Attention, brightness contrast, and assimilation: The influence of relative area*

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A model of information transmission in the visual system which describes the effect of attention on apparent brightness is examined. This model states in part that the luminance of the portion of the visual field which captures the attention is overweighted in arriving at an overall average luminance level across the visual field. As this average must be computed with respect to both luminance and relative area, it is hypothesized that increasing the relative area of the portion of the visual field that captures the attention will result in a greater effect on the apparent brightness of all parts of the visual field. Two predictions, which involve the effect of relative area on apparent brightness, are experimentally tested and confirmed.

Festinger, Coren, and Rivers (1970) have recently proposed a model of information transmission in the visual system which describes the effect of attention on apparent brightness. It is based in part on studies which imply that the best information on the retina is information about change in stimulation (Riggs, Ratliff, Cornsweet, & Cornsweet, 1953; Hartline, 1969). The model assumes that in order to assess the brightness levels of different portions of the visual field, the visual system computes an overall average luminance level (Bühler, 1922; Katz, 1935) and information about luminance differences is symmetrically superimposed on the average. The visual system then assumes uniformity of stimulation between the contours (Krauskopf, 1963; Yarbus, 1967; Gerrits, 1967) such that the brightness level at the contours becomes the brightness level between the contours. Included in the determination of the overall average luminance level is the overweighted luminance of the portion of the visual field which captures the attention (Helson, 1943).

It follows from this model that the apparent brightness of various portions of the visual field should be affected by the luminance of the part which captures the attention. When considering a gray and white display, the gray should be seen as darker if it captures the attention (contrast) and lighter if the white part captures the attention (assimilation). In a gray and black display, the gray should be seen as lighter if it captures the attention (contrast) and darker if the black part captures the attention (assimilation). By manipulating which portion of a gray and white or gray and black display would be likely to capture and hold the

attention, Festinger, Coren, and Rivers (1970) have shown that brightness assimilation seems to occur only if the portion of the display whose brightness is measured is not the part to capture the attention.

This theorized effect of attention is not meant to deny the influence of retinal inhibition on the brightness of a target. It is a separate effect which operates in addition to that of retinal inhibition. If the portion of a visual display which captures the attention is also the portion whose brightness is being measured, then the two influences would be working in the same direction. If the portion of the display which captures the attention is not the portion whose brightness is being measured, then attentional and retinal inhibitory influences would be working in opposite directions.

Another test of this model was made with regard to the Gelb effect. Stewart (1959) demonstrated that a Gelb disk progressively darkens as the area of a white spot placed over it is increased, and concluded that this phenomenon was simply another example of the operation of the laws of brightness contrast. As derived from the attentional model, Brussell and Festinger (1973) predicted that a Gelb disk with either a small white spot or small black spot over it would be seen as darker than the same disk with no spot over it. This was experimentally tested and confirmed.

A Further Specification of the Model

Figure 1 presents the spatial distribution of luminance across the retina resulting from two similar stimulus displays. Let us suppose that the distribution on the left resulted from the presentation of a white spot and gray annulus on a black background. If the area of the white spot was increased by 100% and the area of the annulus decreased by 25%, then the resulting spatial distribution of luminance would be that described in the right half of Fig. 1.

Let us first consider the luminance distribution from the display with the smaller white spot. The white spot has a luminance of 12 units and occupies 10% of the

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Fig. 1. The predicted effect of increasing the relative area of the portion of the visual field which captures the attention on the apparent luminance of all parts of the visual field (in figure, INFO. = information).

visual field. The gray annulus has a luminance of 6 units and occupies 40% of the visual field. The luminance of the black background is 3 units and occupies 50% of the visual field. The overall luminance level of this distribution, which must be determined with respect to both luminance and relative area, would be computed in the following way:

$$3(0.5) + 6(0.4) + 12(0.1).$$

The average luminance level of the visual field occupied by this distribution is 5.1 units. However, if the small and highly luminous spot captures the attention, then its luminance would be overweighted in the determination of the overall luminance level. Supposing for the moment that the overweighting factor is 2, the computation would be:

$$3(0.5) + 6(0.4) + 24(0.1).$$

The overweighted average is 6.3 units.

The visual system must now superimpose the luminance differences on the overweighted average. The information available to the visual system is the average luminance level (6.3 units), the difference in luminance between the background and annulus (3 units), the difference in luminance between the annulus and spot (6 units), and the relative areas of the background (50%), annulus (40%), and spot (10%). With this information, the apparent luminance levels of each portion of the

distribution could be determined if the following equation was solved for x :

$$0.5x + 0.4(x + 3) + 0.1(x + 9) = 6.3$$

where x equals the apparent luminance of the darkest portion of the visual field. Solving this equation for x reveals that the black background should be perceived as though its luminance were 4.2 units, the gray annulus as though its luminance were 7.2 units, and the white spot as though its luminance were 13.2 units.

Let us now consider the distribution on the right side of Fig. 1, in which the area of the spot has been increased by 100% and the area of the gray annulus decreased by 25%. The exact overall luminance level of this distribution would be 5.7 units. However, if the highly luminous spot again captures the attention and the overweighting factor remains constant despite the changes in relative area, then the overweighted average would be equal to 8.1 units. With the information about luminance differences symmetrically superimposed on the overweighted average, the black background should be perceived as though its luminance was 5.4 units (compared to 4.2 units in the first distribution), the gray annulus as though its luminance was 8.4 units (compared to 7.2 units), and the white spot as though its luminance was 14.4 units (compared to 13.2 units).

It must be realized that if the overall luminance level was arrived at by an exact rather than by an overweighted average, then the apparent luminance levels would always be equal to the actual luminance levels. In other words, increasing or decreasing the relative area of any portion of the distribution would have no effect on the apparent brightness of any part of the visual field.

A summary of the effect of changes in relative area on the two distributions presented in Fig. 1 leads us to a hypothesis. Increasing (decreasing) the relative area of the portion of the visual field which captures the attention will result in a greater (lesser) effect on the apparent brightness of all portions of the visual field. This hypothesis specifically predicts that if the relative area of the portion of the visual field which captures the attention is increased and that part is the most highly luminous portion of the field, then the apparent brightness of all parts of the visual field will be enhanced. Similarly, this hypothesis predicts a darkening of all parts of the visual field if the relative area of the attention-capturing part is decreased and that part is the least luminous portion of the field.

Necessary Considerations in Testing the Hypothesis

The ideal test of the hypothesis would involve conditions in which the attention was always captured by one portion of the visual field while the relative area of that portion was varied. In deriving the apparent

luminance levels of all parts of the two distributions presented in Fig. 1, it was assumed that the white spot, rather than the gray annulus, captured the attention. A possible justification for this assumption can be extracted from the work of Graham (1929) and Goldhamer (1934), in which the figure-ground relations of a circular field divided into six sectors was investigated.

Both studies revealed that, if alternating sectors were made to be of equal area and thin, the probability was high that they would be seen as "figure." However, this probability was drastically reduced if these sectors were widened such that they were no longer the thinner three sectors. Generalizing from these results leads us to expect a small spot placed over a relatively large disk to be seen as "figure" and, if briefly presented, to be the portion of the visual field to capture and hold the attention (Festinger et al, 1970). Increasing the diameter of the spot until it covered more than half the area of the disk might, however, result in a figure-ground shift with the annulus rather than the spot more likely to be seen as "figure" and more likely to capture the attention.

The hypothesis was tested using a spot and annulus configuration. In order not to confound any effects due to changes in relative area with any effects due to shifts of attention, the area of the utilized white and black spots was less than half the area of the gray disks over which they were placed. This constraint allowed a greater probability that the spot, rather than the annulus, would capture the attention.

The only exception to the use of relatively small spots was one relatively large white spot and one relatively large black spot. These were included to induce a higher probability that the annulus, rather than the spot, would capture the attention. If the annulus captured the attention, then its luminance would be overweighted in the determination of the overall luminance level across the visual field. The occurrence of a figure-ground shift, when considering a large white spot and thin gray annulus, would lead the attentional model to predict a darkening of both the annulus and the spot. The occurrence of a figure-ground shift, when considering a large black spot and thin gray annulus, would lead the attentional model to predict a lightening of both the annulus and spot.¹

Under normal viewing conditions, any influence of attention would be working in conjunction with that of retinal inhibition. In order to test the hypothesis, it was necessary to separate the effect of these two influences. Thus, we attempted to arrange a situation in which increasing the diameter of a spot surrounded by an annulus only minimally reflected the influence of retinal inhibition.

If we consider a spot and annulus configuration presented under normal binocular viewing conditions, a change in the spot size would result in a change in the magnitude of inhibition within the retina of each eye.

However, if we presented a disk to one eye and a spot to the other eye, then a change in the spot size would result in a change in inhibition within the retina of one eye only. Compared to the binocular condition, the magnitude of the change in retinal inhibition would be greatly reduced as the spot size is varied. Considering a dichoptic presentation, then, is it possible to reduce the influence of retinal inhibition even further?

In studying the determinants of a binocular brightness impression, Levelt (1968, Experiment 5) found the weight assigned to the luminance of a circular field presented to one eye to be a function of the diameter of the circular field. The smaller the diameter, the greater the weight. Thus, it would appear that the weight assigned to the luminance of a region of a monocular field varies inversely with the distance between the contours delineating that region.

The relevance of this finding to our situation is twofold. As the area of the spot presented to one eye is increased, its importance in contributing to the binocular brightness impression would decrease. This could serve to offset partially the influence of retinal inhibition on the apparent brightness of the spot as its diameter is increased. Secondly, the greater the distance between the contour of the spot and the contour of its surrounding field, the smaller the weight assigned to the luminance of the region surrounding the spot. To the extent that the contribution of the region surrounding the spot to the binocular brightness impression is reduced, the influence of retinal inhibition on the apparent brightness of the annulus (when the two monocular fields are fused) will be reduced.

On the basis of the results of the second experiment reported in his monograph, Levelt (1968, p. 49) suggests that the weight assigned to the luminance of a monocular field is decreased as the contours within the field "fade out." With regard to our monocular field, which contains a spot and large surround, perhaps we could reduce further the weight assigned to the luminance of the surround by blurring its contour.

To summarize, we reduced the influence of retinal inhibition through the dichoptic presentation of a disk and a spot, and were probably able to reduce it even further by surrounding the spot with a large field whose contour was blurred. A binocular control condition was also included in the design of the experiment.

METHOD

Apparatus

Figure 2 presents a schematic diagram of the stereoscope used in the experiment. Stimuli were mounted on foam board cards, each of which was 61 x 33 cm. A metal frame was constructed to hold securely two of these cards at any given time. At the far end of the stereoscope, a guide was built to allow the frame to fall smoothly downwards and to successively expose the stimulus display mounted on each card. One pull-type solenoid, located in an appropriate position, halted the frame's descent so that the first stimulus display could be presented. When pulsed, the arm

Fig. 2. Schematic diagram of the apparatus.

of the solenoid released the frame, which again fell until its progress was halted by a second solenoid. At this time, the second stimulus display was in the O's field of view. When the second solenoid was pulsed, the frame containing the stimulus cards dropped out of view, exposing an adapting field.

Two rectangular apertures, placed 31 cm from the eye, created two monocular fields of view whose dimensions subtended visual angles of 14 deg 42 min x 16 deg 32 min. The cards on which the stimuli were mounted were always exposed at a distance of 69 cm behind the apertures, so that when the eye was accommodated to the stimuli, the image of the aperture was blurred on the retina. Everything between the prisms and the stimulus cards was enclosed in a light-tight area.

Figure 3 presents diagrammatic examples of a dichoptic stimulus card (A) and a binocular stimulus card (B). The diameter of the light gray disks (Coloraid No. 2 paper) subtended a visual angle of 3 deg, and the diameter of the white and black spots (Coloraid white and black paper) subtended visual angles of 4 min, 8 min, 30 min, 1 deg 30 min, and 2 deg 30 min. Only in one case in the dichoptic and binocular conditions was the disk presented with no accompanying spot. The background to all of the disks and spots was dark gray (Coloraid No. 8 paper). Since the stimuli to both eyes in the binocular condition were identical, no additional fusional stimuli were necessary. However, on the dichoptic stimulus cards, four fusional stimuli, two to each eye, were placed 11.6 cm above and below the centers of the disk and spot. The dimensions of these stimuli were 15 x 30 min of visual angle. Four identical fusional stimuli were placed on the adapting field.

The display was illuminated by four 15-W incandescent bulbs. Two of the bulbs were located above and below the back of the aperture on the left side and two others were located above and below the back of the aperture on the right side. As measured with a Gamma photometer, the uniform luminance across the gray disks was 5.5 fL, across the white spots 10.0 fL, and across the black spots 0.55 fL. Within 3 deg of any gray disk (the largest stimulus), the uniform luminance across the background was 1.2 fL. Beyond 3 deg, the luminance dropped off by no more than 0.2 fL. The average luminance across the adapting field was 3.4 fL.

Observers

One male and one female adult O participated in the

experiment. As measured by the Keystone visual skills tests, each O had normal or corrected (contact lenses) acuity to 20/20 and normal fusional capabilities. Both Os were naive about the purpose of the experiment.

Procedure

A paired comparison technique was used to assess the relative brightness relations among the gray annuli surrounding the white spots, among the gray annuli surrounding the black spots, among the white spots, and among the black spots. In both the dichoptic and binocular conditions, 51 comparisons, repeated 10 times, were made by each O. These included (a) the five gray annuli surrounding the white spots compared with each other, (b) the five gray annuli surrounding the black spots compared with each other, (c) the five white spots compared with each other, and (d) the five black spots compared with each other. As will become clear further on, it was also necessary to compare (e) the "no spot disk" with the 10 other annuli, and (f) the gray annulus surrounding the smallest white spot with the gray annulus surrounding the smallest black spot. A total of 1,020 comparisons were made by each O.

Within each of the 10 blocks of 102 comparisons per O, the order of the comparisons was randomized and whether a response was asked for in terms of lighter or darker was counterbalanced. The order of presentation within a comparison was counterbalanced across the 10 blocks. In both the dichoptic and binocular conditions, the order of which side of the stimulus card was presented to which eye was also counterbalanced.

Hunter timers were used to pulse the solenoids. The calibration on the timers was ignored, and, with the aid of an oscilloscope, they were set to 2 sec. The interstimulus interval was determined to be 180 msec. The exposure duration was, therefore, 1.82 sec.

After an initial adjustment of the prisms for comfortable fusion, the O was informed that he would be successively presented with two gray disks. In the binocular condition, it represented the fused image of the two gray test fields; in the dichoptic condition, it represented the fused image of the single gray test field presented to one eye and the background presented to the other eye. The O was told that each disk could have a circular white or black area in its center or sometimes be presented as a uniform gray disk. The O was instructed that *after* each pair of presentations, he would be asked whether the first or second gray disk was lighter or darker (i.e., reflected more or less light), whether the first or second white spot was lighter or darker, or whether the first or second black spot was lighter or darker. It was important that the question be asked after the pair of presentations in order to reduce any bias as to where in the visual field the attention would be focused.

Fig. 3. Representations of a dichoptic stimulus card (A) and a binocular stimulus card (B).

After each comparison, the O continued to maintain fusion by viewing the adapting field, while the E prepared the apparatus for the next pair of stimulus presentations. Rest periods were allowed after 15 comparisons, and usually 60 comparisons were made in a day's session. Before collecting the data from any 15 comparisons, the O viewed the adapting field for 5 min.

RESULTS

In order to assess the relative brightness relations among the annuli and spots, eight sets of interval scale values [(2 annulus + 2 spot) $\times$ (dichoptic + binocular)] per O were computed from the raw comparison data. To illustrate how a set of scale values was determined, let us take the general case of arriving at values for the 4- and 8-min black spot stimuli in the dichoptic condition for one O.

One piece of information relevant to the brightness relation between the 4- and 8-min spots was the 10 direct comparisons between them. A Z score was assigned to the proportion of comparisons in which the 4-min spot was reported to be darker (or lighter) than the 8-min spot (normal deviate transformation). If the proportion was 1.00 or 0.00, then Z scores of 2.00 or -2.00 were assigned, respectively (Guilford, 1954). As well as being directly compared to each other, the 4- and 8-min spots were also compared with the 30-min, 1-deg 30-min, and 2-deg 30-min black spots. These remaining comparisons provided three additional estimates of the brightness relation between the 4- and 8-min spots. Z scores were assigned to the proportion of trials that the 4- and 8-min spots were reported to be darker (or lighter) than the 30-min, 1-deg 30-min, and 2-deg 30-min spots. The difference in Z scores between the 4- and 8-min spots with respect to each of these three stimuli was computed unless the scores assigned to both measures was ± 2.00 . The mean Z score difference, across the one direct and three indirect estimates, was taken to represent the mean difference in brightness between the 4- and 8-min black spots. The mean Z score difference between the 8- and 30-min black spots, the 30-min and 1-deg 30-min spots, and the 1-deg 30-min and 2-deg 30-min spots was computed in an identical manner.

The 4-min stimulus was determined to be the

Table 1
The z-Score Differences Between the Annuli Surrounding the 4-Min White and 4-Min Black Spots

O	Dichoptic Condition Comparison		Binocular Condition Comparison	
	Direct	Indirect	Direct	Indirect
1	+1.29	+1.43	+0.25	0.00
2	+0.85	0.00	+1.29	+0.71

brightest black spot and was assigned a scale value of zero.² The 8-min stimulus, which was the second brightest black spot, was assigned a scale value of the mean Z score difference between it and the 4-min spot. The Z score difference between the third (30-min) and second (8-min) brightest black spots was added to the scale value of the 8-min spot to arrive at the value of the 30-min spot. The two remaining black spots were assigned their scale values in the same way.

In both the dichoptic and binocular conditions, the scale values of the annuli surrounding all sizes of white and black spots were anchored to a common point. The only basis for anchoring these values to a common point was the direct comparison of the annulus surrounding the 4-min white spot with the annulus surrounding the 4-min black spot, and the indirect comparison of each with respect to the disk with no spot over it.

With regard to these direct and indirect comparisons, Table 1 presents the Z score difference between the annuli surrounding the 4-min white and 4-min black spots for each O. Positive values indicate the annulus surrounding the black spot to be darker than the annulus surrounding the white spot. As an index of reliability, all of the comparisons which indicated a difference were in the positive direction. Thus, for each O and for both the dichoptic and binocular conditions, the information about the annuli surrounding the 4-min white and 4-min black spots was averaged to determine the Z score difference between them and the Z score difference between each and the "no-spot" stimulus.

Table 2 presents the computed scale values for all stimuli separately for each O. The scale values of the annuli for both the dichoptic and binocular conditions

Table 2
The Scale Values of All Stimuli Presented Separately for Each Observer (O)

Stimulus	Annulus Comparisons				Spot Comparisons			
	Dichoptic		Binocular		Dichoptic		Binocular	
	O 1	O 2	O 1	O 2	O 1	O 2	O 1	O 2
No Spot	0.41	0.41	0.00	0.00	—	—	—	—
4-Min White	0.98	1.49	1.23	1.14	2.12	1.86	1.45	2.06
8-Min White	0.94	1.06	1.45	0.89	1.28	1.10	1.06	1.39
30-Min White	0.63	0.51	2.58	1.78	0.28	0.43	0.74	0.89
1-Deg 30-Min White	-0.29	0.29	3.39	2.13	0.00	0.00	0.20	0.21
2-Deg 30-Min White	-0.13	0.61	3.58	2.28	1.08	1.19	0.00	0.00
4-Min Black	2.36	1.92	1.36	2.14	0.00	0.00	0.00	0.00
8-Min Black	2.54	2.41	1.16	1.64	0.76	0.77	0.67	0.50
30-Min Black	2.79	2.80	0.55	0.64	1.47	2.03	0.71	1.02
1-Deg 30-Min Black	3.14	3.28	0.51	0.68	1.69	2.52	1.09	0.96
2-Deg 30-Min Black	2.23	2.49	-0.17	0.20	1.04	1.37	0.45	0.55

Fig. 4. Relative brightness relations among the gray annuli as a function of increasing the diameter of the white and black spots in the dichoptic condition.

are anchored to the values of their respective "no-spot" stimuli. The higher the scale value, the darker the stimulus. With three exceptions, the table reveals the consistent directional trends for both Os. These exceptions, which are all in the binocular data, occurred between the 4- and 8-min white spot-annulus values, the 30-min and 1-deg 30-min black spot-annulus values, and the 30-min and 1-deg 30-min black spot values. However, due to the overall consistency, it was felt that the data could best be summarized by averaging the scale values for each stimulus across the two Os. Each data point presented in the figures below thus represents the average scale value across the two Os.

Let us first examine the data concerning the gray annuli in the dichoptic condition in which a gray disk and white or black spot were presented separately to each eye. Figure 4 presents the relative brightness relations among these annuli of identical luminance as a function of increasing spot diameter.

As indicated by the graph, the gray annulus lightened as the white spot diameter was increased from 4 min to 1 deg 30 min. The difference between these two points was significant [$t(7) = 2.49, p < .05$]. As the diameter of the black spot was increased from 4 min to 1 deg 30 min, the annulus darkened. The difference between these two points was also significant [$t(7) = 2.67, p < .05$]. The data further reveal that both the annuli surrounding the 4-min white and 4-min black spots were darker than the disk with no spot presented to the other eye [$t(8) = 2.54, p < .05$, and $t(8) = 3.26, p < .05$, respectively].

An inspection of Fig. 4 also indicates that the 2-deg

30-min black spot resulted in a lighter annulus than the 1-deg 30-min black spot [$t(8) = 2.61, p < .05$]. A 2-deg 30-min-diam spot was used to raise the probability that a figure-ground shift would occur. Given a figure-ground shift, the annulus rather than the black spot would be more likely to capture the attention and a lightening of the annulus would be expected. By the same line of reasoning, the annulus surrounding the 2-deg 30-min white spot was expected to be darker than the annulus surrounding the 1-deg 30-min white spot. Although the brightness relation between these two stimuli was in the expected direction, the difference between them was not significant [$t(8) = 0.58, p > .05$].

Figure 5 presents the brightness relations among the gray annuli as a function of increasing the diameter of the white and black spots in the binocular condition. The gray annulus darkened as the diameter of the white spot was increased from 4 min to 2 deg 30 min [$t(8) = 4.08, p < .01$] and lightened as the diameter of the black spot was increased from 4 min to 2 deg 30 min [$t(8) = 3.46, p < .01$]. It should be noted that changes in the apparent brightness of the annulus as a function of spot diameter are in opposite directions in Figs. 4 and 5. However, as was revealed in Fig. 4, an inspection of Fig. 5 also indicates that both the annuli surrounding the 4-min white and 4-min black spots were darker than the disk with no spot over it [$t(6) = 4.84, p < .01$, and $t(8) = 3.05, p < .05$, respectively].

If the hypothesis is correct, then any of the predicted effects must extend to the apparent brightness of all portions of the visual field (see Fig. 1). Thus, in the dichoptic condition, the curves describing the effect of

Fig. 5. Relative brightness relations among the gray annuli as a function of increasing the diameter of the white and black spots in the binocular condition.

increasing the diameter of the white spot on the brightness of the gray annulus and white spot should be identical in shape, as should the curves describing the effect of increasing the diameter of the black spot on the brightness of the gray annulus and black spot.

Figure 6A presents the brightness relations among the white spots of differing diameters when they were presented dichoptically with a gray disk. The white spot lightened as its diameter was increased to 1 deg 30 min and darkened at a 2-deg 30-min diameter. The difference between the 4-min and 1-deg 30-min points was significant [$t(6) = 4.27, p < .01$], but the difference between the 1-deg 30-min and 2-deg 30-min points was not significant [$t(6) = 2.35, p > .05$].

Figure 6B again presents the data describing the effect of increasing the diameter of the white spot on the apparent brightness of the gray annulus in the dichoptic condition. An inspection of the curves presented in Figs. 6A and 6B reveals their similarity in shape, which would be expected from the attentional model.

The brightness relations among the black spots (A) and gray annuli (B) as a function of increasing the spot diameter in the dichoptic condition are presented in Fig. 7. The difference between the 4-min and 1-deg 30-min black spot points was significant [$t(6) = 4.34, p < .01$], as was the difference between the 1-deg 30-min and 2-deg 30-min black spot points [$t(5) = 2.77, p < .05$]. An inspection of the two curves reveals the similar effect of increasing the diameter of the black spot on the apparent brightness of both the spot and annulus.

Fig. 7. The effect of increasing the diameter of the black spot on (A) the relative brightness of the black spot, and on (B) the relative brightness of the gray annulus in the dichoptic condition.

The effect of increasing the diameter of the white or black spots on the apparent brightness of the spots in the binocular condition is presented in Fig. 8. As was not the case in Fig. 6A, Fig. 8A indicates that the white spot lightened as its diameter was increased from 4 min to 2 deg 30 min. The difference between these two points was significant [$t(6) = 5.46, p < .01$]. Figure 8B, which presents the brightness relations among the black spots as a function of diameter, indicates that the black spot darkened to a diameter of 1 deg 30 min and lightened at a diameter of 2 deg 30 min. Whereas the difference between the 4-min and 1-deg 30-min points was significant [$t(6) = 2.53, p < .05$], the difference between the 1-deg 30-min and 2-deg 30-min points was not [$t(6) = 1.51, p > .05$].

DISCUSSION

The hypothesis derived from the model predicted that the luminance of a small spot, surrounded by an annulus, would have a greater impact on the apparent brightness of the visual field as the area of the spot was increased. The greater the relative area of this attention capturing part of the display, the greater the effect of its overweighted luminance. The data from the dichoptic condition, in which the influence of retinal inhibition was reduced, support this hypothesis. Both the white spot and surrounding gray annulus lightened and both the black spot and gray annulus darkened as the area of the respective spots was increased.

Fig. 6. The effect of increasing the diameter of the white spot on (A) the relative brightness of the white spot, and on (B) the relative brightness of the gray annulus in the dichoptic condition.

Fig. 8. Relative brightness relations among (A) the white spots, surrounded by gray annuli, and (B) the black spots, surrounded by gray annuli, as a function of increasing the diameter of the spots in the binocular condition.

It has been suggested that an alternative interpretation of the data might be found in the context of a theory proposed by Helson (1963, 1964, pp. 291-293). On the basis of investigations conducted by Helson and Rohles (1959) and Helson and Joy (1962), it was proposed that a single physiological mechanism could account for both the phenomenon of contrast and assimilation. That single mechanism took the form of a retinal and/or central interaction between the spread of excitation and inhibition. The theory assumes that it is the difference in the intensity of stimulation between adjacent areas of a visual display which determines whether one will obtain contrast or assimilation responses. Small differences in stimulation result in assimilation. Increasing the difference results in a weakening of assimilation and a shift to contrast.

It was further assumed, and for our purposes the most relevant assumption, that increasing the area of one portion of a visual display has the same effect as increasing its luminance. Increasing either the area or luminance would lead to a larger difference in the intensity of stimulation between two adjacent portions of a visual display.

First consider the *annulus* data from the dichoptic condition in the context of Helson's theory. As a gray disk was presented to one eye and a white or black spot to the other eye, there could not be any retinal interaction between the disk and spot. We must therefore consider any interactions as being central, and in doing so, speak of the configuration as a spot surrounded by an annulus.

As the area of the spot is increased, the difference in the intensity of stimulation between the spot and annulus would also be increased. Helson's theory would therefore predict the elicitation of contrast responses. Specifically, it would predict that the annulus surrounding the white spot would have to darken and that the annulus surrounding the black spot would have to lighten as the area of the respective spots is increased. To a spot diameter of 1 deg 30 min, Figs. 6B and 7B indicate just the opposite.

With regard to the *spot* data in the dichoptic condition, the predictions from Helson's theory can be looked at from two points of view. From the point of view of the central interaction between the spot and gray annulus, the difference in the intensity of stimulation between these two "adjacent" areas would increase as the area of the spot was increased. Thus, the white spot would be expected to lighten and the black spot would be expected to darken. From the point of view of the retinal interaction between the spot and its immediate dark gray surround in one monocular field, again the white spot would be expected to lighten and the black spot would be expected to darken as the area of the respective spots was increased. To a spot diameter of 1 deg 30 min, both of these trends are indicated in the data presented in Figs. 6A and 7A.

In all of the curves presented in Figs. 6 and 7, however, the brightness relation between the 1-deg 30-min and 2-deg 30-min data points is in the opposite direction from the remainder of their respective curves. In the case of the annulus data, the relation between the 1-deg 30-min and 2-deg 30-min points is in the direction which Helson's theory would have predicted the entire curve to be. In the case of the spot data, the relation between the 1-deg 30-min and 2-deg 30-min points is in the opposite direction to that which Helson's theory would have to predict.

In the context of the data reported by Graham (1929) and Goldhamer (1934), it seemed likely that at a spot diameter of 2 deg 30 min the figure-ground relations of the configuration would shift and the annulus, rather than the spot, would be seen as "figure." Since the exposure duration was brief (1.82 sec), the annulus would be more likely to capture and hold the attention. From the model, it was therefore expected that both the 2-deg 30-min white spot and the surrounding gray annulus would darken, and that both the 2-deg 30-min black spot and the surrounding gray annulus would lighten.

As mentioned above, these effects are indicated in the data presented in Figs. 6 and 7, respectively. However, only in the case of the black spot and gray annulus was there a significant difference between the 2-deg 30-min and 1-deg 30-min conditions.

Perhaps there was another factor influencing the probability of the annulus's capturing the attention when surrounding a 2-deg 30-min spot. It might be expected that the only situation in which the thin annulus would always be seen as "figure" is that in

which the spot and background are of the same achromatic color. Under these conditions, the ground which "extends" under the annulus would appear to be continuous. As the white spot was less similar in achromatic color to the dark gray background than the black spot, perhaps there was a lower probability of the annulus's being seen as "figure" when it surrounded the white rather than the black spot. If this was the case, then, with a brief exposure and no instructions as to where in the stationary visual field the attention should be focused, the annulus would also be less likely to capture the attention when surrounding the white rather than the black spot. And, to the extent that the annulus did not capture the attention over repeated trials, the mean difference in brightness between the 1-deg 30-min and 2-deg 30-min conditions would be reduced.

In terms of the data, we might also expect more variability in responding to the apparent brightness of the annulus and the 2-deg 30-min white spot than in responding to the annulus and the 2-deg 30-min black spot. When considering the difference between the 1-deg 30-min and the 2-deg 30-min scale values in the dichoptic condition, the variance was greater for the annulus and white spot comparisons (1.72, 1.88) than for the annulus and black spot comparisons (1.06, 0.85).

In conclusion, as the data from the dichoptic condition confirm the predictions derived from the hypothesis and as the alternative interpretation of the data was found to be inadequate, the results of this experiment are taken to provide further evidence in favor of, and a further specification of, the model proposed by Festinger, Coren, and Rivers (1970).

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NOTES

1. These two expectations, which are directly derived from the Festinger et al (1970) model, assume a *shift of attention*. It is important to remember that the hypothesis to be tested, although also derived from the Festinger et al (1970) model, assumes *attention to be held constant*.

2. With one exception, the brightest stimulus for each O within any set of scale values was assigned a value of zero. In the case of the dichoptic-annulus comparisons, each "no-spot" stimulus (the anchoring stimulus, as explained further on) was assigned a common value of 0.41. By doing this, the average value, across the two Os, for the brightest stimulus (the annulus surrounding the 1-deg 30-min white spot) was zero.

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