The Critical Role of Relative Luminance Relations in White's Effect and Grating Induction

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It has been proposed that both White's effect and the grating induction effect are examples of brightness induction phenomena modeled in terms of local spatial filters. We have shown that for these illusions to occur it is necessary that the luminance of the gray target elements falls between that of the inducing stripes of the square-wave pattern. This critical role of luminance relationships is not predicted by existing models of these illusions.

White's effect Brightness induction Grating induction

INTRODUCTION

The appearance of a surface as white, gray, or black is determined, not only by the radiance of that surface but also by the relative radiances of surrounding regions. Conventional models center on lateral inhibition between visual neurons. The textbook example of the simultaneous contrast, illustrated in Fig. 1(a), is thought to be due to receptor cells stimulated by the gray square surrounded by white receiving more inhibition from surrounding cells than those cells stimulated by the other gray square. Often, such concepts are not sufficient to explain the apparent lightness of different regions in complex scenes (Zaidi & Zipser, 1993). For example, White (1979) showed that identical gray bars placed on the black and white bars of a square wave grating appear different but in a direction opposite to what a lateral inhibition model would predict [Fig. 1(b)]. The gray segments on the white phase are more extensively bounded by black borders than by white ones and according to the principles of brightness contrast one would expect them to appear lighter than the gray segments on the white phase, yet they appear darker. The direction of this effect and the observation that the effect is stronger at higher spatial frequencies have led to the assumption that White's effect is an instance of the phenomenon of brightness assimilation rather than brightness contrast. White (1979) reported that even though White's effect is stronger at higher spatial frequencies, unlike the assimilation effect investigated by Helson (1963) it does not disappear at low spatial frequencies. By varying the width of flanking and coaxial bars Moulden and Kingdom (1991) have actually reported a decrease of the effect with increased spatial frequency. This result can be considered a consequence of the particular stimulus conditions they used. Usually demonstrations of the effect of spatial frequency on White's effect use changes in viewing distance to produce changes in spatial frequency. This produces a constant scale change in all dimensions, not just in spatial frequency measured orthogonal to the orientation of the inducing bars as in Moulden and Kingdom's (1991) experiment. Indeed when Moulden and Kingdom varied the height of the test patch as well as its width they found that the effect decreases with the decrease in spatial frequency. This suggests that what has traditionally been described as a one-dimensional spatial frequency effect is in fact a two dimensional spatial scale effect, which depends upon holding the aspect ratio of the test patch (or its phenomenal size and relationship with inducing stripes) constant.

A possible alternative explanation has been proposed in terms of the directional properties of the grating. White himself (1979) has proposed that a grating might have the effect of reducing contrast (or enhancing assimilation) across borders parallel to it and/or enhancing contrast (or reducing assimilation) across borders orthogonal to it. Later he called this "pattern-specific inhibition" (White, 1981) based on the assumption that elongated cortical filters having similar preferred orientations and spatial frequencies, and which receive their input from adjacent retinal locations, might tend to inhibit each other. The effect of such mutual inhibition is to reduce the output of the filters, and consequently,
if the stimulus is a grating to reduce its apparent contrast. The gray bars "carry" this reduced apparent contrast and when they are on the white phase of the grating their contrast with the adjacent black phase is reduced by pattern-specific inhibition, resulting in their appearing darker than they otherwise would.

This explanation is very similar to a model proposed by Foley and McCourt (1985) to explain their grating induction effect in which an illusory grating is perceived in a homogeneous stripe running at right-angles through a sine-wave grating or square-wave grating [Fig. 1(c)]. Both White (White & White, 1985) and Foley and McCourt (1985) agree that White's effect is related to and mediated by, the same mechanism as that underlying the grating induction effect, but they disagree about what that underlying mechanism is. Foley and McCourt (1982) propose that both effects reflect inhibitory processes among cortical filters with small centers and elongated surrounds. Moulden and Kingdom (1989) have proposed a dual mechanism model of White's effect as a unified account of these two phenomena. In their model both mechanisms, one a local contrast mechanism and one a spatially more extensive contrast mechanism, operate to give the coaxial bars a disproportionate weight in their contrasting effect on the gray patches, one which outweighs any contrasting effect of the flanking bars. The local contrast mechanism operates along the entire border of the gray patch. It involves the operation of circularly-symmetric, center-surround receptive fields which are particularly sensitive to the corner intersections of the gray patches and flanking and coaxial bars, and it is this sensitivity to corners that gives the more weight to the coaxial bar in its contrast effect on the gray patch. The second mechanism is more spatially extensive and operates principally along the long axis of the phase of the grating that is coaxial with the gray bar. This mechanism possibly implicates the operation of neurons with small centers and elongated surrounds similar to those suggested by Foley and McCourt (1985).

Zaidi (1989, 1990) claimed that the correspondence between White's effect and grating induction seems to be based on their similarity when the test stripes are narrow. He showed that for test stripes of moderate height, White's effect is present while no grating induction is apparent. If the two effects are affected differently by the same change in spatial parameters, they are unlikely to have the same cause. He further concludes that grating induction is mainly a manifestation of local edge effects whereas White's effect is an example of the combined influences of spatially complex surrounds on a test patch.

We have discovered a new constraint that must be satisfied for White's effect to occur and show that it also applies to the grating induction of Foley and McCourt: the intensity of the gray bars must lie within the range of intensities of the grating stripes. Note what happens to the effects in the following figures. The top panels of Figs 2(a) and 2(b) show modified versions of White's effect type patterns, and demonstrate that the absolute contrast of the inducing grating is not a critical factor. The effect persists even though the difference in the luminances of the inducing stripes is reduced in both cases. However, when the gray test patches are of lower [Fig 2(a, bottom)] or higher [Fig. 2(b, bottom)] luminance than any of the inducing stripes, the inducing stripes have almost no effect on the appearance of the test patches. It should be noted that the luminance of the test patches is the only difference between the top and bottom panels of Figs 2(a) and 2(b). These demonstrations show that the magnitude of the effect is critically dependent on the luminance relationships between inducing and test stripes.

The magnitude of grating induction is the highest when the luminance of the test field is equal to the space average luminance of the inducing grating and when the luminance of the test field departs substantially from the average luminance of the inducing field the grating induction is weakened (McCourt, 1982). Figures 3(a) and 3(b) demonstrate that the grating induction effect seems to be dependent on the same luminance relationships between inducing and test stripes we observed for the White's effect. In Fig. 3(a) we can observe the disappearance of the grating induction for the 4 vertical stripes in the right part of the figure whose luminance is lower than the luminance of the inducing stripes. In Fig. 3(b) we can see that the grating induction is absent for the 4 vertical stripes in the left part of the figure whose luminance is higher than the luminance of the inducing stripes.

Our demonstrations suggest the importance of qualitative relationships for the occurrence of both phenomena that none of the previously mentioned models would predict.

**EXPERIMENT 1: WHITE’S EFFECT**

In our experiment we wanted to systematically examine the critical dependence of White's effect on the luminance relationships between inducing and test stripes. We investigated the size of the effect as a function of the full range of the luminances of the inducing stripes. The luminance of the test patches was always kept constant at a luminance level close to the mean luminance of the screen. In one condition we kept the darker stripes of a square wave grating constant at the lowest luminance level and varied the intensities of the other set of the inducing stripes from low luminance levels to the highest luminance level. For some combinations of the luminances of the inducing stripes, both of the inducing stripes were of lower luminance than the luminance of the test patches. We call this condition the "Double Increment Condition" because the luminance of the test patches was incremental to the luminances of both inducing stripes. In the other condition we kept the lighter stripes of a square wave grating constant at the highest luminance level and varied the intensities of the other set of the inducing stripes from the lowest luminance level to high luminance levels. This condition was called the "Double Decrement Condition" because for some combinations of the luminances of the inducing
FIGURE 1. (a) Simultaneous brightness contrast. The two disks have the same luminance, but the left disk appears brighter than the right. (b) White's illusion: gray bars replacing segments of black and white square-wave grating appear different in a direction opposite from what would be expected on the basis of simultaneous brightness contrast. (c) Grating induction: when uniform stripes (vertical) are placed within a grating, a grating in opposite phase is perceived within the uniform stripes.
stripes the luminance of the test patches was decremental to the luminances of both inducing stripes. Using the adjustment technique we wanted to see whether both sets of gray patches in White's effect pattern: the set of gray patches intersecting lighter stripes and the set of gray patches intersecting darker stripes, show similar changes in appearance as a function of the luminance of the inducing stripes.

Method

Equipment. Stimuli were generated by an Adage 3000 image processor and a VAX 11/750 minicomputer, and presented on a carefully calibrated Tektronix 690SR high-resolution color monitor. Subjects adjusted the luminance of the test patch by moving a hand-held cursor horizontally over a high-resolution graphics tablet. Between trials the computer randomly offsets the relationship between hand position and luminance level to prevent position cues from influencing the adjustments.

Stimuli. The stimulus configuration is presented in Fig. 4. The display subtended 13° vertically and 17° horizontally. The adjustable patch was surrounded with black and white checkerboard pattern (luminance 3.93

(a)

FIGURE 2. Caption opposite.
FIGURE 2. Luminance range constraint and White's illusion. (a) Top: the illusion is still present even though the absolute intensity of the inducing stripes is reduced; bottom: the illusion is absent when the luminance of the gray bars lies outside of the range of the luminances of the inducing stripes: gray bars are the highest luminance within the pattern. (b) Top: the illusion is still present even though the absolute intensity of the inducing stripes is reduced; bottom: the illusion is absent when the gray bars are the lowest luminance within the pattern.

and 117.9 cd/m² respectively) whose purpose was to provide a full black to white scale, which made the adjustments of the variable patch well defined on the lightness dimension. Zaidi and Zipser (1993) found no brightness induction in similar radial patterns.

Double increments condition: the luminance of the darker set of the inducing stripes was 3.93 cd/m² throughout this condition. The luminance of the lighter set of inducing stripes was set at one of seven values: 11.79, 20.96, 32.75, 47.16, 66.81, 89.08, and 117.9 cd/m². The luminance of the gray test patches was 39.3 cd/m².

Double decrements condition: in this condition the luminance of the set of the inducing stripes that was constant throughout the condition was 117.9 cd/m². The luminance of the other set of the inducing stripes was set at one of these seven values: 3.93, 11.79, 20.96, 32.75, 47.16, 66.81, and 89.08 cd/m². The luminance of the gray test patches was 39.3 cd/m² (outside of luminance
FIGURE 3. Luminance range constraint and grating induction. The induced grating pattern is perceived only when the luminance of the vertical stripes lies within the luminance range of the horizontal stripes: (a) the grating induction is absent only in four vertical stripes whose luminance is higher than that of inducing background stripes; (b) the grating induction is absent only in four vertical stripes whose luminance is lower than that of inducing background stripes.
constraint it was decremental to both stripes of the inducing grating).

Procedure. The display was viewed binocularly at a distance of 100 cm. Observers adjusted the luminance of the adjustable patch to match the brightness of the test patch indicated at the beginning of the trial by a cursor. 
A nulling technique was not used because we wanted to keep the stimulus pattern constant. Five matches were recorded for each of the test patches at each of the seven inducing levels in the two conditions.

Subjects. Data were collected on three observers, two of whom (BS and LA) were experienced and one (DA) was naive to the purposes of the experiment.

Results and discussion

The results for three subjects are shown in Figs 5 (double increments condition) and 6 (double decrements condition). The subjects' mean matches are plotted against the luminance of the lighter of the inducing grating stripes in double increments condition. In double decrements condition the subjects' mean matches are plotted against the luminance of the darker of the inducing grating stripes. The dashed vertical and horizontal straight lines represent the physical luminance of the gray patches. The two curves represent the matches for the gray patches on the lighter and darker stripes of the inducing grating as a function of the luminance of the lighter inducing stripes. The squares indicate the matches for the gray test patch on the darker stripe of the inducing grating, and the circles indicate the matches for the gray test patch on the lighter stripe of the inducing grating. The size of the effect is equivalent to the separation of these two curves. The main result for both experimental conditions is that the effect only occurs within the specific luminance relationship between the gray test patches and inducing grating stripes as indicated in the Figs 5 and 6. Only when the luminance of the test patches lie within the range of the intensities of the inducing stripes we observe the data representative of White's effect: the test gray patch on the lighter stripe is perceived as darker in comparison to the test gray patch on the black stripe. The effect did not occur when the test patch luminance was outside the luminance range of the inducing grating's stripes.

FIGURE 4. Stimulus configuration for Experiment 1.
The significant departure from a physical luminance match of test patches. In Fig. 5 (double increments condition) the adjustments for all three subjects in this region highly exceed the physical luminance of the test patches which is indicated by the straight horizontal line. In Fig. 6 (double decrements condition) the adjustments for all three subjects in this region are below the physical luminance of the test patches which is indicated by the straight horizontal line. In both cases the luminances of the test patch are very different from the average.

That is indicated by the data points on the left side of the vertical dashed line that represents the physical luminance of the test gray patch in Fig. 5 and by the data points on the right side of the vertical dashed line in Fig. 6.

An interesting feature about the adjustments outside the luminance range of the inducing grating’s stripes is
luminance of the display and the departures from veridicality might be due to the adaptation processes.

What are the features of obtained results within the luminance constraint? In Fig. 5 (double increments condition) there seems to be a monotonic slope in both curves. As the luminance of the lighter set of the inducing stripes is increasing both test patches undergo the darkening effect. But this darkening effect is much more pronounced for the test patches on the lighter inducing stripes. The test patches on the darker inducing stripes (that are constantly black throughout this condition) are not changing as much even though they share more border with white than the other set of test patches. Part of the explanation of this slope for both curves might be due to the fact that the highest luminance for the whole display is changing with the luminance of the lighter inducing stripes, and what we might be observing is the contrasting effect of the lighter inducing stripes. The support for this interpretation comes also from the Fig. 6 (double decrements condition) where there is no slope for the adjustments of the test patches on the lighter inducing stripes. Note that in this condition (double decrements condition) the highest luminance was constant throughout the experiment. In Fig. 6 there is a slope only for the adjustments of the test patches on the darker stripes of the inducing grating. As the luminance of darker stripes of the inducing grating increases, the lightness adjustments for the test patch lying on these stripes decreases.

As mentioned in the introduction, a number of models have been proposed for White’s effect. None of the models in its present form is able to account for the disappearance of the illusion outside the luminance constraint. According to the various proposed contrast mechanisms White’s effect should be observed over the whole range of intensities of the inducing stripes.

**EXPERIMENT 2: GRATING INDUCTION**

Because the induced grating in grating induction is usually 180 deg out of phase with the inducing grating it has been termed “counterphase brightness induction” (Foley & McCourt, 1985). The magnitude of the grating-induction effect has been studied with respect to a variety of manipulations of the spatial parameters of the induction display. McCourt (1982) showed that the amplitude of the induced grating decreases rapidly with increasing spatial frequency of the inducing grating. Its amplitude decreases in nonlinear fashion as a function of the amplitude of the inducing grating (Foley & McCourt, 1985) and as a function of the inducing field width (McCourt, 1982). Foley and McCourt (1985) propose that effects reflect inhibitory processes among cortical filters with small centers and elongated surrounds unlike previous models that were based on lateral inhibition in concentric receptive fields such as those of the retinogeniculate pathway. Moulden and Kingdom (1991) concluded that local border mechanisms (such as retinal ganglion cells) should not be rejected in favor of cortical mechanisms or vice versa, and that any viable model must include both classes of mechanism.

Zaidi (1989) has shown that the orientation and the spatial frequency of the induced grating can be different from the orientation and spatial frequency of the inducing grating thus opposing Foley and McCourt’s claim that the induced grating has the same orientation and spatial frequency as the inducing grating. Foley and McCourt explain these properties by a class of neurons with narrow centers and elongated receptive fields that are oriented parallel to the axis of orientation of inducing grating. Zaidi’s demonstrations suggest a more general, global account of the phenomenon as just a particular case of classical simultaneous induction where locally induced patches of contrast may combine to generate the percept of the induced grating. Distal parts of the inducing stimulus may affect only the amplitude of the induced modulation.

We set out to investigate the luminance relations necessary for the occurrence of the grating induction suggested by our demonstrations [Figs 3(a) and 3(b)]. We tested the dependence of the grating induction on the same qualitative luminance relations between the target and the inducing regions that we observed in the case of White’s effect. Some of the White’s effect models explicitly linked these two phenomena, explaining them with the same class of physiological mechanisms. The same low-level physiological interactions are usually invoked to explain simultaneous lightness contrast. All traditional or contemporary lateral inhibition models are exclusively based on absolute quantities, and they would not be able to accommodate any dependency of the grating induction effect on the qualitative relations among the pattern’s elements.

**Method**

**Stimuli.** Stimuli were presented on a Macintosh high resolution color monitor. The three different stimuli varied only in the luminance of the stripes of the inducing grating: in Condition 1 the luminances of the stripes in the grating were 0.21 and 9.39 cd/m²; in Condition 2 the luminances were 9.39 and 30.32 cd/m²; and in Condition 3 the luminances of the stripes in the grating were 0.21 and 30.32 cd/m². The luminance of the homogeneous vertical stripes inserted in the grating were the same in the three experimental conditions: 0.65, 1.47, 4.01, 5.62, 11.65, 16.31, 18.84, and 24.5 cd/m².

**Procedure.** The subjects’ task was to indicate whether the induced grating was present for each of the eight test stripes for each of the three stimuli, and, if so to estimate its magnitude on a scale in which 0 means no grating is present and 10 means the induced grating is maximal. A maximal grating was defined as an induced grating in a pattern with black and white background stripes that was shown to the observers at the beginning of the session. The viewing distance was 50 cm.

**Subjects.** Ten undergraduate psychology students served as subjects in this experiment. All had normal or corrected to normal vision. They were naive as to the purpose of the experiment.
Results and discussion

The degree to which the induced grating was perceived is shown in Fig. 7 and its estimated magnitude is shown in Fig. 8, both plotted as function of the luminance of the uniform test stripes. Vertical dashed lines represent the point at which the luminance of the test stripe equals that of either the lighter (Condition 1) or darker (Condition 2) inducing stripes. The data show that with the exception of one data point in Condition 1, the induced illusory grating is perceived mostly when the luminance of the uniform test stripe lies within the range of the luminances of the stripes of the square-wave grating. The curves for Condition 1 and Condition 2 show two clearly separable parts: a substantially higher proportion and estimated magnitude of the induced grating for the test field luminances inside the luminances of the inducing grating and very low proportion and estimated magnitude of the induced grating for the test field luminances outside of the range of the luminance of the inducing grating. These abrupt changes in curves for Condition 1 and Condition 2 happen once the luminance constraint line (vertical dashed line) is crossed. In Condition 3
where the luminance of the test elements was always within the range of the luminances of the inducing stripes, results show different patterns than in Condition 1 or Condition 2. Even though the proportion and estimated magnitude of the induced grating seems to be the highest for test field luminances around the average mean luminance of the inducing grating, these results do not show the same variations in respect to luminance relations as the results in Condition 1 and Condition 2.

McCourt (1982) has stated that the luminance of the test field must not depart substantially from the average luminance of the inducing field, or the grating induction is weakened. Foley and McCourt (1983) proposed that the strength of the grating induction depends on two factors: the amplitude of inducing luminance and the ratio between the test luminance and the inducing luminance (mean luminance of the display). Since we did not use their contrast cancellation technique in our study it is hard to make a direct comparison between the results we obtained and their findings. However we can compare the results we obtained between conditions 2 and 3. Mean luminance of the display was very similar in these conditions: 19.855 and 15.262 cd/m² for Condition 2 and Condition 3 respectively. Thus, the ratios between the test field luminance and the inducing luminance were very similar in both conditions. The results obtained in these conditions were very different and the differences do not seem to be attributable to the difference in the amplitude of the inducing grating. The amplitude of the inducing grating was lower in Condition 2 and one could expect the overall decrease in the proportion and the estimated magnitude of the induced grating. Our data show a different pattern: for test field luminances outside the luminance range of the inducing grating, the proportion and estimated magnitude of the induced grating are substantially lower than in Condition 3. For test field luminances inside the range of the luminances of the inducing grating, the proportion and estimated magnitude of the induced grating were equal or higher to those in Condition 3. Spillman and Levine (1971) got essentially the same results using "modified Hermann grid" patterns consisting of uniform backgrounds and perpendicular intersected and intersecting stripes of different luminances. Their results also showed no induction when the luminance of the intersecting stripes (stripes on the top of the intersected stripes and the background) was outside the range of the luminances of the intersected stripe and background at that location.

CONCLUSIONS

In these two experiments we have demonstrated the importance of qualitative boundaries in the luminance relationships that support the appearance of both White's effect and Foley and McCourt's grating induction: the luminance of the test patches must lie within the range of luminances of the grating stripes. The luminance constraint is not merely another factor affecting the strength of these illusions; when this constraint is violated the effects are not observed. None of the existing models can readily accommodate these findings. Our findings suggest the importance of qualitative relations, primarily the sign of the contrast, among the elements of the pattern.

Although we are not yet able to present an adequate model of these illusions, we have established that the same pattern of relative luminance values required for the appearance of White's effect applies to grating induction as well. Other factors related to more global perceptual interpretation of the displays (suggested by existing T-junctions, X-junctions, transparency) might be responsible for the observed differences in induced percept. Some preliminary demonstrations of depth manipulation of the elements in White's effect have
shown that White's effect occurs when the test bars lie in a plane nearer than the square wave grating, as schematically indicated in Fig. 9(a) (Spehar, Gilchrist & Arend, 1992). However, when the pieces of grating stripes collinear with the test patch lie in a closer plane than the test patches binocular viewing reveals the opposite brightness difference, classical simultaneous contrast [Fig. 9(b)].

**REFERENCES**


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