LIGHTNESS OF SOME SURFACE COLORS COMPARED FOR STEREO-KINETIC DEPTH EFFECTS

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The problem in this study was to examine a series of colors systematically in pairs as stimuli for stereo-kinetic depth perception, with the object of determining the role of surface brightness as a factor. Preliminary observations had indicated that, although chromatic brightness judgments are noteworthy for individual differences, in this situation a definite group tendency favoring darker colors as foreground in the moving patterns might be the rule. We wished to test this assumption.

Two series of experiments were made. The first was conducted as a class experiment. Each student made his own independent written record on forms provided. The full set of trials was carried through twice within the same class hour to secure evidence on the reliability of such observations. In the second experiment a more extensive series of judgments was made, out of class, and under better controlled conditions. Three or four O's served at a time since the nature of the testing situation easily permitted this. All could be at equal distance from the stimulus materials and could view them under the same lighting conditions.

The method of paired comparison was used in both experiments. For the class test there were six pairs, two of these were variant in type from the four others. In the longer experiment 28 stimulus pairs were presented in random order. All of these were of the same type and represented N(N-1)/2 for 8 different colors as described below.

The equipment for such experimentation is not difficult to provide and arrange. The apparatus consisted of a common electrically operated phonograph turntable used at regular 78 rpm rate. Above and just back of the turntable a large mirror was supported at such an angle that seated 0's could comfortably see its reflected image. The view of the turntable was as if looking at it from above and at a distance of about 2 meters. White paper discs with large colored circles inscribed on them were revolved on the turntable. Each disc carried two circles in different colors. The circles were not concentric with the disc or with each other. They crossed each other at two points and were off-set in opposite directions,

Fig. 1. When revolved the colored circles moved back and forth. As one moved to the right the other went to the left. For the usual 0 this moving colored pattern promptly took shape as a short section of a cylinder seen moving on or over the back-ground field of the paper disc. This is known as the Benussi stereo-kinetic depth effect. SKDE for short, and Musatti (11) reports that Benussi discovered it in 1921.

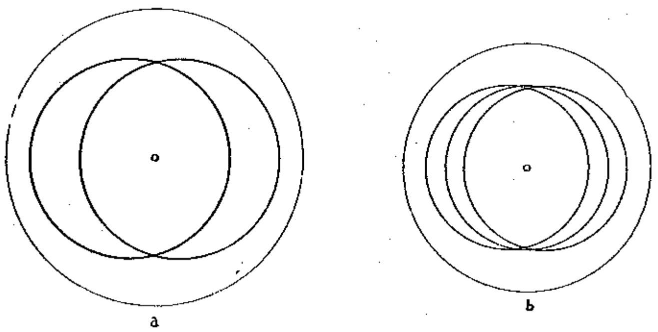

Fig. 1. Diagrams showing the forms of the stimulus discs. See text for further description.

The set of cream white paper discs for the class experiment were 30 cm. in diameter. Each disc carried two colored circles 22 cm. in diameter and the center for each colored circle was displaced 2 cm. from the center of the disc and in opposite directions. See Fig. 1a. The lines on a disc had the flat appearance of two equal and symmetrical crescents facing each other with their points joined. Each crescent was formed of two colors. The maximal width or depth of each crescent was 4 cm. The colors were made from good wax crayons applied by hand around a circular form. The lines inscribed were 3 mm. wide and no other marks were observable on the discs. The six combinations were: purple-blue and red, purple-blue and orange, purple-blue and green, and orange and green. One disc had circles of purple-blue and red but the red line was twice the width of the purple-blue line. The sixth disc carried a red line 3 mm. wide and one made with black India ink 2 mm. wide.

A series of 28 discs were used in the longer experiment. These were 23 cm. in diameter and of good quality white paper. See Fig. 1b. The colored circles were 16.6 cm. in diameter and their centers were offset in opposite directions from the center of the disc so that the two crescents at their widest points measured 38 mm. including the widths of both the lines. The colored lines on this larger series of discs were all of 1 mm. width. On each of these 28 discs a third circle of the same diameter as the colored ones was inscribed concentric with the disc. This third circle was gray and made by lead pencil. The gray center line added body to the SKD figure, divided it into an upper and a lower half, and made the two colored lines more conspicuous by contrast. The colors were of good quality and were laid on with artists' pencils. The colors were carefully matched against Munsell standards (8) (16). Three independent matches were made from three sets of color patches and good agreement was found. The following eight colors described in Munsell notation for hue, value and chroma were used:

Purple Blue:	7.5	PB	4—10	Green:	10	GY	5—6
Red:	5	R	4—12	Orange:	2.5	YR	6—14
Sea Blue:	7.5	PB	5—10	Light Green:	5	GY	7.5—10
Orange Red:	7.5	R	5—12	Yellow:	2.5	Y	8—12

The total range in value was represented by four points, 4 to 8, and the chroma range was from 6 to 14.

The 0's for these experiments were university students. In the class test there were 27, most of them women. They sat at different distances from the mirrored turntable. The lighting was north daylinght with a small supplement from overhead Mazda lamps in large white globes. In the second experiment the 0's were class members and others, students and assistants. There were 15 men and 15 women, 30 subjects in all. They served three or four at a time and had very similar views of the stimuli and hackground. The illumination was primarily daylight.

The instructions were not difficult to follow. The 0's in the class test were requested to do three things: (a) record the color that appeared on top when the SKDE was first seen, (b) record success or failure of their effort to exchange the positions of the colors, and (c) at the end 0's were asked to estimate the depth of the standard figure in cm. This was a general estimate the depth of the standard figure in cm. This was a general estimate, not one for each color pair. The instructions for the longer series, with the 28 discs, were as follows: (a) to record the color that appeared on top when the SKDE was first seen, (b) record a judgment of which of the two colors was the darker, (c) record success or failure in the attempt to exchange the relative positions of the colors, and (d) record a judgment of the affective quality, pleasant or unpleasant, of the color first seen as the front or near part of the SKD figure. Each author took turns in administering the tests in the second experiment.

Results

The class experiment easily captured the attention and interest of those present. The first demonstration was with a disc carrying only black circles.

All the students, used binocular vision and, readily observed a figure having three dimensional quality. Similar figures appeared for all when the pairs of colored circles were presented. The summarized results for 27 0's are shown in Table 1, arranged in two divisions representing Trial I and Trial II. At the end of each set of tests estimates were made for the average figure depth perceived. In Trial I these estimates showed a range of 3-25 cm.,

Table 1. Judgments of colors in terms of stereo-kenetic depth positions. Subects, 27 university students; a group experiment.

Trial I					Trial II				
Color Pairs no.	Color A over Color B		Per Cent Cases	Per Cent Reversal	Color Pairs	Color A over Color B		Per Cent Cases	Per Cent Reversal
31	Blue	Green	81	59	31	Blue	Green	85	44
32	Blue	Orange	96	7	32	Blue	Orange	96	15
33	Blue	Red	96	19	33	Blue	Red	96	22
30	Green	Orange	81	52	30	Green	Orange	93	37
35*	Red	Blue	63	78	35*	Red	Blue	44	63
34**	Black	Red	96	44	34**	Black	Red	96	37

* The red line had double width and was a holder display.
** The black line was drawn with India ink and was less wide than the red line.

M. 12.0, S.D. 6.9 cm. Trial II gave the same range with N 12.4, S.D. 6.6 cm. All six stimulus discs brought out SKDE about equally well. With Nos. 32 and 33 the purple-blue circles stood out in front of the orange and red for 96 per cent of cases, that is, only 1 of 27 Os, at first saw these colors in the opposite relationship in each of the four tests. Also the tendency for the purple-blue to take front position was not easily changed. Only 7 to 22 percent of Os reported being able readily to reverse the depth positions of these colors. The purple-blue and green circles, No. 31, showed blue predominant in 81 and 85 per cent of cases respectively for the two sets, and about twice as many Os were able to reverse the relative positions of this pair. Stimulus pair No. 35 was like No. 33 in showing pb. and red except that the red line was 2 mm. wide and the pb. line 1 mm. Here the red stood out over the blue 63 per cent in Trial I and 44 per cent in Trial II and 2/3 or more of Os were able to affect reversals. As a stimulus variation of a different type No. 34 presented red and black to complete for front position. The red line was more bold with a 3 mm. width of stroke while the black line, drawn with India ink, was only 2 mm. As shown in Table I the black circle took the front position over the prominent red circle for 96

Table 2, Part I. Relation of low color brightness to fore-ground position in stereo-kinetic depth perception, and associated judgment responses made by 15 men and 15 women subjects.

Sti. no.	Color A Name	Color A Hue	Color A Value	Color A Chro.	Color B Name	Color B Hue	Color B Value	Color B Chro.	Front Cases A	Front Cases B	Front Darker +	Front Darker =	Front Darker —	Front Shift Yes	Front Shift No	Color A Pleasant Yes	Color A Pleasant No
23	Blue	7.5 PB	4	12	S. Blue	2.5 PB	5	10	12	18	6	2	4	5	7	8	4
26	Blue	7.5 PB	4	12	Red	5 R	4	12	16	14	8	4	4	11	5	10	6
27	Blue	7.5 PB	4	12	O. Red	7.5 R	5	12	18	12	11	4	3	9	9	15	3
20	Blue	7.5 PB	4	12	Green	10 GY	5	6	29	1	26	3	0	9	20	21	8
11	Blue	7.5 PB	4	12	Orange	2.5 YR	6	14	27	3	20	5	2	11	16	19	8
16	Blue	7.5 PB	4	12	L. Green	5 GY	7.5	10	30	0	29	1	0	3	27	24	6
5	Blue	7.5 PB	4	12	Yellow	2.5 Y	8	12	29	1	27	2	0	4	25	20	9
26	Red	5 R	4	12	Blue	7.5 PB	4	12	14	16	5	4	5	11	3	9	5
24	Red	5 R	4	12	S. Blue	2.5 PB	5	10	22	8	14	5	3	11	11	13	9
28	Red	5 R	4	12	O. Red	7.5 R	5	12	17	13	11	3	3	13	4	15	2
21	Red	5 R	4	12	Green	10 GY	5	6	28	2	27	1	0	8	20	23	5
12	Red	5 R	4	12	Orange	2.5 YR	6	14	23	7	18	4	1	10	13	16	7
17	Red	5 R	4	12	L. Green	5 GY	7.5	10	29	1	27	0	2	1	28	20	9
6	Red	5 R	4	12	Yellow	2.5 Y	8	12	27	3	22	0	5	8	19	20	7
23	S. Blue	2.5 PB	5	10	Blue	7.5 PB	4	12	18	12	18	0	0	7	11	9	9
24	S. Blue	2.5 PB	5	10	Red	5 R	4	12	8	22	1	3	4	4	4	6	2
25	S. Blue	2.5 PB	5	10	O. Red	7.5 R	5	12	16	14	12	3	1	11	5	12	4
19	S. Blue	2.5 PB	5	10	Green	10 GY	5	6	27	3	23	3	1	13	14	21	6
10	S. Blue	2.5 PB	5	10	Orange	2.5 YR	6	14	29	1	20	6	3	11	18	22	7
15	S. Blue	2.5 PB	5	10	L. Green	5 GY	7.5	10	30	0	27	1	2	7	23	24	6
4	S. Blue	2.5 PB	5	10	Yellow	2.5 Y	8	12	29	1	24	1	4	4	25	20	9
27	O. Red	7.5 R	5	12	Blue	7.5 PB	4	12	12	18	2	3	7	11	1	12	0
25	O. Red	7.5 R	5	12	S. Blue	2.5 PB	5	10	14	16	4	6	4	9	5	7	7
28	O. Red	7.5 R	5	12	Red	5 R	4	12	13	17	2	2	9	9	4	10	3
22	O. Red	7.5 R	5	12	Green	10 GY	5	6	15	15	10	1	4	8	7	13	2
13	O. Red	7.5 R	5	12	Orange	2.5 YR	6	14	20	10	13	6	1	15	5	15	5
18	O. Red	7.5 R	5	12	L. Green	5 GY	7.5	10	29	1	27	1	1	8	21	21	8
7	O. Red	7.5 R	5	12	Yellow	2.5 Y	8	12	30	0	26	1	3	9	21	21	9

per cent of coses and only 2/5 of the Os found it possible to bring the red circle out in front part of the time.

In general the first experiment demonstrated that a purple-blue which was darker than the red, orange, and green colors, with which it was paired, showed a strong tendency to appear as the top or front portion of SKD figures resulting, in perception, when pairs of decentered colored circles were revolved. Another general finding was that a color could be made more potent in securing front position by increasing the surface area of its outline, and that a narrow line may be made comparatively so dark as to compete favorably over a saturated middle red that has a 50 per cent wider line.

The results for the second series of experiments consist of 8 sets of seven comparisons which are presented in systematic order in Table 2 Parts 1 and II. At the upper left-hand corner the table begins with Blue 7.5 PB, 4—12, as Color A, in combination with each of the other seven colors used as Color B.

In the column headed Front Cases it is found that Blue won majority decisions as front color against every other color except the Sea Blue where it got 12 as against 18. In the last four sets of comparisons it was almost unanimously given front place. Similar sets of results appear in the second and third blocks of Table 2 for Red 5 R 4—12, and Sea Blue 2.5 PB 5—10, used as Color A in their respective pairings with the other hues. In each case the large majorities for front position are against Green, Orange, Light Green and Yellow which fall behind. Green proved fairly strong against Light Green and Yellow but apparently not quite as effective as was Orange against these same brighter colors. Light Green narrowly surpassed Yellow, which, except for stray cases, was usually at the bottom of the SKD figures.

It is obviously convenient to assign rank positions to the eight colors representing the relative frequencies with which each gained the foreground over all the others considered as a group. This summary appears in Table 3 with rank 1 at the top and 8 at the bottom. While Blue got rank 1, Red lacked only one case of tying that score of 161. Sea Blue was also a close runner up (157). Orange Red received rank 4 with 133 front frequencies, and the remaining four colors showed scores that fell off rapidly. It was possible that some color could have predominated for front in all its paired comparisons with all 30 Os in which unlikely event a score of 210 would have resulted. The various achieved scores compared against the base of theoretical 210 provided the percentages for front frequency shown in Table 3 which range from 76.7 to 12.4 for ranks 1 to 8. The columns for Back Frequency provide the reverse of the above picture. How-

Table 2, Part II. Relation of low color brightness to fore-ground position in stereo-kinetic depth perception, and associated judgment responses.

Sti. No.	Color A				Color B				Front Cases		Front Darker			Front Shift		Color A Pleasant	
	Name	Hue	Value	Chro.	Name	Hue	Value	Chro.	A	B	+	=	—	Yes	No	Yes	No
20	Green	10 CY	5	6	Blue	7.5 PB	4	12	1	29	0	0	1	0	1	1	0
19	Green	10 CY	5	6	S. Blue	2.5 PB	5	10	3	27	1	0	2	2	1	3	0
21	Green	10 CY	5	6	Red	5 R	4	12	2	23	0	0	2	2	0	1	1
22	Green	10 CY	5	6	O. Red	7.5 R	5	12	15	15	9	4	2	11	4	10	5
9	Green	10 CY	5	6	Orange	2.5 YR	6	14	16	14	7	4	5	9	7	9	7
14	Green	10 CY	5	6	L. Green	5 GY	7.5	10	21	9	17	2	2	6	15	16	5
8	Green	10 CY	5	6	Yellow	2.5 Y	8	12	24	6	13	6	5	11	13	17	7
11	Orange	2.5 YR	6	14	Blue	7.5 PB	4	12	3	27	1	0	2	0	3	1	2
10	Orange	2.5 YR	6	14	S. Blue	2.5 PB	5	10	1	29	0	0	1	1	0	1	0
12	Grange	2.5 YR	6	14	Red	5 R	4	12	7	23	0	1	6	6	1	5	2
13	Orange	2.5 YR	6	14	O. Red	7.5 R	5	12	10	20	1	3	6	5	5	4	6
9	Orange	2.5 YR	6	14	Green	10 GY	5	6	14	16	4	2	8	6	3	8	6
8	Grange	2.5 YR	6	14	L. Green	5 GY	7.5	10	23	7	21	0	5	6	17	18	5
1	Orange	2.5 YR	6	14	Yellow	2.5 Y	8	12	29	1	18	8	8	14	15	17	12
16	L. Green	5 GY	7.5	10	Blne	7.5 PB	4	12	0	30	0	0	0	0	0	0	0
15	L. Green	5 GY	7.5	10	S. Blue	2.5 PB	5	10	0	30	0	0	0	0	0	0	0
17	L. Green	5 GY	7.5	10	Red	5 R	4	12	1	29	0	0	1	1	0	0	1
18	L. Green	5 GY	7.5	10	O. Red	7.5 R	5	12	1	29	0	0	1	1	0	1	0
14	L. Green	5 GY	7.5	10	Green	10 GY	5	6	9	21	8	1	0	3	6	4	5
8	L. Green	5 GY	7.5	10	Orange	2.5 YR	6	14	7	23	5	0	2	5	2	4	3
2	L. Green	5 GY	7.5	10	Yellow	2.5 Y	8	12	16	14	2	8	6	9	7	7	9
5	Yellow	2.5 Y	8	12	Blue	7.5 PB	4	12	1	29	1	0	0	0	1	0	1
4	Yellow	2.5 Y	8	12	S. Blue	2.5 PB	5	10	1	29	0	0	1	1	0	0	1
6	Yellow	2.5 Y	8	12	Red	5 R	4	12	3	27	0	0	3	3	0	0	3
7	Yellow	2.5 Y	8	12	O. Red	7.5 R	5	12	0	30	0	0	0	0	0	0	0
3	Yellow	2.5 Y	8	12	Green	10 GY	5	6	6	24	1	2	3	5	1	3	3
1	Yellow	2.5 Y	8	12	Orange	2.5 YR	6	14	1	29	0	0	1	0	1	0	1
2	Yellow	2.5 Y	8	12	L. Green	5 GY	7.5	10	14	16	6	4	4	13	1	6	8

ever, Yellow appeared stronger, 87.6 per cent, in its dominance as back or bottom color than Blue or Red showed for top position.

The frequency with which a color was judged to be the darker of the two in a stimulus pair is also given in Table 3 in terms of percentage.[1] There were three colors: Blue, Red and Sea Blue, that got about 80 per cent of judgments as darker. Orange-Red, and Green got 62.3 and 57.4 respectively, Orange showed 51.8 per cent, while Light Green gave 38.2 and Yellow 26.9 The category of "equal" naturally showed up in these judgments of relative brightness. Judgments of equal brightness amounted to around 10 per cent for Ranks 1, 2, and 3. For Ranks 4 to 7 these percentages increased from 15.0 to 26.5 and for Yellow dropped to 23.1 per cent. The judgments for "brighter" showed fewer than 10 per cent for Blue, Red, and Sea Blue, increased to near 35 per cent for Orange-Red, Orange, Green and Light Green, and totalled just 50 per cent for Yellow.

The subjects tried to shift the relative positions of colors after first having observed their placement in the SKD figure. The reported success in making over these dynamic figures seemed to vary inversely with the brightness of the colors. When Blue, Red or Sea Blue were first seen in front position about 1/3 of the Os reported successful attempts at exchange and 2/3 reported they could not transpose the colors. See Table 3. About 1/2 of the Os reported success in shifting the colors in Ranks 4 to 7, and about 85 percent were able to shift Yellow if it happened to show in front.

The affective judgments for pleasantness, or its lack, in the predominating colors are recorded in percentages in the last column at the right in Table 3. About 73 percent of the judgments were for "pleasant" on the first four colors; Orange-Red had slightly the highest rating. Orange and Green showed 62.1 and 69.6 percentages respectively, Light Green was 47.0 per cent and Yellow 35.0.

The main objective of this research was to test the assumption that darker colors, those having lower notation for value, tend to be seen as foreground in stereo-kinteic figures. In major outline this hypothesis is supported by the results. To make the situation more clear Table 4 has been prepared as a summary to show the values (and incidentally the chromas) associated with the score combinations for the 28 different pairs of colors. Beginning at the left the columns in Table 4 show: Stimulus disc No., Color A, Color B, Top color score, Bottom color score, Value of A, Value of B, Value diff., Chroma A, Chroma B, Chroma diff., and Outcome. In this last column the letter S is used to indicate support of the hypothesis,

(1) Here the base for computing percentage was, in each instance, the number of front cases. For example, Rank 1 showed 161 front cases and (Blue) was judged darker 127 times, 127/161 = 79.0.

Table 3. Surface color lightness and frequency of fore-ground appearance.
Subjeots, 30 university students and assistants, 15 women and 15 men.

Rank	Color Name	Munsell Match			Front Freq.*		Back Freq.		Front Color			Shift		Top Color
		Value	Chro.	Hue	Cases	Per Cent	Cases	Per Cent	Darker Per Cent	Equal Per Cent	Brighter Per Cent	Yes Per Cent	No Per Cent	Pleasant Per Cent
1	Blue	4	12	7.5 PB	161	76.7	49	23.3	79.0	13.0	8.0	32.3	67.7	72.7
2	Red	4	12	5 R	160	76.2	50	23.3	80.6	10.6	8.8	38.7	61.2	72.5
3	S. Blue	5	10	2.5 PB	157	74.8	53	25.2	80.3	10.3	8.9	36.3	63.7	72.6
4	O.Red	5	12	7.5 R	133	63.4	77	36.6	62.3	15.0	32.7	51.8	48.1	74.4
5	Orange	6	14	2.5 YR	87	41.4	123	58.6	51.8	16.1	37.1	43.7	56.3	62.1
6	Green	5	6	10 GY	82	39.0	128	61.0	57.4	19.5	33.1	50.0	50.0	69.6
7	L Green	7.5	10	5 GY	34	16.2	176	83.8	38.2	26.5	35.3	55.9	44.1	47.0
8	Yellow	8	12	2.5 Y	26	12.4	184	87.6	26.9	23.1	50.0	84.6	15.4	35.0

and Sc is used when the result may have been partly due to Color A having a higher chroma as well as a lower value. Sw is used for weak support and NS for no support. Of the 28 instances there are 12 where S seems appropriate, there are 9 Sc outcomes and 5 that have been marked SW. These 5 include 3 instances where a pair of colors had zero difference in value, and one where the value difference was only 0.5 step and the score was 16 to 14. The other SW was No. 9 with 1 step value difference, a —8 chroma difference, and the scores showing 16 to 14.

The hypothesis may be considered well supported when 26 of 28 sets of results turn out in its favor, but what about the two stimulus sets that have been marked NS? Disc No. 23 carried Blue with value 4 and chroma 12, and Sea Blue with value 5 and chroma 10, and the results were 12 to 18, quite opposite to the tendency found for other similar discs. Disc No. 19 carried Sea Blue and Green both of value 5, the Sea Blue had a higher chroma than Green by 4 points but this on the basis of other results, could hardly be expected to bring about a score of 27 to 3, for example, see Nos. 25, 24, and especially 22. Careful inspection of these two stimulus discs revealed technical imperfections in them which had escaped former notice. The Sea Blue line on Disc No. 23 proved to be from 0.1 to 0.2 mm. wider than the Blue line which would increase its contrast with the background. Similarly on Disc No. 19 the Sea Blue line was wider than the Green by 0.1 to 0.2 mm. throughout 3/4 of the circle which probably bears a relation to the disproportionate results of 27 to 3. Therefore it may be concluded that these two seemingly negative sets of results are probably due to technical errors in connection with the stimulation of the subjects.[1]

Chroma rating or "saturation of color", to use an older expression, might be expected to play some part in the structuring of SKD figures. To study this factor effectively the colors in a stimulus pair should be of the same hue and value and differ only in chroma. The colors should be layed on with meticulous care and by some other means than color pencils. One of the best opportunities for revealing an effect of chroma difference in our series of stimuli would appear to be disc No. 22. Here both colors had a value of 5 but between them there was a chroma difference of 6 points and still the scores were 15 to 15. If these results are characteristic it would seem that the influence of chroma difference on SKD figures is of very minor importance in comparison with value difference.

(1) All the stimulus discs were inspected, as mentioned for Nos. 19 and 23 and there were other instances where one color line, measured with a magnifying comparator, was slightly wider than its running mate. It turned out that in the large majority of instances the weaker color, the one having the higher value, was the wider line. Apparently this was a stimulus error effect functioning in connection with the preparation of the stimuli.

Table 4. Summary of results for fore-ground position in relation to hue-value and to hue-chroma.

No.	A	B	T B	Values	Dif.	Chromas	Dif.	Out.
28	Red	O. Red	17 — 13	4 — 5	1	12 — 12	0	S
27	Blue	O. Red	18 — 12	4 — 5	1	12 — 12	0	S
26	Blue	Red	16 — 14	4 — 4	0	12 — 12	0	Sw
25	S. Blue	O. Red	16 — 14	5 — 5	0	10 — 12	—2	Sw
24	Red	S. Blue	22 — 8	4 — 5	1	12 — 10	+2	Sc
23	Blue	S. Blue	12 — 18	4 — 5	1	12 — 10	+2	NS
22	O. Red	Green	15 — 15	5 — 5	0	12 — 6	+6	Sw
21	Red	Green	28 — 2	4 — 5	1	12 — 6	+6	Sc
20	Blue	Green	29 — 1	4 — 5	1	12 — 6	+6	Sc
19	S. Blue	Green	27 — 3	5 — 5	0	10 — 6	+4	NS
18	O. Red	L. Green	29 — 1	5 — 7.5	2.5	12 — 10	+2	Sc
17	Red	L. Green	29 — 1	4 — 7.5	3.5	12 — 10	+2	Sc
16	Blue	L. Green	30 — 0	4 — 7.5	3.5	12 — 10	+2	Sc
15	S. Blue	L. Green	30 — 0	5 — 7.5	2.5	10 — 10	0	S
14	Green	L. Green	21 — 9	5 — 7.5	2.5	6 — 10	—6	Sc
13	O. Red	Orange	20 — 10	5 — 6	1	12 — 14	—2	S
12	Red	Orange	23 — 7	4 — 6	2	12 — 14	—2	S
11	Blue	Orange	27 — 3	4 — 6	2	12 — 14	—2	S
10	S. Blue	Orange	29 — 1	5 — 6	1	10 — 14	—4	S
9	Green	Orange	16 — 14	5 — 6	1	6 — 14	—8	Sw
8	Orange	L. Green	23 — 7	6 — 7.5	1.5	14 — 10	+4	Sc
7	O. Red	Yellow	30 — 0	5 — 8	3	12 — 12	0	S
6	Red	Yellow	27 — 3	4 — 8	4	12 — 12	0	S
5	Blue	Yellow	29 — 1	4 — 8	4	10 — 12	—2	S
4	S. Blue	Yellow	29 — 1	5 — 8	3	10 — 12	—2	S
3	Green	Yellow	24 — 6	5 — 8	3	6 — 12	—6	S
2	L. Green	Yellow	16 — 14	7.5— 8	0.5	10—12	—2	Sw
1	Orange	Yellow	29 — 1	6 — 8	2	14 — 12	+2	Sc

The 28 stimulus pairs may be divided into four groups on the basis of the value differences between paired colors. These groups with their ranges of value points, the number of pairs falling in each group, the total of scores for each and the ratios are as follows:

Group	1	2	3	4
Value range	0—0.5	1	1.5—2.5	3—4
Pairs	5[1]	9[2]	7	7
Total scores	90—60	191—79	182—30	198—12
Ratios	1.5:1	2.42:1	6.06:1	16.5:1

The proportion of "front" judgments was found to increase in approximately direct ration to the difference in value of the stimulus pairs.

Finally in reporting the data from these experiments consideration should be given to the relations found to exist between the degree of front dominance exhibited by different color combinations and the readiness with which the color positions in the SKD figure could be reversed. When the dominance for a particular color relationship registered low a large percentage of Os could change the colors about, but when the dominance was high less than 1/3 could make the reversals. These facts are brought out in the following tabular display:

Range of front judgments	1 to 12,	13 to 15	16 to 22,	23 to 30
Number of tests	19	7	10	17
Total of front scores	89	99	180	472
Total of reversals	86	77	101	137
Percentage of reversals	97	78	56	29

The percentage of those able to make reversals within the pattern of this experiment and with the results grouped as above decreased to 1/3 when the color dominance relation was in the range of 23 to 30. Further fractionation shows for the range 23 to 28, a percentage of 37 and for range 29 to 30 (10 tests) 24 per cent reversals. In general these results give basis for the conclusion that when one color of a pair is considerably darker than the other the resulting perceptual SKDE becomes relatively rigid in the sense that fewer observers, within a limited time, can perceptually manipulate it as an ambiguous reversable dynamic pattern.

(1) Group 1 included No. 19 which gave irregular results. Without No. 19 the ratio for this group was 1.1:1.

(2) Group 2 included No. 23 which gave irregular results. Without No. 23 the ratio for this group was 2.94:1.

Discussion

The moving shadow, cast by a T-shaped form revolved about its vertical axis, provides the stimulus for a wide variety of perceptual interpretations, some as flat expanding and contracting forms, and many others as three dimensional patterns of movement (10) (14). The variety of patterns experienced within several minutes tends to be larger if the observer does not know by what means the shadow is kept in motion. These depth effects supplied by the observer seem quite realistic and when he is naive they are regarded as objective. A depth effect can also be seen from certain plane figures viewed directly, or in a mirror, while they are in rotation as on the turntable of a phonograph (15) (16). These stimulus figures are not such as would usually be placed in the classical reversible perspective group with Necker's Cube and Schroder's Stairs (1). And they are not so drawn as to give the suggestion of motion (9). They have weak potential for depth effect as resting stimuli. Their peculiar effectiveness is when rotary motion is imparted to them and then they seem to have depth and the reversible perspective quality. In fact this effect is often quite challenging due probably to the stimuli taking on new meaning as well as depth with the motion, while the observer feels himself only an unbiased witness. This stereo-kinetic effect was discovered by Benussi in 1921 (11). Explanations of this effect and of other kinetic depth appearances have been presented by Wallach et al (15) (16). Fisher (4) has studied factors influencing the amount of the apparent depth in the SKDE. The figures she used were cones and cylinders and it appeared that the extent of off-set, or spatial separation of the two circles forming the stimulus, was linearly related to the amount of perceived depth. Also the depth was inhansed by monocular viewing.

The reversability of SKD figures and the factors which influence these perceptual selections and shifts appear worthy of investigation.[1] The present study was undertaken with this aim. One factor that was used as a variable was strength or boldness of line. When one of the circles in a stimulus pair was drawn with a line twice the width of that in the other, it was found that the circle with the bolder line tended, in early experiences of Os, to occupy the front or near part of the figure. This result was found when colored lines were used and the color with the narrower line

(1) One such factor, incidentally noted by Fischer (4) was the differential rate of motion between two circles. The circle moving at the greater rate was reportedly seen nearer O most of the time. This would match the pattern of usual perceptual experience. In static reversible figures some conditions make for equipotential in reversal and some work against this condition. See Boring (1) p. 268 and (6).

had formerly been the one most often appearing in front. Doubling the width of what had been showing as the bottom line brought it to the top position and so tended to make this figure irreservable in the other direction. A very black line tended to win out over strong colors made with wider lines. These results varified as majority tendencies found with 27 subjects would seem to define the SKD figures as a type showing "reversal of shape due to reversed gradients of density" (5). Gibson gives some excellent illustrations over this caption (see Fig. 46) and as is usual the lighter areas appear as front or foreground and the darker seem farther away. In the case of the SKD figures developed in our experiments these gradients seem to work in reverse. In both situations the background is white paper, lighted with diffused daylight, and where ever the observer stands he sees one set of relations on the page of the book and the reverse on the white paper disc that is turning around. Gibson shows a picture of Quonset huts that turn into towers when viewed upside down. Here some foreground areas are very dark by reason of their being formed of dense shadows, which is understandable and a natural appearance, due to the direction of solar lighting relative to the observer's position. In the upside down view the sun seems lower than the bases of the towers which appear to have cylindrical shape and round black tops. It is a very effective illusion in which the dark areas occupy the central foreground in both phases of figural interpretation.

The SKDE is not much influenced by being viewed from different angles. Perhaps the simplest explanation of this reversed brightness perspective in these dynamic figures would be that the motion of the stimulus introduces a factor of stress that has to be met and overcome in the process underlying visual perception. The stimulus pattern is revolving, the eye seeks a fixation point by which to guide its pursuit movements, the darker line gives the stronger contrast against the light background and provides the easier feature to maintain in view, and the feature that dominates the central field tends to form the front or near portion of the resulting three dimensional figure. After securing a satisfactory fixation point on the moving stimulus the psychological process of developing the appearance of depth would probably be similar to that involved with other reversible displays.

It would seem that the fore part of this theoretical explanation ought itself to be reversible, or reversed, and that stimulus circles on gray discs in place of white should serve to test the contrast hypothesis in this connection. We have made up such stimulus discs using for them Hering gray paper. It is difficult to achieve good color circles against such surfaces and backgrounds. However, we have found that our grayish white circles characteristically take front position in SKD figures in comparison with circles of light colors thus lending support to the proposed hypothesis.[1]

Film color and surface color are commonly described as having some different characteristics (6). In the SKD figures, we are discussing here, the color is only edge color appearing as the boundry of the figure at both ends and setting it free to move in reference to the background. This edge color we interpret as surface color, it is stable, belongs to the figure and so has form and is localized to the extent of the range of its motion. As surface color it behaves in parallel fashion to that of the figure for when in motion the color **is the figure.** The contour of a stationary figure is also the common boundry between it and its background. In SKD the figure has a top and a bottom but they are seen in motion and seem not to maintain a constant relation to the background. The figure has no side lines as such, they are imaginary lines contributed by O and are reported as curving inward so that the "cylinder" appears narrower in its central portion. Our results confirm those of Wallach et al that the Benussi effect occurs regularly and spontaneously. And it seems to us that the observer contributes more psychological elements to this type of three-dimensional figure than when viewing reversible perspective diagrams.

Colors, especially blue and red, are perceived as if in different planes under many circumstances when they are physically equally near the observer. Red is usually seen as nearer than blue. This advancing and retreating phenomenon in binocular color vision has been explained on the basis of the dispersion circles on the retinas (12) and also as due to chromatic aberration (3). Its optical genesis need not concern us here. In our results when red stands out nearer than blue, as in stimulus No. 24, this relation may be due in part to the advancing character of red. We have no measure of the strength of this factor. On the other hand, the blues, usually considered the most receding of the colors, did not behave in this fashion in the SKDE patterns seen against the white paper discs as background.

Color value or lightness stands out as a major influence in our results and we interpret it as brightness contrast. Colors have also hue and chroma, either or both of these attributes may give rise to psychological judgments of contrast. There are contrasts in color (hue) and contrasts in chroma (saturation). Heterochromatic brightness matching is difficult for all observers with normal color vision (7). With area constant these other aspects of contrast seem to subtract from or add to or otherwise confuse

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(1) Against a neutral gray background circle contrast may be from gray to dark and also from gray to light. These two gradients can be balanced or made obviously unequal. In one or two of our gray discs the contrast between the surface and the dark circle seemed greater than that with the light circle and the dark color predominated as the front of the perceived dynamic figure.

the evaluation of brightness difference. Chapanis and Halsey (2), among others, have made an extensive study related to this matter. After having secured agreement between several Os who, by direct visual comparison, matched the brightness of 342 colored filters so that they all appeared to have the same value, they then determined the Y values, or luminances, of all these filters by the spectrophotometric method. The results show that luminance varies considerably for different hues and that less luminance is required for saturated colors than for desaturated hues. The hue-chroma valence for visual perception seems a concept hard to name. Eindringlichkeit has been suggested (12). Katz defines this term as "insistence", "the power of catching the eye more readily and of holding it more steadily". Pillsbury also quotes from another source: "Insistence is not built secondarily upon simple experiences of brightness, but is itself the more primitive experience."

Hue or saturation in a color may appear as a smiling contenance among a group of sober faces. In other words these features provide perceptual opportunity for contrast. They are especially effective in relation to the viewing of three-dimensional fields and in the creation of both representational and abstract art. The foreground is usually the brighter and or the more saturated color area. Sometimes the reverse relation is used in art or occurs in various object fields (17) and results in equally useful and satisfying perceptual experiences. The SKD figures conform to either one of these sets of contrast relations accordingly as these perceptions are composed on lighter or darker backgrounds.

SUMMARY

The Benussi stereo-kinetic depth effect was studied by means of paper discs carrying pairs of decentered colored circles of different hue and value matched in Munsell notation. The discs were rotated on a phonograph turntable and viewed in a mirror. The problem was to determine the relation of hue value in the structuring of the SKD figure. University students were used as observers in class and in individual experiments. It was found that with pairs of colored circles of equal diameters on white paper discs, the circle with the lower value tended, with the large majority of Os, to form the front of the perceived moving figure. As the stimulus contrast was made stronger the figure became more rigid, that is, resistent to reversible perspective inversion. When gray discs were used in place of white the law of greater contrast determining the foreground of the dynamic figure was again demonstrated. The results are discussed in relation to other color and space perception problems.

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