White's effect: Removing the junctions but preserving the strength of the illusion

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Abstract. White's effect (also known as the Munker–White effect) is a lightness illusion in which, contrary to expectations based on simultaneous contrast and Wallach's rule, a gray rectangle predominantly surrounded by white appears lighter than an identical rectangle that is mainly surrounded by black. The illusion is often explained in terms of T-junctions that are formed by the three-way intersection of the gray rectangle, a black stripe, and a white stripe. I present a circular variant of White's effect in which all the junctions have been removed without signi-ficantly affecting the strength of the illusion, suggesting that junctions are not an important consideration in all versions of White's effect.

1 Introduction

The left side of figure 1 shows an example of White's lightness illusion (White 1979). It consists of a background of alternating black and white stripes onto which gray rectangles have been superimposed. The four gray bars in the top appear lighter than those in the bottom even though in fact they are all identical. This illusion is particularly interesting since arguments based on simultaneous contrast, for example Wallach's ratio rule (Wallach 1948), would predict the opposite as the upper gray rectangles are bordered by more white and less black than the lower.

The right side of figure 1 is an enlargement of a section of the left side, showing the bottom of a gray rectangle and some of the surrounding black and white stripes. At the bottom right-hand edge of the gray rectangle three regions of different lumi-nance join at a point. The edges of these regions form the shape of a horizontal 'T' (a gray 'T' has been superimposed over this region to demonstrate). Many attempts have been made to explain White's illusion in terms of T-junctions defined in this way (eg Anderson 1997; Todorović 1997; Ross and Pessoa 2000).
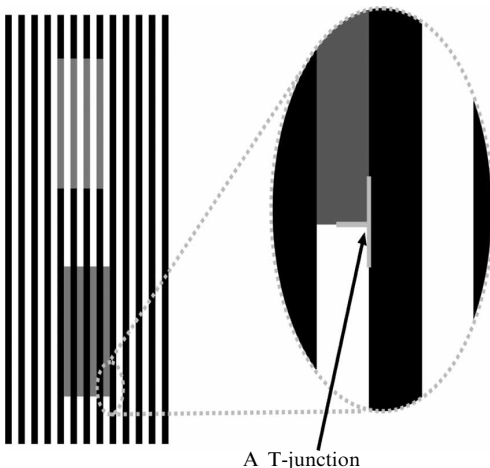

A T-junction

Figure 1. Left: White's effect. The four upper gray bars appear lighter than the lower bars even though they are identical. Right: An enlargement of a portion of White's display showing that at the corners of the gray rec-tangles three regions of different luminance join at an intersection that is often referred to as a 'T-junction'. A horizontal 'T' has been superimposed on this junction to demonstrate.

2 Implicit versus explicit junctions

I have previously demonstrated (Howe 2001) that White's effect could not be explained in terms of such T-junctions. Figure 2 shows a variant of White's effect where the lightness illusion is perceived to be either nullified or inverted relative to that perceived on viewing the conventional White's display (figure 1). The crucial point here is that the T-junctions, formed at the corners of the gray rectangles, are exactly the same in this display as in the conventional White's display. It would seem that theories based solely on T-junctions cannot explain White's effect.
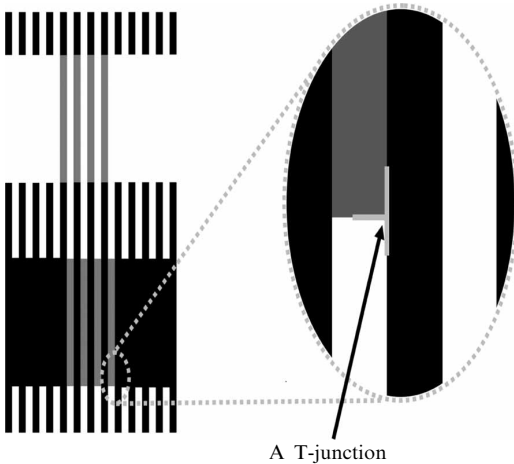

A T-junction

Figure 2. Left: A variation of White's effect where the illusion is either nullified or inverted. Right: An enlargement of the left display showing that the T-junctions (as defined by Anderson 1997, Todorović 1997, and Ross and Pessoa 2000) have not changed.

However, it has been pointed out that this variant of White's display (figure 2) contains illusory contours not present in the original (figure 1). These illusory contours form at the top and bottom of both the white and black horizontal stripes on which the gray bars are embedded. It was suggested by Howe (2001) that these illusory contours could interact with the T-junctions to form implicit X-junctions, a term that has been used previously (Watanabe and Cavanagh 1993). It has been shown that these implicit X-junctions could explain this variant of White's illusion (Howe 2001). This would seem to imply that White's illusion could still be explained in terms of junction structure, providing that junction structure is defined implicitly.

3 Introducing gaps to reduce the salience of the junctions

Figure 3 shows an example of one of the displays of Yazdanbakhsh and colleagues (2002). This display is very similar to the conventional White's display (figure 1), except that gaps have been placed between each gray rectangle and the stripe with which it
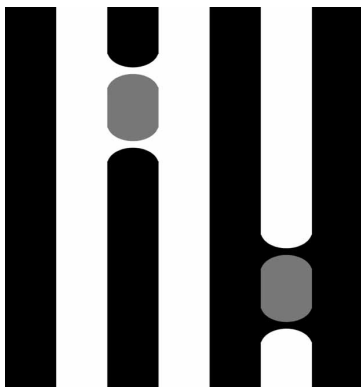

Figure 3. An example of a White's display where the salience of the T-junctions has been reduced (or eliminated depending on the assumed acuity of the hypothesized T-junction detectors) with the resultant lightness illusion also being reduced (Yazdanbakhsh et al 2002).

is aligned. The authors claimed that these gaps completely eliminated the perception of junction structure, but it seems more likely that the gaps merely reduced the salience of the junction structure.

One way to test this assertion would be to measure the response of neural T-junction detectors to such displays. It has been suggested that bipole cells could function in this regard (Grossberg 1997; Kelly and Grossberg 2000). It seems plausible that bipole cells with fine spatial resolution would have their activity reduced by such gaps, but those with coarser resolution may not be affected. It therefore seems likely that introducing gaps would reduce the number of T-junction detectors that respond to the display, which in turn would reduce the salience of the T-junctions. Under the hypothesis that White's illusion is mediated by T-junctions one would expect the magnitude of the illusion to be reduced. This is exactly what Yazdanbakhsh et al observed: for their variant of White's effect they measured the illusory lightness difference to be approximately half that of the conventional White's illusion. It seems that by reducing the salience of the junction structure Yazdanbakhsh et al reduced the strength of the illusion. Consequently, contrary to their opinion, their results cannot completely exclude the influence of T-junctions in White's effect.

4 Removing junctions entirely with the circular White's display

Given the state of the field, it seems necessary to measure exactly how important junction structure is in White's illusion. A rectangular version of White's effect is shown in the top row of figure 4 and a circular variant in the second row. In both the rectangular and the circular versions the gray patches in the left display are perceived to be lighter than those in the right because the former lie on black stripes and the latter on white. None of this is surprising and virtually any theory that can explain the original White's display can also explain the circular variant. White (1979) and Anderson (1997) have observed that lengthening the gray bars in the rectangular White's display (top row) does not affect the illusion. In the third row of figure 4 I lengthen the gray patches in the circular variant of White's display and observe that,
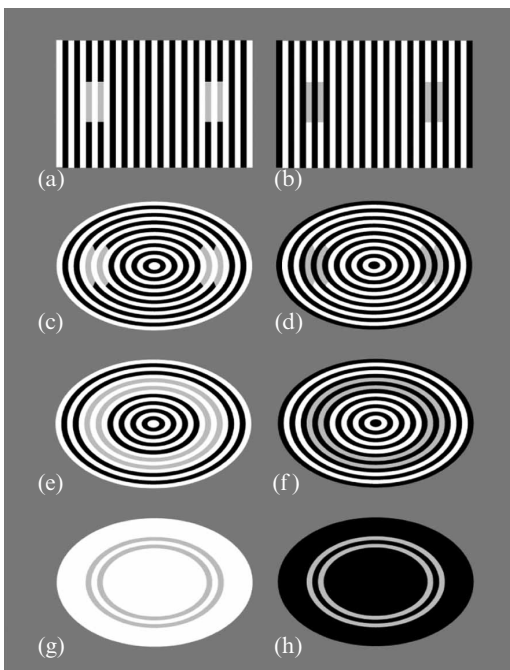

Figure 4. (a) and (b): A rectangular White's display. The gray patches in the right figure appear darker than those in the left. (c) and (d): A circular variant of White's display. The illusion is unchanged. (e) and (f): Extending the gray patches into rings leaves the illusion unchanged. (g) and (h): Removing the grating background dramatically reduces the illusion.

consistent with White's and Anderson's observations for the rectangular White's effect, the illusion doesn't seem to be affected. However, this result is surprising since all junction structure has now been removed owing to the circular geometry of the display. This suggests that junction structure is not an important factor in all versions of White's illusion.

It is possible that, at least for high spatial frequencies, blurring caused by the finite resolution of the eye might play a role in this illusion. To prove that the spatial frequency of my display is not so high that this is the dominant cause, I remove the background grating to produce the bottom row of figure 4. Now the illusion is greatly reduced, showing that the circular version of White's effect cannot be explained by retinal blurring. This, of course, does not rule out the possibility that pattern-specific assimilation, which would be expected to have a physiological basis (Helson 1963; de Weert and van Kruysbergen 1997), might be playing a role in White's effect.

I showed each of the eight displays of figure 4 to ten subjects who had normal or corrected-to-normal vision and whose heads were immobilized by a combined head-and-chin rest. Each display was presented on a gray background on the left of a Dell® Inspiron™ 8200 computer monitor that had been calibrated for luminance with a PhotoResearch® SpectraScan® PR-650 photometer. The displays measured 7.7 deg × 7.7 deg, had a spatial frequency of 2.1 cycles deg^{-1}, and the gray patches in the
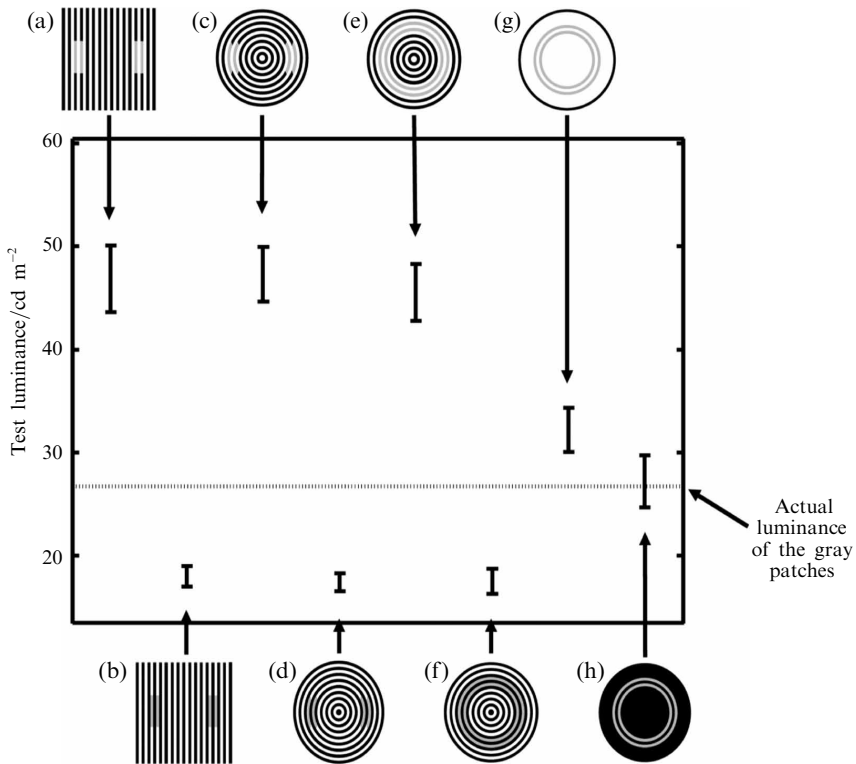

Figure 5. Experimental results. The rectangular White's effect shows a strong lightness illusion with the gray patches on the black stripes (a) appearing much lighter than those on the white stripes (b). The strength of the illusion is the same in the circular variant of White's effect [(c) and (d)], even when the gray patches are lengthened to remove their luminance junctions [(e) and (f)]. This suggests that junctions are not a significant factor, at least, in this particular White's display. Removing the background grating greatly reduces the illusory lightness difference [(g) and (h)], even though this does not change the luminance in the immediate vicinity of the gray patches.

displays were 1.7 deg high. The luminances of the white, gray, and black regions were 162, 26.7, and < 0.5 cd m^{-2}, respectively. On the right of the monitor, a circular test patch was presented on top of a black-and-white checkerboard background. The test patch subtended 1.4 deg and the background subtended 7.7 deg $\times$ 7.7 deg with each check subtending 0.4 deg $\times$ 0.4 deg. The separation between the edge of the checkerboard and the edge of the display was 3.1 deg. Subjects were asked to adjust the lightness of the test patch until it matched the lightness of the gray bars in the display. For each figure this was done twice, once with the test patch initially being black and once with it initially being white. The results are shown in figure 5. All presentations were conducted in a random order. The experiment was performed in accordance with the Harvard protocol for the use of human subjects.

In figure 5, (a) and (b) show the rectangular White's illusion: the gray patches on the black stripes in (a) appear much lighter than those on the white (b). In figure 5, (c) and (d) were created by joining corresponding stripes on the left and right sides of (a) and (b), respectively. The strength of the illusion is unchanged. Furthermore, the strength of the illusion is still unchanged when the gray patches are extended into circles thus eliminating the junction structure [(e) and (f)]. When the striped background was entirely removed the illusion was greatly reduced but not reversed [(g) and (h)].

5 Interpretation of results

It is perhaps easiest to discuss these results in terms of the anchoring theory of lightness perception (Gilchrist et al 1999). Summarized very crudely, this theory suggests that patches of different luminance are grouped together into frameworks with the most luminous being perceived as white. The lightness of every other patch in that framework is then determined by the ratio of that patch's luminance to the luminance of the most luminous patch. As an added complication it seems that objects can belong simultaneously to more than one group, with their lightness being influenced by every framework to which they belong.

In figure 5 there seem to be at least two ways in which the scene in (a) could be segregated. In the first, the figure is separated into a white background, a foreground containing a repeating series of black stripes out of which two holes have been cut, and four gray patches that just happen to be perfectly aligned with the two holes. Alternatively, the scene could be considered to consist of just two groups: a white background and series of black stripes in the foreground, with the slight complication that four of the black stripes have had their middle section painted gray. In this interpretation, the gray patches are grouped with the black stripes. Clearly, the second interpretation is simpler and more regular, with the consequence that the Gestalt law of Prägnanz (Koffka 1935) would suggest that it is favored. The junction structure also favors the second interpretation (Gilchrist et al 1999).

In the group consisting of the gray patches and the black stripes, we see that the gray patches are the most luminous object and so would tend to be seen as white. The gray patches are not actually perceived to be white, because they are also grouped into a global framework containing the white background (Gilchrist et al 1999). In this global framework, the white background, being the most luminous object, is perceived as white causing the less luminous gray patches to be seen as middle-gray. The resultant perception is a compromise between those generated by these two frameworks, so that the gray patches are perceived to be light-gray.

Similar reasoning applies to (b) in figure 5, where the gray patches are grouped with the white stripes. In this framework the white stripes, being the most luminous objects, are perceived to be white, thereby causing the gray patches to be seen as middle-gray. The same reasoning applies to the global framework. This then explains

why the gray patches in (b) are perceived to be middle-gray whereas those in (a) are perceived to be light-gray.

In (c) and (d), both the law of Prägnanz and the junction structure would maintain the same groupings as in (a) and (b), respectively. Since the frameworks have not been altered, the anchoring theory of lightness perception correctly predicts that the strength of the illusion remains the same.

In going from (c) and (d) to (e) and (f), respectively, we find that, even though the T-junctions are removed, the groupings are maintained by the law of Prägnanz. This is presumably why the strength of the illusion remains unaltered.

In going from (e) and (f) to (g) and (h) we see that the black-and-white striped background has been removed. The reduced regularity of the display means that the law of Prägnanz can no longer be applied and, instead, the law of proximity (Koffka 1935) groups the gray patches in (g) with the white background and the gray patches in (h) with the black background. This change in grouping is what causes the illusion to decrease. One might expect the illusion to reverse completely, but there appears to be assimilative effects that prevent this from happening (Helson 1963; de Weert and van Kruysbergen 1997). In particular, assimilation between the gray stripes and the background would lighten the gray stripes in (g) but darken them in (h).

It is perhaps helpful to consider how the anchoring theory could explain findings from two other studies of White's effect (White and White 1985; Spehar et al 1995). In the first, it was found that if, in the rectangular version of White's effect, the gray bars were moved perpendicular to the stripes, then the illusion would decrease and eventually reverse. Figure 6 gives an example of such a display.
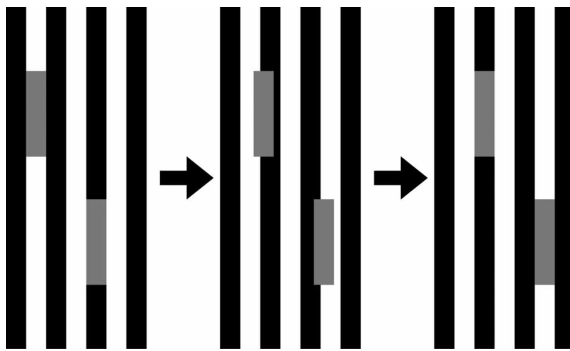

Figure 6. As the gray patches are translated horizontally, the lightness illusion gradually decreases and then reverses (modified from White and White 1985).

This finding can presumably be explained by noting that, as the gray patches are moved, the groupings are altered by the Gestalt law of proximity (Koffka 1935). As the groupings change, then so too must the lightness of the gray patches, as detailed by the anchoring theory of lightness perception. Thus, as the immediate background of each stripe inverts, so too does the illusion.

In the second study, Spehar and colleagues demonstrated that the lightness illusion in White's display occurs only when the luminance of the gray patches lies between the luminance of the light and dark stripes of the background (Spehar et al 1995). Figure 7 illustrates the situation.

In the situation where the luminance of the gray patches is midway between the luminance of the light and dark stripes, the Gestalt law of similarity (Koffka 1935) would tend to group the gray patches with the dark and light stripes equally. However, in the situation where the gray patches are more luminous than both the light and dark stripes, the law of similarity would tend to group both sets of gray patches with the light
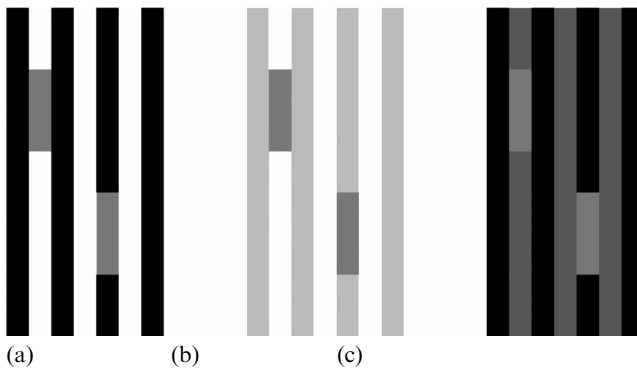
Figure 7. (a) A rectangular White's effect. The gray patch on the light stripe looks much darker than that on the dark stripe even though both gray patches are identical. (b) The luminance of the gray patches is unaltered but is now less than the luminance of the dark stripes. Both gray patches appear to have approximately the same lightness. (c) The luminance of the gray patches is unaltered but the luminance of the light stripes is now less than that of the gray patches. Again, both gray patches appear to have approximately the same lightness. (Modified from Spehar et al 1995.)

stripes. Since both sets of patches now belong to exactly the same frameworks, the anchoring theory of lightness perception predicts that they have the same lightness. Similar reasoning applies to the situation where the gray patches are less luminous than both the light and dark stripes. In this way the law of similarity would seem to be able to explain the observation of Spehar and colleagues that the illusion in White's effect occurs only when the luminance of the gray patches lies between the luminance of the light and dark stripes.

It seems that the anchoring theory of lightness perception is able to explain many aspects of White's effect. However, it does this by invoking grouping mechanisms that might be thought to lack rigor and concreteness, even by the authors' own admission (Gilchrist et al 1999, page 829). Indeed it is not hard to think of situations where different Gestalt grouping laws predict different outcomes, making it unclear as to which outcome should occur.

6 Conclusion

This paper has shown that in a circular variation of White's effect the illusion persisted even when the junction structure was removed. It was suggested that this occurred because the particular modification of White's effect that was studied had a sufficiently regular repeating structure that groupings could be maintained by the Gestalt law of Prägnanz alone. Indeed, when this repeating structure was removed [cf (g) and (h) in figure 5], the illusion was greatly reduced. This does not imply that T-junctions are never a crucial factor in determining the groupings in White's effect. Indeed, in a version of the illusion that was less regular, in that it contained fewer cycles of the square-wave background, it was shown that removing the T-junctions nullified the effect (Moulden and Kingdom 1989). Our results are consistent with the notion that T-junctions are just one of many factors that determine the groupings that in turn determine lightness as detailed by the anchoring theory of lightness perception (Gilchrist et al 1999), a point of view that is increasingly gaining favor (eg Bressan 2001).

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