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Foveal Perceptive Fields in the Human Visual System Measured with Simultaneous Contrast in Grids and Bars *

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Summary. Foveal perceptive fields (center plus surround) for human vision were investigated by means of contrast illusions in grids and bars. The task consisted of determining the size of the retinal area within which photic stimulation of the periphery induces apparent brightness changes of the central portions. The mean of the individual thresholds obtained in four experiments suggests a total field diameter of 17.8 min of arc (with an estimated 4.0′ corresponding to the center) for on- and off-center fields. It is assumed that this average value refers to perceptive fields of retinal ganglion cells. The significance of eye movements and after-images in contrast vision and their possible influence on these measurements is discussed.

Key-Words: Perceptive Field Estimation — Hermann Grid Illusion — Inner Contrast in Bars.

Zusammenfassung. Foveale perceptive Felder (Zentrum und Randzone) für menschliche Wahrnehmung wurden mit Kontrasttäuschungen in Gittern und Balken untersucht. Dabei wurde die Größe des retinalen Areals bestimmt, innerhalb dessen Lichtreizung in der Peripherie eine anschauliche Helligkeitsänderung im Zentrum hervorruft. Der Durchschnittswert der in 4 Experimenten erhaltenen Einzelschwellen läßt einen Gesamtdurchmesser von 17,8 Bogenminuten für on- and off-Zentrumfelder vermuten (mit einem Anteil von ungefähr 4,0′ für das Zentrum allein). Es wird angenommen, daß dieser Wert sich auf perceptive Felder retinaler Neurone bezieht. Die Bedeutung von Augenbewegungen und Nachbildern für das Kontrastsehen und ihr möglicher Einfluß auf diese Messungen wird besprochen.

Schlüsselwörter: Perceptive Feldschätzung — Hermann Gittertäuschung — Binnenkontrast in Balken.

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I. Introduction

This paper attempts to determine the size of foveal perceptive fields[1] in man. For more than 80 years spatial interaction in the human visual system has been investigated by varying stimulus size, adapting field size, area of inducing field, distance between test field and inducing field, and distance between multiple inducing fields. In general, psychophysical studies (summarized by Tschermak, 1929; Pirenne and Marriott, 1959; Brown and Mueller, 1965) showed increment threshold and apparent brightness dependent on these parameters in a direction suggesting a simple excitation—inhibition—disinhibition model. Results for a variety of experimental conditions were interpreted in terms of physiological summation and inhibition within a "visual unit". Its size was inferred from critical values of test field, adapting field, and interstimulus distance for both types of nervous interaction, and the estimated diameters were shown to increase with retinal eccentricity (Hallett, 1963).

Enlargement of perceptive fields, or of the extent of functional couvergence, towards the periphery of the retina was also found with such heterogeneous procedures as simultaneous contrast, flicker interaction, apparent motion, and ocular pursuit movement (Kornhuber and Spillmann, 1964; Spillmann, 1964; Jung and Spillmann, 1970). Especially striking in these results was the quantitative agreement between the optimal width of two intersecting bars, required for eliciting the Hermann grid phenomenon in various retinal regions, and the size of receptive field centers, recorded from optic nerve fibers in the spider monkey (Hubel and Wiesel, 1960). Subsequent experiments using brightness matches in sinusoidal gratings (Bryngdahl, 1964, 1966), and measurements of increment thresholds (Glezer, 1965) confirmed and complemented these findings. The close correspondence between measurements of neuronal field centers and their possible psychophysical equivalents prompted a further use of the grid illusion, this time as an index response for estimating the size of human perceptive fields.

II. The Measurement of Perceptive Field Size with Grids

1. Experiment

In 1960, Baumgartner suggested a neurophysiological explanation for the occurrence of a dark (light) spot at the intersection of white (black) bars crossing each other on a dark (light) background. According to Baumgartner's hypothesis this effect, first described by Hermann (1870), can be attributed to different amounts of lateral inhibition (or excita-

1 As a substitute for "visual unit", the term "perceptive field" was adopted by Jung and Spillmann (1970) to denote the psychophysical correlate of a "receptive field".

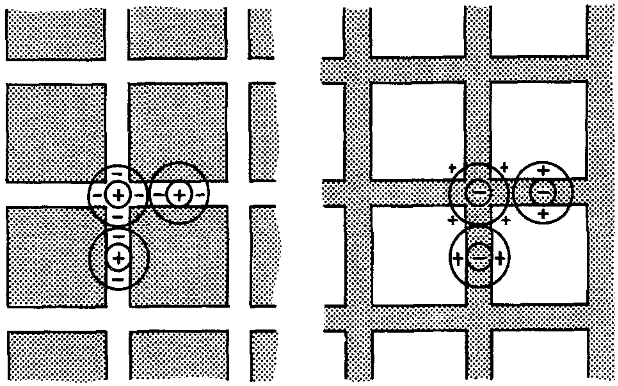

Fig. 1. The two standard versions of the Hermann grid, schematically: dark spots occur at the intersections of the white bars, light ones at the intersections of the black bars. Concentric circles illustrate how receptive fields with excitatory (on-) centers and inhibitory (off-) surrounds, and off-centers with on-surrounds might be illuminated in different positions relative to the patterns in order to account for the illusory effects. It is assumed that the illusion is strongest when the bar width resembles the size of the perceptive field center. Under these conditions the total excitation of neurons "looking" at intersections is about half as much as in neurons stimulated by bars (after Baumgartner, 1960a)

tion) in neurons "looking" at an intersection or a bar, respectively. An on-unit whose perceptive field center coincides with an intersection receives about twice as much inhibition from the intersecting bars (an off-unit half as much excitation from the surrounding squares) as a unit whose perceptive field center is located on a single bar (Fig. 1). Consequently, neurons with field centers on the intersection would signal "darker" in a white grid and "lighter" in a black grid, thus producing the illusion.

Assuming that the phenomenon is strongest if the angular width of the intersecting bars is about the size of the perceptive field center, Baumgartner (1960b) obtained an estimated diameter of 4—5 min of arc (25 μ) for foveal field centers in man. The task of the present study was to measure the size of the whole perceptive field, i.e., center *plus* surround. This was attempted by using three different sets of grids (Fig. 2a).

The first series (A) represents intersections of the original Hermann grid type consisting of white bars only; the second series (B) is made from dark gray bars crossing white ones, and the third series (C) (adopted from Prandtl, 1927 and Ehrenstein, 1954) is comparable with series A, except for the intersections, which are omitted (central gaps). All patterns

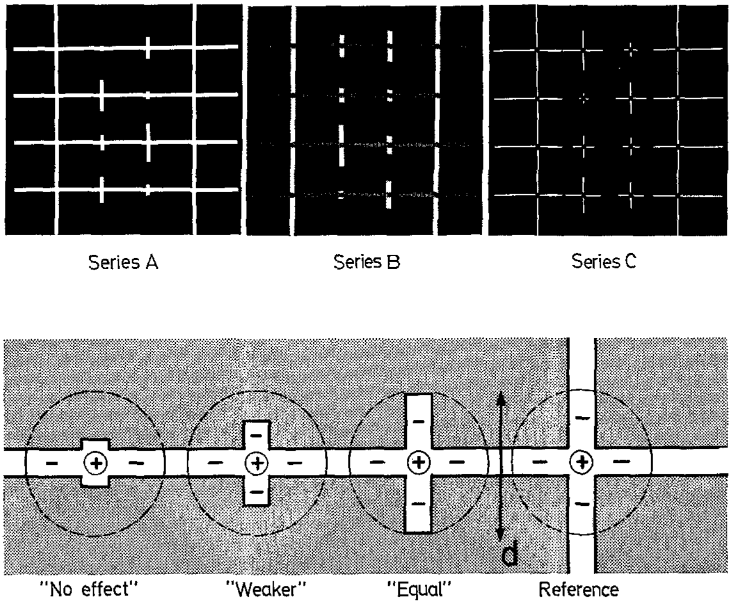

Fig. 2. Examples of modified Hermann grids used in Experiment 1. (a) By most observers, diffuse patches of darkness are reported at the crossings. Each of the "experimental" intersections (with shortened bars) was compared with the nearest "standard" intersection (above, below, left, right) as a reference. Note that for very short bar extensions, no darkening effect shows up at all and that a certain critical bar length is required to produce the maximum illusion. (b) The gradual build-up of the darkening with bar length can be accounted for by a relative increase of lateral inhibition (activation) in receptive fields centered at the intersection over those illuminated primarily by bars. It is assumed that the illusion reaches a maximum when the bars on the retina extend just beyond the inhibitory (excitatory) surround. With central fixation this critical length may resemble the diameter (d) of a foveal perceptive field (center plus surround)

stand against a black background and for most observers exhibit dark spots of different degrees of intensity where horizontal and vertical bars meet. These illusions are tentatively explained by analogy to the Hermann grid effect in Fig. 1. An alternative explanation for series C based on elongated (direction-specific) rather than circular perceptive fields is offered by Jung and Spillmann (1970) and Popp (1970).

By systematically increasing the length of the bars at an A, B, or C type intersection, the darkening should slowly build up, become stronger, and reach a maximum. The largest retinal area within which "lateral" inhibition or activation (from the bar extensions) influences the apparent brightness of its center (intersection) is taken as an indirect measure of the perceptive field size (Fig. 2b). It is implied that series A refers to on-center fields, series B and C to off-center fields.

Method

Each of the three series consisted of four grids which were projected onto a translucent screen from behind. In each grid eight "standard" intersections were provided as reference for eight "experimental" intersections, whose bar extensions (two in series A and B, four in series C) had been symmetrically shortened to various lengths in a random arrangement (Fig. 2a). A total of sixteen experimental bars was chosen and used as contrast stimuli four times each, two times in horizontal and two times in vertical orientation. Their angular length ranged from 5.3′ to 36.8′ in series A, from 5.2′ to 36.4′ in series B, and from 5.0′ to 26.9′ in series C. The bars in series A and B as well as the central gaps in series C were 4.0′ wide whereas the stripes in series C subtended 1.3′.

The observer sat in a dental chair at a distance of 150 cm from the screen. All observations were made binocularly in a normally illuminated room. At the beginning of every session, a regular Hermann grid was shown for demonstration. Then the various modified grids were presented. The subject (*S*) fixated briefly each of the experimental intersections in order to find out whether a dark patch was present for foveal viewing. In case of a "yes" answer, the extent of the darkening was estimated by rapid cross-comparison with the effect in the corresponding standard intersection (directly above, below, to the left or right). For this purpose, "weaker", "equal", and "stronger" were offered as response categories. Although one minute was allotted for each intersection, the *S*s on the average used less than 10 sec for their reports.

Ten naive undergraduates having 20/20 uncorrected vision or better and no significant astigmatism served as paid observers in this and the following three experiments with about two weeks between sessions. Due to the end of the term, three *S*s could not finish the task. Seven *S*s ($n = 28$) were tested in series A, ten *S*s ($n = 40$) in series B, and seven *S*s ($n = 28$) in series C. To obtain "n", the number of observers has to be multiplied with the number of presentations for each intersection.

Results

In Fig. 3 the relative frequencies of occurrence of the three response categories are plotted against the total length of a pair of bar extensions including the intersection. The curves cross each other twice at the 50% level. The first transition (from "no effect" to "weaker than reference") occurs at 10.6′ in series A, at 7.4′ in series B, and at 10.5′ in series C. It indicates the average angular bar length required to produce a just noticeable darkening at the intersection. The second transition (from "weaker" to "equal with reference") is found at 19.6′ for series A, at 16.7′ for series B, and at 17.1′ for series C. It marks the average total length at which the illusion reaches its maximum, i. e., the darkening effects in experimental and standard intersection become indistinguishable. There were no differences between threshold values for horizontal or vertical and first or second presentation. No "stronger" responses were given.

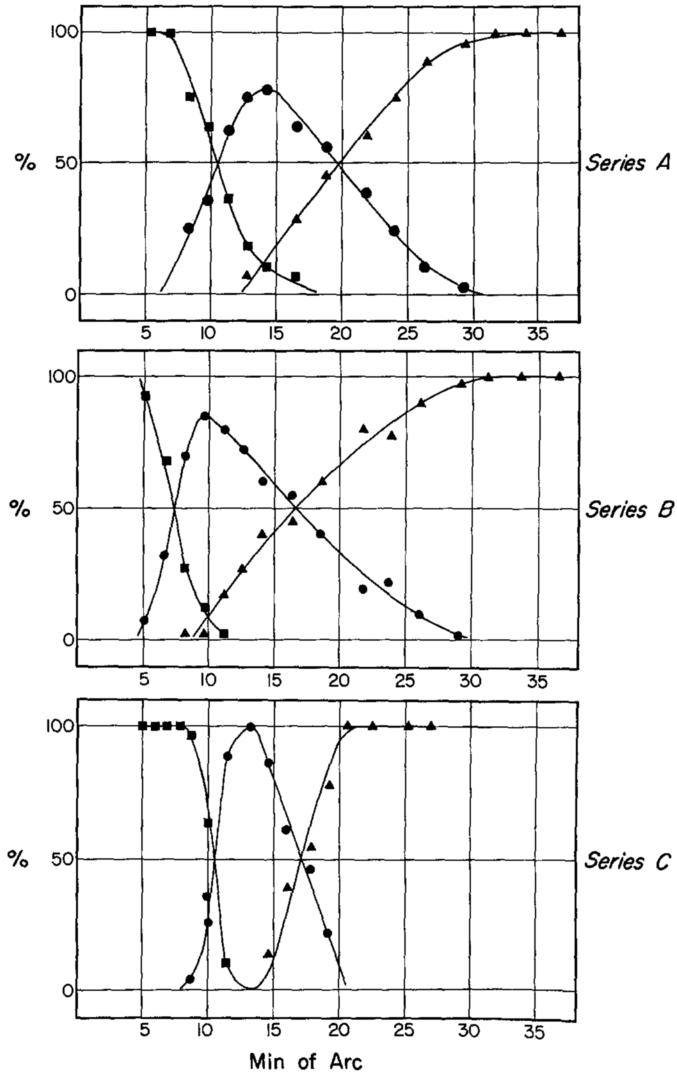

Fig. 3. Percentage distribution of responses for series A ($n = 28$), B ($n = 40$), and C ($n = 28$) as a function of total bar length. The first intersection of the curves at the 50% level (squares and circles) indicates the minimal angular length of a pair of bar extensions necessary to produce a just noticeable darkening effect. The second intersection at the 50% level (circles and triangles) marks the threshold at which the grid illusion reaches a maximum. This length is considered equivalent to the diameter of a foveal perceptive field

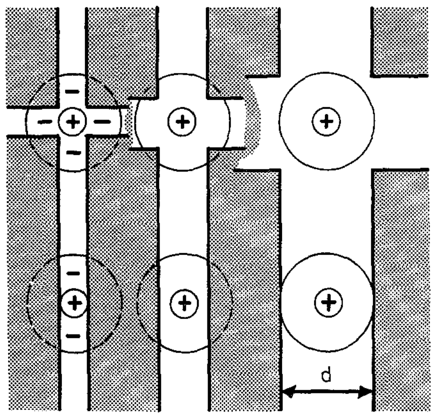

Fig. 4. The Hermann grid effect weakens and finally disappears when the retinal image of the intersection is either too small or too large with respect to the perceptive field center. The reduction of the effect with greater than optimal bar widths is attributed to the decreasing difference in lateral inhibition between perceptive field centers illuminated by bar or intersection, respectively. The illusory effect is assumed to disappear when the amount of inhibition in both fields becomes equal. With central fixation the angular size of the intersection for which the darkening is cancelled may resemble the diameter (d) of a foveal perceptive field (including surround)

2. *Experiment*

For a given intersection, the Hermann grid phenomenon is not restricted to a well defined retinal image size, but instead can be seen over a considerable range of observation distances. However, in comparison with the optimal bar width for which the illusion is strongest, the darkening becomes noticeably weaker when the retinal size of the intersection is either increased or decreased (Baumgartner, 1960b). Neurophysiologically the firing rates of neurons with field centers at intersection or bar, respectively, should become equal and signal identical brightnesses when the intersecting bars approach the perceptive field diameter (Fig. 4). Thus, the upper angular width at which the darkening effect reaches a minimum (rather than a maximum as in Experiment 1) may represent another indirect measure of perceptive field size (Spillmann, 1964).

Actually, the gradual disappearance of the Hermann grid effect with increasing bar width coincides with the emergence of a different phenomenon. In series A a grayish cross (Prandtl, 1927; Hassenstein, 1965) is formed by the inner contrast bands within the horizontal and vertical bar (Experiment 3). In series C a grayish diagonal X can be seen centered within the gap and extending diagonally into the space between adjacent bar segments. The transition from the circular patch confined within the intersection or gap to the well defined cross or X was taken as threshold.

Method

A standard intersection of series A and C was projected on a screen under the same conditions used previously, and observed with central fixation. Beginning at an optimal distance, the *S*, in a roller chair, was slowly moved first toward and then away from the screen, and distances at which the Hermann grid illusion disappeared and reappeared were determined[2]. Six students selected as before served as observers.

Results

For each intersection the two ascending and descending thresholds were pooled and averages ($n = 12$) were obtained. The shortest distance of the eye from the screen for which the Hermann grid effect just disappears (or reappears) corresponds to an angular bar with of 18.7′ for series A and 17.6′ for series C.

III. The Measurement of Perceptive Field Size with Bars

3. Experiment

In this experiment, indirect measurements of the perceptive field size were attempted by observing inner contrast in bars. The term "inner contrast" refers to the occurrence of a subjectively darker (lighter) canal in white (black) bars of a certain width. This contrast stripe running along the midline of the bar is usually accompanied by enhanced edges on either side ("border" or "boundary contrast"). Recordings from single units in the cat during contrast stimulation (Baumgartner, 1960a; Baumgartner and Hakas, 1962) suggest that inner contrast is based on different amounts of lateral excitation (or inhibition) in neurons whose field centers are illuminated by central or peripheral portions of the bar.

Consequently, one would not expect any inner contrast for bars that are not least the size of a perceptive field center. With increasing width, however, inner contrast should build up in strength and become most distinct when the difference in firing rates of neurons "looking" at the midline or the edge of the bar, respectively, reaches a maximum. This situation occurs when the bar width on the retina is about the size of the perceptive field diameter (Fig. 5).

Preliminary estimations of this threshold evoked judgments falling onto such phenomenal scales as "brigthness" (lighter—darker), "sharp-

2 To keep the figure-ground contrast constant, and also to make this experiment more comparable with Exp. 1, 3 and 4, these measurements should have been repeated with a fixed observation distance using the method of constant stimuli (c.*f*. Sindermann and Deeke, 1970).

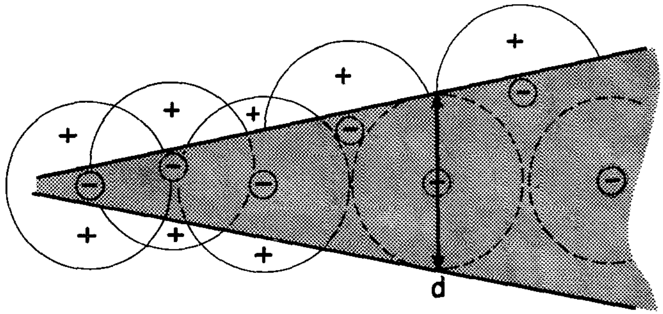

Fig. 5. The concentric circles illustrate how perceptive fields with inhibitory centers and excitatory surrounds might be illuminated by a black stripe of variable width to produce inner contrast (of the central areas) and border contrast (along the edges). Both types of contrast are attributed to a difference in lateral activation of units whose field centers are located on the central or peripheral portion of the stripe, respectively. Inner contrast increases with bar width. It is supposed to be strongest when the surround illumination for fields centered along the midline of the bar reaches a minimum. With central fixation this critical bar width on the retina may resemble the diameter (d) of a foveal perceptive field

ness and clarity" (well defined—fuzzy), "distinctness" (steep—flat gradient), "fluctuation" (stable—labile), "latency" (easy—difficult to perceive). The first two of these response categories were apparently used by Sindermann and Pieper (1965). In the present study latency and total time of occurrence were selected as possible criteria of perceptive field size.

Method

Twenty black vertical bars on a light background (series D) were projected successively under the conditions described in Experiment 1. Bars ranged in width from 2.1′ to 22.5′ and were 2.1° long. They were presented once in random sequence. Fixation was at a small light spot in the center of each bar formed by a tiny pinhole in the slide.

Occurrence and disappearance of inner contrast were signalled by pressing and releasing a telegraph key connected to an event marker (Gerbrands, Pol 6). The criterion used for inner contrast was non-uniformity across the bar, i.e., a lighter band in the middle surrounded by darker edges. Latency was defined as the lapse in time between stimulus onset and the first recorded appearance of inner contrast. Following an initial practice period, bars were exposed at a rate of one every minute, each observation period lasting 15 sec. Ten students from the previous grid experiments served as observers.

Results

In Fig. 6 average latency and average time of appearance of inner contrast (as a percentage of total exposure time) are plotted as a function of bar width. Latency decreases and time of appearance increases as bars

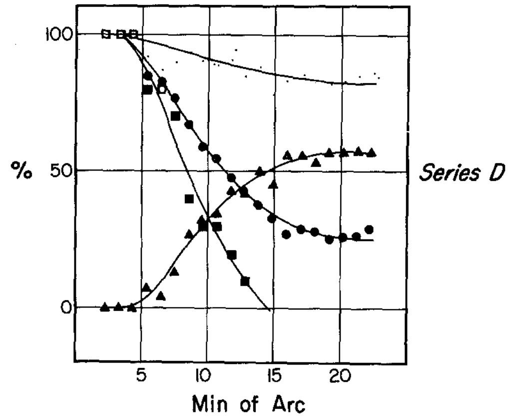

Fig. 6. Average latency (circles) in percent and average time of contrast appearance (triangles) during a total observation period of 15 sec plotted against bar width. It is assumed that the two curves become asymptotic when the bar width is equivalent to the diameter of a perceptive field. Top curve (dots) indicates fading time. The fourth curve (squares) represents the percentage distribution of the observers ($n = 10$) who failed to see inner contrast in narrow stripes

get wider. Both curves level off at about 17.0′. With increasing bar width, short periods of fading are experienced during the perception of inner contrast. No contrast is seen by $50^0/_0$ of the observers ($n = 10$) until the bar width exceeds 8.3′.

4. Experiment

For obtaining additional data on the size of perceptive fields another series (E) was devised that shows inner contrast in a much more pronounced manner than series D. The pattern was similar to series B (Experiment 1) and consisted of vertical gray bars of various widths crossing a horizontal white stripe on a black background (Fig. 7). Depending on bar width, naive observers reported 3 classes of distinct phenomena under these conditions: (a) a dark "streak" closing the gap between the two opposing ends of the white strip; (b) an apparent connection of the same type but lighter and narrower in the middle, like a "double cone" or a "streak with a waist"; (c) no connection, just short dark "stubs" around the white edges with a clear separation between them.

These effects may be explained by analogy to inner and border contrast in Fig. 5. Apparent closure by a dark streak may be attributed to off-center neurons with field centers in the middle of the gap receiving lateral activation from both sides of the white horizontal stripe. As soon as the size of the gap extends beyond the perceptive field boundaries,

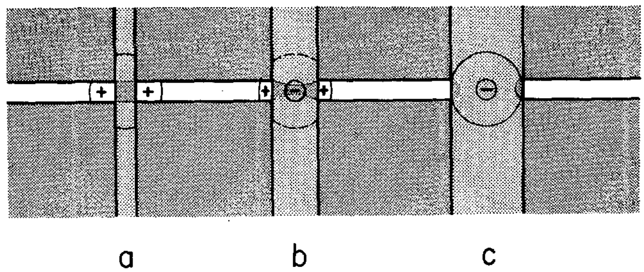

Fig. 7. Depending on bar width, three phenomena can be seen in the gap between the two opposing ends of the white horizontal stripe: (1) A dark band across the gray vertical bar. (2) A dark streak becoming narrower and lighter toward the middle. (3) Short dark stubs around the edges of the white stripe. This last phenomenon represents the spatial distribution of border and inner contrast. By analogy to the model in Fig. 5, it is assumed that the retinal width of the narrowest bar for which apparent closure breaks up resembles the diameter of a foveal perceptive field

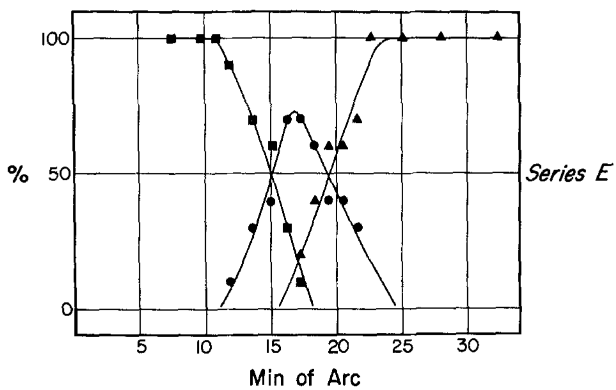

Fig. 8. Relative frequency ($n = 8$) of "closure", partial closure" and "no closure" plotted against bar width. The 50% threshold for curves 1 and 2 (squares and circles) marks the first occurrence of inner contrast. The intersection of curves 2 and 3 (circles and triangles) indicates the threshold at which inner contrast reaches a maximum. This bar width is considered equivalent to the diameter of a foveal perceptive field

lateral interaction for these units becomes a minimum. The result is a shift toward "lighter" that causes the dark connection to break apart leaving a gap with stubs on either side. The width of the gray bar for which this transition occurs is taken as a measure of perceptive field diameter.

Method

Sixteen vertical gray bars crossing a white horizontal stripe on a dark background were presented under the conditions employed previously. Bar width ranged from 7.5′ to 32.3′; bar length was 2.1°; the white stripe subtended 4.0′. The intersections were presented once in random order. Fixation was in the middle of the gap between the two opposite halves of the horizontal stripe. First the *S*s were familiarized with the various illusory effects. Then each intersection was exposed for 2 sec in 1 min intervals. The observations were scored in terms of the three categories listed above. Eight students participated as observers.

Results

In Fig. 8 the relative response frequency ($n = 8$) is plotted for each phenomenon as a function of bar width. Curves 1 and 2 (transition from closure to partial closure) intersect at the 50% level and suggest a threshold width of 15′ as just sufficient for the appearance of inner contrast. The intersection of curves 2 and 3 (transition from partial closure to no closure) indicates that a maximum is reached at 19.3′ bar width.

IV. Discussion

The threshold values from Experiments 1—4 are summarized in the Table. Averaging them again in proportion to the number of observations in each experiment yields a weighted grand mean of 17.8′. This mean value may be considered a psychophysical estimate of the average perceptive field size in the human fovea. It represents a field center of 4.0′ in diameter surrounded by a concentric zone of 6.9′ in witdh. Perceptive fields with on- and off-properties in man seem to have similar diameters as have on- and off-field centers in the monkey (Hubel and Wiesel, 1960; Bryngdahl, 1964; Spillmann, 1964).

Apparently there is no systematic study of foveal receptive field size in animals. Histological measurements of dendritic fields (Honrubia and Elliott, 1970) and recordings from ganglion cells in the area centralis of the cat (Stone and Fabian, 1966) indicate diameters of up to 1.5°. Only the C-type fields ranging from 22′ to 30′ are in the same order of magnitude as the psychophysical estimates obtained in the present study. In humans, Ronchi and Salvi (1965) obtained a field diameter of 20′ to 25′ using a reduced Hermann grid. Sindermann and Pieper (1965) referring to inner contrast in bars reported an average field size of only 7′ to 10′. This latter threshold is similar to the bar width (8.3 min) in Experiment 3 that elicited contrast in 50% of the observers. Remole (1970) gives a minimum of 30′, a value that increases when the bar is presented intermittently.

Results obtained with other procedures and different experimental parameters fall into the same general range. With spatial summation Kincaid, Blackwell and Kristofferson (1960) arrived at a field diameter of 15′ to 30′ for a foveal "element". Using increment thresholds against backgrounds of different size Westheimer (1967) and Enoch and Sunga (1970) found diameters of 5′ to 7′ for the center and 10′ to 17′ for center plus surround. Cutrona and Richards (1969) with a similar technique quoted values of 6′ and 20′, respectively. In order to explain Mach bands on the basis of brightness matches, von Békésy (1960) proposed 1.5′ for the inner and 26.3′ for the outer diameter of a "neural unit". From increment threshold measurements by Fiorentini and associates, Ronchi (1962) derived a total field diameters of 24′.

Table. *Average threshold values (in min of arc) for: minimum length of bar extensions producing the optimal Hermann grid effect (Exp. 1); maximum width of an intersection causing the grid effect to disappear (Exp. 2); minimum bar width eliciting inner contrast with shortest latency and longest total time of appearance (Exp. 3); minimum bar width for producing strongest inner contrast. An asterisk indicates a 50% threshold criterion. All Ss belong to the same group*

Stimulus pattern	*S*s	*N*	Average threshold	Perceptive field type	Method
Exp. 1					
Series A	7	28	19.6′*	on-center	constant stimuli
Series B	10	40	16.7′*	off-center	constant stimuli
Series C	7	28	17.1′*	off-center	constant stimuli
Exp. 2					
Series A	6	12	18.7′	on-center	ascending and
Series C	6	12	17.6′	off-center	descending limits
Exp. 3					
Series D					
Latency	10	10	17.0′	off-center	constant stimuli
Appearance	10	10	17.0′	off-center	constant stimuli
Exp. 4					
Series E	8	8	19.3′*	off-center	constant stimuli
Grand Mean:		150	17.8′		

Weighting functions expressing the excitatory and inhibitory effects of inducing fields (Thomas, 1968; Thomas, Rourke and Wilder, 1968) led to approximate values of 8′ and 25′. Spatial interaction between line stimuli yielded estimates of 2′ and 20′ for center and field (Fiorentini and Mazzantini, 1966).

Spatial thresholds of about the same magnitude appear to be relevant also in experiments on assimilation and contrast, masking and metacontrast, and figural aftereffects. None of the above values, however, takes into account the line-spread function of the human eye during involuntary movements, and only Westheimer's and Bryngdahl's approaches were validated with stabilized retinal images (Teller, Andrews and Barlow, 1966; Gilbert and Fender, 1969).

In contrast to neurophysiological recordings from individual units, psychophysical methods presumably test many perceptive fields which overlap each other. Any interpretation of such measurements therefore implies that the single neuron model holds also for populations of perceptive fields (Jung and Spillmann, 1970). From the data nothing can be said about suggested size differences within such clusters (Sindermann and Deeke, 1970) nor about disinhibitory zones surrounding excitatory and inhibitory areas (Ronchi and Bottai, 1964; Ronchi and Salvi, 1965; Cutrona and Richards, 1969).

The neurons of the perceptive fields determined in this study are likely to be located in the retina. Neurophysiological findings on simul-

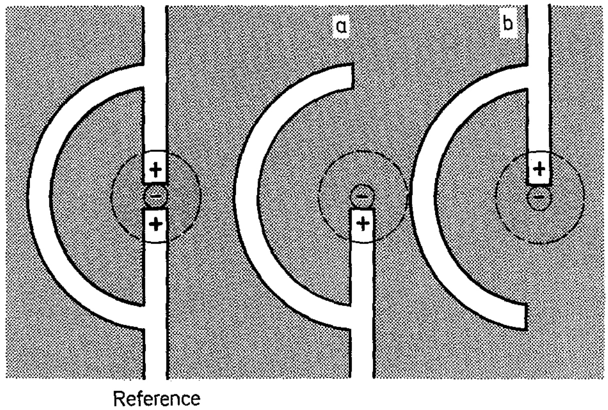

Fig. 9. Confined within the gap between the two vertical bars, a dark patch can be seen mono- and binocularly. Only a small effect, however, is present, if components a and b are presented interocularly, even though the resulting pattern appears as a stable whole. This suggests that the neurons of the perceptive fields responsible for the illusion are located at the retinal level

taneous contrast in *Limulus* (Ratliff and Hartline, 1959), carp (Motokawa, Yamashita and Ogawa, 1961), cat (Baumgartner and Hakas, 1962; Enroth-Cugell and Robson, 1966) and electrophysiological results in man (Motokawa, 1950) demonstrate that simultaneous contrast can occur already at the retinal level. However, a cortical modification of the neuronal pattern by orientation-specific line detectors is conceivable. Enhancement of bars relative to intersections has been reported both for retinal and geniculate ganglion cells. But in "simple" field neurons of area 17 a comparable response increase was restricted to bars and grids orientated parallel to the field axis (Schepelmann, Aschayeri and Baumgartner, 1967). A retinal origin of contrast might explain why neither a convincing Hermann illusion (Julesz, 1965; also Fig. 9) nor changes in increment thresholds (Novak, 1967; Westheimer, 1967) can be observed with interocular stimulation. A cortical contribution in turn may perhaps account for the orientation-specific appearance of the grid effect mentioned below. It should be noted that the limiting spatial disparity for depth vision (Panum's area; Hommer and Schubert, 1963) is about the size of the perceptive field center in the present study, whereas the critical distance for interocular contour interaction (Bottai and Salvi, 1964) is of the same order of magnitude as the total field diameter.

Various workers (Tschermak, 1929; Verheyen, 1961; Rein and Schneider, 1964; Sindermann and Pieper, 1965) have pointed out that the Hermann grid effect as well as inner and border contrast in bars may be partially or entirely accounted for by eye movements and successive contrast. Frequent retinal image shifts within a circle of about 20′ diameter (Ditchburn and Ginsborg, 1953) would prevent local adaptation or "fatigue" in the neighborhood of contours, but not in extended areas between them. As a result borders along luminance steps would be enhanced. This is particularly obvious in the presence of negative afterimages when displaced with respect to the primary stimulus.

It appears that a relative depression of the intersection could produce the brightness changes observed in series A, D and E. However, the argument hardly holds for series B and C for which a lightening should occur. Attempts to show that the contrast illusions used in this study can originate also under quasi-stationary conditions and in the absence of afterimages include the following observations. (1) The Hermann effect exists in grids stabilized on the retina (Spillmann and Kolers, unpublished data). This finding agrees with a result by Riggs, Ratliff and Keesey (1961) that for Mach bands eye movements have only a sustaining but no constituent function. (2) Under free observation the grid illusion can be seen immediately (as the reader can easily confirm). Tachistoscopically it shows up for exposure times shorter than 5 msec (confirmed by Popp, 1970). Similar stimulus durations were found to be sufficient for the occurrence of Mach bands (Davidson and Cornsweet, 1964; Thomas, 1965). (3) The Hermann grid phenomenon persists on a rotating pattern whose peripheral intersections continuously stimulate different parts of the retina. (4) Neurophysiological enhancement in bars and grids comparable to perceived brightness differences is found in cats with immobilized eye muscles (Baumgartner, 1960a; Schepelmann *et al.*, 1967).

Proponents of the eye movement and afterimage hypothesis are left to explain these observations: why the critical lengths and widths yielding maximum contrast in grids and bars is 2 to 3 times the average amplitude of involuntary saccadic eye movements (Ratliff and Riggs, 1950); why the retinal projection of the intersection has to increase up to about 3° in order to produce an illusion in the far periphery of the visual field (Spillmann, 1964); why the darkening in series C patterns (Experiment 1) disappears when surrounded by a thin ring (Ehrenstein, 1954; Jung and Spillmann, 1970), and why it does appear—delineated by "Brueckenlinien"—when the opposing bar segments are reduced to double (Popp, 1966) or even single lines (Ehrenstein, 1954). The neurophysiological model in turn is challenged by the question of why the latency of appearance for inner contrast (Experiment 3) depends on bar width; why the grid phenomenon is reduced in diagonally oriented patterns (Prandtl, 1929; Popp, 1966); and why it fails to show up in the afterimage following an intense flash.

Both the receptive field organization and the eye movement hypothesis may account for one or more of these phenomena: the grayish diagonal cross (Jung and Spillmann, 1970) that is responsible for apparent spider webs (Prandtl, 1927) in series C and related patterns; the flares in series A grids extending from the end of the bars out into the uniform surrounding area; the various shapes of the illusion (Popp, 1966) and the diamond-like spread of retinal induction at the intersection (Motokawa, 1950).

Uncertain is the significance of a recent dispute (Cornsweet and Teller, 1965; Matthews, 1966; Sparrock, 1969) over the absence of predicted threshold increments (Novak and Sperling, 1963; Burkhard, 1966; Westheimer, 1967; Frumkes and Sturr, 1968) or reaction time changes (Payne and Anderson, 1969a, b) in the vicinity of contrast borders. Small threshold alterations reflecting the brightness enhancement at the intersection of a grid (Monjé, 1955) or across a black bar (Harms and Aulhorn, 1955) may fail to occur when tested with the stabilized image technique (Teller, 1968). Since neither eye movements nor after images were controlled in the above experiments, the data may be subject to a similar criticism (Teller, 1965). Their interpretation, therefore, must be considered tentative.

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