1. White's effect in lightness, color and motion

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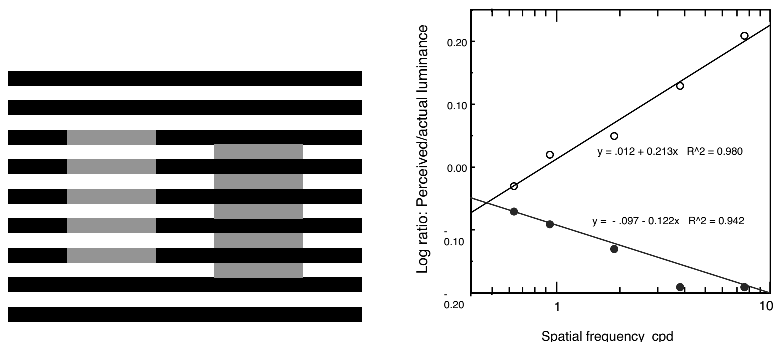
Abstract

In White's (1979) illusion of lightness, the background is a square-wave grating of black and white stripes (Fig. 1a). Grey segments that replace parts of the black stripes look much lighter than grey segments that replace parts of the white stripes. Assimilation from flanking stripes has been proposed, the opposite of simultaneous contrast. We use colored patterns to demonstrate that the perceived hue shifts are a joint function of contrast and assimilation. Simultaneous contrast was relatively stronger at low spatial frequencies, assimilation at high. Both the chromatic and achromatic versions of White's effect were stronger at high spatial frequencies. "Geometrical" theories attempt to explain White's effect with T-junctions, anisotropic lateral inhibition, and elongated receptive fields. But an isotropic random-dot illusion of lightness called "Stuart's Rings" resists any anisotropic explanations. White's illusion also affects motion perception. In "crossover motion," a white and a black bar side by side abruptly exchange luminances on a gray surround. Direction of seen motion depends upon the relative contrast of the bars. On a light [dark] surround the black [white] bar is seen as moving. Thus the bar with the higher contrast is seen as moving in a winner-take-all computation. But if the bars are embedded in long vertical lines, the luminance of these lines is 2.3 times more effective than the surround luminance in determining the seen motion. Thus motion strength is dependent upon White's effect and is computed after it.

1.1 Introduction

White's illusion is shown in Figure 1.1a. The gray rectangles are the same, but the left one looks lighter. This is surprising: By local contrast, the left ones should look darker than the right ones. The left grey stripes have a long border with white and a short border with black. The illusion is reversed from the usual direction (Adelson 2000).



a **b**

Figure 1.1: **a**. White's effect (after White, 1979, 1981). Grey regions look darker when embedded in white stripes and flanked by black stripes than vice versa. **b**, effect increases with spatial frequency; apparently light regions look even lighter (upper curve) and apparently dark regions look even darker (lower curve).

Interpretations of White's effect include:

- End-wise simultaneous contrast from the embedding stripes, plus assimilation from the flanking stripes (White 1979, 1981). Assimilation and contrast are sometimes called positive and negative brightness induction.
- Stimulus geometry: T-junctions (Todorovic, 1997: Zaidi, Spehar and Shy 1997). Patches straddling the stem of a T are grouped together for the lightness computation, and the cross-bar of the T serves as an atmospheric boundary.
- Visual system geometry: Hypothetical elongated receptive fields produce anisotropic brightness induction plus neural filtering (Kingdom and Moulden 1991a, b: Blakeslee and McCourt 1999).
- Visual 'scission' treats the grey regions as separate transparent layers (Anderson, 1997).

This list is by no means exhaustive. Our experiment are limited to low rather than high-level explanations, and they seek to show that White's effect involves both contrast and assimilation, but perhaps no anisotropic geometrical factors.

1.2 Experiment 1. White's effect increases with spatial frequency

White's effect was measured by a matching method. Outside the striped area of Figure 1.1a was a solid grey adjustable patch of the same size (not shown), which the observer adjusted to a perceptual match. All settings were recorded for later analysis.

Setting the magnification of the display to 12, 8, 4, 2 and 1 fixed the spatial frequency of the stripes to 0.627, 0.94, 1.88, 3.76, and 7.53 cpd respectively at a constant viewing distance of 72cm. (We avoided varying the viewing distance, in case this might introduce accommodation-linked chromatic aberrations).

Results are shown in Figure 1b (mean of 2 naïve Ss x 3 readings). Figure 1.1b shows that as the spatial frequency was increased, the apparently lighter patch looked progressively even lighter (upper line in Fig. 1b) and the apparently darker patch looked progressively even darker (lower line in Figure 1.1b). At the highest frequency used (7.53 cpd), the left grey patch looked 0.4 log units lighter, a factor of 2.5, than the right patch.

1.3 Experiment 2. A colored White's effect shows both contrast and assimilation

A grey test patch embedded in a white stripe and flanked by black stripes looks darker. Is this caused by contrast with the embedding white stripe, or by assimilation to the flanking black bars? To find out, we changed the 3 cpd black and white stripes of Figure 1.1a into non-complementary colors, namely cyan (CIE $x = .23$, $y = .31$), and green (CIE $x = .29$, $y = .48$), and plotted the results in CIE color space. Consider a grey patch embedded in cyan (central circle in Figure 1.2a). Any simultaneous contrast from cyan would give it a reddish tinge and shift its perceived hue to the right. Any assimilation toward the flanking green stripes would give it a greenish tinge and shift its perceived hue upwards. In fact, it shifted in both directions, up and to the right (thick arrow in Figure 1.2a) The relative lengths of the vertical and horizontal vectors gives the proportion of assimilation to simultaneous contrast. Likewise, a grey patch embedded in the green stripes shifted down to the left; so both patches shifted in directions parallel to the hypotenuse of the CIE green-grey- cyan triangle. We conclude that both assimilation and simultaneous contrast play a large role in the colored White's effect. Clifford and Spehar (2003) have reached similar conclusions from their experiments.

1.4 Experiment 3. Colored White's effect: Spatial frequency

We now made the stripes orange (CIE $x = .496$, $y = 438$), and magenta ($x = .320$, $y = .165$), and used the same range of spatial frequencies as in Experiment 1. These colored stripes made the grey stripes look compellingly bluish and greenish, and naïve observers often refused to believe that they were really achromatic. They adjusted the hue and saturation of the matching patches by means of color palettes. Results are plotted in CIE color space in Figure 1.2b (mean of 3 Ss x 3 readings). The grey test patches (open circle in center) appeared to be tinged with green (triangles) or blue (squares). This Figure shows that the perceived hues were shifted approximately parallel to the hypotenuse, thus showing a combination of assimilation and simultaneous contrast. These data are replotted in Figure 1.3a to show that the length of the color-shift vec-

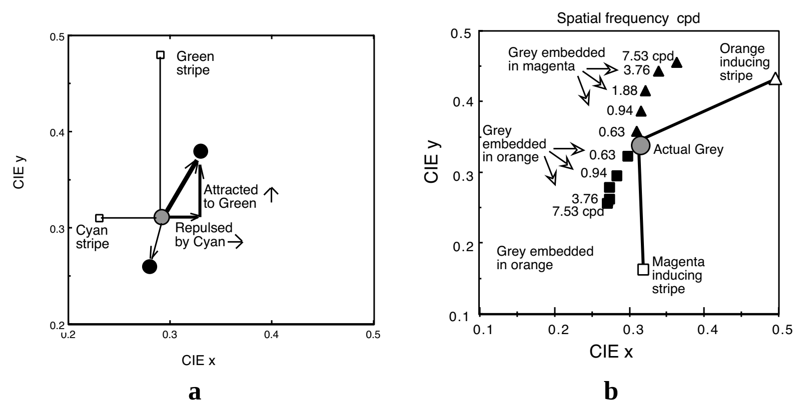


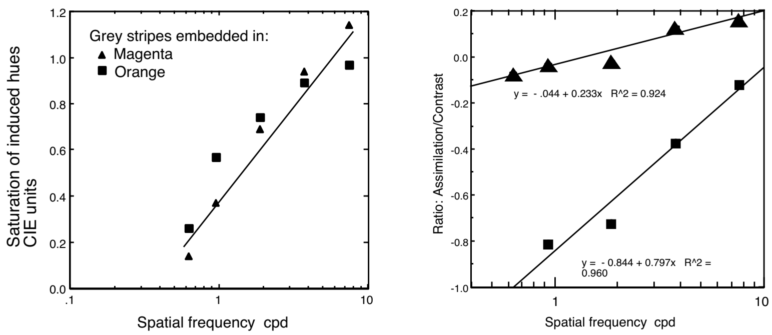
Figure 1.2: Colored White's effect. **a**, grey regions embedded in cyan stripes are repelled by cyan (rightward arrow) and also attracted to flanking green stripes (upward arrow). Opposite is true for grey regions embedded in green. **b**, Embedding stripes were magenta and orange. Grey test regions (central circle) showed increasing color shifts with spatial frequency.

tors, that is the saturation of the induced colors, increased with spatial frequency. In fact both the achromatic and chromatic versions of White's effect increased with spatial frequency.

The direction of these vectors reveals the ratio between the amount of contrast and of assimilation. Note that in Fig. 2b the square data points lie on a downward curve, showing increasing assimilation toward the flanking magenta stripes at higher spatial frequencies. Likewise the uppermost triangles lie on a curve up and to the right, showing that they assimilate toward the flanking orange stripes. In both cases raising the spatial frequency increased the amount of assimilation relative to simultaneous contrast (Fig. 3b). Thus, for grey stripes embedded in magenta (lower curve in Fig. 3b), contrast was more than ten times stronger than assimilation at 0.627 cpd, but was only 1.26 times stronger (0.1 log units) at 7.53 cpd. The slopes of the curves indicate that an octave increase in spatial frequency increased the ratio of assimilation to contrast by 0.8 octaves for stripes embedded in magenta, and by 0.23 octaves for stripes embedded in orange. These results suggest that assimilation has a smaller spatial range than contrast, and this fits with the common observation that fine lines give the most assimilation (Bertulis and Saudargene, 1988; Reid and Shapley 1988). It is also consistent with hypothetical receptive fields with small summatory centers that handle assimilation, and with much larger inhibitory surrounds that handle simultaneous contrast.

1.4.1 Experiment 4. An isotropic brightness illusion: "Stuart's Rings"

Some geometric theories of White's effect invoke the role of T-junctions in the stimulus, or of elongated receptive fields in the stimulus. However, a new *isotropic* bright-

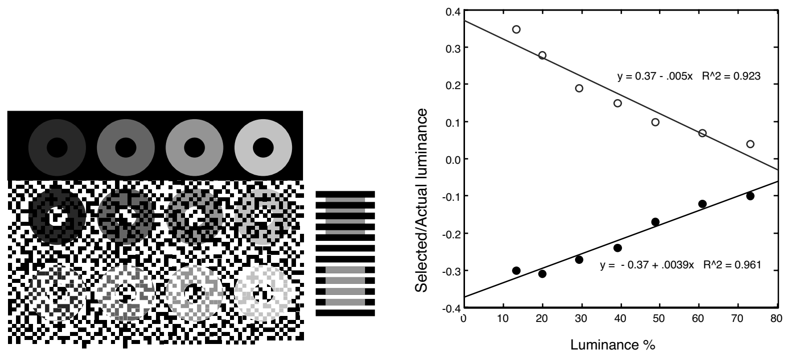


a **b**

Figure 1.3: Replotting data from Figure 1.2b: increasing the spatial frequency increases both **a**, strength of color shift and **b**, ratio of assimilation to contrast.

ness illusion called "Stuart's Rings", which can be stronger than White's effect, seems to rule out these theories. In Figure 4a the grey parts of the rings in each column are identical, but those in the middle row look subjectively darker, and those in the bottom row look subjectively lighter, than the rings in the top row. The perceived lightness shifts are in the same direction as in White's effect, but with random dots instead of horizontal stripes. Thus in the middle row the rings are of interspersed grey and black dots, with the grey dots replacing the white dots of the surround. These rings look dark. In the bottom row the rings are made of interspersed grey and white dots, with the grey dots replacing the black dots of the surround. These rings look light. Compare this with Fig. 1a, where in the grey/black right panel the grey stripes are flanked by black stripes and replacing white stripes. This panel looks dark. In the grey/white left panel the grey stripes are flanked by white stripes and replacing black stripes. This panel looks dark.

This illusion was measured by a matching method. Ring diameters were 1.9^o, and dot diameters were 4 min arc. Two observers adjusted the luminance of the rings in the top row until they appeared to match the lightness of rings either in the middle row, or in the bottom row. Their settings are plotted in Figure 4b (mean of 2 Ss x 3 readings). The x axis shows the actual ring luminances, expressed as a percentage of "white" ($= 108$ cd/m^2). The y axis shows the amount of lightness illusion, where the rings looked darker, unchanged or lighter for $y < 0$, $y = 0$, $y > 0$. Effects were stronger for physically darker rings. In fact the darkest rings that we used (12% of white) looked as much as four times (0.6 log units) lighter in the bottom than in the middle row. These results show that isotropic random-dot patterns can produce strong lightness illusions in the absence of T-junctions or elongated areas. One might argue that "Stuart's Rings" are entirely different from White's effect, but this would gain little since one then would need to develop two separate explanations instead of one!



a **b**

Figure 1.4: **a**, "Stuart's Rings" illusion. All 3 rings in each column are identical grey, but look darker when grey replaces white random dots (middle row) and lighter when grey replaces black random dots (bottom row). b, illusion is greatest for physically darkest rings.

1.5 Experiment 5. White's effect and apparent motion

A bar that alternates between two spatial positions appears to jump back and forth (see reviews by Kolers, 1972; Anstis, 1978, 1980). In "cross-over" motion (Anstis and Mather, 1985), a black and a white bar side by side switch luminances repetitively over time. This display is rarely perceived as stationary flicker in place (Figure 1.5a), because the "suspicious coincidence" (Barlow, 1974) in which one bar appears just as the other disappears, triggers the visual system to apply Occam's razor, namely to adopt the minimum hypothesis about the real world that fits the maximum evidence in the visual input. This minimax is provided by the hypothesis that a single bar is jumping to and fro. But which bar is seen as jumping? This depends on the surround. On a dark surround, the white bar is seen as moving, but on a light surround, the black bar is seen as moving (Figure 1.5b, c). Thus the bar with the higher contrast against the surround gives a stronger motion signal and is seen as moving (Anstis and Mather, 1985).

Does White's effect alter the perceived contrast, and hence motion, of the jumping bars? We varied independently the luminances of the surround, and of long vertical stripes that embedded the jumping bars (Figure 1.5d, e) and found that the stripes overruled the influence of the remaining surround, consistent with White's effect. So we measured the relative strengths of the stripes and the remaining surround, by titrating their luminances and seeing which determined the perceived direction of apparent motion. Fig. 6 shows one frame of a two-frame movie: in the other frame the short black and white bars exchanged luminances. In a, b and c, all the jumping bars are identical, but in a the surround luminance is spatially graded from left to right, so that in the left half of the Figure the white bars appear to move, whilst in the right half the black bars appear to move. A *vertical* line separates these two perceptual half-fields. Now look at

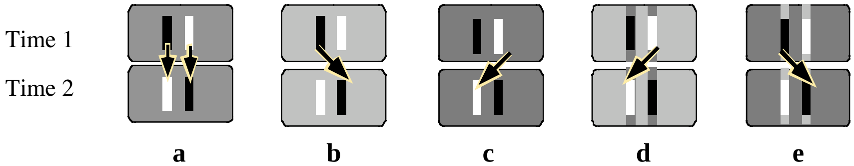


Figure 1.5: A black and a white bar abruptly exchange luminances (Anstis and Mather 1985). **a**, flicker in place is rarely seen. **b**, on a light surround the black bar appears to jump. **c**, on a dark surround the white bar appears to jump. However, **d**, embedding the bars in dark stripes makes the white bar appear to jump, despite the surround, and **e**, embedding the bars in light stripes makes the black bar appear to jump, despite the surround. Conclusion: White's effect alters "crossover" apparent motion.

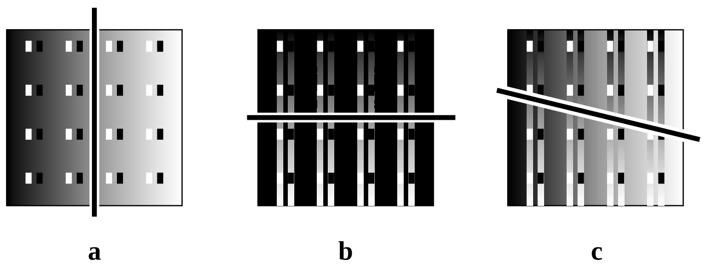


Figure 1.6: White's effect alters "crossover" apparent motion. a, on dark surround at left, white bars seem to jump, and on light surround at right, black bars seem to jump. Bars with higher contrast win. b, on dark embedding bars at top, white bars seem to jump, and on light embedding bars at bottom, black bars seem to jump. c, combining a with b pits surround against embedded bars. Slope of dividing line shows relative influence of surround and embedding stripes.

Figure 1.6b. All the bars are still the same, but now they are embedded in long vertical stripes that are graded from light at the bottom to dark at the top. The surround is black so plays no part in what is seen. In the bottom half of the Figure the white bars appear to move, whilst in the top half the black bars appear to move. A *horizontal* line separates these two perceptual half- fields. In Figure 6 c these two stimuli are combined so that the surround is graded from left to right and in addition the embedding bars are graded from top to bottom.

Eight observers viewed each bar pair in turn through a small hole, and reported whether the white or the black bar seemed to move. The regions in which the black bars versus the white bars appeared to move could be separated by a line, whose slope revealed the relative importance of the surround versus the embedding line. A vertical [or horizontal] separating line would show that only the surround [or only the embedding bars] determined the perceived bar contrast, and motion signal strength. Results are shown in Fig. 6 (mean of 8 Ss x 3 readings). This separating line was

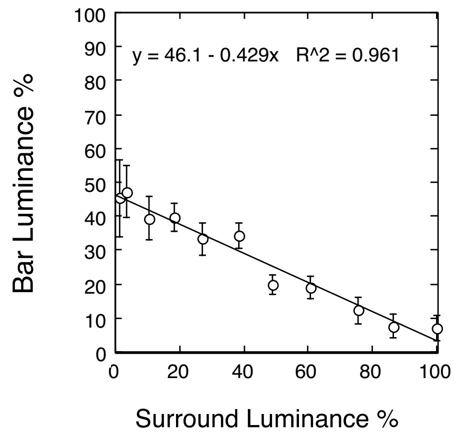


Figure 1.7: Apparent-motion results from stimuli in Figure 1.6. Below the line, bars and surround were dark and white bars appeared to move. Above the line, bars and surround were light and black bar appears to move. Slope of line is .429, showing that luminance of embedding bars is 2.33 ($= 1/.429$) times more important than surround luminance. Conclusion: White's effect strongly influences crossover motion.

oblique. Below the line the surround and embedding bars were dark and the white bar appeared to move. Above the line the opposite was true. The slope of this line was only 0.429, which indicates that the embedding bars were 2.33 ($= 1/.429$) times more important than the surround in determining the bars' contrast for motion. We conclude that White's effect occurs before the motions of the bars are computed

In conclusion, White's effect involves both assimilation and simultaneous contrast: Geometrical theories involving T-junctions and elongates receptive fields might fit White's effect, but they do not explain Stuart's Rings. Finally, White's effect occurs before motion processing and can influence the strength of motion signals.

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References

Adelson, E. H. (2000). Perception and lightness illusions. In M. Gazzaniga (Ed.) *The new cognitive neurosciences, 2nd edn.* Cambridge, MA: MIT Press, 339–351.

Anderson, B. L. (1997). A theory of illusory lightness and transparency in monocular and binocular images: the role of contour junctions. *Perception* 26: 419–453.

Anstis, S. M. (1978), Apparent movement. In R. Held, H. W. Leibowitz, and H.-L. Teuber (Eds.) *Handbook of Sensory Physiology, vol. VIII*, New York: Springer-Verlag, 655–673.

Anstis, S. M. (1980). The perception of apparent movement. *Phil. Trans. Roy. Soc. Lond. B*, 290: 153–168. Reprinted in *The Psychology of Vision*, C. Longuet-Higgins and N. S. Sutherland (Eds.) The Royal Society: London, 153–168.

Anstis, S. M. and Mather, G. (1985). Effects of luminance and contrast on direction of ambiguous apparent motion. *Perception*, 14: 167–179.

Barlow, H. B. (1974). Inductive inference, coding, perception, and language. *Perception* 3: 123–34.

Bertulis, A. V. and Saudargene, D. S. (1988). Spatial parameters of the color assimilation effect. *Sensory Systems*, 2: 204–209.

Blakeslee, B. and McCourt, M. E. (1999). A multiscale spatial filtering account of the White effect, simultaneous brightness contrast and grating induction. *Vis. Res.*, 39: 4361–4377.

Clifford, C. W. G. and Spehar, B. (2003). Using colour to disambiguate contrast and assimilation in White's Effect. Proc. Vision Sciences Annual meeting, Sarasota, FL.

Kingdom, F. and Moulden, B. (1991a). A model for contrast discrimination with incremental and decremental test patches. *Vis. Res.*, 31: 851–858.

Kingdom, F. and Moulden, B. (1991b). White's effect and assimilation. *Vis. Res.*, 31: 151–159.

Kolers, P. A. (1972). *Aspects of Motion Perception*. Pergamon Press: New York.

Reid, R. C. and Shapley, R. (1988). Brightness induction by local contrast and the spatial dependence of assimilation. *Vis. Res.*, 28: 115–132.

Todorovic, D. (1997). Lightness and junctions. *Perception*, 26: 379–394.

White, M. (1979). A new effect of pattern on perceived lightness. *Perception*, 8: 413–416.

White, M. (1981). The effect of the nature of the surround on the perceived lightness of gray bars within square-wave test gratings. *Perception*, 10: 215–230.

Zaidi, Q., Spehar, B. and Shy, M. (1997) Induced effects of backgrounds and foregrounds in three-dimensional configurations: the role of T-junctions. *Perception*, 26:395–408.