STANDARD CURVE AND PHYSIOLOGICAL LIMITS OF DARK ADAPTATION BY MEANS OF THE GOLDMANN-WEEKERS ADAPTOMETER*

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UPON passing from light into darkness the light sensitivity of the eye increases. This phenomenon is explained by an increase in the sensitivity of the photoreceptor cells of the retina (cones and rods) and is called dark adaptation. First investigated by Aubert (1865), dark adaptation is now studied quantitatively through the dark-adaptation curve: the logarithm of the light threshold (ordinate) is plotted against the time in darkness (abscissa) after pre-adaptation to light under standard conditions.

For the last 3 years our dark-adaptation curves have been obtained by means of the Goldmann-Weekers adaptometer.† This photometric precision instrument is so constructed that the examiner can record the logarithm of the light threshold for a given time of dark adaptation directly on semilogarithm paper attached to a drum effecting one rotation per hour. Dark-adaptation curves of different normal individuals are never identical and sometimes vary considerably. In order to make a diagnosis of pathological dark adaptation, it is necessary to obtain data obtained under standard conditions to define the range of the physiological variation. The object of this paper is to determine a standard curve (mean curve) and the physiological limits of dark adaptation by means of the Goldmann-Weekers adaptometer.

For this purpose we performed a total of twenty dark-adaptation examinations (twenty dark-adaptation curves) on a group of twenty normal subjects (including ametropias of from -2.25 to $+3.00$ dioptries) whose ages ranged from 12 to 47 years (average 35).

Technique

The twenty examinations were performed in the following conditions:

- (1) The pupil is fixed in dilatation (eighteen cases with homatropine, two with neosynephrine);
- (2) The examination is monocular;
- (3) 15 minutes of dark adaptation is given before pre-adaptation to light;

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† Haag-Streit, Liebefeld-Berne (Switzerland).

- (4) 5 minutes (± 15 seconds) of pre-adaptation to light is given. The brightness of the adapting field is 1,400 apostilbs (white light)*;
- (5) The threshold is determined at intervals of approximately 1 minute during dark adaptation (for 45 minutes). The test field used in the determination of the threshold is a 12° striped opal glass disk. The stripes are black and white, with 100 per cent. contrast (*i.e.* the black stripes are opaque). The brightness of the white stripes can be varied precisely from $0.55 \times 6 \times 10^{-7}$ to 0.55×6 apostilbs. The threshold is determined by increasing the brightness of the test field until the subject perceives the black and white stripes;
- (6) There is no fixation point (the eye is free to look for the test field).

Statistical Determination of Mean Curve and the Physiological Limits of Dark Adaptation

In the past the following methods have been used to determine a mean curve and the physiological limits of dark adaptation from the aggregate of dark-adaptation curves obtained from a group of normal subjects:

(1) *Graphic Method.*—The aggregate of dark-adaptation curves is plotted on a single graph. Limits chosen empirically to include a large percentage (75 to 100 per cent.) of the curves, constitute the physiological limits of dark adaptation for the corresponding percentage (75 to 100 per cent.) of individuals (*e.g.*, Hecht and Mandelbaum, 1939).

(2) *Mathematical Method using the Arithmetic Mean of the Thresholds.*—This consists in determining a mean value for the aggregate of thresholds corresponding to a given time of dark adaptation.

The mean value (M) is calculated by the formula:

$$M = \frac{\Sigma X}{N}$$

where ΣX = the sum of the threshold values, and N = the number of thresholds. A series of mean values determined in this manner for different times of dark adaptation defines the mean curve. Curves situated on both sides of the mean curve at distances of 1, 2, and 3 standard deviations constitute the limits of physiological variation of the dark-adaptation curve for 68, 95.5, and 99.7 per cent. of individuals respectively. The standard deviation (σ) is calculated by the formula:

$$\sigma = \sqrt{\frac{\Sigma(X - M)^2}{N - 1}}$$

where M = the mean value determined for the mean curve (Matthey, 1932).

(3) *Mathematical Method using the Arithmetic Mean of the Logarithms of the Thresholds.*—The procedure is the same as in (2), except that the logarithms of the thresholds are substituted for the thresholds.

Fleisch and Posternak (1943) were the first to use this method in order to determine a mean curve and the physiological limits of dark adaptation. They noted that the distribution of the aggregate of thresholds, corresponding to a given time of dark adaptation, was clearly asymmetrical: the use of the arithmetic mean of the thresholds would therefore not be justified. On the other hand, the distribution of the aggregate of logarithms of the thresholds was more or less normal: the

* Brightness (French: *luminance*); 1 apostilb (asb) = 0.1 millilambert (mL).

use of the arithmetic mean of the logarithms of the thresholds was therefore indicated.

Our mathematical method comprises the use of the *arithmetic mean of the logarithms of the logarithms of the thresholds (log log threshold)*.* Prof. Linder decided on the use of this method because the statistical analysis of our data revealed that the distribution of the aggregate of logarithms of the thresholds, corresponding to a given time of dark adaptation, was asymmetrical: the use of the arithmetic mean of the logarithms of the thresholds would therefore not be justified. On the other hand, the distribution of the aggregate of the logarithms of the logarithms of the thresholds, corresponding to a given time of dark adaptation, was approximately normal: the use of the arithmetic mean of the logarithms of the logarithms of the thresholds was therefore indicated. The transformation log log of the thresholds is also advised for another reason. It allows us to represent the dark-adaptation curve by a straight line, provided that we take as abscissa the log of the time. The dark-adaptation curve then corresponds to a curve of the analytical type:

$$y = a \cdot e^{\frac{b}{(t-c)^d}}$$

where y represents the threshold value, t the time, a , b , c , d are constants, and e is the basis of the natural logarithm. Similar formulae have been used repeatedly in the natural and actuarial sciences. A mean curve and the superior and inferior fiducial limits were determined.

The Figure (opposite) shows the mean curve (M_c) (standard curve) of dark adaptation and the superior (L_s) and inferior (L_i) fiducial limits. The fiducial limits (L_s and L_i) correspond to the limits of physiological variation of the dark-adaptation curve for 90 per cent. of the individuals; 10 per cent. of normal dark-adaptation curves are situated outside these defined limits (5 per cent. above the superior limit (L_s) and 5 per cent. below the inferior limit (L_i)). Dark-adaptation curves situated below the inferior fiducial limit (L_i) are "hypernormal"; in the diagnosis of pathological dark adaptation, the limit of normal dark-adaptation is therefore one-sided (L_s). A given dark-adaptation curve situated above the superior fiducial limit (L_s) is therefore considered pathological, but in five cases out of a hundred, this particular dark-adaptation curve may nevertheless be normal.

The two segments of each of the dark-adaptation curves (M_c , L_s , and L_i) are evident (solid lines). However, the statistical analysis of the aggregate of thresholds recorded for $11 < t < 14$ minutes, and consequently the exact determination of the break (between primary and secondary adaptation) in the dark-adaptation curve, raise problems beyond the scope of this work.† The two segments of each curve are therefore joined by straight broken lines. The most that can be said with regard to the break in the dark-adaptation

* For further details see Gordon (1956).

† The determination of the break in the dark-adaptation curve will be treated in a future publication.

FIGURE.—Mean (standard) curve (M_c), and superior (L_s and inferior (L_i) fiducial limits of normal variation of the dark-adaptation curve for 90 per cent. of individuals by means of the Goldmann-Weekers adaptometer.

Abscissa = Time (min.) from beginning of pre-adaptation to light.

Ordinate = Threshold brightness of test field in apostilbs (10^7 corresponds to 3.30 apostilbs of brightness of the white stripes of the test field; the scale is logarithmic).

Inset shows portion of graph between 10 and 15 min. corresponding to 5 to 10 min. of dark adaptation with aggregate of individual thresholds (dots) recorded during that interval.

curve is that, for each of the twenty subjects examined, it lies between the upper and lower broken lines.

Summary

The mean (standard) curve and its superior and inferior fiducial limits at a probability of 90 per cent. for dark adaptation measured with the Goldmann-Weekers adaptometer is given. The statistical method employed is based on an arithmetical mean of the logarithms of the logarithms of the threshold (log log threshold). This curve can be used as an exact basis for the measurement of adaptation, under similar conditions of examination. That is monocular examination with a cycloplegic pre-adaptation in twilight for 15 minutes followed by light adaptation of 1,400 apostilbs for 5 minutes. Dark adaptation is tested immediately with a test object of 100 per cent. contrast eliminated by a maximum starting light of 6 lux.

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