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The effect of inner elements of the context figures on the Ebbinghaus illusion

*Milena Vuk and Anja Podlesek**
University of Ljubljana, Department of Psychology, Ljubljana, Slovenia

Abstract: In the Ebbinghaus illusion, the size of a figure is overestimated when it is surrounded by smaller figures and underestimated when it is surrounded by larger figures. The present study examined whether the illusion is also influenced by the additional inner parts of the inducing context figures. A central square was surrounded by two types of context figures: larger and smaller figures. Each type of context figures had either square or circular shape, or was absent from the display. When both larger and smaller figures were presented, smaller figures were added inside the large ones. Data was gathered with the adjustment method. When the Ebbinghaus display was presented to the left of the probe figure, the perceived size of the central square was larger than in conditions with the display presented to the right of the probe figure. Larger context figures alone induced size underestimation and smaller figures induced size overestimation. A clear similarity effect was observed (squares induced larger illusion than circles), so the size contrast effect was most likely the predominant factor of the illusion. When the smaller context figures were added to the larger ones, the underestimation of the size of the central figure was reduced. Although the effects of the larger and smaller context figures were not completely additive, the results showed that the visual system takes into consideration both similar and dissimilar context figures when making size comparisons.

Key words: Ebbinghaus illusion, visual perception, size perception, contextual effects, method of adjustment, illusions

Učinek notranjih delov kontekstnih likov na Ebbinghausovo iluzijo

Milena Vuk in Anja Podlesek
Univerza v Ljubljani, Oddelek za psihologijo, Ljubljana

Povzetek: Pri Ebbinghausovi iluziji pride do precenjevanja velikosti osrednjega lika, kadar je obdan z manjšimi liki, in do podcenjevanja njegove velikosti, kadar je obdan z večjimi liki. V raziskavi smo ugotavljali, ali na iluzijo vplivajo tudi dodatni liki znotraj kontekstnih likov. Osrednji kvadrat smo obdali z dvema vrstama likov, tj. z večjimi in manjšimi liki, ki so bili bodisi kvadrati bodisi krogi bodisi niso bili predvajani. V pogojih, ko so bili predvajani tako večji kot manjši liki, so bili slednji dodani v notranjost večjih likov. Za zbiranje podatkov smo uporabili metodo prilagajanja. Rezultati so pokazali, da je bila

* Naslov / Address: doc. dr. Anja Podlesek, Univerza v Ljubljani, Oddelek za psihologijo, Aškerčeva 2, 1000 Ljubljana, tel.: +386 1 241 11 84, fax.: +386 1 42 59 301, e-mail: anja.podlesek@ff.uni-lj.si

zaznana velikost osrednjega kvadrata večja v primerih, ko je bil Ebbinghausov prikaz predvajan na levi strani zaslona, kot takrat, ko je bil predvajan na desni strani. Ko so bili predvajani samo večji kontekstni liki, je bila velikost osrednjega lika pričakovano podcenjena, ko so bili predvajani samo manjši kontekstni liki, pa precenjena. Jasno je bil izražen učinek podobnosti (kvadrati so povzročili večjo iluzijo kot krogi) kar kaže, da je na pojav iluzije vplival predvsem učinek kontrasta velikosti. Ko so bili večjim likom dodani manjši, se je podcenjevanje velikosti osrednjega kvadrata zmanjšalo. Čeprav učinkovanje večjih in manjših kontekstnih likov ni bilo povsem aditivno, so rezultati pokazali, da vidni sistem pri presojanju velikosti nekega lika upošteva tako podobne kot različne kontekstne like.

Ključne besede: Ebbinghausova iluzija, vidno zaznavanje, zaznavanje velikosti, kontekstni dejavniki, metoda prilagajanja, iluzije

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The Ebbinghaus illusion causes a change in perceived size of an object when surrounded by other objects. In a classical display of the Ebbinghaus illusion, a circle is surrounded by larger or smaller circles. When the central circle is surrounded by larger circles, it appears smaller, and when it is surrounded by smaller circles, it appears larger.

As the ratio of the size of the context circles and the size of the central circle increases, the magnitude of illusion also increases. But the size ratio is only one of many factors that determine the magnitude of illusion. Massaro and Anderson (1971) demonstrated the effect of the number of the context circles on the illusion: The larger the number of the circles surrounding the central one, the stronger the illusion. They also demonstrated the effect of distance between the context circles and the central one: The larger the distance between the central and the context circles, the weaker the illusion. However, a more recent study done by Ehrnstein and Hamada (1995) showed that increasing the distance between the central circle and the context circles increases the Ebbinghaus illusion only when the surrounding circles are larger, but decreases it when the surrounding circles are smaller than the central one. The next factor determining the magnitude of illusion is the size of the display (the framing extent): The larger the framing extent of the display, the smaller the perceived size of the central circle (Weintraub & Schneck, 1986). The orientation of the context circles array (in cardinal axes *vs.* diagonally) also affects the illusion (Ehrnstein & Hamada, 1995; Weintraub & Schneck, 1986). Moreover, the magnitude of illusion depends on experimental procedure. If the task does not require the adjustment of the probe, but instead requires the comparison of the central circle and the probe, and if free eye movements are permitted so that participants may shift glance from one circle to the other, the comparison circle probe may act as a context that determines the perceived size of the central circle. When the probe is larger than the central circle, the central circle may appear smaller, and when the probe is smaller than the central circle, the latter may appear larger (Weintraub & Schneck, 1986).

Massaro and Anderson (1971) explained the Ebbinghaus illusion using size contrast theory. Perceived size of an object depends on the size of the surrounding objects. In the case of the Ebbinghaus illusion, the context circles represent a standard that serves as a comparison in the process of judging the size of the central circle. Size contrast effect causes the observer to exaggerate the relative difference between the sizes of the circles (Weintraub, 1979). When the central circle is surrounded by large circles, the observer exaggerates its relative smallness and so the circle appears smaller. When the central circle is surrounded by smaller circles, the observer exaggerates its relative largeness and so the circle appears larger (Rose & Bressan, 2002).

If the illusion is due to a comparative process and if we assume that it is more likely for the visual system to make comparisons among similar targets than the dissimilar ones, we can reasonably expect that the magnitude of the illusion will depend on the level of similarity between central and context figures. This was indeed confirmed by Coren and Miller (1973; cited in Rose & Bressan, 2001) who varied the level of similarity between the central figure (which was a circle in all conditions) and the context figures (which were circles, hexagons, triangles, and angular shapes). As the similarity between the central and the context figures increased, so did the magnitude of the illusion. Rose and Bressan (2001) who used the same shapes varied both the shape of the central as well as the context circles and again confirmed that increasing the level of similarity between the figures increased the magnitude of the illusion.

Coren and Enns (1993) claimed that the illusion is affected not only by visual similarity between the central and the context figures, but also by their conceptual relatedness. When the central and the context figures were images that belonged to the same semantic category, the illusion was at its strongest. Their experiment, however, did not manage to successfully separate the visual and categorical similarity of the images. Images that belonged to the same semantic category were also visually similar and had similar contours. Images that are conceptually related to the central image might induce a stronger illusion not because of their semantic similarity but simply because of the visual similarity of their contours. An experiment by Jeager and Guenzel (2001) supports this explanation. In that experiment, letters (categorically similar stimuli) and symbols (visually similar stimuli) were used in place of central and context figures. The results showed that visually similar figures induce the size illusion, whereas merely categorically similar figures do not.

Size contrast seems to be a predominant factor in the Ebbinghaus illusion, but some studies (e.g. Jaeger, 1978; Weintraub, 1979) showed that a contour interaction process is also, at least partially, involved. Contour interaction is a sensory interaction at the level of contours or features that causes a distortion in perception of a figure when surrounded by other figures (Wolford & Chambers, 1984), most commonly a distortion of perceived distance between contours. Contours that are in close proximity are known to attract each other, and so distances between them seem smaller than they actually are. With increasing distance between the contours, the contour attraction effect gradually diminishes and eventually contours start to repel, which causes the distance between them to appear greater. If we continue to increase the distance between the contours, contour interaction effect gradually completely disappears (Eriksson, 1970). In an Ebbinghaus illusion display, the central circle and the adjacent inner arcs of the context circles attract, causing overestimation of the central circle size, while the central circle and the outer arcs of the context circles, being further away, repel, causing underestimation of the central circle. Both contour attraction and repulsion interact to determine the perceived size of the central circle (Jaeger, 1978; Rose & Bressan, 2002). When the context circles are small, both inner and outer arcs are in close proximity to the central circle. In this condition contours attract, which causes overestimation of the central circle size. When the context circles are large, the inner arcs are close to the central circle and cause contour attraction, but the outer arcs are more distant and thus cause contour repellence, causing underestimation of the central circle size.

Jaeger (1978) claimed that the Ebbinghaus illusion is induced solely by the contour interaction process. His claim was based on Ehrnstein and Hamada's (1995) research that showed the magnitude of illusion to decrease with increasing distance between the central circle and small context circles and to increase with increasing distance between the central circle and large context circles. In other words, the central circle appeared smaller as the distance between the central circle and the context circles increased, regardless of whether the context circles were large or small. Such a finding was contradictory to the size contrast theory which predicts a decrease in illusion magnitude with increasing distance between the circles in both large and small context circle conditions. Jaeger thus concluded that contour interaction theory is more adequate to explain the Ebbinghaus illusion.

On the other hand, research that demonstrated the effect of similarity between the central and the context circles proved that contour interaction is not sufficient to explain the illusion. A series of experiments by Weintraub and Schneck (1986) showed that the illusion is a function of both contour interaction and size contrast effects and that size contrast always prevails over contour interaction. Even Jaeger himself eventually concluded that size contrast and contour interaction both influence the illusion (Jaeger & Grasso, 1993), and stated that when the context circles are small, contour interaction has a prevailing influence, but when the context circles are large, size contrast has the predominating effect (Jaeger, 1999).

Only the outline of a figure (the figure's contour) seems to cause contour interaction. The inner part of a figure (the part inside the contour) does not have any effect on contour interaction (Eriksson, 1970). Choplin and Medin (1999), who examined the effect of conceptual similarity between the central and the context figures on the illusion, varied the shape of the figures (visual similarity) and images inside those shapes (conceptual similarity). They demonstrated that only visual similarity between the figures had an effect on illusion magnitude and that varying the image inside the figures had no influence on the illusion whatsoever. They concluded that only the outline of a figure has an effect on the illusion, whereas the inner part of the figure plays no role.

Choplin and Medin (1999) also wondered what would happen if the images inside the context figures had the same shape as the central figure. If it is more likely for the visual system to make size comparisons among similar targets than among dissimilar ones, then the inner parts of the figures should also affect the illusion if they were similar enough to the central circle.

The aim of the present study was to determine whether the inner part of the context figures can also influence the perceived size of the central circle. This influence might occur if the inner parts of the figures were visually similar to the central figure, which would make them relevant to the size judgment process that is based on size comparison between similarly shaped figures. In the experiment by Choplin and Medin (1999), however, the central and the context figures had the same or very similar shapes, but the shapes of the images inside the context figures were very different from the shapes of the central figure. It is possible that, when judging the size of the central figure, the visual system compared the central figure to the outer contours of context figures because they were visually much more similar to the central figure than their inner parts. Consequently, the effect of outer contours of the context figures prevailed over the effect of their inner images. We reasoned that if the Ebbinghaus display consisted of visually similar figures and if figures smaller than the central one were placed inside the larger outer figures, the effect of the inner figures would probably interfere with the effect of the outer figures. The outer figures would cause the underestimation and the inner figures would cause the overestimation of the central figure, so that the actual perceived size of the central figure would be something in between its perceived size in conditions with inner figures only and in conditions with outer figures only. We also assumed that the magnitude of the effect of context figures would depend on the level of similarity between the context figures and the central figure. Similar context figures would produce a larger illusion than dissimilar ones.

Method

Participants

Sixteen undergraduate psychology students (13 females and 3 males; 21–24 years old) participated in the experiment. They all reported normal or corrected-to-normal vision and were naive as to the purpose of the experiment.

Stimuli and apparatus

The experiment was performed on a desktop computer. Stimuli were presented on a 19″ (diagonal) CRT display NOKIA Multigraph 446XPRO with resolution 1024 (H) × 768 (V) pixels (subtending 14.1° × 10.7° of visual angle) and a vertical refresh rate of 85 Hz. One pixel measured approx. 0.87 arcmin.

In all experimental conditions, the central shape within the figural composition was a square. To prevent learning during the experiment, the size of the central figure was varied across the trials: the square had either a 110 or a 130 pixel side subtending approx. 1.59 or 1.87 degrees of visual angle. The centre of the square was always located vertically halfway down the screen. Horizontally, it appeared one fourth of the screen width distant from the screen centre.

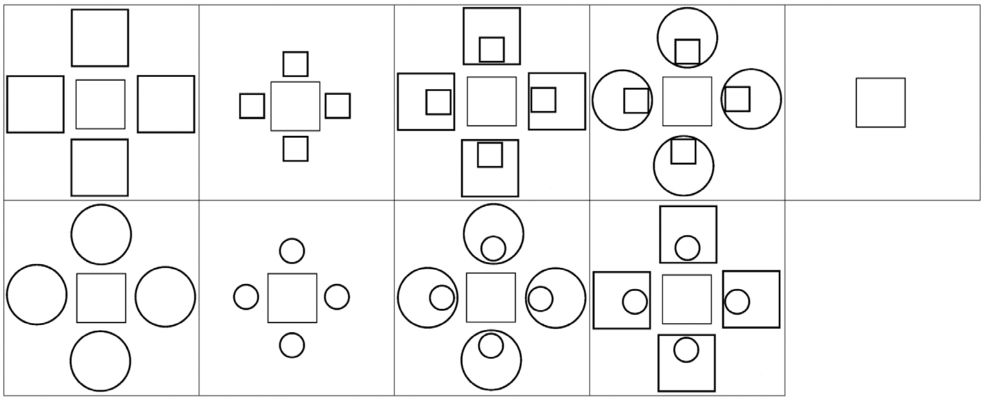

Figure 1. Nine figural compositions, resulting from various combinations of the shape of outer and inner context figures. Three variations of both larger outer and smaller inner figures were used: square, circle, none. Pictures are schematic. The size of the central square varied across the trials (110 vs. 130 pixels).

To the target, i.e. to the central square, four inner and four outer figures were added to create the figural composition. The outer figures were larger than the central figure. The inner figures were smaller than the central one and always (except in the condition with no outer figures) placed inside the larger outer figures. We varied the level of similarity between the figures. The figures surrounding the target (i.e. the context figures) were either squares (similar to the central figure) or circles (dissimilar to the central figure), or were not included in the figural composition. Nine figural compositions were therefore generated as different combinations of outer and inner figures (see Figure 1).

The inner and outer figures were positioned to the left, to the right, above and below the target. The outer contextual figures measured 170 pixels in diameter (approx.

2.45° of visual angle), whereas the inner contextual figures measured 50 pixels in diameter (approx. 0.72° of visual angle). Only the contours of the figures were presented. The contours of the central square and the context figures were black (their lightness was less than 0.5 cd m^{-2}). The background was light grey (its lightness was approx. 60 cd m^{-2}). The contours of all the presented figures measured 1 pixel in width. The distance between the contour of the central square and the contours of the outer context figures was 50 pixels (approx. 0.72° of visual angle), and the distance between the contour of the central square and the contour of the inner context figures was 58 pixels (approx. 0.84° of visual angle). The presentation time of the figural composition was not limited.

Procedure

Observers sat about 143 cm in front of the computer screen. Eye movements was not monitored and head position was not restrained.

At the beginning of each trial a black mask was shown across the whole display, and after 2000 ms a white circle was shown either on the left or on the right side of the display at the location of the succeeding figural composition. The purpose of presenting the white circle was to indicate the location and the size of the figural composition, containing the central and the context figures, so that observers would be able to direct their attention to the proper side of the display and to spread the attention across the whole composition as soon as the composition appeared on the screen. The white circle was presented for 1000 ms. After that time the circle and the black mask vanished and the figural composition appeared on the grey background. At the same time the probe square appeared on the other side of the screen (the target and the probe centres were located symmetrically around the screen centre). The size of the probe was chosen randomly.

Different figural compositions were presented in random order to observers. In half the trials the target appeared on the left side of the screen and in the other half it appeared on the right side of the screen (trials were randomly mixed).

Observers adjusted the size of the probe to the perceived size of the target by pressing the numeric buttons on the keyboard (1 for reducing and 3 for enlarging the size of the probe). They were instructed not to focus the target square in isolation, but to attend to the entire figural composition as much as possible. The adjustments were to be made accurately, but as fast as possible. When satisfied with their adjustment, observers pressed Enter to save the information about the probe size and to start a new trial.

Five adjustments were gathered for each of the 36 experimental conditions (9 figural compositions × 2 sizes of the target × 2 sides of target presentation), which resulted in 180 adjustments for each observer.

Results

In order to combine data obtained in conditions with different target sizes, the size of the probe was calculated as a percentage of the target size. The percentage value above 100 indicates that the adjusted size of the probe was bigger than the size of the target, and the percentage value below 100 indicates that the adjusted size of the probe was smaller than the target.

When only the target was presented with no context figures, the adjusted size of the probe ($M = 100.32$, $SD = 1.20$) did not differ significantly from the real size of the target, t (15) = 1.06, p = .31. Therefore, in the following analysis the adjusted probe size was compared to the target size directly. A three-way repeated-measures analysis of variance (3 – outer contextual figures × 3 – inner contextual figures × 2 – side of display) was used to examine the effects of context figures (Greenhouse-

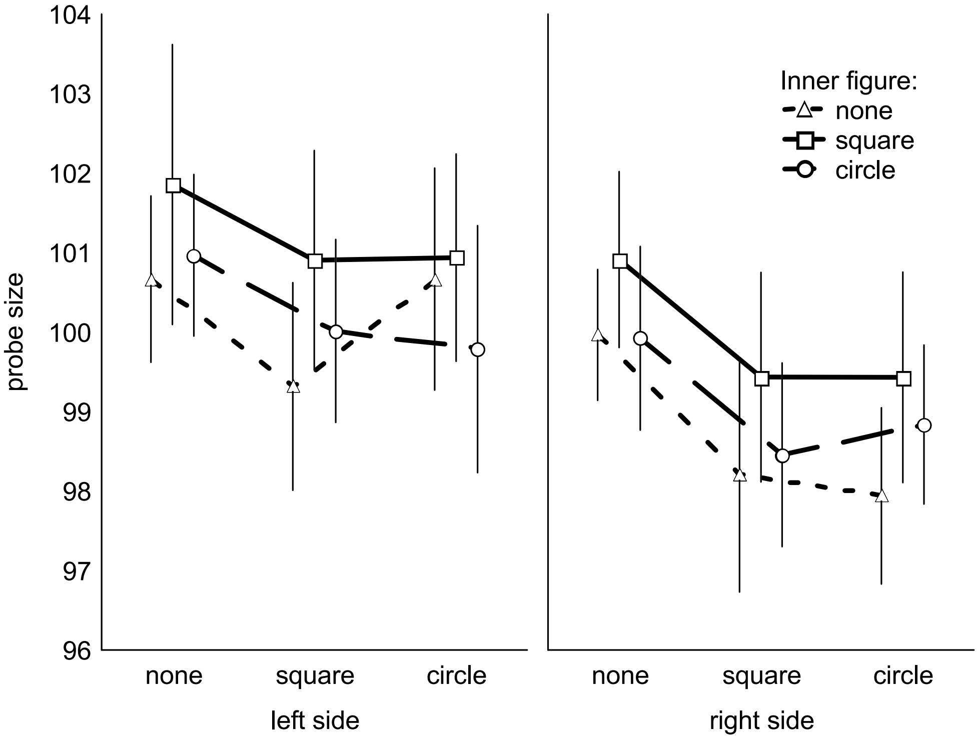

Figure 2. The adjusted size of the probe (expressed as a percentage of target size) when different figural compositions were displayed on the left side of the screen (i.e. to the left of the probe) and on the right side of the screen (to the right of the probe). The variation of the outer-figure shape is shown on the x-axis. Vertical lines denote .95 confidence intervals.

Geisser correction was used whenever non-sphericity was detected in data), and α-level .05 was used for testing hypotheses. Only statistically significant results are described here.

Figure 2 shows the adjusted probe sizes for different figural compositions when the latter were displayed on the left and the right side of the screen. Display side had a statistically significant effect on the magnitude of the Ebbinghaus illusion, F (1, 15) = 9.68, p = .007, *MSE* = 13.24, partial η^2 = .39. In most of the conditions, the probe size was smaller than the target size when figural composition was presented on the right side of the display and the probe was presented on the left side of the display. In contrast, the overall overestimation of the target size can be observed in conditions where the figural composition was presented on the left side of the display, so that adjustments were made to the probe on the right side of the display.

ANOVA indicated a statistically significant three-way interaction, F (4, 60) = 2.86, p = .031, *MSE* = 1.16, partial η^2 = .16. This interaction was mainly due to the specific result obtained in the condition where the figural composition contained only the target surrounded by large circles. When the figural composition was presented on the left side of the visual field, the large outer context circles did not cause underestimation, but even slight overestimation of the size of the central square. However, when the display was presented on the right side of the visual field, the outer context circles induced an underestimation of the central square size that was even stronger than the underestimation induced by the large outer squares (see Figure 2). This is an unexpected result, and it is not in accordance with the similarity effect described by the size contrast theory. Another unexpected result was the interaction between the shape of outer figures and the side of the display, F (2, 30) = 3.90, p = .031, *MSE* = 1.07, partial η^2 = .21. The effect of the display side on the illusion was smaller in conditions with no outer figures than in conditions with outer squares or outer circles.

Although some inconsistencies were present in the results due to the effect of the display side, several general patterns regarding the effects of the figural composition on size illusion can be observed in Figure 2. To demonstrate these effects more evidently, we averaged data across the two sides of the display. The results are shown in Table 1.

The size of the probe was affected by the inner figures, F (1.38, 20.66) = 8.78, p = .004, *MSE* = 5.64, partial η^2 = .37, as well as by the outer figures, F (1.48, 22.24) = 7.31, p = .007, *MSE* = 9.00, partial η^2 = .33. When only outer, i.e. larger figures were present, the target was underestimated (see Table 1, row 1). The underestimation was larger when the outer figures were squares than when they were circles. When only inner, i.e. smaller figures were present, the target was overestimated (Table 1, column 1). As with the effect of outer figures, the size illusion was larger in cases with outer squares than with outer circles. In the conditions with both inner and outer figures the perceived size of the target was generally larger than in conditions with outer figures only and smaller than in conditions with inner figures only. When-

Table 1. *Descriptive statistics for adjustments made in conditions with different context figures.*

	Outer figures						
	None		Squares		Circles		
Inner figures	*M*	*SD*	*M*	*SD*	*M*	*SD*	M_{total}
None	100.32	1.20	98.76	2.30	99.30	2.07	99.39
Squares	101.38	2.51	100.17	2.39	100.18	2.18	100.71
Circles	100.44	1.72	99.24	2.03	99.31	2.15	99.60
M_{total}	100.58		99.46		99.66		99.90

Note. The adjusted size is expressed as a percentage of target size. Adjustments are averaged across the two display locations.

ever the inner figures were added to the outer figures, the target appeared larger (compare rows 1 and 2 and rows 1 and 3 in Table 1). When the inner figures were squares, the change in the magnitude of the illusion was larger than in the case of circular inner figures.

In conditions with both inner and outer context figures, the perceived size of the central square was not an exact average of its perceived size in inner-figure-only and outer-figure-only conditions. The result obtained in the condition where both inner and outer figures were squares (100.17) was closer to the result obtained in the inner-square-only condition (101.38) than to the one obtained in the outer-square-only condition (98.76). On the contrary, in other mixed-size conditions the results were closer to those obtained in the outer-figures-only condition than to those obtained in the inner-figures-only condition (see Table 1). More specifically, when both the outer and the inner figures were circles, perception of the size of the central square (99.31) was closer to perception in the outer-circles-only condition (99.30) than to perception in the inner-circles-only condition (100.44). When the outer figures were different from the inner figures, i.e. when outer figures were squares and inner figures were circles, and when outer figures were circles and the inner figures were squares, the results obtained (99.24 and 100.18, respectively) were closer to the ones obtained in the condition where the inner shapes were excluded from the display (98.76 and 99.30, respectively) than to those obtained in the condition where the outer figures were excluded from the display (100.44 and 101.38, respectively). To summarise, it appears that in the mixed-size conditions the effects of the inner and outer figures were not additive. One of the effects of inner and outer context figures prevailed over the other. When both the inner and the outer context figures were of the same shape as the central figure, the effect of the inner context figures was larger than the effect of the outer figures. When one of the context figures had a shape dissimilar to the shape of the target, the effect of outer figures prevailed over the effect of inner figures.

Discussion

As we predicted, the context figures caused a change in perceived size of the central figure. Large context figures induced underestimation and small context figures induced overestimation of the central square. There was also a strong similarity effect: the illusion was stronger when the context figures had the same shape as the central figure (i.e., when the context figures were squares) and weaker when the context figures were dissimilar to the central figure (i.e., when they were circles). The clearly expressed similarity effect indicates that size contrast is the main factor of the illusion.

In the no-context-figures condition, the size of the central square was slightly overestimated. Since our main interest was the effect of different context figures on the central square size perception, this slight and constant overestimation did not have a substantial impact on the interpretation of the results obtained.

An interesting finding was that the perceived size of the central square depended on the position of the Ebbinghaus display along the horizontal axis. There were certain qualitative side differences, most apparent in the outer-figures-only conditions, but these differences were most probably a consequence of chance rather than of a certain perceptual mechanism, because when small figures were added inside the large context figures, the qualitative differences between the two sides of presentation practically vanished. The more important finding was a fairly large quantitative difference between the two locations of display. The central square was constantly perceived as larger when presented to the left of the probe and as smaller when presented to the right of the probe. Dependence of size contrast on the side of presentation was demonstrated by several studies (e.g., Bondarko & Semenov, 2002; Ehrnstein & Hamada, 1995). However, contrary to our results, in those studies the size of the circle was constantly overestimated when presented on the right side of the visual field. In the study of Bondarko and Semenov (2002) only the size of an isolated circle presented on the right side was overestimated, whereas in the study of Ehrnstein and Hamada (1995) the central circle was perceived as larger when presented on the right side of the visual field across all the conditions. The authors proposed that this might be due to the possible perceptual asymmetries between the left and right visual field and hemispheres. Even though there was no fixation point and the participants were allowed to freely shift glance in all directions without restrictions, making it impossible to strictly separate between the left and right visual field and their related hemispheric projections in the processing of visual size relationships, relative asymmetries in visual projections still remained. This occurred because when the participants shifted their gaze from one side to another, left side figures were presented either foveally or on the left side of the visual field and right side figures were presented either foveally or on the right side of the visual field. According to Ehrnstein and Hamada (1995), their results are in accordance with many studies that report a general tendency to overestimate the size of objects presented in the right side of the visual field. At the moment we have no explanation of why in our study the opposite findings were obtained. The control of participants' handedness or recording of variables that could potentially explain the side differences would be desired in future studies.

Our results showed that adding smaller figures inside the larger context figures influences the perceived size of the central figure in an Ebbinghaus illusion display, and that the extent of this influence is moderated by the similarity between the context figures and the central one. The central square appeared larger when the inner context figures were squares compared to when they were circles or when they were excluded from the display, regardless of whether the outer figures were squares or circles. The similarity effect supports the conclusion that both the inner-figure and the outer-figure effects were induced by size contrast. It can be concluded that, due to the size contrast effect, large outer context figures reduced the perceived size of the central square and at the same time small inner figures increased it. The perceived size of the central square was defined by the effect of both inner and outer context figures and was something in between the sizes obtained in the outer-figures-only and inner-figures-only conditions. The effect of outer and inner figures was, however, not additive.

Ehrnstein and Hamada (1995) examined the additivity of effects in mixed-size conditions with both smaller and larger context circles surrounding the central circle. If the effects were purely additive, the perceived size of the central circle in mixed-size conditions should be half-way in between the perceived size in the non-mixed conditions. The authors found that this was not the case. Although the mixed-size results were in between the non-mixed size results, they were much closer to the results obtained in the large context circles condition. They also discovered that at the same distance from the central circle large context circles had a stronger effect on the illusion than small context circles. In our study, too, the effects of inner and outer figures seemed not to be additive. In most mixed-size conditions, the outer figures had a stronger effect on the illusion than the inner figures.

It is possible that in our study the size contrast was accompanied by the effect of the distance between the central and the context figures and by the effect of contour interaction. In our displays, the distance between the inner context figures and the central square was slightly larger than the distance between the outer context figures and the central square. This was, due to the geometrical differences between circles and squares, the only way to ensure no contact between the contours and the constancy of the distances between the central and the context figures in all of the experimental conditions. According to Eriksson (1970), we could assume that the possible contour interaction effect was caused solely by large outer context figures, whereas the size contrast was induced both by the outer contour of the context figures and by the figures that were placed inside it.

We demonstrated that when making size judgements, the visual system makes size comparisons between the judged figure and the surrounding context figures. In these comparisons it takes into account all the present context figures. For the purpose of comparison, it is more likely that the visual system selects those surrounding figures that have a shape most similar to the shape of the judged figure. However, the presence of a very similar or identical figure does not imply that the rest of the figures will not be considered as a standard for size comparison. Even when the outer figures were squares and inner figures were circles, thus dissimilar to the central figure, the inner figures induced size contrast. If the size judgment process required merely a comparison to a standard, one would expect the outer squares to be sufficient for size comparison and the inner circles to have no effect on the illusion. But it seems that size judgment process involves placing a figure on a size scale, defined by all other currently present figures. Among them, figures that are most similar to the judged figure have the strongest influence on the perception of the size of the judged figure.

The concept of selective attention could perhaps explain our results. Shulman (1992) demonstrated that the perceived size of a central circle in an Ebbinghaus illusion display depends on whether subjects are attending to the context figures and which of the context figures they are attending to when there are different context figures surrounding the central figure. According to Shulman, a selective attention mechanism decides which context figures will be chosen as standards in the process of size comparison. Saenz et al. (2003) described a visual attention mechanism that enhances the activity of cortical neurons that encode relevant stimulus properties such as location, features, and object identity. When observers search for an object with a particular feature, for example a square shape, attention sensitizes neurons with receptive field locators throughout visual space that respond to squares. Selective attention thus has a strong impact on our ability to process multiple stimuli in complex visual scenes. If attention to a stimulus feature enhances the processing of other stimuli with that same feature, this should facilitate the distribution of attention across multiple stimuli with common features compared to opposing features.

When judging the size of a square, attention is directed towards that square, which facilitates the distribution of attention across other squares, so that they have greater influence on the processing of the target than other figures in the same visual field. In displays like ours, squares will thus have bigger impact on the illusion as compared to circles, although circles will also have some influence on the perceived size of the central square.

To sum up, the present study showed that the magnitude of the Ebbinghaus illusion depends on the whole composition of the context figures and that the illusion is affected more by the size of the context figures similar to the central figure than by the size of dissimilar figures. In future, our study could be expanded and the shape of the central target could be varied in addition to varying the shape of the context figures. For example, circles and other simple shapes could be used for the central and context figures, and the magnitude of illusion could be compared in conditions with different combinations of the shape of the central and context figures. It would also be interesting to vary the distance between the central and the inner figures and to observe the changes in the interaction between the outer and the inner figures' effects.

References

Bondarko, V. M., & Semenov, L. A. (2002). Size estimates in Ebbinghaus illusion in adults and children in different age. *Human Physiology*, *30* (1), 24–30.

Choplin, J. M., & Medin, D. L. (1999). Similarity of the perimeters in the Ebbinghaus illusion. *Perception & Psychophysics, 61*, 3–12.

Coren, S., & Enns, T. J. (1993). Size contrast as a function of conceptual similarity between test and inducers. *Perception & Psychophysics*, *54*, 579–588.

Eriksson, E. S. (1970). A field theory of visual illusions. *British Journal of Psychology, 61*, 451–466.

Ehrnstein, W. H., & Hamada, J. (1995). Structural factors of size contrast in the Ebbinghaus illusion. *Japanese Psycological Research, 37* (3), 158–169.

Jaeger, T. (1978). Ebbinghaus illusions: Size contrast or contour interaction phenomena? *Perception & Psychophysics*, *24*, 337–342.

Jaeger, T. B. (1999). Assimilation and contrast in geometrical illusions: A theoretical analysis. *Perceptual and Motor Skills*, *89*, 249–261.

Jaeger, T., & Grasso, K. (1993), Contour lightness and separation effects in the Ebbinghaus illusion. *Perceptual and Motor Skills*, *76*, 255–258.

Jaeger, T., & Gunzel, N. (2001). Similarity and lightness effects in Ebbinghaus illusion created by keyboard characters. *Perceptual and Motor Skills*, *92*, 151–156.

Massaro, D. W., & Anderson, N. H. (1971). Judgmental model of the Ebbinghaus illusion. *Journal of Experimental Psychology*, *89* (1), 147–151.

Rose, D., & Bressan, P. (2002). Going round in circles: Shape effects in the Ebbinghaus illusion. *Spatial Vision*, *15* (2), 191–203.

Saenz, M., Buracas, G. T., & Boynton, G. M. (2003). Global feature-based attention for motion and color. *Vison Research*, *43*, 629–637.

Shulman, G. L. (1992). Attentional Modulation of Size Contrast. *The Quarterly Journal of Experimental Psychology*, *45A* (1), 529–546.

Weintraub, D. J. (1979). Ebbinghaus illusion: Context, contour, and age influence the judged size of a circle amidst circles. *Journal of Experimental Psychology: Human Perception & Performance*, *5*, 353–364.

Weintraub, D. J., & Schneck, M. K. (1986). Fragments of Delboeuf and Ebbinghaus ilusions: Contour/context explorations of misjudged circle size. *Perception & Psychophysics*, *40* (3), 147–158.

Wolford, G., & Chambers, L. (1984). Contour interaction as a function of retinal eccentricity. *Perception & Psychophysics*, *36*, 457–460.

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