BINOCLULAR VISION IN LIGHT ADAPTATION AND DARK ADAPTATION IN NORMAL SUBJECTS AND COAL-MINERS*

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PART I. NORMAL SUBJECTS

IN a previous communication (Campbell and others, 1948), a preliminary comparison was made of the binocular vision of normal subjects and of coal-miners in light adaptation and dark adaptation. The number of subjects then available was rather small, and the investigation has now been repeated with greater precision and in more detail, in order to establish the behaviour of the normal subject in "half-distance" as well as in ordinary "distance" vision.

In the course of examining and training adult subjects on the synoptophore, the orthoptist must become aware of numerous individual variations in binocular vision, but no attempt has been made to correlate or to analyse them.

Our records were made for the purpose of finding a normal base-line with which to compare the behaviour of coal-miners, whose visual environment differs so much from that of light-adapted subjects.

Ninety subjects were taken in three age groups (A, 25-44; B, 45-54; C, 55-70), an irregular age distribution being chosen to demonstrate the behaviour of the young adult (A), the presbyope (B), and the old adult (C). They were ordinary hospital out-patients and volunteers of all classes and occupations who had fusion, excluding those with amblyopia or a manifest strabismus. They all had vision 6/12 or better in each eye, and they included 31 emmetropes, 46 hypermetropes, and thirteen myopes. Those with astigmatism greater than half a diopetre were excluded. Each group contained thirty subjects, and the groups were subsequently used as controls for normal coal-miners and for coal-miners with nystagmus.

METHOD

The visual acuity was recorded in daylight, with and without the glasses which corrected the refractive error, and tests were made with the Maddox wing and Maddox rod. The subjects were also tested on the synoptophore without glasses. The measurements were surprisingly constant and in many instances individuals gave the same results when retested after a lapse of several months.

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The same synoptophore and the same slides were used throughout, together with standard Wratten filters* by which the illumination could be reduced to approximately $\frac{1}{10}$, $\frac{1}{2}$, and $\frac{1}{4}$ of its full value. The synoptophore was calibrated with the slides and filters, *in situ*, both at the beginning and at the end of the series of experiments. The scales on the synoptophore were made faintly luminous by the application of radio-active paint.

No claim is made for the absolute accuracy of the levels of illumination, since both filters and slides gave a diminishing effect with the passage of time, but the relative values remained appreciably the same. In all tests the brightness of the test slide was well above the critical threshold (approximately 0.01 millilamberts) for the dark-adapted eye, and was of such a degree as would not cause "glare" to a normal person. An opal screen was inserted between the lamp and the slide to obtain diffused illumination and the brightness was cut down by adding the appropriate Wratten filter.

The subject was first tested in a well-lighted room, and was then dark-adapted for 45 minutes in a completely darkened room and again tested with illuminations of $\frac{1}{10}$, $\frac{1}{4}$, $\frac{1}{2}$, and full strength, in that order. The orthoptist used a small torch with a red filter when it was necessary to move the patient, or to adjust the instrument.

As the tests proceeded, it became obvious that the most significant changes occurred as between full illumination in the light-adapted eye, and $\frac{1}{10}$ illumination in the dark-adapted eye. The use of full illumination in the dark-adapted eye was sufficient to restore it to a condition of light adaptation, and the eyes returned to the same measurements of binocular function as in light adaptation. The records for $\frac{1}{4}$ and $\frac{1}{2}$ strength illumination showed relatively insignificant intermediate gradations. The records given below are therefore confined to those taken at full and $\frac{1}{10}$ illumination in the light- and dark-adapted eye respectively. The average value, in terms of brightness, with the opal screen *in situ* was then:

"Full" illumination = 72 millilamberts-
| $\frac{1}{10}$ illumination = 7.1 millilamberts.

Binocular performance was judged by measurements taken in the following order:

- (1) SP., by "circle" and "triangle" slides.

Full brightness = 50 millilamberts
 $\frac{1}{10}$ brightness = 4.9 millilamberts

- (2) Fusion and adduction, by "flag" slides.

Full brightness = 38 millilamberts
 $\frac{1}{10}$ brightness = 3.4 millilamberts

- (3) Stereoscopic vision, by a slide showing white circular areas on a black ground.

Full brightness = 23 millilamberts
 $\frac{1}{10}$ brightness = 2.1 millilamberts.

The first served mainly to initiate the subject, and the results are not recorded here in detail.

In its normal condition the synoptophore is constructed to record

* Supplied by Messrs. Kodak, Ltd.

binocular vision as exercised at a distance. Records were also made with a -1.50 D. lens before each eye, to show the power of adduction, and any associated changes in fusion and stereoscopic vision during the exercise of a moderate amount of accommodation, the visual behaviour required being similar to that needed in working at half-distance* without visual aid.

RESULTS

Fusion

IN LIGHT ADAPTATION.—In the unaccommodated state *all* the subjects examined had fusion; 46 per cent. had an angle of 0° , 34 per cent. achieved fusion at from $+1^\circ$ to $+4^\circ$, 9 per cent. were markedly convergent, and the remaining 11 per cent. were divergent (Table I and Fig. 1).

With Accommodation, as might be expected, the majority of subjects showed a markedly convergent angle (Fig. 1); 59 per cent. fused at between $+5^\circ$ and $+10^\circ$, and only 7 per cent. at 0° . Nearly all those who were divergent in distant vision became convergent.

IN DARK ADAPTATION.—Only 26 per cent. of the subjects fused at 0° . Of twenty subjects tested with a test object of only 0.03 millilamberts, 15 per cent. still fused at 0° , and 50 per cent. at $+1^\circ$ to $+4^\circ$. There was a tendency for the fusion angle to become more convergent, except in those subjects who began with a divergent fusion angle.

With Accommodation the behaviour was practically unchanged by dark adaptation.

EFFECT OF ERRORS OF REFRACTION.—The same variations were seen in emmetropes even more clearly than in the average. Myopes and hypermetropes followed the same pattern of performance, except in the unaccommodated eye in dark adaptation, when they both developed a more convergent fusion angle than the emmetropes (Table I).

EFFECT OF AGE.—Individuals of middle and old age (Groups B and C) assumed a greater convergent fusion angle than young adults (Group A), particularly in accommodation (Fig. 2, overleaf). In the light-adapted eye, 77 per cent. of Group C showed a fusion angle of from $+5^\circ$ to $+10^\circ$ in accommodation.

Adduction

In recording the range of adduction, allowance was made for the fusion angle, *e.g.*, if fusion occurred at $+3^\circ$ and the ductions were -5° to 25° , the corrected ductions would be -8° to $+22^\circ$. In this way it was possible to compare the ductions of different individuals. The results showed that the most useful way

* The terms "distance" and "half-distance" used in this paper may be taken as corresponding with vision in the unaccommodated and the accommodated (*i.e.*, tests with -1.50 spheres) states. The term "adduction" has been retained, although in the tests with accommodation for half-distance it might be called convergence.

TABLE I
FUSION ANGLES IN NORMAL SUBJECTS
(Percentages of Total Subjects)

Angle of Fusion (degrees)	Light Adaptation		Dark Adaptation	
	Unaccommodated	Accommodated	Unaccommodated	Accommodated
<i>All Subjects</i> (90) (<i>cf. Fig. 1</i>)				
0	46	7	26	3
+1/+4	34	32	36	30
+5/+10	9	59	25	61
-1/-4	11	2	12	4
None	0	0	1	1
<i>Emmetropes</i> (31)				
0	49	3	45	0
+1/+4	32	40	23	37
+5/+10	0	57	13	60
-1/-4	19	0	19	3
None	0	0	0	0
<i>Hypermetropes</i> (46)				
0	43	11	13	0
+1/+4	33	22	43	22
+5/+10	17	62	31	67
-1/-4	7	5	11	8
None	0	0	2	3
<i>Myopes</i> (13)				
0	46	5	31	17
+1/+4	46	39	38	33
+5/+10	0	56	31	50
-1/-4	8	0	0	0
None	0	0	0	0

FIG. 1.—Fusion angles in light adaptation and dark adaptation (all subjects).

FIG. 2.—Effect of age on fusion angles (all subjects).

of demonstrating the variations was to record the percentage of individuals who shewed adductions of 10° or less, 10° to 19° , and 20° and over. The variations in adduction were found to be negligible throughout and are omitted for the sake of clarity.

IN LIGHT ADAPTATION.—In distance vision the common range of adduction was 10° to 19° for 56 per cent. Twenty-two per cent. had less than 10° , 22 per cent. had over 20° (Fig. 3 and Table II).

FIG. 3.—Range of adduction in light adaptation and dark adaptation (all subjects).

than young adults. In the oldest subjects (Group C) there was a distinct grouping into those with "poor" and those with "good" adduction (Fig. 4).

IN DARK ADAPTATION.—In distance vision the power of adduction was on the whole slightly worse in the dark than in the light. With still lower illumination (0.03 millil.) duction tended to increase.

With Accommodation, adduction showed a tendency to increase, 40 per cent. had a range of 10° to 19° and 34 per cent. over 20° .

EFFECT OF ERRORS OF REFRACTION.—These caused little difference in adduction; myopes gave the poorest performance in distance vision (Table II) while hypermetropes developed the greatest adduction in accommodation.

EFFECT OF AGE.—The power of adduction increased with age in distance vision. In near vision the presbyopes (Group B) showed greater adduction

TABLE II
ADDUCTION IN NORMAL SUBJECTS
(Percentages of Total Subjects)

Angle of Adduction (degrees)	Light Adaptation		Dark Adaptation	
	Unaccommodated	Accommodated	Unaccommodated	Accommodated
<i>All Subjects</i> (90)				
30	8	20	8	19
29-20	14	14	19	22
19-10	56	40	49	38
9-1	21	22	21	12
None	1	4	3	9
<i>Emmetropes</i> (31)				
30	6	14	10	14
29-20	16	9	19	20
19-10	52	49	45	51
9-1	26	28	26	9
None	0	0	0	6
<i>Hypermetropes</i> (46)				
30	7	27	7	22
29-20	15	22	15	30
19-10	63	32	52	30
9-10	13	19	19	13
None	2	0	7	5
<i>Myopes</i> (13)				
30	15	17	8	22
29-20	9	11	15	11
19-10	38	38	46	28
9-1	38	17	31	17
None	0	17	0	22

FIG. 4.—Effect of age on adduction (all subjects).

With Accommodation adduction was better, 38 per cent. having a range of 10° to 19°, and 40 per cent. over 20° (Fig. 3).

EFFECT OF ERRORS OF REFRACTION.—Hypermetropes showed the highest level of adduction in near vision, while myopes showed a low level of adduction, especially those in Group C, many of whom had none whatever (Table II).

EFFECT OF AGE.—Young subjects had the greatest adduction in accommodation, and older subjects in distance vision.

FIG. 5.—Stereoscopic vision (all subjects).

Stereoscopic Vision (Figs 5 and 6, Table III)

Although the slides used for this test were made up of a series of eight white circles on a black ground, each identifiable by a letter, the presbyopes could not read the letters, and yet were able to describe the stereoscopic position of the circles. In other words, the stereoscopic vision test was not dependent on visual acuity. The sense of stereopsis often developed slowly, and the subject was allowed time to become aware of it.

TABLE III
STEREOSCOPIC VISION IN NORMAL SUBJECTS
(Percentages of Total Subjects)

Degree of Stereopsis*	Light Adaptation		Dark Adaptation	
	Unaccommodated	Accommodated	Unaccommodated	Accommodated
<i>All Subjects (90)</i>				
Excellent ...	67	65	60	51
Good... ..	14	21	10	26
Poor	19	14	30	23
<i>Emmetropes (31)</i>				
Excellent ...	81	72	77	60
Good... ..	16	17	10	23
Poor	3	11	13	17
<i>Hypermetropes (46)</i>				
Excellent ...	59	66	52	46
Good... ..	15	26	9	27
Poor	26	8	39	27
<i>Myopes (13)</i>				
Excellent ...	61	50	46	44
Good... ..	8	17	15	28
Poor	31	33	39	28

* Excellent, $\frac{2}{3}$ - $\frac{1}{2}$; Good, $\frac{1}{3}$ - $\frac{1}{4}$; Poor, $\frac{1}{4}$ or less.

FIG. 6.—Effect of age on stereoscopic vision:

A, young subjects, 25–44 years; B, presbyopes, 45–54 years; C, old subjects, 55–70 years.
E, excellent ($\frac{2}{8}$ – $\frac{7}{8}$); G, good ($\frac{6}{8}$ – $\frac{5}{8}$); P, poor ($\frac{4}{8}$ or less).

The results were graded as “excellent” ($\frac{2}{8}$ – $\frac{7}{8}$), “good” ($\frac{6}{8}$ – $\frac{5}{8}$), and “poor” ($\frac{4}{8}$ or less).

IN LIGHT ADAPTATION.—It was found that 67 per cent. of normal

subjects had excellent stereoscopic vision in the distance, and 65 per cent. when the eyes were accommodated (Fig. 5 and Table III).

Emmetropes have better stereoscopic vision than hypermetropes or myopes, the last-named being particularly poor in accommodation (Table III).

Stereoscopic vision declines slightly with age. This confirms our previous findings (Campbell and others, 1948) in distance vision, but shows some improvement in accommodation (Fig. 6).

IN DARK ADAPTATION.—Stereoscopic vision is not so good on the average as in light adaptation, but was well maintained with a test object of brightness only 0.02 millil. Emmetropes are superior to hypermetropes and myopes, particularly in distance vision (Table III). Although 83 per cent. of young subjects have excellent stereoscopic vision in distance vision, there is a decline with age (Fig. 6). Myopes in Group C showed a noticeable failure to achieve stereoscopic vision.

CONCLUSIONS

IN LIGHT ADAPTATION

Fusion.—It appears that quite a high percentage of subjects fuse at 0° and do not exceed an angle of $+4^\circ$. The angle is not influenced by low errors of refraction, but increases with age. Accommodation to -1.50 dioptres causes a most noticeable increase in the angle of fusion, in that only 7 per cent. of our subjects continued to fuse at 0° , while 60 per cent. adopted an angle of $+5^\circ$ to $+10^\circ$. This effect was most marked in older subjects.

Adduction.—The common range of adduction is from 10° to 19° , being poorer in myopes and better in hypermetropes than in emmetropes. It increases in old age.

Accommodation brings about only a slight increase in adduction if one allows for the convergent angle due to fusion. Hypermetropes and presbyopes show the greatest increase, while myopes are exceedingly poor in spite of the fact that they increase their angle of fusion to the same degree as do emmetropes. Subjects in Group C who have a natural amplitude of only about 1.50 dioptres of accommodation fell into two distinct groups (those with "good" and those with "poor" adduction), yet they showed a variation in fusion angle which was similar to that of early presbyopes (Group B).

Stereoscopic Vision.—This was found to be remarkably good in the majority of subjects; it declines with age and is worse in hypermetropes and myopes than in emmetropes. Accommodation slightly improves stereoscopic vision, mainly in hypermetropes.

It appears then that stereoscopic vision is inversely related to fusion and adduction, in the sense that the increase in the angle which

occurs in these functions (in old age, and in hypermetropia) is accompanied by a decline in stereoscopic vision.

On examining the behaviour of a number of subjects with good and with poor stereoscopic vision, we found that there was no difference in the average fusion angle adopted, but that subjects with poor stereoscopic vision failed to increase their adduction under the stimulus of accommodation (Table II).

IN DARK ADAPTATION.—The influence of dark adaptation on binocular performance is comparatively slight.

Fusion.—The normal subject adopts a rather more convergent angle of fusion in distance vision than he does in light adaptation. This effect is more pronounced in myopes and hypermetropes than in emmetropes (Table IV).

Adduction.—This is practically uninfluenced. Myopes show an improved adduction in distance vision, as do subjects in Groups A and C when accommodating. Presbyopes do not adduct so well.

Stereoscopic Vision.—This is not quite so good in distance vision, except in young subjects. It improves with accommodation. Subjects with poor stereoscopic vision show the same failure as in light adaptation to increase their adduction in response to accommodation (Table IV).

It should be borne in mind that in the conditions of our experiments the illumination of the test slides was in every case above the

TABLE IV
RELATIONSHIP OF FUSION ANGLES AND ADDUCTION ANGLES WITH STEREOSCOPIC VISION IN NORMAL SUBJECTS

Vision	Stereoscopic Vision							
	Light Adaptation				Dark Adaptation			
	Poor		Good		Poor		Good	
	No. of Subjects	Average Angle (degrees)	No. of Subjects	Average Angle (degrees)	No. of Subjects	Average Angle (degrees)	No. of Subjects	Average Angle (degrees)
<i>Fusion Angle</i>								
Distance ...	18	1.7	59	1.4	25	3.8	43	2.8
Half-Distance	13	5	77	5.4	18	6.2	66	6
<i>Adduction Angle</i>								
Distance ...	17	14.6	73	14.7	27	13	43	18
Half-Distance	9	7	57	18.5	20	10.7	46	19

critical threshold, and that therefore the normal macular dominance was not disturbed. With a test object of brightness of not less than 2 millilamberts it appears, therefore, that *dark adaptation does not cause any appreciable alteration in binocular vision—other than the adoption of a convergent fusion angle, and a decline of stereoscopic vision.* This applies to the subject who has substantially good binocular vision and good visual acuity; it is exemplified in the emmetrope.

With advancing age the fusion angle becomes still more convergent; adduction fails, but stereoscopic vision remains good. The hypermetrope develops a convergent fusion angle immediately on entering the dark, and has poor stereoscopic vision while retaining good adduction. The myope is characterized by poor adduction, particularly when working at close range, and has very poor stereoscopic vision.

DISCUSSION

These observations help to establish standards for binocular function in the normal adult, and may have some practical application. Three hazardous occupations, night-flying, night-driving, and coal-mining, are carried on in very low illumination. In comparison with the aviator, the night-driver and the coal-miner have the added disadvantage of being frequently subjected to "glare".

Airmen are required to possess first class visual acuity and binocular vision, which is an important safeguard for successful night-flying.

By contrast, the binocular vision of coal-miners is not tested at all, and although an amblyopic man or one with low visual acuity may remain at work underground for years, his actual efficiency is never challenged. We have had the opportunity of examining several hundred men certified as suffering from coal-miners' nystagmus, and amongst those with no oscillations were many whose breakdown was mainly due to a failure of binocular vision, *i.e.*, to the loss of adduction and the development of central suppression in one or both eyes.

The usual time of breakdown is middle age, and high myopes and high hypermetropes are also found among those who have been certified in the absence of oscillations, which is not surprising in view of the fact that they have continued to work until middle age without wearing glasses. It is obviously desirable that a more careful visual examination should be made of entrants to the industry to lessen the wastage of experienced men in the prime of life. The disease carries a high incidence of psychiatric disorder, because of the hazards of the work and the sense of failure which ensues when a miner has

to leave the pit. The possession of good binocular vision would increase the miner's confidence and efficiency.

The night-driver occupies an intermediate position. His visual acuity is usually good, particularly if he is the driver of a public services vehicle, but his binocular vision and sense of stereopsis are not checked. It would be interesting to know to what extent visual defects are responsible for pit accidents and for road accidents which occur in darkness.

REFERENCES

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