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TIME AND INTENSITY AS DETERMINERS OF PERCEIVED SHAPE [1]

H. LEIBOWITZ AND L. E. BOURNE, JR.

University of Wisconsin

It has been demonstrated that a round object viewed obliquely is matched with ellipses which are more circular than would be predicted from geometrical optics (**16**). Such data are examples of the tendency toward "shape constancy," a theoretical condition in which perceived circularity is constant independent of the angle of regard and the corresponding retinal image pattern. Various factors have been shown to affect the extent to which shape constancy occurs. (For a review, see Graham, **7**.) The duration of exposure of the test object is particularly critical; an exposure duration of .01 sec. destroys the tendency towards constancy and produces matches which are in good agreement with the shape of the retinal image (**13**).

The purpose of the present study is to analyze the role of exposure duration and luminance as determiners of the extent to which constancy occurs. To this end, the functional relation between the matched shape of an obliquely viewed disc and the exposure duration is determined. The effect of luminance is investigated in view of the reciprocal relation between exposure time and luminance below the critical duration of about .1 sec. (**3, 4, 5, 6, 8, 10, 11, 15**) and the general importance of luminance as a variable in vision. The results indicate that an exposure longer than the critical duration is required for maximum shape constancy. As a check on the possibility that this may be the result of an experimental artifact, eye-movement records were taken while subjects were making shape judgments.

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Apparatus and Procedure

The basic instrument employed for investigating perceived shape was a modified Dodge tachistoscope utilizing 4-w. fluorescent tubes with preheated filaments as sources. In the stimulus field, which could be exposed from .01 to 1.00 sec. in steps of .01 sec., a white disc 3 cm. in diameter and 2 mm. thick was mounted on a turntable, the surface of which was covered with black "flock" paper (**14**). The turntable could be rotated so as to present the disc at various angles to *S*'s line of vision. The source providing illumination for the disc was mounted directly above and about 8 in. from the surface of the turntable. The "adapting" field presented one of a series of 22 ellipses arranged in order from a circle to an ellipse for which the axis ratio (ratio of minor to major axis) was .054. The ellipses, each with a major axis 3 cm. in length, were drawn mechanically with black India ink on white vellum paper. Field stops in the tachistoscope restricted the field of view for either the disc or any one of the ellipses to a square subtending 4.8° visual angle. The fields were separated by a strip 4.8° wide. The *S* saw alternately either the disc or one of the ellipses at a viewing distance of 31 in., the rest of the field being dark.

The *S*s were instructed to choose the ellipse, by rotation of appropriate knobs, which "looked the most like the disc" and were told to take as much time (as many exposures of the disc) as was required to make a satisfactory match. All *S*s were volunteers from elementary psychology classes and were unaware of the constancy phenomenon, the nature of the apparatus, or the purpose of the experiment. No *S* served for more than one session which, even for the slowest *S*s, was completed within 30 min. All observations were made binocularly with the natural pupil.

TABLE 1

Average Axis Ratios of Matched Ellipses as a Function of Exposure Duration at Three Levels of Luminance

Exposure Duration (Sec.)	Test-Object Luminance (Millilamberts) .01 Mean	.01 SD	.1 Mean	.1 SD	1.0 Mean	1.0 SD
.01	.486	.114	.524	.039	.515	.079
.05	.503	.064	.528	.038	.517	.057
.10	.522	.111	.566	.020	.570	.097
.25	.544	.052	.608	.087	.692	.164
.50	.570	.046	.688	.074	.802	.146
.75	.575	.038	.670	.136	.790	.147
1.00	.590	.043	.737	.145	.842	.117

The effect of exposure duration and luminance on *S*'s matches was investigated with the turntable constant at an angle of 30° to *S*'s line of vision (stimulus axis ratio of .500). Seven groups of seven *S*s each were employed. Three groups were tested at seven durations with luminance as parameter. The durations employed were .01, .05, .10, .25, .50, .75, and 1.00 sec., and the luminance values, constant for a given group, were 10, .1, and .01 ml. Three additional groups were tested at luminance values of 10, 1.0, .32, .1, .032, .01, and .005 ml. with duration constant at either 1.0, .1, or .01 sec.

In order to obtain a source of shorter duration than is possible with the fluorescent tubes, an additional group was tested with a Kemlite electronic DX flash tube providing illuminance for the stimulus. This produces a .0005-sec. flash of extremely high luminance. Because of the difficulties involved in making a photometric match with this source, luminance levels are specified relative to the minimum level at which matches could be made. The *S*s made matches at a level just high enough so that the disc was visible, and at additional levels 3.2, 32, 320, 3200, 32,000 and 320,000 times this value.

Eye-movement records, while *S*s were making shape judgments, were made with an American Optical Company ophthalmograph (1). The *S*s viewed an inclined disc and signaled whether it appeared "rounder" or "flatter" than photographs of the same disc taken at various angles of inclination and presented in random order. The 15 *S*s employed were given two 36-sec. runs while making shape judgments. The duration of the intervals spent in viewing the disc was obtained for the nearest .1 sec. by measuring the film records.

Results

The average data for shape matching and their *SD*'s are presented in Tables 1 and 2. The values relating matched shape to duration with luminance constant are plotted in Fig. 1, while Fig. 2 presents the data obtained as a function of luminance with duration as parameter. The results for the

TABLE 2

Average Axis Ratios of Matched Ellipses as a Function of Log Luminance at Four Durations of Exposure

Log Luminance (Millilamberts)	Duration of Exposure (Seconds) 1.0 Mean	1.0 SD	0.1 Mean	0.1 SD	.01 Mean	.01 SD	Log Relative Luminance*	.0005 Mean	.0005 SD
−2.3	.503[a]	.038	.497[b]	.049	.491[d]	.028	0.0	.503	.020
−2.0	.522	.030	.522	.033	.520[c]	.032	0.5	.527	.020
−1.5	.562	.055	.524	.046	.524[a]	.055	1.5	.512	.021
−1.0	.609	.073	.539	.072	.546	.049	2.5	.512	.020
−0.5	.620	.053	.612	.078	.512	.049	3.5	.547	.058
0.0	.674	.073	.615	.110	.526	.067	4.5	.510	.056
1.0	.694	.085	.644	.154	.543	.117	5.5	.541	.107

* Expressed relative to the lowest level at which matches could be made.
[a] 6 *S*s.
[b] 4 *S*s.
[c] 3 *S*s.
[d] 2 *S*s.

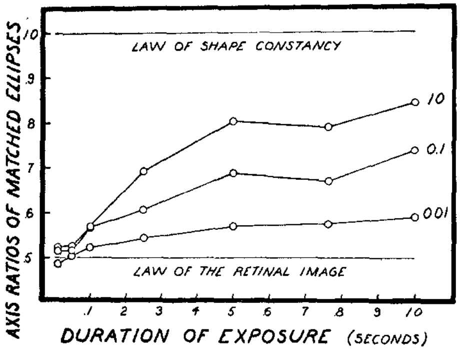

FIG. 1. Mean matched axis ratios for a disc inclined 30° to the horizontal plane as a function of exposure duration with the indicated luminance values as parameter.

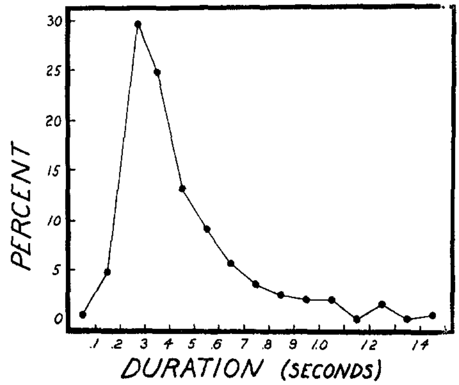

FIG. 3. Percentage of observation time intervals spent viewing the test object while making shape judgments.

.0005-sec. duration are not plotted as they are nearly identical with the data for the .01-sec. duration at comparable luminance levels.

The relationship between matched shape and either luminance or duration is similar. All functions rise rapidly at first with an increase in either variable, and then more slowly, before approaching a limiting value. For conditions near threshold, the axis ratios of the matched ellipses agree with the shape of the retinal image as would be predicted from geometrical optics (law of the retinal image). As either luminance or duration is increased, the axis ratios become larger, tending to approach the theoretical line representing the law of shape constancy. Except for the near threshold conditions, all data fall between the two theoretical extremes. This is typical in visual perception; the data represent a compromise between retinal image properties and object constancy.

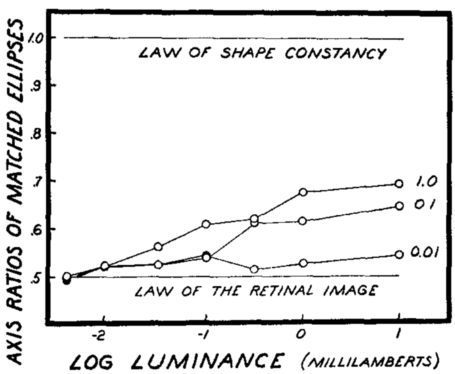

FIG. 2. Mean matched axis ratios for a disc inclined 30° to the horizontal plane as a function of luminance with the indicated exposure durations as parameter.

The eye-movement records were measured to the nearest .1 sec. and the percentage of cases falling in .1-sec. intervals are plotted in Fig. 3.

Discussion

The data of the present experiment indicate that the function relating perceived shape to either duration of exposure or to luminance increases rapidly at first, and then more slowly, before approaching a limiting value. A hypothesis which may be considered in interpreting the observed effects resulting from variation of luminance is that perceptual constancies depend upon the presence in the visual field of stimuli in addition to the discriminative stimulus (7). This is consistent with the demonstration that the tendency toward brightness constancy (12) and size constancy (9) is destroyed when *S*'s visual field is limited to the discriminative stimulus by a reduction screen or similar device. The nature of these "additional" stimuli (probably cues for slant, depth, texture, etc.) and the mechanism by which they influence the tendency toward constancy may not be known with certainty, but it is a reasonable assumption that their luminance values must be high enough to permit discrimination by the observer. As luminance is lowered, visual acuity and intensity discrimination (2) are reduced, as is the tendency toward shape constancy. Thus, acuity, intensity discrimination, and the tendency toward shape constancy are seen to be similarly related to the same independent variable, luminance. In line with the assumption of the importance of "additional" cues in perception, the observed effect of luminance on perceived shape may be attributed to the impairment of acuity and intensity discrimination for these "additional" stimuli in the visual field.

With respect to the variable of exposure duration, it will be convenient to consider separately durations below and above the critical duration of .1 sec. Below critical duration the same visual effect may be produced for the absolute threshold (4, 8), differential threshold (6), grating acuity (5, 15), and span of attention (10) provided the product of intensity and time (i.e., the total energy) remains constant. This reciprocal relation, the Bunsen-Roscoe law, means for the indicated visual measures reduction of exposure time is equivalent, below critical duration, to reduction of luminance. Since in the present study it is demonstrated that luminance is a variable in shape perception, some of the observed effects below .1 sec. may be attributed to the reciprocity effect.

However, all of the variation below critical duration can not be interpreted in the same manner. If duration of exposure were important only as a determiner of the total luminous flux, the curves relating a visual measure to luminance should be superimposable by a shift along the luminance axis proportional to the exposure durations employed. This is true for intensity discrimination (6) and grating acuity (5, 15) but not for perceived shape, as can be seen from curves for the .1-sec. and .01-sec. durations of Fig. 2 and the data for the .0005-sec. exposure listed in Table 2. It is apparent that exposure duration has an effect on perceived shape in addition to its relationship to the total stimulus energy.

Of particular interest is the pronounced effect on the curves, relating matched shape to duration, for values above .1 sec. (Fig. 1). These functions continue to rise beyond the critical duration, leveling off at about .5 sec. The eye-movement records were taken to check the possibility that the time required to shift fixation from the comparison to the test field may account for this result. The eye-movement data (Fig. 3) indicate that 95% of the intervals spent in viewing the test object are longer than .2 to .3 sec. The mean duration is .48 sec. Thus, when time is not restricted, the duration of observation of the test object is of the same order of magnitude as the exposure duration required for the maximum tendency toward constancy in the tachistoscope. It appears, therefore, that the observed diminution of the constancy effect can be attributed to the reduction of the observation time of the test object below the interval normally utilized while making shape judgments. An adequate theory of shape perception must account for the important effect of exposure duration which is effective in addition to its role in the reciprocity relationship of vision.

Summary

1. The function relating matched shape to exposure duration and to luminance was determined by matching ellipses with an obliquely viewed disc.

2. For near-threshold stimulus conditions, the axis ratios of matched ellipses are in agreement with predictions made on the basis of retinal image theory.

3. With increase in either duration or luminance, the matched axis ratios become larger. These functions increase rapidly at first, and then more slowly, before approaching a limiting value.

4. The diminution of the tendency toward perceptual constancy resulting from reduction of luminance is attributed to the impairment of visual acuity and intensity discrimination for the "additional" stimuli in the visual field.

5. Some of the variation due to reduction of exposure below critical duration can be attributed to the reciprocal relation between time and intensity. However, there is an effect both below and above critical duration which represents the influence of exposure time as a determiner of perceived shape in addition to its role in the reciprocity relationship.

6. Eye-movement records, taken while *S*s were making shape judgments, confirm the finding that an exposure longer than the critical duration is required to produce the maximum tendency toward shape constancy.

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