Visual adaptation in relation to brief conditioning stimuli

BY B. H. CRAWFORD, M.Sc.

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Measurements are made of the changes in state of visual adaptation before and after a change in conditioning stimulus. Liminal test stimulus is used as a measure of visual adaptation. It is found that the liminal test stimulus begins to rise 0.1 sec. before the eye is exposed to the conditioning stimulus. The regularity of the rise of liminal test stimulus with decrease of the interval between it and the conditioning stimulus precludes any purely psychological explanation, and the effect is presumed to be due to some nervous interaction in the higher centres of visual reception. The paper further records results of measurement of liminal test stimulus after exposure of the eye to conditioning stimuli of brief duration (recovery of dark adaptation) under a wide variety of conditions, including reversal of test field contrast, effect of superimposed steady background, effect of area of test field, use of equivalent background transformation, personal variation, effect of intensity of conditioning stimulus, effect of spatial and temporal pattern of conditioning stimulus, colour of conditioning stimulus, etc.

INTRODUCTION

The present paper includes accounts of a number of experiments, carried out during various wartime investigations, the results of which extend the range of knowledge of changing visual adaptation. The experiments fall naturally into two groups, a small one including changes in visual adaptation which occur before a change in conditioning stimulus, and a larger one including changes in visual adaptation after the cessation of a more or less brief conditioning stimulus.

Definitions. The stimuli falling upon the retina are described in terms of the external field of view as seen by the subject of the experiment. The conditioning stimulus is the illumination of a large or small part of the field of view which alters the state of adaptation of the eye. The test stimulus is the illumination of a limited part of the field of view whose least perceptible brightness at any particular moment is used as a measure of the state of adaptation of the eye at that moment.

I. CHANGES IN VISUAL ADAPTATION OCCURRING BEFORE A CHANGE IN CONDITIONING STIMULUS

The experiment to be described was originally designed to ascertain whether, on cutting off a conditioning stimulus, there was a discontinuous change in adaptation or whether the state of adaptation changed continuously, though perhaps rapidly, in the period immediately following cut-off. In fact, a continuous change was found, but in addition there occurred the still more interesting phenomenon of a change in state of adaptation before the conditioning stimulus was cut off, also before it was put on.

Apparatus. The plan of the apparatus used is shown in the diagram of figure 1. A single lamp ($B_1$) supplies light for both conditioning and test stimuli. The most
important feature of the apparatus is that the conditioning and test beams are brought to fine foci at the points \( I_c \) and \( I_T \) respectively, where they can be intercepted by a pair of sector disks \( (S) \) mounted on one spindle. This ensures very accurate relative timing of the exposures of the stimuli. The sector disks used are shown in figure 2. Their speed of rotation was controlled stroboscopically, as a synchronous motor was not available at the time, the stroboscopic disk being a

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**Figure 1.** Plan of apparatus, diagrammatic, approximately to scale. \( B_1 \), motor-car headlamp bulb, line filament horizontal, source of light for conditioning and test fields; \( B_2 \), flash-lamp bulb, source of light for fixation points; \( S \), sector disk (see also figure 2); \( P \), reflecting prisms; \( L \), lenses; \( W \), neutral wedges; \( F \), neutral filters; \( D \), diaphragms; \( M_1 \), pellicle mirror; \( M_2 \), plain glass mirror, small angled prism; \( O \), opal glass; \( E \), eye of subject.

**Figure 2.** Sector disks used in apparatus of figure 1. There are two disks superimposed; their relative positions can be altered at will, then clamped and the two disks rotated as one. \( S_c \), sector disk for conditioning field beam; \( S_T \), sector disk for test field beam; \( I_c \), focused image in conditioning field beam; \( I_T \), focused image in test field beam; \( A \), apertures in \( S_c \) to clear the opening of \( S_T \).
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6 in. diameter celluloid protractor marked in half degrees. Illuminated by a neon lamp run from the 50 cycle mains, this gave a period of rotation of the sectors of 7·2 sec. Such a period is convenient for the purpose in hand. The conditioning stimulus occupied a period of 0·524 sec., the test stimulus of 0·010 sec. In carrying out an experiment, the whole cycle of operations—exposure of conditioning stimulus, exposure of test stimulus—was repeated every 7·2 sec., adjustment of intensity of test stimulus being made each time until the threshold value was determined. The period between conditioning and test stimuli was measured for each setting of the relative positions of the sector disks by rotating them slowly and observing the protractor markings through a reading microscope. One division corresponded to 0·010 sec. and interpolation to 0·001 sec. could be easily made with the magnification used.

The angular size of the conditioning field was 12°, of the test field 0·5°. The latter was fixated centrally, so that the following results relate to foveal vision.

Results. These are shown by the curves of figure 3 for the right eye of one subject, B.H.C. The conditioning field was exposed at zero time and cut off at 0·524 sec. The points indicate the times at which the test field was exposed and the corresponding brightnesses at which it was just visible. Negative times indicate exposure of test stimulus before exposure of conditioning stimulus. The most striking result is that the liminal test stimulus begins to rise before the conditioning stimulus is applied to the eye, the first appreciable increase occurring nearly 0·1 sec. before exposure of the conditioning field. A substantial increase of about 10 to 1 is found at 0·02 sec. before exposure of the conditioning field. These intervals before exposure of the conditioning field were measured between the end of the test-field exposure and the beginning of the conditioning field exposure and so represent the period of complete darkness intervening between the two exposures. There is thus no doubt as to the reality of the effect. Some indication of such an effect had been found in earlier work (Stiles & Crawford 1934), but the present measurements place it beyond all doubt.

There seem to be two possible explanations. Either the relatively strong conditioning stimulus overtakes the weaker test stimulus on its way from retina to brain and interferes with its transmission; or the process of perception of the test stimulus, including the receptive processes in the brain, takes an appreciable time of the order of 0·1 sec., so that the impression of a second (large) stimulus within this time interferes with perception of the first stimulus.

It will be noted, in the case of the highest conditioning field brightness, a small rise of liminal test stimulus also occurs before the conditioning stimulus is cut off. Thus it would seem that cessation of a stimulus affects the perceptive mechanism of the brain in the same way as initiation of a stimulus, though to a much smaller degree as measured by the ratio of test stimuli.

As already mentioned, the original object of this experiment was to ascertain whether there was any discontinuous change in adaptation (as measured by liminal test stimulus) on cessation of a conditioning stimulus. The results show that there
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is no discontinuity greater than the probable error of the measurements (about ± 7 %), though the initial rate of fall of liminal test stimulus is very rapid.

The last point to be noted is the high value of liminal test stimulus when the conditioning stimulus is first applied, which then diminishes continuously towards an equilibrium value. With the period of exposure of conditioning stimulus used, about half a second, equilibrium is not attained, but sufficient of the curve is obtained to show that it consists of two parts, an initial rapidly falling part followed by one of more gradual slope. The rapid fall is over in about 0·1 sec., and it may be significant that this period is of the same order as that noted above for the rise of threshold before exposure of the conditioning stimulus.

II. Changes in visual adaptation occurring after a change in conditioning stimulus

In this part of the work the conditioning stimulus was intended to simulate a gunflash and took the following forms:

(a) a single brief flash covering about 60° of the central part of the field of view;
(b) a single brief flash covering a small area away from the direction of view;
(c) a series of brief flashes at regular time intervals covering about 60° of the central part of the field of view.

The magnitude of the conditioning stimulus was measured as the time integrated brightness in candle seconds per square foot ((a) and (c) above) or the time integrated illumination at the eye in foot-candle seconds ((b) above).

The state of visual adaptation was measured by the least perceptible brightness of a test field. Because the original aim of the experiments was to throw light upon certain practical problems, the test field was not fixated in any particular way: it was left to the subject of the experiment to view the test field in whatever way pleased him best. It is interesting to note that in spite of this lack of control of fixation very consistent readings were usually obtained; this implies that a subject tends to adopt, with fair accuracy, that mode of fixation which gives the greatest sensitivity under any given conditions.

Apparatus and methods. The apparatus was modified slightly from time to time to adapt it to the various experiments, but the basic elements remained the same and will now be described. The conditioning stimulus was obtained by flashing on and off two 40 W lamps on a 230 V circuit, timed by a rotating contact drum driven by a synchronous motor. The rate of heating and cooling of such lamps is sufficiently rapid to give a fairly well-defined flash of about 0·1 sec. duration. The lamps for the conditioning stimulus were placed one opposite each eye in small internally whitened boxes with opal glass fronts, thus covering an extended area of the field of view. When used as glare sources away from the line of sight the bare lamps were used.

After the conditioning stimulus, which appeared a little below the horizontal line of sight, the subject looked quickly up to view the test stimulus, an illuminated
disk subtending 0·5° at the eye, the brightness controlled by neutral filters and wedge. In this way, readings of liminal test field brightness could be obtained from about a second after the conditioning stimulus onwards.

For the shorter recovery times, up to about 15 sec., the test stimulus was fixed at a given value and the time interval measured between end of conditioning stimulus and first pick-up of test stimulus. After about 15 sec. the subject, who then had the brightness of the test stimulus under his control, made settings for liminal visibility of the test stimulus at intervals which were noted by the experimenter. All the results can then be plotted as a single recovery curve of liminal test stimulus (or threshold) against time after conditioning stimulus.

II (1) Effect of reversed contrast

Apparatus was set up in which either a black or a white disk could be placed on a grey background whose reflexion factor was adjusted to be half that of the white disk. When the whole was illuminated uniformly the contrast between the black disk and the background was +1·0, while the contrast between the white disk and the background was −1·0, contrast being defined as

\[
\frac{\text{brightness of background} - \text{brightness of object}}{\text{brightness of background}}
\]

The diameter of either disk subtended 0·5° at the eye.

Recovery curves were determined as described above, except that in this case the test stimulus included both background and disk. The results for two subjects are shown in figure 4. All the experimental points are plotted separately, and it is evident from inspection that there is nothing to choose between the results for positive and negative contrast of object against background. This extends to the case of changing state of adaptation, a result hitherto established only for a steady state of adaptation.

II (2) Effect of steady illumination of field of view

Earlier work (Crawford 1937) indicated that a simple relation exists between the recovery of the eye to complete dark adaptation (zero field brightness) and recovery to partial dark adaptation (finite field brightness): the curve of recovery to partial dark adaptation follows the curve of complete dark adaptation until the threshold corresponding to the finite field brightness is nearly reached, then rapidly flattens out and becomes horizontal. The same relation has been extended to the present experimental conditions (binocular recovery from a brief flash, eye pupils and fixation unrestricted). The results for two subjects are shown in figure 5.

II (3) Effect of area of test stimulus

By means of a curve of threshold against background brightness, a recovery curve of threshold against time may be transformed into one of background brightness against time. The background brightnesses are now qualified as 'equivalent',

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and threshold values have been eliminated, formally, from consideration (Luckiesh & Holladay 1925; Holladay 1927; Stiles 1929; Stiles & Crawford 1932; Crawford & Stiles 1935; Stiles & Crawford 1937). The elimination is not only formal, however, but real in many aspects. The one now to be discussed is the effect of size of test object on recovery time.

![Graph](image_url)

**Figure 4**

The experimental work was conducted as follows:

Six test objects were made, circular disks whose diameters subtended at the subject's eye angles of 0.18°, 0.36°, 0.72°, 1.43°, 2.90° and 5.7°. For each object a curve of threshold against background brightness and a recovery curve (zero background brightness) from a brief conditioning stimulus of 48 c.sec./sq.ft. were determined.
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The results are shown in figures 6 and 7. From these experimental curves, recovery curves of equivalent background brightness against time have been deduced, and these are shown in figure 8. It will be seen that the recovery curves for the different sizes of object, originally widely separated, are now coincident within experimental error. The effect of size of object may thus be eliminated by the use of the equivalent background transformation. In a later section (9) it will be shown that it is possible still further to extend this method, with great practical convenience.

**Figure 5**

II (4) Variation between observers

Recovery curves under standard conditions were obtained for twenty-six subjects chosen at random. The standard conditions were: test field, circular, 3° diameter seen against background of zero brightness; conditioning stimulus, brief flash of
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48 c.sec./sq.ft. covering about 60° of the field of view. Three or four runs were made by each observer so as to obtain a representative mean performance. They were made at one sitting, however, so that day to day variation is not included. The results are given in table 1.

Considerable personal variation is shown by these results, and it is interesting to note that an individual may be quick in recovery through the whole process, slow through the whole process, quick at first and slow at the end, or slow at first and quick at the end, relative to the mean performance. Or, in other words, all possible types of recovery curves have been found in a comparatively small group of subjects. For seven of the subjects the equivalent background transformation was made, so that curves of equivalent background brightness against recovery
time were plotted. There was, however, no reduction of personal variation, and in this case the equivalent background transformation is not of value. This indicates that there are real differences in rate of recovery of the photochemical mechanism of the eye, not only differences in the general level of sensitivity.

### Table 1

<table>
<thead>
<tr>
<th>subject</th>
<th>0-00001</th>
<th>0-00003</th>
<th>0-00001</th>
<th>0-000003</th>
<th>0-000001 c./ft.²</th>
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<td>48</td>
<td>83</td>
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<td>280</td>
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<td>87</td>
<td>120</td>
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<td>39</td>
<td>68</td>
<td>155</td>
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<td>22</td>
<td>30</td>
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<td>49</td>
</tr>
<tr>
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<td>52</td>
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<td>geometric mean</td>
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<td>probable variation of a single subject from mean</td>
<td>± 20%</td>
<td>± 25%</td>
<td>± 30%</td>
<td>± 40%</td>
<td>± 50%</td>
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</table>

II (5) **Relation between brightness of conditioning stimulus and recovery time**

Recovery curves were determined by two subjects for a wide range of conditioning stimuli of constant duration but of brightness varying from 0.0005 to 140 c/sec./sq.ft. The test stimulus was an illuminated disk subtending 0·5° at the eye. Results are shown in figures 9 and 10, each recovery curve being the mean of several separate runs. It will be seen from table 1 that the recovery curve of subject B.H.C. is not very different from the mean recovery curve, while that of subject F.J.C.B. is substantially slower, so that the curves of figure 9 are likely to be more nearly those of the average observer than would be a mean of figures 9 and 10.

It will be noticed that for both subjects the shape of the recovery curves changes from simple to complex between the flash brightnesses of 15 and 48 c/sec./sq.ft., an
indication that the response of the scotopic or rod mechanism only is affected by the lower range of conditioning stimuli, while the photopic or cone mechanism participates in the higher range.

**Figure 9**

\[ \text{Flash Brightness (c. sec./ft}^2) \]

\[ \text{log threshold (c./sq-ft)} \]

\[ \text{log time (seconds)} \]

**II (6) Effect of conditioning stimulus off line of sight**

Recovery curves were determined for the two subjects B.H.C. and F.J.C.B. with the conditioning stimulus at 10° and 30° from the line of sight to the test field. For each subject the recovery curves were compared with those for a conditioning stimulus covering the central field (i.e. the curves of figures 9 and 10) and the equivalent curve determined. This is a determination of equivalent background brightness under new conditions, namely the flash covering a broad central area.
of the field of view which is equivalent to the flash covering only a limited excentric area. The values are given in table 2, together with the calculated values from the formula already well established for static conditions, \( \beta = 16E/\theta^2 \), where \( \beta \) is

![Graph](http://rspb.royalsocietypublishing.org/download)

**Table 2**

<table>
<thead>
<tr>
<th>observers</th>
<th>flash illumination at eye (f.c.sec.)</th>
<th>glare angle</th>
<th>equivalent flash brightness (c.sec./sq.ft.)</th>
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<td>B.H.C.</td>
<td>5.4</td>
<td>30°</td>
<td>0.096 0-10</td>
</tr>
<tr>
<td>F.J.C.B.</td>
<td>5.4</td>
<td>30°</td>
<td>0.096 0-11</td>
</tr>
<tr>
<td>B.H.C.</td>
<td>5.4</td>
<td>10°</td>
<td>0.85 1-7</td>
</tr>
<tr>
<td>F.J.C.B.</td>
<td>5.4</td>
<td>10°</td>
<td>0.85 0-83</td>
</tr>
</tbody>
</table>
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equivalent background brightness in c./sq.ft., $E$ is illumination at subject’s eye in f.c., $\theta$ is the glare angle subtended at the eye between conditioning and test stimuli (Stiles & Crawford 1937).

The agreement between calculated and measured values is good, except for one case, and may be taken to indicate that the validity of the background formula may be extended to include recovery of adaptation from brief flashes of light.

II (7) Multiple conditioning stimuli

The application of a more or less rapid succession of conditioning stimuli to the eyes might be expected to set up a somewhat complex state of adaptation, but the application of the equivalent background transformation has enabled some simplification to be made. The first step was to relate the recovery curves after multiple stimuli of different total durations to recovery curves after single stimuli of different intensities. Two types of multiple conditioning stimulus were investigated: one with 1·6 flashes per sec., the other with 6·5 flashes per sec. (These were approximations to the flashes from two common types of automatic gun.) For each type the following recovery curves were determined: a series after single conditioning stimuli covering the necessary range of intensity (about 16:1); a series after multiple conditioning stimuli of total durations up to about 5 sec.; and another series repeating the first series of single stimuli. From these measurements could be deduced the intensity of a single conditioning stimulus equivalent to each of the multiple stimuli. The results are shown in figure 11 for two subjects. The slight difference between the two types of multiple stimulus is within experimental error.

![Graph](https://example.com/graph.png)

**Figure 11**

\[ R = \frac{\text{Intensity of single flash equivalent to burst}}{\text{Intensity of burst}} \]

- B.H.C. 6·5 flashes/sec
- F.J.C.B. 6·9 flashes/sec
- B.H.C. 1·6 flashes/sec
- F.J.C.B. 1·6 flashes/sec

log period of burst (seconds)
and a single mean curve may be taken to represent both types. Up to a total duration of 0.3 sec. the results show that the eye integrates perfectly the conditioning stimulus falling upon it. After this the integration becomes progressively less perfect according to the relation

\[ e = E \sqrt{\frac{p_0}{p}}. \]

where \( e \) is the intensity of the equivalent single conditioning stimulus, \( E \) is the total intensity of the multiple conditioning stimulus, \( p_0 \) is 0.3 (the flash duration at which perfect integration ceases) and \( p \) is the total duration of the multiple conditioning stimulus.

Approximately the same value for \( p_0 \) is derivable from the results of earlier work (Crawford 1946). Inspection of the curves there given shows that for periods of exposure of the conditioning stimulus longer than about 0.3 sec. integration by the eye begins to break down, as indicated by the recovery curves measured subsequent to exposure of the conditioning stimulus.

**Figure 12**

II (8) *Effect of colour of conditioning stimulus*

In §II (5) a hint was obtained that recovery from a brief conditioning stimulus, within most of the range covered by the present experiments, is related only to the scotopic or rod mechanism of the eye. Confirmation of this has been obtained by the use of coloured conditioning stimuli.
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Three conditioning stimuli were used, one red and two green, obtained by placing Board of Trade signal red and signal green filters over the normal white conditioning field. The intensity of red stimulus thus obtained was 4 c.sec./sq.ft. The brightnesses of the two green stimuli were made equal to the red, one by photopic photometry, the other by scotopic photometry. The ratio of physical intensities of the two greens thus determined was 30:1. Recovery curves were obtained after the three conditioning stimuli in order to ascertain which of the two greens, if either, was equivalent to the red.

Results are shown in figure 12 for two subjects. For F.J.C.B. it is, without any doubt, the scotopic green stimulus which is equivalent to the red. For B.H.C. the scotopic green stimulus is nearly equivalent to the red; the small difference may quite possibly be experimental error, as the green recovery curves are the result of single runs only. On the whole, the conclusion is justified that the scotopic green stimulus is equivalent to the red, thus confirming the conclusion reached in §II (5).

II (9) Laboratory tests with natural objects

These tests were designed to demonstrate the application of laboratory measurements to practical problems and to provide an extra check on the validity of the laboratory measurements. Lantern slides of various scenes were projected at low brightness, adjustable to any level from twilight to the darkest night (a range of sky brightness from approximately 10 c./sq.ft. to 10^{-6} c./sq.ft.). For each test an object in the scene was chosen and the general level of brightness adjusted until that object could only just be seen. The subject’s eyes were then exposed to a conditioning stimulus of type (a) and the time measured until he could again see the chosen object. This measured time could be compared with the predicted time.

| Table 3 |
|---------------------------------|-----------------|-----------------|-----------------|
|                                  | flash brightness = 40 c.sec./sq.ft. | flash brightness = 0·13 c.sec./sq.ft. |
|                                  | background brightness (c./sq.ft.) | recovery times (sec.) | background brightness (c./sq.ft.) | recovery times (sec.) |
| flat landscape:                  |                               | observed | predicted | observed | predicted |
| distant house on horizon         | 0·00048                       | 30      | 24       | 0·00056 | 3·2       | 2·6   |
| tree in middle distance          | 0·00001                       | 170     | 120      | 0·00001 | 7·9       | 9·6   |
| clump of trees                   | 0·000014                      | 113     | 100      | 0·00001 | 10        | 9·6   |
| furrows in foreground            | 0·000007                      | 136     | 140      | 0·000005| 17        | 13    |
| Hamburg harbour:                 |                               |         |          |         |           |       |
| zeppelin against clouds          | 0·000025                      | 105     | 80       | 0·000009| 15        | 11    |
| warehouses on jetty              | 0·00001                       | 125     | 120      | 0·000007| 25        | 12    |
| small boat in harbour            | 0·00005                       | 62      | 55       | 0·000004| 5·9       | 5·6   |
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(deduced from the curves of figure 9) corresponding to the brightness level of the scene measured in the immediate neighbourhood of the object. Table 3 gives a small selection of the results obtained.

The agreement between observed and predicted recovery time is fairly good and shows that the general background brightness in the neighbourhood of an object is a sufficient basis for calculation of recovery times, without detailed consideration of the pattern of the object itself, so long as this is on the limit of visibility.

II (10) Effect of area of conditioning stimulus: sighting experiments

In all the preceding work under §II, the conditioning stimulus has been one of two distinct types, either covering a large part (60°) of the central field of view, or quite a small area well away from the line of sight to the test stimulus. In practice, however, it may very often happen that the conditioning stimulus, though covering

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**Figure 13**

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the line of sight to the test stimulus, does so by only a comparatively small margin. In such cases, if the margin is small enough, the subject may be able to see the test stimulus better by glancing more or less sideways so that it falls upon a part of his retina which was not directly illuminated by the conditioning stimulus. That such a method of observation is often used in practice is common knowledge. Some success has now been attained in reducing the subject’s behaviour to a general formula.

One of the scenes and objects used in the preceding section (zeppelin over Hamburg harbour) was chosen and the subject sighted on it with an imitation of a gun-sight. The general brightness level was reduced until the subject reported he could only just lay his sight satisfactorily on the target (zeppelin). A conditioning flash was

\[ \text{Points Observed} \]

\[ \text{Curve Calculated (Deflection of Fixation = 3\degree)} \]

\[ \text{Flash Brightness: 10 C. sec./sq. ft.} \]
\[ \text{Observer: B.H.C.} \]
\[ \text{Reflector Sight: 4 spots at corners of square, diagonal 5\degree} \]

\[ \text{Figure 14} \]
then exposed, projected on the screen and centred on the target, and the time measured until the subject could again lay his sight on the target. The area of the flash was varied, and as it diminished there came a point where the recovery time began to diminish also. Recovery times were very variable, but the mean results appear to be consistent. Figure 13 shows results for an open sight, figure 14 for a reflector sight. The observed curves suggest, for each subject and condition of observation, a certain angular distance by which he can look away from the target and yet be able to align the sight upon it. The calculated curves are worked out on this basis, assuming the deflexions of fixation noted on the diagrams. It is assumed that, so long as the radius of the flash is greater than this critical angle, the recovery time is constant. When the radius of the flash is less than the critical angle the target will be seen outside the after-image of the flash and an equivalent background brightness is calculated using the formula $\beta = 16E/\theta^2$ and graphical integration. From the equivalent background brightness is found the recovery time, using data derived from figure 9. It will be seen that the agreement between observed and calculated curves is not unsatisfactory, and it may be assumed that for a given subject, under given conditions (relating chiefly to the objects and obstructions, such as parts of gun and sight, near his line of sight), there is a critical angle by which he deflects his eyes, after a conditioning flash, in his endeavours to resight on a target.

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References