Colour imperception in unilateral hemisphere-damaged patients¹

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Disturbances of colour recognition after hemispheric cerebral lesions have been repeatedly described in the literature. The attention of the authors, however, has been more often attracted by deficits related to colour naming, colour-sorting (so-called 'colour agnosia'), and colour-object association and to their prevalent occurrence in patients with lesions of the dominant hemisphere (Sittig, 1921; Lange, 1936; Kinsbourne and Warrington, 1964), than by mere impairment of colour-discrimination. Although this last symptom has long been known to follow injury to the central optic pathways in both the contralateral and the ipsilateral visual half-field (Reinhard, 1887; Best, 1917; Teuber, 1960; Critchley, 1965), the frequency of its appearance and the wavelengths of the light spectrum that are preferentially involved are still imperfectly known. Several authors (Axenfeld, 1915; Poppelreuter, 1917; Kleist, 1934; Lehrmitte, Chain, and Aron, 1965; and others) have examined either single cases or small numbers of cases of hemisphere-damaged patients and have come to the conclusion that the errors made by these patients on chromatic ophthalmological tests are more frequent in certain sectors of the light spectrum. They have maintained that error patterns in central dyschromatopsia are comparable with those of retinal (congenital) dyschromatopsia, such as the syndrome of tritanopia (Lhermitte *et al.*, 1965), red-green dyschromatopsia (Poppelreuter, 1917; Pötzl, 1928; Kleist, 1934), or impairment limited to red only or to green only.

In a recent study, De Renzi and Spinnler (1967) have investigated the relationship between behaviour on colour tasks and hemispheric side of lesion in a wide sample of unselected hemisphere-damaged patients, by means of tests requiring subtle colour discrimination, such as the pseudo-isochromatic Ishihara's plates and a matching test of coloured

chips. The study showed that there was a significant inferiority of the right hemisphere-damaged patients in comparison with the left hemisphere-damaged patients, and of patients with visual field defects (VFD) compared with those without VFD. The interaction between the hemispheric side of the lesion and the presence/absence of VFD could not be investigated in that study, since the skewed distribution of the scores entailed the use of a non-parametric analysis of data, which is not suited to the study of interaction. Moreover, as the colour tests used yielded merely a qualitative information about the ability to discriminate colours, errors could not be expressed in terms of wavelengths. In the present study, a quantitative test of colour discrimination—the Farnsworth-Munsell 100 Hue Test (FMT)—yielding normally distributed scores, was employed in order (1) to evaluate the effect of the hemispheric side of lesion, of the presence/absence of VFD, and of their interaction on colour discrimination; (2) to determine the profiles of the error distribution along the colour spectrum in the control patients and in the brain-damaged subgroups; (3) to ascertain, by means of statistical tests, possible differences between the profiles of the different groups.

METHODS

PATIENTS This investigation was carried out on 80 controls and 164 unilaterally hemisphere-damaged patients. The control group (C) was made up of patients hospitalized in the neurological wards who showed neither present nor past evidence of disease involving the central nervous system above the cervical spinal level.

All brain-damaged patients hospitalized in the neurological wards or examined as out-patients from November 1966 to September 1968 were considered for inclusion in the hemisphere-damaged group. Patients were included who (1) showed unmistakable signs of unilateral hemispheric damage on the basis of the clinical examination and of the available neuroradiological, neurosurgical, EEG, and brain-scan findings; (2) were able to take the test—that is, were not physically exhausted or mentally

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confused, etc.; (3) were right-handed on a 10 item questionnaire for handedness. If the patient was a severe aphasic, the questionnaire was filled in by a near relative; (4) had no particular difficulties with colour-discrimination before the onset of the cerebral disease. Out of 202 patients who met criterion 1, 38 were discarded because they did not meet criterion 2 (15 left and 12 right brain-damaged patients), criterion 3 (eight patients), or criterion 4 (three patients with congenital dyschromatosis). Visual field defects were assessed by means of the confrontation test described elsewhere (De Renzi and Spinnler, 1967). Subtler ophthalmological procedures were not carried out, since it was felt that, demanding as they are on the patient's continued collaboration, attention, and insight, they might have been selective at the expense of the patients with the most extensive hemispheric lesions.

The 164 patients who met all criteria constituted the hemisphere-damaged group. This was subdivided into four subgroups according to the affected hemisphere and the presence/absence of homonymous visual field defect: (1) left hemisphere-damaged without VFD—65 patients (L-); (2) left hemisphere-damaged with VFD—36 patients (L+); (3) right hemisphere-damaged patients without VFD—39 patients (R-); (4) right hemisphere-damaged patients with VFD—24 patients (R+).

Aetiology and length of illness (defined according to De Renzi and Faglioni, 1965) were not significantly different in the four hemisphere-damaged subgroups (Table 1).

The average age in years of each subgroup was: C, 50.3; L-, 52.1; L+, 54.9; R-, 49.9; R+, 58.5 (range: 17 to 86 years). The average educational level (in years of schooling) was: C, 5.9; L-, 5.6; L+, 6.9; R-, 6.1; R+, 4.9 (range: 0 to 19 years of schooling).

TESTING PROCEDURE All patients were given the Farnsworth-Munsell 100 Hue Test (Farnsworth, 1943). The test consists of 85 chips of different hues, contained in four boxes. The patient is given all chips of one box and asked to arrange them in a line in the guide box according to hue between the first and the last chip. These two chips are fixed at the ends of the box and serve as a frame of reference. In this study, the patient was seated at the free end of a small square table, of which the other three sides have three walls. The table

and the three walls were covered with black material. Illumination was supplied by means of a lamp with a heat temperature of 6,740°K. The test was preceded by an example performed by the examiner with the first 10 chips of the first box of the FMT. The patient was asked to perform the same task, with the hand ipsilateral to the hemispheric lesion, as soon as the examiner had finished. The demonstration could be repeated several times, until the examiner was satisfied that the patient had clearly grasped the task. All patients were able to understand the task. The patients carried out the entire test in a single sitting. They used both eyes and were allowed to wear their spectacles if necessary. In order to minimize the possible role of visual exploration, the chips of each part of the FMT were grouped on the table in front of the patient within a circular area about 15 cm in diameter. No time limit was set for completing the test, but it never took more than 20 minutes. A score was given to each chip according to its position in the series, following the rules established by Perdriel (1962). This is an error score—that is, a flawless performance gets score 0, and the greater the displacement of the chip, the higher the score.

Instead of carrying out the statistical analyses on the 85 scores, Farnworth's was restricted to five sectors, corresponding to different ranges of hues:

1. R-Y sector (red-yellow), containing 17 chips (from no. 1 to no. 17).
2. Y-G sector (yellow-green), containing 18 chips (from no. 18 to no. 35).
3. G-B (green-blue) sector, containing 18 chips (from no. 36 to no. 53).
4. B-P sector (blue-purple), containing 17 chips (from no. 54 to no. 70).
5. P-R sector (purple-red), containing 15 chips (from no. 71 to no. 85).

As the five sectors do not contain the same number of chips, the average score of all chips in each sector was computed. The performance of each patient was defined by these five averages (sector scores).

STATISTICAL ANALYSES The scores of the five sectors of the FMT diagram, adjusted for age and years of schooling, were submitted to a multivariate analysis of covariance (Anderson, 1958). A factorial-hierarchical design with three criteria of classification (absence/presence of

TABLE 1
AETIOLOGY AND LENGTH OF ILLNESS IN THE FOUR BRAIN-DAMAGED SUBGROUPS

		L- (N = 65)	L+ (N = 36)	R- (N = 39)	R+ (N = 24)	
Aetiology	V	46	28	23	16	$\chi^2 = 8.28$ P: ns (df = 6)
	N	11	3	12	3	
	O	8	5	4	5	
Length of illness (mth*)	≤1	34	16	23	14	$\chi^2 = 4.12$ P: ns (df = 6)
	1-6	17	9	5	5	
	≥6	14	11	11	5	

L = Left hemisphere-damaged patients; R = right hemisphere-damaged patients; +/- = presence/absence of visual field defect; V = vascular; N = neoplastic; O = other aetiology.

*For neoplastic patients length of illness was conventionally considered to be equal to one day (De Renzi and Faglioni, 1965).

brain damage, right/left side of hemispheric lesion, absence/presence of VFD) was used. The second and third criteria were crossed with each other and nested within the first criterion. A non-weighted parametrization was employed (Elston and Bush, 1964). The analysis was carried out according to the model designed by Bock (1963) and by Cole and Grizzle (1966) for repeated measurements and by Morrison (1967) for the analysis of psychological profiles. The error was controlled for each hypothesis (Miller, 1966): the hypothesis was considered to be univariate when it was concerned with the effects of the brain lesion, of the hemispheric side of the lesion, of VFD and of the interaction between the last two factors; tetrivariate, when it was concerned with the effect of the test and its interactions with the preceding factors.

RESULTS

Table 2 shows the mean scores (adjusted for age and years of schooling) obtained by the five experimental subgroups in each of the five sectors. It should be remembered that these are error scores, so that the greater the score, the worse the performance.

The multivariate analysis of co-variance showed that performance of patients with brain lesions was poorer ($P < 0.0001$) than that of patients without brain lesions.

Within the brain-damaged subjects, the interaction between hemispheric side of the lesion and presence/absence of VFD was highly significant ($P < 0.001$). Inspection of the means (reported in

FIG. 1. Mean scores obtained by the five subgroups on the five sectors of the FMT key: L = left hemisphere-damaged patients; R = right hemisphere-damaged patients; +/- = presence/absence of visual field defect. Sectors: R-Y = red-yellow; Y-G = yellow-green; G-B = green-blue; B-P = blue-purple; P-R = purple-red.

Fig. 1) suggests that the significance of this interaction was due to the R+ subgroup, whose performance was much poorer than that of the other three subgroups. This was confirmed when data (adjusted for age and years of schooling) were analysed using

TABLE 2

MEAN SCORES ADJUSTED FOR AGE AND YEARS OF SCHOOLING ON EACH FMT SECTOR FOR THE FIVE SUBGROUPS

Subgroups	Sector scores					Means
	R-Y	Y-G	G-B	B-P	P-R	
C	1.63	1.57	3.38	1.74	2.06	2.07
L+	2.27	2.35	4.35	2.70	2.99	2.93
L-	2.51	3.10	4.69	3.27	3.26	3.36
R+	2.11	2.61	4.55	2.77	2.99	3.00
R-	4.66	5.09	7.00	5.45	4.94	5.42
Means	2.63	2.94	4.79	3.19	3.25	
Multivariate analysis of co-variance						
Effect	df	F	P			
Brain damage (BD)	1/237	50.81	0.0001			
Hemispheric side of lesion (H)	1/237	15.85	0.001			
Visual field defect (VFD)	1/237	27.84	0.0001			
H x VFD	1/237	13.53	0.001			
Sectors (S)	4/234	68.84	0.0001			
BD x S	4/234	1.69	ns			
H x S	4/234	<1	ns			
VFD x S	4/234	1.02	ns			
H x VFD x S	4/234	<1	ns			

Key as in Table I.

TABLE 3
MULTIPLE COMPARISONS OF PERFORMANCES OF THE FIVE EXPERIMENTAL SUBGROUPS

a. Whole test performance					b. Sector performance																			
					R-Y				Y-G				G-B				B-P				P-R			
L - L + R - R +					L - L + R - R +				L - L + R - R +				L - L + R - R +				L - L + R - R +				L - L + R - R +			
C	ns	ns	ns	0.01	ns	ns	ns	0.01	ns	ns	ns	0.01	ns	ns	ns	0.05	ns	ns	ns	0.01	ns	ns	ns	0.05
L -		ns	ns	0.01		ns	ns	0.05		ns	ns	0.01		ns	ns	0.05		ns	ns	0.05		ns	ns	ns
L +			ns	0.01			ns			ns		ns			ns			ns		ns		ns	ns	ns
R -				0.01				0.01				0.01				ns				0.01				ns

Key as in Table 1.

multiple comparison method. As Table 3 (a) shows, the performance of the R+ subgroup on the whole test was significantly inferior to both that of the controls and that of each of the brain-damaged subgroups, while none of these was different from the controls or from one another. The specific impairment of the R+ subgroup was borne out even when the subgroup performances within each of the five sectors were compared (Table 3b), although, in this case, the difference between the performance of the R+ subgroup and that of some other hemisphere-damaged subgroups sometimes failed to reach the level of significance. Therefore, the impairment of the brain-damaged group in comparison with the control groups is to be attributed to the failure of the R+ patients only.

The multivariate analysis of co-variance in Table 2 was intended to answer two additional questions (1) is there any significant difference between performances on the five sectors of the test—that is, are there ranges of hues more involved than others?—and (2) if such differences exist, do they vary between controls and brain-damaged patients, or between the brain-damaged subgroups? The results of the analysis show that a highly significant difference ($P < 0.0001$) did exist between the means of the five sectors (averages of the column totals of Table 2), but that this difference did not vary in the five subgroups, as indicated by the fact that none of the interactions, involving sector effect, was significant. In order to find the sector responsible for the difference, the mean scores on the five sectors were compared with one another using the method described by Roy and Bose (1953). Comparisons were performed both on the pool of all subjects, and separately on each of the five subgroups. In any comparison only the G-B sector (corresponding to the green-blue hues) was found to differ significantly from each of the other sectors. This indicates that the green-blue range of colour was the most difficult one both for the controls and for each of the hemisphere-damaged subgroups.

The above conclusions refer to the subgroups

considered as a whole. In order to analyse more closely the clinical characteristics of the individual patients who showed central dyschromatopsia, we singled out each of them in the following way. For each sector, we calculated the superior limit round the mean score of the control subgroup (C), adjusted for age and years of schooling, beyond which 2.5% of a population of subjects without brain lesions may be expected to fall¹. This limit was compared with the score (adjusted for age and years of schooling) obtained by each hemisphere-damaged patient in the given sector.

We defined as 'deviant' any hemisphere-damaged patient whose score fell below the 2.5% confidence-limit of the control subgroup on at least one sector. Fifteen 'deviant' patients were found.

Table 4 shows their overall clinical characteristics, the sector in which they scored below the confidence limit, and the scores obtained on a number of neuropsychological tests, administered to them in our laboratory for other purposes.

These tests were the following: (1) the Token Test (De Renzi and Vignolo, 1962), a measure of aphasic impairment of language comprehension; in the version employed here the score ranges from 0 to 164; (2) the Ghent Overlapping Figures Test in the multiple-choice version (De Renzi, Scotti, and Spinnler, 1969), and (3) the Profile-Front Faces Test (De Renzi, Faglioni, and Spinnler, 1968)—both (2) and (3) are tasks of subtle visual discrimination (score-range 0 to 32 and 0 to 10, respectively); (4) the Raven Coloured Progressive Matrices, a general intelligence test (score-range 0 to 36); (5) the Copying Crosses Test (De Renzi and Faglioni, 1967), a spatial localization test also sensitive to visual hemi-inattention (Faglioni, Scotti, and Spinnler, 1969).

Scores corresponding to particularly poor per-

¹The following formula was used, in which θ is the superior percentage point in the β -generalized distribution of type 1 inferred from Heck's tables (1960):

$$\text{Limit} = \bar{x}, \text{ adjusted, of } C + \sqrt{\frac{\theta}{1-\theta}} \times \text{deviance of } C.$$

TABLE 4
CLINICAL FEATURES AND TEST PERFORMANCES OF THE 15 'DEVIANT' PATIENTS

Subgroups	Pts	Age	Years of schooling	Aetiology	Length of illness (days)	Sectors, in which pt, fails					Token test	Overlapping figures	Faces test	Raven's PM	Copying Crosses test Score	Visual hemi-inattention
						R-Y	Y-G	G-B	B-P	P-R						
L- (2 out of 65)	1	46	5	N	—	+	—	—	+	—	156	22	10	25	306*	
	2	63	12	V	2	—	+	+	—	—	141	31	9	16	224	
L+ (3 out of 36)	1	59	5	TR	45	—	—	—	+	—	48*	14*	2*	11*	602*	
	2	17	8	TR	97	—	—	—	+	—	38*	30	7*	16	327	
	3	78	5	V	17	+	+	—	+	+	55*	19*	2*	3*	427*	
R- (2 out of 39)	1	61	3	V	15	—	—	—	+	—	127	14*	2*	14*	319*	
	2	64	5	TR	270	—	—	—	—	+	157	23*	3*	21	988*	Present
R+ (8 out of 24)	1	44	5	V	40	+	—	+	+	—	144	9*	1*	8*	343	
	2	68	7	V	1	+	+	+	+	—	146	8*	2*	7*	411	
	3	60	4	V	90	—	—	—	—	+	148	16	3*	8*	253	
	4	61	3	V	10	—	+	+	—	—	160	17	6	8*	939*	Present
	5	71	5	V	150	—	+	+	—	—	146	10*	3*	11*	1,425*	Present
	6	68	4	V	19	—	+	—	—	—	143	12*	2*	5*	585*	
	7	75	3	V	15	—	—	—	+	—	143	7*	1*	13	833*	Present
	8	76	5	N	—	+	+	—	+	—	135	12*	1*	9*	1,054*	Present

N = neoplastic, V = vascular, TR = traumatic. + = deviant score; — = non-deviant score. * = see text.

performances on the tests are marked with an asterisk on Table 4. For the Token Test, the asterisk indicates that the score falls below the cutting score of 124, corresponding to the worst performance of the right brain-damaged patients. For the remaining tests, it indicates that the score falls below the median score of the subgroup to which the patient belongs.

Inspection of Table 4 confirms that most 'deviant' subjects (eight out of 15) belong to the R+ subgroup. The table also shows that no sector is selectively impaired in 'deviant' patients: nine patients fail on sector B-P, seven on Y-G, six on R-Y, five on G-B and three on P-R. Over one half of the patients (eight out of 15) fail on more than one sector with no apparent rule.

The scores of the 15 'deviant' patients on the Ghent Overlapping Figures Test, the Profile-Front Faces Test, the Raven Coloured Progressive Matrices Test, and the Copying Crosses Test were compared with those of the 149 'non-deviant' patients. The two groups were not significantly different with respect to aetiology ($\chi^2 = 0.492$; $df = 2$; $P = ns$) and length of illness ($\chi^2 = 2.565$; $df = 2$; $P = ns$). It was found that the scores of the 'deviant' patients were significantly lower ($P < 0.002$) than those of the 'non-deviant' ones on each of the above-mentioned tests.

DISCUSSION

The results of this study showed that the worse

performance of the right hemisphere-damaged patients and of patients with VFD is to be attributed to the R+ subgroup only, which performs significantly more poorly than both the controls and the other hemisphere-damaged subgroups. No significant difference, on the other hand, emerges between the performances of the control patients and those of the three hemisphere-damaged subgroups, not between one another of these subgroups. The observation that the presence of VFD affects the performance only when it is associated with a lesion of the right hemisphere indicates that the negative effect of VFD is not due to the visual impairment *per se*. The value of VFD consists, rather, in pointing to a lesion of the retro-rolandic areas. In this sense, the specific failure of the R+ patients is to be interpreted as indicating that the retro-rolandic areas of the right hemisphere are crucial for colour-discrimination. This conclusion is in keeping with previous results from our laboratory, showing that right retro-rolandic hemisphere-damaged patients are specifically impaired on tasks requiring subtle perceptual discrimination of a number of visual stimuli, both coloured and not coloured (De Renzi *et al.*, 1969; Faglioni and Spinnler, 1969).

The results of this study do not support the claim that hemisphere-damaged patients with colour imperception ('central dyschromatopsia') are specifically impaired on certain sectors of the light spectrum. Inspection of Fig. 1 shows that brain-damaged patients make more errors on the green-blue sector

of the test, but so do the control patients. The poorer performances of non-brain-damaged subjects on the green-blue sector is known (Verriest, van der Velde, and van der Donck, 1962). Our findings demonstrate that the performance profiles of the brain-damaged patients are virtually identical with those of the non-brain-damaged subjects. The right brain-damaged patients with VFD (R+) are more impaired than the others because they make more errors on all sectors, and not because they selectively fail on any one sector. Likewise, no preferentially impaired sector is found in the selected group of patients with exceedingly poor colour-discrimination ('deviant' patients). As Table 4 shows, these patients may fail on virtually any sector. Therefore, the statement that the error patterns of central dyschromatopsia are strictly comparable with those of retinal dyschromatopsia is not warranted by the present findings.

A study of the performances of the 'deviant' subjects on other visuo-perceptual tests may give us some insight as to the nature of their disturbance. Their poorer performance in comparison with the 'non-deviants' on two perceptually difficult tests not implying colour (such as the Ghent Overlapping Figures Test and the Profile-Front Faces Test) suggests that their colour imperception may be but one aspect of a wider disorder—that is, a defect of subtle perceptual discrimination. In the same sense we can probably interpret the impairment on Raven's Progressive Matrices. This test, though a test of general intelligence at face value, also implies a complex perceptual analysis of visual patterns, and therefore may be sensitive to damage of the cerebral areas, subserving subtle discrimination of visual sense data, as suggested by the findings of De Renzi and Spinnler (1966).

The failure of the 'deviant' patients on the Copying Crosses Test deserves comment. In this test the patient is asked to reproduce a model drawing consisting of a number (up to 16) of small crosses. The model sheet is then superimposed on the answer sheet, and the distance (in mm) between a copied cross and its model is measured. The error score is the sum-total of these distances. Omission of a cross is given a score of 140 mm, equal to half the width of the model sheet. The test was designed as a spatial localization test; however, since omission of a cross is heavily penalized, it turned out to be particularly sensitive to visual hemi-inattention (unilateral spatial neglect), which often causes the patient to neglect one half of the model (Faglioni, Scotti, and Spinnler, 1969).

The question then arises as to whether the FMT, too, is sensitive to hemi-inattention; patients might perform poorly because hemi-inattention prevents them from getting an overall view of the chips to be

arranged in a line in the guide box. Although care was taken to group the chips within a small area of the centre of the residual visual field, the possibility that some patients with severe hemi-inattention were handicapped during the test cannot be excluded. In order to verify this, we singled out patients with hemi-inattention, on the basis of performances on the Copying Crosses Test: patients who omitted at least one cross in a half visual field were defined as having hemi-inattention. We found 17 patients with hemi-inattention, of whom 12 were among the 63 right hemisphere-damaged patients and five among the 101 left hemisphere-damaged ones. Five of them were 'deviant' on the FMT and 12 were 'non-deviant'. This indicates that hemi-inattention was significantly more frequent in the 'deviant' group than in the 'non-deviant' group ($\chi^2 = 12.367$, $P < 0.0005$). However, as it was present in only five out of 15 'deviant' subjects, hemi-inattention cannot be held responsible for the poor performance of all of them on the FMT.

SUMMARY

Eighty control subjects, 101 left hemisphere-damaged patients (65 without and 36 with visual field defects), and 63 right hemisphere-damaged patients (39 without and 24 with visual field defects) were given the Farnsworth-Munsell 100 Hue Test (FMT).

The aims of this investigation were (1) to study the influence of the hemispheric side of lesion, of the presence or absence of homonymous visual field defect and of the interaction of these two factors on colour-discrimination; (2) to evaluate whether the failure of control and brain-damaged patients was specifically related to certain sectors of the colour spectrum; and (3) to ascertain possible differences between the profiles of the different subgroups. Only right hemisphere-damaged patients with visual field defects turned out to be significantly impaired in comparison with both the control subgroup and the other hemisphere-damaged subgroups, which in turn did not differ among themselves. However, the difference between the right hemisphere-damaged patients with visual field defects and the other subgroups was quantitative and not qualitative, since green-blue discrimination was found to be equally difficult for all subjects. When patients with extremely poor FMT scores in comparison with those of the controls were identified, they were found to be impaired also on other non-colour perceptual tests.

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