Dark adaptation and the Hermann grid illusion

EUGENE R. WIST

Whitely Psychology Laboratories, Franklin and Marshall College, Lancaster, Pennsylvania 17603

The latency of the perception of the dark spot at the intersection of a Hermann grid was measured before and after dark adaptation. It was found that dark adaptation significantly increased the latency of perception of the spot while light adaptation had no effect. This finding was predicted from the Jung and Spillman account of the Hermann grid illusion and from the Kuffler et al. finding that inhibitory receptive fields of the cat's retinal ganglion cells are reduced in size and responsiveness after dark adaptation. The significance of this finding in relation to other simultaneous contrast phenomena is discussed.

Wist (1974) found that the visibility of Mach bands is significantly reduced when a stepwise luminance gradient with successive luminance steps staggered in depth is viewed binocularly. When this gradient is monocularly viewed so that all steps appear in the frontoparallel plane, strong Mach bands are visible. Thus the Mach band visibility is dependent on the adjacency in stereoscopic depth of the successive luminance steps, with greater depth adjacency resulting in greater variability. This finding suggests that the lateral inhibition postulated by Ratliff (1965) to be responsible for the Mach band phenomenon at the retinal level can be disinhibited at the cortical level. Furthermore, it is consistent with the findings of several other recent studies on the role of depth adjacency in mediating brightness of whiteness contrast. Gogel and Mershon (1969) found that the magnitude of the simultaneous whiteness contrast between a disk and surround annulus was directly related to the adjacency in perceived depth between these stimuli. Similarly, Mershon (1972) found that the perceived whiteness contrast between two luminous squares was a function of both their lateral and depth separation. Also, Wist and Susen (1973) found that the perceived brightness difference between the two halves of the annulus in the Koffka ring illusion was a function of the perceived stereoscopic depth interval between the line bisecting the annulus and the annulus itself.

Given that depth adjacency has been clearly shown to affect several instances of brightness or whiteness contrast, the question arose as to whether further instances of brightness contrast are similarly affected. The present study was provoked by a failure to find such an effect on the Hermann

grid illusion (Wist, 1974). In this study, a luminous white grid pattern was made to appear closer in depth than its dark background. This was accomplished by using as the background a sheet of aluminum foil perforated with a small number of randomly spaced pinholes and placed in one channel of a tachistoscope. When transilluminated, a mosaic of star-like points, all in the same depth plane as their background, was visible. A grid pattern was placed in a second channel at a nearer distance, resulting in an 8-min-arc binocular disparity between it and the background. Binocularly viewed, the grid appeared to be clearly in front of the background, but monocularly viewed it appeared to be in the same depth plane as the background. Under both conditions, a strong illusion occurred: all 20 subjects tested reported dark spots at the nonfixated intersections of the grid.¹ Thus, depth adjacency did not affect the magnitude of this illusion, although the binocular disparity used was comparable to that used in previous studies (Wist, 1974; Wist & Susen, 1973).

At this point, it appeared that the Hermann grid illusion might be a special case, not susceptible to the depth adjacency effect. Jung and Spillmann (1970) have explained this illusion in terms of the interaction of excitatory and inhibitory receptive fields of retinal ganglion cells, with net inhibition occurring at the grid intersections being responsible for the perception of the dark spots. Their interpretation is consistent with the data thus far available on this illusion (e.g., Jung & Spillmann, 1970; Spillmann, 1971; Spillmann & Levine, 1971). On the basis of their account, if it were possible to reduce the influence of the inhibitory receptive fields of the retinal ganglion cells, the illusion would be attenuated or eliminated. Kuffler, FitzHugh, and Barlow (1957) found that the inhibitory receptive fields of the cat's retinal ganglion cells were reduced in size and responsiveness after dark adaptation. If a generalization from the cat's visual system to man's is allowed, then, consistent with the Jung and Spillmann account, the Hermann grid illusion should disappear or weaken after dark adaptation but return during subsequent

This investigation was supported by Grant EY00268 from the National Eye Research Institute of the U.S. Public Health Service. This paper was written while the author was a "Senior U.S. Scientist Awardee" of the Alexander von Humboldt Foundation at the Department of Neurophysiology of the University of Freiburg, West Germany. Thanks are due Gail Richmond for her assistance in collecting the data and Robert Becklén and Dean Becker for carrying out a preliminary experiment.

light adaptation. The purpose of this study was to test this prediction.

METHOD

Subjects

Nine male and three female college students (ages 18 to 20 years) served as subjects. No screening tests were employed.

Apparatus

A scientific Prototype three-channel tachistoscope was used. The Hermann grid was produced by the transillumination in one of the channels of a milk-Lucite sheet, whose 1.8-mL front surface was masked off so as to produce a single intersection of a vertical and horizontal bar on a dark 0.2-mL ground (see Figure 1). The grid/ground contrast ratio was .80. The fixation point was similarly generated and presented in a second channel. It was located 5 deg to the right of the grid intersection. An adapting field was located in the third channel. It consisted of a transilluminated milk-Lucite sheet, 6.6 deg high $\times$ 9.3 deg wide with a luminance of 5.4 mL. The adapting field, grid, and fixation point were located at an optical distance of 110 cm from the subject's eyes. An electronic clockcounter was triggered at the instant the grid was illuminated and stopped when the subject released a telegraph key. The tachistoscope and its viewing aperture were located in separate rooms, so that complete visual isolation of the subject existed.

Procedure

The subject was seated before the tachistoscope and asked to look at an example of the Hermann grid illusion made of construction paper. Each subject was able to spontaneously report seeing dark gray spots at the grid intersections not fixated. Next, instructions concerning the task were read. The subject was told to release a telegraph key as soon as he detected a gray spot at the intersection of the vertical and horizontal bars of Figure 1. He was also cautioned not to respond to the onset of the grid itself. Two practice trials were administered, after which the subject was cautioned to release the key only if the dark spot appeared. If it failed to appear, the key was not to be released until a signal from the experimenter was received. This signal was given if the subject did not detect the gray spot within 15 sec after exposure of the grid. The importance of maintaining fixation on the fixation point was stressed.

Each of the initial 20 trials was begun with the exposure of the adapting field for 9 sec. This was followed immediately by the appearance of the fixation point alone. One second later, the grid appeared and remained present with the fixation point until the subject released the key or until 15 sec had elapsed, whichever occurred first. After the initial series of 20 trials, a 10-min period of dark adaptation was begun.² At its termination, a second series of 20 trials was initiated under conditions identical to those of the first series, except that the adapting field was eliminated. At the conclusion of these 20 trials, the adapting field was reintroduced for a terminal series of 20 trials. Reaction times (RTs), measured from the onset of the grid to the perception of the dark spot, were recorded with an electronic timer. The rationale for the use of an RT measure was straightforward. After a given degree of dark adaptation, if the illusion disappeared as predicted, then upon presentation of the grid, no gray spot would be seen until a sufficient degree of recovery from dark adaptation occurred. Therefore, RTs after dark adaptation would be elevated in comparison to those obtained after light adaptation.

In addition, at the end of the above three 20-trial blocks, RTs to the onset of the grid itself were measured for 5 trials as a control. Thus a total of 65 trials were administered during the 60-min session. The intertrial interval was 20 sec for all trials, and the subjects received a verbal signal from the experimenter just prior to the onset of the fixation point in each trial. Three

of the 12 subjects served as controls. Rather than dark adapting for 10 min, these subjects viewed the adapting field for 10 min instead.

RESULTS

For each subject, the mean of the 20 predark adaptation RTs and the means of successive blocks of 5 postdark adaptation RTs were determined. From these means, ratios of post- to predark adaptation RTs were calculated separately for each subject and then averaged across the subjects for the figure. This procedure was used in favor of simply averaging the RTs across trial blocks, because it took into account the large individual differences in initial RTs (range: .60 to 3.4 sec). A ratio of 1.0 means that RT was unchanged after dark adaptation, while higher or lower ratios indicate an inhibitory or facilitatory effect, respectively, of dark adaptation on the perception of the dark spot.

As the upper curve in the figure shows, there was a mean 2.5-fold increase in RT for the first block of five trials immediately following dark adaptation. Over subsequent trial blocks, ratios decreased gradually with the recovery from dark adaptation to the terminal value of 1.3 (Trial Block 8). The lower curve represents the results of one of the three control subjects who received 10 min of light adaptation instead of dark adaptation. His RT ratios deviate little from 1.0. The results for the other two control subjects were similar.

The mean RT for the preadaptation trials was 1.77

Figure 1. Mean ratios of post- to pre-dark-adaptation reaction times (RTs) for the perception of a dark spot at intersection of a segment of a Hermann grid as a function of successive blocks of five postadaptation trials. The horizontal line intersecting the ordinate at 1.0 represents the pre-dark-adaptation RT level. Solid circles: mean ratios for nine subjects dark adapted for 10 min just prior to Trial Block 1. The adapting field was reintroduced after the break in this function. Open circles: mean ratios for one of three control subjects light adapted for 10 min just prior to Trial Block 1. The adapting field was always present between trials. Stimulus display not drawn to scale. F.P. = fixation point, 5 deg to right of the center of the grid intersection.

sec, while that for the first 20 postdark adaptation trials (Blocks 1-4 in Figure 1) was 3.50 sec. The mean RT for the final 20 trials (Blocks 4-8 in Figure 1) was 2.85 sec. *t*-tests for related means indicated a significant increase in RT for the first 20 trials (Blocks 1-4) after dark adaptation as compared to the predark adaptation RTs ($t = 2.91$, $df = 8$, $p < .025$) and a significant reduction in RT for the last 20 trials (Blocks 1-4 vs. 5-8, $t = 2.58$, $df = 8$, $p < .025$). Furthermore, while the mean RT for Trial Block 5 was still significantly elevated as compared to the preadaptation mean RT ($t = 2.33$, $df = 8$, $p < .025$), the mean RT for Trial Block 8 was not significantly different from the preadaptation mean RT ($t = 1.37$, $df = 8$, n.s.).

The mean RT for the five terminal trials on which the subjects responded to the grid onset itself was .39 sec ($SD = .64$), almost 1.40 sec shorter than the mean RT of 1.77 sec to the appearance of the dark spot under identical stimulus conditions. The fact that there was no overlap in the two distributions of RTs indicates that the subjects followed the instruction to respond to the dark spot rather than to grid onset during the experimental trials.

DISCUSSION

The results confirm the prediction based on the single-unit data of Kuffler, et al. (1957) and the theoretical account of the Hermann grid illusion offered by Jung and Spillmann (1970). Dark-adapting the retina would appear to attenuate the inhibitory contribution of retinal ganglion cells required for the perception of the dark spot at the grid intersection. Therefore, when the eye is dark adapted, the illusion disappears. As the eye recovers from dark adaptation, the illusion reappears because of the restoration of this inhibitory contribution.

The data are also consistent with those of Schepelmann, Aschayeri, and Baumgartner (1967), who found that simple cortical units in the cat show a reduction in discharge rate when the intersection of a Hermann grid is centered appropriately in their receptive fields. They hypothesized that this reduction corresponds to the perception of the dark spot at the grid intersection for human observers. Unfortunately, no data are available on the effect of dark adaptation on this reduction in discharge rate. On the basis of the present data, it would be predicted that this reduction would be attenuated or disappear after dark adaptation.

In conclusion, it should be noted that in addition to supporting the Jung and Spillmann (1970) account of the Hermann grid illusion, the present study is also consistent with the view that two classes of brightness contrast effects may exist. One class is affected by depth adjacency and includes Mach bands (Wist, 1974) and simultaneous contrast (Gogel & Mershon, 1969; Mershon, 1972) but is not affected

by dark adaptation (Fiorentini & Maffei, 1973). The other class includes the Hermann grid which is affected by dark adaptation but not depth adjacency. At this point, only the Hermann grid illusion has been demonstrated to be a member of this latter class. It remains to be determined whether this illusion is unique or whether other brightness contrast effects also belong in this class.

REFERENCES

- FIorentini, A., & MAFFEI, L. Contrast in night vision. *Vision Research*, 1973, 13, 73-80.
- GOGEL, W. C., & MERSHON, D. H. Depth adjacency in simultaneous contrast. *Perception & Psychophysics*, 1969, 5, 13-17.
- JULESZ, B. *Foundations of cyclopean vision*. Chicago: University of Chicago Press, 1971.
- JUNG, R., & SPILLMANN, L. Receptive field estimation and perceptual integration in human vision. In D. B. Lindsley & F. A. Young (Eds.), *Early experience and visual information processing in perceptual and reading disorders*. Washington, D.C: National Academy of Sciences, 1970.
- KUFFLER, S. W., FITZHUGH, R., & BARLOW, H. B. Maintained activity in the cat's retina in light and darkness. *Journal of General Physiology*, 1957, 40, 683-702.
- MERSHON, D. H. Relative contributions of depth and directional adjacency to simultaneous whiteness contrast. *Vision Research*, 1972, 12, 969-979.
- RATLIFF, F. *Mach bands: Quantitative studies on neural networks in the retina*. New York: Holden-Day, 1965.
- SCHPELMANN, F., ASCHAYERI, H., & BAUMGARTNER, G. Die Reaktionen der "simple field" Neurone in Area 17 der Katze beim Hermann-Gitter Kontrast. *Pflügers Archiv für gesamte Physiologie*, 1967, 294, R57. (Abstract)
- SPILLMANN, L. Foveal perceptive fields in the human visual system measured with simultaneous contrast in grids and bars. *Pflügers Archiv für gesamte Physiologie*, 1971, 326, 281-299.
- SPILLMANN, L., & LEVINE, J. Contrast enhancement in a Hermann grid with variable figure-ground ratio. *Experimental Brain Research*, 1971, 13, 547-559.
- WIST, E. R. Mach bands and depth adjacency. *Bulletin of the Psychonomic Society*, 1974, 3, 97-99.
- WIST, E. R., & SUSEN, P. Evidence for the role of post-retinal processes in simultaneous contrast. *Psychologische Forschung*, 1973, 36, 1-12.

NOTE

1. Julesz (1971) devised a stereoscopic version of the Hermann grid in which the random dot stereogram technique was used to make the horizontal bars appear in front of the vertical ones. He noted that the illusion was present whether the bars appeared in the same or in different depth planes, consistent with the present finding. However, I found that only 3 of 20 subjects tested with his Figure 2. 7-3 were able to report the illusion at all. The speckled surface of the grid elements, a consequence of the random dot technique, appeared to interfere with the generation of the illusion for most subjects.

2. In pilot studies, dark-adaptation periods of up to 30 min were employed with results similar to those presented here with a 10-min dark-adaptation period. This shorter interval was chosen because it was sufficient to carry dark adaptation to a point where the rod-cone break was visible in tests with a recording adaptometer, and the shorter adaptation period allowed completion of an experimental session in much less time.

(Received for publication January 19, 1976;
accepted March 19, 1976.)