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Perceptual organization and White's illusion

Barton L Anderson
Department of Brain and Cognitive Sciences, Massachusetts Institute of Technology, NE-20 447, Cambridge, MA 02139, USA; e-mail: bart@psyche.mit.edu
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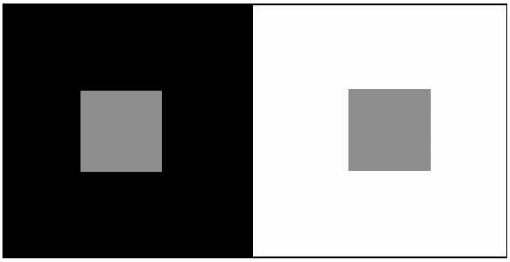
Abstract. The apparent lightness of a surface can be strongly modulated by the spatial context in which it is embedded. Early theories of such context dependence emphasized the role of low-level mechanisms that sense border contrast, whereas a number of recent authors have emphasized the role of perceptual organization in determining perceived lightness. One of the simplest and most theoretically challenging lightness illusions was described by White. This illusion has been explained with a variety of different models, ranging from low-level filter outputs to computations underlying the extraction of mid-level representations of surfaces. Here, I present a new method for determining the organizational forces that shape this illusion. I show that the spatial context of White's pattern not only transforms the apparent lightness of homogeneous target patches, but can also induce dramatic inversions of figure – ground relationships of textured target regions. These phenomena provide new evidence for the role of scission in causing the lightness illusion experienced in White's effect.

1 Introduction

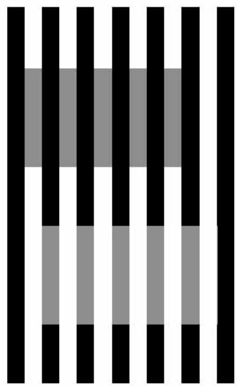
One of the oldest and most fundamental problems of vision involves understanding how the luminance distributions on the retinae are transformed into a perception of brightness or lightness. The brightness of a region refers to the amount of light it appears to emanate. Lightness refers to the proportion of light a surface appears to reflect. Although these terms refer to distinct physical dimensions, it is not always clear how this distinction can or should be made psychologically. In this paper, I will therefore use the term lightness to refer to the perceived gray of an (achromatic) target.

Two general theoretical frameworks have been invoked to explain departures from veridicality in perceived lightness: those that emphasize the role of low-level mechanisms that operate on the 2-D array of luminance values; and those that emphasize the role of perceptual organization and/or surface-level computations.

One of the best known examples of an illusion that has been traditionally explained as the consequence of low-level mechanisms is the phenomenon of simultaneous contrast. A homogeneous gray patch surrounded by a homogeneous light surround appears darker than an identical gray patch surrounded by a dark surround (see figure 1a). The traditional explanation of this illusion is that antagonistic receptive fields sense the contrastive borders surrounding the central targets, and brightness signals are propagated from these borders into the homogeneous interiors of the gray targets (Cornsweet and Teller 1965; Shapley and Enroth-Cugell 1984; Grossberg and Todorović 1988; Paradiso and Nakayama 1991). Despite their appeal, a number of phenomena have been discovered that cast doubt on the generality such mechanisms play in more complex visual contexts. One of the simplest stimuli that revealed the limitations of such edge-based accounts was constructed by White (1979, 1981). This illusion consists of identical gray patches placed on alternating black and white stripes (see figure 1b). The gray patches that fall on the black stripes appear much lighter than those that fall on the white stripes, even when the gray patches in the black stripes are bordered by more white than black (and conversely for the gray patches in the white stripes). Thus, any theory that



(a)



(b)

Figure 1. (a) The simultaneous-contrast illusion. The luminance values of the central gray patches are physically identical, but the gray patch on the dark background appears lighter than the gray patch on the light background. This illusion is usually explained as arising from mechanisms that sense the contrast along the edges of the patterns, and a brightness signal is then propagated into the center of the patches. (b) An example of White's effect. In this pattern, gray targets that interrupt the white bars appears darker than identical gray targets that interrupt the black bars. Note that in this pattern, the gray targets that appear darker are bordered by more black than white, and the targets that appear lighter are bordered by more white than black. This illusion is therefore opposite to what would be predicted on the basis of border contrast.

predicts perceived lightness simply on the basis of edge contrast would predict the opposite illusion to the one actually experienced in White's effect.

Owing to its inescapable impact on theories of lightness perception, White's effect has become an extensive focus of both theoretical and empirical inquiry. A number of theoretical accounts of this illusion have been proposed. One class of explanation treats White's effect within the same edge-based framework as simultaneous contrast, and asserts that the illusion can be understood to be a byproduct of antagonistic receptive field outputs (Foley and McCourt 1985; Moulden and Kingdom 1989; Blakeslee and McCourt 1999). Such models retain the assumption that apparent lightness is determined by the responses of cells sensing the borders of the targets. In one account, it is assumed that White's illusion is caused by the outputs of symmetric center – surround receptive fields that respond differentially to specific regions of the targets (such as corners; see Moulden and Kingdom 1989). Another filter account asserts that the illusion is caused by the outputs of anisotropic, oriented receptive fields (Foley and McCourt 1985; Blakeslee and McCourt 1999). Note that the organizational processes involved in recovering surface properties play no explicit role in such theoretical frameworks.

It has also been suggested that White's effect is due to a process of *assimilation* (White 1981; Taya et al 1995; Ripamonti and Gerbino 2001). Historically, the term assimilation has been applied when a brightness (or lightness) illusion is opposite to that predicted by contrast theories, which is precisely what occurs in White's effect. However, assimilation has not received a single, well-defined meaning, so it is difficult to assess experimentally. It has been typically applied to fine-grained image structure that favors the averaging of local luminance (von Bezold 1862/1876). It has been shown that White's illusion is strongest when the stripes are thin (see White 1979, 1981; Anderson 1997), which presumably increases the probability that many receptive fields will average image luminance. However, there is now ample evidence that luminance

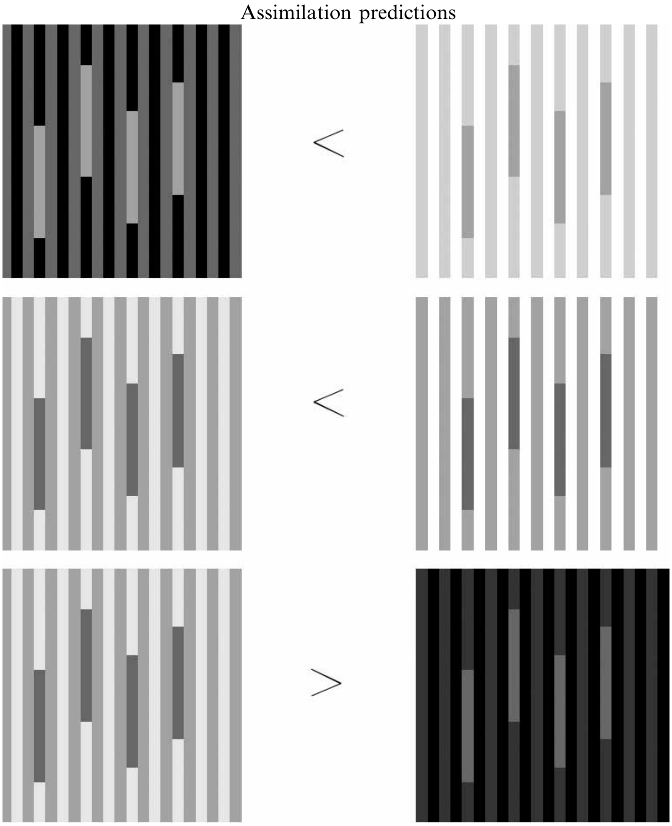


Figure 2. Displays demonstrating the failure of assimilation in correctly predicting the sign of the lightness difference observed in a number of White's displays. The inequalities express which target bars should appear lighter (where 'greater' stands for 'lighter'), under the assumption that assimilation means that the target bars should be a weighted average of their real luminance value and that of its neighbors. Note that in all examples depicted, assimilation fails to predict the correct direction of the perceived lightness difference (reprinted from Anderson 1997).

averaging alone cannot account for many variants of White's effect. A number of authors have designed variants of White's pattern wherein the perceived lightness difference between the targets is in the opposite direction to that predicted by assimilation (Anderson 1997; Ripamonti and Gerbino 2001; see also Kingdom and Moulden 1991). Examples of such stimuli are presented in figure 2.

In contrast to these filtering accounts, a number of authors have proposed that White's illusion is the consequence of grouping and segmentation processes. A common insight of these models is that the T-junctions present in White's display play a critical role in generating the perceived lightness difference. There are at least four theories about how T-junctions contribute to White's illusion. According to one theory, the T-junctions formed by the intersection of the gray target patches and their adjacent stripes provide information that the targets in White's illusion belong to the stripes on which they are embedded (Todorović 1997; Zaidi et al 1997). More specifically, the T-junctions are thought to act as local occlusion cues that cause the gray targets to lie on a homogeneous background that is the color of the stripes on which the targets lie. In this theory, it is assumed that contrast mechanisms operate only on a target and its background, not with respect to nearer, occluding surfaces. These theories essentially reduce White's effect to a simultaneous-contrast display, which places an upper bound on the strength of this illusion: White's effect can only be *as large* or *smaller than* a comparable simultaneous-contrast display (Anderson 1997). The problem with this theory is that many variants of White's illusion—including those originally reported by White (1981)—are substantially *larger* than a comparable simultaneous-contrast display, which implies that this theoretical account is either incomplete or incorrect.

The anchoring theory of lightness (Gilchrist et al 1999) also provides a common explanation for simultaneous contrast and White's illusion. Anchoring theory emerged from the recognition that the visual system needs to overcome an ambiguity in mapping image luminance onto perceived lightness. Because the luminance distributions that reach the eyes are the products of surface reflectance and the illuminant, there is no way to uniquely 'undo' this multiplication and map image luminance onto surface lightness. Part of this mapping problem can be solved by transforming the set of luminance values into a set of relative reflectance values. But in order to transform these relative measures into a set of specific reflectance values (ie perceived lightness), the visual system must 'tie down' the gray scale with an anchor, such as black, mid-gray, or white. Land and McCann (1971) proposed that the highest luminance should be anchored to white, which is known as the highest-luminance rule.

Gilchrist et al's (1999) model suggests how this anchoring constraint may explain a variety of errors in lightness perception. In this model, anchoring occurs within a *framework*, which is a region containing surfaces that are grouped. A core concept of this model is that the visual scene is composed of local and global frameworks, and that anchoring is performed relative to both. This model also emphasizes the importance of *articulation* and *insulation* in constraining how anchoring occurs. Articulation refers to the number of distinct surfaces or objects in a scene (Katz 1935). Insulation refers to the extent to which a local framework is grouped as a separate entity from the global framework (the rest of the scene), which modulates the extent to which anchoring is performed relative to the different frameworks.

In anchoring theory, the traditional simultaneous-contrast display is attributed mostly to the lightening of the target surrounded by black. The local-anchoring rule (highest luminance is white) causes the gray target on black to appear white. However, the global framework (the rest of the display, including the target on the white background) predicts that this target appears its true color (veridical gray). The gray target in the white surround should be perceived (nearly) veridically, because the local and global assignments are the same (target = gray).

A similar anchoring account has been applied to White's display. Gilchrist et al (1999) assert that the T-junctions modulate belongingness in a manner that causes the gray targets to group strongly with the stripes on which they are embedded (similar to the occlusion accounts described above). The illusion would be maximal if the T-junctions caused the targets to be completely insulated from the rest of the display. In this case, the illusion would be explained in precisely the same manner as simultaneous contrast. However, this model asserts that local anchoring becomes stronger with greater articulation, and hence the illusion can be stronger than simultaneous contrast. As with simultaneous contrast, this model predicts that White's effect should be largely a consequence of an illusory lightening of the targets embedded in the black stripes. However, Ripamonti and Gerbino (2001) recently showed both sets of targets in White's display undergo a nearly equal transformation in perceived lightness. As with the previous T-junction accounts, this suggests that there is something either incorrect or incomplete in this account of White's illusion.

More recently, Ripamonti and Gerbino (2001) have suggested that both assimilation and contrast are involved in White's effect (see also Grossberg 1997), although they remain relatively agnostic about the possible meaning of the term 'assimilation'. Like other surface-based accounts, the model proposed that T-junctions modulate the role of contrast and assimilation in creating White's effect. More specifically, these authors argue that the targets in White's display are modulated more strongly when the luminance of a flanking region lies adjacent to the luminance of the target (ie when the luminance of one stripe is greater and that of the other is lesser than the luminance of the target). The advantage of this model is that it provides a coherent qualitative account of White's original display (ie where the luminance of the target lies between that of the flanking stripes), as well as double-increment and double-decrement displays (ie when both targets are brighter or darker than the stripes on which they are placed). Although this model has predictive success, no rationale has been given *why* luminance values that are adjacent to the targets have a larger effect on the targets, so the theoretical motivation for this heuristic remains unclear.

The other surface-level theory of White's illusion argues that the effect arises, at least in part, from a decomposition of the targets into multiple layers (Anderson 1997; cf Kelly and Grossberg 2000). The guiding insight of this account is that this illusion is a manifestation of processes that are typically used to separate—or *scission* (Koffka 1935; Metelli 1970, 1974)—an image region into its multiple, underlying causes. One of the most perceptually salient forms of scission occurs in phenomenal transparency, ie the decomposition of a region into multiple surfaces, one of which is visible through the other. The scission account of White's effects asserts that the gray targets are decomposed into two different layers: a near surface (the targets); and two underlying surfaces, the color of which is determined by the luminance of the stripes on which the targets are embedded. This scission account asserts that White's effect arises because the visual system decomposes the gray targets into a combination of light and dark, and attributes either the light or dark 'components' of the target to an underlying surface. In this account, the color of the stripe on which the target is embedded determines whether the light or dark components are attributed to target. Thus, the targets in the black stripes look lighter because some of the darkness (black) has been 'taken out' of the target and attributed to an underlying (black) background. Similarly, the targets embedded in the white stripes appear darker because some lightness (white) has been 'taken out' of the target and attributed to its underlying layer.

It is important to emphasize that, in the scission account of White's illusion, the T-junctions per se are not the critical stimulus attribute that is responsible for the illusion. Rather, I have previously argued, the contrast variations that occur along the contour forming the top of T-junctions play a critical role in causing the decomposition of an image region into multiple layers. The intuition shaping this theory is that the photometric relationships occurring along the contour provide evidence for an intervening transparent medium. Note that one of the main differences between the scission theory and occlusion theories (or belongingness theories) of White's illusion is the different roles attributed to the contours that form the T-junctions. The occlusion/selective-contrast theories assert that White's illusion is generated by processes that sense the contrast along the T-junction *stem*, whereas the scission theory asserts that the contrast changes occurring along the contour forming the *top* of the T-junction are responsible for initiating White's effect.

The scission account of White's effect asserts that the contrast relationships along the top of the T-junctions in these displays initiate the decomposition of the targets into multiple layers. However, this does not necessarily imply that the targets must appear in front of the adjacent bars for scission to occur. Rather, the scission thesis simply asserts that some of the luminance emanating from the target regions is attributed to a distinct layer, which could occur even if the targets are perceived to lie behind the bars to which they are adjacent (ie in three layers: the occluding bars, the transparent targets, and an underlying background). Although transparency is not always explicitly experienced in White's displays, the efficacy of scission in inducing perceived lightness differences can be demonstrated by providing depth information that unequivocally places the stem of the T-junction in front of the top of the T. This eliminates the possibility that the stem of the T-junction is occluded, and gives rise to vivid percepts of illusory transparent surfaces (Anderson 1997, in press). An example stereogram illustrating the contribution of this decomposition in causing lightness illusions is shown in figure 3 (cf Anderson 1997, in press). Note that, when the gray transparent sectors appear to overlie black inducers, they appear light gray; but when the same sectors appear to overlie white inducers, they appear dark gray. These demonstrations clearly do not demonstrate that White's effect is a consequence of scission, but they do provide an existence proof that lightness transformations can be induced by mechanisms responsible for the decomposition of surfaces into multiple layers.

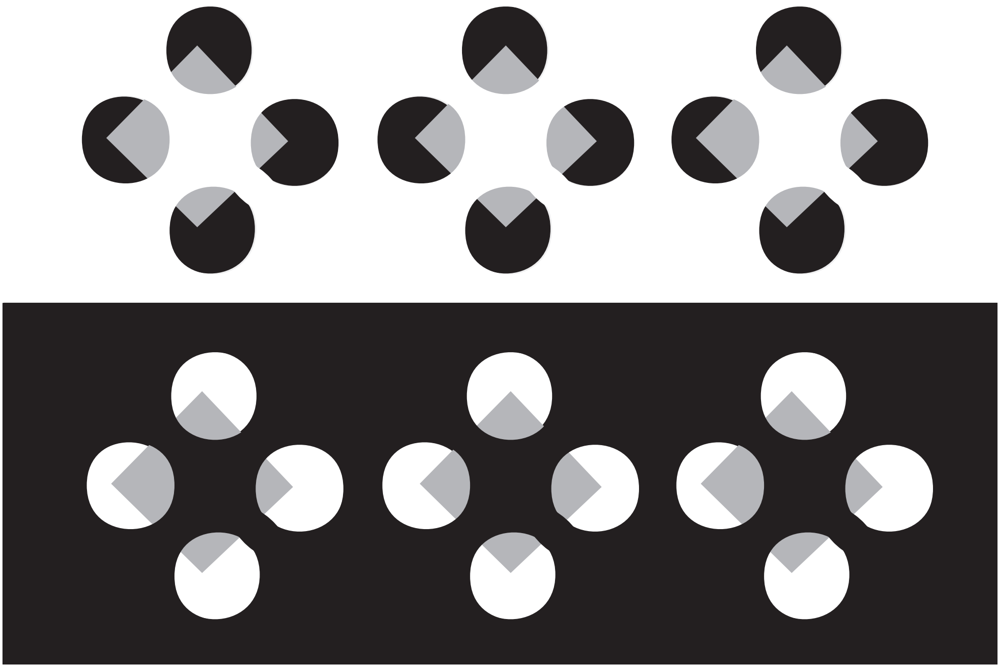


Figure 3. Lightness illusions induced by the perception of transparency. All of the gray sectors in this image are identical. However, when the two columns on the left of the image are cross-fused, a strong percept of illusory transparency is induced. In the top figure, this leads to the percept of 4 white discs being occluded by a dark-gray filter, whereas in the bottom, it leads to a percept of 4 black discs occluded by a light-gray filter (see Anderson 1997, in press).

More recently, it has been shown that even more dramatic lightness transformations can be induced by means of stereoscopic textures (Anderson 1999). Consider the stereograms in figure 4, which depict a texture viewed through an array of three apertures. A depth difference between the boundaries of the aperture and the texture is created with binocular disparity. When the aperture boundary appears in front of the texture, the pattern simply appears as a cloudy black-and-white texture visible through three holes cut in a surface (similar to the dominant monocular percept). However, when the depth order is reversed, a strikingly different percept can be experienced. In this depth configuration, the textured regions appear to split into two layers, the nearer of which appears transparent. Remarkably, the pattern of perceived lightness of the two layers is not fixed, but depends critically on the contrast polarity of the texture relative to the adjacent surround (ie the areas in the image outside of the aperture boundaries). When the adjacent surround is lighter than the textured regions, the texture appears as light clouds hovering in front of three dark discs. But when the adjacent surround is darker that the textured regions, the texture appears as dark clouds hovering in front of light discs. For purposes of the present discussion, the importance of these illusions is that they conclusively demonstrate that scission can induce striking lightness transformations.

The scission explanation of White's illusion may be better appreciated by considering a form of transparency similar to that observed in the stereoscopic textures depicted in figure 4. Consider the kind of transparency that occurs when viewing a distant surface through a 'screen' or 'mesh' rather than a homogeneous filter. To recover the two surface layers in this form of transparency, the visual system must determine which portions of the transparent region are due to the screen, and which are due to the underlying background that is visible through the holes in the screen. In this context, the problem confronting the visual system is essentially a figure–ground problem, ie to determine which portions of the image patch belong to the screen (the occluding figure), and which are the holes in the screen through which the underlying background is visible (the ground). For simplicity, let us assume that the mesh is white and its underlying background is black. This will generate a black-and-white texture. To accurately recover the two surfaces in these images, the visual system must determine that the white components of the texture correspond to the occlusive screen, and that the black portions of the texture are the holes in the screen through which the underlying background is visible.

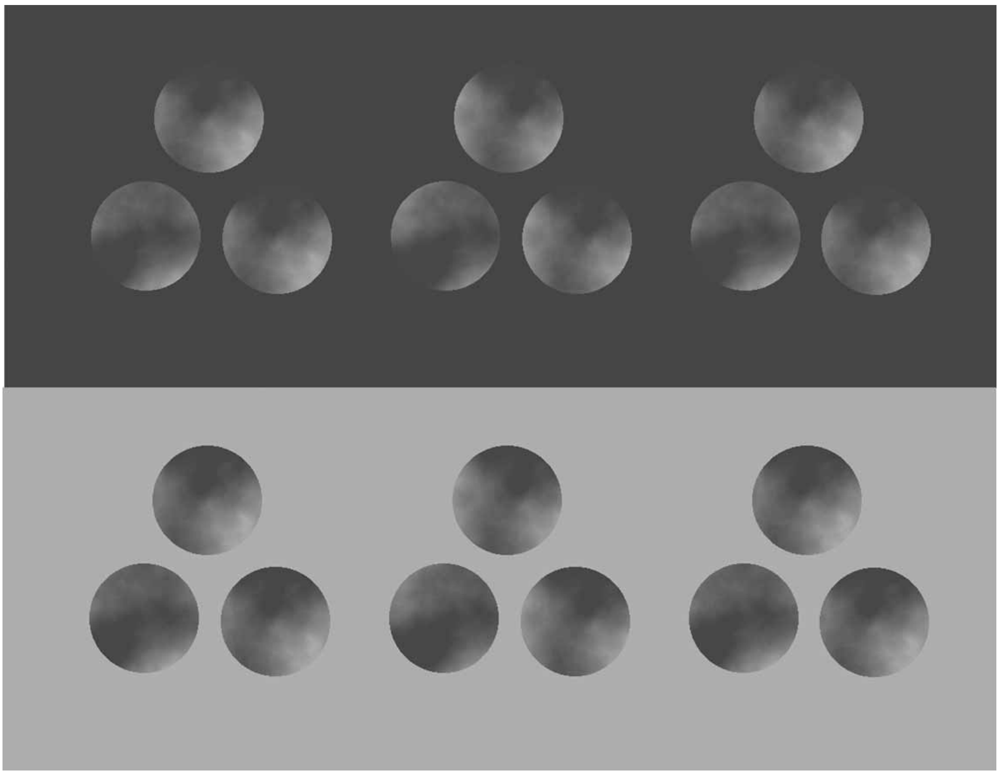


Figure 4. Stereograms demonstrating that a change in the contrast relationships between a texture and its surround can induce inversions in perceived lightness. When the left two columns are cross-fused, the textured regions can appear to split into two layers, the nearer of which is partially transparent. (a) When the surround is lighter than the texture, the transparent layer appears as light clouds in front of three dark discs. (b) When the surround is darker than the texture, the transparent layer appears as dark clouds in front of three light discs. The textures in these two patterns are actually identical. See Anderson (in press) for a detailed explanation of these effects.

The screen metaphor of transparency suggests a way to test the role of scission in White's display. If scission is playing a significant role in causing the lightness illusion experienced in White's display, then it should be possible to induce scission in textures in a manner analogous to parsing an image region into a screen (the occluding figure) and holes (through which an underlying background is visible). For example, if a black-and-white texture is embedded into White's display, the scission account predicts that the black and white components of the texture should undergo a figure – ground inversion when placed in the two different sets of bars. Specifically, we would expect that the white components of the texture should appear as the occlusive screen when embedded in the black bars, and the black components of the texture should appear to form part of the underlying background (visible through the holes in the occluding screen). When the textures are placed in the white bars, the opposite effect should occur, and the black components of the texture should appear as the occlusive screen. Note that no other theory of White's illusion would predict such figure – ground inversions.

2 Experiment 1

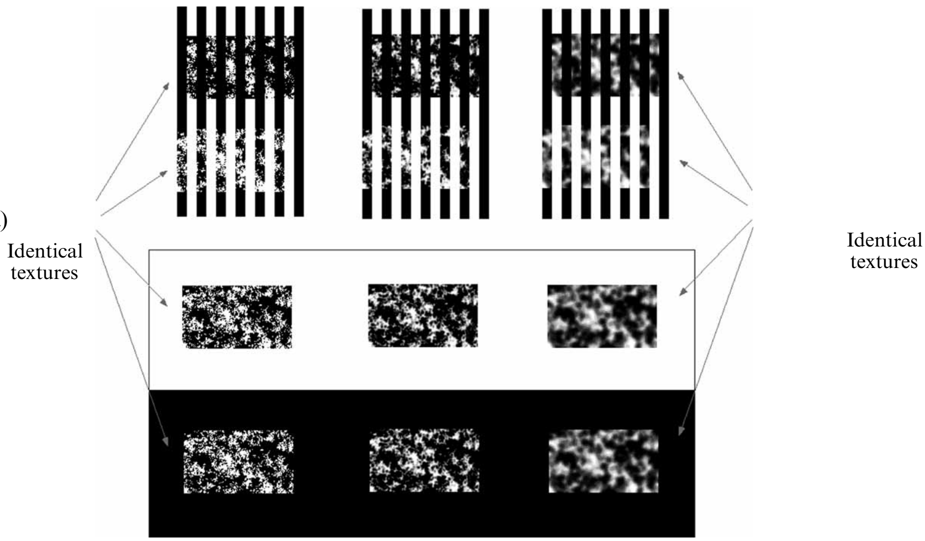
2.1 *Method*

2.1.1 *Participants.* Nine observers with normal or corrected-to-normal vision served as observers in the experiments. They were all naïve as to the purpose of the experiment.

2.2 *Stimuli*

Previous experiments (Anderson 1999) have shown that textured image regions can be perceptually decomposed into multiple layers when stereoscopic depth is present between the texture and its borders. In these studies, it was also observed that scission only occurs for textures whose power spectra varied as f^b, for $b \geqslant 2$ (ie textures with spectra that have similar spatial-frequency content as natural scenes, or with a greater concentration of low frequencies than is present in most natural scenes). Intuitively, this means that there is more contrast energy in the coarse spatial scales than in the fine-grained spatial scale. In order to provide the greatest opportunity of observing scission phenomena in White's illusion, a random 8-bit texture was synthesized by adding the components of a power spectrum that fell as f^{-2}. The phase spectra of these textures were randomized. These textures were then thresholded to create a two-tone black-and-white texture. Variations of these textures were also made by blurring these two-tone images, and then renormalizing the luminance values to span the entire 8-bit range. Similar phenomena reported below were observed with unthresholded versions of the texture as well; the thresholded stimuli were introduced to maximize the chances of observing salient figure – ground reversals.

To evaluate the different theories of White's illusion, a number of stimuli were created with identical textures as target regions. One stimulus was similar to the White's original display, namely a series of equally spaced and equally sized black and white stripes. Small, identical strips of texture were embedded in both the black or white stripes (see figure 5a). In a second display, a single rectangular patch of texture was placed on a uniform black surround and a uniform white surround (figure 5b). This pair of displays served as the simultaneous-contrast analogue of White's display under the assumption that the texture is perceived as a single textured region on a homogeneous background. A third display was an attempt to construct a simultaneous-contrast analogue of the textured White's display under the assumption that no completion occurred. In this image, the thin textured bars that appeared in the white and black stripes of White's display were placed on either a homogeneous white or black background (see figure 5c). A fourth image was created to assess whether these textured variants of White's illusion could be understood with a simple concept of luminance averaging ('assimilation'). In this display, both the textured bars and the untextured bars that fell between them were placed



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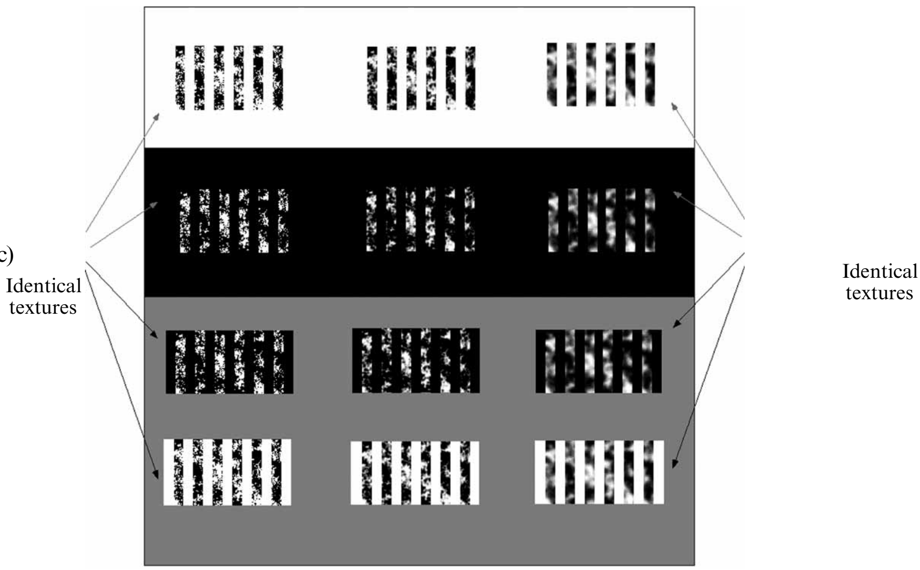
(b)



(c)

(d)

Figure 5. The stimuli used in our experiment. The stimuli in the left column were used as test stimuli; the figures in the right two columns demonstrate that similar effects are observed if the two-tone textures on the left are replaces with continuous luminance modulations. (a) A textured variant of White's effect. The textures in the top and bottom of each figure are physically identical. (b) A control display used to assess an occlusion theory of White's effect. In particular, the occlusion theory states that the T-junctions generated by the textured regions and the adjacent bars provide information that the texture is occluded and appears behind the adjacent bars. This would generate a black-and-white texture lying on a homogeneous white background, or a black-and-white texture lying on a homogeneous black background. (c) A simultaneous-contrast variant of the illusion under the assumption that no completion of the textured region occurs. (d) A control pattern in which the black and white bars of the surround have been replaced by a the mean luminance of these regions.

on a homogeneously colored mid-gray (figure 5d). This gray was the mean luminance of the black and white bars. Thus, the average luminance of the surround of this pattern and the surround of White's display was identical. I reasoned that if White's illusion was due to spatial luminance averaging, then this display should induce an illusion of equal magnitude as the black and white bars of White's effect.

2.3 *Procedure*
Observers were shown the four patterns depicted in figure 5. They were instructed to rank the perceived similarity of the textures within a stimulus in descending order (ie from most dissimilar to most similar). To prevent any theoretical biases from shaping observers' judgments, the instructions were intentionally unspecific about the particular dimensions of the texture that were to be compared. Note also that this rank order does not contain any information about the *direction* of the illusion; it only requires observers to estimate the magnitude of the difference between the two target patches, and order the differences. To determine the direction of the illusion, observers were asked to compare the targets in the three control displays to White's pattern after the rank orderings of difference magnitude had been performed. Their task was to identify which of the two textures in White's display was most similar to a given texture in the test display.

Previous studies evaluating White's effect typically employed some form of matching experiment to determine the perceived lightness or brightness of a target. For the textured patterns used in the present study, the anticipated effect of embedding the textures into White's display was to bias either the luminance maxima or minima within the textures to appear as figure. It was therefore not possible to employ a matching task of the kind(s) used previously (cf White 1981; Taya et al 1995; Ripamonti et al 1998; Blakeslee and McCourt 1999). However, it was possible that observers would experience brightness differences in addition to any shifts in the perceived figure–ground relationships. The instructions to determine which textures appeared most dissimilar, without any explicit specification of the dimensions observers should use to make this comparison, provided the opportunity for observers to use such information in making their similarity judgments if they were experienced.

2.4 *Results and discussion*
All observers reported the same rank order of illusion strength for the four test patterns, which is depicted in figure 6. Owing to the uniformity of these results, all of the differences between the conditions are significant when using virtually any appropriate non-parametric statistic (eg with a sign test, $p \ll 0.0001$). A strong and striking difference was perceived in the textured version of White's display depicted in figure 3a. Observers reported that the textures embedded in the white stripes appeared to be composed predominantly of black speckles, and the textures embedded in the black

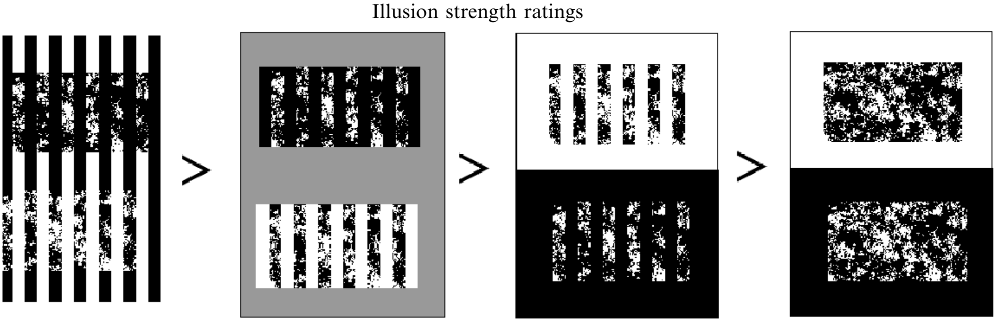


Figure 6. The results of this experiment. All nine observers ranked the illusion in an identical order, from most dissimilar (left) to most similar (right).

stripes appeared to be composed of white speckles. The second strongest difference was reported for the figure in which the black and white bars in the surround were replaced by a mid-gray (figure 5d), which was used to assess the sufficiency of assimilation in providing an account of this illusion. The third strongest difference was obtained for the examples in which the thin textured bars were placed on uniform white and uniform black backgrounds. The weakest difference was obtained for simultaneous-contrast variant of the display where rectangular patches of texture were placed on a homogeneous white and black background. Indeed, seven of the nine observers reported that the textures in this last figure appeared identical.

To gain insight into the meaning of these data, consider the assimilation control pattern, which was the second strongest difference reported by observers. If assimilation *qua* spatial averaging was a sufficient explanation for White's effect, then the observers should have reported that the textured regions in White's display and the assimilation display were equal in their perceived difference. However, all observers reported that White's version of this illusion was stronger than the assimilation test, which implies that something other than a simple luminance averaging process must be playing a role in this illusion. Moreover, although observers uniformly picked out the assimilation control as the second strongest illusion, they were nearly evenly split about the *direction* of the illusion: four of the nine observers reported that the texture flanked by white stripes appeared to be predominantly composed of black material, and stated that the textured regions appeared more similar to the texture flanked by black stripes in White's pattern. Note that the analogous region in White's illusion appeared predominantly composed of white speckles, so this represents a reversal in the perceived direction of the reported difference.

A similar ambiguity was experienced in the pattern in which the textured bands were placed on either a uniform white or a uniform black background (as well as White's original papers; see White 1979, 1981). This pattern (figure 5c) was designed to test theories of White's illusion in which the local texture patches are seen as occluded, but in which no completion between the individual textures is assumed to occur. As with the assimilation display, this did not generate as vivid a perceived difference as White's version of the display. Moreover, observers were again nearly evenly split about the direction of the illusion: five of nine observers reported that the textured bars on the black background appeared to be mostly composed of white material, and that it was more similar to the texture in White's illusion that was flanked by white bars. This, again, represents a reversal in the direction of the illusion experienced in White's pattern, so it seems unlikely that this kind of perceptual organization is playing a role in this illusion.

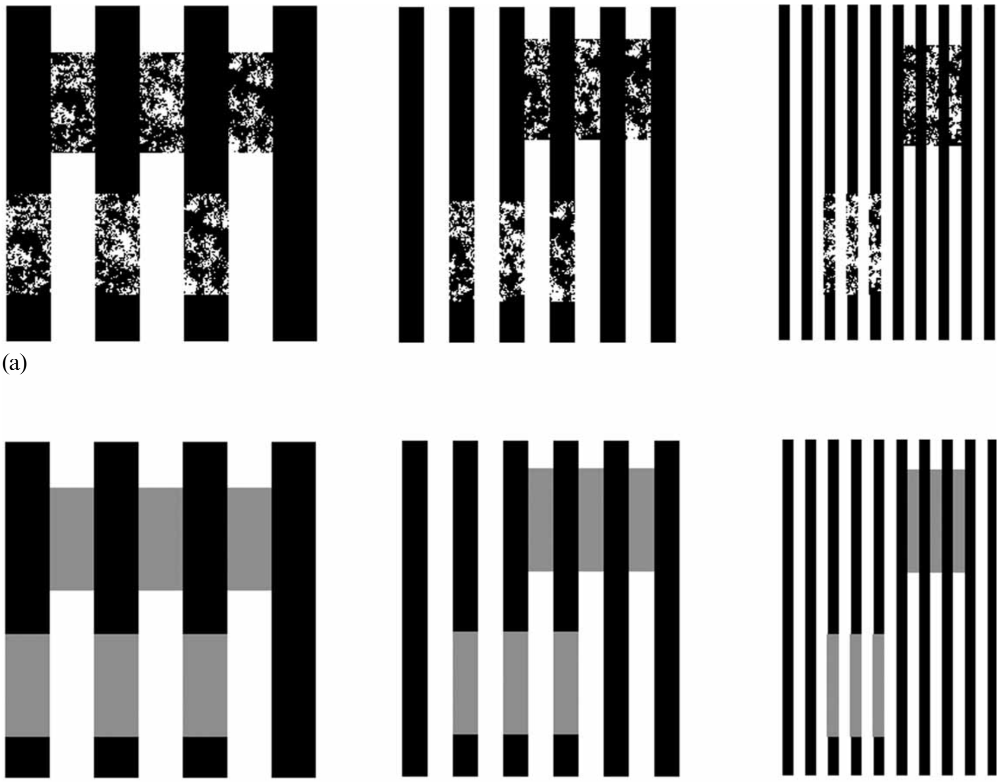
An even smaller perceptual difference was generated by the simultaneous-contrast variant in which completion is assumed to have occurred. This display (figure 5b) generated the weakest illusion of all of the displays considered here. Indeed, no evidence could be found that this perceptual organization played any role in the illusions reported here. Since observers did not report any perceived illusion in this condition, no data were collected to determine the direction of this (nonexistent) difference.

3 General discussion

The results of the experiment described above provide new insight into the organizational forces that contribute to White's effect. All observers reported a vivid difference in the textured targets when they were embedded in White's pattern, and that this difference was stronger then any of the control patterns. These control patterns were designed to assess the sufficiency of contrast and assimilation in explaining the differences experienced in the textured versions of White's displays. The fact that all observers rated the difference in the textured White's pattern as larger than any of the control images indicates that something beyond local contrast computations and/or assimilation is operating in this illusion. Indeed, the primary transformation in the textured targets in White's illusion is a dramatic reversal in the figure–ground relationships of the luminance modulations within the texture, not a transformation in the perceived brightness or lightness of the dark and light components of the texture. Any successful theory of this new effect needs to explain the processes involved in such figure–ground reversals. At this juncture, it would appear that only the scission theory is capable of explaining this difference.

To see this, let us consider the two theories that seem least capable of explaining the new illusions presented here: filter theories, and the occlusion theory. Although these two classes of theories differ in the kinds of computations that are assumed to generate White's (original) effect, they share a general strategy: both seek some means of differentially weighting the edges along the targets. The shared intuition motivating both approaches is that the borders of the targets that would drive the illusion in the opposite direction than that experienced must somehow be 'discounted'. In the filtering models, this is accomplished via the size and/or kind of filter employed (Moulden and Kingdom 1989; Blakeslee and McCourt 1999). In the occlusion and anchoring accounts, this differential weighting occurs by generating separate image layers (or groups), and then assuming that lightness is only determined with respect to a surface and its background (or its local and global framework; see Todorović 1997; Zaidi et al 1997; Gilchrist et al 1999). It is unclear whether these theories could be significantly modified to account for the figure–ground reversals observed in the textured variants of the illusion reported here.

A potentially more promising theory of these phenomena is that some form of assimilation plays a role in both White's illusion and the textured variants presented here (White 1981; Taya et al 1995; Ripamonti et al 1998). One of the first systematic studies of assimilation was performed by Helson (1963). He found that, when thin black bars were interleaved with thin gray bars, observers reported the gray bars as appearing darker, but when thin gray bars were interleaved with thin white bars, the gray bars appeared lighter. When the width of the bars was increased, the effect reversed, and a contrast illusion was observed. The strength of White's illusion does increase as the width of the bars is decreased, providing suggestive evidence that assimilation may be playing a role in (at least) the stronger versions of White's effect. However, no reversal in illusion direction has been reported when the width of the bars in White's pattern are varied (see figure 7b). Indeed, current theories of spatial vision assume that the visual system samples images with multiple-sized filters, so some of these filters will average luminance over some range of sizes. In order to determine what the coarse spatial scales 'see' in White's pattern, we blurred both the classic White's pattern and the textured versions of White's display to the point where the individual bars were no longer perceptible (see figure 8). The results of this process may provide some insight into the role of assimilation in White's effect. When the images are blurred to the point that the bars surrounding the targets are imperceptible, three things occur: the surround becomes an intermediate gray, one of the target regions becomes a luminance increment, and the other becomes a luminance decrement. In the standard White's effect, the targets that appear darker in the original image appear as a luminance decrement in the blurred image, and the targets that appear lighter in the original image appear as a luminance increment (see figure 1b). This correctly recovers the sign of the illusion. Contrast-enhancing mechanisms may also act on this lower resolution representation, causing an even larger apparent difference in apparent lightness than is generated by a simple luminance averaging process. It should be noted, however, that this kind of processing does not explain double-increment and double-decrement displays (Ripamonti and Gerbino 2001).



(a)

(b)

Figure 7. Variants of White's effect and textured White's effect. The number of targets is held constant in each display, and the width of the bars is reduced when progressing from left to right. Note that the strength of White's effect is maximal at the right and minimal at the left for both textured White's effect (a) and for traditional White's effect (b).

In addition to providing some insight into White's original display, the blurred versions of the textured White's pattern also contain information that theoretically could be used to understand the figure – ground inversions experienced in figure 5a. Indeed, at coarse spatial scales, the region that appears as white speckles in the unblurred image appears as a light region in the blurred version of the illusion, and conversely for the region that appears as black speckles. Note, however, that this line of reasoning does not explain why the assimilation control pattern did not generate as large a figure – ground shift in the textured White's images, or why observers were nearly evenly split as to the figure – ground relationships of the texture in the assimilation control pattern. Indeed, when blurred, these images create a nearly identical pattern to that observed in figure 8. Thus, some additional principle is needed to explain the influence the black and white bars in the surround have in resolving the figure – ground relationships of this pattern.

I have previously argued that scission provides the missing theoretical ingredient needed to understand White's illusion and a broad class of related phenomena (Anderson 1997). I argued that the contrast relationships that arise along aligned contours initiate a decomposition of an adjacent region into multiple layers. The intuition shaping this theory is that transparent media can reduce the contrast magnitude of an underlying contour, but such media can not reverse the polarity of contours it overlies. Thus, in principle, the luminance and contrast relationships of contours could provide relatively local information that the visual system uses to determine whether a

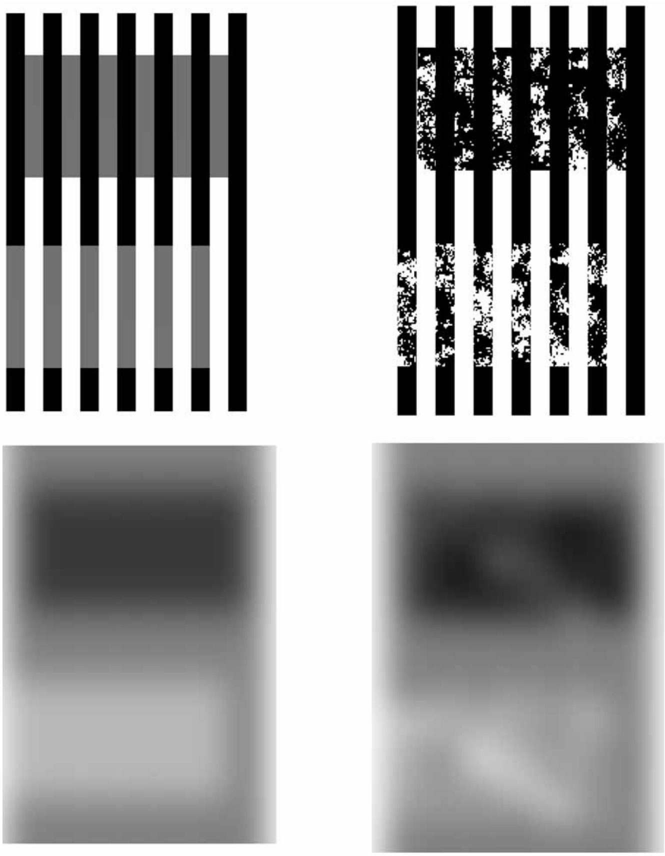


Figure 8. In order to determine what the spatial filters 'see' that sample White's pattern at coarse spatial scales, I blurred both White's illusion (left) or the textured variants of the White's pattern (right) to the point that the bars in the surround were no longer discernible. As can be seen, this process correctly predicts the sign of White's effect, but it does not explain why the textured variant of White's pattern in figure 2a created a larger difference than the assimilation control pattern in figure 2d.

transparent surface layer is present or not. To see how, consider White's original display. The homogeneous gray targets in these images cause a reduction in the contrast magnitude along the black–white contours in the surround, but the contrast polarity of the contours is preserved. The scission theory asserts that this causes the gray targets to be decomposed into two layers, which in turn causes a shift in the apparent lightness of the target regions in a direction opposite to the lightness of the underlying surface that has been 'removed'. Thus, the gray targets in the black bars look lighter, whereas the gray targets in the white bars look darker. A related analysis provides a principled explanation of the new textured variants of White's illusion described here. Consider the textured regions that are embedded in the black bars in the bottom of figure 5a. The white portions within the texture that abut the white bars obliterate the contrast of the contours that enter this region from the surround. This is consistent with the white portions of the texture being an opaque occluding 'screen'. In contra-distinction, the black portions of the texture that abut the white bars generate the same contrast signals as the black–white contours lying outside of the texture. Since the scission thesis requires a contrast change to infer the presence of an occlusive screen, these regions are interpreted as holes that provide an unobscured view of a continuous, underlying black surface (or series of black bars). A similar analysis explains why the opposite figure – ground relationships are observed when the texture is placed in the white bars.

It should be noted that this analysis depends on the presence of high-contrast contours in the surround, which is not a part of the assimilation account. Indeed, the scission account is based on computations that occur along continuous, aligned contours, which are absent in any of the control displays. This theory predicts that the figure – ground relationships of the textured regions are determined by the contrast relationships along the contours entering the target region from the surround. However, if the external contours are not present, the figure – ground relationships of the texture should be ambiguous, which is what our observers report for our control patterns.

It could be argued that these new versions of White's illusion should be regarded as new and specific effects,[1] because they involve figure – ground reversals rather than transformations in perceived lightness. If viewed in this manner, these results would not impact directly on theories of traditional variants of White's illusion. Although this is possible, it seems unlikely. The textured variants of White's effect are modulated by the same properties as traditional variants of White's effect. Consider, eg, the variants of both the textured and traditional White's effect depicted in figure 7. The number of targets is held constant in both sets of images, and the width of the bars is progressively reduced (similar results are observed if the number of targets is varied and the areas of targets are equated). Note that the strength of the illusion increases for both White's original display and the textured versions of his images as the width of the bars is reduced. If these are truly distinct effects, it seems coincidental that they would exhibit such similar dependences on the spatial parameters of the display.

In conclusion, the phenomena presented here provide new evidence for the role of image decomposition—ie scission—in shaping the differences observed in the targets of White's display. These new illusions suggest new ways to evaluate the organizational forces that are responsible for the computation of surface lightness, and a new experimental strategy to determine spatial contexts that induce scission.

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[1] This view was suggested by an anonymous reviewer.

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