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COMMUNICATIONS

VISION AND ILLUMINATION IN COAL MINES WITH REFERENCE TO MINERS' NYSTAGMUS

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PART I

In spite of individual opinions to the contrary (1, p. 18; 2) it is now generally agreed (3, p. 322; 4, pp. 201-202; 5, pp. 6 and 60; 6, p. 7; 7, pp. 238-239; 8, p. 509) by medical authorities that deficient illumination is the chief factor in causing miners' nystagmus though it is admitted that other contributory causes may exist. The low power of dark adaption of the fovea prevents the functioning of this part of the retina in very dim lighting such as generally obtains underground in coal mines, and it is believed that it is the long continued inability to make use of foveal vision that causes mine-workers to develop nystagmus after years of work underground. (9, p. 113) (The average age of mine-workers when the disease becomes so bad that they can no longer work in the mine is about 42 years, and the average number of years spent working underground about 26 years.) (5, p. 51). Whether or not it is continued difficulty in fixating vision that is the immediate cause of the disease is a question that is not easy to answer. At illuminations so low that the fovea cannot function properly it is undoubtedly difficult to fixate, but there is evidence to show that fixation can

actually be accomplished at values of brightness considerably below those commonly met with in mining practice. (10) It is, however, significant that in cases of congenital total colour blindness in which it is believed that vision is mediated exclusively by the retinal rods and in which, consequently, foveal vision is impossible, symptoms of nystagmus, irrespective of the subject's occupation, are almost invariably present. (11, p. 198; 12, p. 257).

It would seem safe, then, to assume that to abolish nystagmus we must provide sufficient illumination to allow the fovea to function normally (whether for fixation purposes alone or not) and this paper is devoted to an examination of the evidence available as to what is the minimum illumination necessary for this purpose.

It is usually accepted that the so-called point of change-over from peripheral to foveal (or from rod to cone) vision is shown by the knee or bend in the brightness—acuity graph and brightness—critical flicker frequency graph and it is proposed to examine the available evidence. Incidentally, it is worth keeping in mind that the threshold brightness of the fovea is considerably lower than the brightness at the knee of either of the above curves. According to comparatively recent work by Hecht (13), the average value of the threshold for 15 subjects was 3.37×10^{-4} ml. ($=10^{-5}$ c./sq. ft. approximately). This figure was for a test object subtending an angle of 2.5° at the retina and the image was thus within the limits of the rod-free area, although extending outside the true foveal area.

Taking first the brightness-acuity curve, the author has plotted König's classical results (14) in Fig. 1. König's original figures for his own eye for white light have been used after grouping certain of his numerous points and converting his brightness units to candles per square foot (c./sq. ft.) units (on the assumption that König's unit was equivalent to 0.0213 c./sq. ft.)* It will be observed that the centre of the bend near the foot of the curve occurs at a value of brightness of $3.3 \log.$ c./sq. ft. ($=0.002$ c./sq. ft.), the bend straightening out at about $3.5 \log.$ c./sq. ft. ($=0.003$ c./sq. ft.). The corresponding values of acuity are not of interest to us and, indeed, are only relative.

Hecht (15, p. 259) estimates the value of brightness at the knee of König's brightness—acuity curve to be 0.0072 ml. ($=0.0021$ c./sq. ft.)—a figure that appears to have been accepted by several authorities on miners' nystagmus.

According to Hecht (16), the data of Roelofs and Zeeman (1919) on the relation between brightness and acuity give, after the

* König's unit of illumination was that of a Hefner lamp at a distance of 1 metre. The co-efficient of reflection for the white paper used is assumed to be 0.8.

FIG. 1.—Objective brightness and visual acuity (König's data)

FIG. 2.—Objective brightness and critical speed of flicker (Porter's data)

necessary modification for units, a curve fitting in very closely with, and corroborating, that of König.

Most other published experimental results on the brightness-acuity relation are not of value to us as they were not carried to sufficiently low values of brightness or the conditions were not completely controlled or adequately noted or, else, readings were too far apart on the brightness scale to define the curve with sufficient closeness near the knee.

The brightness—critical frequency graph is generally very similar in shape to the graph for the brightness-acuity relation and may also be considered as being made up of two lines more or less straight lying at an angle to each other. Porter's (17) results for white light are plotted in Fig. 2. After converting his illumination units to candle/sq. foot brightness units on the assumption that the average reflection factor of the illuminated half-black, half-white rotating disc used by him was 0.5. It will be seen that the knee or corner of the curve is very sharp and occurs at a brightness of $3.57 \log. c./sq. ft.$ ($=0.0037 c./sq. ft.$). Porter, himself, points out that the apparently sudden break in the line may in reality be only a rather sharp curve.

Ives' (18) graph for white light is essentially the same as that given by Porter and consists of two straight lines at different inclinations meeting at a point or sharp bend. He states that this point corresponds to an illumination of 2.5 of his illumination units. Allowing for the average reflection factor of the rotating disc used, this is equivalent to an objective brightness of 0.38 candles per square metre ($=0.036 c./sq. ft.$). Ives, however, used an artificial pupil of 1 sq. mm. aperture in viewing his disc and, hence, his brightness values cannot be directly compared with those of other workers using a naked pupil. The retinal illumination, on the other hand, can be at once determined and is 0.38 photon* which is considerably below the figure of 0.89 photon which, as shown later, is the retinal illumination produced on an eye with an average size natural pupil by a field brightness of 0.004 c./sq. ft.

More recent work bearing on the subject has been done by Lythgoe and Tansley (19) in connection with the adaptation of the eye. Whereas both Porter and Ives had used comparatively large fields of view and did not seriously attempt to confine the image of the flickering light source precisely to one or other part of the retina Lythgoe and Tansley used a source subtending only 1° at the eye whose image, therefore, just fell inside the limits of the foveal area when the light was regarded directly. They measured the critical frequency-brightness relation when the image of the

* See footnote to p. 139.

light source fell on the retina at angular distances from the fovea of 0° , 10° , 50° and 90° respectively and with varying brightnesses of background or surroundings. Their results show that only under certain conditions is the relation depicted by two straight lines meeting sharply at a point, but that, in general, the lines are curved, and while composed of two distinct portions inclined

FIG. 3.—Objective brightness and critical frequency of flicker (Lythgoe and Tansley's data)

Curve A—Centre of fovea. Curve B— 10° from centre of fovea

to each other, the knee of the curve is not sharp or well-defined. Fig. 3 shows in terms of our brightness units the average results for three observers and for two positions of the image on the retina, *viz.*, at 0° and 10° from the fovea. (It represents the particular case where the surrounds were the same brightness as the test-patch.) As might be expected, on the assumption that the lower part of the previous curves for acuity and for flicker represent rod or scotopic vision and the upper part cone or photopic vision, the lower portion of the curve for 0° (*i.e.*, where the image fell entirely within the rodless fovea) is missing. At 10° from

the fovea where both rods and cones are found in the retina the curve shows a definite bend or knee at approximately $\bar{3}\cdot4$ log. c./sq. ft. ($=0\cdot0025$ c./sq. ft.) the upper comparatively straight part of the curve commencing at a brightness of about $\bar{3}\cdot6$ log. c./sq. ft. ($=0\cdot004$ c./sq. ft.).

Further, Lythgoe and Tansley's original curves appear to show that the point of change-over does not occur at the same brightness for parts of the retina at different distances from the fovea, but that, as the periphery is approached, it occurs at higher values and with even less definiteness, the curve for 90° (not reproduced), for example, having a much less pronounced "knee" than that at 10° . Still more recent work has been done by Hecht and Verrijp (20, 21) and their curves would appear not only to confirm but to emphasise this point. They measured the critical-frequency brightness relation at points 5° and 15° from the fovea for one subject and at 5° and 20° for another, as well as at the fovea itself. (Unfortunately, there is some ambiguity as to the value of their unit of retinal illumination.) We are, however, concerned chiefly with that part of the retina at or very near the fovea which, when the light is sufficient to enable it to function normally (*i.e.*, above the change-over brightness), provides the means of accurate fixation and possesses the greatest power to discriminate form and may be considered as being most used by the worker.

Hecht has developed a photochemical theory of vision which he has applied to the explanation and quantitative analysis of two experimentally determined relations: (a) visual acuity and brightness and (b) visual discrimination of intensity and brightness. The first relation has already been discussed above from the point of view of the direct experimental evidence. Hecht's theory applied to the evidence shows that if the point of change-over from rod to cone vision is considered to occur when the calculated visual acuity values for cones are equal to those for rods, then this point corresponds to a brightness slightly less than $0\cdot00269$ ml. ($=0\cdot000796$ c./sq. ft.) (16, Table 1, p. 265.) On the other hand, when Hecht applies his theory to the discrimination of intensity brightness relation he finds that the point of change-over occurs at a brightness somewhere between $0\cdot00732$ ml. ($=0\cdot020216$ c./sq. ft.) and $0\cdot0190$ ml. ($=0\cdot00562$ c./sq. ft.) (15, p. 259.) This is a value some three to seven times that just mentioned as obtained from the acuity-brightness relation. (The intensity discrimination-brightness relation plotted as a curve does not exhibit any direct evidence as to the point of change-over, there being no sudden change of direction of the curve anywhere.)

While it is possible that Hecht's analysis does show in a general way what is happening in the retina of the eye (for example, why

acuity varies with illumination in the way it does), his quantitative deductions must be treated with considerable reserve owing to the nature of the assumptions which he makes.

Tabulating the various values of objective-brightness mentioned above corresponding to the point of change-over we have

	Candles per sq. foot
1. <i>Brightness-Acuity curve</i> (König), centre of knee ...	0·002
Do. foot of upper straight portion ...	0·033
Do. change of slope (according to Hecht)	0·0021
Do. Hecht's photo - chemical analysis— below	0·000796
2. <i>Brightness-Flicker curve</i> (Porter), intersection of straight lines	0·0037
Do. (Lythgoe & Tansley), centre of bend	0·0025
Do. do. foot of upper straight portion ...	0·004
3. <i>Brightness - Intensity - Discrimination relation</i> , Hecht's photo-chemical analysis ...to	0·00216 0·00562

Neglecting those figures of Hecht based solely on theoretical analysis and dividing the remainder into two groups according as they represent (a) the actual point of change-over from rod to cone vision, *i.e.*, the point of intersection of the two lines forming the graph or the centre of the connecting bend or (b) the point where the change-over may be considered complete in those graphs where it is not sharply defined, *i.e.*, where the curve straightens out after the bend, we have an average value of 0·0026 c./sq. ft. for the former and 0·0035 for the latter. Now it is not known how much, if any, above the change-over point the brightness and, hence, the illumination must be maintained to prevent nystagmus and some factor of safety would appear desirable. The author suggests a value of 0·004 c./sq. ft. as a round minimum value to be modified if necessary in the light of future experience or experimental work. The somewhat indefinite nature of the figure must be emphasised. It is obvious from the weight of evidence produced that the change-over is not sudden or sharp-cut.

Now, since the change-over from rod to cone vision is a retinal process it is to be expected that it will correspond to a definite value of retinal illumination which is a function of both the objective brightness and the pupillary aperture. Since (with the exception of Ives who, as stated, used an artificial pupil) none of the investigators concerned recorded the pupil apertures of their subjects, we can but assume that they were average normal values. Hence, if all mine-workers had average size pupils a coal-face brightness of 0·004 c./sq. ft. ought to be sufficient to prevent

nystagmus. However, pupil apertures vary widely from one individual to another and allowance should be made for the smallest normal pupils met with in practice.

FIG. 4.—Objective brightness and pupil aperture (P. Reeves' data)

FIG. 5.—Objective brightness and pupil aperture (Holladay)

Measurements of pupil apertures at the low brightnesses concerned appear to have been made (with any accuracy) for only comparatively few subjects and even amongst these large variations occur. Reeves (22, Table II, p. 339), Holladay (23, p. 310) and Lythgoe (24, pp. 37-42; Table XIV, 24, p. 75) have published values for seven, three and five subjects respectively. The author has plotted the maximum, average and minimum values* against objective brightness in c./sq. ft. units for each of these groups. (See Figs. 4, 5 and 6 respectively.) (Nutting (25, p. 10), also, has published figures, but he gives only average values and does not state how many subjects were tested. Moreover, he used a method of measurement which is probably not very accurate.) It will be observed that the smallest values of pupil area at low values of brightness for any of the 15 subjects are given by Lythgoe's minimum curve. The author considers that in view of the small number of subjects for whom data are available up to the present the values given by the last mentioned curves should not be considered as abnormal, but as the smallest normal likely to be met with.

It is perhaps worth noting at this point how large a number of factors affect the pupil size of a given individual at any given field brightness. Published accounts of measurements do not always give full particulars of all the experimental conditions and lack of uniformity may account for some of the difference between the results of one observer and another. Moreover, it is always well to keep in mind the conditions under which laboratory work has been done when applying the results to practical problems. For instance, neither Reeves nor Nutting states how great an angle the illuminated surface used in their tests subtended at the eye, and recent work (26, 27) has shown that for at least certain ranges of illumination the pupillary area depends on the apparent size of the surface viewed as well as on the brightness of it. On the other hand, in the work of Lythgoe and of Holladay it is clear that the surface viewed (the inside of an illuminated chamber) completely filled the field of vision. Again, the closing or shading of one eye appreciably affects the pupillary size of the other (22); while the size is also affected by the accommodation or convergence of the eyes (23). Glare in the field of vision causes a reduction of pupil diameter (23; 28. Appendix pp. 59-63), especially for low values of field brightness. Finally, the size of pupil is affected by age and disease and artificially by the use of drugs.

It is also worth bearing in mind that the figures of pupillary size quoted in this paper are based on the diameter of the pupil

* The maximum (or minimum) curve for each group of subjects does not necessarily refer throughout to a particular individual in the group since the individual who has the greatest (or least) pupillary area of the group for one brightness may not have it at another.

ascertained by methods which really measure the image of the pupil formed by the refracting media of the eye, whereas the actual diameter is slightly different from this by an amount which varies with the accommodation. The correction is small and no allowance has been made for it.

FIG. 6.—Objective brightness and pupil aperture (R. J. Lythgoe's data)

FIG. 7.—Objective brightness and pupil aperture
(Average for 15 subjects)

It remains then to determine the value of the objective brightness to give with so small a pupil, as that recorded by Lythgoe, a retinal illumination equal to that produced by a field of 0.004 c./sq. ft. brightness on an "average" eye. It is first necessary to ascertain what this retinal illumination is. For this purpose the author has drawn in Fig. 7 a curve connecting pupil aperture with objective brightness for an "average" pupil based on the average

FIG. 8.—Objective brightness and effective retinal illumination (Average pupil)

of the three averages of Reeves, Holladay and Lythgoe, duly weighted for the number of subjects tested by each. The effective retinal illumination for such an average pupil corresponding to various values of field brightness has then been plotted (Fig. 8) using the graph in Fig. 7 as a basis. The effective retinal illumination measured in "photons"* is taken to be the product of the field brightness in candles per sq. metre, the corresponding pupillary area in sq. millimetres and the pupil efficiency at that area. (The latter factor has been dealt with by Stiles and Crawford

* This unit was introduced originally by Troland (b) in 1916 and defined by him

(b) Bibliography 30, p. 113 (footnote).

Do. 31, p. 950 (footnote).

briefly as "the illumination of the retina corresponding with a stimulus—surface brightness of one candle per square metre, and an effective pupillary area of one square millimetre." It is as well to point out that at least three writers have since misleadingly described the photon as the retinal illumination corresponding to a brightness of one millilambert and a pupil area of one square millimetre.

(29) in a recent paper where it is shown that the luminous efficiency of rays entering the pupil at different points is not constant, but is greater for rays near the centre than for those near the side. In effect, for instance, a pupil of 50 sq. mm. area is only about half as effective per sq. mm. of area as one of 1 sq. mm. From the published curves the author infers that the relation between

FIG. 9.—Area of pupil and luminous efficiency (Stiles and Crawford's data)

FIG. 10.—Objective brightness and effective retinal illumination (Lythgoe's minimum values of pupil aperture)

the pupil efficiency, E , and pupil area, a (in sq. mm.), is given by the expression

$$\log_{10} E = -0.006a.$$

Fig. 9 has been plotted connecting values of E and a , and from this values of E were read off as required for the present purpose.).

From Fig. 8 it is seen that the effective retinal illumination for an average pupil corresponding to a field brightness of 0.004 c./sq. ft. ($\bar{3.6}$ log. c./sq. ft.) is 0.89 photon ($\bar{1.95}$ log. photon). Then, referring to Fig. 10, where is shown a similar curve to Fig. 8, but based on those smallest values of pupil aperture recorded (by Lythgoe) it will be observed that the field brightness necessary to produce a retinal illumination of 0.89 photon is 0.010 c./sq. ft. ($\bar{2.0}$ log. c./sq. ft.).

Hence, if the various assumptions made are accepted, it is clear that to prevent nystagmus the lighting at the coal-face must be arranged to provide a brightness of at least 0.01 c./sq. ft. on the coal surface.

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PART II

Taking an objective brightness of 0.01 c./sq. ft. as the minimum value required to prevent nystagmus, let us see what illumination is necessary to produce this brightness on a coal face.

The reflection factor of coal is very low and it appears difficult to get reliable figures. In the first Report of the Miners' Nystagmus Committee (1, p. 41) it is stated that the amount of light reflected from coal surfaces varies considerably and is from 5 to 16 per cent. of the incident light. Llewellyn (2, p. 72) gives values ranging from 3 to 12 per cent., while Whitaker (3, Table IV, p. 7) gives a value for coal dust of 4 to 5 per cent. In the case of two

pits, Roche (4) states that the light reflected from the "slip" was 15 and 7.5 per cent. respectively. Assuming a figure of 8 per cent. as a working basis which is probably not far from an average value, the necessary illumination required is found* to be 0.4 ft. candle.

This is a considerably higher value than has been advocated up to the present for the purpose of ensuring foveal vision and so preventing nystagmus. Thus, Dr. Roche (4) in 1931 and the Miners' Nystagmus Committee of the Medical Research Council in their Third Report (1932) both give the required illumination as being 0.136 ft. candles, or 0.272 ft. candles for coal surfaces reflecting 10 or 5 per cent. respectively of the incident light.

Turning to the practical question of the provision of a minimum coal-face illumination of 0.4 ft. candles, it is obvious that the luminous output required from any lamp will be largely determined by the area over which the stated illumination must be provided. With a light normally fixed in one position for appreciable periods, such as a miner's hand-lamp or an electric mains lamp, the area to be lit is considerable. It depends on the nature of the work and should include all surfaces or points at which the worker may, or may have to, look with direct vision for the purpose of his work with the exception of long distance glances, *e.g.*, down a roadway. The illumination required can be provided over any area by means of electric lamps run off the mains where such are practicable, or even by stationary battery-fed lamps. It may also be provided by means of electric-pneumatic lamps of approved type driven by compressed air if a supply is available. It is, however, impracticable to provide the illumination by means of any kind of safety hand-lamp. The average distance at which a hand-lamp is placed in practice by a miner from his work is about 4ft. 6ins. (5, p. 156) and at this distance it would require a lamp giving over 8 cp. to illuminate the coal-face to 0.4 ft. candle even at the mere point of the face directly opposite the lamp. To illuminate a circular area of 6ft. diameter (or a rectangular area 6ft. diagonal) on the face so that no part of the area had a less illumination than the figure given would necessitate a lamp giving over 14 cp. The most modern, largest and heaviest electric safety hand-lamps are not even claimed to give more than about 4 cp. in any direction; while the same applies to the latest types of flame safety lamp.

In the case of cap lamps the matter is rather different. The cap lamp moves with the head and need illuminate only that part of the working area which the miner is for the moment facing

* The illumination, E. ft.-candles, required to produce a brightness of B. candles/sq. ft. on a surface of a reflection factor γ is given by the well-known relation

$$E = \pi B/\gamma$$

and within which his direct gaze must for the moment fall. (In addition, it ought to provide "side" illumination of less intensity for peripheral vision. This is referred to more fully below.) It is practicable, therefore, to concentrate the most of the light within a comparatively small angle by means of a polished concave reflector placed at the back of the bulb. It is, of course, possible to provide a reflector for a hand-lamp for use when the lamp is hung up at the working point and some lamps are actually so fitted, but it is obviously not practicable to concentrate the beam so much as in the case of a cap lamp. In such cases the reflector is used more as a shield to prevent glare rather than to concentrate the light. Again, the cap lamp is, at least when used by workers at the coal-face, considerably nearer the work than a hand-lamp would be, and the candle-power required for a given illumination correspondingly less. Unfortunately, it must be admitted that the wearing of a cap lamp and the necessary separate battery becomes a real burden under some mining conditions.

The cap lamp is, then, required to provide the necessary illumination (0.4 ft. c.) at the normal working distance on surfaces and objects only within the maximum solid angle relative to the head over which a man during work normally uses central or foveal vision. Now it is relatively easy to measure the maximum angle for a given head position over which a man *can* direct his eyes. MacMillan gives the figure as approximately 90° (6, p. 257). It is not so easy to say what is the covering angle within which the eyes *are normally* directed during work. The attempt to look directly (even momentarily) at objects at a great angle from the direction in which the head is facing causes strain and, where possible, a person naturally moves the head to avoid such strain. The deviation of direct gaze is thus naturally limited, but the question is, by how much? Some experimental work would appear to require to be done on this point with reference to practical mining conditions where unusual postures and cramped positions will probably affect the matter considerably. Assuming in the absence of definite information that the angle is 30° in all directions from the "straight-ahead" line of vision, that is, a solid angle of 60° , and assuming that the miner is working with his head 2ft. 6ins. from, and directly facing, the coal-face it follows that the lamp is required to illuminate up to the desired intensity an area of the face about 3ft. in diameter.

That modern electric safety cap lamps are capable of such a performance is evident from measurements made in a recent photometric (5, Table I, p. 157) survey of coal-face illumination (to be referred to again later). Two 4-volt cap lamps of the latest type placed 2ft. 6ins. from the face were found to give (as the average of

the two) an illumination of 0.77 ft. c.* on the face at the edge of a 3ft. diameter circle at the centre of which the beam from the lamps was directed. The measurement was made after only two hours' burning and not at the end of a shift when the candle-power of the lamps would be less, due to the voltage drop in the battery, but there would appear to be ample margin to allow for this.

The author would here emphasise the desirability of considering the advocated figure of 0.4 ft.c. as a strictly minimum one to be secured under all conditions and throughout the entire shift. Coal dust on the lamp glasses and in the atmosphere, falling battery voltages, old bulbs, etc., all affect the illumination adversely, and if allowance be made for all the factors involved the figure will probably require to be several times higher under the best conditions.

It may be pointed out here (as already briefly mentioned) that it is not alone sufficient that a cap lamp should provide directly in front of it a circle of light of the brightness and size necessary for unrestricted foveal vision. If the illumination falls off very sharply to zero outside the circle all objects not inside the narrow cone of light at any moment are virtually in darkness and this is undesirable. If the general surroundings underground were of a bright character such objects might be sufficiently illuminated by indirect light reflected off the directly lit area, but in a coal mine where all surfaces are very dark in colour this is not to be expected. The wearer of a cap lamp designed to give a concentrated beam, but with little or no "side" light is thus prevented from using peripheral vision to the full angular extent and cannot see objects at all on one side or another outside the concentrated cone of light without turning his head so that the cap lamp throws light on them. A person normally depends (sub-consciously) on peripheral vision to keep him constantly aware in a general way of objects around him and, particularly, for "picking-up" or "catching sight of" moving objects—for which peripheral vision is specially sensitive. If, then, a miner is denied the use of peripheral vision, except over a limited angle, he becomes subject to danger from moving objects which he cannot see until possibly too late.

The peripheral field of view of a normal individual with the head fixed and the eyes looking straight ahead extends some 100° on either side of the head, or a total angular width of 200° . The total vertical field is about 120° (70° downward and 50° upward). By moving the eyes alone while keeping the head fixed the above angular limits may, of course, be increased.

* The actual published figure given is 0.90 ft. c. but this was measured with the photometer directly facing the lamp. The figure of 0.77 ft. c. given above is corrected for the angle of incidence and gives the illumination on the coal-face itself.

It would appear, then, that an ideal cap lamp should provide a central beam of, say, 60° total width and of an intensity sufficient to illuminate the coal surfaces (at normal distances) to 0.4 ft. candle and, in addition, an outer concentric beam extending to a total width of 200° horizontally and 120° vertically and of considerably less intensity. Even such a lamp would not allow for extreme peripheral vision with the eyes averted from the direct "straight-ahead" position, but such a loss would probably not in practice have any very serious effect on vision or safety. It is interesting to note that the American mining regulations (7) specify a minimum total angle of distribution of 130° for permissible cap lamps, while the author understands that it is proposed to specify a figure of 100° in the new British regulations.

It is of interest to compare with the proposed minimum illumination of 0.4 ft.c. the values actually obtaining in practice as measured photometrically at the coal-face under ordinary working conditions. In Great Britain several such illumination surveys have been carried out in the past and one of the most recent and possibly most comprehensive was the investigation made by Barber, Emmett and Jones (5), some of whose measurements have been quoted above. Their figures are averages for a large number of lamps, usually 100 or more of each type. They measured the illumination on the coal-face opposite the lamp as placed by the miner (on the average 4ft. 6ins. from the coal-face) and at distances up to 4 feet radially outwards along the face. At 4 feet from the centre-point opposite the lamp, the average illuminations range from 0.0005 ft.c.* for old-type oil lamps to 0.034 ft.c.* for modern-type electric hand lamps (excluding a few so-called 6 c.p. alkaline lamps). These figures may best be left to speak for themselves. The average illumination given by 140 2-volt cap lamps was 0.30 ft.c.* measured at a point 1ft. 6ins. outwards along the face from the centre point of the beam opposite the lamps which were placed 2ft. 6ins. from the face. This latter figure is, at least, of the same order as the minimum one herein advocated, and it no doubt explains the well-known fact that in cap lamp mines the rate of incidence of nystagmus is considerably lower than in those mines where safety hand lamps are used. Thus, in Scotland where cap lamps are used to a much greater extent than in England, the percentage number of nystagmus cases is markedly less than in England. Again, in the United States of America cap lamps are almost exclusively used in both gassy and non-gassy coal mines and in that country miners' nystagmus is relatively unknown. Some preliminary figures for a survey of illumination in American coal mines by the United States Bureau of Mines have been given

*After correction for the angle of incidence.

recently in a paper by C. W. Owings (8, Tables III and IV). These figures, which are averages for hundreds of lamps, indicate that with the modern permissible electric cap lamps in use there the illumination on the coal face reaches values of 6.55 ft.c. and 1.64 ft.c. at distances of 2ft. and 4ft. respectively from the lamp, measured in each case at 10° from the axis of the beam. An older type of permissible cap lamp gave 1.05 ft.c. and 0.26 ft.c. for the same respective distances from the face. These figures are not actual measurements of illumination on the coal face, but were obtained by means of a photometer box and illumination meter and are evidently calculated on the inverse-square law. The photometer was used underground.

It may be remarked that there are, of course, other considerations than that of nystagmus to be taken into account when deciding on the minimum intensity of mine lighting and it is not to be inferred that an illumination of 0.4 ft.c. in a coal mine is to be taken as good lighting in an industrial sense. Such is far from the case. To be comparable with modern practice in general industrial lighting the illumination would need to be increased very many times above this figure. An illumination of 0.4 ft.c. on a coal surface of 8 per cent. reflection factor is equivalent in brightness to no more than 0.08 ft.c. on a surface of 40 per cent. factor—a factor much more typical of ordinary normal surroundings. Indeed, if allowance is made in the case of the coal mine for the much smaller percentage of *indirect* light falling on the work, *i.e.*, by double and multiple reflection from the dark surroundings (where white-washing is not applied) the equivalent figure for bright or normal surroundings will be well under 0.08 ft.c. It is hardly necessary to observe that such an illumination would not be tolerated for a moment in even the poorest or most ill-equipped factory or works.

It is, admittedly, very difficult safely to provide adequate illumination in mines, especially gassy mines, and though the recent trend of progress is encouraging, very much remains to be done both from the point of view of improving the miserable conditions under which the miner works and also from that of increasing industrial efficiency—two aims which are by no means unrelated to each other.

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INJURIES OF THE EYE CAUSED BY SPORTS*

BY

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BUDAPEST

WE find numerous relations between the organ of sight and sport. In the first place we may investigate what claims must be laid on the functions of the eye in order to be successful in the various branches of sport. Thus, besides good central vision, great significance must be attached to a free field of vision, good stereoscopic sight and a good light sense. Doyne, whose observations are published in detail in the "American Encyclopedia of Ophthalmology," dealt with this question most exhaustively. More recently Sir David Munro gave a valuable review of the significance of the visual factor in sport, with especial regard to flying. Wirgman rendered account of the significance of errors of refraction in rifle practice; and it is conspicuous that two of the five prize-winners had an amblyopic eye. Good centering of glasses is very important. I will mention here that special spectacles are made for the use of marksmen. Another interesting question relates to what branches of sport the various eye patients may follow. In general, we may say that eye patients suffering from inflammatory conditions such as acute catarrh, iritis, etc., individuals inclined to haemorrhage, *e.g.*, Eales's disease, should avoid all branches of physical culture. The highly myopic should also be excluded from sport, because of their tendency to detachment of the retina. We know these facts since Lindner and Röth made experiments on the phantom. Individuals so inclined may sustain detachment not only through a minor, direct injury to the eye, but also indirectly, from a swift change of position, shock or physical strain.

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