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When is a background equivalent? Sparse chromatic context revisited

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Abstract

Jenness and Shevell (Vision Res 1995;35:797–805) reported that a red background with white dots scattered on it has a different influence on a target's apparent colour than an equivalent uniform background. We show that this finding depends on what one considers an equivalent background. Jenness and Shevell averaged the chromaticity and luminance of the background with the dots, and 'superimposed' the target onto this new background. This changed the luminance and chromaticity of both the target and the surround. We show that if only the surround is changed, it is irrelevant whether the latter is red with white dots scattered over it, or a uniform field with the same space averaged chromaticity and luminance. Our findings are consistent with a local contrast mechanism that has a limited spatial resolution.

Keywords: Colour appearance; Chromatic induction; Adaptation; Colour constancy

1. Introduction

Jenness and Shevell [1] found that adding a few randomly distributed white dots—a sparse chromatic context—to a red background substantially changed the background's influence on the perceived colour. Most importantly, this influence was not found when the background was replaced with a uniform one of the same space averaged chromaticity and luminance. They suggested that the distribution of chromaticity in a scene has an influence beyond that of changing the average chromaticity of the target's immediate surrounding. We argue that this is not so. When Jenness and Shevell replaced their background they changed the chromaticity and luminance of both the target and the surround. The present study shows that if the target is not changed, a red surround with white dots and a uniform one of the same space averaged chromaticity and luminance do have the same influence.

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2. Methods

The stimuli were presented on an Apple 13 inch Trinitron monitor driven by an Apple Macintosh LC computer with 8 bit resolution per gun. The stimulus was viewed from a distance of 1.14 m in an almost dark room. Luminance was measured with a Minolta LS-110 luminance meter. Some of the routines of Pelli and Zhang's [2] 'VideoToolbox' were used in programming the displays.

Fig. 1A shows a schematic representation of the stimulus. The target, an 8' arc wide ring with an inner diameter of 39' arc, is superimposed on a 4.7° diameter circular background. Fig. 1B–F show the contributions of the red, green and blue guns to the luminance along the white line in Fig. 1A, for the different experimental conditions. The values of ΔG are the average values set by subject FWC for the chosen value of ΔR (0.67 cd/m^2), and will be discussed in the results section. In each part of the figure, the central, black bar indicates the level at the target, and the flanking grey bars indicate the level in the surround. The additional thin grey bars and dents in Fig. 1C represent the dots. The arrows show how ΔR and ΔG are defined for each condition.

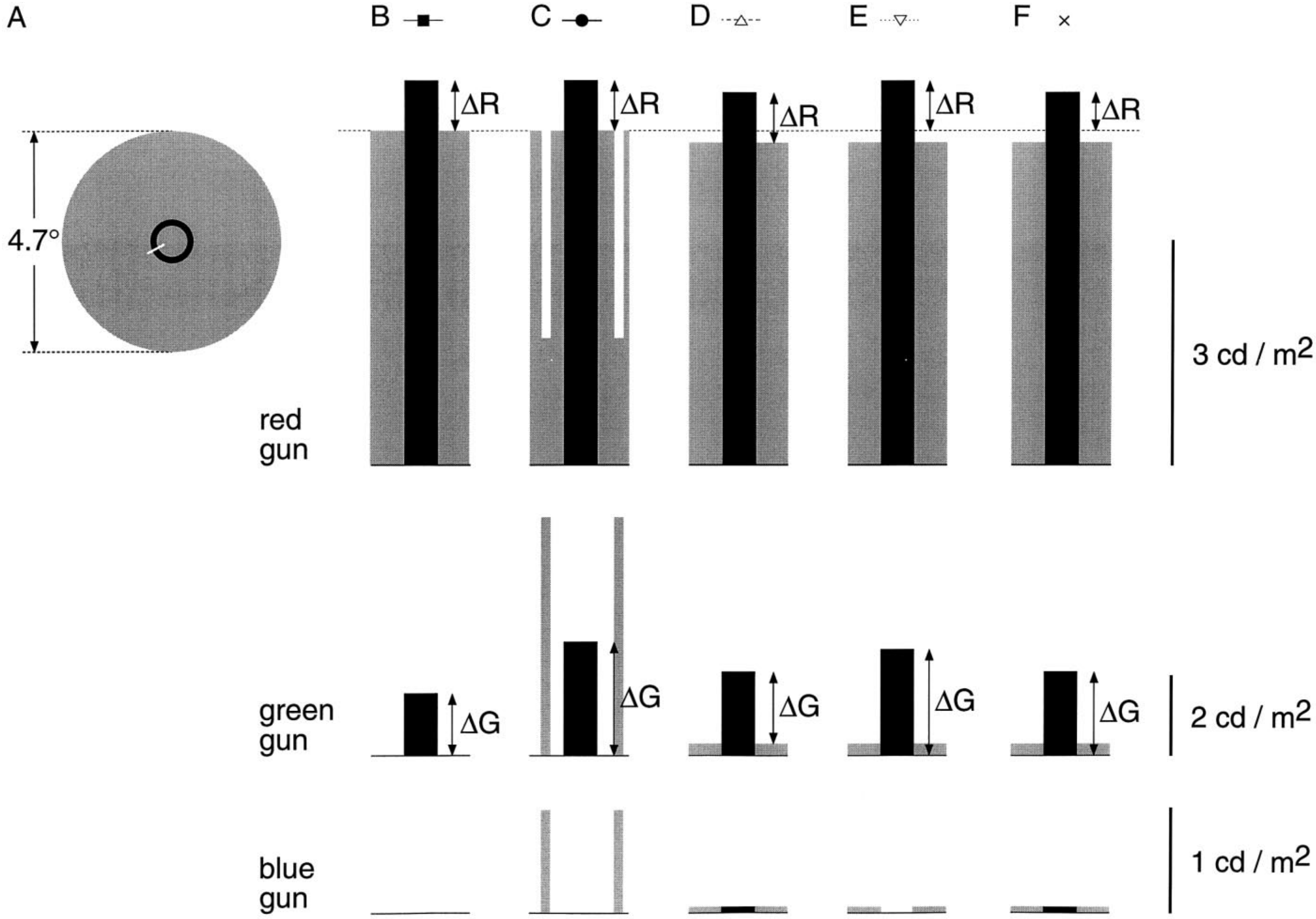

Fig. 1. Schematic representation of the stimulus. A: Target ring superimposed on a disk shaped background. B–F: Outputs of the red, green and blue guns along the white line in A. Black regions: luminance at the target. Grey regions: luminance in the surround. The subjects' task was to set the value of ΔG so that the ring appeared 'neither red nor green' (for various values of ΔR). The shown values of ΔG are the average settings of subject FWC in these conditions (ΔR = 0.67 cd/m^2). B: Red background. C: Red background with white dots. Dots are regions with a much lower luminance from the red gun and a much higher luminance from the green and blue guns. D: Equivalent background. The background in B—onto which ΔR and ΔG are superimposed—is replaced by one with the same space averaged luminance and chromaticity as the surround in C. E: Equivalent surround. Only the surround in B is replaced by a uniform field with the same space averaged luminance and chromaticity as the surround in C. F: The same luminances as in D, with ΔR and ΔG defined relative to the same level as in the other conditions, rather than relative to the adjacent surface. The symbols at the top indicate how each condition is represented in Fig. 2.

Fig. 1B shows the values for a uniform red background (CIE: $x = 0.60$, $y = 0.32$; red gun only; 4.4 cd/m^2). Fig. 1C shows the values for a red background with white dots (two of which are visible in the figure). The white dots were distributed at random over the surface of the background, but were never in direct contact with the ring. Each dot was 2 × 2 pixels, corresponding with about 2 × 2' arc (CIE: $x = 0.27$, $y = 0.28$; 1.7, 6.0 and 1.0 cd/m^2 for the red, green and blue gun, respectively). Together the dots covered 5% of the surround. In both cases ΔR and ΔG were measured with respect to the directly adjacent part of the background.

Fig. 1D shows the values for a uniform background with the same space averaged luminance and chromaticity as the background with the dots (CIE: $x = 0.57$, $y = 0.32$; 4.3, 0.3 and 0.06 cd/m^2 for the red, green and blue gun, respectively, these values being as close as we could get to 0.95 times each gun's value for the red background plus 0.05 times its value for the dots). Notice that because ΔR and ΔG are still measured relative to the directly adjacent background, and the latter has been changed, they are now measured from a different level than in B and C. As a result, the luminance from the red gun is not only lower in the background, but also at the target (we will return to this issue in the results section, when explaining Fig. 1F). Superimposing the target on the equivalent background also introduced a contribution from the blue gun to the luminance at the target.

Fig. 1E shows a fourth condition, that was not studied by Jenness and Shevell. As in the former condi-

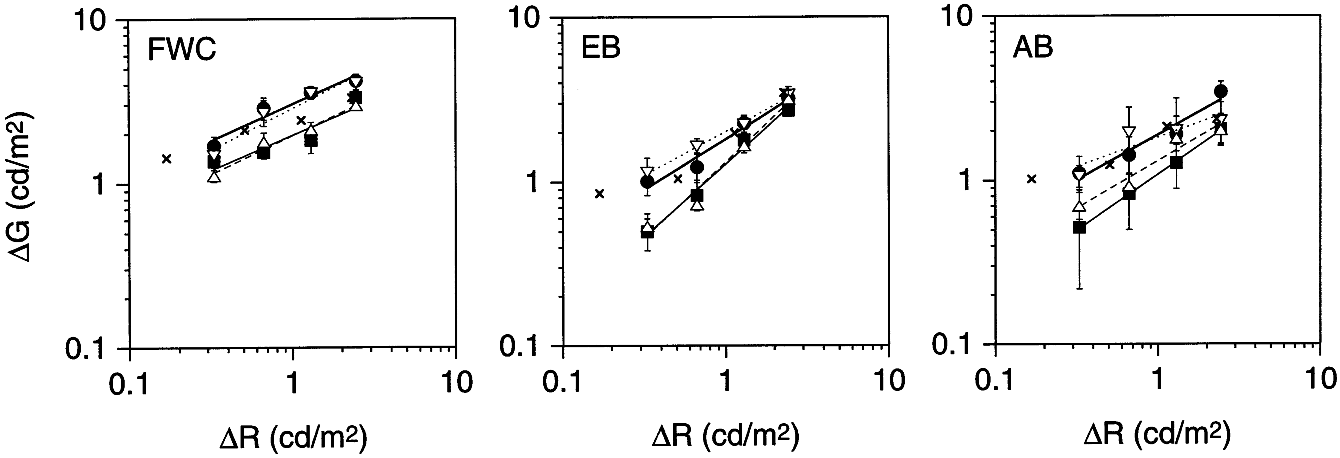

Fig. 2. Average set values of ΔG (with their standard deviations) for each value of ΔR, condition and subject. The symbols represent the red background (solid squares), the red background with white dots (solid circles), the equivalent background (upward pointing triangles) and the equivalent surround (downward pointing triangles). The crosses show the values of the equivalent background condition when interpreted as shown in Fig. 1F.

tion (Fig. 1D), the surround with the dots was replaced by a uniform surround with the same space averaged chromaticity and luminance. However, the red and blue guns' contributions to the target were kept as they were for the first two conditions (Fig. 1B and C), as were the levels from which ΔR and ΔG were measured. Thus only the distribution of the luminance and chromaticity in the surround was different from that in the condition with the dots (compare Fig. 1C and E). We will refer to this condition as having an equivalent surround rather than an equivalent background.

Three subjects took part in the experiment. Two were the authors and the third was a naive paid volunteer. All had normal (or corrected to normal) vision. Their task was to set the ring to appear 'neither red nor green'. They did so by manipulating the output of the green gun (ΔG) with the arrow keys of the computer's keyboard.

The four conditions were presented in separate sessions, each consisting of two runs for each of four values of ΔR, with eight settings within each run. Each session started with 5 min of dark adaptation and another 5 min of adaptation to the background. Each run started with the subject setting the ring to appear 'neither red nor green'. They then adapted to this stimulus for 2 min, after which they continued to adjust the level of ΔG. They indicated that they were satisfied with their setting by pressing the 'control' key. This saved the setting and gave ΔG a small offset to ensure that they made a new setting each time. After eight such settings a new run was chosen at random from the ones that remained to be done (until all eight runs had been completed). We calculated the means and standard deviations of the logarithms of the 16 ΔG settings (two runs of eight settings each) for each condition and value of ΔR.

3. Results

The levels of the green gun depicted in Fig. 1 show one subject's average settings for a single level of ΔR (0.67 cd/m^2). The subject needed considerably more light from the green gun when dots were added to the red surround: ΔG is considerably larger in C than in B. He also needed more light from the green gun when the same change in the average colour of the surround was achieved by changing the uniform luminance and chromaticity of the surround, rather than by adding white dots to it: The value of ΔG is similar in E and C.

For the equivalent background the situation is more complicated. The subject clearly needed less light from the green gun in this condition (D) than when dots were added to the surround (C), but there was also less light from the red gun at the target. Jenness and Shevell defined ΔR and ΔG with respect to the immediate surrounding (see Fig. 1D), rather than with respect to a fixed level. This choice was presumably based on two assumptions: that the perceived colour of the target depends on its difference from the background (as proposed by Walraven [3][1]); and that this difference is determined with a high spatial resolution (otherwise it would have been more appropriate to define ΔR and ΔG relative to the guns' average luminance levels in the surround—i.e. to their levels for the equivalent background—when dots were added to the red surround). Fig. 1F shows what would happen if the same level were to be used to define ΔR and ΔG for the equivalent background condition (D), as for the other conditions.

[1] In fact, Walraven found shifts between his plots of log ΔR versus log ΔG for different background luminances, which he attributed to colour selective influences of the background luminance on a (von Kries like) gain factor.

Although the set value of ΔG is smaller than it was for the background with the dots, the corresponding value of ΔR is now also smaller.

The average settings of all three subjects are shown in Fig. 2. Adding white dots clearly influenced the settings made by all three subjects (compare circles with squares). When the target was superimposed on a uniform background with the same average chromaticity, the settings were similar to those for the original red background (compare upward pointing triangles with squares). These results are consistent with Jenness and Shevell's findings for the same conditions.

Our new finding is that replacing only the surround with a uniform surface of an equivalent average chromaticity has the same effect as does adding white dots (compare downward pointing triangles with circles). Redefining ΔR and ΔG for the equivalent background condition in the manner shown in Fig. 1F, confirms the independent results from our new condition (see crosses in Fig. 2). The advantage of running the equivalent surround as a separate condition, is that it allowed us to obtain the same values of ΔR on the ordinate and to eliminate the contribution of the blue gun to the target.

4. Discussion

We conclude that it is unnecessary to postulate an effect of adding sparse dots beyond that of changing the space averaged chromaticity and luminance of the surround. Human colour vision is known to rely heavily on contrasts at surfaces' edges [3–5], presumably because the ratio between each type of cone's responses to light from adjacent surfaces is almost independent of the illumination[2] [6–8]. The local contrast between target and surround for the red background with dots (Fig. 1C) is identical to that for the red background without the dots (Fig. 1B), because the dots were never in direct contact with the target. Nevertheless, the influence of the surround in the presence of the dots (circles in Fig. 2) was more similar to that for the equivalent surround (downward pointing triangles in Fig. 2). Our explanation for this apparent discrepancy is that contrast is determined by a mechanism with a limited spatial resolution.

The proposal that the spatial resolution of the mechanism that determines contrast is limited, is consistent with previous studies on chromatic induction. For simple stimuli, the influence of the surrounding decreases exponentially with the distance from the edge [7,9]. Nevertheless, it does not become negligible until the separation reaches about 2° [7], which more or less coincides with the extent of the surround in the present study. Moreover, when the contrast differs along the surface's boundary, the separate influences appear to be combined by linear spatial averaging [10–12].

The distribution of chromaticity in a scene is often assumed to have influences beyond that of determining the average chromaticity of the target's immediate surrounding. The main reason for expecting such influences, is that it seems evident that local ratios have to be combined in a clever manner to prevent surfaces' reflectance properties from being misjudged when the adjacent surfaces are spectrally biased [6,7]. However, the influence of distant surfaces has been found to be very limited [13,14]. We must therefore avoid making large errors when the surrounding is spectrally biased in some other manner.

Our suggestion is that the temporal properties of adaptation play a critical role. Adaptation is cone-selective [15] and very well localised on the retina [16]. However, eye movements expose each part of the retina to light from many surfaces, so that distant surfaces could influence a surface's perceived colour by affecting the state of adaptation [17–19]. The temporal properties of adaptation are suitable for such influences: adaptation starts very quickly, but is only complete after several seconds [20] or even minutes [21]. As a result, the state of adaptation may not always be optimal for coding the local spatial contrast, but the resulting temporal contrast reduces the influence of a chromatically biased immediate surrounding (as shown in [14]).

In cancellation studies such as the present one, in which subjects are instructed to fixate the target (and there is little else to see anyway), the influence of spatial contrast is very much enhanced by the continuous adaptation to the—thereby gradually changing—set colour. The continuous cycle of: adapting to the colour one has set, this influencing the perceived chromaticity, and a new setting being made to account for the changed precept, may explain why the effect is large, but takes so long to build up, under these, rather artificial, conditions [22].

Some studies have found complex spatial influences far beyond those described above (e.g. [19,23–26]). In those cases subjects were clearly using additional information to interpret the chromatic content of the retinal image, such as the direct information—provided by the experimenter—that the only difference between two images is their illumination (e.g. [24]), or the less direct information—contained in their experience—that luminance depends on surface slant (in [23]). It is evident that such information can influence the interpretation of the retinal image, and that such influences can be very complex. However, before such influences take

[2] Assuming that the illumination does not change at the edge, that adaptation keeps the cones' responses within their linear range [20], that the state of adaptation is the same at both sides of the edge, and that the interactions between the spectral composition of the illuminant and spectral properties of the surface's reflectance are negligible [27,28].

place, colour vision appears to be governed by local contrast and adaptation.

References

[1] Jenness JW, Shevell SK. Color appearance with sparse chromatic context. Vision Res 1995;35:797–805.

[2] Pelli DG, Zhang L. Accurate control of contrast on microcomputer displays. Vision Res 1991;31:1337–50.

[3] Walraven J. Discounting the background-The missing link in the explanation of chromatic induction. Vision Res 1976;16:289–95.

[4] Krauskopf J. Effect of retinal image stabilization on the appearance of heterochromatic targets. J Opt Soc Am 1963;53:741–4.

[5] Shevell SK, Holliday I, Whittle P. Two separate neural mechanisms of brightness induction. Vision Res 1992;32:2331–40.

[6] Land EH, McCann JJ. Lightness and retinex theory. J Opt Soc Am 1971;61:1–11.

[7] Brenner E, Cornelissen FW. Spatial interactions in color vision depend on distances between boundaries. Naturwissenschaften 1991;78:70–3.

[8] Foster DH, Nascimento SMC, Craven BJ, Linnell KJ, Cornelissen FW, Brenner E. Four issues concerning colour constancy and relational colour constancy. Vision Res 1997;37:1341–5.

[9] Yund EW, Armington JC. Color and brightness contrast effects as a function of spatial variables. Vision Res 1975;15:917–29.

[10] Brenner E, Cornelissen F, Nuboer JFW. Some spatial aspects of simultaneous colour contrast. In: Kulikowski JJ, Dickinson CM, Murray IJ, editors. Seeing Contour and Colour. Oxford: Pergamon, 1989:311–6.

[11] Zaidi Q, Zipser N. Induced contrast from radial patterns. Vision Res 1993;33:1281–6.

[12] Hel-Or HZ, Zhang X-M, Wandell BA. Effects of patterned backgrounds on color appearance. Invest Ophthalmol Visual Sci 1996;37:1065.

[13] Valberg A, Lange-Malecki B. Colour constancy' in mondrian patterns: a partial cancellation of physical chromaticity shifts by simultaneous contrast. Vision Res 1990;30:371–80.

[14] Cornelissen FW, Brenner E. On the role and nature of adaptation in chromatic induction. In: Blum B, editor. Channels in the Visual Nervous System: Neurophysiology, Psychophysics and Models. London: Freund, 1991:109–23.

[15] Chaparro A, Stromeyer III CF, Chen G, Kronauer RE. Human cones appear to adapt at low light levels: measurements on the red-green detection mechanism. Vision Res 1995;35:3103–18.

[16] Cicerone CM, Hayhoe MM, MacLeod DIA. The spread of adaptation in human foveal and parafoveal cone vision. Vision Res 1990;30:1603–15.

[17] Shevell SK. Unambiguous evidence for the additive effect in chromatic adaptation. Vision Res 1980;20:637–9.

[18] Lennie P, D'Zmura M. Mechanisms of color vision. CRC Crit Rev Neurobiol 1988;3:333–400.

[19] Cornelissen FW, Brenner E. Simultaneous colour constancy revisited: an analysis of viewing strategies. Vision Res 1995;35:2431–48.

[20] Hayhoe MM, Benimoff NI, Hood DC. The time-course of multiplicative and subtractive adaptation process. Vision Res 1987;27:1981–96.

[21] Fairchild MD, Reniff L. Time course of chromatic adaptation for color-appearance judgments. J Opt Soc Am A 1995;12:824–33.

[22] Cornelissen FW, Brenner E. Ignoring sparse chromatic context. Perception 1996;25:Suppl 17.

[23] Gilchrist AL. The perception of surface blacks and whites. Sci Am 1979;240:112–24.

[24] Arend L, Reeves A. Simultaneous color constancy. J Opt Soc Am A 1986;3:1743–51.

[25] Schirillo J, Reeves A, Arend L. Perceived lightness, but not brightness, of achromatic surfaces depends on perceived depth information. Percept Psychophys 1990;48:82–90.

[26] Sugita Y. Propagation of colour information across borders. NeuroReport 1992;3:683–4.

[27] Foster DH, Nascimento SMC. Relational colour constancy from invariant cone-excitation ratios. Proc R Soc London, B 1994;257:115–21.

[28] Young RA. Color vision and the retinex theory. Science 1987;238:1731–2.