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The Scintillating Grid Illusion

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Disk-shaped luminance increments were added to the intersections of a Hermann grid consisting of medium grey bars on a black background. Illusory spots, darker than the background, were perceived as flashing within the white disks with each flick of the eye. This striking phenomenon may be referred to as the scintillating grid illusion. We determined the conditions necessary for cancelling the Hermann grid illusion, as well as the luminance requirements and the size ratio between disks and bars that elicits the scintillation effect. The fact that scanning eye movements are necessary to produce the scintillation effect sets it apart from the Hermann grid illusion. © 1997 Elsevier Science Ltd. All rights reserved.

Hermann grid illusion Scintillation effect Brightness perception Eye movements

INTRODUCTION

The original Hermann grid illusion is characterised by light spots perceived at the intersections of a dark grid on a white background. These illusory spots were first reported by Brewster (1844) and Hermann (1870). Hering (1878) showed that dark illusory spots occur in a pattern of opposite contrast polarity (for a review see Spillmann, 1994). Baumgartner (1960, 1990) attributed this illusion to the differential stimulation of ON- or OFF-centre receptive fields, resulting in a net darkening or brightening, respectively. Troscianko (1982) measured the strength of the "hollow" Hermann grid illusion by locally increasing the luminance of the intersections until the grey spots could no longer be seen. The luminance required for cancellation provided a measure for the strength of the illusion. Bergen (1985) modified the standard Hermann grid by low-pass filtering. This operation resulted in a blurred grid whose intersections were more luminant than the bars. In such a grid, dark patches can be seen at the intersections during eye movement. This effect is the topic of this study.

We first superimposed small uniform disks, increments or decrements, onto the intersections of a Hermann grid to cancel the illusory grey spots. As a result, we observed a striking phenomenon: scintillating dark spots within the white disks and scintillating light spots within the black disks (Fig. 1). These spots were perceived predominantly in peripheral vision, but can also be observed foveally with certain spatial conditions. As in the case of the Hermann grid illusion (Spillmann & Levine, 1971), the illusory dark spots were stronger than the illusory light spots.

In anticipation of more distinct effects we selected the dark version (Fig. 1, left) and then asked the following questions: first, what is the luminance of the disks required to cancel the illusory dark spots in the Hermann grid for various combinations of bar luminance and background luminance? Second, what is the relationship between the rated strength of the dark spots in the scintillating grid illusion on the one hand and the luminances of the disks, the bars, and the background, on the other, when two parameters are kept constant? Last, how does rated strength depend on disk size and bar width?

METHODS

Fifteen students, nine females and six males, who were naïve as to the purpose of the experiment served as subjects. They had normal or corrected-to-normal visual acuity and normal contrast sensitivity. Grid patterns representing a matrix of 8 × 6 intersections were generated by an IBM 80486/50 computer (frame rate 100 Hz, 256 grey levels) and displayed on the screen of an EIZO 17″ RGB monitor (Model T560i-T, Sony Trinitron tube). Luminances were measured with a Minolta Luminance Meter (Model LS 100). The subject's head was supported by a chin rest located 70 cm away from the monitor. Unless specified otherwise, the angular dimensions of the stimulus were as follows: bar width 0.31 deg, background square width 1.54 deg, and disk diameter 0.43 deg. The ratio between the diameter of the disks and the width of the bars was chosen on the basis of a pilot study and was 1.4:1. Experiments were performed with free viewing of the stimulus patterns and there was no time limit for the subjects to respond.

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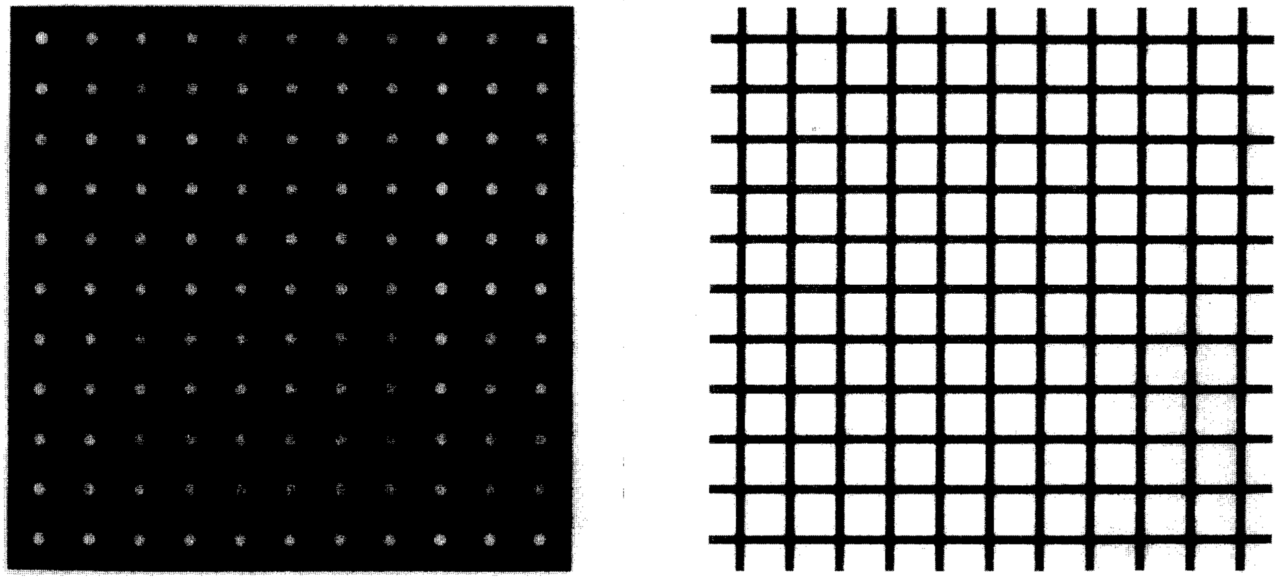


FIGURE 1. Scintillation effect. Dark illusory spots are perceived within the white disks (left) and light illusory spots within the black disks (right). These spots are seen best in the periphery where they blink, or scintillate, with each eye movement. Note that the spots can also be seen foveally when the observation distance is increased. The scintillation effect disappears with steady fixation. These patterns are shown here for demonstration only and are not identical with the stimulus patterns used in the experiments.

Experiment 1: cancellation of the Hermann grid illusion

Using a matching task, the subjects were asked to adjust the luminance of the disks until the illusion was cancelled. There were seven luminances for the bars, ranging from 0.42 to 42.5 cd/m^2 and three luminances for the background, ranging from 0.03 to 6.77 cd/m^2. This resulted in Michelson contrasts varying from 0.25 to 0.99. Experimental conditions were randomized for each subject across bar luminance and background luminance. Four conditions where disk luminance was below bar luminance were not tested. The resulting 17 conditions were repeated three times.

Results

Figure 2 shows cancellation luminance of the disks as a function of bar luminance for three background luminances. Data points in this and subsequent figures are averages of 45 individual settings. Values of mean cancelling disk luminance specify combinations of bar and background luminances at which the Hermann grid illusion can just be cancelled by appropriate disk luminance. At higher bar and lower background luminances the cancelling disk luminance is proportionately higher than at lower bar luminances; that is, the contrast between bar and background luminances must be proportionately greater. This implies that the strength of the Hermann grid is proportionately greater at higher bar luminances as well as greater bar/background luminance difference.

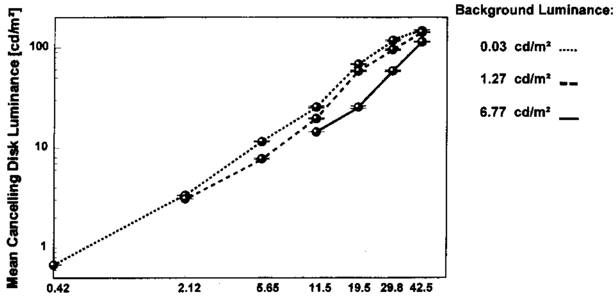


FIGURE 2. The disk luminance required for cancelling the illusory spots in the Hermann grid at different background luminances is plotted as a function of bar luminance. In this and the following figures, data points are averages of 45 individual ratings of 15 subjects. The vertical bars indicate ± 1 standard error.

The scintillation effect occurred only when the luminance adjustments for the disks were above the luminance required for nulling. In the following experiments we studied the requirements for this effect.

Experiment 2: the scintillation effect as a function of disk luminance

For a given luminance of the bars (11.5 cd/m^2) and the background (1.27 cd/m^2), we presented disks of different luminances ranging from 0.42 to 142 cd/m^2. Spatial parameters were held constant (bars 0.31 deg, background 1.54 deg, disks 0.43 deg). Owing to the fact that the Hermann grid illusion is easily eliminated by small increases of disk luminance above the bar luminance (Troscianko, 1982), we used 11 fine shades of disk luminances for the Hermann grid illusion and eight more coarse shades for the scintillation effect. The subjects were asked to rate the "strength" of the illusory dark spots for each grid. Specifically, they were to use a rating scale on which a value of "1" would indicate no illusion, ratings of "2" to "4" would indicate an illusion that was

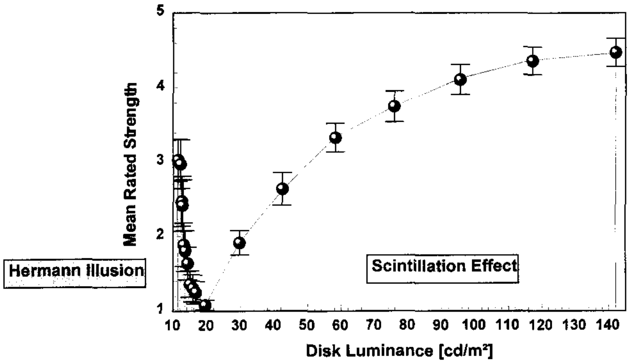


FIGURE 3. Mean rated strength of the Hermann grid illusion (descending branch on left) and the scintillation effect (ascending branch to the right) is plotted as a function of disk luminance. The maximum Hermann grid illusion (rating of 3) occurs when no disk is superimposed onto the intersections. Bar luminance, 11.5 cd/m^2; background luminance, 1.27 cd/m^2. The maximum scintillation effect (rating above 4) occurs when the luminance of the disk is a factor of 10 above that of the bars. The vertical bars indicate ± 1 standard error.

stronger (darker, or more numerous remained open, we did not attempt to avoid ratings based upon the perceived number of illusory spots rather than the perceived individual strength), and "5" would be allowed if the illusion they expected from a particular imagined grid was found to be optimal in a preliminary study for some subjects, including the authors. Following these general points the subjects were asked, according to the rating scale, to assign a number to the perceived illusory strength.

Disk luminances were varied randomly but separately for Hermann grid illusion and the scintillation effect. For each disk luminance three measurements were made consecutively. This procedure was adopted in all further experiments.

Results

Figure 3 shows the mean rated strength of the grey spots at the intersections. In effect, Fig. 3 is actually two figures: one shows the reduction in strength of the Hermann grid illusion as a function of increased disk luminance (left hand side, marked as "Hermann Illusion"), while the other depicts the increase in the strength of the scintillation effect (right-hand side, marked as "Scintillation Effect") with further increasing disk luminance.

Experiment 3: variation of bar luminance

To determine the effect of bar luminance, test stimuli were selected for a disk luminance that produced the maximal scintillation effect (Fig. 3) and a bar luminance that permitted a range of responses without encountering ceiling or floor effects. Thus, for a given luminance of the disks (142 cd/m^2) and the background (1.27 cd/m^2), we randomly presented bars with 12 different luminances ranging from 1.5 to 30 cd/m^2. The subjects and rating procedure were the same as in Experiment 2.

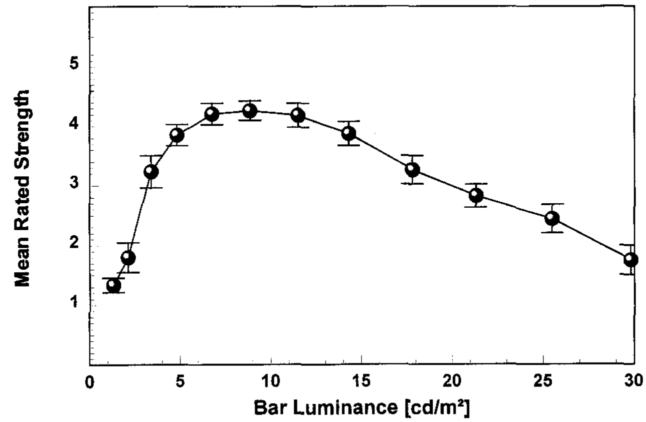


FIGURE 4. Mean rated strength of the scintillation effect is plotted as a function of bar luminance. Disk luminance, 142 cd/m^2; background luminance, 1.27 cd/m^2. The vertical bars indicate ± 1 standard error.

Results

Figure 4 shows the results. The mean rated strength of the scintillating spots first increases rapidly with increasing bar luminance up to a maximum rating of about 4, at which point bar luminances are approximately seven times greater than the background luminance. With a further increase of bar luminance the scintillation effect decreases.

Experiment 4: variation of background luminance

Conditions for a maximum scintillation effect determined in Experiments 2 and 3 (Figs 3 and 4) were used to study the effect of variation in background luminance. For a given luminance of the disks (142 cd/m^2) and the bars (11.5 cd/m^2), we randomly presented backgrounds with 11 different luminances ranging from 0.03 to 11.5 cd/m^2.

Results

Figure 5 shows the mean rated strength plotted as a function of background luminance. The curve decreases

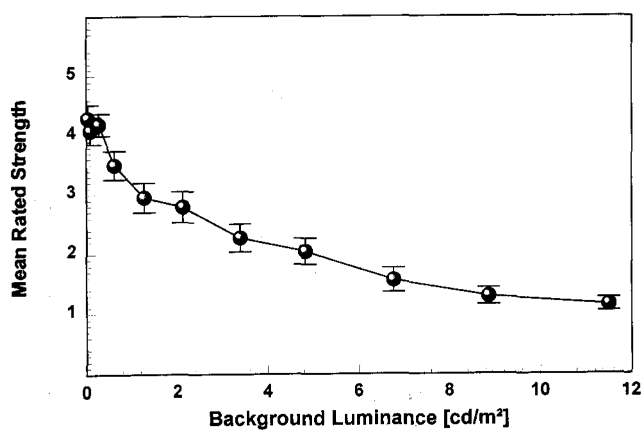


FIGURE 5. Mean rated strength of the scintillation effect is plotted as a function of background luminance. Disk luminance, 142 cd/m^2; bar luminance, 11.5 cd/m^2. The vertical bars indicate ± 1 standard error.

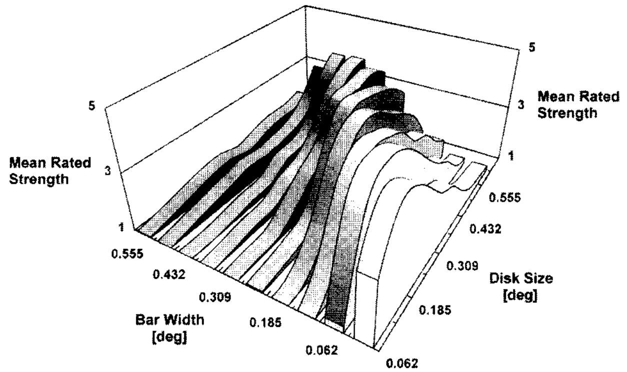


FIGURE 6. Mean rated strength of the scintillation effect is plotted as a function of disk size with bar width as parameter. Background luminance was 0.03 cd/m^2.

monotonically and reaches a magnitude of 1 (no effect) when the luminances of the background and bar are equal (i.e., no grid present). A pronounced scintillation effect is observed only with the lowest background luminances.

Experiment 5: variation of disk size and bar width

In this experiment the strength of the scintillation effect was measured as a function of the spatial parameters of the stimulus pattern. There were ten disk sizes (ranging from 0.06 to 0.6 deg) and ten bar widths (ranging from 0.06 to 0.6 deg), while background size was kept constant (1.54 deg). Disk luminance was 142 cd/m^2, bar luminance was 11.5 cd/m^2, and background luminance was 0.03 cd/m^2.

Results

Figure 6 shows that for a given bar width, the mean rated strength of the scintillation effect first increases with increasing disk size, reaches a peak and thereafter decreases. Rated strength is maximum when the ratio between disk size and bar width is approximately 1.4:1 (range 1.2:1 to 2:1). With increasing bar width, curves start out shallow indicating that the scintillation effect is virtually absent for disk sizes smaller than the bar. Within the range of bar widths used, a peak was reached only for the smaller widths.

SUMMARY OF RESULTS

The results obtained in this study show that the strength of the Hermann grid illusion varies with bar and background luminance (Fig. 2). For a given combination of bar and background luminances the Hermann grid illusion shifts over to the scintillation effect (Fig. 3). When the disk luminance was 12 times the background luminance, the intensity of the scintillation effect exceeded greatly that of the Hermann grid illusion. Furthermore, for combinations of disk and background luminance or disk and bar luminance, the scintillation effect could only be seen within a rather narrow range of stimulus parameters. The effect was strongest when the bar luminance was about seven times greater than the background luminance (Fig. 4) and when the background luminance was low (Fig. 5). At the same time, the ratio between disk size and bar width had to be about 1.4:1 (Fig. 6).

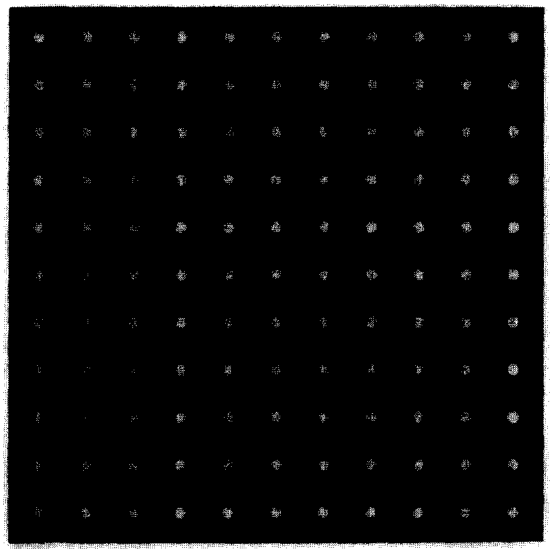
DISCUSSION

Our results indicate at least three prerequisites for the scintillation effect:

1. A grid capable of eliciting the perception of the classical Hermann grid illusion must be present.
2. Luminance increments or decrements which exceed those required to cancel the Hermann grid illusion must be superimposed on the intersections.
3. Stimulation must be brief. With steady fixation the scintillation effect subsides and quickly disappears. Voluntary scanning eye movements were used to produce brief stimulation. The question of whether such scanning eye movements are necessary or only sufficient remains open.

Concerning the first prerequisite, it might be suggested that the scintillation effect could be accounted for in terms of a Mexican hat model with single small concentric receptive fields producing more lateral inhibition at the crossings than anywhere else (Baumgartner, 1960, 1990). As stated above, a grid capable of producing the illusory spots of the Hermann grid is a prerequisite for the effect; hence lateral inhibition mechanisms are involved and obviously necessary but not sufficient. One could assume after examining Fig. 1 that an even larger concentric receptive field with a centre corresponding in size to that of a white disk and centred on one of them would be sufficient to account for the effect. This receptive field would have to possess a large surround encompassing neighbouring disks. On the basis of such a model, one would expect the scintillation effect to be present in Figs 7(a, b). This is not the case, as can be seen by comparing Figs 1 and 7. Both fulfil the requirements of such a receptive field, but the scintillation effect is observed only in Fig. 1, where the disks are superimposed on the intersections. Preliminary observations suggest that a minimum of 3×3 evenly spaced intersections with superimposed spots is required to produce the effect. Thus, a model which fails to take into account the distribution of the disks in relation to the intersections is not sufficient. A more complex receptive field responsive to this distribution as well as to eye movements and sensitive to orientation would be required. Furthermore, since a minimum of elements is required—the illusion does not occur with an isolated intersection, as in the case of the Hermann grid (Wolfe, 1984)—the effect does not fit in well with a model involving purely "local" inhibitory and excitatory interactions. The requirement of a minimum number of orderly arranged elements suggests the participation of global, in addition to local, processes.

Von der Heydt *et al.* (1991) found cells in areas V1 and V2 in the monkey which responded to gratings and other periodic patterns but not to single bars and edges. They a)



b)

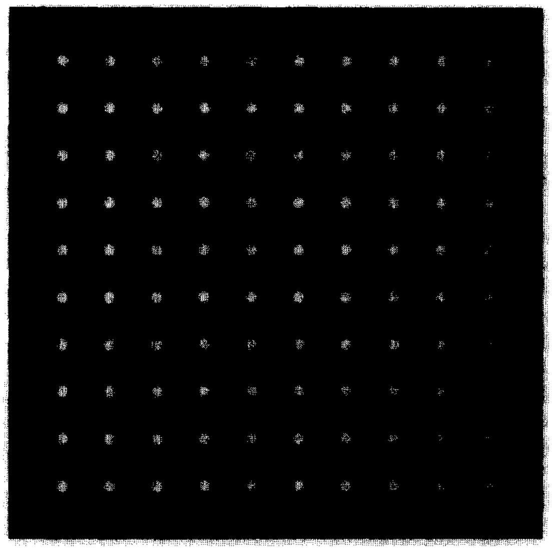


FIGURE 7. The scintillation effect becomes weak or even absent in some spatial variations.

regarded their observations as being incompatible with linear filter mechanisms. These properties are compatible with our observation that a periodic pattern is required for the scintillation effect: multiple, evenly spaced disks located at corresponding intersections. Furthermore this observation may indicate an involvement of global cortical mechanisms of the kind proposed for the linking and grouping of features across distance (Eckhorn, 1991). Eckhorn *et al.* (1992) regard the "linking field" as enabling the receptive field properties of neurones in different parts of the visual field to be linked into perceptual wholes. An interesting property of such linking fields is that they are transiently constructed by the neurones involved in the co-operative process. This property fits in nicely with the scintillating character of the illusion. The considerations of Spillmann and Ehrenstein (1996) of global processes in relation to the neuronal basis of Gestalt phenomena also agree well with this line of reasoning.

We have not as yet systematically investigated the influence of temporal factors on the illusion. Brief exposures of the Hermann grid in the dark adapted eye eliminate the dark spots (Wist, 1976). If the temporal, as well as the spatial conditions for producing the Hermann grid illusion are necessary requirements for the scintillation effect, then dark adaptation should eliminate it as well. Furthermore, it must be determined whether the effect of scanning eye movements reduces the necessity of stimulating receptive fields briefly. Preliminary experiments in which the effect of slow pursuit eye movements were investigated indicate a weaker scintillation effect as compared to saccadic eye movements. In this context, saccadic omission or suppression (Campbell & Wurtz, 1978; Corfield *et al.*, 1978) may also play a role.

Furthermore, neurophysiological experiments extending the work of Schepelmann *et al.* (1967) on the Hermann grid to the scintillation effect could provide more concrete information concerning the nature of the underlying receptive field organization. Using a Hermann grid, they recorded from single visual cortical cells in the cat, whose firing rate was reduced when stimulated simultaneously with horizontal and vertical bars, as opposed to stimulation with either bar alone. They interpreted this decrease in firing rate as the neural correlate of the darkening at the intersection. If the receptive field characteristics required for the scintillation effect are similar to those of the Hermann grid illusion, then the positioning of a disk at the intersections whose luminance is at least twice that of the bars should result in an even greater reduction of firing rate. The prediction based on the results of the present experiments would be that this would not occur, since only local processing would be involved.

CONCLUSION

The fact that stimulus conditions resulting in the Hermann grid illusion are necessary but not sufficient for producing the scintillation effect implies that a neurophysiological account of it must go beyond one based on lateral inhibition within single receptive fields. Both the conditions necessary for producing the scintillation effect beyond those required for the Hermann grid and its unique perceptual quality justify regarding it as a separate perceptual phenomenon.

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