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The scintillating grid illusion in stereo-depth

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Abstract

The dark scintillating dots occurring on a gray-on-black, modified Hermann grid [Schrauf, M., Lingelbach, B., & Wist, E. R. (1997). The scintillating grid illusion. *Vision Research*, *37*, 1033–1038] were studied in stereo-depth by assigning various degrees of disparity to the white inducing disks. Dependent on the sign of disparity, the disks and the dark illusory spots within them appeared to lie either in the same plane, in front of, or behind the grid. At zero disparity, illusory strength was maximum and was the same for stereo, binocular and monocular viewing. With increasing disparity, the illusion became progressively weaker; however, the decrease for stereo-patterns was significantly less than for control patterns presented binocularly or monocularly. These results suggest a central contribution to the scintillation effect. © 2000 Published by Elsevier Science Ltd. All rights reserved.

Keywords: Scintillating grid illusion; Illusory brightness; Stereo-depth; Visual illusion

1. Introduction

In an earlier study, Schrauf, Lingelbach and Wist (1997) introduced a striking phenomenon called ‘The Scintillating Grid Illusion’. This phenomenon was marked by dark illusory spots flashing on small white disks added to the intersections of a gray-on-black Hermann grid. It can best be observed with moving eyes and in peripheral vision, similar to the effect described by Bergen (1985) for a low-pass filtered Hermann grid. For an explanation, Schrauf et al. (1997) proposed a two-stage model: (i) processing of the stimulus in retinal receptive fields; and (ii) a central site with more complex receptive fields for the generation of the scintillating grid illusion. The need for a cortical component is evidenced by the fact that there has to be a number of orderly arranged intersections to produce the effect, as has been previously observed for the dark illusory spots in a regular Hermann grid (Wolfe, 1984). A higher-level contribution is also suggested by the relatively long fixation periods required for an optimum illusion: 210–350 ms with strict fixation (Schrauf & Wist, 1996) and 250–550 ms during free scanning (Böhm, Schrauf, Wölwer & Wist, 1997). Here, we test for a cortical contribution to the scintillation effect by presenting the grid inducing pattern stereoscopically.

Brightness illusions that persist with stereoscopic presentation of their component parts include the Gelb effect (Mershon & Gogel, 1970), Koffka’s ring (Wist & Susen, 1973), the Ehrenstein illusion (Spillmann, Fuld & Gerrits, 1976), the Hermann grid illusion (Julesz, 1971; Troscianko, 1982), and the Munker-White effect (Taya, Ehrenstein & Cavonius, 1995). In this study we ask whether and to what extent the scintillating grid illusion persists, if the inducing pattern is presented in stereo-depth with various retinal disparities.

2. Methods

2.1. Apparatus and stimuli

Scintillating grid stereograms were generated on an IBM 80486 computer and laser-printed with a high resolution, multi-gray-level laser printer on white paper.

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Patterns consisted of a medium-gray grid on a black background with a white disk superimposed onto each intersection. Michelson contrasts between the individual stimulus components were as follows: white disks/gray bars, $C=0.64$; white disks/black background, $C=0.90$; and gray bars/black background, $C=0.64$. There were 11 × 11 intersections on a square background field subtending 18.6° on a side. The width of the gray bars was 19 arcmin, the diameter of the white inducing disks 28 arcmin, and the width of the black background squares 86 arcmin. Pair members of each stereogram were optically combined using a Zeiss prism stereoscope and viewed under daylight (800 lux) at a distance of 28.5 cm.

Stereoscopic depth was produced by introducing a disparity between the white disks and the gray-on-black grid. Disparity was defined by the offset of the disks relative to the grid intersections. Thirteen disparities, crossed and uncrossed, were used ranging from 0 to 18 arcmin with a step size of 1.5 arcmin. With crossed disparities, disks appeared to float above the intersections (for a demonstration see Fig. 1), whereas with uncrossed disparities, they were perceived as lying behind. Experiment 1 employed horizontal disparities whereby positive values denote disks that were shifted 'inward', for the right eye to the left and for the left eye to the right. In comparison, Experiment 2 used vertical disparities, where positive values refer to disks that were shifted upward for the right eye and downward for the left eye. In the case of negative values, all directions are reversed. To compare the results obtained with stereo-vision (two eyes viewing disparate images), Experiment 3 stimulus patterns were presented through the stereoscope either binocularly (both eyes viewing identical stimuli) or monocularly (the dominant eye viewing). This was done to assess the effect of lateral displacement of the disks when they were perceived coplanar with the grid (i.e. no stereo-depth). In this experiment, disks were shifted to the right relative to the intersections.

An attempt to test the scintillation illusion also dichoptically, by showing the white disks on a black background to one eye and the grid pattern to the other, produced binocular rivalry in the areas of the intersections making observation of the dark fluctuating dots uncertain, if not impossible. This problem of binocular rivalry is well-known from studies of geometrical optical illusions (e.g. Schiller & Wiener, 1962).

2.2. Procedure

The order of presentations was permutated between experimental conditions and the sequence of the individual stimuli within each experiment randomized. Each stimulus pair was presented once only to each observer. There was no time limit for giving a response. Subjects rated the strength of the illusory spots for each grid using a scale between 1 and 5. A value of '1' denoted no illusion, ratings of '2' to '4' an illusion of increasing strength, and '5' an illusion as strong as that in a binocularly viewed reference grid presented with no lateral displacement of the disks. Subjects were asked to report whether or not they could fuse the stereo-stimuli.

2.3. Subjects

Twelve volunteers, four females and eight males, mean age 31.8 years, all naive as to the purpose of the study, served as observers. All had normal or corrected-to-normal visual acuity, normal stereo-vision, and normal contrast sensitivity (according to the Snellen test, the TNO Soesterberg stereo-test, and the Vistech VCTS 6000 vision contrast test).

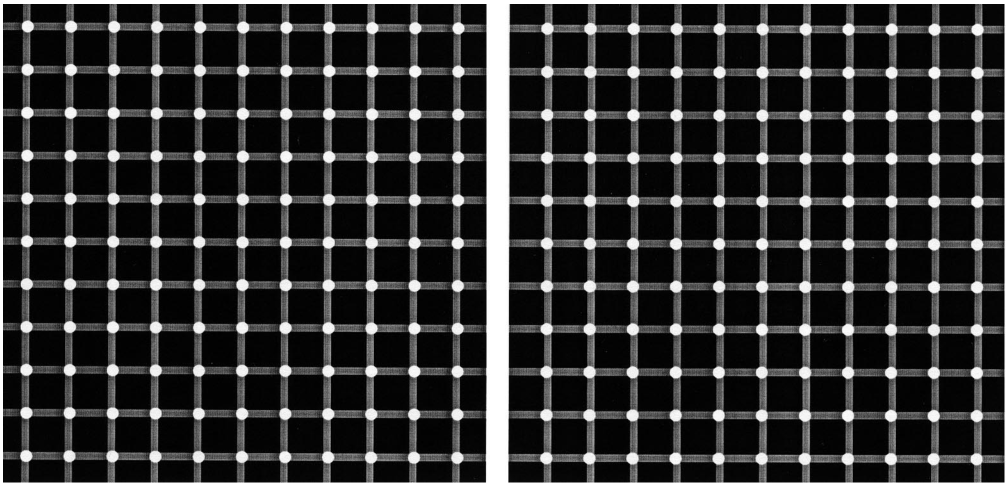

Fig. 1. Stereoscopic demonstration of the scintillating grid illusion for cross fusion. Readers able to free-fuse will observe dark flashing spots centered on the white disks which should appear to lie above the grid. The illusion occurs with each flick of the eye and is most pronounced in the periphery.

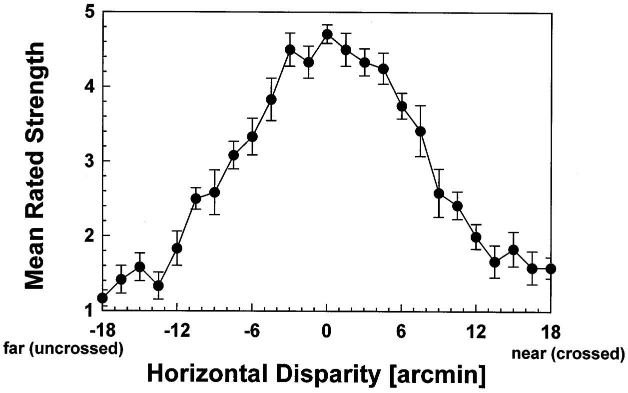

Fig. 2. Mean rated strength of the scintillation effect as a function of horizontal disparity of the disks. Negative values refer to uncrossed, positive values to crossed disparities. Here and in the following legends, data points are means of 12 ratings. Vertical bars equal ± 1 S.E.

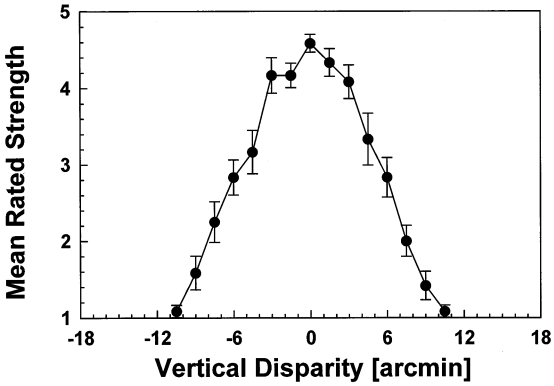

Fig. 3. Mean rated strength of the scintillation effect as a function of vertical disparity of the disks. Negative values refer to uncrossed, positive values to crossed disparities. Vertical bars equal ± 1 S.E.

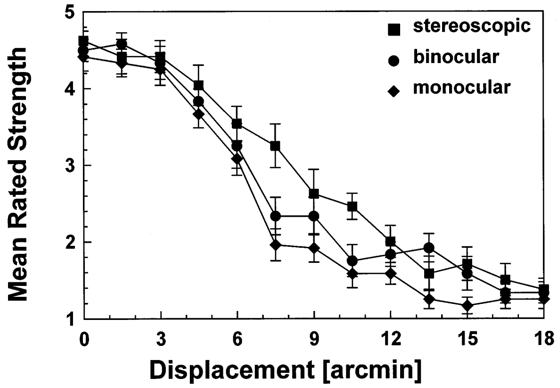

Fig. 4. Mean rated strength of the scintillation effect as a function of displacement of the white disks relative to the intersections for stereo (squares), binocular (circles), and monocular (diamonds) viewing. Vertical bars equal ± 1 S.E.

3. Experiment 1: the effect of horizontal disparity

3.1. Results

All subjects reported seeing the dark scintillating spots despite the fact that the white disks appeared to lie in front (elevated) or behind the induction grid (recessed). Fig. 2 shows the results of mean-rated strength (ordinate) as a function of horizontal disparity (abscissa). A maximum rating of about 4.5 was obtained for disparities ranging from 0 to 1.5 arcmin in the crossed condition and 0–3 arcmin in the uncrossed condition. With increasing stereo-depth, the rated strength of the illusory spots decreased monotonically. Ratings fell below a value of 2 at disparities larger than 13.5 arcmin (crossed) and 12 arcmin (uncrossed). The illusion at these disparities was therefore assumed to be absent. Data for crossed and uncrossed disparity did not differ ($P = 0.38$). Also, as disparity increased, the scintillating spots progressively thinned out from the central area leaving only a few dark spots in the outer periphery of the grid.

4. Experiment 2: the effect of vertical disparity

4.1. Results

Fig. 3 shows mean-rated strength of the illusory dark spots plotted as a function of vertical disparity. A maximum rating of about 4.5 was reached only for zero disparity, followed by a steep decline on either side of the maximum. This fall-off in response strength was more rapid than for horizontal disparity in Fig. 2, reaching a rating of less than 2 at a disparity of ± 9 arcmin (crossed and uncrossed). For disparities larger than ± 10.5 arcmin, binocular fusion of the stereoscopic stimuli could no longer be achieved.

5. Experiment 3: the effect of coplanar horizontal shifts

5.1. Results

This control experiment was performed to find out to what extent the lateral displacement of the disks per se was responsible for the results obtained with stereodepth. Fig. 4 plots mean-rated strength against the rightward shift of the disks for binocular (circles) and monocular (diamonds) viewing. In addition, mean values for crossed and uncrossed disparity (from Experiment 1) are plotted for comparison (squares). Values on the abscissa refer to the lateral shifts of the white disks relative to the grid intersections in one eye for all three conditions. In the monocular and binocular conditions, the shift is simply the displacement of the disk relative to the grid intersection in one eye (the shifts being identical in the two eyes in the binocular condition). In the stereoscopic condition, it is again the displacement of the disk relative to the grid intersection in one eye (the shifts being equal in magnitude, but opposite in sign, in the two eyes in this condition).

Curves for all three conditions exhibit a maximum rating of about 4.5 at or near zero shift. Thereafter, they decrease, however, with different slopes. Ratings for monocular viewing fall off the fastest, followed by those for binocular viewing and then stereo-viewing, the latter ones falling off the least. Ratings for the three conditions fall below a value of 2 ('illusion not seen') at different intercepts: 7.5 arcmin (monocular), 10.5 arcmin (binocular), and 13.5 arcmin (stereo).

The differences (rank-sum test for ordinal-scale data of dependent samples, Krauth, 1988) between the results obtained with the monocular and binocular conditions are highly significant ($P < 0.0001$, $Z = 3.85$), and so are the differences between the results obtained with binocular and stereo-presentation ($P = 0.005$, $Z = 2.57$). Note, however, that these significances derive from the difference in ratings for disk displacements ranging from 3 to 12 arcmin only. Below and above this range of disparities, there is no difference in perceived strength of the illusory spots between viewing conditions.

6. Discussion

The present study shows that the scintillation grid effect not only persists in stereo-depth, the strength of the illusion is actually enhanced relative to monocular and binocular viewing for moderate disk displacements (Fig. 4). From these results, we conclude that there is a cortical contribution to the scintillation effect. However, the finding that the strength of the scintillating dark spots is strongly affected by the displacement of the disks relative to the grid intersections in one eye only manifests that the major component of the illusion is retinal in origin.

The fact that response ratings for all three experimental conditions were about the same when the inducing disks were centered on the intersections (zero disparity/zero shift), likely represents a ceiling effect because stimuli and percepts under these conditions were identical (coplanar). Similarly, the observation that the three curves converged, when the disparities became too large for the stereo-stimuli to fuse, probably represents a floor effect.

The superiority of the scintillating grid illusion when presented in stereo-view is unlikely to be due to inferior accommodation with monocular presentation or an increased number of fixational eye movements with stereo-presentation. The reasons are as follows: (i) Subjects uniformly reported for all three viewing conditions that the stimuli had been in focus. (ii) There is no evidence that spontaneous eye movements are more pronounced with stereoscopically fused patterns than with monocular viewing. (iii) The fall-off in our data with an increasing shift of the white superimposed disks is less pronounced for horizontal disparity (Experiment 1) than for vertical disparity (Experiment 2), suggesting a specific contribution of stereo-depth.

What might be the neurophysiological substrate of the cortical component of the scintillation effect? Binocular cells in areas V1 and V2 of the macaque have been shown to respond best within 6 arcmin of zero disparity (Poggio & Fischer, 1977; Fischer & Poggio, 1979) and could potentially be candidates to account for our results. Also, it is known that most cortical cells respond more vigorously to binocular than to monocular stimuli (Anzai, Bearse, Freeman & Cai, 1995), with the difference in response becoming smaller with increasing disparity (Cagenello, Arditi & Halpern, 1993).

The progressive disappearance of illusory spots from the center of the display with increasing disparity (Experiment 1) is also observed with monocular and binocular viewing. We therefore assume that it results from the lateral displacement of the disks relative to the intersections, suggesting that the spatial limit for the offset of the disks is smaller in para- and perifoveal regions than at larger eccentricities. This difference is reminiscent of the regular Hermann grid illusion which tends to be absent in foveal vision, but requires increasingly wider bars for the illusory spots to be seen in the periphery (Jung & Spillmann, 1970).

In summary, we have demonstrated that the scintillating grid illusion exists in stereo-depth and that it is stronger than in monocularly and binocularly presented control patterns having the same amount of disk displacement. This finding together with the fact that the illusion is seen on white disks that are perceptually elevated (or recessed) in space, suggests that the mechanism eliciting the perception of the scintillating spots has access to the mechanisms producing stereo-depth. We therefore conclude that there is a cortical, albeit small, contribution to the perception of the scintillating grid illusion.

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