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COMMUNICATIONS

A STUDY OF THE CENTRAL AND PERIPHERAL
LIGHT AND DARK ADAPTATIONS WITH
VARYING BACKGROUNDS

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EXETER

If the light threshold be defined as the least amount of light seen on a black background, and the light difference as the least amount of black seen on a white background, it is obvious that these extremes are joined together by an infinite number of intermediate positions from each of which a departure may be made in either direction of sensations lighter or darker than the background. In the present paper it is proposed to investigate the least differences in either direction at intermediate points, as well as in the one possible direction at the two extreme positions. The enquiry is directed to the peripheral as well as to the central capacity for discrimination, and the time required for adaptation.

The backgrounds used for the fields were:—

- (1) Black velvet;
- (2) 15 per cent. white;
- (3) 76 per cent. white;

on a screen two metres square at a distance of one metre from the observer. The velvet gives the blackest background obtainable. The intensity of the white screen is governed by the phenomena of dazzle, so that a white value of 240 foot candles (daylight) is the highest that can be usefully employed. The right eye of the

writer of this paper was used, having a corrected vision 6/5, a full field, a dark adaptation a little above normal, and a slight over-sensitivity to bright lights.

Peripheral Field.—As the field for 3/1000 is the widest that can be measured on a screen two metres square, 3 mm. discs were used as test objects, varying from black velvet through a series of greys to white, mounted on Traquair's rod for the velvet screen, on brake wire painted with colour similar to the screen for the other backgrounds. Light reflected from the screens and discs was measured by the Holophane Lumeter, which measures from 0.0025 to 20000 ft. candles. In the experiments a daylight illumination of 240 ft. candles was the highest used, as reflected from a white screen. Variations from full daylight were obtained by dark blinds.

According to definition the outline of the field of vision (isopter) for any particular object and illumination is also a threshold, for anything less than that is not perceived at that line. This must be qualified for the absolute limit of the field of vision, where the smallest or least illuminated object perceived must be taken as the threshold.

The average of the eight principal meridians was ascertained, neglecting the blind spot; each point on the field charts represents such an average meridian, these being the co-ordinates, the abscissae being the light values of the discs.

A preliminary investigation was made upon the field of vision in the fully adapted eye under various illuminations with the backgrounds already given.

ADAPTED EYE

TABLE I.—VELVET SCREEN

GRAPH A			GRAPH B		GRAPH C		GRAPH D	
	Disc values — Foot candles	Average meridia.	Disc values — f.cs.	Average meridia.	Disc values — f.cs.	Average meridia.	Disc values — f.cs.	Average meridia.
White	·0525	33	4 0	41·5	45·0	46	95	46
	·025	26	1·9	40·0	21·5	44	45	43
	·0079	20	0·6	36·0	6·7	41·5	14·2	40·5
	·0044	12	0·34	26·0	3·82	36	8·05	37
Black	—	—	0·0	8·25	0 53	18	1·25	23

TABLE II.—15 PER CENT. WHITE SCREEN

	GRAPH E		GRAPH F		GRAPH G	
	D.V.	A.M.	D.V.	A.M.	D.V.	A.M.
White	4.5	38.5	35.0	38.5	90.0	38
	2.16	27	16.6	32.5	43	35
Screen	0.7	0	5.35	0	13.8	0
	0.675	3.0	4.55	16.5	13.5	8
	0.383	13.5	2.9	22	7.65	24
Velvet	0.0	36	0	35	0	37

TABLE III.—76 PER CENT. WHITE SCREEN

	GRAPH H		GRAPH I	
	D.V.	A.M.	D.V.	A.M.
White	5.5	6.5	95.0	7
Screen	4.05	0	70	0
	2.6	31.0	45.5	30
	0.85	33	14.2	33
	0.51	34.5	8	35
Velvet	0	35	0	38.5

D.V. = Disc values in foot candles.
A.M. = Average meridia.

The obvious characteristic of the graphs A-D (velvet screen) is the steep rise to the 35°-40° meridians in the four graphs and the slow rise thence to the highest point reached in B, C, and D graphs. It means a great discrimination of differences of illumination up to the 35° meridian, a slighter discrimination beyond this to the edge of the field. The result of this is a very marked angle, above and below which the graph is nearly straight. The angle corresponds fairly well with the same grey disc in each graph; the 8.35 per cent. marking the beginning and the 15 per cent. disc the finish of the bend. If the light values be reduced to percentages and charted (see Chart IV), this correspondence will be seen more clearly, but the angles are less marked as the illumination gets further below 45 ft. candles white value.

Some practical points arise. A considerable difference in illumination, from 4 to 95 ft. candles make a difference in size of the field of only 5.5° . The former would mean a dull winter day about 3 p.m., the latter a bright day without direct sunlight; so that the size of the field is fairly constant within wide limits of lighting. Grey is occasionally useful in testing fields for lowered light threshold, the importance of using a tint near the angle of

[NOTE.—In some Graphs the base lines for the abscissae and co-ordinates are omitted, being indicated by dashes adjoining the scales.]

the graph is obvious, a reflecting value of 12 per cent. would be a good average to employ. For it is at the bend that a loss of sensitivity will make the greatest difference to the field and graph.

The fields on the 76 per cent. white screen will now be considered. Although the graph for a 5.5 foot candles white value is much steeper than that for 95 foot candles, when it was drawn on a percentage light value it was found nearly to agree in shape with the latter. Working from the screen value as zero, it will be seen that the rise on either side is decidedly less steep than with the velvet screen graphs, although an angle is shown at meridian 30° . The highest meridians for black on this screen are less than for white in the velvet screen group, although there

is as much alteration in light values as in C. and B. velvet screen graphs and the size of the discs is the same.

A special series of finely graduated grey discs was used to investigate the slope from zero in I. to the angle corresponding to the 45.5° f.c. value, to ascertain if it were as shown. Allowing for small margins of error it was correct.

Thus it will be seen that the field up to 35° on a white background is less susceptible to slight differences from white than it is to equal white differences from a black background.

The fields on the 15 per cent. white background show an intermediate position between the velvet and 74 per cent. white screens. The highest point is less than with the velvet screen while the ascent from zero with discs blacker than the screen is decidedly steeper than with discs whiter than the screen. To put this another way, the black-light differences are more readily appreciated than the white-light differences.

Fields under dark adaptation.—In some cases a preliminary field was taken with the eye fully adapted to the room illumination. This is shown in the graphs by a horizontal black line, from which a vertical line descends to the zero meridian. The

room was then darkened, the fields being taken at 0, 3, 10, 20, and 30 minutes, or at 0, 5, 15, 25, and 30 minutes. Only velvet and white discs were used. For the intermediate screens between black and white both discs were employed. The backgrounds used were:—Velvet; 31 per cent. white; 50 per cent. white; 69 per cent. white; white. No precautions as to the size of the pupil were taken. It is obvious that a 3 mm. disc at 1 metre subtends an angle well within the size of the smallest pupil obtained under the highest illumination used.

The results are shown in Tables IV to VIII, and in Graphs 1 to 17.

The following conclusions can be arrived at from inspection of Tables IV-VIII and Graphs 1-17.

(1) The general shape of the adaptation graphs resembles those showing the sensitivity of the adapted eye fields in Tables I, II, III and Graphs A-H, the time factor replacing the illumination factor.

(2) The rise of sensitivity is rapid; full or nearly full adaptation is reached in most cases in ten minutes. The more sensitive central part of the field recovers more quickly than the peripheral, so that there is an angle corresponding to the 30°-35° meridia.

(3) In a distinct proportion of the graphs there is a slight fall in the size of the fields in the last ten minutes; not only does the periphery recover slowly, but it soon suffers from fatigue. This occurs not only in the higher meridians above 30°, but also in graphs of lower maxima, it is a frequent occurrence at all levels, *e.g.*, graph 11.

FIELD DARK ADAPTATION

TABLE IV—VELVET SCREEN—WHITE 3 mm. DISC

White light in foot candles before test	35'0	90'0	12'0	30'0	4'0	90'0	6'0	225'0	12'0
During test ...	30'0	5'76	3'0	1'5	1'25	1'25	0'04	0'035	0'015
Average meridia. before ...	42'5	43'5	41'0	42'5	—	43'5	42	—	—
During 0 mins. ...	37	38'5	33	30	32'5	22	12	7	12
Adaptation 3 mins.	42'5	—	40	40	33	28	25'5	8'5	22
10 mins.	—	—	42	41	40'5	29'5	33	30	30'5
20 mins.	—	—	43	38'5	42	31	31	33	30
30 mins.	—	—	40	40	43'5	30'5	33	37	25

TABLE V Screen 31 per cent. white				TABLE VI 50 per cent. white				TABLE VII 69 per cent. white	TABLE VIII 100 per cent. white				
Screen value in ft. candle				30				19.2	130				
Before test ... 30				0.065				0.425	9-5.25				
During test ... 0.225				0.0125				0.04	0.04				
Average meridians before ...				W. disc	B. disc	W. disc	B. disc	W. disc	B. disc	W. disc	B. disc	W. disc	B. disc
During 0 mins. ...				33	26	29	29	5	5	8	16	—	—
Adaptation 3 mins.				—	—	—	—	—	—	8	22.5	—	—
5 mins.				23	24	9	5	11.5	14	—	—	—	—
10 mins.				—	—	—	—	—	—	13.5	22.	—	—
15 mins.				25	26	9.5	5	16	14	—	—	—	—
20 mins.				—	—	—	—	—	—	14.5	22.5	—	—
25 mins.				—	—	—	—	16.	20	—	—	—	—
30 mins.				22	28	4.5	1.5	17.	19	18	22.0	—	—

W. disc = White disc. B. disc = Black disc.

(4) There is a rough correspondence between the maxima during adaptation and the maxima of sensitivity in the fully adapted eye.

(5) In the grey fields of 69 per cent. and 50 per cent. white there is a higher level for the black disc. In the 31 per cent. white there is little difference at the 0.225 ft. candle level, at 0.0125 f.c. the black meridians are decidedly lower than the white. It must be borne in mind that the illumination difference between the screen and the discs is greater for the black in the 61 per cent. screen, for the white in the 31 per cent. screen; it is only in the 50 per cent. screen that the difference is the same for the two discs. Yet in both graphs for the 50 per cent. screen the black disc has the higher meridian, *i.e.*, the adapting eye responds more to the black differences just as the adapted eye responds to finer differences in dark objects.

(6) The initial fall in the size of the field bears a general relation to the depth to which the light is lowered rather than to the height from which it falls. An exception is graph 8 (velvet screen), where the decrease was from 240 ft. candles to 0.035 f.c., a great difference. In this case the initial meridian was 6°, as compared with graph 9, where a fall from 12 f.c. to 0.015 f.c. was accompanied by a fall to meridian 10°.

(7) The maxima reached in the illuminations from 30 f.c. to 1.25 f.c. vary between 40° and 43° , an unimportant difference, and not occurring in a consistent order. From 1 ft. candle downwards there tends to be a distinct lowering in the maxima, though 37° for 0.035 f.c. is an exception. In the slight differences for a large range of higher illumination and the more marked differences for low illuminations, the results with the adapting eye are like the maxima for the adapted eye, as would be expected.

It may fairly be stated that the adapted normal eye gives information of similar information to the adapting eye, granted two conditions. The first is that half-an-hour be allowed for adaptation in low illuminations, the second that the investigation is carried out with discs of graduated greys. On the whole it is probably easier to use black or white discs to ascertain the increase in the fields during adaptation, rather than to test the fields by graduated greys after adaptation.

Light Threshold and Difference Tests—Macular Region

No attempt was made to distinguish between foveal and para-foveal perception; it is a distinction difficult to make in untrained observers. It was noticed, however, that objects were seen best defined by looking 4° above them, though they could always be seen in this case by direct vision, but less well defined.

The tests were made in five groups, the backgrounds being the screens used in the peripheral adaptation tests. In all but the velvet screen a circular disc 9 cm. in diameter, covered with paper like the screen, had mounted on its centre a segment of lighter or darker paper. The disc was rotated by a small dynamo, so that the segment then made a disc 14 mm. in diameter in the centre of the large disc, lighter or darker as the case might be. The smallest segment that could be distinguished during rotation was taken as the measure of the light difference, its value being calculated thus:—

Percentage light value of large disc less

Percentage light value of sector

= per cent. light difference.

$$\frac{\text{Angle of sector}}{360^{\circ}} \times \text{Light difference} \times \text{Light value of screen}$$

= Actual light difference in foot candles. The reciprocal of this was taken as the sensitivity, and used in the graphs. The advantage of using the sensitivity is that the curve records the increased perception as a rise; if the actual difference perceived is recorded, the part of the curve showing the greater perception is practically flat, so that it fails to give the impression of increased sensitivity.

The disc used was the largest that could be rotated by the dynamo at one's disposal. The size of the sector was arbitrary, it was chosen because it could be conveniently seen at a metre distance, yet was small enough to be well within the boundaries of the parafoveal area and to subtend an angle less than the smallest pupil, so that the size of the latter could be neglected.

In the case of the light threshold a different method was employed. A white or grey disc 17 cm. in diameter had one half covered by velvet. In front of this was a disc covered with velvet from which an annulus of 180°, 1.0 cm. wide was cut out. By rotating the annulus disc any proportion from 180° to 2.5° of the white (or grey) half of the posterior disc could be exposed. When the two discs were rotated together sufficiently quickly, the exposed sector was thus diluted by black. It was viewed through an opening in a velvet-covered screen of approximately the same size as the sector in the light difference tests. The light value was thus estimated:—

$$\begin{aligned} & \text{Light value of white (or grey)} \times \frac{\text{angle exposed}}{360^\circ} \\ & = \text{light value of sector exposed in screen opening.} \end{aligned}$$

Daylight was used for illuminations as low as .01 ft. candles. Below this electric light from a frosted bulb was used, this being reduced by diaphragms to the required illumination. If this were not sufficient, glasses of smoke tint were added.

With each of the five screens employed a number of observations were made with different illuminations, each observation lasting half-an-hour. As in the case of the field adaptation tests, a series of tests was made at intervals during the half hour, the final sector readings forming the basis for the estimation of the threshold and light differences respectively. Like the field tests, in the 31 per cent., 50 per cent., and 61 per cent. white screens the least differences were calculated in both directions.

Summary of Central Adaptation Test

A = White value of disc in ft. candles at 1 metre from disc.

W = Percentage of white difference of sector from screen
 $\div 100 \times \text{angle of sector} \div 360^\circ$.

A W = Value of white difference in ft. candles.

$\frac{1}{A W}$ = Sensitivity to white difference.

B = Percentage of black difference of sector from screen
 $\div 100 \times \text{angle of sector} \div 360^\circ$.

A B = Black difference in ft. candles.

$\frac{1}{A B}$ = Sensitivity to black difference.

TABLE IX—CENTRAL ADAPTATION
VELVET SCREEN (Annulus 31 per cent. White)

A	Angle exposed	W	A W	$\frac{1}{A W}$	Log A	Log $\frac{1}{A W}$	Graph reference
140	2.5°	0.00215	0.3	3.3	2.14	0.51	22
95	2.5	0.00215	0.204	4.9	1.98	0.69	
60	2.5	0.00215	0.127	7.5	1.77	0.87	
13	5	0.0043	0.056	18	1.11	1.25	
5	7.5	0.0065	0.032	32	0.7	1.5	21
1.4	20	0.0173	0.024	41.5	0.146	1.62	
1.0	12.5	0.0103	0.0107	92.5	0.0	1.96	20
0.5	15	0.0136	0.0072	156	1.7	2.19	
0.05	30	0.026	0.00128	782	2.7	2.89	
0.03	40°	0.0345	0.00102	980	2.47	2.99	
0.015	40°	0.0345	0.00052	1923	2.176	3.28	
0.01	40°	0.0345	0.00034	2925	2.0	3.46	
0.0015	25°	0.0214	0.000032	31250	3.176	4.49	19
0.000156	100°	0.0865	0.0000132	75000	4.19	4.87	18
0.0000315	Nil	—	Nil	—	—	—	

TABLE X—CENTRAL ADAPTATION

WHITE SECTORS							31 per cent. White Screen					BLACK SECTORS		
A	W	A W	$\frac{1}{A W}$	$\log \frac{1}{A}$	$\log \frac{1}{A W}$	B	A B	$\frac{1}{A B}$	$\log \frac{1}{A B}$	Graph reference				
35.0	0.0026	0.091	11	1.54	1.04	0.0021	0.0735	13	1.11	27				
14.25	0.004	0.057	17.6	1.45	1.24	0.0021	0.0299	34	1.53					
8.0	0.004	0.032	31	0.9	1.49	0.0043	0.0344	29	1.46					
4.0	0.0039	0.0156	64	0.6	1.8	0.0043	0.0172	58	1.76					
1.5	0.0079	0.0118	84	0.176	1.92	0.0086	0.0129	77	1.88					
0.85	0.0079	0.0067	149	1.92	2.17	0.0172	0.0146	68	1.83					
0.45	0.0079	0.00353	286	1.65	2.45	0.0086	0.00085	260	2.41					
0.186	0.0079	0.00146	685	1.27	2.84	0.0086	0.00158	633	2.8	26				
0.055	0.0079	0.00043	2026	2.74	3.31	0.0086	0.00047	2128	3.32	25				
0.015	0.0236	0.000355	2800	2.17	3.44	0.0172	0.000256	4000	3.6					
0.0134	0.0236	0.000332	3030	2.12	3.48	0.0258	0.000345	2900	3.46					
0.0065	0.030	0.000195	5128	3.81	3.7	0.039	0.000252	3948	3.6					
0.00174	0.045	0.000078	12771	3.24	4.1	0.077	0.000134	7464	3.87					
0.0012	0.095	0.000114	8770	3.08	3.94	0.073	0.000156	6410	3.8					
0.0008	0.095	0.000076	13160	4.9	4.11	0.155	0.000124	8060	3.9	24				
0.0002	0.156	0.0000312	32000	4.3	4.5	0.26	0.000052	19200	4.28	23				
0.000084	0.515	0.000043	23256	—	—	Nil	—	—	—	—				

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TABLE XI—CENTRAL ADAPTATION

WHITE SECTORS				50 per cent. White Screen			BLACK SECTORS			
A	W	A W	$\frac{1}{A W}$	$\log \frac{1}{A}$	$\log \frac{1}{A W}$	B	A B	$\frac{1}{A B}$	$\log \frac{1}{A B}$	Graph reference
87.0	0.004	0.35	2.85	1.94	0.45	0.0012	0.105	9.5	0.97	31
27	0.008	0.216	4.6	1.43	0.66	0.0025	0.068	15.	1.17	
13	0.008	0.104	9.6	1.11	0.98	0.0076	0.098	11.	1.04	
1.8	0.008	0.0144	69.4	0.25	1.84	0.0076	0.0137	73.5	1.86	30
0.19	0.016	0.00304	329	1.27	2.51	0.011	0.00208	476	2.86	29
0.03	0.074	0.00222	708	2.47	2.84	0.03	0.0009	1111	3.04	
0.01	0.074	0.00074	1351	2.0	3.13	0.03	0.0003	3333	3.52	
0.000475	0.25	0.000086	11630	4.67	4.06	0.187	0.0000895	11300	4.05	28
0.00023	0.25	0.000047	21000	4.36	4.32	0.187	0.000043	23200	4.36	
0.00016	0.5	0.00008	12500	4.2	4.09	0.5	0.00008	12500	4.09	
0.000032	Nil	—	—	5.5	—	Nil	—	—	—	—

TABLE XII—CENTRAL ADAPTATION

WHITE SECTORS					69 per cent. White Screen					BLACK SECTORS				
A	W	A W	$\frac{1}{A W}$	$\log \frac{1}{A}$	$\log \frac{1}{A W}$	B	A B	$\frac{1}{A B}$	$\log \frac{1}{A B}$	Graph reference				
160.0	0.0056	0.896	1.1	2.2	0.04	0.0053	0.848	1.2	0.07	35				
19.0	0.0056	0.106	9.4	1.27	0.97	0.0053	0.1007	9.9	0.99	34				
8.75	0.004	0.035	29	0.93	1.46	0.0062	0.054	18.0	1.25					
2.75	0.008	0.022	46	0.43	1.66	0.0091	0.0243	40	1.6					
1.15	0.004	0.0046	217	0.06	2.33	0.0062	0.0072	139	2.14					
0.445	0.0088	0.0039	253	1.65	2.4	0.0062	0.0028	357	2.55	33				
0.188	0.0176	0.0033	300	1.27	2.47	0.015	0.0028	357	2.55					
0.125	0.0062	0.00077	1290	1.09	3.11	0.0062	0.0028	1290	3.11					
0.055	0.0088	0.00044	2250	2.74	3.35	0.0122	0.00067	1490	3.17					
0.052	0.0088	0.000457	2170	2.71	3.33	0.0122	0.00063	1590	3.2	32				
0.031	0.013	0.0004	2500	2.49	3.39	0.0122	0.00035	2850	3.45					
0.026	0.027	0.0007	1430	2.41	3.15	0.0275	0.00072	1400	3.14					
0.0032	0.15	0.00048	2060	3.5	3.31	0.172	0.00054	1852	3.26					
0.00051	0.51	0.000108	9121	4.7	3.96	0.51	0.00026	3840	3.58	32				
0.00021	Nil	—	—	4.32	—	0.69	0.000145	6900	3.83					

TABLE XIII—CENTRAL ADAPTATION

WHITE SCREEN

A	B	A B	$\frac{1}{A B}$	$\log \frac{1}{A}$	$\log \frac{1}{A B}$	Graph reference
200	0.007	1.4	0.7	2.3	1.84	40
160	0.007	1.12	0.9	2.2	1.95	
100	0.0065	0.65	1.5	2.0	0.176	
60	0.0065	0.384	2.6	1.77	0.41	
14	0.007	0.098	10.0	1.14	1.0	
3.5	0.007	0.0245	41	0.54	1.61	39
1.4	0.007	0.0098	102	0.146	2.0	
0.65	0.007	0.00455	222	1.81	2.34	
0.175	0.0069	0.0012	825	1.24	2.91	38
0.1	0.0069	0.00069	1420	1.0	3.152	
0.06	0.0069	0.000414	2417	2.77	3.38	
0.04	0.02	0.0008	1250	2.6	3.09	
0.0041	0.16	0.000656	1526	3.61	3.18	
0.00065	0.25	0.000162	6150	4.81	3.79	37
0.0004	0.5	0.0002	5000	4.602	3.69	
0.000276	0.31	0.000085	11700	4.44	4.06	36
0.00003	Nil	—	—	—	—	—

The central adaptation will be considered from three points of view. (1) The behaviour of the eye in the single experiments. (2) The curves showing the summation of the results of these under different illuminations. (3) Some mathematical considerations.

(1) An inspection of the graphs 18-40 showing the progress of adaptation in the individual experiments gives these results. With the velvet screen the progress is fairly steady and uniform during the half hour, the slope on the whole being less steep than with other screens but a greater height being reached. An exception is the test with .000156 ft. candle (sensitivity=75000) illumination, where the maximum sensitivity is reached at 20 minutes and so can rise no higher.

The three grey screens, with the exception of the white sector in a 31 per cent. white screen value of .00174 ft. candles, show a rise to the maximum before 30 minutes, most of them a quicker rise but a decreased height as the screen contains more white.

The white screen tests conform to the quick rise to the maxima, but are less quick than the grey screens and have a higher rise.

Thus there is a general principle that the presence of the white in the screen causes a quicker rise but a lesser height as compared with the velvet screen. The greater rise of sensitivity in the white as compared with 69 per cent. white screen is probably psychical. The problem presented is simpler; only one possibility is presented, that of dark difference; a less difficult problem than dealing with slight differences in two directions. The quicker central rise with screens containing white forms a contrast with the slower rise of sensitivity under similar circumstances in the field graphs E-I.

In considering the graphs and tables it must be remembered that in the lower illuminations it sometimes happens (*e.g.*, 50 per cent. screen (Graph 28) $A = 0.00016$ ft. candles—sensitivity 12500) that no difference is perceived for some time, and that the first result may be the final result or nearly so. Near the highest sensitivity point (*e.g.*, lowest perceived illumination) the range of sensitivity may be very narrow during adaptation.

(2) The summation curves J to N show the variations in light and dark differences at various illuminations for the five screens; each point on the curves is the maximum found for a particular experiment. As in the field experiments, with the grey screens there are two possibilities, a white and a black difference, each of which is separately plotted on the same graph; for the black and white screens only one graph is required.

In the adaptation summary and log graphs the graph for white difference is continuous, that for the black difference is interrupted.

One characteristic of all the summation graphs is the very steep rise of sensitivity as the illumination becomes lower. This continues through the whole series of points in any one graph. Although the part of the graphs corresponding with the higher illuminations appears flatter, this is only apparent, not real; as is shown by the special inset graph for the higher illuminations, which has the same shape as for the lower. The steep rise in the summation curves is a mathematical result of taking the reciprocal

$\left(\frac{1}{A W} \text{ or } \frac{1}{A B}\right)$ as the co-ordinates.

e.g., let $A W = 1. \frac{1}{A W} = 1$

let $A W = \cdot 01 \frac{1}{A W} = 100$ and so on.

As will be shown later, if Weber's law holds, W . is constant, and the sensitivity will vary inversely as A , the light value of the screen.

There is a progressive fall in the maxima for different backgrounds, passing from velvet, as they contain more white, up to 69 per cent. white; but a slight rise from this to white.

TABLE XIV—MAXIMUM SENSITIVITY

SCREEN	WHITE SECTOR		BLACK SECTOR	
	AW	$\frac{1}{A W}$	A B	$\frac{1}{A B}$
Velvet	0'0000132	75000	—	—
31 per cent. White	0 0000312	32000	0'000052	19200
50 per cent. White	0'000047	21000	0'000043	23200
69 per cent. White	0'000108	9121	0'000145	6900
White	—	—	0'000085	11700

In this property the summation graphs show the same characteristic as the graphs for the individual experiments; as would be natural if the results of the tests were consistent.

An inspection of the summation graphs shows that the velvet screen gave the most consistent curve, the white screen being next in order. The irregularity of the latter is between 0.04 ft. candles and 0.1 ft. illumination, where there is an apparent slight rise in sensitiveness. The three grey screen results are more irregular than the white screen, especially the 31 per cent. screen; in which there are three small intermediate peaks and the black and white sector graphs cross twice. The 50 per cent. graph shows no intermediate peak, but a decided variation in the height of the black sector graph above that for the white sector.

The relative position of the white and black sector graphs varies much in the three grey screens, but is most consistent in the 50 per cent. screen, where the black is above the white graph. On the whole, it can be stated that there is not a great difference between the black and white light differences with these screens; it is better to assume that the irregularities are due to errors of observation, owing to the difficulty in detecting small differences on a grey background, but that in the 31 per cent. and 69 per cent. white the sensitivity is generally less for black than for white differences in the low illuminations. While this would seem natural for the 31 per cent. screen, with less contrast between the screen and the black sector, it is not what would be expected in the 69 per cent. screen, where there was a greater contrast between the screen and the black sector.

LIGHT AND DARK ADAPTATIONS

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(3) *Mathematical considerations.*—The summation curves, made up of a number of estimates of the least light difference under varying degrees of illuminations, with varying backgrounds, are really tests of Weber's law, from which Fechner's law is a mathematical deduction.

These graphs have for abscissae the illuminations of the disc (A) and for co-ordinates the light difference reciprocals of the sectors $\left(\frac{1}{A. W.} \text{ or } \frac{1}{A. B.}\right)$ or annulus in the case of the velvet screen.

Fechner's law is usually shown in a graph with the logs of the variations in the stimulus as the abscissae, and the least differences of stimuli observed as the co-ordinates, or their reciprocals, accord-

ing to whether the recorder wishes to state the actual differences or fineness of sensitivity.

In the present series it is submitted that the better plan is to plot the logs of the sensitivities against those of the illuminations, as this gives a straight line graph while Weber's law prevails, as the following considerations show:—

Let n be any number.

$$\frac{1}{n} = R \text{ (reciprocal), then } \log 1 - \log n = \log R.$$

$$- \log n = \log R.$$

and a graph of these will give a straight line slope. $\frac{\log R, \text{ of}}{- \log n}$

value $\frac{1}{1}$, the slope progressing negatively relatively to n .

Summation Graphs (Logs Values)

$$\frac{1}{A W} = \frac{1}{A} \times \frac{1}{W}$$

$$\text{Log } \frac{1}{A W} = \text{Log } \frac{1}{A} + \text{Log } \frac{1}{W}$$

$$\text{Log } \frac{1}{A} = - \text{Log } A \text{ (see above).}$$

W being the least proportional difference perceived in the experiments, and being a constant if Weber's law holds.

The slope of the graph is

$$\frac{\text{Log } \frac{1}{A W}}{\text{Log } A} = \frac{\text{Log } \frac{1}{A}}{\text{Log } A} + \frac{\text{Log } \frac{1}{W}}{\text{Log } A}$$

and must remain unchanged since

$$\text{Log } \frac{1}{A} = - \text{Log } A \text{ and } \text{Log } \frac{1}{W} \text{ is a constant.}$$

Therefore the graph is a straight line as long as it obeys Weber's law.

Thus the advantage of plotting the logs against each other is that, allowing for experimental errors, a deviation in the graph from a straight line shows when Weber's law ceases to be true, while the slopes show the value of the increment of decrease or increase of light difference with varying backgrounds.

If the log values of the light differences $\left(\frac{1}{A.W.} \text{ or } \frac{1}{A.B.} \right)$ be divided by the log light value (A) the slope is found, and can be expressed as an angle. The co-ordinates in the log graphs are $\text{Log } \frac{1}{A.W.}$ values, the abscissae $\text{Log } A$ values; W (or $B.$, as the case may be) being the constant in Weber's law.

The following table shows the range in logs of Weber's law with varying backgrounds, and the slope values and angles found in these ranges:—

TABLE XV—WEBER'S LAW RANGE (Chart T)

Screen	$\frac{\text{Log Sensitivity}}{\text{Log Illumination}} = \frac{\text{Range Log } \frac{1}{A} W}{-\text{Log } A}$		Slope	Angle
Velvet	$\frac{4.87 - 0.51}{3.81 + 2.4}$	$\frac{4.36}{5.95}$	0.73	36°
31 per cent. White	$\frac{3.31 - 1.92}{1.26 + 0.176}$	$\frac{1.39}{1.436}$	0.96	43° 48'
50 per cent. White	$\frac{4.32 - 0.45}{3.64 + 1.94}$	$\frac{3.87}{5.58}$	0.695	34° 48'
69 per cent. White	$\frac{3.35 - 0.04}{1.26 + 2.2}$	$\frac{3.31}{3.46}$	0.953	43° 40'
White	$\frac{3.38 + 0.16}{1.23 + 2.3}$	$\frac{3.54}{3.53}$	1.003	45° 6'

The succeeding table shows the logs of Table XV reduced to ordinary numerals.

TABLE XVI—WEBER'S LAW RANGE

Screen	Range of Sensitivities	Range of Least Differences	A
	$\frac{1}{W A}$ or $\frac{1}{B A}$	$\frac{W A}{\text{Foot candles}}$ or $\frac{B A}{\text{Foot candles}}$	Foot candles
Velvet	75000 - 3.3	0.0000132 - 0.3	0.000156 - 140.0
31 per cent. White	2026 - 84 (W)	0.00043 - 0.0118 (W)	0.055 - 1.5
50 per cent. White	21000 - 2.85 (W)	0.000047 - 0.35 (W)	0.00023 - 87.5
69 per cent. White	2170 - 1.1	0.000457 - 0.896 (W)	0.031 - 160
White	2147 - 0.7	0.000414 - 1.4 (B)	0.06 - 200

(W) = White difference. (B) = Black difference.

For convenience a summary of the complete ranges investigated is shown.

TABLE XVII

Screen	Ranges of Sensi- ivities		Ranges of Least Difference		Ranges of A (ft. candles)	Zero of Sensitivi- ties A
	$\frac{1}{W A}$	$\frac{1}{W B}$	W A	A B		
Velvet	75000 - 3·3	—	·0000132 - 0·3	—	·000156 - 140·0	·0000315
31 per cent. white	32000 - 11	19200 - 13	·0000312 - 0·091	·000052 - 0·073	·0002 - 35·0	·00084 B
50 per cent. white	21000 - 2·85	23200 - 9·5	·000047 - 0·35	·000043 - 0·105	·00023 - 87·5	·000032
69 per cent. white	9121 - 1·1	900 - 1·2	·000108 - 0·896	·000145 - 0·848	W ·00051 - 160·0 B ·00021 - 160·0	·00021 W
White	—	11700 - 0·7	—	·000085 - 1·4	·000276 - 200·0	·00003

The normal shape of a curve dealing with a response to a varying stimulus is:—A gradual rise passing into a more or less steep slope, a rounded top, a more or less steep descent, passing by a less steep slope to zero. Doubtless the log summation curves should show this form theoretically, but some factors at work introduce difficulties. An inspection of the log graphs and tables will show that zero sensation is reached between 4·45 and 5·4 (A values), the sensitivity drop being from log 4·87 (black) and log 3·83 (black sector 69 per cent. screen) to infinity. Inevitably the fall is very steep and must approach a straight line, impossible to register with the means at one's disposal, since it meant an integration of sensitivity between 0·000156 and 0·00003 ft. candles. Moreover, correct judgment in these low illuminations is greatly interfered with by the intrinsic light production in the retina, which makes sensations very similar to those caused by real light differences.

At the other end of the curve difficulties of dazzle arise. Here the subjective sensation with the white screen at 200 ft. candles illumination was of the white of the screen flowing in and obliterating the light difference perceived, so that the latter was seen momentarily and then erased. Nevertheless, Weber's law held good for this particular value.

Thus of the two ends of the curves it may be said that the method of their terminations is uncertain, but that the fall for low

illuminations is very steep and that the decrease of slope for high illuminations is not marked, though shown best in the log curve for the 31 per cent. screen. It is assumed in Graph T that the final fall in sensitivity with low illuminations follows Weber's law, it cannot deviate greatly.

For the purpose of Weber's law the five graphs fall naturally into two groups according to the slope, one comprising the velvet and 50 per cent. screen graphs with slopes of 36° and $34^\circ.8'$ respectively, the other of the 31 per cent., 69 per cent., and white screens with slopes of $43^\circ.48'$, $43^\circ.40'$, and $45^\circ.6'$ (see Graph T and Table XV).

The velvet and 50 per cent. screens give the longest range for Weber's law, from the highest illumination used to the apices of the curves the law holds. Moreover, the ascents are nearly

parallel. If the value of the velvet screen line be taken in the same vertical line as apex of the 50 per cent. ($\text{Log } A = 4.36$), it is found to be $\log 4.7$, = 50000 sensitivity as against 21000 for the 50 per cent., rather more than twice as much.

If, similarly, the numerical value of the sensitivities of the differences of these two screens be taken corresponding to $\log A = 1.95$, they are :—

Velvet screen 5
50% „ 2.85

The middle term is given by $A = .1$ ($\text{Log } T.0$), where the sensitivities are :—

Velvet screen 631
50% „ 315

the difference being 50 per cent., as are the screens, the 50 per cent. screen giving a sensitivity value half of that of the velvet screen.

The 69 per cent. and the white screen are also practically identical in slope, the angles being $43^{\circ}.40'$ and $45^{\circ}.6'$ respectively. They are nearly identical in extent towards the lower illuminations, the difference being within the margins of error. But the range of Weber's law is much less than with the velvet and 50 per cent. screens, the upper range of sensitivities for this being:—

69% — 2250
White 2417

Above this range the log graphs for these screens remain in close agreement, so that their apices are very near each other.

The 31 per cent. screen has the least range for this law, between A values of log 0.6 and $\bar{2}.74$, with sensitivities 84 and 2026 respectively. Above this range the slope is lessened till the apex is reached between the velvet and 50 per cent. peaks. A similar loss of slope below the Weber's law range places the 31 per cent. graph above the velvet screen graph for the higher illumination (A) values.

Excluding the 31 per cent. screen, the change of angle does not occur at the middle term (50 per cent.) of the series, but between it and the 69 per cent. screen.

The relative positions of the peaks and lower ends of the five graphs require some consideration. In the Graph showing the extent of Weber's law the peaks of the 31 per cent., 69 per cent., and white screen graphs are indicated—those for velvet and 50 per cent. are shown as the upper range for the Weber's law. It will be seen that their order from above down is:—

Velvet	Log 4.87	Sensitivities 75000
31% white	„ 4.5	32000
50% „	„ 4.32	21000
69% „	„ 3.96	9121
White	„ 4.06	11700

the last two being as logs nearly equal.

But if a vertical section be taken at $\bar{3}.5$ position, corresponding with the 69 per cent. screen peak, it will be seen that the white screen graph is at the same level as the 69 per cent. graph. So that comparing these two graphs in different positions, it will be seen that they are always near each other and cross once—they may be taken as practically equal for any given illumination within their common range.

Light Adaptation.—With the exception of the 31 per cent. screen graphs, Weber's law holds at the lower ends of the graphs, corresponding to the higher illuminations, as far as the experiments were taken. As the middle of the room in which the

experiments were conducted was illuminated by daylight to about 10 to 20 ft. candles, the graphs for values of A above 20 ft. candles (log 1.3) become studies in light adaptation. As pointed out above, Weber's law holds for these illuminations except for screen 31 per cent. white. The great majority of the final light differences with screens except velvet were reached in 10 minutes, only occasionally were they reached after 15 or 20 minutes. This is shown in the graphs 23-40 of the individual tests.

It is to be noted that at log A = 0.05 all the graphs coincide except that for the 50 per cent. screen, with a sensitivity value of

$\log \frac{1}{A \cdot W}$ and $\log \frac{1}{A \cdot B}$ of $2.0 = 100$, A being 1.12 ft. candles.

The results of the log graphs are that :—

(1) The apices show a decrease in height as there is more white in the screen till 69 per cent., after which there is a slight rise for the white screen.

(2) Weber's law holds over a wide area of illumination from 140 to 0.000156 ft. candles for the velvet screen, 87.5 to 0.00016 for the 50 per cent. screen with a slope of 0.73 and 0.69 respectively.

(3) For the white and 69 per cent. screens the slope for Weber's law is steeper, shorter and practically identical with each other.

(4) The 31 per cent. screen graph behaves erratically. In the short extent in which Weber's law holds it agrees with the white and 69 per cent. screens almost exactly. Above this it gradually reaches an apex between those for the black and 50 per cent. screens, but not in any closely proportional position. At its lower end it is again anomalous in that it is above the velvet screen graph, so that it behaves in its whole extent more like the typical sensation curve than the others, within the range of illuminations used; but only at the expense of its conformity with Weber's law.

The experiments on the grey screens and central perception have no present practical bearing upon the light threshold and light difference as at present used. They have an interest inasmuch as they indicate that the amount and kind of response which exists with the black and white screens spreads in and meets somewhere between the 50 per cent. and 69 per cent. screens, and not at the 50 per cent. screen as might have been expected. That this is the case with the range of Weber's law, as well as the difference of slope, points to an essential difference in the reaction to small differences of stimulus with black and white backgrounds respectively.

In considering the two tests of light difference and light threshold there are some practical points upon which there is no general agreement, with the resultant that only vague comparisons can be made between different observer's results. It would seem

very important that standards should be set up, so that the tests should be as comparable as in the ordinary visual field or central vision tests. The following points require consideration :—

- I. The size of the illuminated area.
- II. The illumination, its kind and method of variation.
- III. The distance of the observer.
- IV. The duration of adaptation.
- V. Daylight threshold tests.
- VI. Standards of normality.

Speaking generally, these should be made to conform as measurements to the metric system; that is, they should be convenient parts or multiples of metric standards.

I. The size of the illuminated area. In the present experiments a sector of 0.75 cm. radius was used. Perhaps it would have been simpler to have chosen 1 cm. or 0.5 cm. as the radius, as in the annulus method. This aims at testing the foveal and parafoveal areas only. Ferree, Rand and Stoll (ref. *a*) intentionally use a much larger area, to include a portion of the field outside the parafoveal area. This they do following on their demonstration that this larger area is more sensitive per unit area than the more central portion. Granted this greater sensitivity, it would seem better to keep the inner and outer areas distinct in testing rather than use two areas of different sensitivities together in one test. The results of the field tests for dark adaptation would point to this method as useful for testing the field sensitivity apart from the central region.

II. Should the illumination in the threshold test be reflected from the test object, as in Forster's original method and as used in the present work, or be transmitted through it as in Nagel's apparatus? The writer used reflected light in all these experiments, largely on the score of expense, the apparatus was easily and cheaply constructed. That it answered its purpose is shown by the range of Weber's law found. For the threshold test electric light is best, it can be graduated by an iris diaphragm and smoked glasses.

For the light difference test daylight answers admirably, avoiding the use of a room especially prepared, which is impracticable for most clinicians. But for comparable results a photometer is necessary.

A two metre square white screen is necessary to give the necessary uniform background in the light difference test if the distance is one metre.

The light adaptation tests were made in diffuse daylight in the consulting room, with the white screen about 1.25 metres from the window, this answered excellently. In this country it would be unusual to get more than 150 ft. candle daylight illumination of

the screen. However the latter be lighted, 150 ft. candles would be quite enough to give a reliable result without dazzle, the latter making the results uncertain at high illuminations.

III. In the present work one metre was the distance between the observer and the object. This is a simple measurement and greatly eases calculations.

IV. The time allowed for adaptation is important; half-an-hour should be allowed for dark adaptation, a quarter-hour for light adaptation. Most observers agree that the greater part of central dark adaptation occurs in half-an-hour, but beyond this a slight gradual rise continues for a further 40 or 60 minutes. An inspection of the individual graphs for the velvet screen confirms the steady rise in most cases during the half hour given to each experiment, while the conformity with Weber's law in this series gives a further reason for considering this time sufficient; anything short of this will run a great risk of error. Moreover, it is very important that any clinical test should be reliable, the implications are so important. The steady rise during the half hour has been confirmed in other cases than the writer's eye, in searching for a normal standard, under the same conditions as these experiments.

The question whether any safe deduction can be made from an observation made on the light threshold under ordinary daylight is difficult. The graphs illustrating Weber's law show that this obtains with a velvet or white background at high illuminations, in a normal eye the constant W (or B) holds. It is this constant which is measured in Percival's disc test, the light factor being omitted. But the crucial question is whether the sensitivity continues to follow this law in the lower illuminations. Certainly this is not so always, as in a glaucoma case in which by the ring test in daylight the threshold was normal, but a test in the dark room during half-an-hour showed a very great diminution of threshold sensitivity. So that no safe deduction can be made from a normal threshold result in daylight; greatly reduced illumination is necessary.

V. As in other functions of the body, there is no hard and fast normal in the light threshold. Even a moderate departure from the usual may not be pathological, as long as the sensitivity which exists is sufficient for the ordinary duties of life under reduced illumination. The speed of adaptation, and the consequent manner in which sensitivity rises, may not affect the ultimate threshold reached, but may be most important in elucidating difficulties from which people suffer. Yet it is the final result which is the criterion of the threshold. It is evident that there are many aspects of this subject, but a preliminary to their accurate investigation is the adoption of standards, so that the work of different observers should be co-ordinated.

Comparison of Peripheral and Central Adaptation

(a) In each there is a lowering of sensitivity at the onset of decreased illumination, followed by an increase after a lapse of time; usually 10-15 minutes for the field, 30 minutes for central perception with the velvet screen, less with those having a proportion of white in the screen.

The essential differences between these two sets of tests are:—

(b) In the field test the object is moved, in the central it is fixed; in the field test the increased sensitivity is registered spatially, in the central as an increase in intensity of sensation. But it should be noted that, if any one spot in the field be taken, this would show an increase in intensity of sensation, as shown in the graphs A-I for the adapted eye, as compared with the graphs 1-17.

(c) In the field test the object has a fixed proportional value, in the central test this is altered as the adaptation progresses.

(d) While the central adaptation follows to some extent Weber's law, no mathematical formula was found to express the field adaptation.

(e) A tendency to exhaustion was found in the field which was never noticed in the central tests, the portion of the field tested extending to 45° from the line of vision. This is striking, for this was the 3/1000 field, which is relatively the most stable portion of the field in glaucoma and cavernous atrophy, thus contrasting with the tendency to exhaustion under physiological conditions.

If it be assumed that in the field adaptation tests the exhaustion is in the retinal visual elements, and that in glaucoma and cavernous atrophy the resistance is in the nerve fibres, a feasible explanation is found.

In conclusion the writer wishes to express his thanks to Professor Newman, D.Sc., of the University College of the South West, for much help and advice during the conduction of these experiments.

A CASE OF UNILATERAL ANOPHTHALMOS WITH A CYST

BY

KANJI KANDA

JAPAN

ANOPHTHALMOS is one of the rare congenital anomalies in which, in spite of the name, a small or rudimentary eyeball is found usually in the lower lid. It is bilateral in almost all cases; and if the orbital integument is prolonged and covers the partially developed eyeball, then it is called cryptophthalmos.