**A STUDY OF DIET IN RELATION TO HEALTH.
DARK ADAPTATION AS AN INDEX OF
ADEQUATE VITAMIN A INTAKE***

**II.—A New Photometer for Measuring Rate of
Dark Adaptation**

BY

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In the first paper of this series (Mutch and Griffith, 1937) the results were reported of a preliminary study in which a modification of Edmund and Clemmesen's method (1936) was used to assess degrees of dark adaptation by measuring the power of distinction with a series of test letters ranging from black to near white over a wide light range. The test was incorporated in the scheme of an extensive clinical and dietary survey, in order that its usefulness for diagnosing vitamin A deficiency might be judged. However, it soon became apparent to the field worker in charge of this test that the results were difficult to interpret in many cases owing to the presence of two variables (*i.e.*, the light control by means of Tscherning glasses, and the range of test letters). The power of distinction might be excellent at the low illuminations and poor at high illuminations or vice versa. For this reason a new adaptometer was designed, using a black test letter only and with another type of light control which could measure finer gradations than the Tscherning glasses. The new apparatus had the further advantage that the principles involved were the same as in the other apparatuses designed for the same purpose, *i.e.*, measuring a light threshold only, and not involving any estimation of power of distinction between greys.

The Apparatus

General Construction.—The instrument† is built within a long narrow wooden box, 100 cm. long, 20 cm. broad, and 20 cm. high, supported on a tilting framework so that it can be set at any angle convenient to the observer, who looks into it as D (Fig. 1). It

* This work was done in connection with the Carnegie United Kingdom Trust dietary survey.

† In the description of survey results to follow in the next paper of this series, the apparatus will be referred to as the Rowett adaptometer.

FIG. 1.

is divided by partitions into four compartments, as indicated in the figure, the first of which contains the light source *S*, and has its walls painted matt white; the other compartments have dark stained walls. A hole 8 cm. square, cut in partition *A*, is covered with a rather dense opal glass (Chance's Pot opal), and a similar hole in partition *C* is covered with a thinner plate of opal glass (Chance's single flashed opal). The compartment to the left of *C* is a viewing chamber, the subject looking into it with both eyes towards the illuminated surface of *C*, resting his head against a metal visor fitted into the end of the box at *D*. The illumination of the opal surface *C* can be varied in steps by turning a wheel diaphragm inserted in front of a circular aperture in screen *B*; the diaphragm has nine circular holes of graded diameter, any one of which can be brought on to the axis of the instrument and held there by a spring and ball catch, the hole being indicated to the operator by a number engraved on the exposed edge of the disc. Aperture 9, the largest, is also indicated by a notch which can be

felt in the dark, and the progressively smaller apertures follow in descending numerical order as the disc is rotated.

The holes were designed to range in diameter from 1.20 cm. to 0.075 cm., giving a range of illumination of surface C in proportion to their areas, that is, of 256:1, the illumination being halved by each change from one hole to the next smaller. It was not considered worth while to have special tools made for drilling the apertures and their diameters were not exactly those specified to the mechanic. The actual diameters and corresponding illuminations of the screen C are given in Table I.

TABLE I

APERTURE	DIAMETER cm.	ILLUMINATION	
		Micro-lux	Milli-ft.-cndls.
9	1.13	2790	0.260
8	0.795	1390	0.129
7	0.570	710	0.066
6	0.420	388	0.036
5	0.320	225	0.021
4	0.205	92	0.0086
3	0.132	44	0.0041
2	0.096	23	0.0021
1	0.059	8.7	0.00081

Test Object.—The test object used during the course of this work was a letter E of dimensions as in Fig. 2, cut from black paper and mounted between two lantern slide cover plates. It can be dropped into a slot so as to lie about half an inch in front of the opal glass C on the observer's side and it can be withdrawn by the operator by means of a wire bridle, turned and reinserted easily and quickly, even in complete darkness. The subject sees the test object against the feebly lighted surface C, the brightness of which is controlled by the diaphragm setting. He knows he must look for the form E, but does not know in which direction the E has been turned when inserted by the operator.

The E test object was adopted as it had been found satisfactory in the method of Mutch and Griffith. After the survey work (to be described in the next paper) was completed, we compared the curves obtained with the E test object with those obtained using one which was thought might have certain advantages over the E. This consisted of a rectangle 5 cm. x 3 cm. cut out of black paper and mounted between two lantern slide covers as shown in

FIG. 2.

Area of Square - - - = 53.29 sq. cm.
 Area of E - - - = 15.07 sq. cm.
 Light passing area - - - = 38.22 sq. cm.

FIG. 3.

Fig. 3. The light-passing area of the slide is the same as that with the E. In practice, the subject is told to look for a square U of light. Comparative tests with these two test objects will be described later in this paper.

Light Source.—The source of light is a 6 volt 3 watt motor side-lamp bulb, operated at 5.00 volts from a 6 volt car battery. A good quality moving-coil voltmeter is permanently connected across the bulb and the voltage set to 5.00 volts by the use of a variable resistance. Occasional inspection of the meter during the course of a run is adequate to check electrical constancy so as to hold the illumination constant to ± 3 per cent. Control measurements made of the decrease in lumens output from several such lamps under operating conditions showed a drop of about 20 per cent. during the first 100 hours of use, after which the output decreased much more slowly, falling about 6 per cent. in the next 200 hours of use. The lamps used for routine work were therefore "aged" for 100 hours before being inserted in the instrument and were discarded after a further 200 hours of use. In order to secure initial uniformity, several dozen lamps were obtained from the manufacturers, and by photometric tests those individual lamps were selected which had a lumen output within ± 5 per cent. of the average. This control is essential, since the manufacturers' tolerance for lumens output for this class of lamp is stated as ± 15 per cent. and is therefore too wide for the purpose of the test. No significant differences were found in the response of the selected lamps to the ageing process, nor was trouble experienced from uncertain contact in lamp holders. The method described above for the control of the light source was adopted in preference to any method involving the use of a photo-cell because the control meter, a robust voltmeter, could be trusted to withstand a degree of rough handling which an adequately sensitive photo-electric measuring system would not endure.

Photometry of the Test Surface.—In order to ensure similarity between the instruments used in the routine tests and to make the results comparable with those of other observers, it was necessary to know the absolute brightness of the test surface. A rough estimate based on the measured intensity of the illumination of surface A (114 lux), on the geometry of the apparatus, and on the transmission factors of the opal glasses, indicated that the illumination of the test surface when aperture 3 of the diaphragm is in use must be in the order of 10^{-3} lux. A photographic method of photometry was chosen for the final evaluation. The standard source was an electric bulb calibrated against a Vernon Harcourt pentane lamp in the Physics laboratory of the University of Aberdeen, set up with suitable diaphragms at 410 cm. from a reference surface on which an Ilford Hypersensitive Panchromatic

plate could be exposed by withdrawal of the shutter of a special cassette. The cassette permitted light to reach a strip only of the plate and in front of this strip was an optical wedge of density rising in steps of 0.15 to 8.83. After exposure in this way a second strip of the plate was exposed in the same cassette for the same time in the plane C of the adaptometer, but without the optical wedge. On development, the plate therefore showed two blackened strips side by side, one evenly blackened by exposure in plane C, the other with blackening increasing in steps from exposure to the standard source, behind the optical wedge. By comparison of the blackening of the two strips in a photo-electric densitometer, the density of the wedge step requisite to reduce the calibration density to equality with that at plane C could be found, and hence the absolute value of the intensity at C was determinable. The values obtained are given in Table I. The illumination is not quite uniform over the whole of the test object: at aperture 3, for instance, it ranges from 44 microlux at the centre to 32 microlux at the corner where it is least.

When full allowance is made for variation of lamps and for electrical fluctuation, it is certain that the illumination at the centre of the test surface does not vary by more than ± 10 per cent. from the average, either during a run or on separate runs. Since the "Weber-Fechner fraction" at intensities of the order of 10^{-3} lux is not less than 50 per cent. (Hecht, 1924), this degree of variation in our apparatus cannot be significant; therefore elaboration designed to secure closer control of illumination is not justified. In support of this contention it may be stated that no advantage is obtained by decreasing the "step" of the diaphragm. Trials made in which the illumination was decreased in steps of 50 per cent. showed that such a step scarcely exceeded the observer's limit of discrimination of brightness. This would be expected from Hecht's results.

Technique

The instrument was originally used to determine the smallest aperture at which the E could be distinguished after fifteen minutes' preliminary dark adaptation, five minutes thereafter being allowed for the test. However, it became apparent that if the subject was left in the dark for longer than 15 minutes, he could, in many cases, obtain a lower reading. Hence preliminary experiments were started with time curves, and these not only confirmed the suggestion but indicated that the threshold at twenty minutes was greatly affected by the lighting to which the subject had been exposed before he entered the dark room. This is

explained by Graph I, showing curves* on the same subject after exposure to strong sunlight, and after being in a badly illuminated room.

Further work was therefore directed towards obtaining a method whereby this effect of antecedent light could be eliminated, as in this stage it was obvious that one subject could give a slow or rapid curve, depending on his previous environment.

The following technique was found to be satisfactory.

The subject is dark adapted until, at aperture 2, he can say which way the E is pointing. As will be shown later, this represents practically complete dark adaptation. The retina is then "bleached" on the apparatus now to be described, after which the test proper commences.

The bleaching apparatus is a modification of that used by Stargardt (1937), and consists of a metal bowl 2 feet in diameter and 18 inches deep, lined with plaster of Paris. The subject's head is supported on a chin rest on the lower edge of the bowl. Above his head is a 150 watt "pearl" electric globe, in the circuit of which a variable resistance is incorporated to control the effect of mains fluctuations. The subject is made ready in darkness with his chin on the rest, immediately following the preliminary dark adaptation and is warned that a bright light is going to be switched on. He is told to blink rapidly until the initial dazzle has passed off and then is required to keep his eyes open. Bleaching is timed by stop watch to take place for 4 minutes, after which the subject returns to the adaptometer for the test.

During the bleaching period, the operator should see that the subject does not close his eyes. With this type of bleaching apparatus, it is easy to keep the subject under observation.

The intensity of illumination of the surface of the bleaching bowl, measured with a visually corrected photo-electric cell, had a value of 93 foot candles at the point directly opposite the eye position, diminishing to 88 foot candles 60° from the centre. The intensity of the light and duration of exposure for bleaching were chosen by trial, firstly giving a rate of adaptation slow enough to be determined reasonably accurately, and secondly not so strong that undue discomfort is experienced by the subject.

A resistance for controlling mains fluctuations is essential. At the Rowett Institute the mains voltage is 230, and a recording voltmeter showed a daily maximum variation of ± 15 per cent. The lamp in the bleaching apparatus is controlled to run at about 200 volts. Constancy of illumination is ensured by frequent

* Since the illumination is increased by doubling at each step, the aperture numbers are the logarithms to the base 2 of the illumination, that at aperture 1 being unity. The curves are therefore logarithmic plots.

checks with an Ilford photo-electric meter, which was found adequately sensitive for the purpose.

In order to ascertain what effect uncontrolled mains fluctuations would have on the subsequent dark adaptation curve, six trained subjects were tested with the bleaching light at 180 volts and again at 220 volts. Table II shows the averages of the curves obtained. It will be seen that there is a significant difference between them.

TABLE II
Effect on Curve of Voltage Fluctuations
(Averages of 6 Curves)

Aperture	9	8	7	6	5	4	3	2
Bleaching lamp at 180 volts - -	M. S. 0 51	M. S. 1 29	M. S. 2 16	M. S. 3 22	M. S. 4 30	M. S. 6 15	M. S. 8 30	M. S. 12 30
Bleaching lamp at 220 volts - -	2 9	2 47	4 8	4 53	6 47	8 32	10 51	14 16

After the bleaching the test proper begins. The adaptometer light is switched on, the diaphragm is set at aperture 9, and the subject looks into the eyepiece. In order to encourage the use of peripheral vision, he is told to look to one side. As dark adaptation proceeds, the subject shortly sees the illuminated square, and says in which direction the arms of the E are pointing. The time from the commencement of dark adaptation is taken by stop watch and recorded by one observer. Another observer rotates the diaphragm to aperture 8, and changes the direction of the E. The same procedure is followed down the scale to aperture 2.

It is found that some subjects, especially children, guess the direction of the E before they see it, and so give wrong responses. This is understandable, as an illumination approaching the threshold of light perception has to be looked for in each case. Hence from apertures 7 to 3 inclusive, two consecutive correct responses and at aperture 2 three consecutive correct responses, or a series of two correct, one wrong and two more correct responses are required. The time of the first correct response of the series is taken as the "time taken to aperture 2."

Curves obtained using the full technique as described above will be referred to as "standard curves."

Critique of Method

(1) *Effect of previous Light on subsequent Dark Adaptation.*—It is necessary to amplify our comments on the effect of previous light on the preliminary dark adaptation in order to justify this somewhat tedious technique.

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It will be seen from Graph 1 that the curves recorded for one person after varying previous lighting conditions are not parallel; the time taken from aperture 9 to 2 is longer when the previous light is stronger. Thus a simple assessment of this time does not give constant results. Furthermore, a preliminary dark adaptation of ten minutes followed by bleaching is inadequate to eliminate the effect of previous light. This is shown in Graph 2 where the subject was previously in strong outdoor light. A curve after 10 minutes' dark adaptation followed by bleaching (No. 2) and a standard curve (No. 3) are shown. This point was checked in two other subjects and similar results were obtained. The subject

D. McE., aged 10 years.

Curves I, II - 9/6/38.

Curves III, IV - 10/6/38.

Aperture	Curve I		Curve II		Curve III		Curve IV	
	M.	S.	M.	S.	M.	S.	M.	S.
9	4	15	1	0	0	37	1	15
8	5	7	1	38	1	37	1	40
7	5	43	2	9	2	13	2	14
6	7	10	2	50	2	43	2	54
5	9	0	3	37	3	45	5	20
4	10	35	5	52	5	40	6	10
3	12	45	10	0	10	0	10	12
2	19	35	12	5	11	0	10	58

whose curve is illustrated has consistently given, over several tests, some of the most rapid curves we have timed, and so might be expected to recover from the effects of strong illumination more quickly than the average. It appears, therefore, that complete dark adaptation is required in order to eliminate the effect of antecedent light. In further support of this contention it may be pointed out that Matthey (1933) has demonstrated that full preliminary dark adaptation is required in order to ensure a standard curve independent of previous light.

A. J., aged 18 years.

6/1/39.

Twenty minutes in sun and snow, followed by 10 minutes dark adaptation :

9	8	7	6	5	4	3	2
M. S.	M. S.	M. S.	M. S.				
5 23	6 40	7 53	9 21	...	...	...	...

Thereafter, 4 minutes standard bleaching :

M. S.	M. S.	M. S.	M. S.	M. S.	M. S.	M. S.	M. S.
1 10	1 52	2 20	3 46	5 55	7 06	10 24	13 37

Four minutes standard bleaching on completion of above :

M. S.	M. S.	M. S.	M. S.	M. S.	M. S.	M. S.	M. S.
0 38	0 50	1 16	1 52	2 35	3 42	6 00	7 46

26/1/39.

I. M., aged 10 years.

That our technique does, in fact, eliminate this effect of previous light is shown by Graph 1, which gives standard curves on one subject taken after strong outdoor light and after dim indoor light. Graph 3 shows that the technique is also effective in a subject whose curve is very much slower. The method was checked in this way on 10 children, with 32 pairs of preliminary and standard curves, and we are satisfied that the standard curve is independent of previous light conditions in all cases.

We consider this a point of great importance, and it is likely that the results of all methods, which adapt only for a short fixed period before experimental bleaching, must fluctuate considerably, depending on conditions of light previous to the test.

Another fact which was observed during this part of the work may be mentioned here. As the weather in the north of Scotland is not often brilliant enough to cause sufficient deflection of the dark adaptation curve for the purpose of testing our technique adequately, an attempt was made to use an artificial light source, consisting of four 200 watt lamps reflected at a distance of 2 feet from a whitewashed sheet. The interesting fact emerged that this brilliant artificial light, which was uncomfortable to look at from close quarters, had not nearly as much deflecting power as weak winter light (not sunshine), reflected from snow. There appears to be a qualitative difference in lights as far as retardation of dark adaptation is concerned.

(2) *The Visual Threshold and Impaired Dark Adaptation.*—It is of interest to compare the illumination of the test object with those at which clinical night blindness might be expected to make itself felt. Lythgoe (1938) gives the illumination of full moonlight as 1/100 foot-candle. The illumination of the test object at aperture 9 is therefore roughly 1/40 that of a surface illuminated by full moonlight. Lythgoe also states that the threshold of vision is 0.001 millifoot candle. Comparing this with the illumination of the test object at aperture 2 (allowing about 20 per cent. reduction of illumination of screen C owing to absorption of light by the slide), it will be seen that the resulting figure (0.0016 millifoot candle) is about 50 per cent. above the threshold of vision of the fully dark adapted eye. At aperture 1 the illumination will be about 30 per cent. below Lythgoe's threshold.

In the range between apertures 9 and 2, therefore, we should expect to find evidence of impaired power of dark adaptation.

With regard to the criteria by which impaired power of dark adaptation may be judged, two views have been held: (a) that it is the rate of adaptation which is affected and that everyone ultimately reaches the same light threshold when completely dark adapted, and (b) that the light threshold of the completely dark

adapted eye is changed. Tansley (1939) considers that night blindness of both types exists.

The former view, as interpreted in practice, assumes significance for all readings after bleaching. In the Birch-Hirschfeld and biophotometer methods, judgment is made on one or more of a series of readings taken during the 10 minutes following exposure to the experimental bleaching light. Corlette *et al.* (1938), using the biophotometer, base their diagnosis of normality solely on the readings taken at 20 seconds. Tansley (1939) points out the danger of this proceeding and our data support her warning. In certain cases (*e.g.*, those shown in Graphs 1 and 3) there are consistent differences, between a subject adapting rapidly and one adapting slowly, at each illumination throughout the standard curves. But in many cases, those who adapted slowly showed the delay only at the end, at apertures 3 and 2, and were within the normal range to aperture 4.

Wald, Jeghers and Arminio (1938), on the other hand, consider that adaptation is complete in from 30 to 45 minutes and that judgment should be based on the light threshold at that time. When their subject was on a diet of low vitamin A content, they found the threshold "at complete dark adaptation" to be 50 times that when he was taking a normal diet with a supplement of a vitamin A concentrate.

From our standard curves, it appears that even subjects who adapt very slowly can always adapt to aperture 2 if they are given long enough. In point of fact, out of several hundred persons tested, only one, a child who did not complain of night blindness, was found who could not give readings at aperture 2, and this was probably due to the fact that the only test made could not be prolonged for more than 3 hours. Our experience of subjectively night blind cases is very limited, but the above conclusions hold good for the subclinical forms of night blindness, for the testing of which this apparatus was designed. There does, however, appear to be a threshold difference in different subjects between apertures 2 and 1, but this seems to be independent of the previous rate of adaptation. Only a small proportion of cases in which it has been tried have seen the test object at aperture 1 even after very prolonged adaptation. All but one of these showed rates of adaptation as good as or better than the general average. On the other hand, a few who gave rapid curves were tested in a darkened bedroom after dark adapting while asleep all night, and could not see the test object at aperture 1, although at aperture 2 it was immediately and easily seen.

At this point it is necessary to state that the time when the subject can say which way the E is pointing at any aperture is

not precisely the same as the light threshold represented by the illumination of the test field. There is an appreciable delay between the time when the light is first seen and the time when the E can be accurately made out. For practical purposes, however, the latter time can be considered as the time of reaching the threshold, since the interval between the curves for the absolute light threshold and that obtained using the test letter is not large, and the two curves diverge only slightly.

It has been said previously that we tried a simplified test object, the U, in an endeavour to reduce this interval. With this slide, the vision required to resolve the light seen is considerably less, and as the shape of the lighted area is less complicated, the delay between the first perception of light and the resolution of the direction of the object might be expected to be less.

The average times of 17 comparative pairs of curves with the E and with the U on 9 subjects are shown in Table III. In order to eliminate any effect of practice or fatigue, each subject (except one) was tested four times as follows: In the first session a standard curve was taken using the E test object, then the subject was "bleached" again and tested with the U. At a separate session, the same procedure was followed, reversing the order of the test objects.

TABLE III

Aperture	9	8	7	6	5	4	3	2
Average of 17 curves using "E" test object - - -	M. S. 1 3	M. S. 2 40	M. S. 1 33	M. S. 3 4	M. S. 5 14	M. S. 7 20	M. S. 10 38	M. S. 13 52
Average of 17 curves using "U" test object - - -	M. S. 1 6	M. S. 1 43	M. S. 2 43	M. S. 3 38	M. S. 4 49	M. S. 6 44	M. S. 8 57	M. S. 11 43

On comparing the curves, it will be seen that the difference between the curves is not large, except at apertures 3 and 2, where the U is resolved considerably sooner. This is to be expected owing to the relatively slower progress of the curve at its "dark" end, which causes the longer interval between the time when the test light becomes visible and that when the test object is resolved.

In future work, therefore, we intend to use the U test object. However, we see no reason to suspect any results obtained with the E, as the error involved is small and its effect is constantly in one direction.

(3) *Peripheral Vision*.—A series of experiments was made on a small number of adult subjects to determine the field through which the E could be orientated correctly. The visual fields were

first mapped out on a Skeel perimeter with the 3 mm. disc. A printed E of the same size as that used in the adaptometer was then substituted for the disc, in such a way that it could be rotated, and the fields mapped out again. A contraction of the field for all subjects of from 5° to 15° was found. In one subject only the field was contracted to between 20° and 30° , but as this subject in tests showed a rapid rate of adaptation, better than the average, this contraction of the field of vision can have had no significant effect on the test.

(4) *Effect of Visual Defects.*—The size and distance from the eye of the test letter is such that an important effect of moderate errors of refraction was not expected. The point was checked however, on 11 children used in intensive studies. Of these, 7 had normal vision, and 4 were astigmatic. Of the latter, one with moderate astigmatism showed the slowest dark adaptation curve of the series; one with high astigmatism gave a normal curve; the remaining two, one with mixed astigmatism and one with very high astigmatism, showed excellent dark adaptation curves.

In practice, it was found that many children with marked hypermetropia or myopia did better without spectacles.

(5) *The "Wave" Phenomenon.*—Kyrieleis (1938) and Müller (1931) have shown that when the course of dark adaptation is mapped out, the curve is not smooth, but in waves. We have observed that this phenomenon is often very obvious at the lower apertures, especially at the lowest, its effect being that the subject may be able to see the E once or twice, then not again until after an interval. Its importance from the point of view of technique is that one should not assume that an isolated correct response is a lucky guess. For the same reason, we do not require the three responses on aperture 2 to occur within any time limit.

An attempt was made to determine if this wave had any definite frequency by timing a series of responses on the lowest aperture, *i.e.*, when the adaptation curve was almost parallel to the base line. The time taken to change the letter is about five seconds, so theoretically a correct answer should have been obtained about every six or seven seconds. In practice there were frequently intervals varying from a few seconds to five minutes between the readings. There was no regular grouping of the responses, so that no regular rhythm of the wave could be ascertained.

(6) *Practice Factor.*—A total of 79 duplicate pairs of standard curves were taken on 14 children, both on successive days and immediate repeats. In these there was no evidence of a practice factor. The times taken to reach aperture 2 were identical in two pairs; the second was shorter in 25 pairs and longer in 52 pairs.

Repeated tests have been done on several adult and child subjects in the course of our routine work and there seems to be little or no improvement with practice, either subjective or objective. It is possible that a few subjects will not show an optimum result on a first test owing to lack of intelligence or proper co-operation. However, in our opinion, the practice factor must be negligible owing to the very close agreement obtained between curves taken on any one subject, on the same day or successive days.

(7) *Subjective Influences from the Worker.*—Many cases (mainly workers in the Rowett Institute) have been tested several times and by several combinations of observers. There is no evidence that different observers tend to obtain different results. With children as subjects, while it is not possible to improve results by suggestion beyond the optimum allowed by physiological processes, it is possible to get worse results if the child's concentration is allowed to slacken.

We believe that the method will give accurate and consistent results with any skilled observer.

(8) *Presence of Light during Course of Dark Adaptation.*—As it is impossible to have an absolutely dark room in which to conduct this test, the question arose as to whether the presence of a small amount of light during dark adaptation would affect the curve. Furthermore, Lythgoe and Phillips (1938) suggest that even subliminal light stimuli may retard the course of dark adaptation, so that the constant illumination of the test object may affect the curve.

The following experiments were therefore conducted on a small number of subjects. When the subject was fully adapted (*i.e.*, could see at aperture 2) the diaphragm was rotated back to aperture 9. The illuminated field then appears relatively brilliant. It was found that after looking at the E for 10 minutes under these conditions, the subject could still determine its position at aperture 2, immediately after the change to that aperture. Repeat tests were conducted exposing the eyes to aperture 3 in the same way, with negative results on the course of adaptation. As a further check, one subject had her standard curve taken, then was re-bleached. On going back to the adaptometer she was left looking at aperture 9 until the time had elapsed which she took to reach aperture 2 previously, when the diaphragm was rotated to aperture 2. She was able to give correct responses immediately, *i.e.*, dark adaptation had been proceeding at least as fast as previously in spite of continuous exposure to a comparatively bright light.

The evidence of Allen and Dallenbach (1938) who have studied the effect of light flashes on the course of dark adaptation is in the same direction.

Discussion

The above apparatus has, we feel, several points of advantage over any other similar apparatus yet designed, especially for routine use with children. The large test object and binocular viewing chamber make the readings reasonably easy from the subject's point of view. There is no possibility of obtaining quicker results by bringing the head nearer the test object. We also believe that it is absolutely necessary to have a test object with which the response can be checked with certainty. With our apparatus it is easy for the observer to encourage the subject to keep looking, but short of a leading question he cannot indicate the correct response. Thus with a co-operative subject the responses can represent only the course of a physiological process, except through a high degree of luck in guessing. In methods where there is no such check on veracity, and especially where a threshold response has to be determined at a specific time, it is all too easy for the observer to suggest to the subject when the response is to be expected, even by the tone of his voice.

No other published method, designed for assessing degrees of vitamin A deficiency, consistently eliminates the effect of antecedent light. The two most widely used instruments for this type of work are the biophotometer in America, and Harris's modification of the Birch-Hirschfeld photometer in this country. With these instruments the technique used limits the preliminary dark adaptation period to ten minutes, irrespective of previous light, so that on bleaching some subjects will be fully adapted, others only partially adapted. Wald, Jeghers and Arminio do not appear to allow any preliminary dark adaptation before experimental bleaching. As is shown in Graph II, the dark adaptation curve, after 10 minutes' preliminary adaptation and bleaching, can vary very widely from that obtained after full preliminary adaptation, depending on previous light conditions. It must vary still more where no preliminary adaptation is allowed. It is necessary to emphasise this point, as it appears to be the major technical fault in these methods.

The bleaching apparatus used in both these techniques is also open to criticism. That used in conjunction with the Birch-Hirschfeld photometer is not of even illumination over its surface, and there is no method of controlling its intensity accurately. The bleaching screen in the biophotometer is so small that the bleaching is localised to a small area of the retina.

On both the above apparatuses the only method of checking the accuracy of a response is by recording the points first of appearance and then of disappearance of the light, with judgments

liable to subjective errors. The Birch-Hirschfeld apparatus has the additional handicap of a very small test light and no viewing chamber, so that in the dark the subject has to look for relatively tiny spots of very faint light without any material guide as to their whereabouts.

Criticism of the biophotometer has recently been forthcoming from certain sources (Palmer and Blumberg, 1937; Palmer, 1938; Gridgeman and Wilkinson, 1938; Isaacs, *et al.* 1938). We believe that the above points of technique may be partly responsible for the dissatisfaction expressed by these workers.

It should be noted that the method here described differs from most others in using white light for the test. This will be discussed in the next paper of this series in which the results will be reported of an investigation into rates of dark adaptation obtained in groups of subjects whose diets differed widely.

We take this opportunity to express our indebtedness to Professor J. A. Carroll for granting us facilities in the Department of Natural Philosophy of the University of Aberdeen for development and standardisation of the adaptometer.

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