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

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PART II. COAL-MINERS

Having established the behaviour of the normal subject when tested on the synoptophore under specified conditions of light adaptation and dark adaptation (Campbell and others, 1951), we have used the same methods to examine a large number of coal-miners (some employed on the coal-face, and some certified as suffering from coal-miners' nystagmus).

In our former observations (Campbell and others, 1948), the number of subjects available was too small for a detailed comparison, but it was obvious that normal coal-miners have remarkably high levels of stereoscopic vision and adduction. They tend to adopt an abnormal fixation in the dark since they habitually look upwards, and, in addition, the corneal reflexes are high.

We have now recorded the results as simply as possible, and have, therefore, omitted the actual synoptophore readings. Additional information is included as to the effect of age, and the degree of accommodation for half-distance, since both these factors enter into the miner's normal working life.

NORMAL COAL-MINERS

The visual acuity of the normal miners (90 subjects) was not so good on the whole as that of the non-mining controls (Campbell

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and others, 1951) but 65 per cent. had a visual acuity of at least 6/12 in the poorer eye, and only 3 per cent. less than 6/24. The group included very few subjects with large errors of refraction.

**Fusion**

**In Light Adaptation.**—The accompanying figures show that in unaccommodated vision the fusion angle in miners is much the same as in normal individuals, i.e., approximately 45 per cent. fused at 0° in the light, and 30 per cent. in the dark (Fig. 7, a, c), and a further 40 per cent. fused at between +1° and +4° in both light- and dark-adaptation. Age has little effect (Fig. 8, a, c).

*With Accommodation for Half-Distance* (to −1.50 ds) quite a number of miners continue to maintain fusion at 0° (30 per cent. in the light and 25 per cent. in the dark, in comparison with non-miners' 7 per cent. and 2 per cent. respectively, Fig. 7, b, d). The remainder do not develop so large a convergent angle in the light (Fig. 8, b, f) as do non-miners. 50 per cent. of older subjects (as compared with 77 per cent. of non-miners) in Groups B and C developed a fusion angle of +5° to +10° (Fig. 8, b, f).

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**Fig. 8.**—Effect of age on fusion angles in normal subjects (e)–(h), and in coal-miners (a)–(d).
Fig. 9.—Effect of age on adduction in normal coal-miners (a)–(d) and in coal-miners with nystagmus (e)–(l).
BINOCULAR VISION. II. COAL-MINERS

In Dark Adaptation.—In distant vision the fusion curves were similar for subjects of all ages (Fig. 8, c) while in the half-distance, as in the case of non-miners (Fig. 8, d, h) the curves for subjects in Groups B and C were identical.

It may be concluded that prolonged work in the dark steadies the angle of fusion.

Adduction

In 121 subjects of all ages, adduction was maintained at a high level, both in light- and dark-adaptation, with or without accommodation (Fig. 9). Adduction improved with accommodation in accordance with the recognized behaviour of the eye, but miners of advanced years did not fail (Fig. 9, a to d) as one might expect; in fact, in dark adaptation 60 per cent. of the men in Group C (over 54 years of age) had an adduction of 20° or over. These observations suggest that long-continued work in the dark prolongs the ability to perform adduction, even at an age when accommodation is normally failing.

Stereoscopic Vision

The stereoscopic vision of coal-miners is exceptionally good, particularly in accommodation, when an improvement occurs which is not shown by non-mining subjects (Fig. 10). This is true for all age groups (Fig. 11, overleaf). Dark adaptation appears to have little effect on stereoscopic vision.

Subjects Suffering from Coal-Miners' Nystagmus

In the cases of coal-miners' nystagmus, of whom 275 were examined, it was found that the binocular vision of those certified for longer than three months differed from that of those certified more
recently. This may have been due to a return to life in the daylight, or to the psychological effects of a long period of visual disability.

**CLINICAL OBSERVATIONS.**—A careful analysis of miners afflicted with oscillations has shown that various stages of disability can occur:

(a) Cases of unilateral oscillation are often found in the early stages of the disease, or during recovery. Wellwood Ferguson (1951) has shown that the ambit of movement occurs round the axis of astigmatism, if any.

(b) Oscillations may be present in the *upward gaze* only, and the subject can steady his eyes by looking down, and by tilting his head backwards, *i.e.*, by action of the extensor muscles of the neck. This leads to an appreciable improvement in visual acuity. If this extensor movement is combined with the upward gaze the oscillations are accentuated.

(c) Oscillations may be present in the *horizontal gaze* also. In this case the miner attempts to control his eyes by quick lateral movements, or by avert his face so as to maintain his eyes in a position of lateral deviation. In the former case he may show alternating macular suppression, and in the latter, persistent macular suppression of the 'forward' eye. The postures of backward head tilt, and of rotation of the face, which are characteristic of miners afflicted with nystagmus, have previously been ascribed to photophobia.

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**FIG. 11.**—Effect of age on stereoscopic vision in normal subjects and in coal-miners, distance and half-distance.

A, young subjects, 25-44 years; B, presbyopes, 45-54 years; C, old subjects, 55-70 years.
(d) In the most severe cases oscillations occur in every direction and are uncontrollable. The subject may then be hyper-excitabile, and afflicted with tremors of the head and body muscles, or flaccid and apathetic.

The presence of oscillations, particularly of the first degree, does not necessarily take away the ability to perform the tests for binocular vision, indeed, quite a number of the men had good binocular vision. On the synoptophore tests the subjects mostly complain of photophobia and giddiness even with a low illumination of the test object. It is these symptoms rather than the actual oscillations which render the subject unable to perform a binocular vision test.

In our series of 200 cases there were 43 per cent. of subjects with obvious defects of binocular vision. Only a few of these defects (6 per cent.) were associated with large errors of refraction, and in these cases the oscillations were usually absent, i.e., they were subjects whose binocular vision would have failed whatever occupation they were in.

The remainder suffered mainly from poor adduction, over-convergence and macular suppression. The last probably develops, as we have already suggested, as a defensive mechanism at the onset of oscillations, and is always to be found in those subjects who show constant lateral deviation of the eyes and of the face. Similarly, the over-convergence is of a 'voluntary' type and is plainly used as a mechanism with which to check the oscillations.

Visual acuity fails in coal-miners' nystagmus owing to the presence of oscillations and is often diminished in the emmetropic subject. It is often impossible to do a refraction in the early stages of the disease and, indeed, the subject often appears to be over-accommodating. For this reason the cases submitted to the test on the synoptophore were selected from those in whom photophobia and giddiness were at a minimum. In fact, 25 per cent. of those tested had 6/12 vision or better, 40 per cent. had 6/24 or 6/18, and 35 per cent. under 6/24 in the poorer eye.

The standards of brightness used in each test were the same as those employed for the non-miners and normal coal-miners:

<table>
<thead>
<tr>
<th>Adaptation</th>
<th>Test Brightness (millilamberts)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fusion and Adduction</td>
</tr>
<tr>
<td>Light</td>
<td>... ... ... ...</td>
</tr>
<tr>
<td>Dark</td>
<td>... ... ... ...</td>
</tr>
</tbody>
</table>

- Test Brightness (millilamberts)
RESULTS

Fusion

The cases of coal-miners' nystagmus follow the same pattern as those of normal coal-miners (Fig. 12). Recovery in all of them is in the direction of a less convergent angle of fusion (cf. Fig. 12, c, d, with Fig. 12, a, b), but the process is retarded with age. A surprising number of subjects regain fusion at 0°.

Adduction

There is an obvious failure of adduction in the early stages of this disease (see Table V). Young subjects in half-distant vision in light adaptation (Fig. 9, e to l), and old subjects in distant vision in dark adaptation, were the only groups to show a degree of adduction comparable with that of normal coal-miners.

In the process of natural recovery, as judged by 81 cases certified for longer than 3 months, the performance in distant vision was still poor, while accommodation stimulated adduction (Fig. 9, f, h). Young subjects, particularly when dark adapted, fell into two groups: 50 per cent. had an adduction of over 20°, and 30 per cent. had poor adduction under 10°. Old subjects showed a more even performance.
TABLE V

COMPARISON OF ADDUCTION ANGLE IN NON-MINERS, NORMAL COAL-MINERS, AND COAL-MINERS WITH NYSTAGMUS

<table>
<thead>
<tr>
<th>Group</th>
<th>Percentage of Subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Light Adaptation</td>
</tr>
<tr>
<td></td>
<td>Distance</td>
</tr>
<tr>
<td></td>
<td>Adduction Angle (degrees)</td>
</tr>
<tr>
<td></td>
<td>(&lt;10°)</td>
</tr>
<tr>
<td>Non-miners (90)</td>
<td>22</td>
</tr>
<tr>
<td>Normal (121)</td>
<td>28</td>
</tr>
<tr>
<td>With recent Nystagmus(71)</td>
<td>44</td>
</tr>
<tr>
<td>Recovering from Nystagmus (81)</td>
<td>51</td>
</tr>
</tbody>
</table>

Stereoscopic Vision

In all our tests, subjects afflicted with coal-miners’ nystagmus had poorer stereoscopic vision than normal coal-miners (Figs 10 and 13). In the early months after certification their stereoscopic vision was equal to that of non-miners when unaccommodated, and showed a slight decline in dark adaptation, and with age. In accommodation their performance was better than that of non-miners (Figs 10 and 13).

In the later months, and during the period of “natural” recovery, stereoscopic vision in the unaccommodated eye showed a further failure, and was very poor in 40 per cent. of subjects in every age group (Fig. 14, overleaf).

The effect of accommodation in causing an improvement in stereoscopic vision is again seen (see Fig. 13) and the performance resembles that of the normal coal-miner, rather than that of the non-miner (cf. Figs 10 and 13).

The relationship between stereoscopic vision and adduction previously described (Campbell and others, 1948) viz., that coal-miners with good stereoscopic vision have a good level of adduction, whereas those with poor stereoscopic vision have hardly any power of adduction, still proved to be true after our analysis of a much larger number of cases.

A few additional tests were made on the synoptophore on a group of twenty non-miners and twenty cases of coal-miners’ nystagmus,
using 1/1000 Wratten filters which gave the following test-brightnesses, which were still above the critical threshold:

<table>
<thead>
<tr>
<th>Adaptation</th>
<th>Test Brightness (millilamberts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td></td>
</tr>
<tr>
<td>Dark</td>
<td></td>
</tr>
<tr>
<td>Fusion and Adduction</td>
<td>3.4</td>
</tr>
<tr>
<td>Stereoscopic Vision</td>
<td>0.034</td>
</tr>
</tbody>
</table>

Fig. 15 shows that under these conditions the normal subject still maintains his binocular functions in dark adaptation, but amongst the coal-miners' nystagmus cases there was a complete failure of stereoscopic vision in four cases, of fusion in six, and of adduction in fourteen. No non-miner showed total failure of these functions.
Binocular Vision. II. Coal-Miners

**Fusion** 3.4 m.lamberts

0 10 15

+7 4° +5° +10° -7° -4° none

0 10 15

Adduction 3.4 m.lamberts

0 10 15

20 20

Stereoscopic Vision

2.1 m.lamberts

0 10 15

8-7 6-5 4-0

0.034 m.lamberts

0.021 m.lamberts

Miners' nystagmus

20 cases

Non-miners

20 cases

Fig. 15.—Binocular vision (Fusion, Adduction, and Stereopsis) in minimal illumination in non-miners, and in coal-miners with nystagmus.

On further reduction of brightness the test patches began to scintillate in a corpuscular manner. They were suffused with waves of colour (lime-green and mauve) and no binocular records were possible.
CONCLUSIONS

In our former communication (Campbell and others, 1948) it was suggested that a breakdown in binocular vision might occur under conditions of low illumination and that this might be one of the primary causes for the onset of coal-miners' nystagmus. More recent observations (Campbell and others, 1951), show that in normal subjects dark adaptation per se does not cause such a breakdown, and that coal-miners who have worked for many years underground possess better binocular vision than non-mining subjects. The failure which occurs in coal-miners' nystagmus appears to be the result and not the cause of the oscillations. Probably the most useful binocular function and the last to be affected by dark adaptation, is stereoscopic vision. Nevertheless, it would appear to be eminently desirable to check the binocular vision of men who are to be skilled workers, e.g., coal-getters and repairers, in the mining industry, and to exclude those with high errors of refraction. Hypermetropes over-converge, myopes have poor adduction, and both groups have poor stereoscopic vision. In addition, the visual acuity of the hypermetrope will fail in the prime of life, while the myope is usually a poor dark adapter.

From our experience, orthoptic training is of great value, in appropriate cases, in resorting the binocular vision of men afflicted with nystagmus, and in expediting their recovery. Macular suppression can be overcome and adduction improved, and the stimulation of mental interest is a most valuable part of their rehabilitation. The chief difficulty in giving out-patient treatment is the fact that miners live in villages remote from orthoptic centres. It is desirable that orthoptic training should form part of a residential course of rehabilitation.

A brief study of the data on illumination in coal-mines makes it obvious that the coal-miner suffers from repeated changes of illumination, so that at one moment he can see, and at the next he cannot. At a distance of 4 feet even the most modern cap-lamp gives an average incident light of only 0.6 foot candles, which when reflected from the surface of the coal is reduced to something like 0.03 foot-candles. The overhead lighting on rail junctions where haulage hands are engaged in the dangerous occupation of coupling heavy trucks, gives an incident light which is often as low as 0.01 of a foot-candle, and there are long stretches of roadway which are quite dark because of absence of lighting, or to the reduction of its radiance by a coating of dirt.

The introduction of the modern cap-lamp, and the experimental installation of better types of mains' lighting and of fluorescent strip lighting at the coal-face, should do much to improve the illumination,
and it may not be too much to hope that the general level could be maintained above 0.1 foot-candle in every part of a coal-mine, which would at least enable a man to use his binocular vision. Even that would be a low standard in comparison with the minimum requirements in factories (0.5 foot-candle at floor level where people employed shall pass, and 6 foot-candles at a level of 3 feet above the floor where people are working).

We wish to record our thanks to the Medical Research Council for a grant towards the expense of the orthoptic investigations, and to the National Coal Board for financial assistance with the clinical research relating to coal-miners.

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