Article

PERCEPTION

Perception
2015, Vol. 44(12) 1383–1399

DOI: 10.1177/0301006615607118
pec.sagepub.com
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Grouping Factors and the Reverse Contrast Illusion

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Abstract

In simultaneous lightness contrast, two identical gray target squares lying on backgrounds of different intensities appear different in lightness. Traditionally, this illusion was explained by lateral inhibitory mechanisms operating retinotopically. More recently, spatial filtering models have been preferred. We report tests of an anchoring theory account in which the illusion is attributed to grouping rules used by the visual system to compute lightness. We parametrically varied the belongingness of two gray target bars to their respective backgrounds so that they either appeared to group with a set of bars flanking them, or they appeared to group with their respective backgrounds. In all variations, the retinal adjacency of the gray squares and their backgrounds was essentially unchanged. We report data from seven experiments showing that manipulation of the grouping rules governs the size and direction of the simultaneous lightness contrast illusion. These results support the idea that simultaneous lightness contrast is the product of anchoring within perceptual groups.

Keywords

lightness perception, simultaneous lightness contrast, anchoring theory, grouping factors, reverse contrast

Introduction

The simultaneous lightness contrast illusion has a classic status because it shows so clearly that the perceived grayness of a surface (called lightness) does not correlate with the intensity of light it reflects to the eye (called luminance), except in the special case in which illumination does not vary. Something about the context plays a crucial role. But what? In the 19th

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century, Hering (1874/1964) proposed that the answer lies in "reciprocal interactions in the somatic visual field." Specifically, although the two squares produce equal degrees of neural excitation at the retina, the intense stimulation produced by the white background suppresses the neural excitation of the square region it surrounds. Following the discovery of lateral inhibition in the middle 20th century, Hering's account became an almost universally accepted explanation of simultaneous lightness contrast. In recent decades, the illusion has been attributed to spatial filtering mechanisms operating on the retinal image (Blakeslee & McCourt, 1999, 2004).

Until recently, no Gestalt (so-called mid-level) explanation of simultaneous lightness contrast has been put forward. Anchoring theory (Gilchrist et al., 1999) provided the theoretical background for a novel account of this illusion. Central to this approach is the concept of frame of reference, that is, a group of image regions that are perceptually grouped together, with corresponding grouping rules. The theoretical claims about the role of frames of reference in the simultaneous lightness contrast illusion have been examined in a series of experiments by Economou, Zdravkovic, and Gilchrist (2007). In that study, the predictions of anchoring theory were pitted against those of spatial filter models and the conclusions favor the mid-level explanation proposed by anchoring theory.

The basic claim of anchoring theory is that the lightness of a given target surface is a weighted average of the lightness value computed for that target in its local frame of reference and in the global framework. In the simultaneous contrast illusion, these frameworks are quite obvious; the display can be said to consist of two local frameworks, each composed of a target and its immediate surround, and a global framework, consisting of the entire display. Strictly speaking, the global framework refers to the entire visual field, but as the larger context surrounding the illusion is a constant in our experiments, we will treat the simultaneous contrast illusion itself as the global framework. Local frameworks generally follow the traditional gestalt grouping principles. In the domain of lightness perception, several important factors have been identified, including surroundedness, proximity, coplanarity, and type of junction (Gilchrist et al., 1999). Within any framework, the computed lightness value of a surface is given by the simple formula "Perceived reflectance = Target luminance/Highest luminance × 90%."

Thus, while the two targets have the same value in the global framework, they have very different values in their local frameworks. The target surrounded by black, in its local framework, has a value of white because it *is* the highest luminance within that framework. The target surrounded by white, in its local framework has gray value similar to its actual value (though darkened somewhat by some normalization of the range[1]). But although the two local values (middle gray vs. white) are quite different, the final perceived values, once the global values (equal for the targets) are factored in, are not. An equivalent interpretation of this illusion was outlined by John McCann in 1987. The weight assigned to local frameworks appears to depend mainly on the number of elements it contains called articulation (Arend & Goldstein, 1987; Burzlaff, 1931; Gilchrist & Annan, 2002; Kardos, 1934; Katz, 1935). In the case of simultaneous contrast, the two local frameworks are poorly articulated, and thus, the illusion is only roughly 10% as large as it would be were it based solely on the local values as suggested by Wallach (1948). But despite the modest weights on the local values, they are seen as the source of the illusion. More broadly, the claim is that simultaneous lightness contrast is the product of anchoring within perceptual groups

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[1] According to the scale normalization component of anchoring theory, the range of perceived values tends to normalize on the (30:1) range from white to black. When the actual range is less than 30:1, as in the white background plus gray target, some expansion occurs. The same occurs on the black background, but this affects only the background, not the target, given that the range expands away from the anchor.

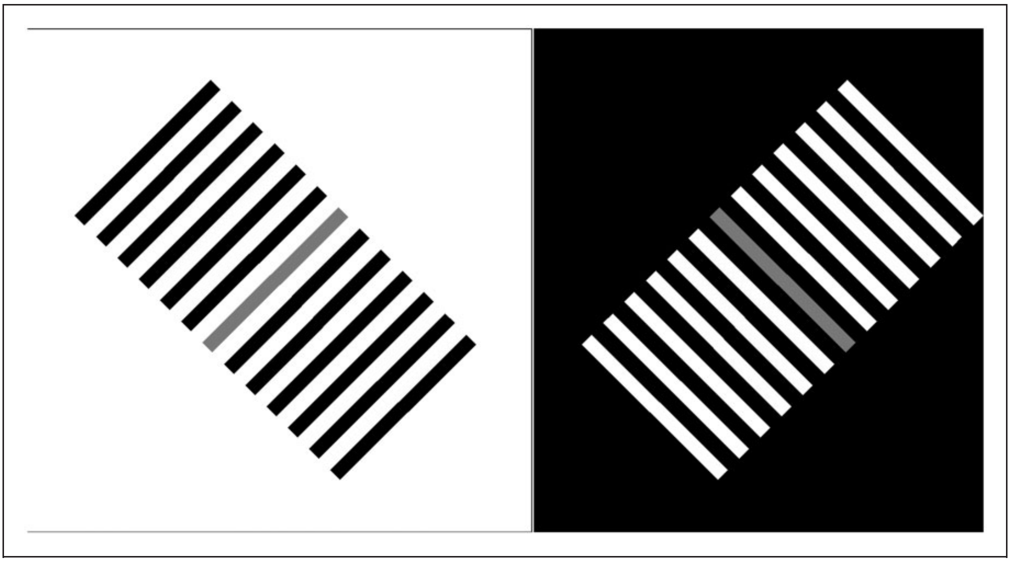

Figure 1. The reverse contrast illusion. Even though the gray bar on the right is totally surrounded by black, it appears darker than the identical bar on the left.

(Economou et al., 2007). The contrast effect is produced, not because the targets are retinally adjacent to their respective backgrounds, but because they are perceptually grouped with their backgrounds due to surroundedness. Although the two concepts might seem similar, they are different.

Consistent with this view of the illusion, we reasoned that it would be possible to use perceptual grouping to reverse the direction of the illusion.

In Figure 1, we present a variation of simultaneous contrast that illustrates the role of perceptual organization by reversing the direction of the illusion (Economou et al., 2007). The gray bar on the right, even though totally surrounded by black, appears darker than the target on the left, which is totally surrounded by white. We reversed the direction of the illusion by creating a new local framework consisting of the target bar plus the flanking bars. This new framework competes with the original framework consisting of the target bar plus its immediate (black or white) background. Thus, in this more complex display, each target bar is a member of two local frameworks as well as the global framework.

This pattern makes the role of grouping plain to see. Bressan (2001) and Agostini and Galmonte (2002) have reported reverse contrast effects using analogous patterns.

We further reasoned that by manipulating the grouping factors (Wertheimer, 1923) on which each group of bars depends, we should be able to change the strength of the lightness illusion.

General Methods

For Experiments 1 through 7, the stimuli were presented on a CRT screen. The illusion measured 36 cm wide by 18 cm high. Each bar was 65 mm by 7 mm. Luminance values were 0.89 cd/m^2 for the black background and black bars, 25.0 cd/m^2 for the white background and white bars, and 7.91 cd/m^2 for the gray target bars. The observer was seated in a chair at a viewing distance of approximately 70 cm. Thus, each bar subtended a visual angle of 5.3° (length) and 0.57° (width), and each background subtended 14.7°. We employed a between-subjects design (i.e., a separate groups of observers was used for every condition in every experiment). Subjects were asked to pick a chip from a standard Munsell scale that matched the lightness of each of the two targets in the stimulus. The difference between the targets gave the strength of the illusion.

The subjects were undergraduate students at Rutgers University who volunteered to satisfy a course requirement. The experiments were carried out in accordance with the relevant institutional and national regulations and legislation and with the World Medical Association Helsinki Declaration as revised in October 2008.

Experiments

Experiment 1: Articulation Variation

Our first experiment tested the effect of the number of flanking bars in the group. Katz (1935) was the first to observe that the degree of lightness constancy depends on the number of elements, which he called articulation, within an illumination framework. What Katz meant by articulation was a general complexity of a scene, although in his experiments he varied articulation by manipulating the number of surfaces belonging to an illumination framework (for a review, see Gilchrist & Annan, 2002). The important role of articulation can be seen in many empirical reports, including early studies by Burzlaff (1931) and Henneman (1935) and more recent work by Schirillo and Arend (1995), Cataliotti and Gilchrist, 1995), and Economouet al. (2007).

Within anchoring theory (Gilchrist, 2006; Gilchrist et al, 1999), the degree of articulation within a framework, defined as the number of elements composing the framework,[2] primarily determines the weight of the lightness value computed within that framework. In our reverse contrast display, the local framework that is composed of the target plus its flanking bars is well articulated compared with the group composed of the target plus its retinally adjacent (large black or white) background. Apparently, the weight given to this flanking-bar framework is sufficient to reverse the ordinary contrast effect. If this analysis is valid, then we expect to find a decrease in the size of reverse contrast with decreasing articulation.

Method. Four displays were used in this experiment: a standard contrast display and the basic reverse contrast display with 12, 6, and 2 flanking bars for each target, as indicated by the icons in Figure 2. Each display was seen by a different group of observers, numbering 16, 11, 12, and 12 observers, respectively, from top to bottom. Data from the zero-bar standard contrast display are reported in Figures 2 to 7 as well, and data from the full 12-bar reversed display are reported in all figures except Figure 4.

Results. The size and direction of the illusion is presented in Figure 2. The x-axis shows the difference in matched reflectance for the two target bars. The vertical line represents the veridical percept or no illusion. Bars extending to the left of the line show a standard simultaneous contrast effect, while bars extending to the right of the line indicate a reversed effect.

As can be seen from this graph, the largest reverse contrast effect was obtained when articulation was highest. Decreasing articulation resulted in smaller reverse contrast effects and a standard contrast effect was obtained, of course, in the control condition with no

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[2] There are some reports claiming that the number of distinct luminance values is also an articulation factor (Soranzo et al., 2006; Zdravkovic, 2007). For the purposes of this paper, however, the operational definition of articulation considers only the number of surfaces and not luminances.

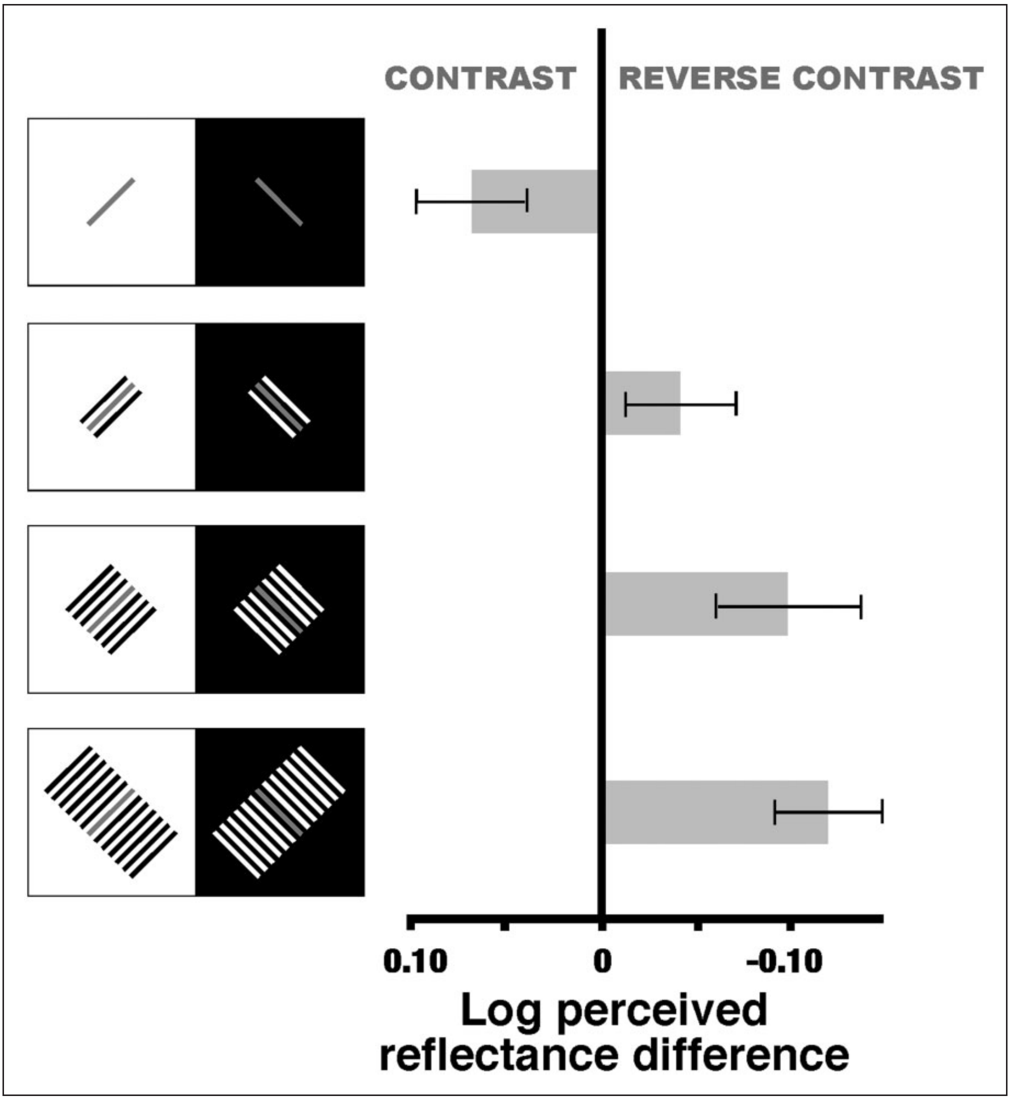

Figure 2. Lightness versus articulation. The reverse contrast effect decreases with decreasing articulation.

flanking bars. The overall effect of articulation on target lightness was significant, one-way analysis of variance (ANOVA): $F(3, 47) = 7.13$, $p > .001$. The difference between the effect observed for the standard reverse contrast condition and that for the two flanking-bar conditions was also significant, $t(22) = -1.72$, $p < .05$.

Discussion. The results confirm the anchoring theory prediction that with increased articulation, the reverse contrast effect goes in a direction consistent with the lightness computations in the flanking-bar framework. Reducing the number of elements in that framework, however, gradually shifts the direction of the effect to that produced by the framework consisting of the target and its immediate background. It should be noted that in this experiment, articulation covaries with framework size, known to be a factor in framework strength (Gilchrist et al., 1999). However, the effect of articulation is much

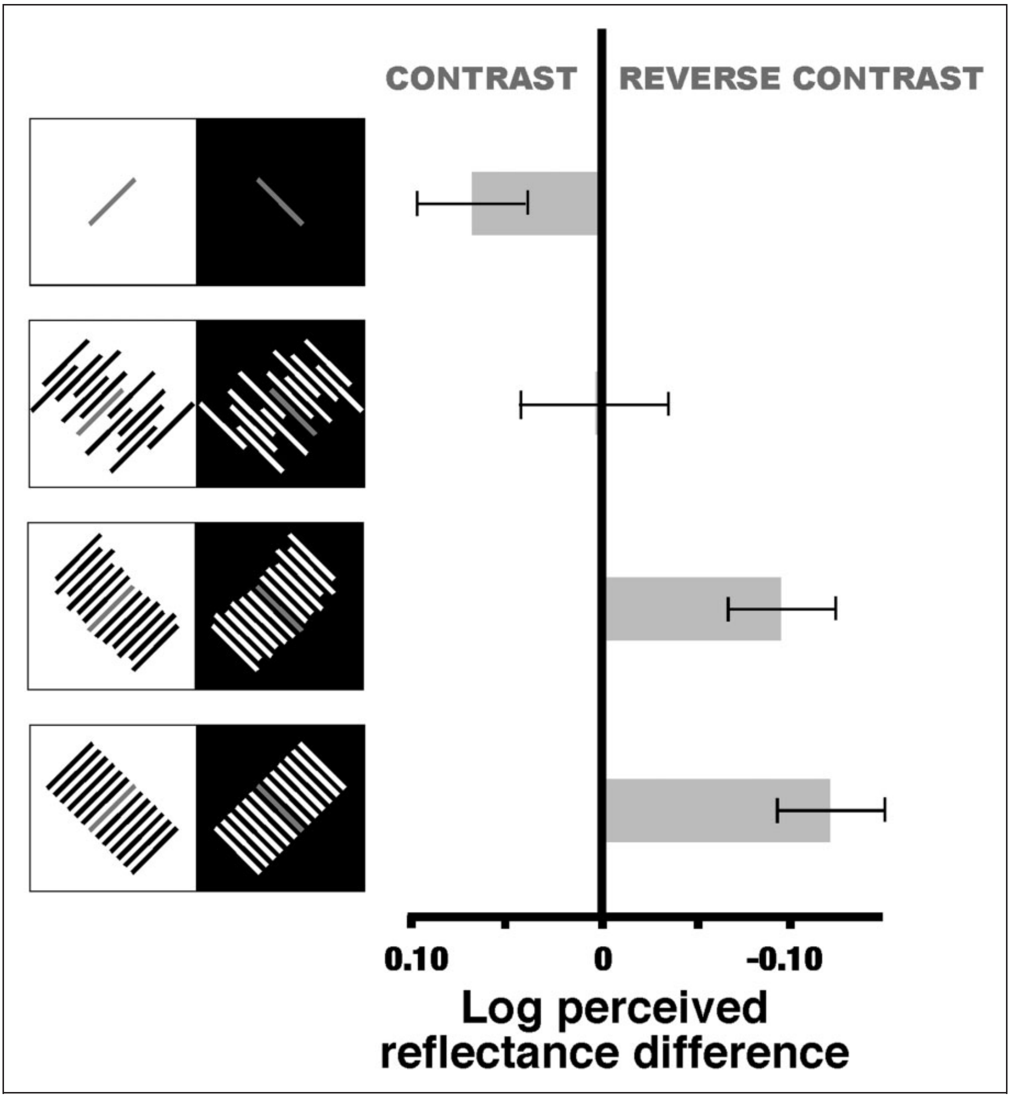

Figure 3. Lightness versus good continuation of the endpoints. The reverse contrast effect decreases with decreased good continuation.

larger than the effect of framework size; it is likely that our effect is due mainly to articulation.

Experiment 2: Good Continuation Variation

Experiment 2 tested the effect of the alignment (good continuation) of the endpoints of the bars. Good continuation is an old gestalt grouping principle. It has been shown to affect shape perception (Kanizsa, 1979) and subjective contours. Our hypothesis was that disrupting the alignment of the endpoints would weaken the group and thus produce a smaller reverse contrast effect.

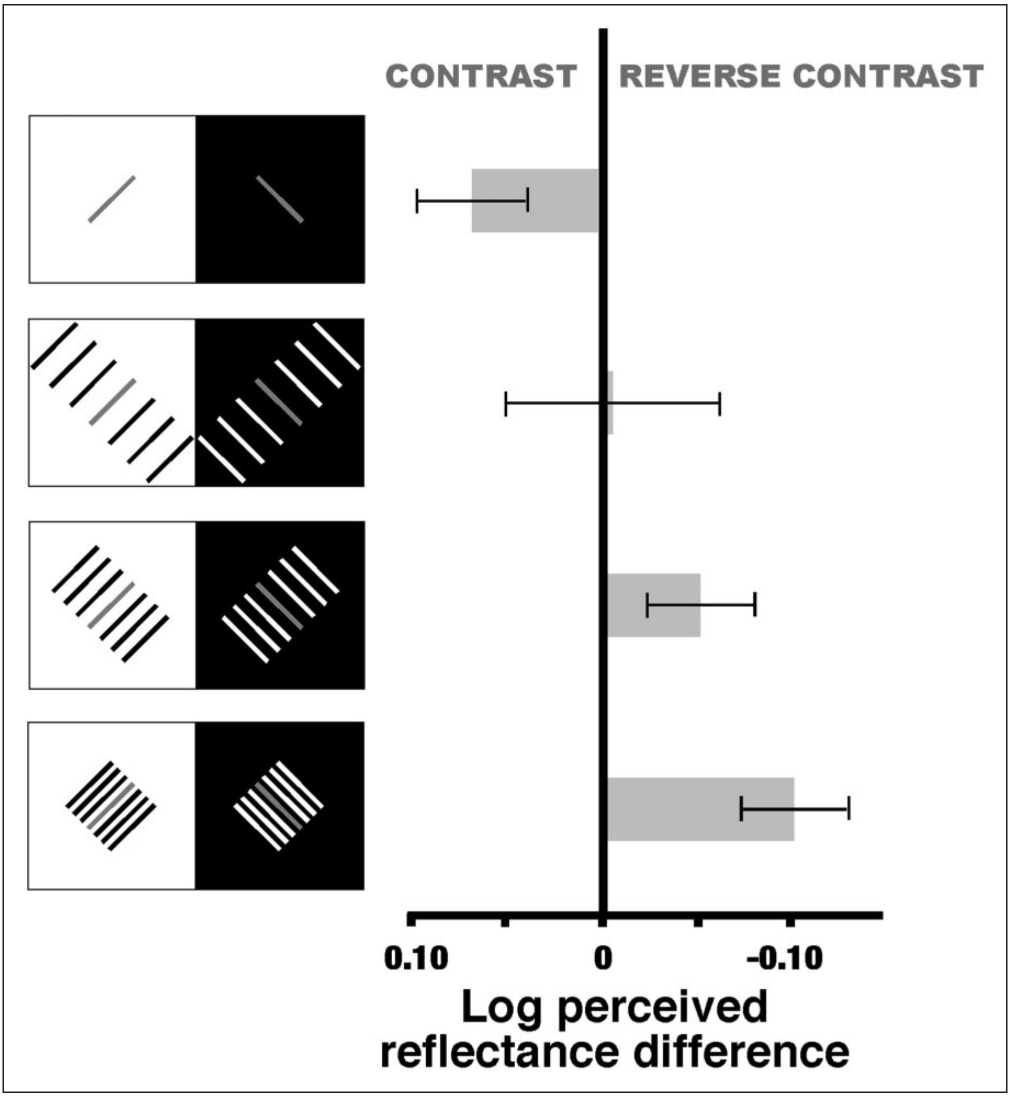

Figure 4. Lightness versus proximity.

Method. Two new displays representing two degrees of misalignment (moderate and pronounced) of the endpoints were used (Figure 4). A separate group of 12 observers viewed each of the new displays.

Results. The results are shown in Figure 3, along with those for the two standard displays of the previous experiment. The reverse contrast effect declined significantly as the disruption of the alignment of the bar endpoints became more pronounced, one-way ANOVA: $F(2, 33) = 3.82$, $p < .05$.

The size of the reverse illusion in the standard condition (0.12 log units) was significantly larger than that observed in the condition with pronounced misalignment (0.01 log units) [$t(22) = -2.38$, $p < .05$]. Also the reverse illusion from the moderate misalignment condition (0.10 log units) was statistically larger than that in the pronounced misalignment condition ($t(22) = -2.15$, $p < .05$).

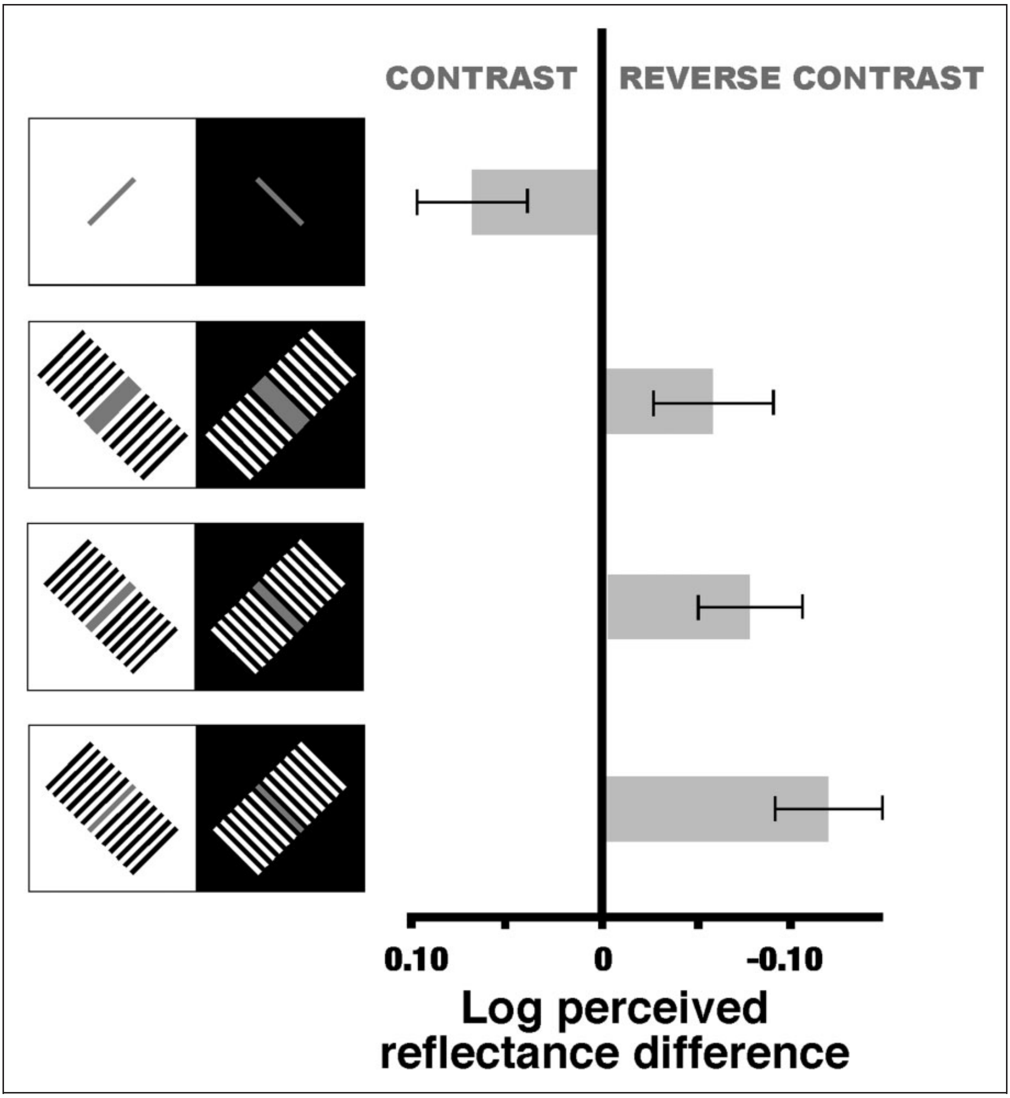

Figure 5. Lightness versus similarity.

Discussion. These results are consistent with our grouping hypothesis. Good continuation between the target and flanking bars results in strong reverse contrast effects. Disruption of the good continuation of this group, however, gradually weakens the effect.

Experiment 3: Proximity Variation

This experiment tested the effect of proximity among the bars. According to gestalt theory, the belongingness among elements of a group (and thus the strength of the group) should increase with an increase in their proximity (Rock & Brosgole, 1964). For reverse contrast, this means that increasing the distance between the bars should weaken the illusion.

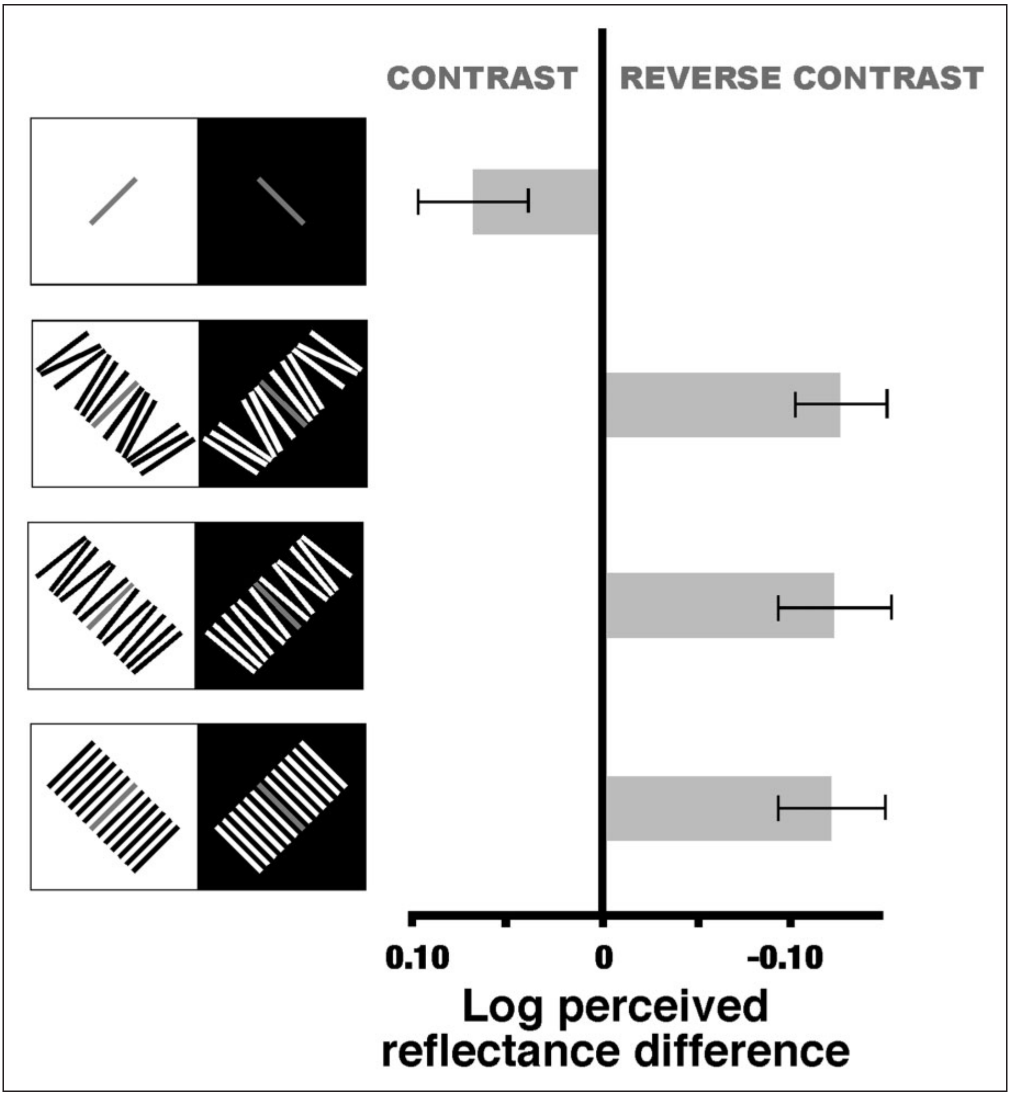

Figure 6. Lightness versus orientation similarity. Changing the orientation of all bars did not affect the reverse contrast illusion.

Method. To allow for increased separation between bars, the six-bar display from Experiment 1 was compared with two additional displays that were created by doubling the original 7-mm distance between the bars to 14 mm for one display (moderate proximity condition), and doubling this to 28 mm for the second display (poor proximity condition). Two separate groups of 10 subjects viewed the new displays.

Results. The results are shown in Figure 4. The overall effect of proximity did not reach statistical significance, one-way ANOVA: $F(2, 27) = 1.41$, $p > .05$.

Discussion. Although our results failed to show a significant effect of proximity on reverse contrast (RC), the trend in the data and the established role of proximity in lightness

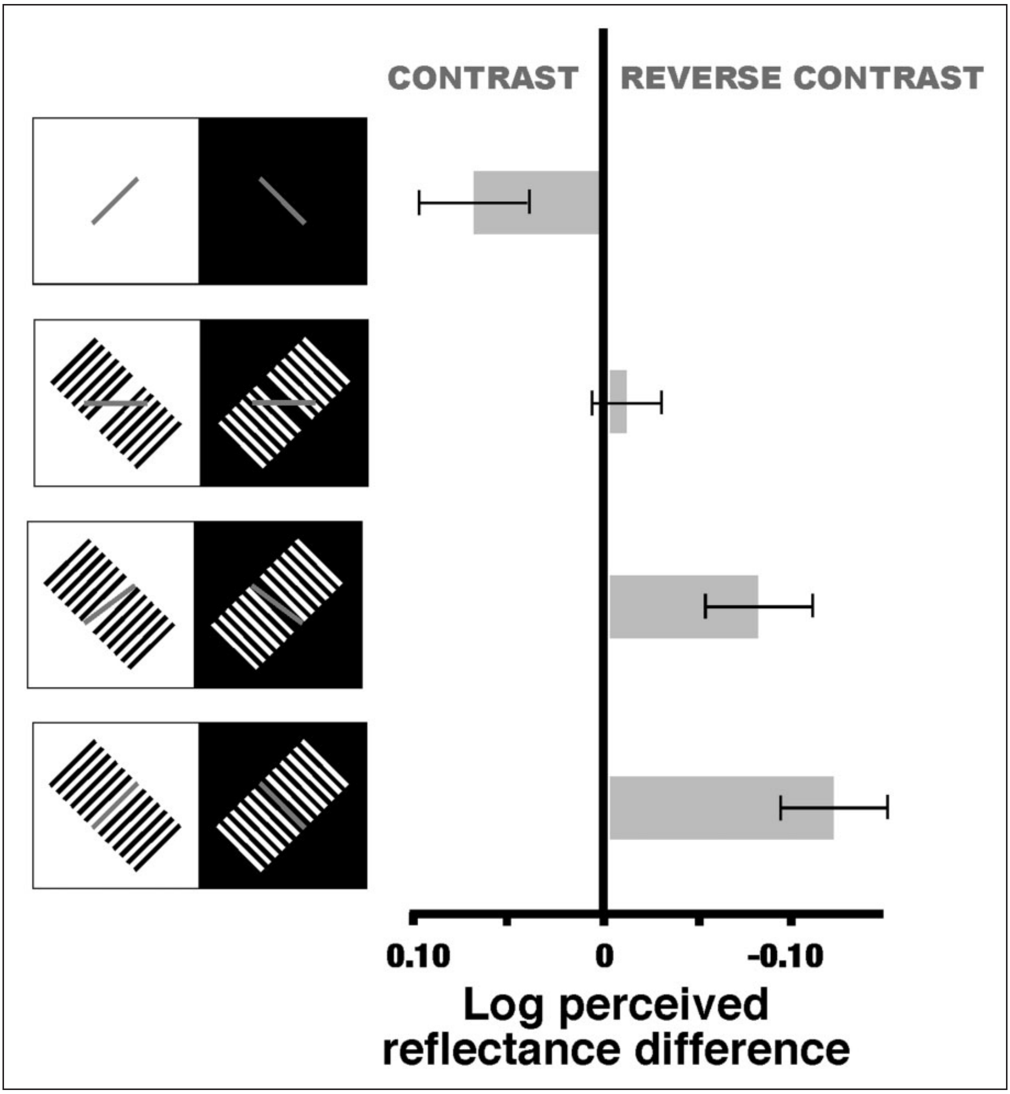

Figure 7. Lightness versus target orientation. The reverse contrast effect decreases as the orientation of the target bar changes.

(Leibowitz, Mote, & Thurlow, 1953; Newson, 1958) suggest that a larger separation among bars would have produced a significant effect on illusion size.

Experiment 4: Similarity Variation

Method. Next, we tested the effect of similarity between target-bar width and flanking-bar width. Two additional displays were created by increasing bar width to 14 mm (moderate similarity) and 28 mm (poor similarity), respectively. We predicted a decreased reverse contrast effect as bar width similarity increased. Two additional groups of 10 subjects each viewed the two new displays.

Results and discussion. The results from Experiment 4 are shown in Figure 5. The overall effect of similarity did not reach statistical significance, one-way ANOVA: $F(2, 29) = 0.95$, $p > .05$, although the pattern of results hints that a larger increase of the target-bar width would produce significance.

Experiment 5: Orientation Variation

This experiment tested the effect of the common orientation of the bars on reverse contrast. Our hypothesis was that differences in bar orientation would result in a weaker group and a weaker reverse contrast illusion.

Method. Two new displays were designed, one in which the bars were rotated (clockwise and counterclockwise) by 3°–7°, and one by 8°–17°. Two separate groups of 11 and 10 subjects, respectively, viewed the new displays.

Results. The results are shown in Figure 6. To our surprise, disrupting the bars' common orientation did not affect reverse contrast. The means between the three conditions were virtually identical (0.12, 0.12, and 0.13 log units, respectively) and the overall effect of orientation was not significant, one way ANOVA: $F(2, 30) = 0.03$, $p = .93$.

Discussion. These results did not confirm the hypothesis that disrupting common orientation will weaken the reverse contrast illusion. Gillam (1987), however, has shown that, when endpoints retain their alignment, the endpoints of a set of parallel bars form a weaker contour than those of a group of bars with scrambled orientation. It is possible then that the reason for the null result obtained in this experiment is that the strength of the group decreased by means of orientation similarity but increased by means of contour strengthening, and the two effects cancelled each other out. This idea was tested in the next experiment.

Experiment 6: Target Orientation

In Experiment 6, the orientation of only the target bar was varied, allowing a test of orientation similarity without changing the strength of the contour.

Method. The displays for Experiment 6 are shown in Figure 7. Two new displays were created by rotating the target bars 7° for one display (small rotation) and 45° for the second display (large rotation). Two groups of 10 subjects each viewed the two new displays.

Results. The results from this experiment are shown in Figure 7. As the orientation of the target bars deviated from the orientation of the flanking bars, the reverse contrast effect grew smaller. The overall effect of target orientation on the size of the illusion was significant, one-way ANOVA: $F(2, 29) = 3.49$, $p < .05$. In addition, the reversed effect for the standard reverse contrast condition (0.12 log units) was significantly larger than the effect for the large rotation condition (0.01 log units), $t(17) = -2.75$, $p < .01$. The reversed effect from the small rotation condition (0.08 log units) was also significantly larger than that of the large rotation condition, $t(18) = -1.92$, $p < .05$.

Discussion. These results are consistent with the hypothesis that common orientation between target and flanking bars functions as a grouping factor that affects lightness. Rotating the flanking bars weakens their belongingness to the group and shifts the direction of the effect.

These results support our suggestion that we failed to obtain an effect for common orientation in Experiment 5 because the weakening of the group by orientation dissimilarity, was counterbalanced by a strengthening of the contour formed by the bar ends.

It should also be noted that in the large rotation condition, the target bars come into direct adjacency with the flanking bars. This is not a problem because, according to traditional contrast models, such contact should work against contrast between target and background thus increasing the reverse contrast effect. However, the opposite occurred.

Experiment 7: Stereo Depth Variation

In Experiment 7, we manipulated grouping strength using variations in perceived depth. Each target bar in the reverse contrast display can be said to be a member of two competing frameworks: (a) target plus flanking bars and (b) target plus immediate background. Complete belongingness with the background results in a standard contrast effect while belongingness with the flanking bars results in a reversed effect.

A way to test this idea comes from experiments done by Gilchrist in 1980. In these experiments, Gilchrist varied the apparent position of a target surface in depth. The results show that surfaces that appear to belong to the same plane will group with each other while surfaces that appear to belong to different planes will not. Gilchrist coined the term *coplanar ratio principle* to describe the effect and to distinguish it from the simpler ratio principle that had been proposed earlier by Wallach in his seminal 1948 paper. According to the coplanar ratio principle, the lightness of a surface will be affected mainly by the surfaces that appear to belong to the same plane and not by other surfaces that are placed in different planes even if retinally they are closer together. The idea that contrast phenomena depend on depth relations among the surfaces in the scene had been proposed and tested earlier by Kardos (1934). It should be possible then to obtain similar depth effects by varying the depth relations among the target bars, the black and white backgrounds, and the flanking bars.

Method. Five displays (each 33 cm by 24.5 cm), using horizontal bars, were created on a calibrated 21″ silicon graphics image monitor with stereo glasses. The monitor was approximately 70 cm from the observer's eye. Luminance values were as follows: black ground and bars, 0.89; white ground and bars: 111; and target bars: 42.7 cd/m^2.

In the first display (bottom icon in Figure 8), all bars and backgrounds appeared at the same depth in the frontal plane. In the second display, the black and white backgrounds were moved backward by an apparent distance of 10 cm (judged by E. E. and one other observer) while the target bars and their flanking bars remained at the nearer plane. In the third display, the target bars were moved halfway between the flanking bars and the backgrounds (same method as above was used). In the fourth display, the targets were moved into the same plane with the backgrounds. In the final display, the flanking bars were eliminated creating a standard contrast display.

A paper Munsell chart (33 cm by 10 cm) under normal room illumination (white patch luminance = 103 cd/m^2) was presented to the right of the subject.

A separate group of 10 subjects matched the lightness of the gray targets in each of the five conditions.

Results. The results from the depth variation experiments, shown in Figure 8, are consistent with our hypothesis and Gilchrist's coplanar ratio principle. The overall effect of coplanarity on the reverse contrast effect was significant, one-way ANOVA: $F(3, 36) = 4.65$, $p < .01$. The mean illusion size for the standard reverse contrast display was 0.17 log units. In the second

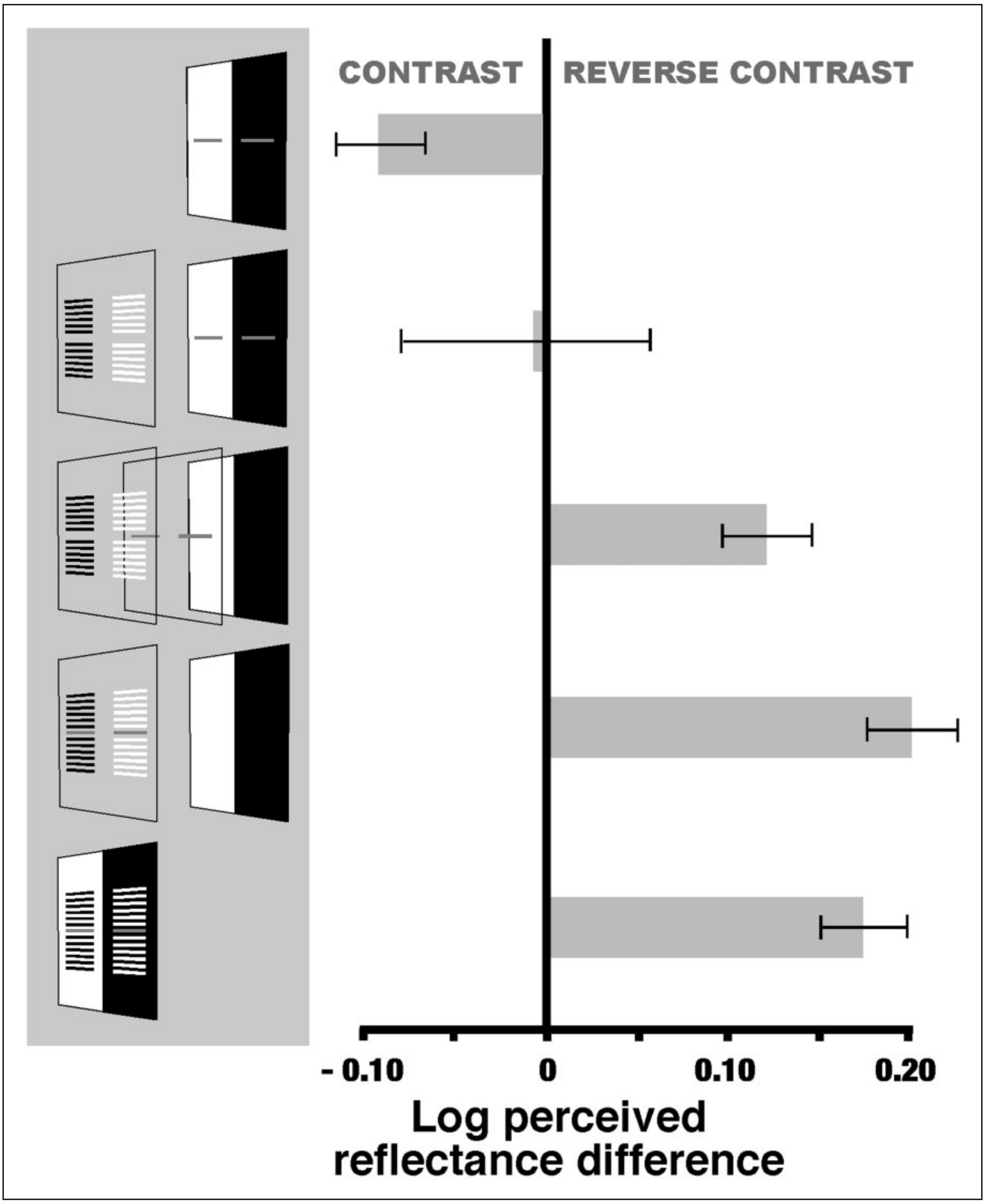

Figure 8. Data from the stereo experiment. Reverse contrast effects are stronger when the target bar appears at the same plane with the flanking bars.

condition (target coplanar with bars but not with background), the reversed effect was 0.20 log units, slightly increased from the first condition, although the difference was not statistically significant, $t(18) = 0.91$, $p > .05$. In the third condition (target between bars and background), the reversed effect was 0.12 units, significantly smaller than the effect observed in the second condition, in which the targets are coplanar with the bars, $t(18) = -1.93$, $p < .05$. In the fourth condition (target coplanar with background), the illusion was eliminated (0.01 log units, standard contrast direction). Finally in the control contrast condition, a standard contrast effect was obtained (0.09 log units).

However, one important difference should be noted. The effect of coplanarity in this experiment, was not all-or-none as suggested originally by Gilchrist but rather gradual as suggested by Kardos (1934) and amended by Gilchrist (2006). For example, in Condition 3, when the target bars appear in a plane halfway between the flanking bars and the background, the contrast illusion is half as great as in Condition 2 when the target and flanking bars are in the same plane. This suggests that the flanking bars continue to exert an influence on the target's lightness even when they are not in the same plane.

In these results, we also see an effect of depth on lightness in the absence of the extended luminance range found to be necessary by Gilchrist (1980), although these lightness effects are much smaller than those found by Gilchrist (see also Radonjić & Gilchrist, 2013).

General Discussion

The simultaneous lightness contrast illusion has been rather consistently and almost universally attributed to a low-level inhibitory effect. The lightness of each target contrasts with (i.e., is pushed away from) the lightness of its immediately adjacent neighbor. On the other hand, the mid-level account represented by anchoring theory argues that target lightness contrasts with the background region to which it perceptually belongs. In the classic simultaneous contrast illusion, these alternative explanations are confounded.

Perceptual grouping has been shown to influence many perceived qualitiessuch as perceived motion (Johansson, 1950) and perceived transparency (Metelli, 1970). Our results may be the first to show a parametric effect of perceptual grouping on lightness. However, the idea of a grouping/lightness linkage is a gestalt idea and can be found at least as early as 1924 in the work of Benary, a student of Wertheimer. The Benary effect shows that the perceived lightness of a gray triangle can be influenced by whether it is perceptually grouped with a black cross or its white background, even though the two triangles have adjacent neighbors of identical luminance. Coren (1969) manipulated the stereo depth relations among the gray triangles, the black cross, and the white background of the Benary effect and obtained results that are highly analogous to those we obtained in Experiment 7 (see Gilchrist, 2006, p. 323).

The Benary effect is weak. But in 1979, Michael White presented a much stronger version based on the same logic. In White's illusion, gray bars are placed on a black and white square wave pattern. Those bars that are collinear with, and thus appear to belong to, the black stripes appear lighter than those that are collinear with, and appear to belong to, the white stripes, creating an illusion opposite to what would be expected based on adjacent neighbors. White's illusion and the closely related Todorović illusion (1997) show an effect up to twice the strength of a simple simultaneous contrast display. Following the appearance of White's illusion, complete reverse contrast illusions—illusions in which a gray target completely surrounded by white appears lighter than an identical gray target completely surrounded by black—were reported by several labs (Agostini & Galmonte, 2002, Bressan, 2001; Economou et al., 2007). These reverse contrast illusions follow the same scheme. The gray target on a black background is made to appear to belong to a pattern of white elements placed on the black background, while the converse is done for the other target.

Koffka (1935) invoked the role of perceptual grouping in lightness, writing "a field part ***x*** is determined in its appearance by its 'appurtenance' to other field parts. The more ***x*** belongs to the field part ***y***, the more will its ***whiteness*** be determined by the gradient ***xy***, and the less it belongs to the part ***z***, the less will its whiteness depend on the gradient ***xz***" (p. 246).

If the contrast illusion is a product of anchoring within perceptual groups, it should be possible to modulate the strength, and indeed the direction, of the illusion merely by manipulating grouping factors. We varied four grouping factors that quite obviously support the perception of the groups of bars: bar similarity, bar proximity, bar orientation, and good continuation of bar end points. In general, reduction in the strength of these factors was associated with a reduction in the magnitude of the lightness illusion. Varying the number of bars in each group also modulated illusion strength. In our final experiment, we varied the proximity in depth between target and flanking bars and between the target bars and their backgrounds, obtaining results consistent with the grouping hypothesis.

Why might lightness depend on perceptual grouping? Helmholtz (1866/1924) suggested that, to achieve constancy, the illumination level must be taken into account. But requiring the system to know the illumination level is unrealistic and unnecessary. All the visual system needs to know is which patches in the retinal image share the *same* level of illumination. If patches in the proximal stimulus can be perceptually grouped by illumination level, computation of lightness within each group becomes quite simple. The highest luminance within the group is treated as white and the lightness of any darker patch depends merely on the luminance ratio between that patch and the highest luminance. In addition, however, one must factor in the interactions among such groups, known as codetermination (Gilchrist, 2006; Kardos, 1934). This computation is not only simpler than that implied by Helmholtz, but it is more consistent with empirical results. It predicts both lightness illusions and failures of lightness constancy, in addition to predicting constancy to the extent that it exists. Indeed, the Helmholtzian formula would not appear to predict lightness illusions such as our reverse contrast illusion, the Benary effect, or White's illusion.

But how does the idea of grouping by illumination level predict such illusions? Regions of common illumination are not discovered by extra-sensory perception. There must be factors in the retinal image, cues if you will, that indicate illumination shifts. For example, penumbrae typically signal cast illumination edges, and T-junctions typically indicate occlusion/depth boundaries associated with a change in illumination. However, such cues can often be found even in the absence of any shift of illumination, and when this occurs, relatively weak lightness illusions can result.

We are aware of no spatial filtering model that can account for either our basic reverse contrast illusion or our variations. We have tested our basic reverse contrast stimulus against two prominent filtering models. Blakeslee and McCourt's oriented difference of Gaussians (ODOG) model (Blakeslee, Cope, & McCourt, 2015) is probably the most widely accepted model, but it fails to predict even the direction of the illusion, predicting simple contrast instead. Shapiro and Lu (2011) have shown that a simple high-pass filter model can predict many lightness illusions using a kernel size based on the size of the target. However, we have found that it fails to predict our reverse contrast effect using either the width or the length of the target bar as kernel size. Finally, it is safe to say that, at present, no spatial filtering model can account for our results in the depth variation experiment because the retinal image remained constant across our conditions.

As far as we are aware, there are no lightness or brightness theories that predict reverse contrast except anchoring theory (Gilchrist, 2006) and Bressan's (2006) double anchoring theory.

However, spatial filtering appears to be a physiological fact, and it may be that edge integration, a key component in gestalt models, is achieved at the neural level by spatial filtering (Rudd, 2010). Indeed, it may be that center/surround receptive fields of multiple scales could be organized to group retinal patches by illumination level.

Acknowledgments

We would like to thank Professor Zili Liu for his help in setting up the conditions for Experiment 7.

Commercial Relationships

None.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This research was supported by grants from the National Science Foundation (BCS-1230793) and the National Institutes of Health (R25 60825-06).

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