VISUAL ACUITY THRESHOLDS IN AMBLYOPES*

BY

H. SAIDUZZAFAR AND C. M. RUBEN

*Orthoptic Research Department, High Holborn Branch, Moorfields Eye Hospital
(Head of Department: T. Keith Lyle, C.B.E., F.R.C.S.)*

THE use of the visuscope in an amblyopic eye helps to determine the part of the retina used during uniocular fixation. However, it is also important to know from a clinical standpoint whether the fovea is inhibited through a peripheral or a central mechanism, and whether in a particular case, the resolving power of the rods or the cones is affected.

Various authors have studied the behaviour of the amblyopic eye in order to establish the nature of the inhibitory scotoma, especially under conditions of altered illumination. Thus, Ludvig (1942) found that some cases of amblyopia ex anopsia showed a reduced light differential threshold, and Irvine (1948) reported changes in the "light differential sensitivity" in amblyopic eyes. These findings indicated that the retinal sensitivity might be altered because of a peripheral mechanism, but this observation has not been followed up until recently. Enoch (1957, 1959a, b), working on the directional sensitivity of the amblyopic retina, suggested the possibility that amblyopia in squint has a varied aetiology, and that in some cases the fovea may be pathological although appearing normal when examined with the ophthalmoscope.

There are, however, cases with definite central suppression, in which fixation and visual acuity improve considerably with occlusion and pleoptic treatment. Wald and Burian (1944) found the light sense unimpaired in cases of amblyopia accompanying strabismus, and they suggested that the inhibition was cortical rather than retinal. von Noorden and Burian (1959a, b) also found that the amblyopic eye with squint differed from the normal eye as well as from eyes showing retinal pathology. They compared the behaviour of the three groups using neutral density filters, and their findings confirmed the view that in squint-amblyopes the deterioration in vision was due mainly to central suppression.

Oppel and Kranke (1958) and Oppel (1960) examined the dark-adaptation curves of a large series of amblyopes, and concluded that squint-amblyopes

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showed a defect of cone-function, and could be differentiated from cases of retinal pathology wherein the retinal sensitivity as a whole was reduced.

It was felt that this work needed further elucidation, especially to compare the normal with the amblyopic eye in squint amblyopes, measuring the absolute light thresholds as a function of time, and the visual acuity thresholds (or resolution capacity of the eye) as a function of illumination; in this way it was hoped to gain useful information regarding the two distinct mechanisms concerned in the reduction of vision in these cases. This was considered important from the point of view of the prognosis for pleoptic treatment.

Material and Methods

25 children with uniocular amblyopia following squint of varying degree, with or without eccentric fixation, were examined. They were all between 10 and 15 years of age, and in every case the vision was 0.3* or better in the affected eye. All parts of the test were performed on each eye separately, and in alternate cases the amblyopic eye was examined first.

The Goldmann-Weekers dark adaptometer was used for this investigation. It has an arrangement for inserting interchangeable test-plates, as well as filters and wedges when necessary. The test-plate subtends an angle of 11° at the eye, while 4.5° from its upper border a small red fixation light is projected into the white inner surface of the sphere (David, 1956).

Preliminary Procedures.—The visual acuity for lines and single letters was recorded in the clinic under standard conditions, and also the visuscope fixation for each eye.

Dark-adaptation Tests.—The built-in luxmeter was used before each examination to check the illumination of the inner surface of the sphere (2,800 to 3,000 lux) and of the test-plate (6 lux).

(a) **ABSOLUTE THRESHOLDS FOR WHITE LIGHT.**—Pre-adaptation was given at 3,000 lux for 5 minutes, after which the dark-adaptation curve for 20 minutes was obtained, recording the thresholds every minute. The 100 per cent. contrast black-and-white stripes were used for this part of the test, while the patient concentrated on the red light for fixation.

(b) **VISUAL ACUITY THRESHOLDS.**—After the 20th minute, the 100 per cent. contrast test-plate was replaced by a translucent plate carrying graded opto-types in the form of numerals which could be presented one by one. The level of illumination behind the test-plate was slowly increased until the patient could read the largest opto-types. This point was recorded on the charts and represented the background illumination for a visual acuity of 0.1; the next set of opto-types was quickly moved into the line of vision, and the required threshold was similarly recorded. The procedure was continued until all the opto-types had been read, or until the maximum illumination of 7 log. units had been reached.

* The visual acuity has been expressed in decimal values, e.g.

0.1 = 6/60
0.25 = 6/24, and so on.

Results

A typical example of the dark-adaptation curve and visual acuity thresholds thus obtained is shown in Fig. 1. The left-hand side of the figure shows the dark-adaptation of the normal as compared with the amblyopic eye, the ordinate representing the illumination in log. units, and the abscissa the time in minutes. It will be seen that the normal thresholds were higher at first, but after the 11th minute they intersected those of the amblyopic eye and subsequently remained lower. Although the amblyopic curves do fall within the normal range it is significant that in this series the majority of amblyopic curves were in the lower limits of normal.

FIG. 1.—Dark-adaptation curve and visual acuity thresholds of a patient with squint and uni-ocular amblyopia.

The visual acuity thresholds are shown on the right-hand side of the diagram; the ordinate represents the log. illumination as before, but the abscissa now represents the visual acuity levels from 0.1 to 0.6 respectively. It will be seen that, whereas the normal eye required only $10^{5.4}$ log. units for a visual acuity of 0.3, the amblyopic eye required $10^{6.6}$ log. units. This tendency is found even more markedly when the amblyopic group of eyes is compared with the normal.

Results of Group Comparison, Normal and Amblyopic Eyes

(a) *Absolute Thresholds for White Light.*—In order to compare the course of dark-adaptation in the 25 cases, the means of the log. illumination for the

normal and amblyopic group were calculated for every minute in the dark (Table I).

TABLE I
MEANS OF LOG. ILLUMINATION
ABSOLUTE THRESHOLDS OF NORMAL AND AMBLYOPIC EYES
Mean of Log. Illumination n> 25

Minutes in Dark		1	2	3	4	5	6	7	8	9	10
Eye	Normal	5.3252	4.9728	4.6912	4.4780	4.3304	4.1536	3.9944	3.6872	3.4436	3.2412
	Amblyopic	5.3012	4.9596	4.6892	4.4900	4.3444	4.2256	4.0168	3.7756	3.5012	3.3052
Minutes in Dark		11	12	13	14	15	16	17	18	19	20
Eye	Normal	3.0948	2.9100	2.7088	2.5264	2.4292	2.3668	2.3160	2.2812	2.2584	2.2380
	Amblyopic	3.1684	3.0416	2.9108	2.7268	2.6124	2.5244	2.4520	2.3980	2.3672	2.3044

From these mean values the two dark-adaptation curves were constructed, showing the trends in the two groups of eyes (Fig. 2).

FIG. 2.—Absolute thresholds in 25 subjects. Mean values for log. illumination, in normal and amblyopic eyes. (From *Brit. orthopt. J.* (1962), 19, 32).

It is found that for the first 11 minutes the curves almost coincide, but after the 12th minute the amblyopic thresholds are somewhat higher, reaching a maximum difference at the 13th minute. To assess the significance of these differences (Table II, opposite), they were subjected to analysis of variance, the unit used for the calculation being

$$100 (A - N),$$

where A and N were the means of log. illumination for normal and amblyopic eye respectively.

TABLE II

MEAN DIFFERENCES BETWEEN THE ABSOLUTE THRESHOLDS OF THE NORMAL AND AMBLYOPIC EYES, WITH THEIR STANDARD ERRORS

Time (min.)	1	2	3	4	5	6	7	8	9	10
Mean Threshold Difference*	-2.40	-1.32	-0.20	1.20	1.40	7.20	2.24	8.84	5.76	6.40
Standard Error of the Mean	6.590	6.976	7.196	4.674	5.234	6.315	7.240	6.556	5.478	3.983
Time (min.)	11	12	13	14	15	16	17	18	19	20
Mean Threshold Difference*	7.36	13.16	20.20	20.04	18.32	15.76	13.60	11.68	10.88	10.64
Standard Error of the Mean	4.841	6.488	6.966	5.866	5.335	5.011	3.785	3.129	3.107	3.269

* 100 (A-N)
A = Mean of log. illumination for Amblyopic eye
N = Mean of log. illumination for Normal eye

This analysis of variance (Table III) showed that up to the 12th minute the differences were not significant, while from the 13th minute onwards they were significant at the 1 per cent. level.* For the sake of brevity only six examples of the analysis have been given in Table III; and the F ratio was used to test the significance of the results (Snedecor, 1946).†

TABLE III

EXAMPLES OF THE ANALYSIS OF VARIANCE FOR ABSOLUTE THRESHOLDS AT SIX TIME-STAGES

Time	Due to	Degrees of Freedom	Sums of Squares	Mean Square	F Ratio
1st Minute	Hypothesis Error and so on up to the 12th minute	1 24	144.00 26060.00	144.00 1085.83	
13th Minute	Hypothesis Error	1 24	10201.00 29118.00	10201.00 1213.25	8.408*
14th Minute	Hypothesis Error and so on up to the 17th minute	1 24	10040.04 20646.96	10040.04 860.29	11.671*
18th Minute	Hypothesis Error	1 24	3410.56 5873.44	3410.56 244.73	13.936*
19th Minute	Hypothesis Error	1 24	2959.63 5790.64	2959.36 241.28	12.265*
20th Minute	Hypothesis Error	1 24	2830.24 6411.76	2830.24 267.16	10.593*

*1 per cent. F with (1,24) d.f. = 7.82
0.1 per cent. F with (1,24) d.f. = 14.03
Hence * = 0.01 > p > 0.001

* 0.01 > p > 0.001; i.e. the probability that the differences occurred by chance is less than 1 in 100.

† F ratio is a variance ratio (after Fisher) $\frac{\text{Mean Square of Group means}}{\text{Mean Square of Individuals}}$

Thus the amblyopic group as a whole showed a tendency for reduced retinal sensitivity for scotopic thresholds, although individual cases varied in their responses, some showing entirely normal absolute thresholds.

(b) *Visual Acuity Thresholds*.—The threshold background illumination required by each eye to read the various sizes of opto-types (visual acuity: 0.1 to 0.6) is given in Table IV. The means of the log illumination were calculated for four levels of visual acuity, because thereafter the data for the amblyopic eyes dwindled and were insufficient for a comparative study. Table IV shows that beyond the visual acuity level of 0.2 the performance of the amblyopic eyes was variable, so that only three out of the 24 cases could attain the visual acuity level of 0.6, whereas all the normal eyes attained this vision within the given range of illumination.

TABLE IV
VISUAL ACUITY THRESHOLDS

Case No.	V.A. 0.1		V.A. 0.2		V.A. 0.3		V.A. 0.4		V.A. 0.5		V.A. 0.6	
	N.E.	A.E.	N.E.	A.E.	N.E.	A.E.	N.E.	A.E.	N.E.	A.E.	N.E.	A.E.
II	5.10	5.22	5.30	6.35	5.70	7.00	6.17	—	6.35	—	6.50	—
III	5.35	6.35	5.40	7.00	6.10	—	6.12	—	6.18	—	6.35	—
IVa	4.60	5.50	5.20	6.10	5.40	6.50	5.60	7.00	6.10	—	6.40	—
V	5.30	5.25	5.30	5.50	5.60	5.60	6.40	6.15	6.60	6.38	6.60	6.50
VII	4.80	6.16	5.25	7.00	5.40	—	6.10	—	6.12	—	6.30	—
IX	6.16	6.14	6.20	6.50	6.32	—	6.60	—	6.80	—	7.00	—
X	4.25	5.30	4.50	6.12	4.85	6.60	5.20	—	5.55	—	6.18	—
XI	6.15	5.40	6.15	6.40	6.15	7.00	6.25	—	6.40	—	6.40	—
XII	5.18	5.40	5.82	6.21	5.82	7.00	6.11	—	6.15	—	6.21	—
XIII	5.10	5.30	5.16	5.80	5.21	6.30	5.60	7.00	6.12	—	6.35	—
XIV	5.50	5.21	5.52	5.80	6.10	6.14	6.12	6.85	6.28	7.00	6.80	—
XV	4.40	5.36	5.40	5.80	5.60	6.15	5.80	6.40	6.20	6.60	6.60	—
XVI	5.18	5.80	5.30	6.11	5.42	6.24	5.80	7.00	6.18	—	6.28	—
XVII	4.55	4.60	5.18	5.22	5.35	5.40	5.60	6.21	6.16	6.60	6.25	6.80
XVIII	5.15	6.30	5.30	6.40	5.50	6.50	6.14	7.00	6.20	—	6.40	—
XIX	5.10	5.35	5.25	6.11	5.30	6.60	5.40	6.80	5.55	—	6.16	—
XX	5.12	6.15	5.20	6.15	5.40	6.40	5.80	6.60	6.10	6.60	6.35	—
IVb	5.15	5.25	5.22	5.90	5.42	6.50	6.15	7.00	6.31	—	6.50	—
XXI	5.10	5.15	5.60	5.40	6.10	5.80	6.35	7.00	6.50	—	6.60	—
XXII	5.10	5.30	5.35	6.40	5.60	7.10	6.10	—	6.18	—	6.30	—
Xb	5.10	5.40	5.32	6.35	5.40	7.10	5.60	—	6.10	—	6.20	—
XXV	5.20	5.21	5.40	5.50	6.12	6.15	6.25	6.40	6.40	7.10	6.95	—
XXVI	5.21	5.80	5.31	6.40	5.60	6.90	5.80	—	6.18	—	6.42	—
XXVII	5.12	5.40	5.30	5.50	5.40	5.62	5.80	6.16	6.18	6.30	6.40	7.10
Sum	122.97	132.30	128.93	146.02	134.86	134.60	142.86	93.57	148.89	49.58		
n	24.00	24.00	24.00	24.00	24.00	21.00	24.00	14.00	24.00	7.00	24.00	3.00
Mean	5.12	5.51	5.37	6.08	5.62	6.41	5.95	6.68	Not used for analysis			

V.A. = Visual acuity level
N.E. = Normal eye
A.E. = Amblyopic eye
The figures represent values for log. illumination

Fig. 3 (opposite) is a composite scatter diagram of the data in Table IV, comparing the visual acuity thresholds of the amblyopic eye with those of the normal eye.*

* In cases in which the subject could read some but not all the opto-types of a given size even at maximum illumination, the points were recorded with a small arrow mark at the top of the illumination scale.

FIG. 3.—Visual acuity thresholds. Scatter diagram comparing trends in normal and amblyopic eyes. Arrow marks at top of illumination scale indicate the subject's inability to read all the optotypes of a given size, even at maximum illumination. (From *Brit. orthopt. J.* (1962), 19, 33).

A quantitative analysis was made to measure the magnitude of the difference between the normal and the amblyopic eye at various levels of illumination, as well as the extent of the variability of the data and of the observed differences (Table V).

TABLE V
DIFFERENCE BETWEEN VISUAL ACUITY THRESHOLDS,
WITH THEIR STANDARD ERRORS

Eye	Normal		Amblyopic		Mean Difference	Standard Error of Difference
Visual Acuity Levels	Mean log. Illumination	Standard Error of the Mean	Mean log. Illumination	Standard Error of the Mean		
0.1	5.124	0.0887	5.512	0.0887	0.388	0.1254
0.2	5.372	0.0823	6.084	0.0823	0.712	0.1164
0.3	5.619	0.0896	6.410	0.0958	0.791	0.1312
0.4	5.952	0.0704	6.684	0.0921	0.732	0.1159

The analysis of variance for the first four visual acuity levels is shown in Table VI (overleaf). The F ratio was significant at the 1 per cent. level for

TABLE VI
ANALYSIS OF VARIANCE: VISUAL ACUITY THRESHOLDS

Visual Acuity	Due to	Degrees of Freedom	Sums of Squares	Mean Square	F Ratio
0.1	Hypothesis Error	1 46	1.8135 8.6834	1.8135 0.1888	9.605*
0.2	Hypothesis Error	1 46	6.0847 7.4836	6.0847 0.1627	37.40†
0.3	Hypothesis Error	1 43	6.9962 8.2875	6.9962 0.1927	36.31†
0.4	Hypothesis Error	1 36	4.7258 4.2782	4.7258 0.1188	39.78†

* = $0.01 > p > 0.001$

† = $0.001 > p > 0.0001$

the large opto-types (visual acuity level: 0.1), and for succeeding levels it was significant at the 0.1 per cent. level ($0.001 > p > 0.0001$). It was also found that the individual subjects showed a remarkable uniformity of response in spite of their young age and visual handicap.

In the normal group of eyes it was found that the log. illumination bore a linear relationship to the variation in visual acuity over the range of the present investigation. This relationship, as estimated from the data in Table IV, was as follows:

$$\text{Log. illumination} = 4.845 + 0.269 L$$

where L is the visual acuity level.

The standard error of the slope of this line was 0.0163.

Apart from the group analyses, a study of individual cases on the basis of their absolute and visual acuity thresholds showed that they fell into three distinct types:

- (i) Those with raised absolute thresholds.
- (ii) Those in whom the visual acuity thresholds (resolution capacity) were altered.
- (iii) Those in whom both the absolute and the visual acuity thresholds were defective.

These observations however confirm the view that there are at least two different mechanisms which might be disturbed in the squint amblyopes, *viz.* the generalized retinal sensitivity and the resolution capacity of the eye.

Visuscope Fixation as Related to Visual Acuity Thresholds

According to their visuscope fixation the amblyopic eyes of the 24 subjects thus examined were divided into the three following groups in order to find

out whether there was any clear relationship between the fixation and the resolution capacity:

- (1) Those with foveal or juxtafoveal fixation.
- (2) Those with parafoveal fixation (up to 2° from the fovea).
- (3) The cases with widely eccentric fixation.

The trend of the visual acuity thresholds in each of the groups, shown in Fig. 4, can be compared with those of the normal eyes, shown on the left-hand side of Fig. 3. The trend in Group I closely resembles the normal pattern, while the thresholds in Group 2 show a steep upward trend, so that most of the subjects had a final visual acuity of less than 0.3 even at maximum illumination. Group 3 comprised only three subjects and was therefore inconclusive. No statistical analysis was carried out for this comparison because the data were meagre, and the number of cases in each group were not comparable.

FIG. 4.—Visual acuity thresholds. Amblyopic eyes classified according to the visuscope fixation. (From *Brit. orthopt. J.* (1962), 19, 34).

Discussion

The inhibition in cases with squint amblyopia appears to differ in its mechanism from case to case; for this reason there is a great variability in the response to pleoptic treatment, and hence it is necessary to know more about the mechanisms involved in amblyopia. It is also important to know

whether the resolving power of the amblyopic eye is inhibited at the scotopic level or at the photopic level, or whether both these mechanisms are disturbed.

In the present study it was found that on the average, the absolute threshold in the amblyopic eyes was significantly higher than in the normal group of eyes, especially after the 13th minute (Table III). None of these cases showed any ophthalmoscopic signs of retinal pathology.

When the resolution power of the eye was tested for small optotypes, the difference in behaviour between the two groups of eyes was even greater. Thus, it can be seen from the statistical analysis (Table VI) that for the visual acuity level of 0.1 the differences were significant at the 1 per cent. level as indicated by the F ratio. On the other hand, when the background illumination entered the photopic range for discrimination of small optotypes (0.2, 0.3, and 0.4), the differences were significant at the 0.1 per cent. level. In this way a comparison of the two groups revealed considerable differences between the normal and the amblyopic eyes.

In the individual case too, a study of the dark-adaptation curves and the visual acuity thresholds revealed that two types of information could be obtained. First, the slope of the line correlating visual acuity with the background illumination indicated an alteration in the resolution capacity of the cone-apparatus, which is mainly concerned in squint amblyopia.

Secondly, by relating the different visual acuity thresholds to the point α^* on the dark-adaptation curve, it was possible to determine whether the visual defect involved the scotopic or the photopic resolution power or both.

These results encourage us to believe that this test should be simplified so that it may be performed rapidly, modifying the procedure as follows:

Instead of completely recording the whole test for one eye, and then repeating it for the other eye, it should be possible to pre-adapt the two eyes simultaneously, and rapidly determine the point α^* . Thereafter the patient could sit aside with dark-adapting polaroid goggles (or in another room in the dark) until the 20th minute. Thereafter, working with each eye alternately, one could determine the absolute threshold at the 20th minute, the cone thresholds using the red filter and the visual acuity thresholds for large and small opto-types respectively; thereby a composite and complete picture of the visual processes could be gained, comparing the normal with the amblyopic eye.

If the visuscope fixation is recorded in each eye, and the above rapid tests are performed before and after pleoptic treatment, one can find out the extent to which the treatment actually affects the resolution capacity of an amblyopic eye. On a sufficiently large series, this information would be of great value. Visual improvement is usually judged on the basis of visual acuity under intense illumination, but the method here described opens up the possibility of assessing the effect of pleoptic treatment on four distinct visual mechanisms as follows:

- (1) Absolute thresholds for 100 per cent. contrast test-object (rod threshold).
- (2) Cone thresholds (red filter).

* α = Intersection of cone slope with rod slope on the dark-adaptation curve.

- (3) Visual acuity thresholds for large opto-types; background illumination below the point α (rod resolving power).
- (4) Visual acuity thresholds for small opto-types; illumination above the point α (cone resolving power).

This would ultimately be helpful in determining the prognosis and in carrying out the treatment according to the specific requirements of the individual patient. It would of course be necessary to perform all the other tests for amblyopia in addition.

Summary

(1) The absolute thresholds up to the 20th minute, as well as the visual acuity thresholds, were determined in a series of squint amblyopes.

(2) The amblyopic eyes were compared with the normal eyes, and the differences when subjected to statistical analysis proved to be highly significant; this was especially marked with regard to the resolution capacity of the cone-mechanism.

(3) On the basis of these findings, it is suggested that the test may be simplified and performed rapidly before and after pleoptic treatment; the information so gained would be valuable in classifying cases of amblyopia and assessing the prognosis.

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