Research Report

PERCEPTUAL ORGANIZATION OVERCOMES THE EFFECTS OF LOCAL SURROUND IN DETERMINING SIMULTANEOUS LIGHTNESS CONTRAST

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Abstract—*Lightness induction can occur on the basis of the immediate surround of a region (local interactions) and also on the basis of global factors of perceptual organization. The experiments reported in this article used novel displays that made it possible to differentiate the contributions of these two kinds of factors. The experiments demonstrated, for the first time, that when higher-level factors act contemporaneously with lower-level factors, the contrast effect induced by the global-organization principle of perceptual belongingness overcomes the effect due to retinal lateral inhibition.*

It is well known that a gray surface surrounded by a light background appears darker than an identical gray surface surrounded by a dark background. This phenomenon is called simultaneous lightness contrast.

Recordings from the nerve fibers of the eye of the *Limulus* (Hartline, Wagner, & Ratliff, 1956) demonstrated that the firing rate of a receptor stimulated by a certain amount of light is diminished when the neighboring receptors are stimulated by the same illumination. In mammals, this physiological mechanism is called lateral inhibition because it is transmitted laterally across the retina. In humans, horizontal and amacrine cells of the retina can provide a pathway for transmitting inhibitory signals from one receptor to another.

Lateral-inhibition models (Cornsweet, 1970; Hurvich & Jameson, 1957) explain the simultaneous-contrast effect by claiming that the receptors stimulated by the light background send inhibition to the receptors stimulated by the gray surface, causing its perceptual darkening. However, the receptors stimulated by the dark background send little inhibition to nearby receptors, and, therefore, there is not a darkening effect. The induction of perceived lightness described by these models is also referred to as local contrast.

In other examples of simultaneous contrast, higher-level processes must be taken into account (Adelson, 1993; Agostini & Proffitt, 1993; Benary, 1924/1939; Gilchrist, 1980; Logvinenko, 1999; Schirillo, 1999a, 1999b; Todorović, 1997; White, 1979). These examples have been explained according to principles of perceptual organization (Gilchrist et al., 1999; Wertheimer, 1923/1939); that is, according to these explanations, the perceived color of a surface is determined primarily by the global contrast between the surface and the other colored surfaces to which it perceptually belongs and not simply by low-level processes of local contrast involving lateral inhibition. The term perceptual belongingness refers to the result of a connection process that unifies the specific perceptual attributes arising from perceptual spatial articulation, which is the result of a perceptual organization process selecting specific physical spatial relationships of a visual pattern.

Consider the following example. If a number of identical small disks are equidistantly spaced along the perimeter of a circle, perceptual organization processes acting on the physical attributes of this pattern will give rise to the perception of a circle of small disks. In other words, the circle arises from perceptual spatial articulation. Each individual disk then appears to belong to the circle. It is in this way that perceptual spatial articulation determines the specific belongingness relationships among the elements.

As mentioned, perceptual belongingness also determines the perception of the surface colors of areas in the visual field. Therefore, the lightness of a region is the result of the influence of one or more belongingness relationships (Agostini & Galmonte, 1999). In short, if an element in the visual field is necessary to complete a perceptual unit, then that element belongs to that unit. The features (color, size, orientation, etc.) of that element are affected by the features (color, size, orientation, etc.) of the unit to which it belongs.

Nevertheless, lateral inhibition is the predominant explanation of contrast phenomena. We report here a study testing a novel display with which, for the first time, we directly compared the effects of perceptual belongingness and local surround. Our results indicate that the contrast effect due to perceptual belongingness overrules local contrast.

EXPERIMENT 1

Our first experiment involved a simultaneous comparison. The experimental displays, which were presented on a computer screen, were two medium-gray dashed cubes,[1] one that had dark inducer corners and was placed on a light inducer background and a second that had light inducer corners and was placed on a dark inducer background (see Fig. 1). The light and the dark inducers at the corners had the same luminances as the light and dark fields. According to the local-contrast explanations of simultaneous contrast, the effect is determined only by the influence of the immediate surrounding regions; that is, it is determined only by the contrast between the medium-gray dashed lines and the inducer backgrounds. Moreover, the use of dashed lines particularly favored lateral-inhibition processes because each single element in these lines was totally surrounded by the background, and local contrast is more effective when the target is completely surrounded by the inducing field than when it is not.

On the contrary, according to the belongingness explanation, the medium-gray dashed lines are also contrasted with the color of the inducer corners. In fact, according to the previous definition of perceptual belongingness, the dashed lines are necessary to complete the cube and therefore belong to the corners, which, being of a different color, should affect the perceived color of the dashed lines.

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1. In this article, we use the term “medium gray” to refer to “middle gray” as used in the lightness literature.

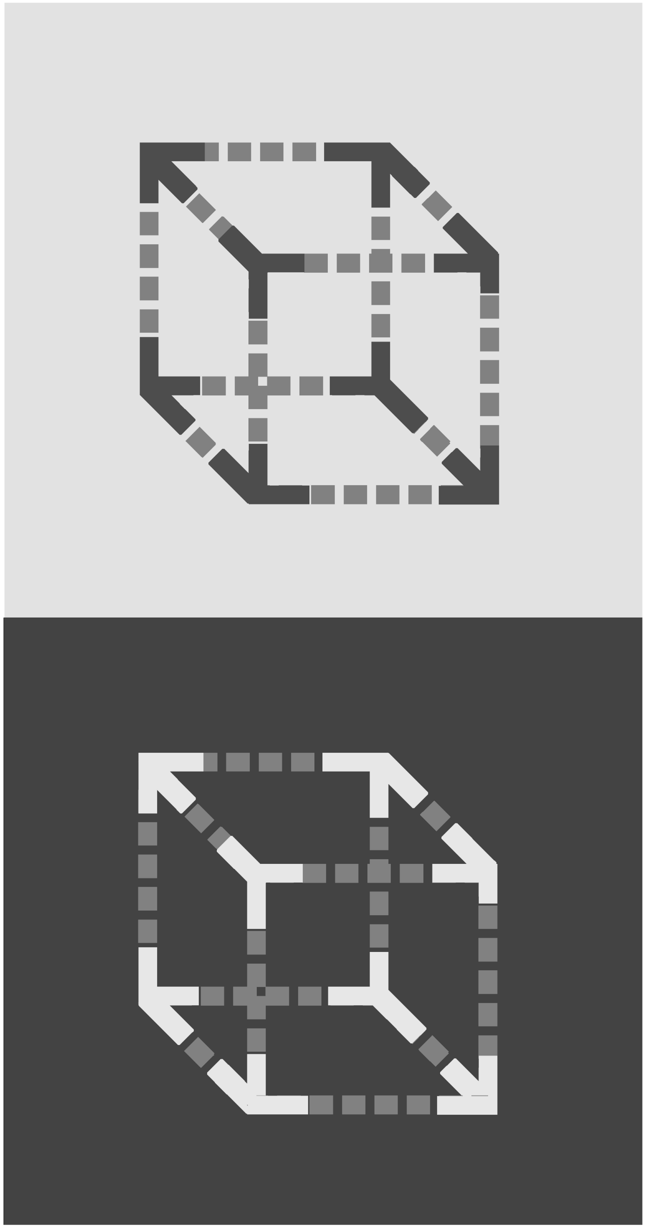

Fig. 1. The experimental display in Experiment 1. Observers were instructed to perceive the two cubes as wholes and then indicate which one was perceived lighter (or darker).

If local contrast prevails, then the medium-gray dashed lines of the cube surrounded by the light background should be perceived darker than the medium-gray dashed lines of the cube placed on the dark background; if belongingness prevails, the perceptual outcome should be the opposite because the inducer corners to which the dashed lines belong are dark when the background is light and light when the background is dark.

Twenty observers performed a two-alternative forced-choice task while viewing these cubes. The task was to indicate which cube (dashed parts) appeared lighter (or darker). The position of the cubes on the screen (left/right) and the question to be answered (lighter/darker) were counterbalanced.

It is important to emphasize that before observers performed the simultaneous lightness comparison, they were asked to perceive both cubes as three-dimensional structures and then to perceptually reverse them a couple of times. This procedure guaranteed a global judgment rather than a local one.

The results clearly favored perceptual belongingness. In fact, 20 of the 20 observers perceived the medium-gray dashed lines belonging to the dark inducer corners as lighter than the medium-gray dashed lines belonging to the light inducer corners.

EXPERIMENT 2

Many studies reported in the literature have focused on quantifying the size of local contrast, which has usually been found to be rather small and dependent on factors such as the spatial distribution of luminances and the number of luminances used to construct the display. (For a more detailed review of these issues, see Agostini & Bruno, 1996.)

In order to quantify the size of the effect found in Experiment 1, we performed a second experiment. In the experimental condition, we tested the same two cubes from Experiment 1, but this time separately (see Fig. 2). We asked observers to perform a matching task using a gray scale placed on the same background with the cube in each display. Placing the scale on the same background guaranteed that any local-contrast effects of the background on the scale elements would be the same as any local-contrast effects of the background on the elements of the test display. As a result, performance on the task reflected the strength of global factors only.

We also ran two control conditions. In the first, we tested two displays that were identical to the two experimental displays except that the inducer corners were, in this case, the same medium gray as the dashed target regions (see Fig. 3). Given that the dashed lines and the corners were the same shade of gray, we expected there would be no induction effect. In the second control condition, we controlled also for the luminance of the inducer corners. The two displays were identical to the experimental ones except that, in this case, disks having the same area and luminance (see Fig. 4) replaced the inducer corners. Under these conditions, the percept is that of a dashed cube that has all its corners occluded by disks. In this case, we did not expect the disks to affect the perceived shade of the dashed lines because the lines did not belong to the disks but amodally completed a cube behind them. Sixty observers, 10 for each display, participated in Experiment 2.

The method employed in this experiment can reveal high-level effects that act beyond the effects of the surround because the target regions and the scale are both affected by the same surround. Therefore, in all the conditions, the magnitude of the local-contrast effect is equivalent. Comparing the size of the contrast effect between each experimental display and its corresponding control displays provides a relative measure of the strength of belongingness.

In both control conditions, we expected veridical judgments because eliminating the belongingness factor left only the local-contrast factor, and the effect of local contrast was canceled out by virtue of the scale being placed on the same background. Specifically, in the first control condition, the inducer corners were replaced by identical regions having the same color as the dashed lines, whereas in the second control condition, the disks had the same luminance and area as the inducer corners of the experimental displays but did not belong to the rest of the cube.

Observers were asked to perceive the cube as a whole and then to perceptually reverse it a couple of times before matching the lightness

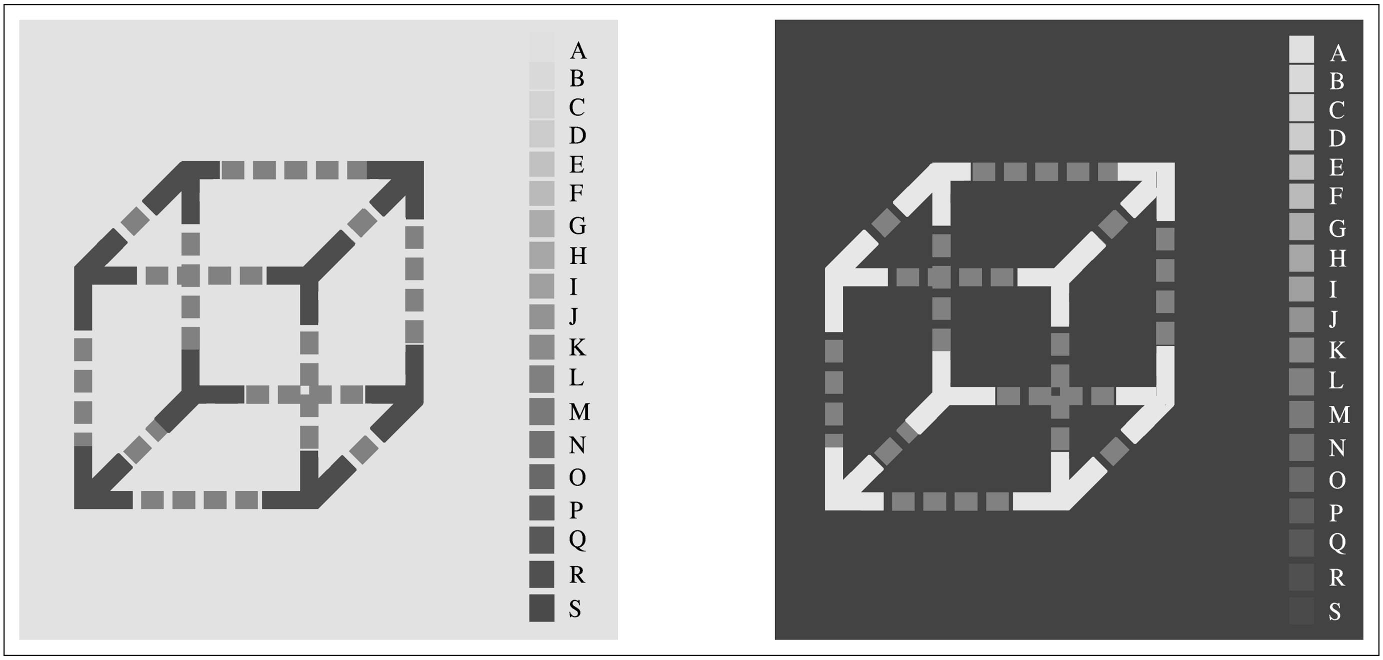

Fig. 2. The two experimental displays in Experiment 2. Observers were instructed to perceive the cube as a whole and then to select from the Munsell scale the shade of gray most similar to that of the dashed lines.

of the medium-gray dashed lines with the patches on the scale. This procedure guaranteed a global judgment rather than a local one.

The results are depicted in Figure 5. A factorial analysis of variance performed on the differences between the mean judgments of the observers and the objective value (5.5 Munsell units) for all the conditions revealed a main effect of display, $F(5, 54) = 31.5$, $p < .0001$. A Fisher post hoc analysis indicated that this effect was entirely due to the differences between the two experimental displays and between each experimental display and its respective control displays (*p*s $< .0001$). In each control condition, the differences between the two displays were

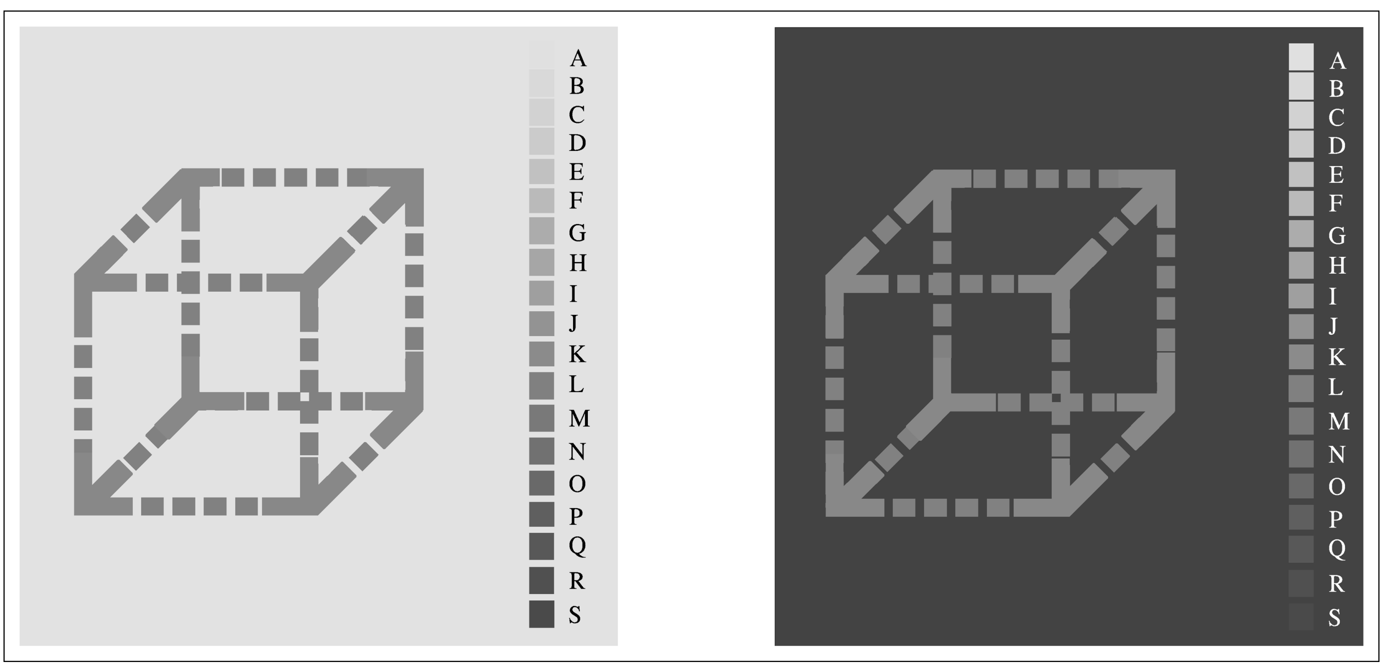

Fig. 3. Displays used in the first control condition in Experiment 2. In these displays, the inducer corners were filled by the same gray as the dashed lines. Observers were instructed to perceive the cube as a whole and then to select from the Munsell scale the shade of gray most similar to that of the dashed lines.

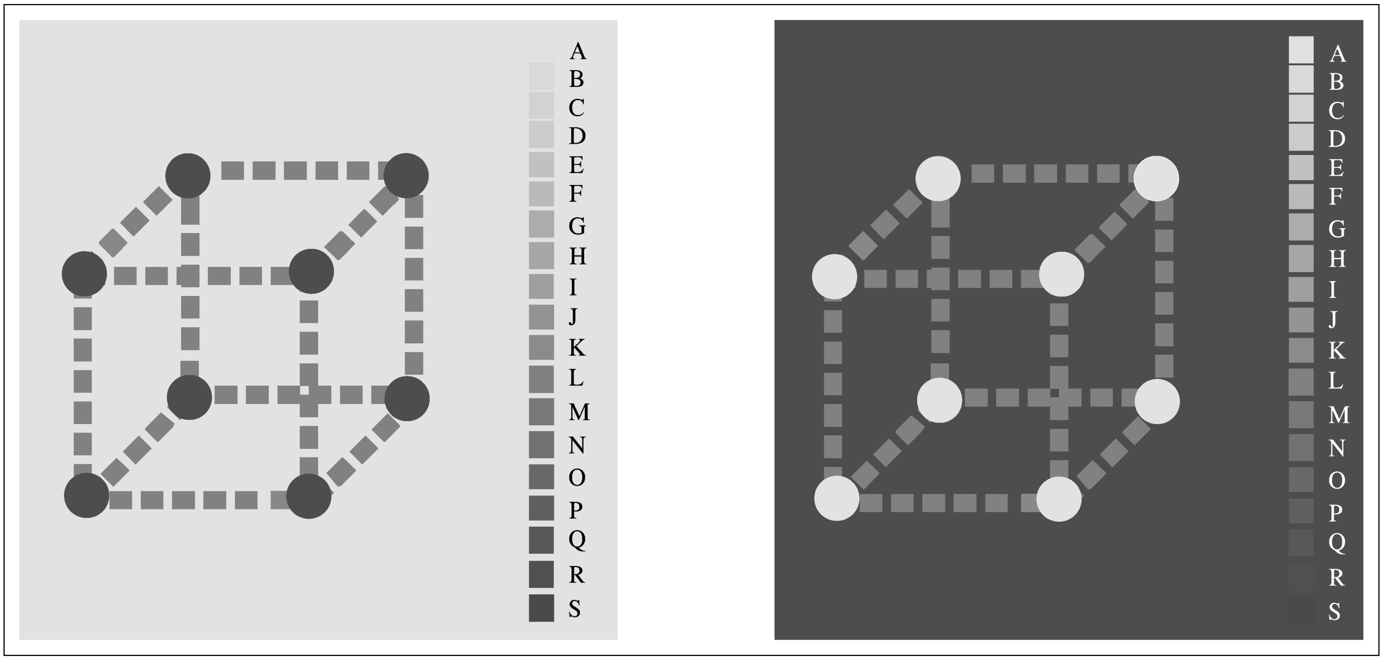

Fig. 4. Displays of the second control condition in Experiment 2. In these displays, disks having the same area and luminance as the inducer corners of the experimental condition replaced the corners. Under these conditions, the percept is that of a dashed cube that has all corners occluded by disks. Observers were instructed to perceive the cube as a whole and then to select from the Munsell scale the shade of gray most similar to that of the dashed lines.

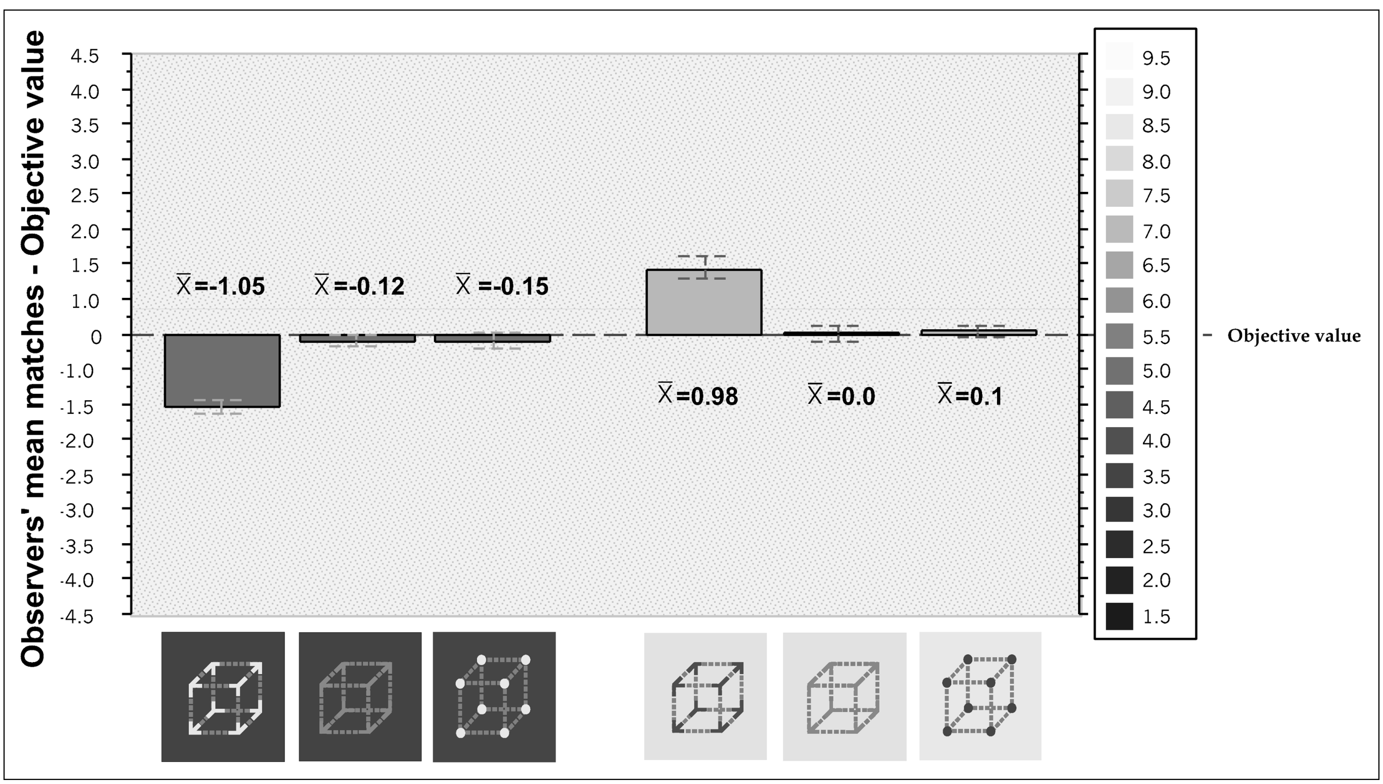

Fig. 5. Results of Experiment 2. For each display, the histogram shows the difference between the objective value of the gray target region and the observers' mean judgment of the gray target region.

not significant; the differences between comparable displays of the two control conditions were not significant either. Also, a one-sample *t* test showed that the observers' judgments were not statistically different from the objective value in each for the four control displays.

The difference between the mean value of the matches and the objective value for each of the two experimental displays was different from zero in the direction of simultaneous lightness contrast; that is, inducer corners of higher luminance produced lower matches, and vice versa. When belongingness was no longer a contributing factor to the effect (i.e., in each of the control conditions), the difference between observers' judgments and the objective value was statistically indistinguishable from zero.

This pattern of results indicates that the observed effect is not due to assimilation from the background, but rather is due to contrast with the inducers at the corners. If assimilation were the mechanism underlying the effect, hiding or removing the corners should have had no effect on the perceptual outcome.

It is important to note that each experimental display must be compared with its two control displays. The results reported in Figure 5 are a relative measure of the strength of belongingness; the lightness matches for the two experimental displays cannot be compared directly because they were obtained using the same scale on two different backgrounds. But because the means of the observers' matches for all four control displays were not statistically different from the objective value, it is proper to make an indirect comparison between the matches for the two experimental displays.

Observers' matches for the experimental displays indicated that the dashed lines belonging to the dark inducer corners appeared lighter than the dashed lines belonging to the light inducer corners. Specifically, the difference in the values of the matches corresponded to approximately 2 Munsell units. This difference, which is attributable to the global factor only, was symmetrically distributed.

CONCLUSION

The first experiment shows that in a direct comparison, global factors prevail over local ones in determining lightness contrast, whereas the second experiment provides a measure of the size of the contrast effect induced by belongingness in a stimulation condition in which the local influence has been "silenced." In light of the results of these experiments, we can infer that the total size of the induction effect due to local factors must be smaller than the total size of the induction effect due to global factors.

Even though the stimuli were designed to favor local contrast, low-level explanations fail to explain the results. The results are inconsistent with the traditional explanations of perceptual contrast phenomena because they show that when low- and high-level mechanisms act simultaneously, the latter overcome the former. It is important to remember that the results of the present research do not mean either that local contrast does not affect lightness or that the effect of local contrast is canceled by high-level factors. What our results demonstrate is that under conditions in which it is possible to measure the relative strength of perceptual organizational factors, belongingness prevails over local contrast. Therefore, in order to account for these results, induction models (e.g., Blakeslee & McCourt, 1999; Ross & Pessoa, 2000) must also include higher-level processes that compute perceptual belongingness relationships.

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