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A MIRROR-RECORDER FOR PHOTOGRAPHING THE COMPENSATORY MOVEMENTS OF CLOSED EYES

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Any project that involves photographic records of reactive compensatory eye-movements, as in the ocular nystagmus of rotation, is embarrassed by a unique technical difficulty that has hitherto been prohibitive. In order to register eye-movements that are pure compensations, free from visual stimuli and visual controls, the records must be taken either in the dark or from closed eyes. Both conditions make photographic technique somewhat difficult. Photography in the dark seems quite impracticable. Photographing the position of the eye through closed eyelids for a long time seemed no less so.

Neither the dark nor closed eyelids are necessarily prohibitive. But for many years the technical difficulties prevented our completing the description of the five types of eye-movements in the horizontal meridian plane of the field of regard which was begun in 1903.¹ Discussing the reactive compensatory eye-movements in that paper, in contradistinction from the coördinate compensatory, I was obliged to say: "Unfortunately, the essential condition of the phenomenon in pure form is that the eyes be closed. This, however, precludes a quantitative investigation by any of the methods at hand." The first photographic records of the reactive compensatory eye-movements were taken by Holt.² He avoided the technical difficulties by frankly

¹ *Am. Jr. Physiology*, 1903, 8, 307-329.

² *Harvard Psychological Studies*, Vol. II., 1906, 57-66.

keeping the eyes open, and recorded the eye-movements by our method of the corneal reflection. The difficulty of revolving the long enlarging camera with the subject was avoided by confining his records to the post-rotation nystagmus ('after-nystagmus') which could be photographed by leaving the camera fixed and rotating the subject into position.

From time to time I planned various solutions of the technical difficulties. None of them materialized satisfactorily. Many years ago I tried to work out a pneumatic transmission system depending on the eccentric cornea. Recorders of this order have been used by Schackwitz,¹ Buys², and others. The published records show the same faults that deterred me from utilizing this method.³

Presumably the best method hitherto published is that of Struycken.⁴ He is reported to have photographed a minute polished ball mounted on three feet and attached to the cornea by minute hooks. A total reflection prism in front of the lens permitted simultaneous records of both horizontal and vertical components. I know the method only second-hand.⁵ But like the method of the corneal reflection it seems to depend on keeping the eye open. The use of the total reflection prism is a technical expedient of unlimited usefulness. Whether the mode of attaching the polished ball is an improvement over Judd's Chinese white spot⁶ and my paraffined tissue paper mounting⁷ can only be determined by experience. Personally I confess to some prejudice in favor of a technique that makes the least demands on the subject's ability to stand discomfort.

The possibility of photographing the movements of the eyes in visual darkness by means of the ultra-violet light did not escape us. In view of the possible deleterious effects of ultra-violet light, we hesitated to use it.

In 1916, with the help of my laboratory students we began

¹ *Zsch. f. Psychol.*, 1912, 63, 442-453.

² *Internat Zentralbl. f. Ohrenhk.*, 1910, 9, 57-65.

³ *Psychological Bulletin*, 1916, 13, 422.

⁴ *Ned. Tijdschr. v. Gen.*, 1918, 1, 621.

⁵ *Zeitsch. f. Psy.*, 1920, 85, 345.

⁶ *Yale Psychological Studies*, New Series, 1905, Vol. I., No. 1.

⁷ *Monograph Supplement Psychol. Rev.*, 1907, No. 35.

to record photographically the eye-movements that were hidden under closed lids. This is the method that the present paper is to report.

THEORY OF THE MIRROR-RECORDER FOR CLOSED EYES

The principle of the recorder is that a surface which presses against the lid and is free to move will tend to assume a position tangential to the underlying corneal surface. That is to say, a mirror which reflects a recording beam of light, will be rotated from side to side as the apex of the cornea passes underneath.

Assuming for convenience an appropriate source of illumination and a suitable recording camera, the relation between eye-movement and records from a mirror resting on the eye-lid over the cornea will depend on the following considerations:

1. A mirror which is pressed lightly against the lid over the cornea will always tend to assume a position tangential to the surface of the cornea on which it rests as far as this is permitted by its mounting. For example, if the apex of the cornea moves clockwise underneath that part of the lid against which a mirror is resting, and if the mirror is free to rotate on an axis that is parallel to the axis of the eye's rotation, as the apex of the cornea passes underneath the mirror it will rotate the latter counter-clockwise. A recording beam of light from the mirror will consequently be rotated counter-clockwise when the eye rotates clockwise. With a fixed source of light its angular displacement will be double that of the mirror.

2. The angular displacement of the mirror will depend on the following factors: (a) The angular displacement of the eye. (b) The geometrical relationship between the radius of curvature of the cornea and that of the eyeball. The greater the differences in curvature the greater will be the movement of the mirror. (c) The relative position of the mirror with respect to the apex of the cornea. The greatest conceivable angular rotation of the mirror would result if the apex of a cornea of zero radius of curvature, infinitely

eccentric to the globe of the eye, just passed the axis of the recording mirror. On the contrary, no movement of mirror would result if it rested on a spherical eyeball while the latter rotated on its geometrical center. (d) The thickness and stiffness of the intervening lid. If the lid were totally unyielding all movement of the mirror would cease. If the lid conformed absolutely to the underlying surface it would operate on the geometrical relations as an increased radius of curvature of the cornea. (e) The intercurrent movements of the lid. Unless the lid is prevented from moving, voluntarily or by a lid-holder, all lid-movements will operate to move the mirror as though the eye moved.

For obvious reasons it is unnecessary to express these factors in the form of an equation. It would not be simple, and it would be worse than useless in practice if it gave the illusory security in uncontrolled results that mathematical elaboration sometimes produces. A relatively simple geometrical construction (Fig. 1) will indicate the primary relationship between the cornea and globe of the eye as it affects the movement of the recording mirror.

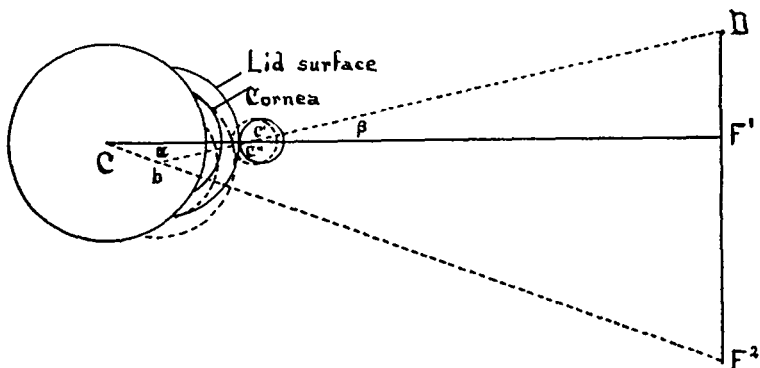


FIG. 1.

In Fig. 1 let CF^1 and the dotted line CF^2 represent successive positions of the line of regard, 20° apart. A recording mirror mounted with its axis on the line CF^1 at the point c^1 , and resting on the closed lid over the apex of the cornea, will project a recording beam of light which originates at F^1 along the line of its incidence and back to the point of its

origin. When the line of regard moves clockwise to the position CF^2 , the mirror will move to a new position tangential to the surface of the cornea which now underlies it, and the recording beam will be deflected counter-clockwise. In this new position of the mirror the line bD drawn from the center of curvature of the cornea at its second position through the axis of rotation of the mirror will be normal to the surface of the mirror. The consequent deflection of a recording beam of light originating at F^1 will be $c''F^1(\tan 2\beta)$. Since $\angle\beta$ is known from our knowledge of the triangle Cbc'' , the ideal displacement of the recording light for any angle of eye-movement is directly calculable. Unfortunately, however, we have at present no way of controlling the position of the closed eye with sufficient accuracy to insure the optimum position of the mirror on a principal meridian of the cornea. Our theoretical construction is practically of little use as a basis for the quantitative evaluation of the records.

The thickness of the lid (condition *d*) operates to increase the effective diameter of the cornea about 1.5 mm. to 2 mm.

Movements of the eyelid (condition *e*) seriously complicate every record where they occur. The experimenter must learn to recognize the main forms of lid curves. The most common seems to be due to the lid-reflex and consists of a movement of the closed lid downward and nasalward. This always produces a sharp break in the eye curve in the same direction, with a slow recovery. It is quite unmistakable. Lid-movements which are coördinate with eye-movements and troublesome lid-tremors may be eliminated by a suitable eyelid holder pressing the lashes or a fold of the skin of the eyelid against the orbital edge of the superior maxillary bone. I have found no way to eliminate the reflex lid-movements. A lid-holder only reduces their amplitude.

It is obvious that our warning against trusting the geometrical constructs is quite justified. Each set-up must be empirically controlled, and the empirical data must be checked as often as necessary to prevent changes in the significant factors.

In my own case I have been interested principally with

the time relations of the various phases of the eye-movements. Quantitative spatial interpretations will force themselves on our attention in a later paper when we come to discuss the adequacy of the eye-compensations. In that connection we shall discuss the empirical controls. All forms of eye-movement recorders, even under the most favorable techniques with the eyes open, are less well adapted to record positions of the point of regard than they are the direction and duration of movements.¹ In this respect the mirror recorder is no exception. All spatial interpretation of eye-movement records must be undertaken with full understanding of the difficulties involved. They have as much credibility as their controls guarantee, no more.

With this proviso the mirror recorder furnishes a useful and economical instrument for a considerable number of experimental projects and class-room demonstrations. It will demonstrate the main characteristics of the eye-movements in reading, to an entire class. Wherever binocular reading is not demanded it will record the number, duration, and approximate positions of the reading pauses in experimental studies of reading. Its technical advantages over other forms of photographic recorders for these purposes are its ease of adjustment, freedom from abnormal lighting, economy of material and time, and low first cost.

Wherever conjugate movements of the eyes may be postulated, this recorder furnishes the simplest experimental technique for control of the eye-movements in experimental studies of any mental process where they may be supposed to interact. It is adequate for the study of the velocity of eye-movements, and the characteristics of pursuit movements. It is more especially indicated whenever it is desirable to observe or record the action of closed eyes.

CONSTRUCTION OF THE MIRROR-RECORDER

The principles of the mirror-recorder permit the widest possible variations in construction to meet experimental conditions. Wherever the head may be fixed we use a simple adjustable arm to hold the mirror against the lid.

¹ *Psychological Review Monograph Supplement*, No. 35, pp. 84 ff.

This would be represented by one of the mirror-arms of the complete instrument which we will describe in detail.

Our mirror-recorder was designed to meet the following requirements:

1. A rigid frame which can be attached to any shaped head and will not vibrate when the head moves. This must be so made that the adjustable attachments for the recording mirrors will interfere least with the supports for the head and other experimental attachments.

2. Attachments to this frame must hold the mirrors against the eyelids with a gentle and even pressure. They must be adjustable horizontally to interocular distance; vertically, to the horizontal meridian of the eye. Secondary adjustments must permit the direction of the recording beam to the slit of the recording camera.

3. The recording mirrors should project a sharply defined image of suitable shape and dimensions. They must be so mounted on the arms that hold them, that they are free to rotate in conformity to the position of the cornea. At least, they must rotate freely on an axis that is parallel to the axis of the eye-movements which they are to record.

Several successive models of the recorder were constructed to meet these requirements. Only the final form will be described. It is pictured in Fig. 2 and in Fig. 3.

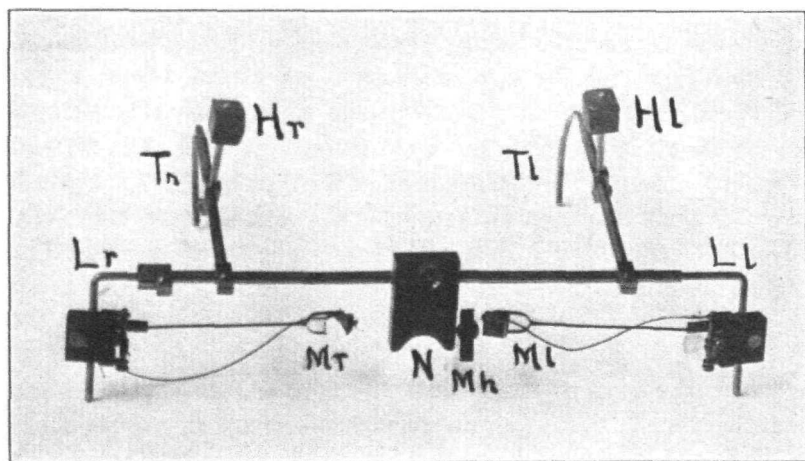


FIG. 2.

The frame resembles a spectacle frame with adjustable nose-piece, temples, and secondary side supports to the head. These five supports make the frame quite rigid and free from accidental vibration. The skeleton of the frame is constructed from $\frac{1}{8}$ in. brass tubing and resembles in form a capital letter *E*. The central offset from the stem would

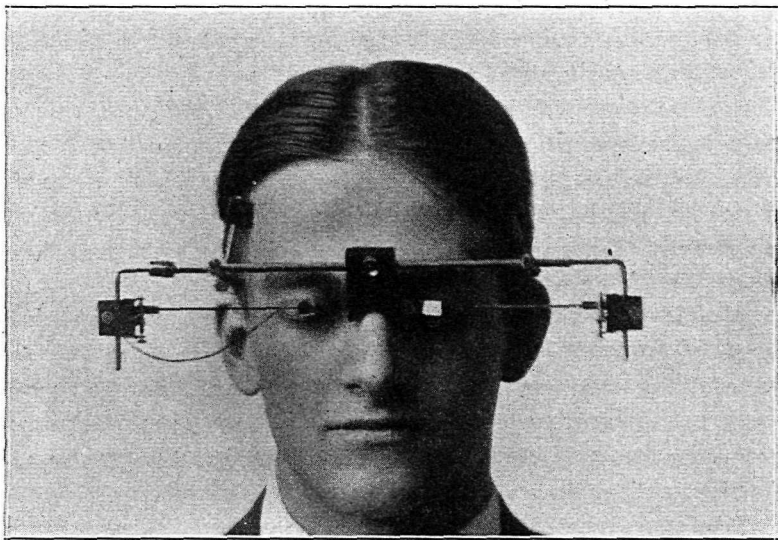


FIG. 3.

represent the nosepiece, Fig. 1, *N*. It is made of hard rubber, shaped to rest on the bridge of the nose, and may be clamped to the main stem at any angle to the temples. The longer offsets at the top and bottom of the *E* represent the temple tubes that hold the adjustable "riding" temple bars *Tr* and *Tl*. The temple tubes are made of $\frac{1}{8}$ in. tubing like the main stem. They may be adjusted to any position on the main stem corresponding to the width of the subject's head. The riding temple bars fit somewhat snugly into the temple tubes and are adjusted to fit over the ears of the subject when the frame is put on.

Into the ends of the main stem tube are thrust the longer arms of two L bars, *Lr* and *Ll*. On their shorter arms these L bars carry hard rubber blocks which may be clamped at

various heights and angles. To these are attached the small cone bearings that carry the light steel arms on which the recording mirrors are pivoted, *Mr* and *MI*.

Starting with the recording mirrors we may recapitulate the supporting members as follows: Each recording mirror is held against the closed eyelid by a light forked, steel bar (see Fig. 3). The axis of this bar is on a hard rubber block which is clamped to the short arm of an L bar. The long arm of the latter slides in and out of the main tube stem to adjust the mirrors to the correct pupillary distance, and to the position of the resting eyes. When properly adjusted these bars hold the mirrors gently against the eyelids. They are free to move horizontally as the apex of the cornea passes underneath the mirrors. The mirror arms terminate in a fork which is drilled to receive a needle, the axis of the small block that holds the mirror.

In adjusting the frame to a subject we follow this general routine:

1. The temple tubes are loosened on the main stem and separated just enough to permit the riding temple bars to clear the subject's head.

2. The riding temple bars are adjusted behind the ears to hold the frame firmly in place without discomfort.

3. The vertical offsets from the temple tubes, *Hr* and *HI*, are pressed gently but firmly against the head above the frame.

4. The subject is then brought into position on the experimental table, facing the recording camera. The head-line mirror *Mh* is adjusted until the image of the recording light falls across the exposure slit of the camera.

5. Then, one after the other, the mirror arms are adjusted to bring the eye-recording mirrors in contact with the lids at such positions and angles that each rests as accurately as possible over the apex of the cornea, while projecting the recording beam of light onto the exposure slit of the recording camera.

Fig. 3 shows the instrument in position for binocular records.

The recording camera for use with the mirror recorder should accommodate photographic film or paper as wide as five inches. We find the Dodge-Cline camera useful. It takes plateholders which are fitted with adapters for paper.

Our experimentation with sources of the recording light extended over several months. We find the most satisfactory source of the recording beam to be a commercial 100-watt nitrogen-filled incandescent lamp with a horseshoe-shaped filament. This we house to cut out irrelevant illumination, and place on the recording camera at a suitable height, with the plane of the filament in the sagittal plane of the subject's head. A plane mirror placed just above the slit at forty-five degrees to the vertical front of the camera reflects the recording beam to the concave mirrors of the mirror recorder. These in turn project a sharp image of the incandescent filament across the exposure slit of the recording camera. We find the horseshoe filament preferable to the arc light not only because it requires less attention and is steadier, but also because a recording line crossing the exposure slit is safer than a point of light from the arc-crater. Such a line does not leave the slit in slight movements of the head.

Any rapid photographic paper will give satisfactory records if the illumination is properly adjusted. We are best pleased with 'Insurance Bromide No. 2.' For slow records we interpose a filter between the lamp and the eyes. Paper will give excellent records up to 6 cm. per 1". Beyond that speed, if the slit is kept fine, we get better results with plates.