THE EFFECTS OF HUE AND BRIGHTNESS ON THE SIZE PERCEPTION

TADASU OYAMA AND REIKO NANRI

Hokkaido University

It has long been noticed by artists, psychologists and other specialists on color that some colors make objects appear larger and some color smaller (Arnheim, 1954). However only a few experimental studies have been done on this problem. Warden and Flynn (1931) asked their subjects to rank according to apparent size eight rectangular cartons which were identical in physical size but different in color, but could not obtain consistent results, ranking order being different from one serial arrangement on the display-shelf to another. Gundlach and Macoubrey (1926) repeated the same experiment by means of two different methods, the method of rank order and the method of paired comparison, and showed that both methods gave highly correlated results, brighter carton appearing larger than the darker. Tamaike (1935) found that the hue and brightness of background also affected the apparent size of circular figure. Recently Ohshima and his collaborators (1952) reported that there were some interaction-effects between the hue of figure and background, and Bevan and Duke (1953) showed in their experiment in an outdoor field the existence of some effect of hue other than the above-mentioned effect of brightness of figure.

The following experiments were planned to measure more systematically the effects of the hue and brightness of both figure and background on the apparent size, and to clarify the ambiguous tendencies found in the previous experiments.

METHOD

Apparatus : A wooden screen, 80 cm. high

and 90 cm. wide, covering by a gray cardboard whose lightness was approximately 7.5/ in Munsell value, stood vertically 115 cm. from the subjects who sat on a chair and observed the stimulus figure binocularly. As shown in Fig. 1, two apertures, 20 cm. $\times$ 20 cm., were cut from the left upper part and the right lower part of the screen. The middle between these two apertures was nearly on a level with the subject's eyes.

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 at the level of 2 foot-candles by a Standard Illuminator of Japan Color Research Institute, which was matched with the C.I.E. Standard Source C (6500°K) and placed right side of the subject's head. The space between the subject and the screen was covered by four wooden screens, top, bottom, right and left, which constituted together a tunnel. The inner surfaces of these screens were painted medium gray (approximately 6.5/ in value).

Stimulus Materials: The standard stimulus consisted of two sheets of colored papers, a larger sheet with a circular hole, 6 cm. in diameter, at the center and a smaller sheet which was exposed behind the hole. These two sheets were pressed firmly by a supporter against the back of the stimulus screen. Accordingly the smaller sheet appeared as a circular figure and the larger sheet as its background. This set-up was characterized in such point that the possible physical error in the preparation of the stimuli was eliminated, because the outline of circular figure was determined by the hole of the larger sheet and consequently the physical size of figures was absolutely the same as far as they were on the same background. When

Fig. 1. The standard and the comparison stimulus on the stimulus screen.

the figure and background were the same with each other in hue and brightness, the contour of figure appeared somewhat vague, but was distinct enough to be judged regarding its apparent size.

These colored sheets were made from the standard colored papers of Japan Color Research Institute. Their hue and brightness were varied from one condition to another and will be described in each of the following experiments.

The comparison stimuli consisted of a series of white cardboards, on the center of each of which an outline circle was drawn by India ink. The diameter of circle was varied from 47 mm. to 72 mm. in 1 mm. steps, and the width of the outline always 0.5 mm.

Procedure: The method of limits was used for the measurements of PSE for each of standard stimuli, and for a control stimulus which was an outline circle, 6 cm. in diameter, on white cardboard, just like the comparison stimuli but was exposed in the left upper aperture. Two ascending and two descending series were used for each standard stimulus in Exp. I and III, and one ascending and one descending series in Exp. II.

The condition of background remained the same during an experimental session. The order of the sessions for different backgrounds was varied from a subject to a subject and was nearly balanced in the whole group. The order

of presentation of the stimulus figures on a background was also varied from a subject to a subject and was approximately balanced in the total group.

The subjects were instructed to compare the size of the standard and the comparison stimulus by free regard and to report in three categories "larger", "smaller" and "doubtful".

Subjects: 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

Achromatic Figures on Achromatic Backgrounds.

Conditions and Procedure: Six circular figures whose lightness varied from black to white (1.7/, 3.5/, 4.4/, 6.3/, 8.2/, and 9.4/ in Munsell value respectively) were presented on the three backgrounds, black (1.7/), medium gray (5.4/) and white (9.4/). Six subjects served in six experimental sessions, two for each background. In one session, the apparent size of each of the six figures was measured by means of one ascending and one descending series of comparison circles. The control stimulus mentioned above was added to them in the two sessions randomly chosen.

Results: The average PSEs for each combination of figure and background and for the control figure are shown in Table 1. The fact that the average apparent size of the control stimulus (57.88 mm.) was smaller than its physical size (60 mm.) meant that the figure placed at the left upper position appeared smaller than the figure at the right lower even if they were physically the same in size, shape, lightness etc. Table 1 shows that the apparent sizes of solid circles were always smaller than the outline circle (the control stimulus) and increased as the lightness of figure increased and as the lightness of background decreased. These tendencies are observed also from Fig. 2, in which the apparent size of figure is represented as a function of the logarithm of reflectance of figure.

Table 1
Average apparent size (in mm.) as a function of the lightness of figure
and the lightness of background (Exp. I).

The lightness of background	The lightness of figure (in Munsell value)					
	1.7/	3.5/	4.4/	6.3/	8.2/	9.4/
Black (1.7/)	56.17	56.75	56.67	56.96	57.09	57.21
Gray (5.4/)	55.40	55.71	55.56	56.17	56.48	56.83
White (9.4/)	55.33	55.48	55.58	55.88	56.06	56.48

Control = 57.88

Table 2
Analysis of variance of apparent sizes in Exp. I.

Source	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>
Figure (F)	34.89	5	6.58	16.22**
Background (B)	39.46	2	19.73	45.88**
Subject (S)	499.22	5	99.84	232.20**
F × B	2.88	10	0.29	
F × S	12.86	25	0.51	
B × S	22.79	10	2.28	5.30**
F × B × S	21.50	50	0.43	
Total	633.59	107

Fig. 2. The apparent size as a function of logarithmic reflectance of figure. "Black", "gray" and "white" indicate the brightness of background. The horizontal broken line represents the average apparent size of the control figure (an outline circle). One mm. in the ordinate corresponds to three minutes in visual angle.

The rank correlations (Kendall's τ) between the lightness of figures and their average apparent sizes were +0.93 on both of the black and gray backgrounds

and +1.00 on the white background. The values are statistically significant at the levels of 0.83% and 0.14% respectively (Siegel, 1956).

The analysis of variance summarized in Table 2 indicates that the effects of Figure and Background as well as the effect of Subject are significant beyond the 1%-level. Because of the procedure of the present study, Background includes the session-to-session variation. The interaction between Background and Subject is also significant beyond the 1%-level. The effects of Background and Subject are significant beyond the 1%-level even when their interaction is adopted as the error (F 's of 8.65 and 43.81, with df 's 2/10 and 5/10). It is to be noticed that the interaction between Figure and Background is insignificant.

These analyses reveal that the apparent size of a circular figure increases gradually as its lightness increases and it decreases

as the lightness of background increases and that the effect of figure and the effect of background are additive. These results contradict with Tamaike's, according to which the figure with the same brightness as the background always had the maximal apparent size and the apparent size decreased as the brightness difference between the figure and the background increased. However Tamaike's experiment was done in such situation that the immediate background was not large enough and circularly bounded by the second background. This boundary line might give some effects on the size perception of the inner circle as in the illusion of concentric circles and these effects might be a function of the clarity of inner contour (Ogasawara, 1952; Oyama, 1960 a, b).

EXPERIMENT II

Chromatic Figures on Achromatic Backgrounds.

Conditions and Procedure: The stimulus figures were four chromatic figures, Red (4.0 R 3.7/12.0 in Munsell notations), Yellow (7.5 Y 8.5/12.0), Green (6.0 G 5.2/9.0) and Blue (2.5 PB 4.0/10.0), and three achromatic figures whose lightness were approximately matched to those of the chromatic figures (3.7/, 5.5/, and 8.4/ in value). The backgrounds were the same three as used in Exp. I. Eight subjects, five of which were common with Exp. I, served in three sessions, one for each background. The rest of the procedure was strictly the same as in Exp. I.

Results: The average values are pre-

Table 3

Average apparent size as a function of the hue and lightness of figure and the hue and lightness of background (Exp. II).

Background	Figure						
	Red	Yellow	Green	Blue	Gray (3.7/)	(5.5/)	(8.4/)
Black	57.13	57.63	57.44	56.94	56.84	57.40	57.59
Gray	56.66	57.75	56.56	56.38	56.56	56.63	57.56
White	56.44	57.13	56.22	56.25	56.28	56.63	56.81

Control = 58.21

Table 4

Analysis of variance of apparent sizes in the chromatic series of Exp. II.

Source	SS	df	MS	F
Figure (F)	13.27	3	4.42	12.63**
Background (B)	9.64	2	4.82	13.77**
Subject (S)	273.71	7	39.10	111.71**
F × B	2.54	6	0.42	
F × S	4.73	21	0.22	
B × S	10.49	14	0.74	2.11*
F × B × S	14.74	42	0.35	
Total	329.13	95		

Table 5
Analysis of variance of apparent sizes in the achromatic series of Exp. II.

Source	SS	df	MS	F
Figure (F)	6.99	2	3.50	14.58**
Background (B)	6.02	2	3.01	12.54**
Subject (S)	213.51	7	30.50	127.08**
F×B	1.63	4	0.41	1.71
F×S	5.70	14	0.41	1.71
B×S	7.59	14	0.54	2.25*
F×B×S	6.76	28	0.24	
Total	248.21	71		

sented in Table 3. The apparent size of yellow figure was always largest in the chromatic series, and those of red, green and blue figures were nearly the same with each other. They all decreased as the background became lighter. The analysis of variance of the chromatic series shown in Table 4, indicates that Figure, Background, Subject and B×S are significant beyond the 1%-level. Background and Subject are significant beyond the 1%-level also when B×S is used as the error (F 's of 6.53 and 52.94, with df 's 2/14 and 7/14). F×B is insignificant again. These results are just in the same line with those of Exp. I.

The results of achromatic series in Table 3 also show the similar effects of the lightness of figure and background as those found in Exp. I. As shown in Table 5, Figure, Background and Subject are significant beyond the 1%-level and B×S is beyond the 5%-level. Background and Subject are significant beyond the 5%- and the 1%-levels respectively when B×S is used as the error (F 's of 5.57 and 56.48, with df 's 2/14, and 7/14).

To examine whether the effect of hue found in the chromatic series could be attributed to the effect of brightness, Yellow and Gray (8.4/), Green and Gray (5.5/), Red and Gray (3.7/), and Blue and Gray (3.7/) were paired and tested by the analysis of variance, respectively. The results of analyses showed that Background

and Subject were significant in all pairs but no Figure and no F×B reached the significance level. These mean that there are no special effect of chromatic figure and the effect of hue should be attributed to the effect of lightness.

EXPERIMENT III

Achromatic and Chromatic Figures on Chromatic Backgrounds.

Conditions and Procedure: Seven figures in Exp. II were used again in this experiment. Backgrounds were Red (5.0 R 4.2/3.0), Yellow (5.0 Y 8.5/12.0), Green (5.0 G 5.5/8.5), and Blue (2.5 PB 4.3/10.0). They were slightly different in hue, lightness or saturation from the corresponding figures. Eight subjects served in six sessions, two for each background. Four of the subjects were common with Exp. II. The rest of the procedure was the same as in Exp. I and II.

Results: The average apparent sizes of the chromatic series in Table 6 show such tendencies that yellow figures appear larger than the other figures and the figures appear smaller on the yellow background than on the other backgrounds. The analysis of variance shown in Table 7 indicates that Figure, Background, Subject and B×S are significant beyond the 1%-level as in Exp. I and II, and that, in this experiment, F×B and F×S are also significant beyond the 1%-level and the 5%-level, respectively. Figure and Sub-

Table 6
Average apparent size as a function of the hue and brightness of figure
and those of background (Exp. III).

Background	Figure						
	Red	Yellow	Green	Blue	Gray (3.7/)	(5.5/)	(8.4/)
Red	57.91	58.42	58.63	58.39	58.36	58.50	58.68
Yellow	57.55	58.05	57.64	57.36	57.63	57.77	58.14
Green	58.00	58.74	58.03	57.99	57.83	58.42	58.83
Blue	58.29	58.67	58.70	57.33	57.88	58.81	59.07

Control=59.45

Table 7
Analysis of variance of apparent sizes in the chromatic series of Exp. III.

Source	SS	df	MS	F
Figure (F)	19.60	3	6.53	13.33**
Background (B)	19.30	3	6.43	13.16**
Subject (S)	368.41	7	52.63	107.41**
F×B	15.84	9	1.76	3.59**
F×S	18.55	21	0.88	1.80*
B×S	39.82	21	1.90	3.88**
F×B×S	30.83	63	0.49	
Total	512.35	127		

Table 8
Analysis of variance of apparent sizes in the achromatic series of Exp. III.

Source	SS	df	MS	F
Figure (F)	18.44	2	9.22	22.49**
Background (B)	16.03	3	5.34	13.02**
Subject (S)	240.48	7	34.35	83.78**
F×B	5.26	6	0.88	
F×S	8.33	14	0.60	
B×S	22.51	21	1.07	2.61**
F×B×S	17.37	42	0.41	
Total	328.41	95		

ject are significant even when $F \times S$ is used as the error (F 's of 7.42 and 59.57, with df 's of 3/21 and 7/21; $p < 0.01$), and Background and Subject are significant also when $B \times S$ is used as the error (F 's of 3.38 and 27.70 with df 's of 3/21 and 7/21; $p < 0.05$ and $p < 0.01$).

It is very interesting that the interaction between Figure and Background was significant only in the experiment in which both figures and backgrounds were chromatic. This significant interaction was supposed to be caused mostly by the tendencies that, on the green and yellow

backgrounds, the yellow figure appeared largest but, on the red and blue background, it is smaller than the green figure. It can not be decided yet whether these tendencies are intrinsic in this phenomenon or the results of chance, because it is highly probable that the variance of an interaction in one of five analyses of variance performed in one study goes beyond the 5%-level of significance only by chance. Ohshima et al (1952) suggested that a figure on the background with similar hue appeared smaller and a figure on the background of complementary hue appeared larger. In the results of this experiment, there may be found a weak tendency to support the former part of their suggestion, but nothing to support the latter part.

The results of the achromatic series in Table 6 shows that, also on chromatic backgrounds, a figure of lighter gray appears larger than a figure of darker gray and that a figure appears smaller on the yellow background than on the other backgrounds. According to the analysis of variance shown in Table 8, Figure, Background, Subject, and $B \times S$ are significant beyond the 1%-level, and $F \times B$ and $F \times S$ are insignificant as in Exp. I and II. Background and Subject are significant also when $B \times S$ is used as the error (F 's of 4.99 and 32.10, with df 's of 3/21 and 7/21; $p < 0.01$).

As in Exp. II, each chromatic figure was paired with an achromatic figure of approximately the same lightness, and was tested by the analysis of variance. Background, Subject and $B \times S$ in all pairs, Figure in Yellow-and-Gray (9.4/) pair, and $F \times B$ and $F \times S$ in Red-and-Gray (3.7/) pair were revealed to be significant. These analyses support generally the conclusion of Exp. II that the effect of color on the apparent size is due to its lightness, except that yellow figures appeared smaller than the corresponding gray figure and red figures behaved slightly differently from the corresponding gray. These exceptions should be ex-

amined by further experimentations.

DISCUSSION

Through the three experiments of the present study, it was found that the effect of the brightness of figure and that of ground were highly significant but the interaction between them insignificant or, if any, slight. The general tendencies found were that the apparent size of figure increased as its brightness increased and as the brightness of background decreased, regardless of the hue of figure and background.

In these aspects, the effect of color on the apparent size resembled the effect of color on the apparent weight in which darker objects appeared heavier (Kimura, 1950; Payne, 1958; Warden, 1931), and was different from those on the apparent depth and warmth, in which hue was the most important factor, Red was the most advancing and the warmest color and Blue was the most receding and the coldest color (Kimura, 1950; Newhall, 1941; Oyama & Yamamura, 1960).

The effect of brightness found in this study might be explained by "irradiation" (Helmholtz, 1910; Obonai & Asano 1937). An inner field which is brighter than its surrounding may extend its boundary outwards, and a surrounding field which is brighter than the inner field may extend its boundary inwards. This irradiation phenomenon is just in the same line with the phenomenon treated in this study. However "irradiation" itself has not been analyzed enough to be an explanatory principle. This study merely suggests the existence of some intimate relations between these two phenomena.

SUMMARY

The apparent size of circular solid figures of various hue and brightness on backgrounds of various hue and brightness was measured by a psychophysical method. The first series used was achromatic figures

on achromatic backgrounds, the second series was chromatic figures (Red, Yellow, Green and Blue) on achromatic backgrounds, and the last was achromatic and chromatic figures on chromatic backgrounds (Red, Yellow, Green and Blue).

The general tendencies found in these series were:

1. Solid figures appeared smaller than the outline figure.

2. The apparent size of figure increased as its brightness increased, irrespective of hue.

3. The apparent size of figure decreased as the brightness of background increased, irrespective of hue.

4. These two factors affected the apparent size in an additive fashion, and no special interaction between them was found with a following exception.

5. There was a possibility of interaction when both figure and ground were chromatic, but this interaction was supposed to be weaker as compared with the main effects of figure and ground.

These results suggested that the effect of color on the apparent size is similar with that on the apparent weight but different from those on the apparent depth and warmth, and that there are intimate relations between this phenomenon and "irradiation".

REFERENCES

- ARNHEIM, R. *Art and visual perception*. Barkley: Univ. Calif. Press, 1954.
- BEVAN, W., & DUKES, W. F. Color as a variable in the judgement of size. *Amer. J. Psychol.*, 1953, **66**, 283-288.
- GRUNDLACH, C., & MACOUBREY, C. The effect of color on apparent size. *Amer. J. Psychol.*, 1926, **37**, 398-401.
- HELMHOLTZ, H., von. *Handbuch der physiologische Optik*. Hamburg: Verlag von Leopold Voss, 1910.
- KIMURA, T. Apparent warmth and heaviness of colours. *Jap. J. Psychol.*, 1950, **20**, No. 2, 33-36 (Japanese text with English summary).
- NEWHALL, S. M. Warmth and coolness of colors. *Psychol. Rev.*, 1941, **4**, 198-211.
- OBONAI, T., & ASANO, T. Contributions to the study of psychophysical induction: IX. The study of the retinal irradiation. *Jap. J. Psychol.*, 1937, **12**, (Japanese text, 1-12, English summary, 1-2).
- OGASAWARA, J. Displacement-effect of concentric circles. *Jap. J. Psychol.*, 1952, **22**, 224-234 (Japanese text with English summary).
- OHSHIMA, M., KUROE, T., ENDO, K., HASE, S., & YAMANAKA, H. Influence of colour on the judgement of size. *Report of Institute of Science of Labour*, 1952, No. 46, 8-11.
- OYAMA, T. Japanese studies on the so-called geometrical-optical illusions. *Psychologia* (Kyoto University), 1960, **3**, 7-20.
- OYAMA, T. The illusion of concentric circles as a function of hue and brightness. (in preparation).
- OYAMA, T., & YAMAMURA, T. The effect of hue and brightness on the depth perception in normal and color-blind subjects. *Psychologia* (Kyoto University), 1960, **3**, (in press).
- PAYNE, M. C., Jr. Apparent weight as a function of color. *Amer. J. Psychol.*, 1958, **71**, 725-730.
- SIEGEL, S. *Nonparametric statistics for the behavioral sciences*. New York: McGraw-Hill, 1956.
- TAMAIKE, J. On the change of the phenomenal size in correspondence with the structure of visual field. *Jap. J. Psychol.*, 1935, **10**, (Japanese text, 745-755, English summary, 64).
- TAYLOR, C. D. Visual perception versus visual plus kinaesthetic perception in judging colored weights. *J. gen. Psychol.*, 1930, **4**, 229-246.
- WARDEN, C. J., & FLYNN, E. L. The effect of color on apparent size and weight. *Amer. J. Psychol.*, 1931, **43**, 109-111.

(Received April 1, 1960)