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Dependence of color on context in a case of cortical color vision deficiency

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Abstract

Color constancy depends on sensitivity to change in both illumination spectral properties and object position. We investigated this latter form of color constancy by asking a cerebral achromatopsic to name the colors of papers that were presented atop black, gray or white backgrounds under identical illumination. Comparison of color names across background conditions reveals poor constancy, characterized by a contrasting of foreground and background values that is not corrected by proper anchoring.

Keywords: Color; Color constancy; Color deficiency; Cerebral achromatopsia

1. Introduction

We report here a case study in which color naming is used to investigate color and lightness perception by a cerebral achromatopsic. Observers with cerebral achromatopsia lose color sensation and report that the world appears in shades of gray [1–7]. The cortical locus of their visual deficiency makes them ideal observers in experiments on color perception that are likely to involve both retinal and cortical processing [8]. The present results on how color naming depends on background luminance level suggest that contrast processing is present but that anchoring processes are absent in this case of cerebral achromatopsia.

2. Clinical details

Observer JPC is a 46-year-old former florist who suffered bilateral occipito-temporal lesions as a result of physical aggression. He has been described as a cerebral achromatopsic in a previous study by Cavanagh et al. [9]. He shows a visual field loss in the superior left quadrant with macular sparing and an additional loss in the superior right in the periphery beyond 15°. The lower fields are intact. His acuity and contrast sensitivity are within a normal range and he reads without difficulty. JPC displays normal electroretinographic responses to stimuli designed to separate rod from cone responses, and vice versa, which suggests that the defects described below are central to the retina. He reports that his subjective impression is of living in a world of shades of gray. Like many patients with a color vision disturbance of cortical origin, he demonstrates visual agnosia and prospagnosia.

The results from testing JPC's color vision are more complex. When asked to match surface colors or lights presented on a CRT, his choice of color is random, although he matches reliably gray lights presented on a CRT. He can sometimes detect a colored light placed among gray lights of varying level correctly if it is a reddish or yellowish one. In such a task, he shows some residual chromatic sense, referring to the reddish lights or surfaces as 'teinté' (tinted or hued). His spectral sensitivity in a bright surround displays a single peak near 550 nm (T. Troscianko, personal communication). He makes large errors on the FM 100-hue test (total error score = 888) showing no axis. His panel D-15 arrangements, on the other hand, show a scotopic axis,

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Table 1
The 17 color name constituents of the five color-name categories used by observer JPC

Noir	Gris	Marron	Teinté	Blanc
'Noir'	'Gris'	'Marron'	'Teinté, marron'	'Blanc'
'Bien noir'	'Gris clair'	'Marron foncé'	'Teinté, rouge'	'Blanc cassé'
	'Gris foncé'	'Marron clair'	'Teinté, rose'	'Presque blanc'
			'Teinté, jaune'	
			'Teinté, orange'	
			'Rouge'	

The name 'rouge' was only used once by JPC, in the black background condition.

for both standard and enlarged (10°) versions. These results contrast with his performance on a minimum motion photometry task, in which his matches between the colors generated by CRT guns fall in the normal range and are distinct from those of congenital dichromats [9]. This also contrasts with his anomaloscope matches (T. Troscianko, personal communication). He accepts a match near that of the normal, but his matches to the red and green endpoints fall along a protan line. On average, he can detect, with difficulty, about 66% of the numerals on the Ishihara color plates, but his performance is inconsistent in that it seems unrelated to a color axis or to the severity of the defect. In addition, the plates identified vary from sitting to sitting.

On balance, it seems that JPC can sometimes detect spectral differences without being able to evaluate chromatic differences, as has been suggested to occur in certain cases of cerebral achromatopsia [10]. Does JPC suffer from cerebral achromatopsia or simply a dyschromatopsia? This is a more difficult question to answer, as it seems unlikely that cerebral achromatopsia is a single fixed syndrome. It is clear, however, that JPC suffers a severe disturbance of his color sense that is secondary to his cortical lesions.

3. Methods

The task of observer JPC was to name the colors of pieces of paper placed sequentially in front of him upon a table in a well-lit room. The papers were placed atop a background of white paper, gray paper or black velvet. These backgrounds had luminances of 1.2, 16.7 and 48.6 cd/m^2, respectively. A Minolta chromameter CS-100 was used to measure stimulus luminance and CIE 1931 standard observer chromaticity.

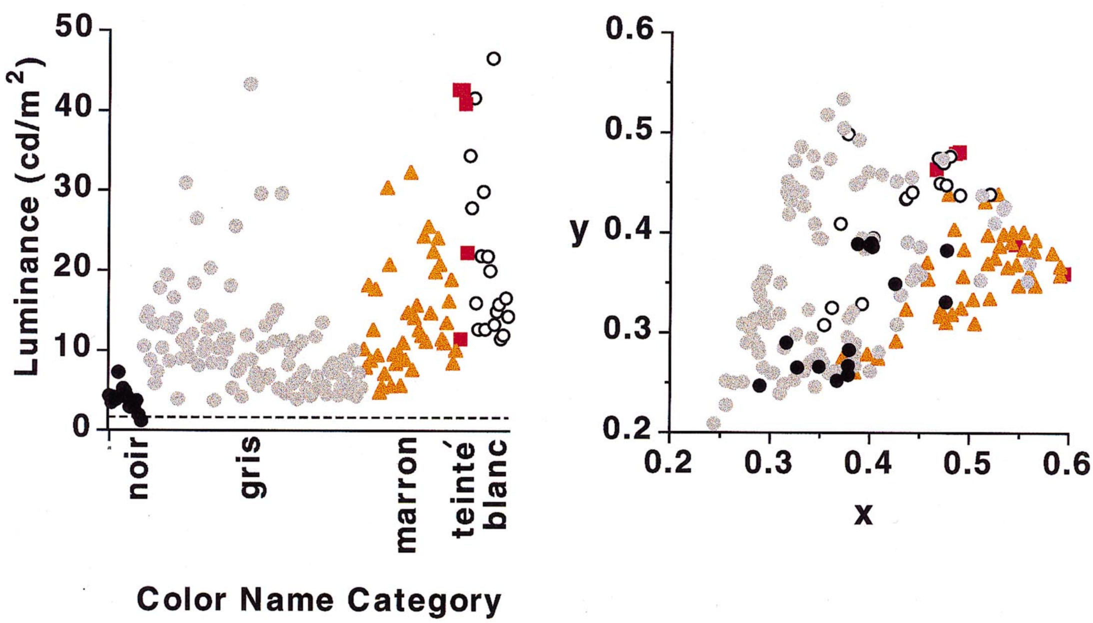

Fig. 1. Results of color naming against a black background for observer JPC. Each plotted point represents a single piece of paper. (A) Paper luminance plotted in terms of color name; the luminance of each named paper is plotted in a separate column. The color name used for the paper is indicated both by its symbol and by its position along the horizontal axis, which varies among color-name categories noir (black disk), gris (gray disk), marron (triangle), teinté (square) and blanc (unfilled circle). The background luminance level is indicated by the dashed horizontal line. (B) Paper chromaticity plotted in terms of color name. See text for details.

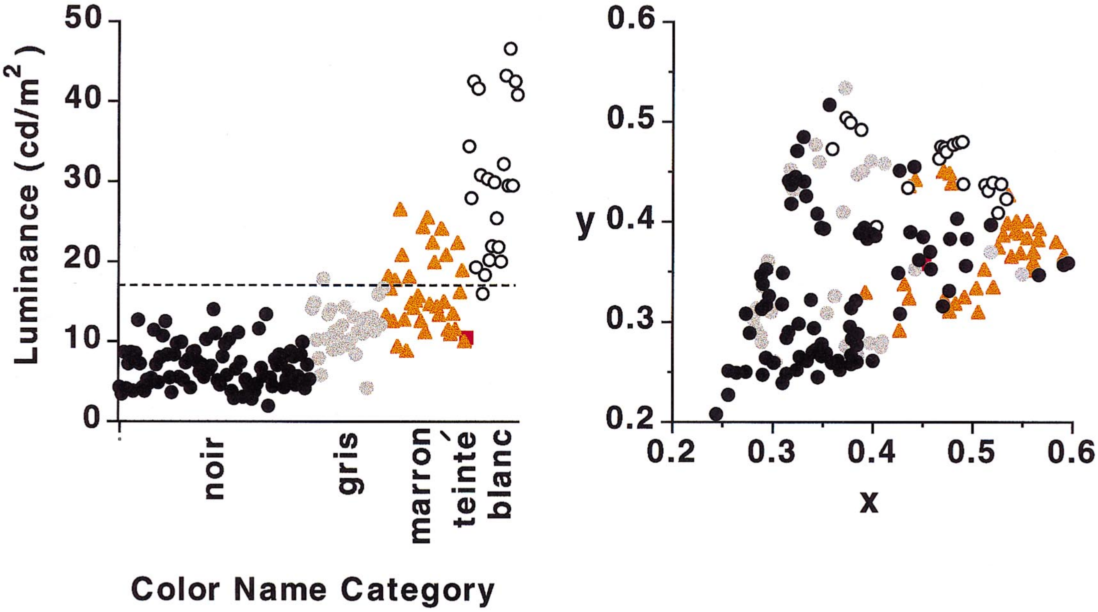

Fig. 2. Results of color naming against a gray background for observer JPC. See Fig. 1 caption and text for details.

A total of 175 Color Aid™ papers were shown. This series included ten papers of neutral color (black, gray or white) and 165 papers identified by color-normal observers as colored. The papers were of size 12.5 × 7.5 cm and were viewed at a distance of approximately 40 cm. The papers were viewed during sequential sessions atop the black, gray and white backgrounds. The backgrounds were 60 cm high × 80 cm diameter. The observer viewed freely the well-lit room during the course of the experiments. Color naming by two male color-normal observers was also tested under these conditions.

4. Results of color naming

Observer JPC used a total of 17 different color names to name the 175 papers in the three background conditions. Comparing color names across conditions shows that JPC uses color names that depend strongly on background value. To aid analysis, we grouped together similar names to form a total of five color-naming categories for JPC: noir (black), gris (gray), marron (brown), teinté (tinted) and blanc (white). Table 1 shows how the color names were grouped to produce the five categories.

4.1. Black background

In Fig. 1 are shown the results of color-naming against a black background by observer JPC. Each point refers to an individual Color Aid™ paper. Fig. 1(A) shows the luminances of each paper and its color-name category. The 14 papers named noir are shown by filled disks and have relatively low luminance. The luminance of the background is indicated by the dashed line. The papers named gris span a wide range of luminances, while those named marron, teinté and blanc are, on average, progressively more luminous.

The CIE 1931 (x, y) chromaticities of the papers are plotted in Fig. 1(B), which shows that the papers in categories marron and teinté fall in the range of chromaticities that correspond to 'warm' colors.

4.2. Gray background

The results for observer JPC with a gray background are shown in Fig. 2. A greater number of papers (85) are now named noir, and the number of papers named marron or teinté is reduced. The latter still fall in the warm region of the chromaticity diagram.

4.3. White background

Of 175 total papers viewed by JPC against a white background, 160 were called noir. Fig. 3(A) shows that only the brightest papers were called something other than noir. Fig. 3(B) shows that these exceptional papers were, with one exception, in the yellow–orange region of color space. No papers were named marron.

4.4. Variability in color naming

Observer JPC's color-naming varies as background luminance is changed. A simple rule helps to understand much, if not all, of the variation: if the luminance of a paper is less than the luminance of the background against which it is viewed, then it is likely to be called

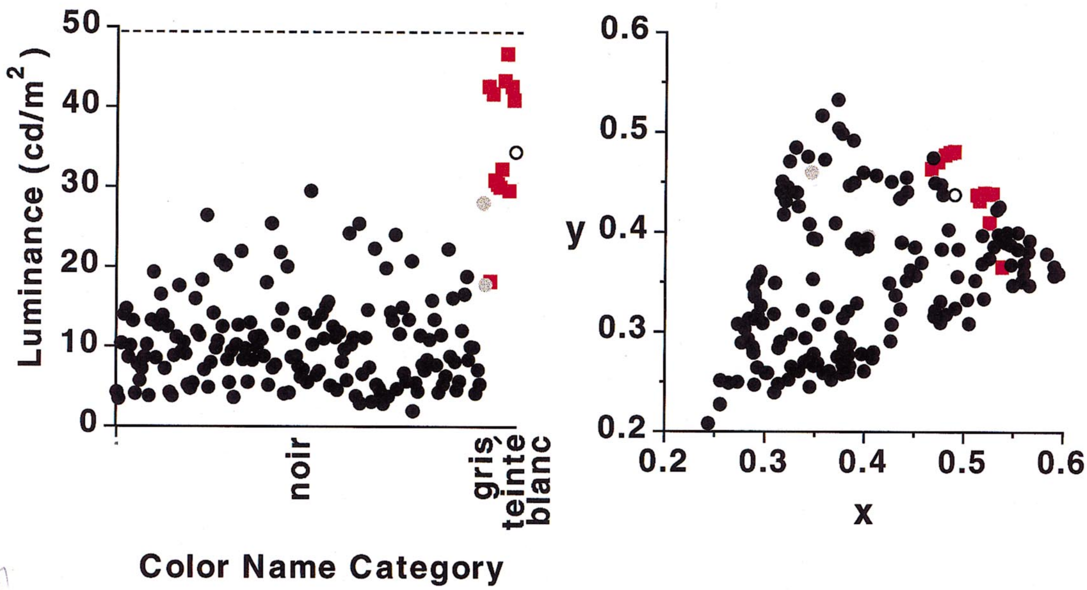

Fig. 3. Results of color naming against a white background for observer JPC. See Fig. 1 caption and text for details.

noir, but if the luminance of the paper is greater than the background, then it is likely to be called something else. The horizontal dashed lines in Fig. 1(A), 2(A) and 3(A) indicate the background luminance levels of 1.2, 16.7 and 48.6 cd/m^2 in the black, gray and white background conditions, respectively. Comparing color names to these levels shows that the simple rule accounts in an approximate fashion for a substantial part of the variability. The variation in color naming is thus consistent with visual processing which contrasts paper and background values to produce a color name.

We computed κ (kappa) statistics, measures of agreement between categories [11], to quantify variation in color naming. The value of κ for the comparison of white and black background color naming by JPC is 0.031, which does not differ significantly from zero: constancy is absent. Values of κ for the two color-normal observers were 0.644 and 0.793.

5. Discussion

The results of the color-naming experiment show that observer JPC exhibits a surprisingly large variation in color-naming as background luminance is varied.

For normal observers, substituting a white background for a black background while keeping illumination constant reduces the lightness of a test surface by about 1.5 Munsell Value steps [12]. Normals thus exhibit a failure of constancy as background value is changed [13,14]. Yet this failure is small when compared to the lack of constancy exhibited by observer JPC. Indeed, normals exhibit a high degree of lightness constancy when background value is changed, and this suggests that they anchor their judgments of lightness to a standard that depends little on the immediate background, under normal circumstances [15,16]. Our results indicate that a cortical lesion can disrupt this process. These results are complemented by the recent study of Bramwell et al. [17] of an achromatopsic observer; their results suggest the presence of contrast processing that can extract illumination-invariant ratios of luminances of adjacent surfaces.

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