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EFFECT OF AGE UPON DARK ADAPTATION

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It is a matter of common observation that older people are less well able to 'see in the dark' than younger people. Nevertheless, some workers who have drawn up standards of normality of dark adaptation, in order, for example, to detect deficiency of vitamin A, have failed to allow for this [e.g. Jeans, Blanchard & Satterthwaite, 1941]. Moreover, other workers have definitely stated that dark adaptation is unaffected by age [Korb, 1939]. Stewart [1941], however, found an appreciable deterioration with age. These discrepancies in the literature may in part be due to differences in the technique of measuring dark adaptation. Jeans and his colleagues and also Korb measured the early part of the process, that is, the adaptation mainly of the cones, whilst the technique adopted by Stewart measured almost entirely the adaptation of the rods. It might then appear that cone adaptation deteriorates with age but that rod adaptation is unaffected. Yet Hecht & Mandelbaum [1939] have found very little change in rod threshold with increasing age but an appreciable rise in cone threshold [Mandelbaum, 1941].

It is clear then that the question of variation of dark adaptation with age is by no means settled. Moreover, if dark adaptation does in fact deteriorate with age, two further questions arise: first, is the extent of the deterioration sufficient to make it necessary to allow for this in setting up standards of normality; and second, what is the cause of the deterioration?

During the past two years, we have measured the dark adaptation (final rod threshold) in over two thousand individuals between the ages of 10 and 70 and we believe that our results go some way towards answering these questions. We have found a progressive lowering of the power of dark adaptation with advancing years, we have determined its extent and we have been able to find a likely explanation of the phenomenon.

EXPERIMENTAL

Material

Since the various groups we have studied show slight but definite difference in the average value of dark adaptation [Robertson & Yudkin, 1944] we shall, in this paper, confine our attention to the results obtained with a single group of

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subjects. This group, the largest of those examined by us, is one of 758 Birmingham factory workers (516 men and 242 women). The youngest were 14 years old, the oldest was a man of 71.

Technique

Dark adaptation was measured by the Crookes' adaptometer, modified as described in previous communications [Yudkin, 1941; and Yudkin, Robertson & Yudkin, 1943]. Although complete curves of dark adaptation have been taken for several hundred of the subjects whom we have examined, our routine procedure in survey work, including the study of the Birmingham factory workers, is to measure only the final rod threshold in the following manner. Groups of three or four subjects enter a dark room directly from their work, without any previous light adaptation. After they have been in the dark for 35 or 40 min., the dark adaptation of each subject is measured by noting the minimal intensity of light which he can just see. This is done by increasing the light until the test object is quite readily discernible and then decreasing the light until it just disappears; the illumination at which this occurs is the value recorded. The light is increased and decreased in this way several times until consistent readings are obtained. Usually four or five readings are sufficient and this occupies about 2 min. The three or four subjects in each group are tested in turn and then tested a second time in the same order. It is the second value which is taken as the measure of the subject's capacity for dark adaptation. It is found that the second value is almost always lower than the first and this improved performance is undoubtedly due to a learning factor; testing a third or fourth time rarely results in any further appreciable improvement. The improvement between the first and second tests is not due to a continuation of the process of dark adaptation, for it is known that dark adaptation, beginning with the moderate light adaptation with which our subjects usually start the test, is almost complete within 30 min. Moreover, the same improvement at the second test occurs even if the first test is performed after, say, 1 hr. in the dark and followed by a second test after a further 5 min.

Results

The results are summarized in Table 1. There was no significant difference between the men and the women; we may therefore consider the results for both sexes together (Fig. 1).

Range of final rod threshold

The total range of the final rod threshold is 1·65 log $\mu\mu$ lamberts (from 2·70 to 4·35 log $\mu\mu$l.). Most workers have recorded a total range of just over one log unit, i.e. a range of some ten times. However they usually have not studied subjects of the higher age groups here reported. Moreover, the number of our subjects with the lowest thresholds is small; if one excludes the two worst

TABLE 1. Variation of dark adaptation (final rod threshold) with age

Age group	Men: No. examined	Men: Threshold, log μμl. Mean	Men: Highest	Men: Lowest	Women: No. examined	Women: Threshold, log μμl. Mean	Women: Highest	Women: Lowest
14–19	91	3·15	2·70	3·55	101	3·15	2·70	3·55
20–24	76	3·23	2·70	3·70	71	3·21	2·70	3·80
25–29	52	3·22	2·70	3·70	32	3·22	2·85	3·70
30–34	61	3·27	2·80	3·80	15	3·29	2·90	3·55
35–39	57	3·36	2·80	4·15	11	3·35	3·05	3·70
40–44	42	3·44	2·90	3·95	5	3·28	3·15	3·40
45–49	47	3·46	3·05	3·90	4	3·56	3·35	3·75
50–54	39	3·50	2·90	4·35	3	3·43	3·05	3·80
55–59	30	3·67	3·05	4·15	—	—	—	—
60–64	14	3·75	3·40	4·15	—	—	—	—
65–69	6	3·66	3·55	3·80	—	—	—	—
70–74	1	3·55	—	—	—	—	—	—

Age group	Men and Women: No. examined	Threshold, log μμl. Mean	Highest	Lowest
14–19	192	3·15	2·70	3·55
20–24	147	3·21	2·70	3·80
25–29	84	3·22	2·70	3·70
30–34	76	3·29	2·80	3·80
35–39	68	3·35	2·80	4·15
40–44	47	3·42	2·90	3·95
45–49	51	3·47	3·05	3·90
50–54	42	3·50	2·90	4·35
55–59	30	3·67	3·05	4·15
60–64	14	3·75	3·40	4·15
65–69	6	3·66	3·55	3·80
70–74	1	3·55	—	—

subjects below the age of 49 or the ten worst subjects of all ages the range is 1·2 log units.

There is an indication in the figures cited in Table 1 that the range of variation in final rod threshold increases with age. For example, between the ages of 20 and 30 it is 1·10 log units and between 50 and 60 it is 1·45 log units [see also Stewart, 1941]. This increase is not very large but it is possible that, had the number of subjects in the higher age groups been as great as in the lower age groups, still higher or lower extreme values might have been found in the former. The average values for each range of age are seen in Fig. 1. The average increase in threshold is about 0·12 log units for an increase of 10 years in age; between the ages of 20 and 30, the increase is 0·10 units and between the ages of 50 and 60, 0·15 log units. The greater deviation of the points from the line at the higher age can be attributed to the small number of subjects who were examined at this age. The correlation coefficient, r, between age and final rod threshold is 0·56, which is highly significant. This degree of correlation might be compared, for example, with the correlation coefficient of 0·46 for the physical resemblance between children and their parents.

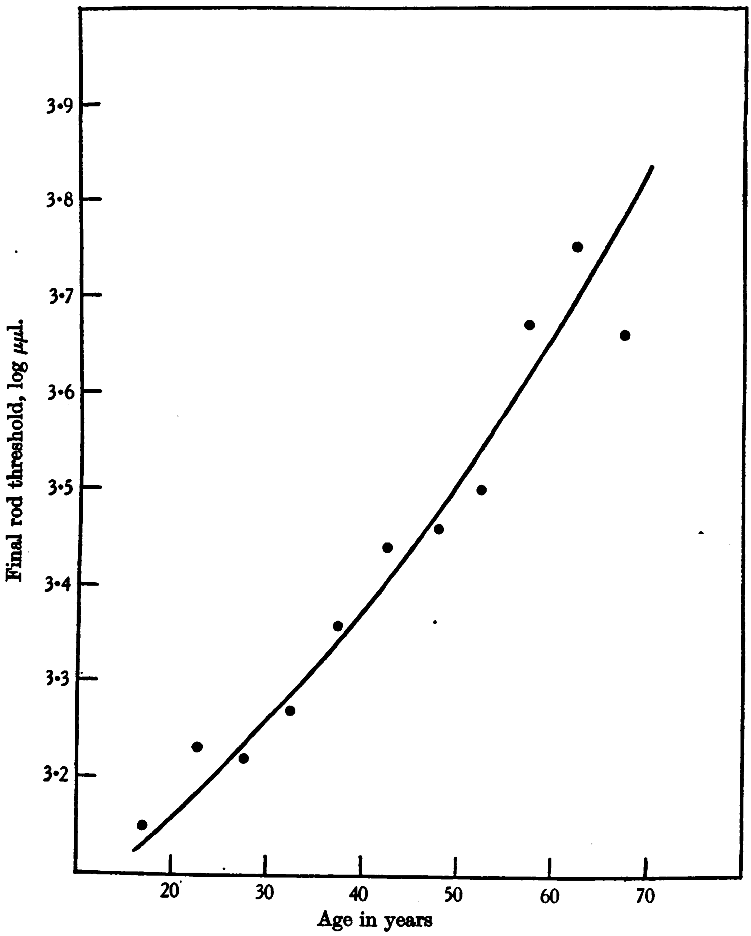

Fig. 1. Variation of dark adaptation with age.

Discussion

Cause of deterioration of dark adaptation with age

Booher & Williams [1938] suggested that the poorer performance of older subjects with the bio-photometer might be due to their diminished visual acuity. With their apparatus visual acuity affects performance, since the test involves perception of small spots of light. With the apparatus which we have used visual acuity plays a very small part; the test object in our apparatus is large, subtending an angle of 6° at the eye, and moreover the subject is encouraged to look for the presence or absence of light rather than the outline of the test object. Decreased visual acuity is therefore unlikely to be the cause of the deterioration of performance with age which occurs with our apparatus.

Other workers have suggested other reasons for the poorer dark adaptation of older people and these have been summarized by Ferree, Rand & Lewis [1935]. Although they were studying a somewhat different problem, namely the effect of low illumination on visual acuity, the factors which they discuss include those which might apply to the deterioration of dark adaptation. They state: 'Among the reasons why an old eye needs more light, and for that reason derives more benefit from an increase in the amount of light, the following five may be mentioned: its smaller pupil, the inferior imaging power of its refracting media, the diminished transparency of the media, the decay in all its processes of adaptation and adjustment and the failing powers of the retina itself.'

Age, pupil size and dark adaptation

Of the five factors mentioned by Ferree and his collaborators the first can perhaps most readily be measured and its possible effect on dark adaptation quantitatively studied. Let us for a moment assume that the other factors such as sensitivity of the retina and transparency of the ocular media do not change with advancing years. Then, as the pupil diminishes in size with age, and thus the amount of light entering the eye decreases, it would be necessary to increase the amount of external illumination proportionately in order to produce the same effect on the retina. If the pupil at 40 years has, let us say, an area half that of the pupil at 20 years, the amount of external light necessary to produce minimal stimulation after complete dark-adaptation will be twice as much at 40 years as at 20 years. If then we know the average size of the dark-adapted pupil at different ages we can calculate the relative amount of external light which will be just perceptible by a dark-adapted eye of different ages; given this threshold for any one age, we can thus calculate the threshold for different ages. (The possible bearing of the Stiles-Crawford phenomenon on these considerations will be discussed below.)

Although we have not been able to measure the actual size of the pupils of our subjects, data on the average size of the dark-adapted pupils at various ages have been published [Nitsche & Günther, 1930]. These values are shown

TABLE 2. Variation of amount of light reaching retina due to change in pupil size with age

Age	Radius of pupil mm. [from Nitsche & Günther, 1930]	Area of pupil mm.^{2}	Proportion of incident light reaching retina*
20	4·0	50·2	178
30	3·5	38·3	136
40	3·0	28·2	100
50	2·5	19·6	69·5
60	2·05	13·2	46·8
70	1·6	8·05	28·1

* Proportion of incident light reaching retina at age of 40 has been given the arbitrary value of 100.

in Table 2, wherein are also shown the relative amounts of incident light that would reach the retina at different ages from a constant source. If at 40 years

TABLE 3

Age	'Expected' threshold $\mu\mu l.$	'Expected' threshold log $\mu\mu l.$	'Observed' threshold log $\mu\mu l.$ (from Fig. 1)
20	1350	3·13	3·16
30	1840	3·26	3·26
40	2400	3·38	3·38
50	3460	3·54	3·50
60	5130	3·71	3·65
70	8750	3·94	3·81

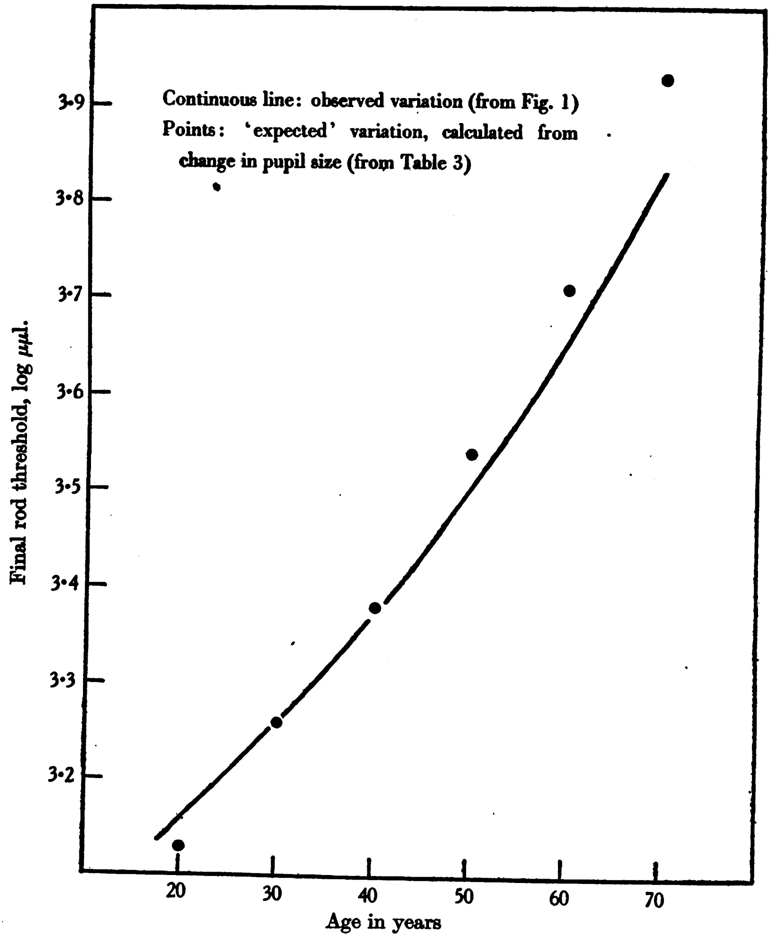

Fig. 2. 'Expected' variation of dark adaptation with age due to diminution of pupil size with age.

this amount is given the arbitrary value of 100, at 20 years it would be 178 and at 60 years 46·8 (Table 2, column 4). From Fig. 1 the value of the threshold at

40 years is 2400 $\mu\mu$l. or 3·38 log $\mu\mu$l. From this value and the relative values given in Table 2 we may now calculate the expected thresholds at other ages (Table 3). When these values are compared with the actual values obtained by us, the agreement is found to be very close (Fig. 2).

It seems legitimate therefore to conclude that the deterioration of dark adaptation with age can be explained entirely by the decrease in the size of the pupil with age. It is not necessary to assume either a decreased sensitivity of the retina or a diminished transparency of the ocular media or any other supposed or possible change in order to explain the phenomenon. It should however be emphasized that our discussion has been concerned with the average dark adaptation in groups of individuals. The effect of pupil size on determining the dark adaptation in a single individual can only be assessed by direct measurement of the pupil. Such measurements would also make it possible to discover the extent to which the range of variation in dark adaptation in a given age group is due to variations in pupil size.

The Stiles-Crawford effect

Stiles & Crawford [1933] showed that the luminous efficiency of the periphery of the pupil is less than that of the central portion so that the visual effect of light with increased size of pupil does not increase as rapidly as the area of the pupil. If this were true in all conditions, we should expect that the smaller pupil of older subjects would be proportionately more efficient than the larger pupil of younger subjects; the threshold would then not increase as rapidly with age as we have calculated from the decrease in area. A more detailed consideration of the reported work on the Stiles-Crawford effect, however, shows that it is legitimate to assume a strict proportionality between pupil area and apparent brightness in the conditions which obtained in our experiments. The original observations of Stiles and Crawford and the confirmatory work of Dziobek [1934] and Wright & Nelson [1936] were all carried out with a fairly high field brightness; later work suggests that, for conditions approaching complete dark adaptation, the effect disappears. Crawford [1937] showed that the light passing through the periphery has less apparent brightness only if the field brightness is high or if it is the fovea which is being stimulated. In conditions of low brightness and parafoveal stimulation the luminous efficiency of the light is independent of the part of the pupil at which it enters. Sloan [1940] has followed this by an assessment of the effect of pupil size on the threshold of the dark-adapted eye. She finds that the product, threshold $\times$ size of pupil, is sensibly constant so that the visible effect of threshold brightness is directly proportional to the area of the pupil. Our calculations of the effect of the diminishing size of pupil with age on the threshold of the dark-adapted eye are therefore justified.

Standards of normality

Since the normal range of dark adaptation is fairly wide, the comparison of individual values with any fixed 'standards of normality' is not very satisfactory. Such standards might be of some use, however, in assessing the general status of dark adaptation in a large group, the distribution of the values being compared with the distribution obtained from a supposedly normal group. But even so our results indicate that, in such comparisons, it is necessary to take into account the effect of age. We have adopted this method in comparing various groups of subjects and these results will be reported in a later communication.

Summary

1. By measuring the final rod threshold of 758 factory workers between the ages of 14 and 71, it has been shown that there is a progressive deterioration of average dark adaptation with increasing age.
2. For an increase of 10 years in age, this deterioration ranges from about 0·10 log unit between the ages of 20 and 30 years to about 0·15 log unit between the ages of 50 and 60.
3. It is possible to explain this phenomenon quantitatively by the progressive decrease in the size of the pupil with advancing years.
4. The bearing of these findings on the question of setting up standards of normality of dark adaptation is discussed.

References

Booher, L. E. & Williams, D. E. [1938]. *J. Nutrit.* **16**, 343.

Crawford, B. H. [1937]. *Proc. Roy. Soc.* B, **124**, 81.

Dziobek, W. [1934]. *Licht*, **4**, 150.

Ferree, C. E., Rand, G. & Lewis, E. F. [1935]. *Arch. Ophthal., N.Y.*, **13**, 212.

Hecht, S. & Mandelbaum, J. [1939]. *J. Amer. med. Ass.* **112**, 1910.

Jeans, P. C., Blanchard, E. L. & Satterthwaite, F. E. [1941]. *J. Pediat.* **18**, 170.

Korb, J. H. [1939]. *Nav. Med. Bull., Wash.*, **37**, 392.

Mandelbaum, J. [1941]. *Arch. Ophthal., N.Y.*, **26**, 203.

Nitsche & Günther [1930]. Quoted by Luckiesh, M. & Moss, F. M., *The Science of Seeing* (p. 92 [1937]). London: Macmillan and Co.

Robertson, G. W. & Yudkin, J. [1944]. *J. Hyg., Camb.* (in the Press).

Sloan, L. L. [1940]. *Arch. Ophthal., N.Y.*, **24**, 258.

Stewart, C. P. [1941]. *Edinb. med. J.* **48**, 217.

Stiles, W. S. & Crawford, B. H. [1933]. *Proc. Roy. Soc.* B, **112**, 428.

Wright, W. D. & Nelson, J. H. [1936]. *Proc. Phys. Soc.* **48**, 401.

Yudkin, S. [1941]. *Brit. J. Ophthal.* **24**, 231; *Lancet*, **2**, 787.

Yudkin, J., Robertson, G. W. & Yudkin, S. [1943]. *Lancet*, **2**, 10.