THE EFFECT OF ATTENTION ON BRIGHTNESS CONTRAST AND ASSIMILATION

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Abstract. This paper reports three experiments that attempted to answer questions about the conditions under which brightness assimilation and brightness contrast are obtained. Brightness assimilation was found only under circumstances in which the gray portion of the visual display—the gray portion being compared with some other standard gray—was not the focus of attention. When attention was focused on this gray, brightness contrast was obtained. A theoretical explanation is offered in terms of the effect of attention on perceived average brightness.

The phenomenon of simultaneous brightness contrast is well known: a gray patch on a black ground appears brighter than the same gray patch on a white ground. The phenomenon is pervasive and its parameters have been thoroughly studied.[1] In addition, the facts and theories about lateral inhibition[2] seem adequate to account for brightness contrast.

At the same time there are a number of annoying facts that are not easy to reconcile with the phenomenon of contrast. These facts have also been well known for a long time. Von Bezold, in 1874, described what he called a "spreading phenomenon" that has since come to be called brightness assimilation.[3] It is, essentially, the opposite of brightness contrast, but it seems to occur only

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[1] A. L. Diamond, Foveal simultaneous brightness contrast as a function of inducing and test-field luminances, *J. exp. Psychol.*, 45, 1953, 304–314; A. L. Diamond, Foveal simultaneous contrast as a function of inducing-field area, *J. exp. Psychol.*, 50, 1955, 144–152; A. L. Diamond, Simultaneous contrast as a function of test-field area, *J. exp. Psychol.*, 64, 1962, 336–345; A. L. Diamond, Brightness of a field as a function of its area, *J. opt. Soc. Amer.*, 52, 1962, 700–706; E. G. Heinemann, Simultaneous brightness induction as a function of inducing and test field luminances, *J. exp. Psychol.*, 50, 1955, 89–96; H. Leibowitz, M. A. Mote, and W. R. Thurlow, Simultaneous contrast as a function of separation between test and inducing fields, *J. exp. Psychol.*, 46, 1953, 453–456.

[2] A. L. Diamond, A theory of depression and enhancement in the brightness response, *Psychol. Rev.*, 67, 1960, 168–199; F. Ratliff, *Mach Bands: Quantitative Studies on Neural Networks in the Retina*, 1965.

[3] W. von Bezold, *The Theory of Color and Its Relation to Art and Art-Industry*, S. R. Koehler (trans.), 1876.

in rather special circumstances. For example, if one places thin white striations on a gray background, one observes that the gray seems lighter than an identical gray with black striations on it. The phenomenon has been studied by many.[4] Among them, Helson has attempted to explain the conditions under which contrast or assimilation occurs in terms of adaptation level.[5] This explanation, however, is only partially successful. Beck, for example (see n. 4), found that Helson's theory does not account for the total range of his data.

In addition to the complexity introduced by the phenomenon of brightness assimilation, there are reports in the literature of 'cognitive' factors that affect the magnitude of brightness contrast and assimilation. Some of these reports are concerned with the effects of 'figural' qualities of the visual display. Koffka, for example, demonstrated different contrast effects on a reversible figure depending on which aspect of the visual display is seen as figure and which as ground.[6] Several investigators have also demonstrated unusual brightness-contrast effects depending on whether a gray triangle appears to be on top of a black shape or adjacent to it.[7] Other cognitive factors are related to experience. For example, Beck (see n. 4) reported that with repeated exposure to stimuli that usually produce assimilation responses, observers begin to report brightness contrast.

Coren attempted to specify, under well-controlled conditions, the effect of 'figure' on brightness contrast.[8] In one experiment he

[4] J. Beck, Contrast and assimilation in brightness judgments, *Psychon. Sci.*, 1, 1966, 342–344; R. W. Burnham, Bezold's color mixture effect, this JOURNAL, 66, 1953, 378–385; R. M. Evans, *An Introduction to Color*, 1948; H. Helson and V. L. Joy, Domains of lightness contrast and assimilation, *Psychol. Beitr.*, 6, 1962, 405–415; H. Helson and F. G. Rohles, A quantitative study of reversal of classical lightness contrast, this JOURNAL, 72, 1959, 530–538; S. M. Newhall, The reversal of simultaneous lightness contrast, *J. exp. Psychol.*, 31, 1942, 393–409; J. A. Steger, Visual lightness assimilation and contrast as a function of differential stimulation, this JOURNAL, 82, 1969, 56–72.

[5] H. Helson, Studies of anomalous contrast and assimilation, *J. opt. Soc. Amer.*, 53, 1963, 179–184; H. Helson, *Adaptation-Level Theory*, 1964.

[6] K. Koffka, *Principles of Gestalt Psychology*, 1935.

[7] W. Benary, Beobachtungen zu einen Experiment über Helligkeitskontrast, *Psychol. Forsch.*, 5, 1924, 131–142; W. T. Mikesell and M. Bentley, Configuration and brightness contrast, *J. exp. Psychol.*, 13, 1930, 1–23; J. G. Jenkins, Perceptual determinants in plane designs, *J. exp. Psychol.*, 13, 1930, 24–46.

[8] S. Coren, Brightness contrast as a function of figure-ground relations, *J. exp. Psychol.*, 80, 1969, 517–524.

used a display that was seen as a gray rabbit on a black (or white) background. Rotated 180°, however, the display was seen as a gray space between two black (or white) faces of women. Thus, he could have the observers match the brightness of the identical gray in the identical stimulus display when that gray was figure and when it was ground. In another experiment he used stereoscopic stimuli to control which part of the display was seen as figure. A gray disc was made to stand out in front of a black (or white) ring, or the ring was made to stand out in front of the gray. Since observers perceive the part of the display that stands out in front as the figure, he could, again, have them match the brightness of the identical gray in a nearly identical stimulus display when the gray was seen as figure and when it was seen as ground. The results are rather clear. When the gray that is matched is seen as figure, there is significantly more brightness contrast than when that identical gray is seen as ground. Thus, there does seem to be a cognitive factor influencing the magnitude of brightness contrast.

To say that a cognitive factor such as the perception of figure affects simultaneous brightness contrast is interesting but not entirely satisfying. One would like to know how this cognitive factor operates, how it interacts with lateral inhibitory processes, and what the mechanisms are by means of which the magnitude of contrast is altered. A possible, relatively simple, theory suggests itself.

The visual system transmits information primarily about changes that occur, and not very much about steady retinal states. Evidence for this statement comes from both neurophysiological and psychological studies. Thus Hartline, on the basis of physiological evidence, stated that "the visual system is almost exclusively organized to detect change and motion."[9] The same conclusion was reached by others, on the basis of work with stabilized retinal images. It is well known that a stabilized image produced on the retina (so that normal eye movements no longer produce changes in stimulation) rapidly disappears.[10] In other words, if

[9] H. K. Hartline, Visual receptors and retinal interaction, *Science*, 164, 1969, 270–278, at p. 275.

[10] R. M. Pritchard, W. Heron, and D. O. Hebb, Visual perception approached by the method of stabilized images, *Canad. J. Psychol.*, 14, 1960, 67–77; L. A. Riggs, F. Ratliff, J. C. Cornsweet, and T. N. Cornsweet, The disappearance of steadily fixated visual test objects, *J. opt. Soc. Amer.*, 43, 1953, 495–501.

there are no changes in stimulation on the retina, visual input seems to stop. This carries the implication that in normal vision, small continual eye movements produce changes in stimulation on the retina in the neighborhood of contours—that is, the neighborhood of sharp differences in intensity. This continual change in the stimulation of retinal receptors keeps information flowing in the visual system.

But if the visual system does not in fact transmit much information about steady retinal states, the attempt to explain normal visual experience presents some problems. For example, what happens if an observer looks at a large black square on a white background, maintaining reasonable fixation in the center of the square? Presumably there is considerable information input from the contour but little or none from the center of the uniform black square. How, then, does the observer see a uniform black square? It must be that the central nervous system, in the absence of reliable input from some area, assumes uniformity between contours.

A convincing demonstration of this process was provided by Krauskopf.[11] The observer in this experiment is presented with a stabilized disc surrounded by a nonstabilized colored annulus. After a few seconds the stabilized disc fades and disappears. But what does the observer see then? He does not, of course, see an empty hole in a colored annulus. He simply sees a uniformly colored circle in his visual field. The same result has also been reported by Yarbus and Gerrits.[12] Krauskopf (see n. 11) summarized the theoretical conclusions to be drawn as follows:

> It would seem that information indicating the existence of contours between regions of the visual field determine how the regions themselves are perceived. Under normal fixation conditions, responses generated by the movement of the disk-annulus border over the receptors signal the existence of a change in stimulation between the disk and annulus. Under prolonged stabilized viewing, such information is absent and the whole field is seen in the color of the annulus since there only is information concerning the change in stimulation between the surround and the annulus. (p. 743)

One might be tempted to maintain, on the basis of this kind of evidence, that no information at all is transmitted about steady

[11] J. Krauskopf, Effect of retinal image stabilization on the appearance of heterochromatic targets, *J. opt. Soc. Amer.*, 53, 1963, 741–743.

[12] A. L. Yarbus, *Eye Movements and Vision*, B. Haigh (trans.), 1967; H. J. M. Gerrits, Observations with stabilized retinal images and their neural correlates, doctoral dissertation, Catholic University of Nijmegen, 1967.

states on the retina. This is not a plausible assertion, however, considering other neurophysiological evidence. Microelectrode recordings in the optic tract and in the lateral geniculate show that the firing rates for steady states are directly related to the intensity of stimulation on the retina.[13] Nevertheless, these differences are small compared to the transient responses that signal the magnitude of change. We can at least maintain, therefore, that information about steady states is relatively poor and unreliable.

If the visual system does not transmit much reliable information about steady states, but only about changes that occur, then what determines the perception of absolute brightness levels? We would like to propose that the visual system takes a crude average of the relatively unreliable input about steady states across the entire visual field to establish an absolute brightness level. We would further like to suggest that areas of the visual field with 'figural' characteristics are overweighted in the computation of this crude average. Differences in brightness—that is, the changes in stimulation produced in the neighborhood of contours by continual eye movements—are then superimposed on this weighted average of brightness.

The proposal that absolute brightness level is derived from a weighted average over the entire visual field is not a new idea. For example, in the attempt to explain the phenomena of brightness and color constancy, investigators such as Katz and Bühler proposed that the observer directly perceives the absolute level of illumination, this perception being derived from the entire visual field.[14] More recently, Helson, addressing himself to the same problem, stated that "background reflectance, by virtue of the large area of background and because background furnishes the border for all samples in the field, is the most important single factor in the visual field determining *adaptation reflectance which is to be regarded as a weighted mean reflectance of all parts of the visual scene*" (italics ours).[15] In general, of course, Helson's concept of adaptation level is similar in nature to our own proposal.

If such an overweighting of 'figure' occurs, the average bright-

[13] O. Creutzfeldt, J. M. Fuster, A. Herz, and M. Straschill, Some problems of information transmission in the visual system, in *Brain and Conscious Experience*, J. C. Eccles (ed.), 1966.

[14] D. Katz, *The World of Color*, 1935; K. Bühler, *Handbuch de Psychologie*, 1922.

[15] H. Helson, Some factors and implications of color constancy, *J. opt. Soc. Amer.*, 33, 1943, 555–567, at p. 562.

ness of a display in which the figure is brighter than the ground would be raised somewhat. The average brightness would be lowered on displays in which the figure was darker than the ground. Assuming that the information about differences in brightness is symmetrically superimposed on this weighted average of brightness, this would result in displacement of the brightness of all parts of the visual display. We can thus deduce the following effects. If a gray figure on a white ground is compared to an identical gray figure on a black ground, the perceived brightness of the former gray would be less than that of the latter gray. Thus, for figures one would observe brightness contrast. On the other hand, if one compares a gray ground with a white figure on it to an identical gray ground that has a black figure on it, the former gray would be perceived as brighter than the latter gray. Thus, for ground one would observe brightness assimilation. The combined effects of this process and the processes of lateral inhibition that push toward contrast might be expected to produce stronger effects for brightness contrast than for brightness assimilation.

The preceding analysis suggests that 'figure' contrasts from 'ground' and that 'ground' assimilates to 'figure.' However, Coren reported no instances of brightness assimilation in his data (see n. 8). He found brightness contrast for ground as well as for figure. His data showed only that there is more contrast when the test gray is figure.

Let us examine what is meant by 'figure' and by 'ground,' and consider why there might be a difference in the weighting given to these different parts of the visual field. We generally denote as figure that part of the visual field which captures the attention of the observer. This is the part of the display that he 'looks at,' that he examines, to which he is prepared to respond. The rest is background, to which he 'pays less attention.' Let us propose that it is the act of attention that produces the overweighing in the absolute brightness averaging and not the quality of 'figure' per se. Our theoretical suggestion then can be revised as follows: That part of the visual field which captures attention shows the phenomenon of *brightness contrast;* those parts of the visual field which are *not* attended to are likely to show *brightness assimilation.*

If this is a correct formulation, we can then offer a tentative explanation of why Coren found no brightness assimilation in his study (see n. 8). If the observer is asked to match the brightness of a test gray with a variable gray, then regardless of whether that test gray is figure or ground, regardless of whether it would normally capture his attention or not, he is forced to pay some attention to the gray he is required to match. Thus, since the observer is always paying some attention to the gray, Coren obtained brightness contrast in all conditions. The distribution of attention over the display, however, is not the same when the gray is figure and when the gray is ground. This results in a difference in the magnitude of brightness contrast among the different conditions.

If this relatively simple hypothesis can integrate and explain brightness contrast, brightness assimilation, and the effect of some 'cognitive' factors on these phenomena, then it must, of course, be able to deal with the known circumstances under which brightness assimilation is normally obtained. These known circumstances should turn out to be instances in which the observer does not carefully attend to the test gray he is judging. Therefore, let us consider in detail those displays that normally produce brightness assimilation.

The reader will recall that the kind of display which produces assimilation responses is one in which there are thin white (or black) striations on a gray ground. This has been shown both by Helson and Rohles and by Helson and Joy (see n. 4). Their data show that when the black or white stripes were thinner than the interspaced gray stripes, brightness assimilation was obtained. When, however, the gray stripes are thinner than the black or white stripes, brightness contrast is produced. Thin lines on a display are more likely to capture the attention and to be seen as 'figure,' thus producing the contrast or assimilation results that are found. Several investigators studied this question systematically and found, indeed, that the thinner portions of a reversible stimulus are more likely to be seen as figure than its broader portions.[16]

We come to the conclusion, then, that displays which normally produce brightness assimilation are ones in which the test gray is seen as background. However, in explaining Coren's data we conjectured that asking the subject to match a test gray must force his attention onto that gray to some extent. How do displays that consistently produce brightness assimilation avoid this problem?

[16] C. H. Graham, Area, color, and brightness difference in a reversible configuration, *J. gen. Psychol.*, 2, 1929, 470–483; H. Goldhamer, The influence of area, position, and brightness in the visual perception of a reversible configuration, this JOURNAL, 46, 1934, 189–206; T. Oyama, Figure-ground dominance as a function of sector angle, brightness, hue, and orientation, *J. exp. Psychol.*, 60, 1960, 299–305.

Let us examine, in detail, the procedures used in experiments that report brightness assimilation. These experiments typically present two gray rectangles side by side, one bearing thin white lines and the other bearing thin black lines. The observer is not asked to do any matching but is simply asked to report which gray looks lighter. In other words, the response asked for does not require very careful attention to the gray. In addition, the stimulus-exposure times are always kept brief, typically about three seconds. In short, when the test gray is ground and the response required does not force attention to the test gray, and when the presentation time is brief enough so that the figure captures the attention effectively for that period of time, then one obtains brightness assimilation.

Our speculations are, of course, amenable to experimental testing. If the task facing the observer is one that forces attention to the test gray, then figures that normally produce assimilation should show contrast.

EXPERIMENT I

This experiment was designed to answer the question about the effect of the method of measurement on whether one observes brightness contrast or brightness assimilation. The methods of paired comparison with brief exposures and of brightness matching were employed, both with stimuli that have been used in assimilation studies and with stimuli that typically produce brightness contrast.

Method

Stimuli. The *'assimilation stimuli'* were 10-cm. squares of gray paper (35% reflectance) with regularly spaced black (2.4% reflectance) or white (82% reflectance) vertical lines that were 6 mm. wide. The intervening gray stripes were 12 mm. wide. The *'contrast stimuli'* were the same size and consisted of a gray vertical bar, 38 mm. wide, in the center, flanked by two black or two white bars, each being 31 mm. in width. Five *practice stimuli* were also used. Three of these were uniform grays: one 19% reflectance, another 35% reflectance, and the third 50% reflectance. The two other practice stimuli contained either a white or a black 38-mm. square in the center of a 35%-reflectance gray.

Apparatus. The observer viewed the stimuli through a 23 cm. × 38 cm. rectangular aperture equipped with a manual shutter. The stimuli were mounted 85 cm. behind the aperture on a black (2% reflectance) background.

For paired-comparison judgments two stimuli were displayed simultaneously 5 cm. apart. To obtain brightness matches, one stimulus was presented at a time. The observer, by turning a handle mounted on his right, could vary the size of the black and white sectors on a spinning Gerbrands differential rotor. Readings were taken in degrees of white from the rotor shaft and later converted to percent reflectance.

The light incident on the stimuli was provided by a ring of ten 15-w. tungsten light bulbs mounted out of view behind the rectangular aperture. A filtered d.c. power source was used in order to eliminate stroboscopic effects on the rotor face. The lights produced a uniform flux of 50.3 ftc. at the plane of the stimuli.

Subjects. Ten paid volunteers were recruited on the campus of Stanford University. All had 20/20 visual acuity, normal or corrected.

Procedure. Each *S* made both paired-comparison judgments and direct brightness matchings of the stimuli. Half of the *S*s did the paired comparisons first, and the other half did the brightness matchings first. For the brightness-matching situation, one stimulus was presented at a time and *S* set the rotor so that it matched the gray of the stimulus. Two matches were made, one starting with the rotor face obviously darker than the gray and another starting with the rotor face obviously lighter. The order of stimulus presentation follows. Each *S* first matched the uniform practice grays of 19% and 50% reflectance in mixed order. Matches were then made for the 35%-reflectance uniform gray, the same gray as on the test stimuli. The four test stimuli—two assimilation stimuli and two contrast stimuli—were then presented in mixed order.

To obtain paired comparisons, two stimuli—one with white and one with black—were simultaneously presented for 3 sec. and *S* was asked to state on which side, left or right, the gray was lighter. He was told to guess if uncertain. The two assimilation stimuli were presented side by side four times, and the two contrast stimuli were presented together four times. Two other pairs—one consisting of the black square on gray and the white square on gray, another of the 19%- and 50%-reflectance uniform grays—were each presented twice. The order of presentation of these stimulus pairs was random. Which stimulus in the pair appeared on the left or the right was balanced.

Results

With judgments made using the paired-comparison procedure and a 3-sec. exposure, we would expect the 'assimilation stimuli' to produce assimilation responses (the gray with white to be judged lighter) and the 'contrast stimuli' to produce contrast responses (the gray with black to be judged lighter). This is what was found, as Figure 1 shows. Seven subjects gave contrast responses on all four presentations of the contrast stimulus pair. Two gave three contrast responses and one assimilation response, and only one subject gave one contrast and three assimilation re-

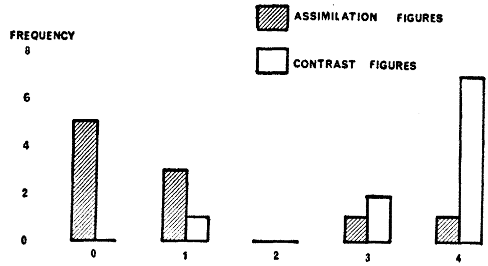

FIG. 1. Distribution of number of contrast responses out of four stimulus presentations for three-second exposure; paired-comparison technique

sponses (significantly different from chance, $p < .01$, Kolmogorov-Smirnov test).[17] The picture is quite different for the assimilation stimulus pair. Five subjects gave assimilation responses on each of the four presentations; three did so on three of the four presentations. Only two subjects gave more contrast than assimilation responses (significantly different from chance, $p < .05$, Kolmogorov-Smirnov test). The two distributions were, of course, significantly different from each other ($p < .01$).

These results simply replicate what has been reported in the literature.[18] With relatively thin black or white lines on a gray background, and with brief exposure in a paired comparison, one obtains brightness assimilation. The important point comes in comparing these results with the results obtained on the same stimulus figures using brightness matching. And as Table I shows, these results were quite different from those obtained by paired comparison. Here there was no longer any difference in the results produced by the 'assimilation' and by the 'contrast stimuli.' Both stimulus types produced brightness contrast. The gray with the white inducer was seen as significantly darker than the gray with the black inducer for both the contrast ($p < .01$, $t = 5.91$) and the assimilation stimuli ($p < .01$, $t = 7.60$). Using this procedure for measurement, brightness assimilation did not occur.

Discussion

The data are consistent with the idea that the difficulty in obtaining brightness assimilation, even when the test gray is background, lies in the measurement procedure that forces the observer

[17] S. Siegel, *Nonparametric Statistics for the Behavioral Sciences,* 1956.
[18] See Helson (n. 5 above).

TABLE I

MEAN MATCH SETTINGS ON DIFFERENTIAL ROTOR, IN PERCENT REFLECTANCE, FOR TEST GRAY IN CONTRAST AND ASSIMILATION CONFIGURATION: EXPERIMENT I

	Configuration		
	Contrast	Assimilation	Base gray
White inducer	20.2	20.8	35.1
Black inducer	38.2	34.5	

to pay attention to that gray. This could well be the reason that Coren did not obtain anything but brightness contrast (see n. 8). Thus, it is still possible to maintain the hypothesis that the part of the visual field to which the observer pays attention shows contrast effects while the part to which he does not attend shows brightness assimilation.

Presumably, the reason that we did obtain evidence of brightness assimilation with the proper stimuli on a 3-sec. exposure is that the thin black or white lines captured the observer's attention and the exposure time was too short for him to redirect his attention to the gray to which he was supposed to be responding. If this is a correct interpretation, then one might expect that, even using a paired-comparison procedure, the assimilation responses would tend to disappear if the presentation times for the stimuli were longer. With a longer presentation time, the observer would be able to shift his attention to the gray, and if this happened, the measurements would show brightness contrast. Experiment II was designed to investigate this question.

EXPERIMENT II

Method

The stimuli, the apparatus, and the general procedure were all similar to the paired-comparison portion of Experiment I. In this experiment the illumination incident on the stimulus plane was 30 ftc. In addition to a condition under which the pairs of *'assimilation'* and *'contrast stimuli'* were exposed for *3 sec.*, another condition was run in which the same stimulus pairs were exposed for *10 sec.* In this latter condition the *S*s were told to pay careful attention to the gray on the stimuli and were instructed not to respond until the shutter was closed at the end of 10 sec.

Subjects. Twenty *Ss* with 20/20 normal or corrected vision were recruited from the New School for Social Research. Ten of them, randomly assigned, were in the 3-sec. exposure condition and the other ten were in the 10-sec. exposure condition.

Results

The results, in terms of the number of contrast responses obtained in the four presentations of the stimulus pairs, are presented in Figure 2. It is clear that for the 3-sec. exposure time, the results

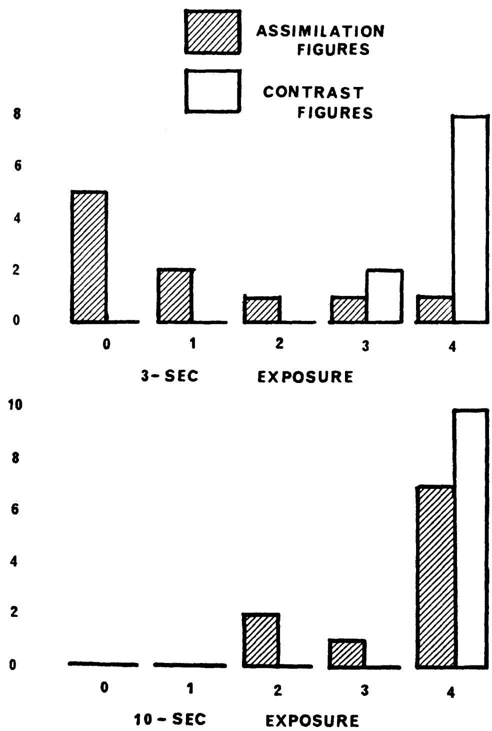

Fig. 2. Distribution of number of contrast responses out of four stimulus presentations as a function of exposure duration; paired-comparison technique

closely replicate the findings from Experiment I. All of the statistical comparisons, analyzed as in Experiment I, were also similarly significant. Again, we obtained assimilation responses from the 'assimilation stimuli' ($p < .05$) and contrast responses from the 'contrast stimuli' ($p < .01$).

The results for the 10-sec. exposure condition are very different.

When the subject was encouraged to pay attention to the gray, and when enough time was provided for the subject to attend to the gray, both types of stimuli yielded primarily contrast. responses. The difference in responses to the assimilation stimulus pair between the two experimental conditions was significant ($p < .01$, $t = 5.55$).

Discussion

Experiments I and II make the same single point. If one provides conditions that direct the observer's attention to the gray in those stimulus configurations which presumably produce brightness assimilation, one then observes only brightness contrast. Brightness assimilation seems to occur if, and only if, the observer's attention is caught and held by that part of the visual display which is *not* being judged. In the case of these so-called assimilation stimuli, the parts of the display that catch and hold the attention for brief periods are the thin black or white striations.

If our hypothesis of the effect of attention on whether one obtains contrast or assimilation is correct, however, the crucial aspect is not the existence of thin black or white striations. The crucial aspect is, rather, in capturing and holding the attention of the observer so that the test gray is not attended to even though it is the part of the display that must be judged. One should be able to devise other stimulus configurations that, at least for short periods of time, also attract and hold the attention of the observer. If our explanation is correct, these should also produce assimilation responses. And since moving objects in the visual field tend strongly to capture the attention of an observer, we should be able to use this property of movement to hold attention and thereby to produce brightness-assimilation responses for stimulus configurations that would normally show brightness contrast. Experiment III was designed to examine this question.

EXPERIMENT III

This experiment compared the responses to four different stimulus-pattern and stimulus-presentation conditions. For some stimuli, the figure was gray and the background was black or white. Since the figure captures the attention and the figure is the area to be judged by the observer, only contrast responses should be obtained here, whether the figure is stationary or moving. For other stimuli, the figure was black or white and the background was gray, the gray being the part of the display to be judged. When these latter stimuli are exposed for 10 sec., there is sufficient time for attention to be shifted to the gray, and hence we would expect primarily contrast responses. When they are exposed for only 3 sec., there is less certainty that the observer has time to attend to the gray, and hence we would expect sometimes to obtain brightness contrast and sometimes brightness assimilation. And if, with these same stimuli presented for 3 sec., the black or white figure is made to move continually, this should help to capture and hold attention to the figure. Under these circumstances we would expect the gray to show primarily brightness assimilation.

Method

Stimuli. Each stimulus subtended a visual angle of 9°10′ in width and 6° 28′ in height. It was divided into two equal parts by a vertical black line 10′ wide. Each stimulus had a pattern of gray and white on one side and an identical pattern with black instead of white on the other side. The gray was always 31% reflectance. Depending on the material used for constructing the stimuli, the blacks varied from 1.5% to 2.4% reflectance and the whites from 86% to 88% reflectance.

Four *'contrast stimuli'* were prepared, using a gray figure on black and on white backgrounds. Two of these, a star and an H were *stationary.* For the other two, a circle moved from right to left and back, or a square moved up and down. The *moving* stimuli were made by preparing two or three stimuli in each of which the figure was in a different position so that when presented in succession at proper temporal intervals, apparent movement was seen.

Twelve sets of *'potential-assimilation stimuli'* were prepared. These contained on one side a black, and on the other side an identical white, figure on a gray background. Each of these sets could be presented as a *moving* figure, or one of the set could be presented as a *stationary* figure. Thus, for example, one set showed a 0 changing into a 3, which then changed into an 8 and then changed back again. For a comparable stationary figure, only the 8 was presented. In another set an arrowhead could be made to flip back and forth from left to right. For a stationary figure an arrowhead pointing in just one direction was used. Two *practice stimuli* were also used. These had physically unequal grays on the two sides.

Apparatus. The stimuli were presented in a three-channel tachistoscope (Scientific Prototype Model GB320). The light incident on the plane of the stimulus was adjusted to 35.5 ftc. for each channel.

Subjects. Twenty-six paid volunteers were recruited from the New School for Social Research. All had 20/25 or better visual acuity, normal or corrected. Two of these *S*s gave incorrect responses on the practice stimuli with unequal grays and were discarded without further collection of data. This left 24 *S*s in the experiment proper.

Procedure. Each *S* was shown the four contrast stimuli and the twelve potential-assimilation stimuli. For any one *S*, four of the potential-assimilation stimuli were presented stationary for *10 sec.*, four were stationary for *3 sec.*, and four were moving for *3 sec.* The presentation mode was balanced so that over all *S*s, each stimulus was in each mode equally often. The contrast stimuli were all presented for 3 sec. To minimize any possible order effects, the 16 stimuli were presented in blocks of four, each block containing one contrast stimulus, one 3-sec., one 10-sec., and one moving potential-assimilation stimulus. The order of presentation within each block was also balanced.

Each *S* was instructed not to respond until the termination of each stimulus presentation. He was then to describe the stimuli and to indicate on which side of the stimulus the gray was lighter. He was asked to guess if uncertain. The instruction to describe the figures was intended to heighten the likelihood that *S* would pay some attention to the figure on each stimulus.

Results

Each subject made four judgments in each stimulus-presentation mode. A score from zero through four was given to each subject for each mode according to the number of contrast responses. If the subject did not give a contrast response, it was, of course, an assimilation response. Table II presents the means and standard deviations of this measure for the four presentation modes.

The 'contrast stimuli,' whether moving or stationary, yielded contrast responses almost exclusively. Twenty-two of the subjects gave four contrast responses; the other two subjects gave three contrast responses out of a possible four. Thus, when the gray to be judged was also the figure, so that all attention was centered on it, unequivocal brightness contrast was obtained.

TABLE II

MEAN NUMBER OF CONTRAST RESPONSES OUT OF FOUR STIMULUS PRESENTATIONS: EXPERIMENT III

	Contrast figures	Assimilation figures		
	3-sec.	10-sec. stationary	3-sec. stationary	3-sec. moving
Mean number of contrast responses	3.92	2.63	1.96	1.17
(*SD*)	(.28)	(1.21)	(.81)	(.82)

The 'potential-assimilation stimuli,' when presented for 10 sec. as stationary patterns, still yielded primarily contrast responses, although considerably fewer than did the contrast stimuli. The difference between these two was significant ($p < .01$ using a sign test). Eighteen subjects showed fewer contrast responses, five showed the same number, and only one showed more, on the 10-sec. stationary exposure than on the contrast stimuli. Contrast responses were obtained significantly more often than chance, however ($p < .05$). Fifteen subjects gave three or four contrast responses, while only four of them gave zero or one. The difference between the contrast stimuli and the 10-sec. stationary potential-assimilation stimuli was as expected, although not compelling from a theoretical point of view. After all, the amount of black or white that presumably produces the contrast was markedly different between these two sets of stimuli.

The comparison between the 10-sec. and the 3-sec. stationary conditions is more relevant theoretically. Here the subjects were comparing identical stimuli, the only difference being the duration of presentation. When these stimuli were presented for only 3 sec., significantly fewer contrast responses were obtained ($p < .01$). Seventeen subjects showed fewer contrast responses, four the same number, and only three give more contrast responses on the 3- than on the 10-sec. exposure. This again was in line with expectation. If the exposure time is so brief as to interfere with the transfer of attention from the figure to the gray, we would expect fewer reports of contrast. Again, however, the comparison was not compelling since we did not obtain, on the 3-sec. exposure, significantly more assimilation than chance would allow. The average was almost exactly 2.0, and one might argue that in a brief exposure, with little opportunity for examination, observers simply guessed, thus yielding chance results. This seems implausible since the contrast stimuli were also only presented for 3 sec., and the responses were clearly contrast responses. Nevertheless, it is a possibility.

The critical comparison lies between the 3-sec. stationary condition and the 3-sec. moving condition. This difference was highly significant ($p < .01$). Seventeen subjects gave fewer contrast responses, six the same number, and only one gave more on these moving stimuli than on the stationary ones. Furthermore, with the moving stimuli, significant evidence of brightness assimilation was obtained ($p < .01$). Only two subjects gave three or four contrast responses. Eighteen subjects gave zero or one contrast response. In other words, with this brief, 3-sec. exposure, and with a stimulus where the figure so moved as to capture the attention of the observer, brightness assimilation with stimulus patterns that are not normally considered assimilation stimuli was obtained.

Discussion and Conclusions

The data from all three experiments are consistent with the theoretical explanation that we advanced. It is necessary, however, to look at other possible interpretations. The main alternative explanation that suggests itself concerns possible differential eye-movement patterns between different conditions. After all, eye movements and fixation points were not controlled in any of the experiments; the observers were free to move their eyes at will. It is quite plausible to suppose that an observer's eyes fixate differently depending upon what attracts his attention and depending upon the task. There are two separate ways in which such eye-movement differences could affect measurements of brightness contrast. First of all, there could be differences in magnitude of contrast depending upon the position of the image on the retina. Secondly, if the eye movements are different, the sequence of successive brightness contrasts could be different. Since our measures undoubtedly reflect a combination of simultaneous and successive brightness contrast, this might explain our data. Let us consider each of these possibilities.

As to the first possibility, let us begin by saying that we have found contrast effects if the observer pays attention to the test gray, and assimilation effects if the observer's attention is held away from the test gray. If we attempted to explain this result in terms of eye fixation and consequent different regions of the retina on which the image falls, we could restate it as follows. If the test gray falls in or near the fovea, one obtains contrast, and if the test gray falls on the retinal periphery, one obtains assimilation. The results would be adequately explained if one found that brightness-contrast effects were strongest at or near the fovea.

Unfortunately, we have not been able to find any good data in the literature that bears on this question. What little we have been able to find seems to indicate the opposite. Tschermak, considering the Schumann grid effect, came to the conclusion that contrast is stronger on the periphery of the retina than on or near the fovea.[19] More recently, Alpern measured the magnitude of meta-

[19] A. Tschermak, Über kontrast und irradiation, *Ergebn. Physiol.*, 2, 1903, 726–798.

contrast with the retinal position of the test field varying from foveal to 4.25° off the fovea and found steady increases in the magnitude of metacontrast as the test patch moves away from the fovea into the periphery.[20] This perhaps supports the conclusion reached by Tschermak, but it seems highly unlikely that the mechanisms involved in metacontrast are the same as those in simultaneous brightness contrast. From existing data, it is not possible to reject completely the explanations based upon difference in fixation patterns between the various conditions. On the other hand, indirect evidence makes it seem implausible.

As to the second possibility, let us ask whether the data can be explained in terms of successive contrast effects. If an observer fixates first, say, a white figure and then fixates a gray ground, successive contrast would occur and, presumably, produce a more marked contrast response. Perhaps in a 10-sec. exposure this occurs more frequently than in a 3-sec. exposure, since there is more time for such eye movements. It is, however, difficult to see how this process could produce assimilation responses. In addition, it does not seem that this process adequately explains the large number of assimilation responses obtained with moving stimuli, for when the white figure moves, there is a period of time in which that part of the retina previously stimulated by white is stimulated by gray. This, presumably, should add to the contrast effect rather than produce assimilation. It does not seem plausible to the authors that all of the results reported above can be explained in terms of different eye-movement patterns.

In order to explain the known facts about the perception of brightness, it is necessary to begin to formulate a theory about the processing of information in the visual system. What information does and does not get transmitted? What is done with the information that is transmitted? We have brought together a number of statements to form a partial theory about visual information processing. Few of these statements are new, but bringing them together seems to help explain the seemingly contradictory phenomena of brightness contrast and brightness assimilation. This theory can be summarized as follows:

1. The visual system transmits information primarily about changes that occur on the retina and transmits little information about steady states.

[20] M. Alpern, Metacontrast, *J. opt. Soc. Amer.,* 43, 1953, 648–657.

2. Because of continual eye movements, changes in stimulation on the retina occur in the neighborhood of contours—in the neighborhood of sharp intensity (or wavelength) differences.
3. The visual system interpolates between contours and assumes uniformity of stimulation in areas from which little or no information arrives.
4. Absolute brightness levels are arrived at by an averaging over the entire visual field.
5. Those areas to which the observer pays attention are overweighted in arriving at this averaged, absolute, brightness level.
6. Information about changes (magnitude of difference on two sides of a contour) is symmetrically superimposed on this absolute brightness level.

We believe that this model can account for much of the data on brightness contrast and brightness assimilation. Furthermore, we have shown that by controlling exposure conditions in accordance with implications from this model, one can produce contrast with stimuli that normally yield assimilation and assimilation with stimuli that normally produce contrast.