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Chapter I

METHODS OF OBSERVING AND RECORDING EYE MOVEMENTS

(1) Direct Observation

The first attempts at observing and measuring eye movements were made by methods of direct observation. Thus Javal(74) in 1878 observed eye movements during reading by reflection from a mirror. In 1898 Erdmann and Dodge(46) improved this technique by studying the reflected movements through a telescope. These workers were able to determine approximately the number of movements and fixation pauses, but could not measure their duration. Since then the method of direct observation has frequently been used to observe the path of voluntary eye movements and the position of the eye while fixating a point. Thus Barnes(6) in 1905 and Loring (94) in 1915 used very similar methods to measure the angle of torsion of the eye in making oblique movements. The subject of the experiment was required to fixate the object glass of a telescope mounted facing him on a horizontal perimeter, and the cross wires of the eye-piece were focussed upon one of the striae of the iris. The telescope was rotated to another position, the subject's eye following the objective. The angle of rotation of the cross wires necessary to focus them again upon the stria gave the angle of torsion. A more delicate modification of this method was designed by Dr Barany(5), and is described in detail by the writer in another place (145). Öhrwall (109) and Sundberg (140) observed both inter- and intra-fixation movements by means of a Blix's ophthalmometer (13). The eye was illuminated by light from a glow lamp, which passed through one of the microscopes of the ophthalmometer. The other microscope, the eye-piece of which was fitted with a micrometer scale, was focussed upon the eye, and the position of one of the striae of the iris, or of one of the blood-vessels of the conjunctiva, noted on the scale. Movements of the stria, as the eye moved from one position to another, could be measured directly on the scale.

The direct method has been used again in recent years to estimate the number of fixation pauses in reading. In its simplest form, the peep-hole method of Miles (102), a hole about $\frac{1}{4}$ in. in diameter was made in the middle of the copy to be read. The experimenter held the copy straight in front of the reader, with his own eye close up to the hole. In this way he could gauge the direction of the reader's line of regard, and with a little practice could count the movements of slow readers and children, without distracting the reader. A more elaborate method was devised by Newhall (105) (see Fig. 1). The reader's head was at *S*, where he gripped the horizontal bar with his teeth, and read the copy supported vertically at *R*. The telescope *T*, containing a 20 diopter convex lens at *L*, was trained on the reader's right eye by moving the carrier *C* on a universal joint (underneath the tube) attached to the fixed board *B*. The distance of the experimenter's eye from the lens was just less than the focal length, so that a virtual erect magnified image of the reader's eye was obtained by focussing the lens correctly. The lamp *M* was used simply to produce a general illumination of the reader's eye; it was out of the reader's field of view. For counting the eye movements, a vein or the outer edge of the iris was observed.

Early attempts at measuring the speed of voluntary eye movements were also made by Lamansky (90) and Guillery (63), by the after-image method.

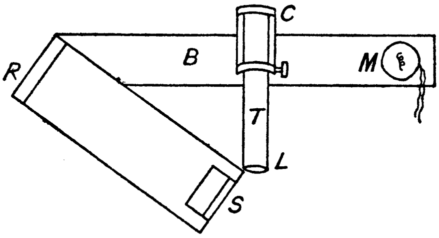

Fig. 1. Diagram of Newhall's apparatus for observing eye movements.

Lamansky found the number of after-images which were produced with intermittent illumination as the eye moved across the field. This method was also utilized by Erdmann and Dodge (46). But it relies too much upon the introspective report of the subject to be very satisfactory.

(2) Devices Attached to the Eye

The first systematic attempt at measuring the speed as well as the number of eye movements in reading was made by Huey (70), using the method invented by Ahrens (2) and adapted by Delabarre (33). Ahrens attempted to record eye movements by attaching to the cornea a light ivory cup, to the apex of which was fastened a bristle which traced on a smoked drum. Delabarre made a thin plaster-of-paris cast of an artificial eye, and trimmed it to the shape of the observer's cornea. The eyelids were propped open, the cornea anaesthetized, and the plaster cast fitted over it. A hole had been drilled in the centre of the cast through which the observer could see to read. A piece of wire, embedded in the plaster with one end projecting, was connected by a thread to a lever tracing on a smoked drum. Huey replaced the wire by a light tubular lever of celloidin and glass connected to a light thin aluminium lever which traced on the drum. A 'spark' time recorder was also used; an electric current from an induction coil, interrupted at regular intervals by a tuning fork, passed through the pointer, causing a spot of soot to fly off the drum at each interruption. This method has been fully described, because Huey made considerable use of it to study eye movements in reading. He claimed that it did no harm to the eye, but acknowledged that the latter frequently felt strained for a time after the cast had been removed.

Orchansky (110), and Marx and Trendelenburg (98), used light metal capsules for the eye. These had small mirrors fastened to them which reflected light from a bright source. In the work of Marx and Trendelenburg the reflected light was focussed on to a strip of bromide paper driven by a clockwork kymograph. By this method even the smallest involuntary tremors could be recorded. It seems to have been delicate and accurate. The experimental period, while the capsule was in position on the eye, did not last more than half a minute. Wiedersheim (155) also employed this method. Struycken (139) is reported to have photographed a minute sphere, mounted on three legs which were attached by hooks to the cornea. It is clear that these capsule methods are all open to the objection that they may interfere with the normal movements of the eye. The drag on the eyeball and the cocainization of the cornea are liable to retard movement. Moreover there is always a danger of some permanent injury to the eye. Consequently Judd, McAllister and Steele (77) evolved a method in which a very much smaller and less dangerous object was attached to the cornea. This consisted of a small flake of Chinese white paint, specially prepared, and attached to the cornea slightly below and on the nasal side of the pupil. It was fairly easily applied and manipulated into the right position, and once there remained firm; if by mistake it was lost under the lid, it was quickly dissolved and did no harm. The movements of this white spot, illuminated by daylight, were recorded by a kinematographic camera, driven at first by hand, but in later experiments by a motor. A time marker connected to the driving handle traced on a kymograph. Later a double camera was constructed with two films and shutters; the exposure of one coincided with the closure of the other, so that the record was continuous. The position of the head was fixed as far as possible by the use of head and teeth grips. Any head movements not eliminated were recorded by the reflection of light from a small steel ball, or a small concave mirror, fastened to a wire spectacle frame.

The chief defect of this method was the immense labour involved in determining the path of the eye movements from the films. For each section of the film the position of the white spot had to be referred to the point of reference provided by the spectacle frame, and the distance measured and recorded on a chart. It was, however, used extensively by these workers for measuring the direction and duration of intra-fixation movements, movements made in viewing optical illusions, and movements of convergence and divergence. The same method has since been used by Totten (144) for recording the eye movements of rabbits.

(3) Photographic Recording

Judd (77) claimed that his method gave a more accurate representation of the path of the eye movements than the purely photographic method of Dodge and Cline (37). But by a method which he has described in detail, Dodge (41) proved that his photographic method was equally accurate. Though the technique is somewhat difficult, this method is so much more convenient and reliable than any other that it has been employed, with various modifications, by all the later workers on eye movements in reading.

Dodge's method (37) was an improvement on one originally used by Stratton (137, 138) to record the movements of the eyes in viewing diagrams. Since in the latter the movements were all photographed upon a single fixed plate, the field was kept in darkness, except for the diagram to be viewed. Moreover, only the number and direction of the movements could be recorded. Dodge and Cline(37) modified this method to measure the angular velocity of eye

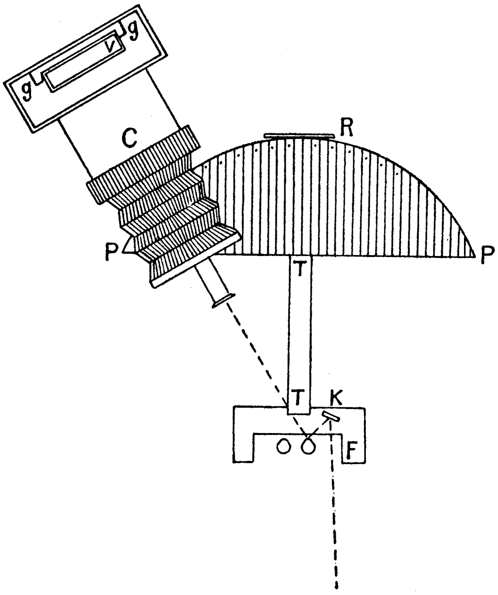

Fig. 2. Horizontal section of Dodge and Cline's apparatus for photographing eye movements.

movements by recording them upon a moving photographic plate. A small piece of white cardboard *K* (see Fig. 2) was illuminated by light from a window behind the observer; and the reflected image of *K* from the cornea, called the 'bright spot', fell upon the horizontal slit of the recording camera *C*, which could be moved round the perimeter *PP* until focussed in the right position. The observer's head was kept in position by a wooden chin-rest *F*; and he was instructed to look through a tube *TT* at the fixation marks, which consisted of vertical knitting-needles fixed on to the circumference of the perimeter. The recording apparatus (see Fig. 3) consisted of a photographic plate carried on a framework *V* which fell vertically between brass grooves *gg*. To the base of the framework was attached the piston of an air-pump *R*. The working of the pump caused the piston to fall at a constant rate which could be regulated by suitable stoppages applied to the exit pipe. In a later modification of this apparatus(38) an oil-pump was substituted for the air-pump; the oil, as it was ejected from the bottom, was returned to the top of the barrel by means of a pipe. This arrangement gave smoother working.

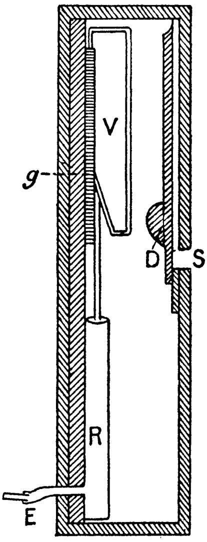

Fig. 3. Vertical section of Dodge and Cline's moving-plate camera.

Dearborn(32), and later Dodge himself(41), studying the movements of the eyes in reading, used an arc lamp as the source of illumination. The rays were rendered parallel by intercepting lenses, and were stopped down to a suitable brightness. Dodge used an alternating current arc lamp giving a series of discrete flashes at regular intervals, and thus obviated the use of a time marker. Piltz (119), Coburn (25), Koch (83) and Weiss (152) all used some variant of the photographic method for recording eye movements, but not the movements made in reading. Their methods are fully described by the writer (145) elsewhere.

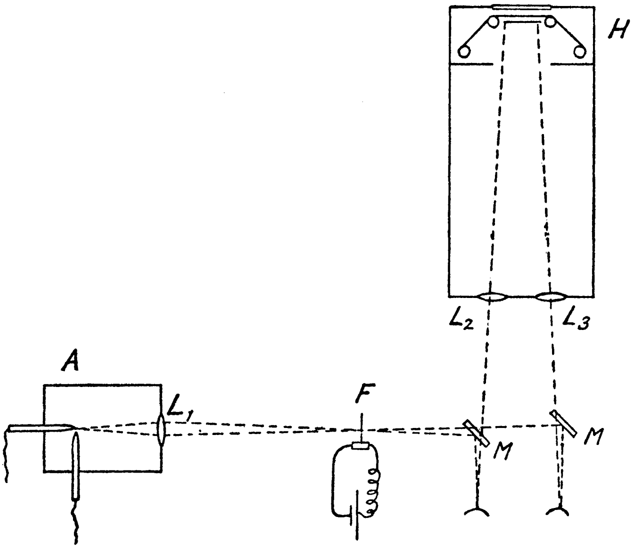

Fig. 4. Diagram of Schmidt's apparatus for photographing eye movements.

The photographic method was used on a large scale for recording eye movements in reading by Schmidt (128), C. T. Gray (59), Judd (81, 82) and Buswell (19). Schmidt's method is shown diagrammatically in Fig. 4. Light from an arc lamp *A* was focussed by a lens L_1 to a point, at which was interposed a tuning-fork interrupter *F* vibrating at a rate of 25 or

50 per second. The light was thus transmitted in discrete flashes, 25 or 50 per second. Later a 400-watt nitrogen-filled bulb was used as the source of illumination. The light was then reflected by thin glass mirrors *M*, *M* on to the corneas of the eyes, and back through the mirrors to the camera; and then focussed by lenses L_2, L_3 to fall on the film (see Fig. 4). The film-holder *H* could simultaneously expose vertically and horizontally moving films; upon the former were recorded the horizontal components of the eye movements and

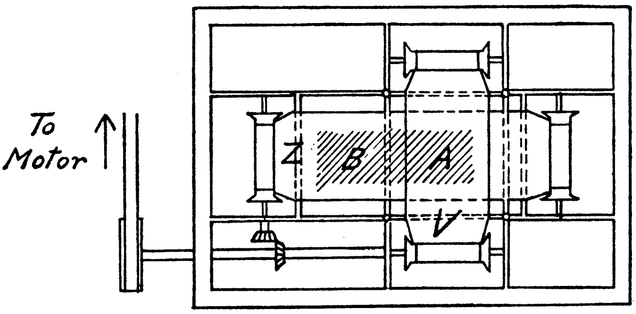

Fig. 5. Diagram of the film-holder of C. T. Gray's apparatus for photographing eye movements.

upon the latter the vertical components. In C.T. Gray's method, the light was rendered parallel by a double convex lens, before reflection from the mirrors. The film holder of C. T. Gray's camera is shown from in front in Fig. 5. Light passed through the focussing lenses to fall on the vertically moving film *V* as at *A*, and on the horizontally moving film *Z* as at *B*. The camera lenses could be focussed simultaneously or separately, and the images of the bright spots on the corneas