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RESEARCH NOTE

WHITE'S EFFECT AND ASSIMILATION

FREDERICK KINGDOM* and BERNARD MOULDEN
Physiological Laboratory, University of Cambridge, Downing Street, Cambridge CB2 3EG and
Department of Psychology, Building 3, Earley Gate, Whiteknights, Reading RG6 2AL, U.K.

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Abstract—White's effect is a phenomenon in which grey bars replacing segments of the white phase of a square-wave grating appear darker than those replacing segments of the black phase. The direction of the brightness difference is consistent with brightness assimilation rather than with brightness contrast. We present data from two experiments which measure the degree of the brightness difference in stimuli consisting of just three inducing bars and a single grey test bar, as a function of various spatial manipulations of the inducing and test bars. The spatial manipulations were chosen to maximise the opportunity for assimilation effects to manifest themselves. The results do not support the view that assimilation is an important component of the effect. The data are shown to be consistent with our model of brightness induction in which both a local and a more spatially extensive contrast mechanism operate to produce White's effect.

INTRODUCTION

In White's (1979) effect, grey bars which replace segments of the white phase of a square-wave grating appear darker than identical bars which replace segments of the black phase. Figure 1 illustrates the effect. The phenomenon poses a particular problem for theories of brightness induction for the following reason. Examination of the figure will show that the grey segments on the white phase are bounded by black borders which are more extensive than the white ones. According to the principles of brightness contrast, one would therefore expect them to appear lighter than the segments on the dark phase (which are bordered proportionately more by white regions); this is the opposite of what is observed. The direction of the effect is therefore not consistent with expectations based on the operation of simultaneous contrast and is in the direction of the phenomenon known as "assimilation".

The classical version of the assimilation effect was first demonstrated by von Bezold (1876), who showed that a uniformly coloured background could be lightened by overlaid thin white lines and darkened by overlaid thin black lines.

The critical property of stimuli showing these classical assimilation effects is that they contain high spatial frequency information. It is well established that there is a reduction in apparent contrast in gratings of high spatial frequency (Kulikowski, 1976), which is held to be principally attributable to optical blurring (Campbell & Green, 1965), and this may be part of the explanation for some assimilation effects.

Jameson and Hurvich (1975) have implicated a neural mechanism: they suggest that the mechanism subserving the encoding of lightness pools its input from a greater area of the visual field than that subserving the description of fine detail, thus tending to average out the differences in lightness within a pattern. This is analogous to a striking effect that occurs with gratings modulated in both colour and luminance. As spatial frequency is increased a point is reached where the colour contrast disappears altogether, yet brightness contrast remains. This is a consequence of the fact that the mechanism subserving colour contrast pools its information over a greater area than that serving brightness contrast (DeValois & DeValois, 1987), just as Jameson and Hurvich suggest happens with lightness information versus structure information.

We (Moulden & Kingdom, 1989) have provided evidence that there are two mechanisms

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*Author to whom correspondence should be addressed.

involved in White's effect, one a spatially local and one a spatially extensive effect. Both operate in the direction of contrast rather than assimilation. The spatially local effect operates all along the borders of the test patch, but produces a particularly strong signal in the corner intersections of the test patch with the coaxial bar. It is the strong corner signal that disproportionately weights the coaxial bar relative to the flank in inducing brightness into the test patch. The more spatially extensive mechanism operates to allow the coaxial bar to exert an influence on the brightness of the test patch throughout its length. Further details of the model will be provided in the Discussion. We have argued that these two mechanisms are sufficient to provide a full account of White's effect. However, given that White's effect is in the direction of assimilation, and given that White (1981) has specifically implicated assimilation as responsible for the increase of the effect with spatial frequency (the spatial frequency dependence is readily observed by viewing Fig. 1 at various distances), it was therefore of interest to us to discover whether there was indeed any evidence to suggest that a third component, assimilation, might also need to be taken into account.

In order that our results should be comparable with those from our previous work we have employed the same type of stimuli, and they are illustrated in Fig. 2. The pair of patterns in Fig. 2 can be thought of as the elemental components of Fig. 1. Both experiments described below involve the manipulation of the spatial parameters of these stimuli in such a way as to maximize the opportunity for assimilation effects to manifest themselves if they occur at all.

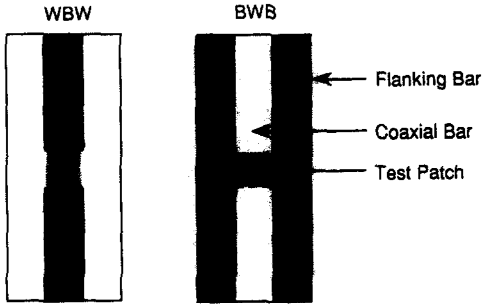

Fig. 2. The basic stimulus arrangement. The WBW and BWB patterns are the elemental parts of Fig. 1. WBW = white–black–white; BWB = black–white–black. In the experiments described the widths and heights of the flanking, coaxial and test patches were varied and the effect on the brightness of the test patch in each of the WBW and BWB pairs measured.

METHOD

Stimulus generation

All stimuli were generated by an 8-bit Pluto II graphics display system interfaced to a Corvus Concept host computer. The stimuli were displayed on a Barco Industries type 2 TVMR monochrome TV monitor. The programmes were written in Pascal using ASM68K assembly language subroutines to interface the host and graphics computers. The 256 grey levels available on the Pluto were calibrated using a photometric filter. The pixels on the screen were 0.68 mm in height by 0.33 mm in width subtending 2.03 by 0.98 min arc respectively at the viewing distance of 114 cm used throughout the experiments described.

Subjects

The two authors acted as subjects in both experiments. Both were experienced psychophysical observers. FK had normal, and BM had corrected vision.

Stimuli

The basic stimulus arrangement is illustrated in Fig. 2. As can be seen, rather than employing a whole grating as the inducing stimulus, we have chosen to use just three inducing bars and one grey patch for each member of the pair of stimuli producing the effect. The two stimuli are referred to as BWB (black–white–black) and WBW (white–black–white), thus describing the luminance arrangement of the three inducing bars in each. The inducing bars are referred to either as flanking the grey bar or as being coaxial with it.

The luminance characteristics of the stimuli were as follows: background = 20.0 cd/m^2, black bars = 0.1 cd/m^2, white bars = 40.0 cd/m^2. The grey test patches in Experiment 1 were 20.0 cd/m^2. In Experiment 2, two test patch luminances were employed, 16.0 cd/m^2 and 18.0 cd/m^2. The precise spatial characteristics of the stimuli will be described separately for each experiment.

Procedure

On each trial, a given member of the stimulus pair (BWB or WBW) was alternated in time with a match stimulus, which had the same spatial dimensions as the test patch and was on the same background as the test stimuli. The test and match stimuli were each presented for

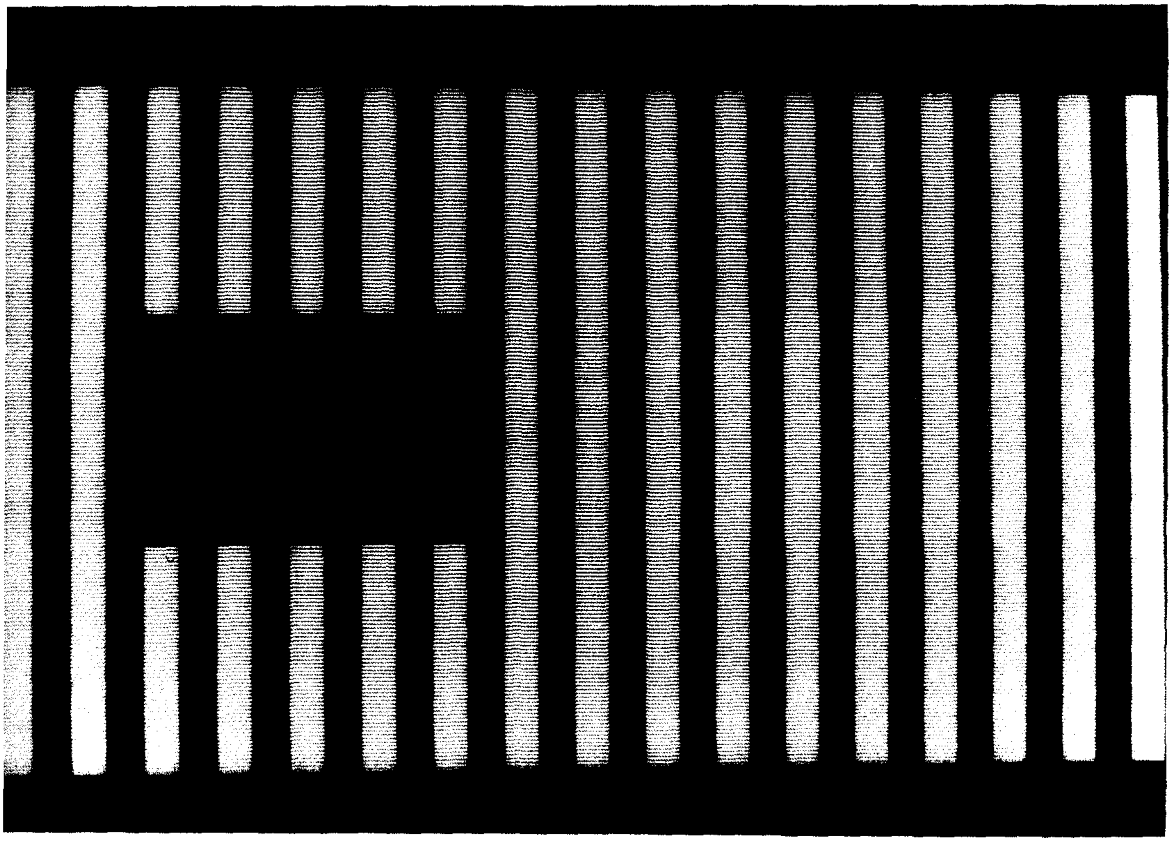

Fig. 1. White's (1979) effect. In the figure the short grey bars lying along the white phase of the grating are identical in luminance to those lying along the black phase, yet appear quite different in brightness.

0.5 sec and there was an ISI (interval–stimulus–interval) of 1.0 sec between match and test, and 3.0 sec between test and match. The longer test–match ISI was designed to reduce the build up of after-images produced by the presence of the test stimulus. The subject's task was to adjust the luminance of the match stimulus until it appeared equally bright as the test stimulus, the subject's response being indicated by a button press.

Analysis of results

For each experiment, the various conditions were randomly presented, and for each condition both subjects made five measurements. The matched luminance values were converted into percentage differences between match and test patch luminance at the PSE (point of subjective equality). These values were averaged across the five trials for each condition, and in Experiment 2, where two test patch luminances were employed, across the two test patch luminance values. Standard errors for each of the WBW and BWB conditions were computed for each subject from the test–match percentage difference values. A measure of the magnitude of White's effect for a given stimulus condition was then calculated as the difference in the mean values between the WBW and BWB pairs. The standard error of the magnitude of White's effect for each subject was computed as the square root of the sums of squares of the standard errors for each of the WBW and BWB conditions.

EXPERIMENT 1

Effect of bar width for a constant height test patch.

Introduction

If it is the case that assimilation is a major factor in producing White's effect then one would predict that narrowing the bars would increase the magnitude of the effect since any blurring across the flanking bar/test patch border would have its greatest proportional effect when the test patch was narrow. We therefore decided to test this prediction by measuring the magnitude of the BWB—WBW brightness difference as a function of bar width. The widths were chosen to be well within the range over which an increase in spatial frequency produces an increase in the effect.

Spatial dimensions

The narrowest and widest width stimuli of the range employed in the experiment are illustrated in Fig. 3. The total height of all the stimuli was constant at 3.14 deg, and the height of the test grey patch constant at 0.4 deg. Five bar width conditions were employed, 0.1, 0.2, 0.4, 0.8 and 1.6 deg. If the test stimuli were 1.5 cycles of a continuous grating the fundamental spatial frequencies of those gratings would be 5.0, 2.5, 1.25, 0.63 and 0.31 c/deg (cycles per degree) respectively.

Results

The results are shown in Fig. 4, which plots the magnitude of the brightness difference between the BWB and WBW conditions (that is, the magnitude of White's effect for the stimuli employed) as a function of bar width. As can be seen there is a clear linear trend in both subjects' data in the direction of an *increase* of the effect with bar width, that is a *decrease* of the effect with increased spatial frequency.

Discussion

It is clear that the evidence from this experiment is not consistent with any simple prediction concerning the operation of an assimilation effect. Indeed, at first sight the results appear to be in direct conflict with the reported effect of spatial frequency on White's effect, where an increase in the effect is seen with an increase in spatial frequency.

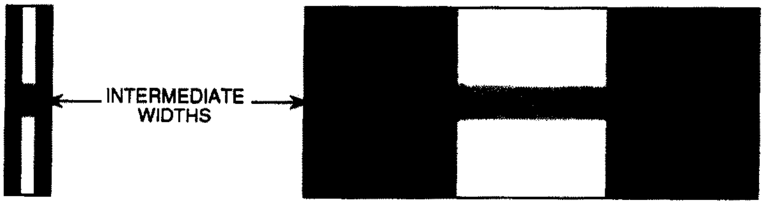

Fig. 3. Stimuli employed in Experiment 1. The smallest and largest width BWB conditions are shown. The overall width of the stimuli shown are 0.3 and 4.8 deg respectively. Three intermediate width stimuli (not shown) were also employed with overall widths 0.6, 1.2 and 2.4 deg. The height of all stimuli was 3.14 deg. Test bar height was fixed at 0.4 deg.

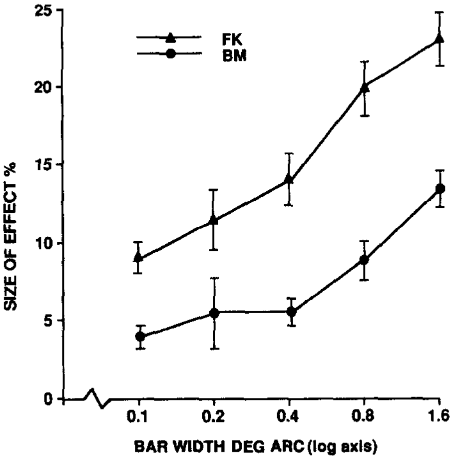

Fig. 4. Results of Experiment 1. The graph plots the magnitude of the brightness difference between the test patches in the WBW and BWB conditions (ordinate) as a function of bar width (abscissa). Both subjects' data are presented on the same graph.

This is almost certainly a consequence of the particular stimulus conditions we used. Previous demonstrations of the effect of spatial frequency on White's effect have used changes in viewing distance to produce changes in spatial frequency. This of course produces a constant scale change in all dimensions (including test patch height), not just in spatial frequency measured orthogonal to the orientation of the inducing bars. This led us to conclude that what has previously 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 constant. In order to investigate this we conducted a second experiment, part of which enabled us to study the effect of scale changes as opposed to one-dimensional spatial frequency changes, by varying the height of the test patch as well as its width.

By increasing the test patch height we would also, we reasoned, further enhance the chances for any assimilation effect to reveal itself, on the following grounds. Since assimilation in this kind of configuration is held to operate, crucially, across the vertical borders of the test patch then it might be expected that increasing the extent of that border should, if it has any influence at all, increase the magnitude of the effect. We were particularly interested in this prediction because, as we explain below, our model predicts a *decrease* in the magnitude of the effect in these circumstances.

EXPERIMENT 2

Effect of test bar height at three spatial scales.

Spatial dimensions

The BWB stimuli employed in this experiment are illustrated in Fig. 5. The dimensions of the stimuli having the smallest spatial scale (Figs 5a and b) were as follows. Height = 1 deg; bar width = 0.2 deg; test bar height = 0.2 deg (Fig. 5a) and 0.6 deg (Fig. 5b). The remaining two spatial scales of stimuli (Figs 5c–f) were produced by successive doublings of these measurements. Thus the three bar width conditions were 0.2, 0.4 and 0.8 deg, corresponding to spatial frequencies of 2.5, 1.25 and 0.63 c/deg. The aspect ratios of the test patches were therefore 1:1—the "short" condition (Figs 5a, c and e) and 1:3—the "tall" condition (Figs 5b, d and f).

Results

The results are shown in Fig. 6. As in Fig. 3, this figure plots the magnitude of the

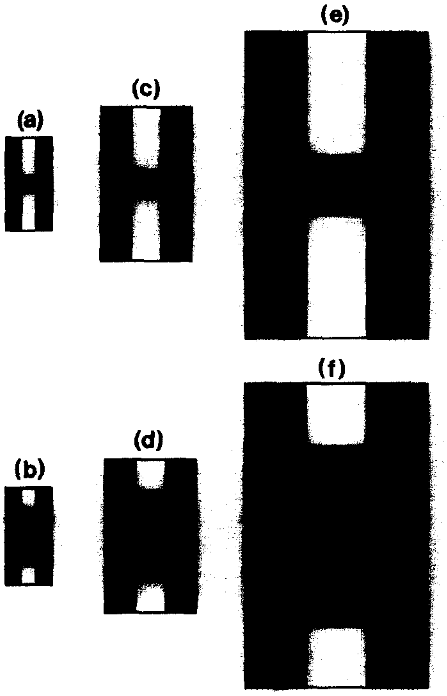

Fig. 5. Stimuli employed in Experiment 2. Only the BWB conditions are shown. In (a), (c) and (e) the "short" test patch aspect ratio is 1:1; in (b), (d) and (f) the "tall" test patch has an aspect ratio of 1:3. Stimuli (b) and (c) are produced by successive doubling in size of (a). Stimuli (e) and (f) are produced by successive doubling of (d). Overall dimensions and spatial frequencies of stimuli are as follows: (a, b) 0.6 × 1 deg, 2.5 c/deg; (c, d) 1.2 × 2 deg, 1.25 c/deg; (e, f) 2.4 × 4 deg, 0.63 c/deg.

BWB–WBW brightness difference as a function of bar width at each of two aspect ratios of test patch.

Notice first the effect of test patch aspect ratio on the magnitude of the effect. In all except one condition (BMs bar width = 0.4 deg condition), a change from a short to a tall test patch significantly reduced the magnitude of the effect. Secondly notice the effect of *bar width*: an increase in bar width significantly reduces the magnitude of the effect. For the widest bar and "tall" test patch condition FK in fact shows a reversal of White's effect, but as the standard error of this data point shows, the effect is not significantly different from zero.

The effect of spatial frequency (measured orthogonal to the inducing bars) in this experiment is the opposite of that found in the previous experiment: here the magnitude of the effect increases with spatial frequency, just as in White's original demonstration.

GENERAL DISCUSSION

We have provided two lines of evidence which together suggest that assimilation is not an important factor in producing the brightness difference between the grey bars in Fig. 1. This conclusion is consistent with suggestions in the literature (for example, Helson, 1963; Hamada, 1984) that assimilation effects are generally found only in stimuli having rather higher spatial frequencies (above about 4 c/deg) than those at which the effect of spatial frequency is observed to have an influence on White's effect.

With a fixed-height test patch we found that a decrease in bar width *reduced* the magnitude of the effect. Any blurring (whether optical or neural) of luminance across the flanking bar/test patch border would be expected to have its greatest proportional effect on the brightness of the latter when the bars were relatively thin, the opposite of what was found.

We also showed that for a fixed-width test patch the effect decreased with test patch height at all bar widths (except for one subject at one bar width), rather than increasing (or perhaps remaining unchanged) as assimilation would predict.

Finally, when the height:width aspect ratio was held constant, the size of the effect *increased* with a decrease in spatial scale.

We conclude first that the "spatial frequency" effect on White's phenomenon is actually a two-dimensional scale effect. Second, on the basis of these results we cannot, and do not wish to, argue that no assimilation effect whatsoever is operating in the stimuli we have used; what we do assert, however, is that its influence must be at best very small, and that if it exists at all it does not vary in the expected way as a function of the spatial characteristics of the stimuli.

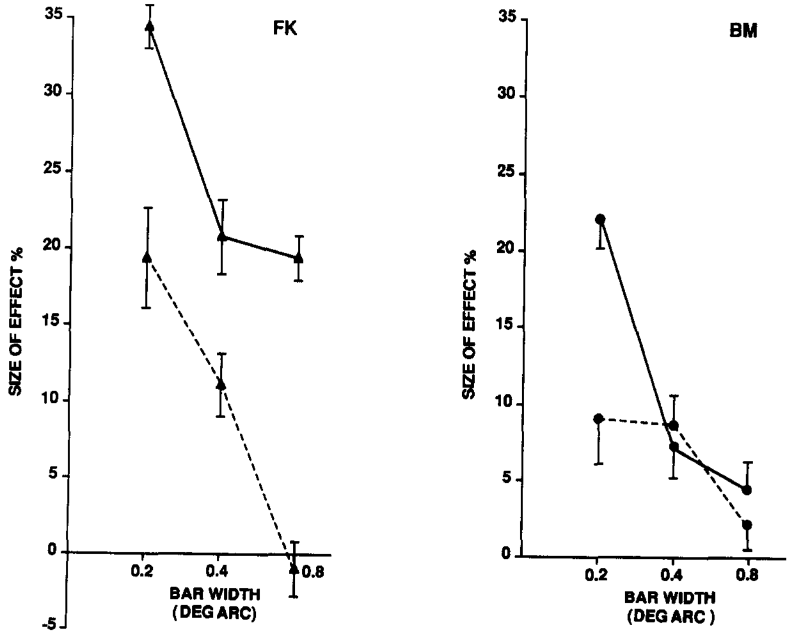

Fig. 6. Results of Experiment 2. Magnitude of the WBW–BWB test patch brightness difference (ordinate) as a function of bar width (abscissa). Continuous line = "short" test patch conditions; dashed line = "tall" test patch conditions. Note that, unlike in Fig. 4, an increase in bar width *reduces* the size of the effect.

Third, of the empirical results we have described none suggest the need to incorporate an extra factor into our model, since all of them are consistent with the operation of the dual-mechanism model we have previously proposed. We shall now describe the way in which that model accounts for the observed effects.

We mentioned earlier the dual mechanism model of White's effect (Moulden & Kingdom, 1989). In the model both mechanisms operate to give the coaxial bars a disproportionate weighting in their contrasting effect on the grey test patches, a weighting which outweighs any contrasting effect of the flanking bars, even when the aspect ratio of the test patches favours the influence of the latter. The first mechanism is a contrast mechanism which operates locally along the entire border of the grey patch. It involves the operation of circularly-symmetric, centre-surround receptive fields such as those of retinal ganglion cells. These receptive fields are particularly sensitive to the corner intersections of the test, flank and coaxial bars. It is this sensitivity to the corners which in part weights the coaxial bar in its contrast effect on the grey patch. The second mechanism, which acts in synergy with the first, is more spatially extensive, and enables the full length of the coaxial bar to exert influence the brightness of the grey patch through simultaneous contrast. It possibly implicates the operation of neurones with small centres and elongated surrounds.

This dual-mechanism model is entirely consistent with the data provided here. For example, the different effects of spatial frequency that were noted, depending on whether the aspect ratio of the test patch covaried with spatial frequency or not, are readily explained by the model. With the aspect ratio held constant (as in Experiment 2), the increase in magnitude of the effect with spatial frequency occurs, we would argue, from the fact that the proportional contribution of the local corner mechanism to the contrasting effect of the coaxial bars becomes greater as the width of the coaxial bar diminishes. The remaining opposing contrast effects of the flank and coaxial bars remain in strict proportion. On the other hand, when test patch height is held constant (as in Experiment 1), and the aspect ratio of the patch changes to favour the influence of the flank bar (i.e. when bar width is decreased), the increase in flank contrast outweighs any increase in the influence of the corner mechanism.

For the effects of test patch height, our model correctly predicts the reduction in the magnitude of White's effect with test patch height. We argue that the proportional amount of flanking bar contrast along the test patch border will increase with test patch height and therefore will act to reduce the magnitude of the effect, albeit never sufficiently to completely nullify it.

It is worth noting that for the 0.4 deg bar width stimuli employed in these experiments, the stimulus used in Experiment 1 was identical to that of the short test height condition in Experiment 2, except for (a) a difference in the overall height of the stimuli and (b) a difference in the test patch luminances. The overall stimulus height was 3.14 deg for Experiment 1 and 2.0 deg for Experiment 2. The test patch luminance was 20.0 cd/m^2 in Experiment 1 and 16.0 and 18.0 cd/m^2 in Experiment 2. The magnitude of the measured effects for these conditions were as follows. Experiment 1: FK = 14%; BM = 5%. Experiment 2: FK = 21%; BM = 7%. The smaller effect in Experiment 1 was almost certainly a result of employing a higher luminance of test patch (20.0 cd/m^2). In Experiment 1, in which two test patch luminances of 16 cd/m^2 and 18 cd/m^2 were employed, the magnitude of the effect was smaller in the latter (18 cd/m^2) condition (by about 5% in both subjects), suggesting a trend towards a smaller size of the effect as test patch luminance increased. The most likely reason for this is that as the luminance of the perceptually decremental test patch approached that of the background (background luminance was fixed throughout at 20.0 cd/m^2), the match had to be made within a smaller and smaller perceptual "window" whose upper limit was set by the background level.

Apart from the effect of the overall height of the stimuli just described, the results of these experiments can be explained solely on the basis of the local border mechanism, without recourse to the secondary spatially extensive mechanism isolated in the experiments of Moulden and Kingdom (1989).

Finally it is worth noting that although we have implicated the second, spatially extensive, mechanism as operating on the coaxial bars, it would operate on the flank bar if the width of the latter were extended. This leads to the as yet untested prediction that an increase in flank bar width, with all other spatial parameters held constant, will reduce the magnitude of White's effect.

SUMMARY

(1) With the height of the test patch held constant, the magnitude of White's (1979) effect was found to *decrease* as bar width was decreased (or spatial frequency increased).

(2) With the aspect ratio of the test patch held constant, the magnitude of White's effect *increased* as bar width was decreased (or spatial frequency increased).

(3) As the height of the test patch was increased, the magnitude of White's effect *decreased.*

(4) These results were interpreted as being incompatible with the suggestion that brightness assimilation between the test patch and the inducing bars on its flanks was a significant factor in producing White's effect.

(5) The results instead were interpreted to imply that brightness contrast was the principal factor producing White's effect under the conditions employed. The dual mechanism model of Moulden and Kingdom (1989) was shown to provide an adequate account of the nature of those brightness contrast mechanisms.

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