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A halo visual illusion

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Abstract. A visual illusion consisting of transparent halos extending beyond the boundaries of rotating discs is reported. The effect can be obtained by rotating a variety of black-and-white discs at moderate speeds. It is not due solely to rods, as opposed to cones, and does not appear to be explainable in terms of intermittent stimulation of portions of visual fields of fixed visual angle.

When any of a class of black-and-white discs, such as the ones shown in figure 1, is rotated at moderate speeds, colors appear. This phenomenon of subjective colors has a long history with many independent discoveries (Cohen and Gordon 1949). In the course of a classroom demonstration of subjective colors in which disc d shown in figure 1 was used, several students, who were not quite certain of what illusion they were supposed to see, noticed a halo of transparent light located in the plane of and surrounding the disc. The halo was described as looking as if there were a string being dragged around, or water being spun off, the disc. Once seen, the halo is visible immediately upon viewing of the disc. Although similar discs have been observed for over a century and although it has been known that the subjective colors on one area of a disc spread slightly to (Roelofs and Zeeman 1958) and are influenced by (Fry 1933) the properties of adjacent areas, no report of a halo obtained from a spinning disc can be found. The closest report to the effect is

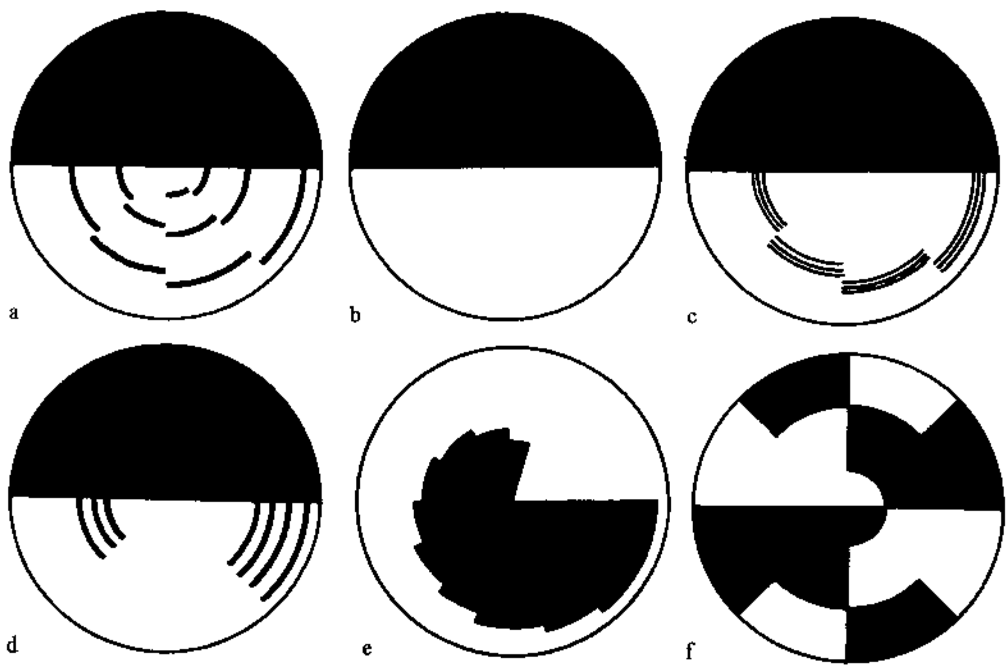

Figure 1. Discs capable of producing subjective colors.

Bartley's (1936, 1939) description of light in the visual field surrounding a stationary flashing light. Unlike the present halo effect, Bartley reports light in the whole visual field as well as in the area immediately surrounding the stimulus.

Several replications of this informal observation of a halo were made by varying illumination, speed of rotation, design, size, and distance of the disc. In the first experiment fourteen naive, undergraduate volunteers viewed a 12·7 cm diameter version of the disc, which was rotating at 740 rev min^{-1}, a speed which produced the maximum halo for the experimenters. The subjects sat in a classroom, lit only by the normal overhead fluorescent lights, at a distance of 2 to 5 m from the disc and at angles of from 0° to 60° from the axis of rotation. While eye movements were not monitored, the 1·3 cm shaft on which the disc was mounted provided a good fixation point. The subjects were asked simply to look at the disc and describe in writing what they saw. They were then told that earlier some people had reported seeing a halo surrounding the disc, and were asked to indicate if they also saw the halo. If they saw the halo, a questionnaire asked them to describe it by answering specific questions.

Of the fourteen subjects, four reported seeing the halo with no prompt, six more reported seeing the halo when asked to look for it, and four never reported seeing the halo. For the ten subjects who reported seeing the halo, two saw colors in the halo, and nine saw it flickering as opposed to being uniform. On a four-point scale from 'very vivid—very easy to see' (4·0) to 'not at all vivid—very hard to see (1·0) the average rating was 2·0 or 'not very vivid—hard to see' (S.D. = 0·82, range of 3 to 1). The halo extended an average of 4·27 cm from the disc (S.D. = 2·46, range of 1 to 9 cm).

Experiment 2 replicated experiment 1 with fourteen naive subjects. The only change was that the illumination now came from a 500 W slide projector. A slide containing a transparent circular center was inserted in the projector so that the resulting spotlight just covered the disc.

The spotlight proved much more favorable to viewing the halo. Of the fourteen subjects, nine reported seeing the halo with no prompt, three more reported seeing the halo when asked to look for it, and two never reported seeing the halo. For the twelve subjects who reported seeing the halo, seven saw colors in the halo, and ten saw it flickering as opposed to being uniform. On the same four-point scale used in the previous experiment, the average rating was 3·0 or 'moderately vivid—easy to see' (S.D. = 0·60, range of 4 to 2). The halo extended an average of 12·93 cm from the disc (S.D. = 5·64, range of 5 to 23 cm). Thus, with the spotlight, the halo appeared present to more people, and appeared more intense [$t(20) = 3{\cdot}30$, $p < 0{\cdot}01$] and larger [$t(20) = 4{\cdot}50$, $p < 0{\cdot}001$].

In the third experiment ten undergraduate volunteers observed 12·7 cm diameter versions of the six discs shown in figure 1. The discs were rotated at 740 rev min^{-1} and illuminated by a spotlight from a 500 W slide projector. The subjects, who saw the discs in different random orders, sat 2 m from the discs. They were asked to judge if each disc produced a halo, and, if so, how far from the disc it extended and how intense it appeared, assuming that the disc itself had an intensity of 1000. While there were significant differences in the size [$F(5,45) = 19{\cdot}61$, $p < 0{\cdot}001$] and intensity [$F(5,45) = 5{\cdot}79$, $p < 0{\cdot}001$] among the discs, all but one of the discs produced halos for all subjects. The one remaining disc, disc f, produced halos for six out of ten subjects. Thus, the halo, while affected by the disc used, is not peculiar to one specific disc.

The subjects were then presented with disc d of figure 1 not rotating, and rotating at 11400 rev min^{-1}, which is well above the speed at which any pattern except for concentric rings could be seen. Only one subject reported a halo when the disc was stationary (size = $0 \cdot 6$ cm, intensity = 100), and no subject reported a halo when the disc was rotating at 11400 rev min^{-1}. Thus it appears that intermittent stimulation at rates which the visual system can detect is necessary for a vivid halo.

The disc was then rotated at 740 rev min^{-1} and a red filter (Wratten 24) was placed in the beam of the light falling on the disc. The filter reduced the overall illumination to approximately 30% of its original illumination; and removed most of the light which the rods could respond to. All ten subjects saw the halo. Its mean intensity relative to the disc was 355 (S.D. = 138, range of 100 to 500), which is not significantly different from the intensity of the halo the disc caused without the filter (mean = 360, S.D. = 183, range of 100 to 750). The halo, however, did decrease from $13 \cdot 21$ cm (S.D. = $5 \cdot 84$, range of 5 to 25 cm) to $8 \cdot 76$ cm (S.D. = $5 \cdot 02$, range of 2 to 22 cm); [$t(9) = 3 \cdot 05$, $p < 0 \cdot 05$]. Parametric studies in which intensity is varied will be needed to interpret these results fully, however, when the above results are coupled with the reports of colors in the halo it seems very likely that the halo is not due solely to stimulation of the rods.

If the effect of rotating discs with black and white portions is alternately to stimulate and not stimulate areas of the retina and thereby to stimulate visual fields of fixed visual angle, then it is possible that the halo is caused by intermittently stimulating portions of visual fields that extend beyond the boundaries of the disc into areas that correspond to the location of the halo. If this were the case, then the size of the halo would be determined by a fixed visual angle corresponding to the size of the visual fields. The fourth experiment was undertaken to test this possibility.

A 15 cm and a 30 cm diameter version of disc d shown in figure 1 were viewed at distances of 1 and 2 m. Sixteen subjects individually viewed all four disc–distance combinations. Only one disc–distance combination was visible at a time and the order of presentation was randomized across subjects. The discs were lit by a 500 W 3400 K photoflood light located 60 cm to the left of the subject and 60 cm above the axis of rotation.

If the halo is caused by stimulating portions of visual fields with fixed visual angles, then distance and not disc size should affect the size of the halo. That is, discs at the 2 m distance should have twice as large a halo as the discs at the 1 m distance. In fact, distance had no statistically significant effect [$F(1,15) = 1 \cdot 17$, $p > 0 \cdot 25$] while size of disc did [$F(1,15) = 12 \cdot 54$, $p < 0 \cdot 005$]. The mean ratio of the size of halo produced by the 30 cm and the 15 cm disc was $1 \cdot 90$, which is significantly different from the $1 \cdot 0$ or no effect [$t(31) = 5 \cdot 43$, $p < 0 \cdot 005$] but is not significantly different from $2 \cdot 0$ or the ratio of the disc diameters [$t(31) = 0 \cdot 63$, $p > 0 \cdot 25$]. Thus, the hypothesis that the halo is caused by intermittent stimulation of portions of the visual field of fixed visual angle is not supported.

While the physiological mechanism of the halo remains a mystery, one possible explanation for the results found here as well as those of Bartley (1936, 1939) is that scattered light surrounding and less intense than the image of the stimulus itself fails to be laterally inhibited because the less intense scattered light takes longer to cause neural activity than does more intense light. Thus the neural activitiy from the light scattered from a white section of the disc reaches the synapse responsible for lateral inhibition 180° out of phase with the neural activity from the image of that white section itself. The neural activity from the scattered light would thereby be subject to lateral inhibition from a black section of the disc, and would not be completely suppressed.

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