BRIGHTNESS PERCEPTION AND BINOCULAR ADAPTATION*

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IN many cases of heterophoria and heterotropia there seems to be a reduced sensation of brightness in one eye. This diminished sense of brightness may be present when the vision of that eye is full and equal to the other eye and when there is little or no difference in refraction of each eye.

The "difference" between the vision in each eye is a symptom which the patient notices when he uses one eye at a time. To all routine tests the eye is in no way defective but an intelligent patient checking his own visual acuity on a Snellen chart and seeing for himself that there is no difference between the vision of each eye still says that the vision of one eye is "not so good". In everyday life this inequality seems to be very definite once it has been noticed. One man aged 40 had 6/5 in each eye and a manifest hypermetropia of 1 diopetre right and left. In spite of esophoria and a distinct preference for one eye, he said that his "weaker" eye was excellent for night driving because he used it when approaching strong headlights. His "good" eye was dazzled but if he shut it and used the other he had no sensation of glare.

The loss of brightness appears to be present to some extent over the whole field. Not only does print look less black with the non-dominant eye but the whole white background of the page appears to be less white. One patient read down a Snellen chart with one eye first and then, as he changed to his other eye, he said that the extra light put on had made the chart brighter. He had not realized that the difference was in his eye and not in the lighting.

More often patients complain that colours are not the same with each eye. On questioning, the colour itself appears to be unchanged, but it is "less intense", "less bright", "less brilliant", as compared to the effect seen by the other eye. This colour difference was mentioned so often that it was decided to test it in detail. A group of patients was tested with Ishihara colour plates, taking the separate colour dots in turn and asking the patient if the colour seen by each

* Received for publication November 7, 1950.

eye was the same, or, if not, what was the difference. Out of thirty reasonably good observers not one said that there was any change in the actual colour. The number was read easily but in each case a difference was noticed when the colour as seen by the non-dominant eye was compared with that seen by the dominant eye. The difference, although definite, was difficult to explain, and the test became tedious to the patient after five minutes. Usually the patient said that the pale pink and orange dots were "dusty", "faded", or "paler". The same sort of change was noticed to a lesser degree on the green and green-blue dots. The probability that the loss of brightness on the pinks was greater than that on the greens was strengthened by a tendency for the pink numbers to appear less marked, but the green numbers more marked with the non-dominant eye, although the green spots themselves were slightly less bright; this may be due to the greater loss in the pink-spot background and the less relative difference in the green.

METHOD

Since the tests required accuracy, 100 patients were selected for their reliability in observation. They included cases of simple heterophoria in which there was no history of amblyopia; cases of heterophoria in which one eye had been amblyopic before treatment but as a result of treatment had recovered normal visual acuity (with glasses if necessary); cases of heterophoria in which one eye was still amblyopic, the visual acuity in this eye being less than the normal visual acuity of the dominant eye. These patients were investigated for light adaptability and for suppression.

For the purpose of this paper the vision of the non-dominant eye was compared with the dominant eye on Snellen's type; any difference in the visual acuity, as difference in numbers of letters read in the line, was noted. Part 6/5 was not considered as equal to full 6/5, and where the vision was said to be normal, each eye saw at least 6/6 and the vision in the two eyes was equal on the test type at 6 m. distance.

Apparatus.—The patients were examined on an orthoptoscope in order that the usual tests for binocular vision could be used. Care was taken that suppression did not occur and that the images fell along the visual axis of each eye so that the stimulation was bi-foveal.

The lamps, checked individually against a photometer, were equal in luminance. The current was shunted through separate resistances so that the voltage going through each lamp could be checked on a scale and adjusted. The slides were made so that they gave the same light reading.

Calibration of Light.—The amount of light presented to each retina was adjusted by the use of Ilford's neutral density filters. These filters were cut to lens size and slotted into the lens holders in the eye-pieces of the orthoptoscope. They were used in a series of 1 per cent. differences from neutral density 2.00 to density 1.0 (allowing 1 per cent., 2 per cent., 3 per cent. up to 10 per cent.; in a series of 5 per cent. differences from neutral density 1.0 (10 per cent.) to density 0.52 (30 per cent.); in 10 per cent.

differences to density 0.30 (50 per cent.); and in 20 per cent. differences to density 0.05 (90 per cent.). The difficulty the patient found in giving accurate answers increased as the density of the filter decreased. Between a filter of density 2.0 and of density 1.0 a patient could see the difference of 1 per cent. in the light transmitted and be consistent in his answers on each examination. When the filter was between density 1.0 (10 per cent.) and 0.52 (30 per cent.) the patient could distinguish a difference of 5 per cent. in the light transmitted. When the density permitted more than 50 per cent. of light to pass, the patient had difficulty in giving accurate answers for a difference of 20 per cent. in the light transmitted.

Procedure.—The measurements were taken in a dimly lit room during some 30 min. at each visit. The slides used were white designs on a black background. Black designs on a white background were used from time to time, to find out whether these altered the results, but no alteration was found.

Stereograms representing buckets, tunnels, cones, and similar objects were so drawn that when the outside rings were fused the inside dots or rings were seen central, but at a nearer or more distant plane than the outside ring. A person with a pair of eyes of normal visual acuity (wearing glasses if necessary) fused such a stereogram and saw the centre correctly centred when the amount of light transmitted through each slide was equal. If the light in front of one eye was reduced, the centre remained in the correct position until the reduction was such that only 1 per cent. (varying slightly with the individual) of the full light was passed through the slide. If this was tried again, reducing the light in front of the second eye and giving the first eye full light, the same reading occurred. Thus it appeared that in stereoscopic fusion a normal pair of eyes did not appreciate a difference in the amount of light transmitted to each eye separately until that difference was in the region of 99 per cent. of the full light. These numbers were found in the conditions under which the test was made in the orthoptoscope and perhaps a wider range would have been found if the initial intensity of the light source had been higher.

RESULTS

In the group of patients under discussion this adaptability was lost. With equal intensity of light on each slide these patients fused a stereogram easily and saw the component parts in different planes. They could put a hand behind the instrument and indicate the varying positions of these planes correctly. Controls such as small dots above and below, or to the right and left, were not suppressed by either eye although one control was said by some patients to be less bright than the other. When asked whether the centre of the stereogram was really central, careful observation gave the answer that the tunnel receded slightly towards the side of the slide seen by the dominant eye. To correct this bias and obtain an accurately balanced stereogram the light transmitted to the dominant eye had to be reduced in some cases to $\frac{1}{100}$ or even less before the stereogram was balanced correctly. Where the dominant eye needed less than 1 per cent. to balance the full light given to the fellow eye, accurate measurement became difficult, since the initial power of the lamps was not high enough to allow for so much diminution.

Great care was taken during the test that the light fell along the visual axes. Stiles and Crawford (1933) have shown that the retina has a marked directional sensitivity and that oblique rays incident on the retina give a marked reduction in the sensation of brightness. The marked reduction in the light-balance adaptability occurs in one eye in these cases when the incident light is not oblique but directed along the visual axis to the fovea.

Of the 100 selected cases, 50 either had had amblyopia ex anopsia or still had unequal vision from this cause. The other 50 had equal vision in each eye and had no history of previous amblyopia. All the cases had normal retinal correspondence and good fusion, with some if not full stereoscopic vision. All had some degree of heterophoria, varying from those who had residual heterophoria after treatment of heterotropia to those who had never had more than a small degree of ocular muscle imbalance for near vision.

TABLE
BINOCULAR LIGHT-BALANCE ADAPTABILITY

26 patients		24 patients		50 patients	
Unequal vision		Vision now equal and normal		Vision equal and normal in each eye	
Weak eye 6/12 or more		Treated amblyopia		No previous amblyopia	
Percentage	Balance	Percentage	Balance	Percentage	Balance
27	$\frac{1}{2} : 100$				
50	1 : 100	71	1 : 100	30	1 : 100
23	2 to 10 : 100	29	2 to 10 : 100	28	2 to 10 : 100
				12	11 to 50 : 100
				14	variable approx. 50 to 90 : 100
				16	normal balance adaptability

The adaptability to differences of binocular light balance was compared in three groups of cases, the results being shown in the Table. In the first group, each patient had an amblyopic eye in which the visual acuity was at least one line less than in the other eye but not less than 6/12. In the second group, both eyes now had equal visual acuity but one amblyopic eye had previously been successfully treated. In the third group, there was no history of amblyopia, the vision of each eye being equal and normal. There

was no marked degree of anisometropia or high refractive error; any refractive error present was corrected by spectacles. Some degree of heterophoria was present in each case.

It appears from the Table that a diminished light-sensitivity balance is present in a very high proportion of these cases, and that a marked diminution of light balance can be present without affecting the visual acuity, but that when the visual acuity is reduced there is always present a marked relative loss of light-balance adaptability.

The 16 per cent. of cases (see foot of last column) who showed no alteration in light balance were compared with the rest. They included cases of exophoria and esophoria, with or without vertical heterophoria. The refraction was in some patients myopic and in others hypermetropic, with or without small degrees of astigmatism. Only one possible factor showed as a consistent difference from the other cases. This was that each had an unusually wide amplitude of fusion in spite of the heterophoria.

Several of the patients who were most aware of the lack of brightness and fullness of colour in one eye as compared with the other had only very slight reduction (if any) from the normal light balance. The patients with heterophoria for one range, such as constant exophoria for near vision only, seemed to be more inclined to complain of the lack of brightness in the non-dominant eye, but this diminished response was more difficult to demonstrate. The patients with heterophoria which was manifest for longer periods and at more ranges were less aware of a light difference between the two eyes, but in these cases it was easier to demonstrate a reduction of light balance in the non-dominant eye.

DISCUSSION

Since this condition is frequently found in eyes which have been amblyopic, a connection with suppression suggests itself. Although suppression of the usual small dots used as controls does not occur, these controls are of necessity out of the centre of the diagram and therefore a fine mesh or dot suppression could be occurring. An effort was made to find out if this was so. Chavasse "retinal rivalry" slides No. 8 (Figs 1 and 2, opposite) were used. One slide presented rings composed of eight dots, the rings varying in size so that the largest subtended an angle of 50' and the smallest an angle of 5'. The companion slide had a centre dot with two vertical and two lateral dots, the centre dot acting as a control when the peripheral dots coincided with four of the dots in the opposite rings. The centre dots varied in size, the largest subtended an angle of 10' and the smallest an angle of 1'. Using these slides in examining a series of patients, the results were not consistent. Monocular suppression

FIG. 1.—Rings graded in size: largest subtends an angle of 10', smallest an angle of 5'.

FIG. 2.— Central control dots graded in size: largest subtends an angle of 10', smallest an angle of 1'.

might occur in the largest ring control subtending 50', and yet no dominance was found on a stereogram. A patient who had a

marked ocular dominance might not suppress the control subtending 1' more easily with the weaker eye than with the other. On the whole, however, there did seem to be a tendency for the less dominant eye to suppress the 1'-size control more often than did the dominant eye, but this tendency was not commensurate with the marked loss of adaptability to the intensity of light.

The use of these slides did not settle the question whether the diminished brightness of the light as seen by one eye is a type of extenuated suppression or whether it is a condition of overall reduced sensitivity to light. Suppression, even in the case of an adult, generally tends to become more intense if left untreated, and heterophoria tends to increase in degree. But a treated amblyope left with equal vision, good binocular vision, a slight degree of heterophoria, and a marked inequality to brightness at the age of 8 years, may remain almost unchanged. Some cases have been examined yearly for 10 to 15 years with no intervening treatment other than the correction of refractive errors. Each year the vision, ocular muscle balance, and brightness inequality remain the same. It seems that a suppressing eye is generally less sensitive to brightness, although in some cases this is not so. An eye with diminished brightness does not necessarily suppress, but in some cases it does so. Probably every case of previous deep amblyopia is left with diminished sensitivity to brightness whether the tendency to suppression remains or not.

Vogt (1939) and Wald and Burian (1944), measuring the absolute light threshold of deeply amblyopic eyes against the fellow eye, found:

the absolute threshold was normal, foveally and peripherally, in cones and rods, and in light and dark adaptation. It must be concluded that the entire apparatus of simple light perception is normal in these subjects.

Stiles and Crawford (1933) have demonstrated that the sensation of brightness from a light source entering through the periphery of the pupil is much less than the same light entering through the centre. In the cases being investigated the difference in light balance suggests that it is as if the light were entering through the centre of the pupil of the dominant eye and through the periphery of the non-dominant eye. This is carefully guarded against during all the tests. What is true is that, in ordinary life, at certain times and distances, the non-dominant eye, when the heterophoria becomes manifest, is stimulated by oblique rays at the same time as the dominant eye is stimulated by rays entering centrally. It would appear that some change occurs in the reaction of the foveal cones which prevents them from reacting normally when the light rays are directed straight into them.

Wright and Nelson (1936) suggested that the Stiles and Crawford effect might be due to the difference in the amount of reflection from the retinal elements. Bárány (1946) tried to confirm this and that

the intensity of stimulation should also depend on the plane of polarization. Stanworth and Naylor (1950) point out that consideration of the effects of the bi-refringence of the ocular media supports the view that Bárány's negative results do not exclude the explanation of the Stiles-Crawford effect advanced by Wright and Nelson. If the intensity of stimulation does depend on the plane of polarization, is it possible that constant or intermittent stimulation of the foveal cells by oblique rays may cause a lasting (not necessarily permanent) alteration in the reaction of these cells when the rays are direct?

Those patients who complain only of a diminished sense of brightness in one eye present a separate problem. The cause of the defect is not in the retinal elements which deal with form vision since the visual acuity is normal, nor is it in the mechanism of colour perception because that also is normal.

In many cases the binocular adaptability to differences of light balance is normal. The symptom remains unchanged for long periods and does not appear to vary at all with conditions of health or fatigue. It remains the same if the other eye is shut completely, or kept open but covered with an occluder, or if binocular vision is being used. This suggests that the site of the defect is not central but peripheral and may be in the receptor mechanism of the eye itself.

From time to time the possibility of a separate brightness-perceiving mechanism has been suggested. Dartnall (1948) has shown that, in the presence of its bleached products, the spectral distribution of light absorbed by visual purple is modified so that the maximum moves towards the red. In the limiting case studied, the displaced curve agrees closely with the photopic-luminosity curve, apart from certain deviations later pointed out by Thomson (1949). Moreover these deviations occur in spectral regions where Granit has shown modulator activity. The inference is that visual purple and the rods are responsible for the mediation of luminosity at both scotopic and photopic levels, but that the final form of the photopic sensitivity curve is modified by participation of the hue mechanisms.

"Brightness", "brilliance", "dazzle", and "shine" are words frequently used by patients to explain the type of visual loss experienced in one eye. Of these effects, "dazzle" and "shine" are normally caused by the impact of polarized light on the eye, and the inability to perceive these effects seems to suggest that the eye cannot react normally to polarized light, but the results of an investigation of this question are not yet available. Also, since such an eye is otherwise normal, a mechanism might exist in the normal eye whereby brightness is perceived by a process in cells or pigments which react specifically to polarized light.

Polarized light in nature, especially in the sky, must form a considerable amount of the total light perceived. It is interesting to speculate that, since polarization occurs at fixed angles of reflection, this could be a factor in the directional flights of birds if they possessed a special mechanism for dealing with these rays. Lighthouses cause more disasters in bird flight when there is a mist, the particles of which would alter the usual reflections from the lamp.

SUMMARY

(1) A patient can have a diminished sense of brightness in one eye which has normal visual acuity equal to that of the other eye.

(2) A marked loss of adaptability to differences of binocular light balance can be present in one eye in a patient with normal equal visual acuity in each eye.

(3) A marked loss of adaptability to binocular light differences is always present in an amblyopic eye.

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