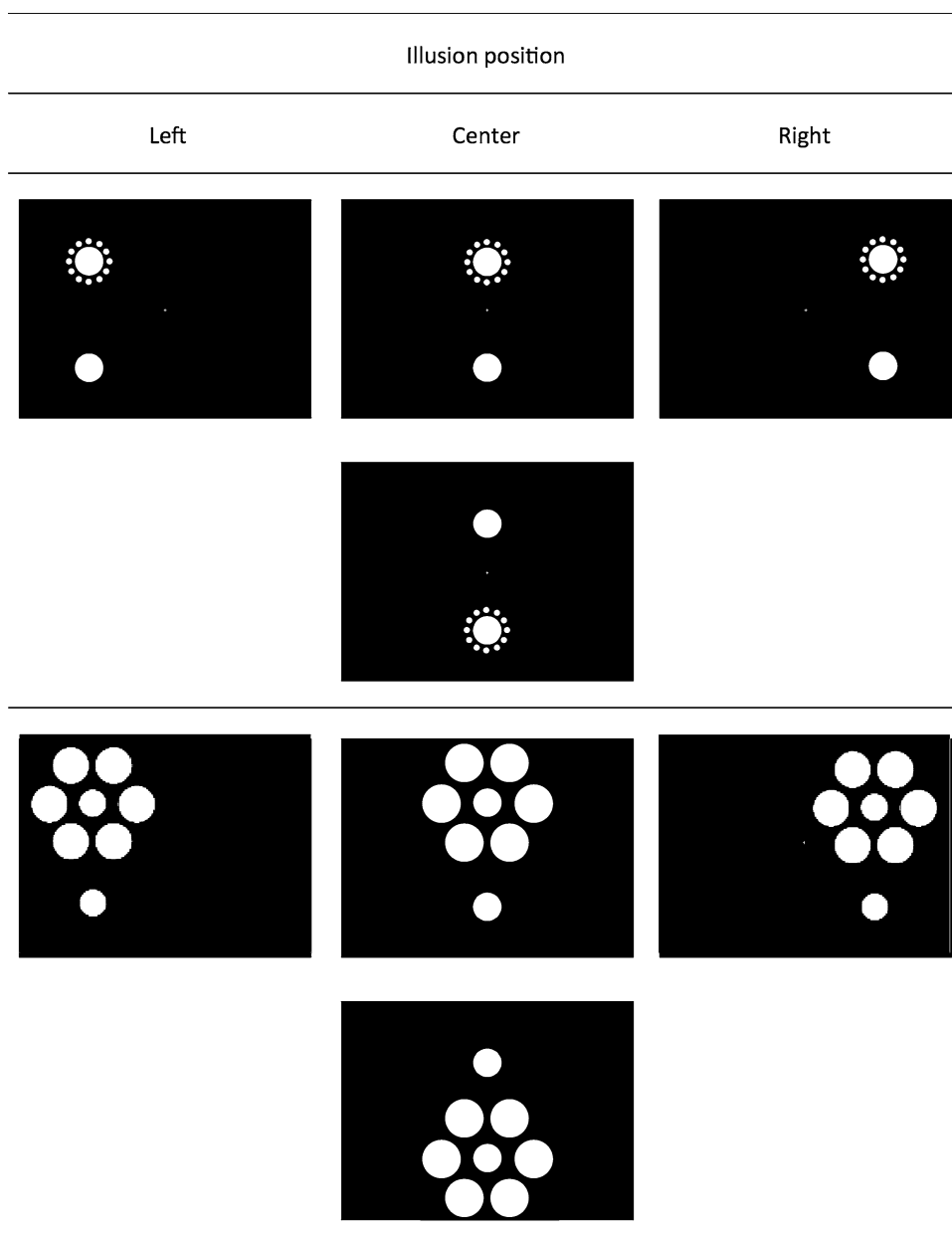
Apparatus

The apparatus was the same as in Experiments 1 and 2.

Stimulus

In Experiment 3, the stimulus was the same as in Experiment 2, with the exception that the illusion figure and comparison disk were presented above and below the fixation (see Fig. 6), in the same manner as the center condition of Experiment 2. The distance between the fixation and the center of the figure was manipulated to equal their visibility (see Experiment 2 “Methods”). In the left and right position conditions, the distance between the centerline of the

Fig. 6 Stimulus examples in Experiment 3. In the left panel, Ebbinghaus illusion figures were presented on the left side, and in the right panel, figures were presented on the right side. The central panel shows the center condition, where the Ebbinghaus figure was positioned higher or lower relative to the center fixation point. The upper was the Small inducer condition and the lower was the Large inducer condition



display, and the center of the figure, was 10.92° for both conditions.

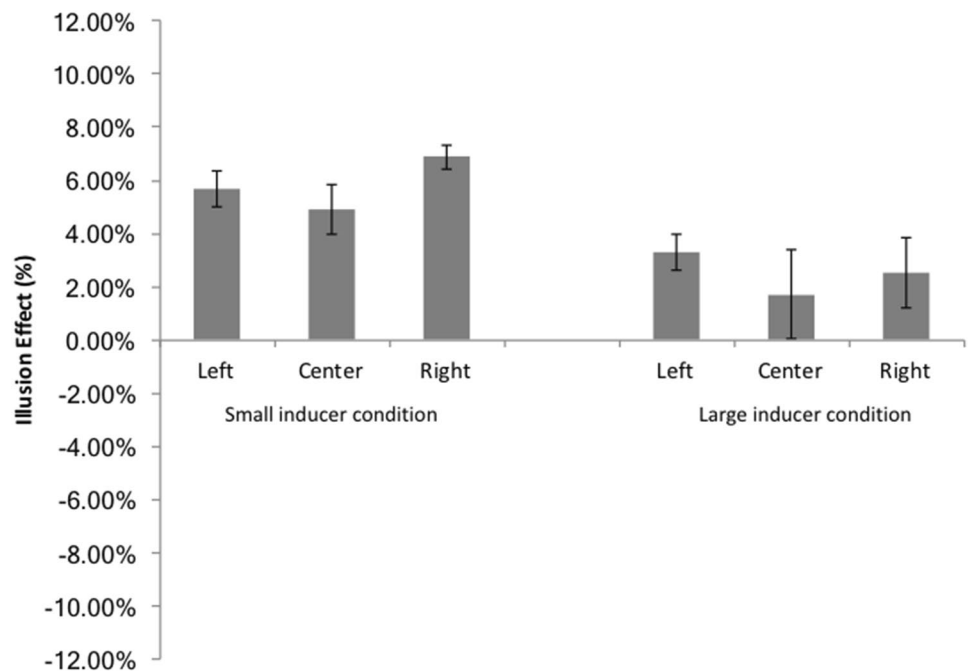
Task and procedure

The task and procedure were almost identical to those of Experiment 2, except for the left and right position conditions. In these conditions, the illusion figure and comparison disk were aligned vertically, and presented within the left or right visual fields, respectively. Participants completed four practice trials prior to the experiment. Participants were instructed to judge whether the above or below disk was larger than the other disk by pressing the “Y” or “B” key with their left or right index fingers. The left–right condition

and the above–below (center) condition were performed in different sessions. There were 40 trials for each condition, except the above and below condition. As there was no significant difference between the above and below conditions in Experiment 2, 20 trials each were completed for the above and below conditions, and these 40 trials were utilized together as the center condition trials. Therefore, participants completed a total of 860 trials, divided into 28 blocks for left–right conditions, and 14 blocks for the center condition. Participants received a short break after each block and session. Task order, block order, and trial order were counterbalanced across participants.

In each trial, a fixation cross appeared for 500 ms, followed by an Ebbinghaus illusion and a comparison disk.

Fig. 7 Mean illusion effects from Experiment 3. Error bars show the 95% confidence interval of the mean (calculated by the method of Beguley 2012). Higher scores indicate a greater illusion



Although the fixation cross appeared during the trial, it was overlaid by the illusion figures only in the center condition of the large inducer condition. Thus, there was no fixation in this condition. Whereas, it was popular to briefly (under 150 ms) present the stimulus in the left or right visual field in the study of hemispheric asymmetry, Grabowska et al. (1992) suggested that short tachistoscopic presentations would reduce the illusory effects. Therefore, the target illusion and comparison disk were presented for 700 ms, in an effort to encourage discernment between the left and right visual fields.

Results and discussion

The illusion effect was calculated the same way as in Experiment 2 (see Fig. 7). Data were entered into a 2 (Inducer Size: Small and Large) \times 3 (Position: left, right, or center) mixed-design ANOVA. Although the main effects of Position and Size approached significance [position: $F(2,36) = 2.90$, $p = 0.068$, $\eta^2 = 0.139$; size: $F(1,18) = 3.63$, $p = 0.073$, $\eta^2 = 0.168$], post-hoc comparisons revealed no significant differences ($ps > 0.05$). The interaction of Size and Position also approached significance [$F(2,36) = 2.83$, $p = 0.072$, $\eta^2 = 0.136$]. To investigate a priori hypotheses, the Position of each size condition was analyzed by a one-way ANOVA. In the Small condition, there was a significant main effect of Position [$F(2,20) = 4.68$, $p = 0.022$, $\eta^2 = 0.435$]. Post-hoc comparisons (multiple t test with Bonferroni correction) for this main effect revealed that the small inducer Ebbinghaus illusion figures were overestimated more when positioned within the right visual field ($M = 6.90\%$, $SE = 1.40\%$) rather than in

the left ($M = 5.70\%$, $SE = 1.30\%$) and/or center ($M = 4.90\%$, $SE = 1.30\%$) fields (all $ps < 0.05$). There was no significant difference between the left and center field conditions ($p = 1.00$). Additionally, there was no main effect in this comparison [$F(2,20) = 0.96$, $p = 0.404$, $\eta^2 = 0.107$]. The illusion effect of the Large condition was very small, and opposite to the prediction; therefore, the overall illusion effect of the Large condition was compared to 0. The results of this comparison revealed no significant illusion effect in the Large condition [$t(8) = 2.10$, $p = 0.069$, $r = 0.60$].

In Experiment 3, the laterality effect for the small context Ebbinghaus illusion was observed again. It was suggested that this laterality was caused by an increasing illusion effect in the right-position condition. However, the illusion effect disappeared in the large context Ebbinghaus illusion. The reason behind the disappearance of this illusion effect is not clear. However, the illusion effect of the Large inducer condition in Experiment 3 was originally weak, as there was a problem with the stimulus and presentation style in this condition. In Experiment 3, the figures were presented vertically and the distance between the target and comparison disks was too short to enable the inducers to affect the perceived size of the comparison disks. Furthermore, the presentation time was short, making comparisons between the large inducers and target disks difficult.

General discussion

This study examined the left and right alignment effect of the Ebbinghaus illusion. In Experiment 1, the size of the target disk of a small context Ebbinghaus illusion was perceived to be larger in the right-position condition than it was in the left-position condition. In Experiments 2 and 3, the target disk was perceived to be larger in the right-position condition than it was in the left- and center-position conditions, in the small context condition. Therefore, it is suggested that the result of Experiment 1 was produced, not by a decrease of the illusion effect in the left-position condition, but rather by an increase of the illusion effect in the right-position condition. Although it should be noted that previous studies proposed a RH/LVF advantage for processing visual illusion, the laterality of the Ebbinghaus illusion was inverted (i.e., an LH/RVF advantage).

The results of this study are consistent with the prediction that the Ebbinghaus illusion requires local visual information processing to show the LH/RVF advantage (i.e., increasing the visual illusion effect). It has been suggested that visual illusions that show an LVF/RH advantage require global information processing. For example, the Müller–Lyer illusion, which consists of two parts (e.g., a main line and arrows), shows an RH/LVF advantage. To produce the Müller–Lyer illusion, perception of all parts of the illusion is required through global spatial attention. Therefore, the effect of the Müller–Lyer illusion would result in an RH/LVF advantage. In support of this point, Clem and Pollack (1975) reported a right hemispheric advantage for the Müller–Lyer illusion. However, when the two components of the illusion were presented in succession, the opposite result was observed (i.e., a left hemispheric advantage). These results can be explained by the separated presentation task requiring attention to local parts, and then, an integration of these parts in an analytic fashion. As the LH/RVF displays an advantage for local and analytic processing, this would produce a greater illusion effect for the successive Müller–Lyer illusion.

Developmental studies have been conducted concerning visual illusions and global/local spatial attention processing, and optical illusions have been categorized into two types: Type I illusions and Type II illusions (Clem and Pollack 1975). The illusion effects of the Type I category should decrease with age, while the effect of the illusion in the Type II category should increase with age. Although there are different theories as to how to categorize illusions into these two types, the Müller–Lyer illusion is typically categorized as a Type I illusion, while the Ebbinghaus illusion is categorized as a Type II illusion. It has been suggested that Type I illusions are reliant upon sensory processes such as contour interaction, while Type II

illusions are thought to be related to higher-level cognition (e.g., successive comparison). In the development of the Ebbinghaus illusion, studies proposed that perception of the illusion was not observed in young children (Doherty et al. 2010). However, there was no such tendency in the Müller–Lyer illusion. Furthermore, there is a difference in developmental pattern for global/local processing and laterality. Roe et al. (1999) suggested that younger children show an advantage in attending to the global level of objects, and the LVF/RH advantage was observed in these children. However, the RVF/LH advantage for local-level discriminations was not observed in the youngest participants (Moses et al. 2002). These results suggest that hemispheric asymmetry for global/local level processing become mature by 14 years of age. Thus, the increasing effect of the Ebbinghaus illusion on the LH/RVF would be caused by the LH advantage for attending to local information, and the absence of an illusion effect in young children would reflect immaturity of the left hemisphere in lateralization for local processing.

Although the fixation point was presented throughout the experiment, the stimuli were presented until participants responded. Participants could move their eyes freely so that the right and left visual fields continuously changed during the trial. In fact, many left and right hemisphere advantage studies have used very short presentation times (under 150 ms) to avoid eye movement. Hence, the method of this study could not guarantee that participants kept their gaze within the left and right visual fields. Therefore, future research that controls the presentation time of the stimulus is needed. However, there have been many laterality studies with free viewing conditions (Voyer et al. 2012). The free viewing laterality studies suggest that the left and right hemispheres play different roles, not only in processing already entered information, but also in controlling attention to capture information from the external world.

In this study, it was suggested that the alignment effect was produced during processing to control attention to local or global information in the Ebbinghaus illusion. This laterality alignment effect was observed only in the Small inducer condition, and there was no difference between the left and right position in the Large inducer condition. If there was a local attentional bias to the left side, position effects on the large inducers should have been observed. This lack of laterality could be caused by a non-appropriate stimulus size in the large size condition. The ratio of target and inducer disk size was small in the large inducer condition (target: 2.52° , inducer: 3.19° , ratio = 1:1.27). Furthermore, the number of inducers was reduced in the large size condition. Because of these stimulus problems, the illusion effect was diminished, and, consequently, laterality for the large size condition could not be observed. In fact, the illusion effect was not

observed in Experiment 3. Furthermore, it is possible that the over and underestimated Ebbinghaus illusions arise from different illusion-producing processes (Jaeger 1978). In the future, researchers should manipulate the Large inducer condition appropriately, and investigate whether the array effect is observed in a large inducer Ebbinghaus illusion.

Methodological problems in these experiments can be identified. First, the number of contextual disks and the distance between the target and inducer disks were different in the large and small inducer conditions. The figure was displayed until the response in Experiments 1 and 2, so the scanning opportunities were indeterminate for both large and small inducer figures in these experiments. The presence of a fixation cross was inconsistent across inducers and their positions. Furthermore, there were different proximities of the comparison disks and inducers for the large and small inducer conditions. Because the size of inducers and the comparison disks were almost equal in the large condition, the effect of illusion would decline. There were also many problems, especially in the Large inducer condition; however, these are important only when comparing the large to the small inducer illusion. In this study, the left and right placement effect was compared so that these concerns would not pose severe problems in the experiments.

The results of this study suggest that the array of Ebbinghaus illusion figures affects the amount of the illusion perceived. Especially in the Small inducer condition, the illusion effect increased in the right visual field. It is possible that this laterality was caused by hemispheric asymmetry for the processing of local/global spatial attention. This raises questions concerning the hypothesis that the right hemispheric advantage for operating spatial attention would produce a laterality effect (especially an RH/LVF advantage) on visual illusions. The left and right hemisphere display different advantages for local and global visual spatial attention. Therefore, the laterality of the illusion was determined by the mechanism of the visual illusion, and more specifically, by what kind of information was needed. This study indicates the possibility that the laterality of a visual illusion could be the means to investigate the mechanisms of visual illusions.

There are two principle ways of explaining the Ebbinghaus illusion. One is the cognitive account, claiming that a comparison and contrast of the size of the contextual and central disks produces the Ebbinghaus illusion. The other is the sensory account, claiming that the perceptual, sensory-level contour interaction produces the Ebbinghaus illusion. In this study, the left hemisphere produced a greater magnitude in the Ebbinghaus illusion for small inducers. The left hemisphere has a processing advantage in local attention and analysis of elements. It is suggested that the Ebbinghaus illusion is produced by this analytic processing of the

comparison and contrast of the contextual and central figures. Therefore, the hemispheric asymmetries shown in this study support the cognitive account.

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Compliance with ethical standards

Conflict of interest The author declares that there is no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. All experimental procedures were approved by the Institutional Review Board of the Teikyo University Psychology Department (no. 227).

Informed consent Informed consent was obtained from all individual participants included in the study.

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