THE EFFECT OF HUE AND BRIGHTNESS ON THE SIZE-ILLUSION OF CONCENTRIC CIRCLES: A FURTHER STUDY

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Since Delboeuf (1893), it has been noticed that the inner circle of concentric circles such as B in Fig. 1 appears larger than the circle such as A which is physically the same in size and that the outer circle of B appears smaller than circle C which is again physically the same in size. Morinaga (1935) and Ogasawara (1952) found in their systematic studies that both these size-illusions are maximal when the size ratio between the outer and inner circles is 3:2, regardless of their absolute size (Oyama, 1960 a).

Oyama (1962) studied the effect of hue and brightness on the overestimation of size of inner circle, and reached the following conclusions:

1. The similarity or dissimilarity in hue and brightness between the two concentric circles has no effect on this illusion.

2. The illusion increases as the brightness-difference of the outer (inducing) circle from background increases, and it decreases as the brightness-difference of the inner (test) circle from background increases. But, further increase in the brightness-differences beyond a comparatively small zone does not affect the illusion.

3. Hue does not have an effect per se. The effect of color in this illusion is attributable solely to the effect of brightness-difference from background.

Conclusion 1 is especially interesting. If the solid line in Fig. 1 represents one color and the broken line another, and if the similarity between the outer and inner circles is a favorable condition for illusion, the illusion of inner circle should be greater in B than in D and in E than in F. His results however, did not support this expectation. Consequently neither the Gestalt principle of similarity nor any explanation based on the phenomenological characteristic of "ring" or "doughnut" is useful in the explanation of this illusion. Conclusions 2 and 3 are in the line with Benussi's (1902) conclusion in his study on Zöllner’s illusion.

In the present study, it was attempted to examine these problems again in the illusion of outer circle of concentric circles.

METHOD

Apparatus. A wooden screen, 80 cm. high and 90 cm. wide, covered by a white cardboard whose brightness was 9.0/ in Munsell value, stood vertically 115 cm. from S who sat on a chair and observed the stimulus figures binocularly. Two square apertures, 20 cm. ×20 cm., were cut from the screen. The right lower corner of one aperture was located 10 cm. above and 10 cm. to the left of the left upper corner.
of the other aperture. The center between the two apertures coincided with the center of the screen and was nearly on a level with S’s eyes. This apparatus was the same as one used by Oyama and Nanri (1960) and Oyama (1962).

The standard stimulus was exposed in the left upper aperture and the comparison stimulus was in the right lower aperture. The stimulus screen was illuminated by a Standard Illuminator of Japan Color Research Institute which was matched with C.I.E. Standard Source C (6500°K), and was placed at the right side of S’s back. The illuminance on the screen was two foot-candles.

Stimulus materials. Each of the standard stimuli consisted of two concentric outline circles which were cut precisely from the standard colored papers of Japan Color Research Institute and pasted very carefully on a white card (9.0/ in Munsell value). The diameters of the inner and outer circles were always 60 mm. and 90 mm. respectively and the width of circular outline was always 2 mm. The value of diameter was measured from the middle point of outline of one side to that of the other side of each circle. From the observation distance of the present study, the diameters of the circles were 3° and 4.5° in visual angle, respectively, and the width was 6'. The control stimuli, which were the same as the standard stimuli except that the inner circles were eliminated, were also prepared. Hue and brightness of the colored papers used will be described in each experiment.

The comparison stimuli consisted of a series of 36 white cards, on which black outline circles, drawn in India ink, were centered. The diameter of circle was varied from 65 mm. to 100 mm. in 1 mm. steps, and the width was always 0.5 mm.

General procedure. Subjects observed each standard or control stimulus twice, and were asked to compare the apparent size of the outer circle of standard stimulus or control circle with the comparison circle by free regard and to report in three categories, “larger,” “smaller” and “doubtful”. The method of limits with one ascending and one descending series was used to obtain a PSE in each observation.

Measure. The difference between the average PSE of the two observations for each illusional figure and the average PSE for the corresponding control figure was adopted as the measure of illusion.

Subjects. A staff member and students of the department of psychology served as subjects. They all had normal color vision and normal acuity, although some of them wore glasses.

Experiment I

Experiment I was designed to analyze the effects of brightness, or brightness-difference from the background, of the outer and inner circles on the illusion.

Procedure. Four achromatic stimulus-series, Bk-, MGr-, LG-, and W-series were used. Each series consisted of four illusional figures and one control figure. The outer circles were black (N 1.5/ in Munsell Renotation²) in Bk-series, medium gray (N 4.7/) in MGr-series, light gray (N 8.0/) in LG-series, and white (N 9.3/) in W-series. The inner circles in each series were made from the same four achromatic colors. The control figure for each series was the same in size and brightness as the outer circles of the standard figures.

Four subjects served in four sessions. In each session, all figures in two of the four stimulus-series were exposed in a randomized order which was different from subject to subject. Every figure was exposed twice in the whole experiment.

Results. Underestimation of outer circle in size occurred under every conditions of this experiment. The four lines in Fig. 2 show the average magnitudes of underestimation in the four series of stimulus-figures. The illusion was greatest in W-series and least in Bk-series. In MGr- and LG-series it was approximately on the same middle level.

The four curves are similar in shape with each other. They are flat when the inner

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² These values of Munsell Renotation were determined by visual comparison with Jap. Stand. Assoc. (ed.), Hyoujun Shikihyo (Standard Chart of Colors), Tokyo, Nihon Kikaku Kyokai, 1959.
Size-Illusion of Concentric Circles

FIG. 2. Magnitude of illusion as a function of the brightness of inner and outer circles (Results of Experiment I).

The abscissa represents the brightness of inner circle in Munsell value and the ordinate represents the magnitude of illusion (underestimation of outer circle in size, in millimeters or minutes of arc. Each line indicates each series of experiment in which the brightness of outer circle is fixed. The vertical broken line shows the brightness of background.

TABLE 1

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>Variance</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer Circle (O)</td>
<td>36.50</td>
<td>3</td>
<td>12.17</td>
<td>36.88**</td>
</tr>
<tr>
<td>Inner Circle (I)</td>
<td>20.75</td>
<td>3</td>
<td>6.92</td>
<td>20.96**</td>
</tr>
<tr>
<td>Subject (S)</td>
<td>192.28</td>
<td>3</td>
<td>64.09</td>
<td>194.21**</td>
</tr>
<tr>
<td>O × I</td>
<td>2.34</td>
<td>9</td>
<td>0.26</td>
<td></td>
</tr>
<tr>
<td>O × S</td>
<td>18.10</td>
<td>9</td>
<td>2.01</td>
<td>6.09**</td>
</tr>
<tr>
<td>I × S</td>
<td>4.36</td>
<td>9</td>
<td>0.48</td>
<td></td>
</tr>
<tr>
<td>O × I × S</td>
<td>9.00</td>
<td>27</td>
<td>0.33</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>283.33</td>
<td>63</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

** Significant beyond the 1% level.

circle varies in brightness from 1.5 to 4.7 and begin to show a decrease when the brightness reaches 8.0 from whence they decrease rapidly to 9.3. It should be noted that the brightest inner circle was slightly brighter than the background and that the absolute magnitude of brightness-difference seemed to act in the same manner even when the direction of difference was changed from negative to positive.

The analysis of variance of these results, shown in Table 1, indicates that the effects of the outer circle (O), the inner circle (I), the subject (S), and the interaction between the outer circle and the subject (O × S) were statistically significant when the secondary interaction (O × I × S) was adopted as the error, while the other primary interactions (O × I and I × S) were insignificant. The results of this analysis were just in the same line with the tendencies found in Fig. 2. If the similarity in brightness between the outer and the inner circles was a determining factor of this illusion, the illusions of the outer circles with various brightness should be affected in different manners by the brightness of the inner circles. The interaction between the outer and inner circles (O × I) was, however, insignificant. Accordingly the hypothesis of similarity was not supported.

Because the physical errors in making the stimulus figures have no systematic relation with the brightness of either outer or inner circles and were absolutely independent of the subjects, their effects should be involved in O × I. The effects of the outer and inner circles were significant beyond the 1% level again when this interaction was adopted as the error (Fs of 46.42 and 26.62, with dfs of 3 9). This means that the effects of the outer and inner circles were not ascribable to physical errors. In this experiment, different outer circles were presented in different sessions, and consequently O × S was supposed to involve session-to-session variations in individual subjects. The effects of outer circle and subject were also significant beyond the 5% and the 1% levels, respectively, when this interaction was adopted as error (Fs of 6.05 and 31.73, with dfs of 3 9).

Tukey's (1951) contrast test using the Studentized range indicated that all of the differences among stimulus-series, except between MGr- and LGr-series, were
significant beyond the 1% level when \( O \times I \times S \) was used as the error. Tukey's test also showed that all of the differences among four inner circles were significant beyond the 1% level, except that the difference between the medium and light grays was significant beyond the 5% level and the difference between black and medium gray was insignificant.

**Experiment II**

In Experiment II, three saturated colors, red, yellow and blue, and two grays, whose lightness were approximately equal to the yellow, and to the red and blue, respectively, were used in both the outer and inner circles, and the effect of hue on the illusion was examined.

**Procedure.** Five series of stimulus figures, R-, Y-, B-, LGr- and DMGr-series were used. Each series consisted of five illusional figures and a control figure. The outer circles were red (5.0 R 4.0/12.0 in Munsell Renotation) in the R-series, yellow (7.5 Y 8.3/11.0) in the Y-series, blue (2.5 PB 4.0/10.0) in the B-series, light gray (N 8.0/) in the LGr-series and slightly dark medium gray (N 4.0/) in the DMGr-series. The inner circles of five illusional figures in each series were made from the same five colors. The single circles of the five control figures were the same in size and color as the outer circles of the corresponding illusional figures.

Four subjects, three of whom had experienced Experiment I, served in five sessions. In each session, two series of figures were used. Each subject observed each series twice in the whole experiment. The order of observations was different among subjects.

**Results.** Average magnitudes of illusion (underestimation in size) in 25 figures used in this experiment are shown in Table 2, in which each row represents each series (outer circle) and each column represents each inner circle. An inspection of this table reveals that the illusions in the Y- and LGr-Series markedly greater than the other series, and that the illusions caused by yellow or light gray inner circles were slightly smaller than those by the other inner circles. These facts suggest that greater illusions occur in outer circles of light colors than in those of dark colors, and that smaller illusions are induced by inner circles of light colors than by those of dark colors. There seems to be no peculiarity in the illusion of any figure which consisted of two concentric circles of an identical color.

The analysis of variance shown in Table 3 indicates that the effects of \( O \), \( I \), \( S \), and \( O \times I \times S \) were significant beyond the 1% level, while \( O \times I \) and \( I \times S \) were insignificant, when \( O \times I \times S \) was used as the error. \( O \) and \( I \) were significant beyond the 1% level also when \( O \times I \) was used as the error (\( F \)s of 22.47 and 5.08, with \( df \)s of 4/16). \( O \)
and \( S \) were also significant beyond the 5% and 1% levels, respectively, when \( O \times S \) was adopted as the error (\( F_s \) of 5.37, and 64.64 , with \( df \)'s of 4/12 and 3/12).

Tukey's contrast test indicated that the difference of the Y-, LGr- and R-series from the B- and DMGr-series was significant beyond the 1% level when \( O \times I \times S \) was used as the error. All of the differences among the Y-, LGr- and R-series, and the difference between the B- and the DMGr-series were insignificant. Tukey's test also showed that the difference between illusions induced by red, blue and medium-gray inner-circles and the illusions by yellow inner-circles was significant beyond the 1% level, and that the difference between the illusions by medium-gray inner-circles and the illusion by light-gray was significant beyond the 5% level. There was no significant difference either among the illusions by the red, blue and medium-gray circles or between the illusions by the yellow and by the light-gray circles.

These analyses suggest that the illusion varies systematically as the colors of the outer and inner circles vary, but it was not affected by the similarity or dissimilarity between these colors. The effect of yellow was approximately equal to the effect of light gray with similar lightness and the effects of red and blue were approximately equal to the effect of medium gray with similar lightness, whether these colors were used in the outer or in the inner circles, except that significantly greater illusions occurred in the red outer-circles than in the medium-gray outer-circles. With this exception, no effect of hue could be found and all of the rest effects of colors were attributable to the effect of brightness.

### DISCUSSION

The results of the present study are generally in line with the conclusions of the previous study (Oyama, 1962).

The interaction between the outer and inner circles was statistically insignificant again in two experiments. It means that there was no effect of similarity in hue brightness between the circles on this illusion. Consequently the illusion should have no intimate relation with the perceptual grouping, in which the similarity plays a very important role as indicated by Wertheimer (1923), and with the ring-shaped appearance which was assumed to be essential to this illusion by Koffka (1931), Cymbalistyj (1949) and Ogasawara (1952). If this illusion is caused by some physiological induction in retinal or cortical field as suggested by Motokawa's (1950) or Köhler-Wallach's (1944) theory, such induction should be independent of the similarity between the physiological correlates of colors. It may be concluded that none of these theories is useful to explain this illusion.

The effects of the brightness of outer and inner circles were highly significant in both of the two experiments. The illusion increased as the brightness-difference of the inducing (inner) circle from background increased, and it decreased as the brightness-difference of the test (outer) circle from background increased. These tendencies are just the same with those found in the previous study, where the inner-outer relation was reversed and with those found by Wada (1956) who used white and dark-gray circles on black background and measured both illusions in the outer and inner circles.

No effect of hue per se was found again in this study, except that significantly larger illusion was occurred in the red outer-circles than in the blue and medium-gray outer-circles with the same brightness. This exception should be examined by further studies.

The close relationships between figural after-effect and this illusion have been suggested from many similarities between these two phenomena (Sagara and Oyama, 1957). The effects of hue and brightness on figural after-effect were studied by several investigators. Hochberg and Triebel (1955) found some effect of the
brightness-difference from background but no effect of hue. Pollack (1958), Graham (1961) and Hochberg, Day and Hardy there was no effect of similarity in hue or brightness between the circles on this illusion. Consequently the illusion should (1960) also reported effects of brightness-difference. Day (1959) and Oyama (1960, b) could not find effect of either hue or brightness. These results should be considered together with the results of the present experiments.

SUMMARY

The present study attempted to examine whether the three conclusions in the previous study of the senior author on the illusion of the inner circle of the concentric circles held also in the illusion of the outer circle. The experimental results supported the previous conclusions with an exception concerning the effect of hue.

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