Depth adjacency in simultaneous contrast[1]

WALTER C. GOGEL[2] AND DONALD H. MERSHON
UNIVERSITY OF CALIFORNIA, SANTA BARBARA

The Gelb phenomenon, as an example of whiteness contrast, was investigated with three amounts of separation in depth between the test and induction disc. The cue of binocular disparity was used to vary the perceived depth between the discs. It was found that the magnitude of the contrast effect decreased with an increase in the perceived depth between the two discs. This change was regarded as an instance of the adjacency principle. The problem of whether the binocular disparity cue per se or perceived depth was the significant variable was discussed. The consequences of the results were considered with respect to the relation between whiteness constancy and whiteness contrast and the problem of neural localization of the contrast effect.

Adjacency is an important variable in the perception of object characteristics. The significance of this factor is expressed in the adjacency principle (Gogel, 1965b) which states that the effectiveness of cues between objects in determining perceived object characteristics is inversely related to the relative separation of the objects. The adjacency principle has been demonstrated to apply to the perception of depth from binocular disparity or size cues (Gogel, 1963, 1965b, 1967) but it also can be applied to other perceived characteristics such as the perceived whiteness of objects. For objects in the same fronto-parallel plane, the magnitude of the whiteness contrast between a test and induction object is inversely related to the separation between the objects (Freeman, 1967). However, adjacency can occur in depth as well as in a fronto-parallel plane, and it has been demonstrated that the former as well as the latter type of adjacency can be important in determining perceived characteristics (Gogel, 1963). The purpose of the present study is to explore the possibility that depth adjacency is a significant factor in the determination of simultaneous whiteness contrast.

If a large black disc is presented under strong illumination in an otherwise totally dark visual field, the disc will appear to be white or whitish-grey. If a small white disc with a luminance much greater than that of the large disc is placed on the large disc, the large disc will decrease sharply in perceived whiteness. This decrease in perceived whiteness is known as the Gelb effect. Stewart (1959) has shown that, contrary to what had been previously assumed, the Gelb effect can be explained as a contrast phenomenon since it follows the general laws of contrast. The size and location of the small disc on the large disc predictably modifies the apparent whiteness of the large disc. In the present study the Gelb effect was measured with different apparent separations in depth between the large and small disc. It is expected, if depth adjacency is an important factor in whiteness contrast, that increasing the apparent depth separation between the two discs will decrease the darkening effect that the small disc has upon the perceived whiteness of the larger disc.

A change in fronto-parallel separation involves a change in relative retinal position. A change in only radial depth, however, produces little change in the relative positions of objects on the retina even though binocular observation is used. It follows that, if a change in radial depth position alone is found to be significant in this study, factors other than relative retinal location must be involved in simultaneous whiteness contrast, i.e., the contrast phenomenon is not determined solely at the retinal level of organization. Furthermore, if it can be demonstrated that the significance of the depth dimension for the induction effect is independent of the particular depth cues used in registering the depth dimension, it is likely that the important factor in the adjacency effect is perceived depth rather than particular cues to depth. This result would suggest the possibility that perceived relative separation is the important factor in the adjacency principle irrespective of the dimension (fronto-parallel or depth) in which the separation occurs. It is for this reason that perceived as well as physical depth was measured in the present study.

METHOD

Apparatus

The apparatus used is illustrated in Fig. 1. The large disc was generated by an enclosure labeled B_1 with the back inside surface covered by a homogeneous black paper. At the front of the enclosure was a circular aperture (20.5 cm in diam) through which a portion of the black surface was visible. This surface was illuminated by a circular fluorescent light (L_1) located directly behind the circular aperture and invisible to O. The back surface of the enclosure appeared at the distance of the aperture (284 cm from O) producing a circular disc of light (A_1) with a visual angle of 4.1 deg (cf. Lichten & Lurie, 1950). This disc is called the large disc. Another circular disc of light called the small disc was produced at the aperture A_2 by the combination of a stationary fluorescent light source (L_2) and a movable cover, B_2, containing the aperture. No portion of this light source or its surround was visible except through the aperture. By moving the cover forward or backward (toward or away from O) the experimenter (E) could place the small disc produced by the aperture A_2 at specified distances from O. The size of the small aperture was varied by inserting slides with different circular openings in a slide holder at the aperture. The sizes of the openings in the slides used at the different distances produced a disc of light of constant visual angle (1 deg 40 min). The view of the small disc at A_2 could be completely obscured by an opaque slide. The small disc A_2 was visible to O binocularly by reflection from mirror M. The luminance of the small disc alone and the large disc alone as measured from the position of O was 156.2 and .79 ft-L, respectively. Both discs were viewed binocularly throughout the experiment.

The partially-reflecting, partially-transmitting mirror M permitted O to see the large and small disc simultaneously.

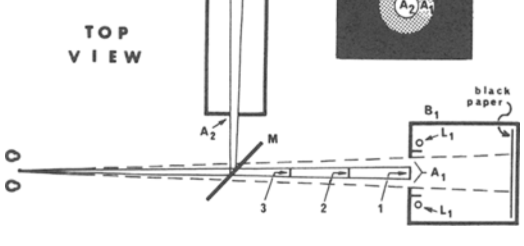

Fig. 1. Schematic drawing illustrating the apparatus and conditions of the experiment.

The inset drawing of Fig. 1 shows a front view of the simultaneous presentation of the two discs as seen from the position of O with the stippled area representing the darker (large) disc. As is indicated, the center of the small disc was always in the same apparent direction as the center of the large disc. The stereoscopic depth position of the small disc, however, was not always the same as that of the large disc. Depending upon the adjusted position of the cover B_2, the small disc could be placed at one of three stereoscopic positions represented in Fig. 1 by the small vertical bars numbered 1, 2, and 3. Since both discs were viewed binocularly, the apparent depth between the large and small disc was produced by the cue of binocular disparity. At Position 1, the small disc was stereoscopically at the distance of the large disc. At Positions 2 and 3, the small disc was stereoscopically the equivalent of 43.5 and 87.0 cm, respectively, in front of the large disc. Throughout the experiment nothing was visible except the discs (either the large disc alone or the small and large disc together) presented in an otherwise totally dark visual field. This was accomplished by covering all surfaces (except the lighted surfaces generating the discs) with black velveteen and providing baffles to restrict the O's view to the vicinity of the discs. The viewing position of O was in a booth which could be made totally dark and which contained a chin rest and an eyepiece for binocular observation. A shutter at the viewing position was used to occlude O's view of both discs when required. To eliminate possible blurring of the images of the discs on the retina due to differences in accommodation between the discs (when the small disc was at Positions 2 or 3) the eyepieces contained small restrictive artificial pupils (1.0 mm in diam). These were used for all the observations of the experiment. The artificial pupils were positioned as close as possible to O's eyes and were adjusted in separation to match his interpupillary distance. E communicated with O by a system of microphones and speakers. A continuous white noise was presented to O, when E was not speaking to him, in order to mask any noise generated in presenting the conditions of the experiment.

Observers

The sixty Os used in the experiment were students in an introductory course in psychology and were naive with respect to the purpose of the experiment. Each O had a stereoacuity of at least 40 sec of arc as determined by a Keystone test of stereoacuity and a visual (vernier) acuity of at least 20/20 (both near and far) in each eye as determined by using the Keystone Orthoscope. The interpupillary distance of each O was measured with a Mark I Naval Interpupillometer.

Procedure

To provide a scale of perceived whiteness, each O was given practice in identifying six Munsell patches in the white-to-black dimension (Munsell Nos. 2.0, 3.5, 5.0, 6.5, 8.0, and 9.5). These were presented in a separate room, one at a time, against a large medium grey background (Munsell No. 5). The Os were given a number to be associated with each patch. The whitest patch was numbered 6 and the blackest 1 with the remaining patches numbered appropriately. The Os learned this scale to a criterion of three correct repetitions with the patches presented in randomly ordered blocks of trials. For each O, the training on the scale of whiteness followed the determination of his vernier acuity, stereoacuity, and interpupillary distance.

After the training period, O was shown the observation position and remained in the dark for 5 min before being presented with any stimulus. The large disc alone was always presented first and O was asked to indicate its perceived whiteness W′ by referring in memory to the whiteness scale learned previously. After this report the shutter was closed, the small disc was readied for presentation, and 30 sec later the shutter at the observation position was raised to present the large and small disc simultaneously to O. The O was asked whether the *large* disc appeared "whiter, blacker, or the same" as when he saw it last. If O reported a change in whiteness, he was asked to use a number on the whiteness scale to indicate the new perceived whiteness of the *large* disc. Following this, he verbally indicated (in feet or inches or in some combination of both) the apparent distance of the large disc from himself and the apparent depth between the two discs. The presentation of the large disc followed by a simultaneous presentation of the two discs with one of the three depth separations will be called a condition of separation. The presentation procedure was identical for each of the three conditions of separation with 2½ min of complete darkness between successive conditions of separation. The reason for presenting the large disc alone before presenting the two discs simultaneously in each condition of separation was to determine that no residual effect upon the large disc remained from the previous stimulus presentation. Newson (1958) had found, for example, that following an induction effect the test object did not always return immediately to its previous value. Fractions of units on the whiteness scale were used by O when necessary and the whiteness reports throughout the study were made only with respect to the large disc. Each of six possible orders of the three conditions of separation of the discs was presented to 10 different Os.

RESULTS

The average results and standard deviations of the perceived whiteness (W′) of the large disc, the perceived depth (d′) between the discs and the perceived distance (D′) of the large disc from O are given in Table 1 with the distance responses converted to centimeters. The upper portion of Table 1 labeled "All Presentations" presents the data based on all 60 Os for each condition of separation of the discs regardless of the order of presentation. These data are the most sensitive of the experiment for determining whether perceived depth separation is a factor in simultaneous contrast, since the same Os (and all Os) are involved in each data point. The remaining portions of Table 1 fractionate the data into first, second, and third presentations. These data are the results from each of the conditions of separation considering the order (first, second, (or third) in which these conditions of separation were presented. Different groups of 20 Os were involved in each order of presentation for each condition of separation.

The difference between the perceived whiteness W′ of the large disc with the small disc absent and with the small disc present is the amount of induction effect resulting from the presence of the small disc. For example, the average W′ difference of 1.11 ("All Presentations") for zero separation is the decrease in apparent whiteness of the large disc resulting from the introduction of the small disc for the case in which the discs were equidistant. This is a measure of the usual Gelb effect. From the "All Presentations" data it will be noted that the Gelb effect progressively decreases as the distance of the small disc in front of the large disc increases. This decrease is the result expected if either physical (stereoscopic) or perceived depth is the significant factor in the application of the adjacency principle to simultaneous contrast. The statistical significance of the change in the W′ differences of Table 1 as a function of the physical (stereoscopic) depth between the discs was tested using the analysis of variance (Lindquist, 1953). For the "All Presentations" data, the W′ differences were significant at the .005 level (Treatments by Subjects design, F = 5.81, df = 2/118). This is the main result of the experiment and supports the conclusion that stereoscopic separation is important in simultaneous whiteness contrast. The fractionated data of Table 1 also tends to

Table 1

Perceived Whiteness W′ of the Large Disc, Perceived Depth d′ (in cm) Between the Large and Small Disc, and Perceived Distance D′ (in cm) of the Large Disc from 0 as a Function of the Physical Depth d Between the Discs. On the Scale of W′, Full White is Six and Black is One.

			Physical Depth Between Discs								
			0 cm			43.5 cm			87.0 cm		
			Small Disc Absent	Small Disc Present	Diff	Small Disc Absent	Small Disc Present	Diff	Small Disc Absent	Small Disc Present	Diff
All Presentations	W′	Mean	3.84	2.73	1.11	3.87	3.05	0.82	3.81	3.13	0.68
		SD	0.70	0.80	0.86	0.73	0.66	0.84	0.70	0.91	0.70
	d′	Mean		−1.5			32.8			51.5	
		SD		23.6			38.9			56.1	
	D′	Mean		112.8			118.6			118.9	
		SD		92.5			94.7			106.7	
First Presentations	W′	Mean	4.10	2.75	1.35	4.15	2.85	1.30	3.92	3.22	0.70
		SD	0.77	0.73	0.94	0.71	0.68	0.84	0.78	0.75	0.68
	d′	Mean		0.1			38.3			44.8	
		SD		22.7			51.7			47.3	
	D′	Mean		116.5			122.7			114.9	
		SD		102.9			107.1			94.2	
Second Presentations	W′	Mean	3.79	2.73	1.06	3.69	3.10	0.59	3.60	3.02	0.58
		SD	0.53	0.67	0.77	0.79	0.47	0.72	0.72	1.09	0.77
	d′	Mean		−4.5			27.1			47.8	
		SD		33.3			30.9			51.6	
	D′	Mean		119.2			112.6			105 4	
		SD		75.2			89.9			90.0	
Third Presentations	W′	Mean	3.62	2.69	0.93	3.78	3.19	0.59	3.91	3.13	0.78
		SD	0.70	0.97	0.81	0.60	0.75	0.73	0.55	0.85	0.61
	d′	Mean		−0.1			33.1			61.8	
		SD		4.8			29.3			66.3	
	D′	Mean		102.6			120.4			136.2	
		SD		96.2			85.4			129.1	

support this conclusion. In every case the largest disc separation showed less of an average difference in W′ than the zero disc separation. The 43.5-cm disc separation gave smaller differences in W′ than the zero disc separation in every case and larger differences in W′ than the largest disc separation in two out of the three cases. Only in the case of the first presentations, however, were the W′ differences significant at the .05 level (one-tailed) between the different conditions of separation (F = 3.63, 2.50, and 1.09 for the first, second, and third presentations, respectively, df = 2/57).

According to Table 1, for all the conditions of separation, the magnitude of the Gelb (induction) effect was greater for first than for either second or third presentations. An analysis of variance of the average values of the first, second, and third presentations resulted in significance at the .02 level of confidence (Treatments by Subjects design, F = 5.42, df = 2/118). The average magnitude of this decrease (.32) was relatively large, being about 2/3 as large as the change in the Gelb effect between the zero and largest separation of the discs. This decrease in induction between first and subsequent presentations did not affect the comparison between the average induction effects from the different conditions of separation since each condition of separation was presented first equally often. It did, however, add variance to the distributions on which these comparisons are based and thus tended to decrease the precision of the experiment.

As was expected, the average value of d′ in Table 1 increased with an increase in the physical distance (d) between the two discs. It will be noted from the "All Presentations" data that doubling the physical depth between the discs did not result on the average in a doubling of the perceived interval. This result is in the direction expected from several previous studies of the perception of depth from the binocular disparity cue (Foley, 1967; Gogel, 1960).

From the D′ data of Table 1, the perceived distance of the large disc from O did not differ appreciably as a function of the distance between the discs. According to the results from "All Presentations" this perceived distance (about 3.8 ft) is considerably less than the physical distance of the disc (9.3 ft). In the present experiment the only cue to the perceived distance of the large disc from O (perceived egocentric distance) is the cue of the convergence of the eyes. The lack of veridicality of D′ and the large standard deviations between Os associated with the perceptions of the egocentric distance of the large disc reflects the general inadequacy of convergence as a cue to egocentric distance (Heineman, Nachmias, & Tulving, 1959; Gogel, 1961). This is to be contrasted with the consistent increase in the perceived depth d′ between the discs as a function of the increases in the binocular disparity between the discs.

The two discs were not always perceptually equidistant when the binocular disparity between them was zero. In computing d′ in Table 1, a report that the small disc was in front of the large disc was listed as positive, a report that the small disc was behind the large disc was listed as negative. If, however, perceived rather than physical depth or depth simulated by binocular disparity is the significant factor in the adjacency effect, the perception that the small disc is, for example, 4 in. behind the large disc should have the same effect on perceived whiteness as the perception that the small disc is 4 in. in front of the large disc. It seems reasonable, therefore, to compute average values of d′ without regard to sign, i.e., without regard to the direction of the perceived depth between the two discs. Fig. 2 shows the average whiteness differences for the "All Presentations" data of Table 1 plotted against the average d′ values computed in this absolute sense for each of the three conditions of separation. It can be concluded from Fig. 2 that the decrease in the

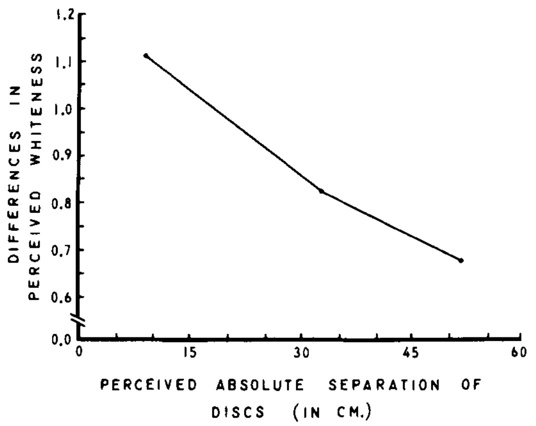

Fig. 2. Average differences in whiteness as a function of average perceived depths between the discs, computed without regard to the direction of the perceived separation. The data points showing the smallest, middle, and largest perceived absolute separation were obtained from the 0, 43.5, and 87 cm conditions of separation, respectively.

induction effect is approximately a linear function of the perceived depth between the induction and test object.

DISCUSSION

Types of Adjacency

The central conclusion of this study is that the whiteness induction occurring between two objects of different luminance is a decreasing function of their separation in stereoscopic depth. The data of Fig. 2 indicate that this conclusion can be expressed with equal validity in terms of perceived or in terms of physical (stereoscopic) depth. Certainly there is no reason to expect that the same results would not have occurred if cue systems other than binocular disparity had produced the perceived depth between the discs. What is needed is a series of experiments in which the contrast effect is investigated as a function of perceived radial depth with the depth produced by different cues. Although such data are not available, there are several observations in the literature which are consistent with the hypothesis that whiteness induction is inversely related to *perceived* radial separation. Hering (1964, pp. 10-11) noted that a grey paper viewed in strong illumination looked darker than a distant white wall under weak illumination when both were viewed binocularly. When, however, monocular observation was used and the wall and paper were perceived to be in the same plane, the colors of the two appeared to be the same. This is clearly an instance of a change in perceived depth between two surfaces resulting in a change in their perceived whiteness. Katz, as reported in Woodworth and Schlosberg (1954), viewed a white disc through the reduced illumination produced by a rotating episcotister. The disc appeared as a white disc behind the plane of the episcotister when viewed from a close distance but as a grey disc in the plane of the episcotister when viewed from a large distance. Again, a change in phenomenal depth resulted in a change in perceived whiteness. In both of these instances the perception that the two surfaces were at different distances probably was the result of the binocular disparity cue. When the effectiveness of the binocular disparity cue was eliminated (by monocular observation) or reduced (by viewing from a large distance), the surfaces appeared equidistant and the whiteness induction effect was increased. The perceptual factor that would cause two surfaces to appear equidistant in the absence of strong distance cues has been termed the "equidistance tendency" and this tendency has been demonstrated to occur under a variety of situations (Gogel, 1965a; Roelofs, 1961). It is clear, therefore, in the observations of Hering and Katz that the factor which produced apparent equidistance (the equidistance tendency) was different from the factor (binocular disparity) that produced the apparent separation of the surfaces in depth. This supports the hypothesis that the effect of depth separation on whiteness contrast is best expressed in terms of perceived depth rather than in terms of particular depth cues.

If both fronto-parallel and depth separation are important variables in whiteness induction, it is likely that both of these dimensions should be described in perceptual terms. It can be hypothesized further that the inverse relation between whiteness induction and the perceived separation of the induction and test object is independent of the dimension in which this separation occurs. It should be clear, however, that this hypothesis, although parsimoneous, needs to be demonstrated. The hypothesis would require, for example, that a particular fronto-parallel displacement of the induction object from the test object would result in a modification of whiteness equivalent to the effect of a *perceptually* equal displacement in radial depth. It is not at all certain that this result would be obtained. Although the induction effect in the present study was approximately a linear function of perceived displacement, there is evidence (Newson, 1958) that this does not apply throughout the range of fronto-parallel displacement. Other aspects of the above hypothesis also require examination. For example, Newson also found that a brighter inducing field will tend to control the perceived color of the test object even though it is less adjacent to the test object than another induction object of less luminance. This indicates that the factor of perceived relative separation is only one of the factors important in the determination of the induction effect.

Theoretical Consequences

Neural localization. The hypothesis that whiteness induction varies inversely with the perceived separation of the objects has two general consequences. First, it suggests that, to some extent at least, the induction effect occurs at or above the same level of neural organization as do the factors determining perceived separation. It is improbable that the results from the present experiment can be explained by neural events occurring only at the retinal level, since the retinal separations were little changed by the introduction of the binocular disparity cue. The largest binocular disparity involved a symmetrical displacement in each eye of 17.1 min of arc. Since the small disc always was directionally superimposed on the large disc, it is unlikely that this small displacement could explain the change in the induction effects obtained in the present study (cf. Stewart, 1959). It is interesting to speculate whether the induction effect between the discs would have disappeared completely had the discs been sufficiently far separated in depth. According to the "All Presentations" data a reduction of 39% occurred in the induction effect between the 0- and 87-cm separation. Although this change in separation is rather large in terms of the binocular disparity cue, it is not large compared with the depth separations, either physical or perceived, that could have been used. It is possible, therefore, that the contrast effect could completely disappear with a sufficiently large separation. If this occurred, it would suggest that the total contrast effect is localized at or above the neural level mediating the perception of depth.

Synthesis of whiteness constancy and whiteness contrast. The second consequence of this experiment concerns the possible interrelation of whiteness contrast and whiteness constancy. There have been persistent attempts to explain whiteness ("brightness") constancy in terms of contrast (cf. Freeman, 1967). A major difficulty in such efforts is that the two kinds of phenomena are usually measured under different conditions. Whiteness contrast studies generally are conducted with all of the induction and test surfaces located in the same fronto-parallel plane. Whiteness constancy studies, on the other hand, usually are conducted in situations in which objects or surfaces surrounding the test surfaces are at different distances. The present experiment permits a rapprochement of the two kinds of situations in that contrast effects differed systematically with depth separations. If a significant variable in contrast effects is the perceived distribution in depth of the induction surfaces, it is clear that the possibility that contrast induction is basic to whiteness constancy is strengthened. The usual explanation of depth effects in whiteness constancy is that the perception of depth provides an additional source of information concerning the distribution of illumination in the visual field and, therefore, assists in achieving whiteness constancy. The present experiment provides an alternative and conceptually simpler explanation of the effect of depth in whiteness constancy than does the explanation involving the perception of illumination. It is also clear, however, that since the perception of depth relations can be of consequence in whiteness induction, contrast effects involve more complex processes than have generally been considered heretofore.

The experimental conditions of the present study have been described in terms of the Gelb effect. In the conditions in which the large and small disc were equidistant the experimental situation also resembles the ring and disc type of experiment used by Wallach (1948). The outer portion of the large disc constitutes the ring and the small disc constitutes the center disc of the configuration used by Wallach. It is clear that the conditions and results of the present experiment can be applied to a range of situations, with the most general type of situation involving a number of objects or surfaces of various luminances distributed in three-dimensional space. It is suggested that the relative spatial distributions of surfaces as well as their relative luminances are important in determining the perceptions of their whiteness characteristics. Such a view is labeled relational in distinction to the view that apparent whiteness is determined by taking illumination into account.

Contrary to the relational approach is an experiment by Hochberg and Beck (1954) which suggests that the apparent orientation of a surface with respect to the perceived direction of illumination, as indicated by cast shadows, is a factor in perceived whiteness. Hochberg and Beck remark that, if the cues provided by these shadows are missing, the main effects of the experiment disappear. A grey cardboard surface in the form of a trapezoid was presented upright on a black floor. When viewed from the observation position, the cardboard (target) appeared to be a rectangle lying on the black floor. The O could be induced to see the target as perpendicular by (a) seeing a rod moving behind the target, (b) seeing the target move through an arc, or (c) by using binocular observation. With the illumination from above it was found that the target appeared less bright when it was perceived as flat on the floor than when it was perceived as upright. Epstein (1961) questioned the generality of these findings in that he was unable to obtain consistent differences in the perceived brightness of a white triangle having a constant physical, but a differing apparent, orientation with respect to a slanted checkerboard background. It is not clear, however, whether in the study by Epstein, the kind of shadows that were considered essential to the experiment by Hochberg and Beck were available for O. The present study avoids the possibility of the perception of the direction of illumination in that no cast shadows were present and no objects except the two discs were visible. It follows that the question of the possible effect of the perception of the conditions of illumination is not important in interpreting the present results. This question is of consequence, however, in applying the conclusions from the present experiment to a synthesis of the phenomena of whiteness constancy and whiteness contrast. To the extent that whiteness constancy involves the perception of conditions of illumination, it is distinct from whiteness contrast.

Additional Considerations

The results from the present study encourage the extension of the adjacency principle to other perceived characteristics of objects. Obviously, the perception of chromatic as well as achromatic colors can be studied in a manner similar to that used in the present experiment. It should also be noted that the description of the significant aspect of the displacement variable in terms of perceptual rather than physical changes is a description of a relation between two perceptual events. The present experiment suggests that an hypothesis in which one perceptual event, e.g., perceived separation, determines another, e.g., perceived whiteness, possesses considerable explanatory and predictive ability. Perhaps such relationships rather than being ignored, as has often been the case, should be explored for their predictive merit.

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NOTES

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2. Address: Department of Psychology, University of California, Santa Barbara, Calif. 93106.

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