Brit. J. Ophthal., 35, 21.

MEASUREMENT OF BINOCULAR EYE MOVEMENTS OF SUBJECTS IN THE SITTING POSITION*

BY

MARY P. LORD

Chelsea Polytechnic and Imperial College of Science and Technology, London

It has been suggested (Marshall and Talbot, 1942) that the faculty of depth perception is, to a considerable extent, dependent on the occurrence of small independent movements of the two retinæ. Moreover, exact knowledge of eye movements is necessary for a proper understanding of many other visual phenomena and is likely to be of clinical interest also.

Since the photo-electric corneal reflex method of measuring eye movements (Lord, 1948) has the highest sensitivity consistent with little interference with the subject, this method has been extended to the measurement of binocular eye movements ; with the new apparatus, records are taken with the subject sitting up.

Experimental Method

The principle is similar to that used in the investigations on supine subjects (Lord, 1948 ; 1949). At present, simultaneous investigations of both eyes, in one direction at a time, can be made. It is hoped eventually to expand the apparatus so that movements of both eyes in two directions can be recorded simultaneously. For completeness, the principle of the expanded apparatus will be described here.

When the subject looks binocularly at the fixation target, each cornea is irradiated by an ultra-violet beam (λ 3650A) directed towards the appropriate blind spot so that the subject is practically unaware of the ultra-violet beams. At each cornea, partial reflection of the ultra-violet beam occurs and each reflected beam strikes a half-aluminised mirror where it is divided so that one part falls on a horizontal straight-edge (or wedge (Lord and Wright, 1949), direction of increasing density vertical) and the other on a vertical straight-edge (or wedge, direction of increasing density horizontal). As the eyes move, more or less radiation passes each straight-edge (or wedge) and that passing is focused onto an electron multiplier photocell ; the output of each multiplier is amplified and fed to a cathode ray tube ; the vertical traces on the four tubes are

* Received for publication September 19, 1950.

photographed simultaneously, one above the other, on a continuously moving film travelling in the horizontal direction. Dots at intervals of 0.02 sec. are marked along the middle of the film by focusing on it the image of a point illuminated by a discharge lamp in series with a half-wave rectifier. The eye movements can be deduced from the four records on the film.

APPARATUS.—A general view of the apparatus is shown in Fig. 1. The subject sits on the stool (St) and bites on the dental impression mouthpiece (Mp). Parts of the covering of the right and left eye optical systems (CO_R and CO_L respectively) can be discerned. A_R and A_L are amplifiers ; DT is a box containing two cathode ray tubes ; the moving film camera for photographing the tube traces is situated under stool (St) ; T is a table for the use of the operator. The various parts of the apparatus are described in detail below :

(i) *Optical System.*—The lay-out of the optical system is shown in Fig. 2. Since the right-eye and left-eye optical systems are similar, only that for the right eye is labelled. As far as possible, the lettering corresponds with that of Figs 1 and 2 in Lord (1948). The system (indicated by suffix V), for use with the beam reflected from the half-aluminized mirror ($M_{1/2}$) remains to be added ; it is a replica of that (indicated by suffix H) used with the beam transmitted by $M_{1/2}$.

The distance from the high-pressure mercury vapour source (S) of ultra-violet radiation to the subject's cornea (C) has been reduced to $3\frac{5}{8}$ ft., *i.e.*, to approximately half the value employed in the apparatus for investigations on supine subjects ; the mode of image formation at the cornea is, however, unchanged. This has been accomplished by reducing the side of the square aperture (S_1), the focal length of each of the lenses (L_1) and (L_2), and the distance from C of S_1 and L_1 ; the side of the square aperture (S_2) is unchanged and is situated as before in the focal plane of lens (L_2), whose distance from C is unchanged. The change from the supine to the upright posture has enabled the mirror, M_1 (Lord, 1945) to be dispensed with. The part of the ultra-violet beam reflected at the cornea is directed along the axis of lens (L_3) by the mirror (M) ; the focal length of lens (L_3), the optical-path length from C to L_3, and that from L_3 to each straight-edge (E_H) and (E_V) are unchanged, and so also, therefore, is the mode of image formation at E_H and E_V. The optical-path distance between C and each electron multiplier (EM_H) and (EM_V) has also been reduced to $3\frac{5}{8}$ ft., but the position and focal length of each cylindrical lens (L_H), (L'_H), (L_V) and (L'_V) are such that the mode of image formation at EM_H and EM_V is unchanged.

The fixation target (F) can be set at various distances from the subject, as indicated in Fig. 2, but is always arranged to lie on the visual axis of the subject's right eye when this eye is looking straight ahead. Hence, when F is fixated binocularly, the direction of the visual axis of the left eye is different for each position of F. The direction of the left-eye ultra-violet beam must, therefore, be adjustable if this beam is to fall on the blind spot whatever the position of F. This adjustment is secured by mounting the left-eye optical system on a platform which can be rotated about a vertical axis passing through the nodal point of the subject's left eye (Fig. 2) ; Wh_1 (Fig. 1) is the wheel controlling this movement. Since the inter-pupillary distance varies from subject to subject, it is also necessary for the horizontal separation of the right- and left-eye optical systems to be adjustable. This is provided for by mounting the platform

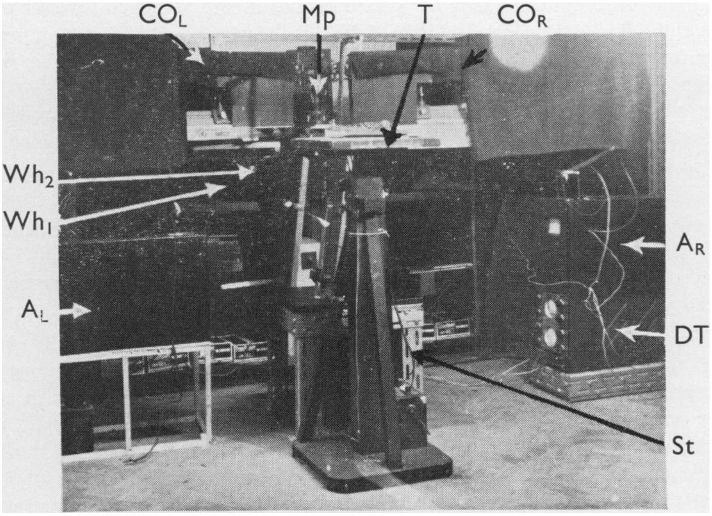


FIG. 1.—General view of the apparatus

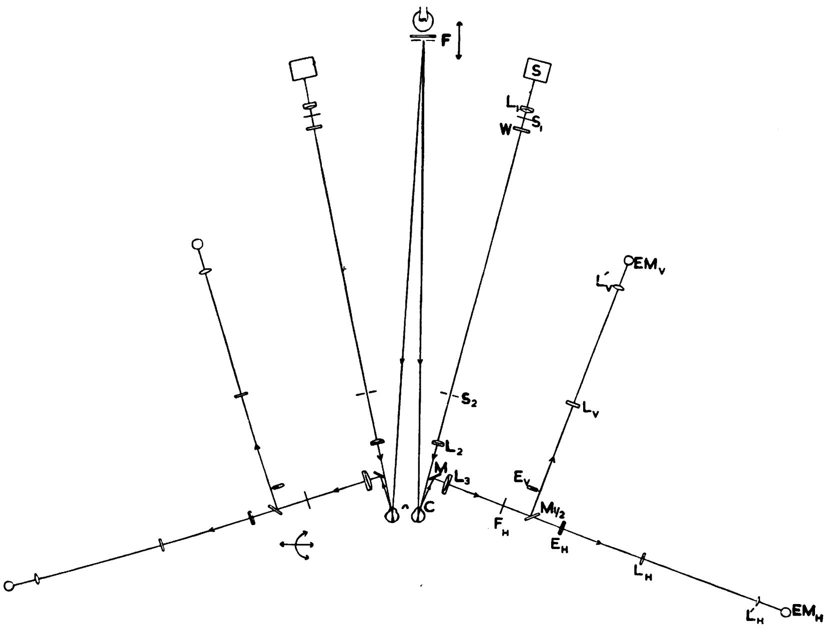


FIG. 2.—Lay-out of the optical system

bearing the left-eye optical system on a slide so that it can be moved towards or away from the right-eye system (Fig. 2) ; Wh_2 (Fig. 1) is the wheel controlling this movement.

It was found that the wearing of spectacles by the subject did not interfere with the investigations, and any refractive errors are corrected in this way.

Using an artificial cornea, the system was calibrated in the same manner as the apparatus for investigations on supine subjects ; similar results were obtained.

(ii) *Electrical System.*—This is also similar to that used in the investigations on supine subjects. To enable the same maximum sensitivity (6 mm. screen deflection per minute of eye movement) to be attained with less ultra-violet radiation incident on the subject's cornea, the value of the resistance in the multiplier output circuit has been increased three-fold. As the circuit diagram in Lord (1948) contained some errors, an amended diagram is shown in Fig. 3.

(iii) *Positioning the Subject.*—A " close-up " of the mouthpiece holder is shown in Fig. 4 ; the fixation target (F) is also visible. To facilitate the positioning of the subject, provision has been made for various rotations of the mouthpiece in addition to the customary three mutually perpendicular translations. K_1, K_2, and K_3 are the knobs controlling the conventional side to side, back and forth, and vertical translations respectively. Turning knob (K_4) causes the mouthpiece to be rotated about a horizontal axis passing through the centre of rotation of the subject's right eye ; movement of the platform (P), which is pivoted about the point (A), produces rotation of the mouthpiece about a vertical axis passing through the centre of rotation of the subject's right eye.

When sufficiently dark-adapted, the subject bites on the mouthpiece and adjusts the position of his head by manipulating knobs (K_1), (K_2), and (K_3) only, until the correct relativity (Lord, 1948 ; 1949) of the fixation target, blue haze, and ultra-violet beam for the right eye is attained, and the blue haze is as sharp as possible. Then, by manipulation of K_4, P, and Wh_2 only, the subject secures the correct relativity and focus for the left eye also ; theoretically this process does not alter the position of the centre of rotation of the right eye. The subject continues with the right-eye and left-eye adjustments in turn until fluorescent patches are visible to the operator on both left- and right-eye fluorescent screens (Fig. 2, F_H). The operator then continues with the two sets of adjustments until each fluorescent patch is in focus and incident upon the central phosphorescent dot of its fluorescent screen. Recording is then carried out as previously described (Lord, 1949). In contrast to the supine case, up and down movements produce changes in the amount of light passing the horizontal straight-edge (E_H), and side to side movements produce changes in the amount passing the vertical straight-edge (E_V). To obtain side to side records with the uncompleted apparatus, E_H is replaced by E_V.

RESULTS

The apparatus has been used for the investigation of monocular-fixation eye movements (Lord, 1950a) and of a case of nystagmus (Lord, 1950b) in addition to the binocular-fixation head and eye movements to be described here.

To record head movements, an artificial cornea (Lord and Wright, 1948) was attached to the skull in the usual manner, except that it was situated on the nasal side of the subject's left eye rather than in front of the right eye ; it was thus possible to record head movements while the subject fixated binocularly. Records for W.D.W. and

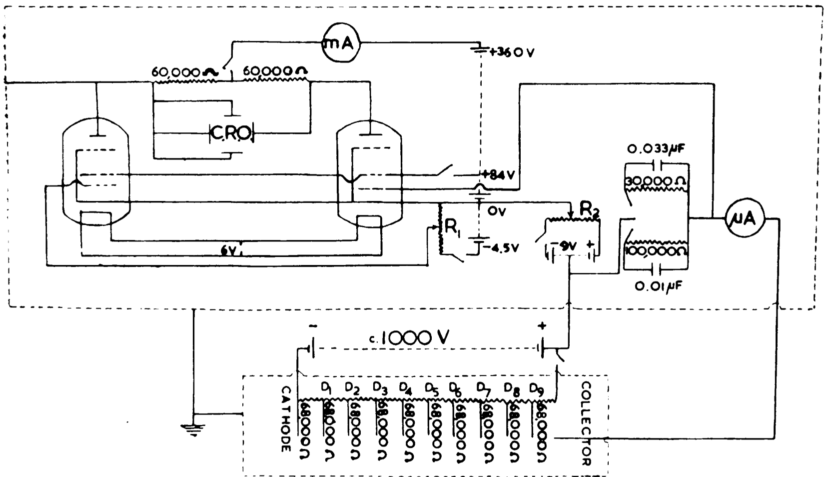


FIG. 3.—Circuits used with each multiplier

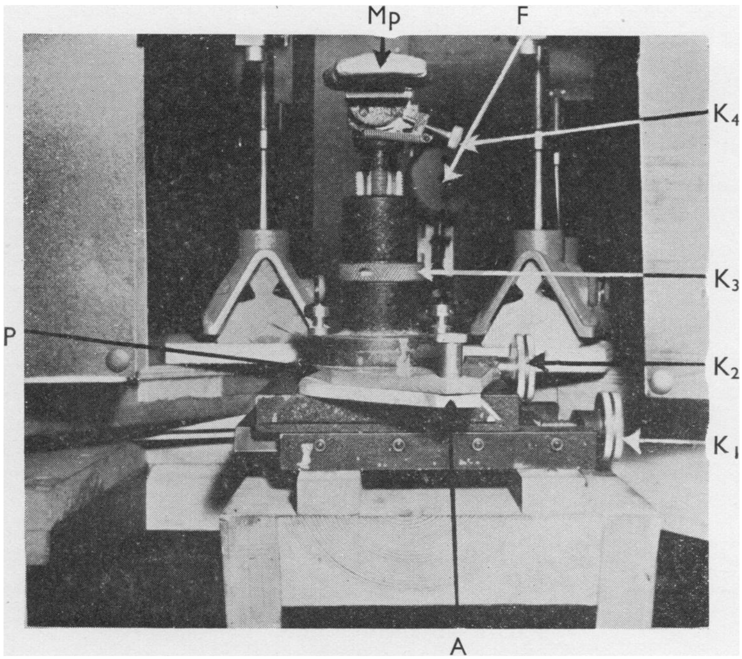


FIG. 4.—Close-up of the mouth-piece holder

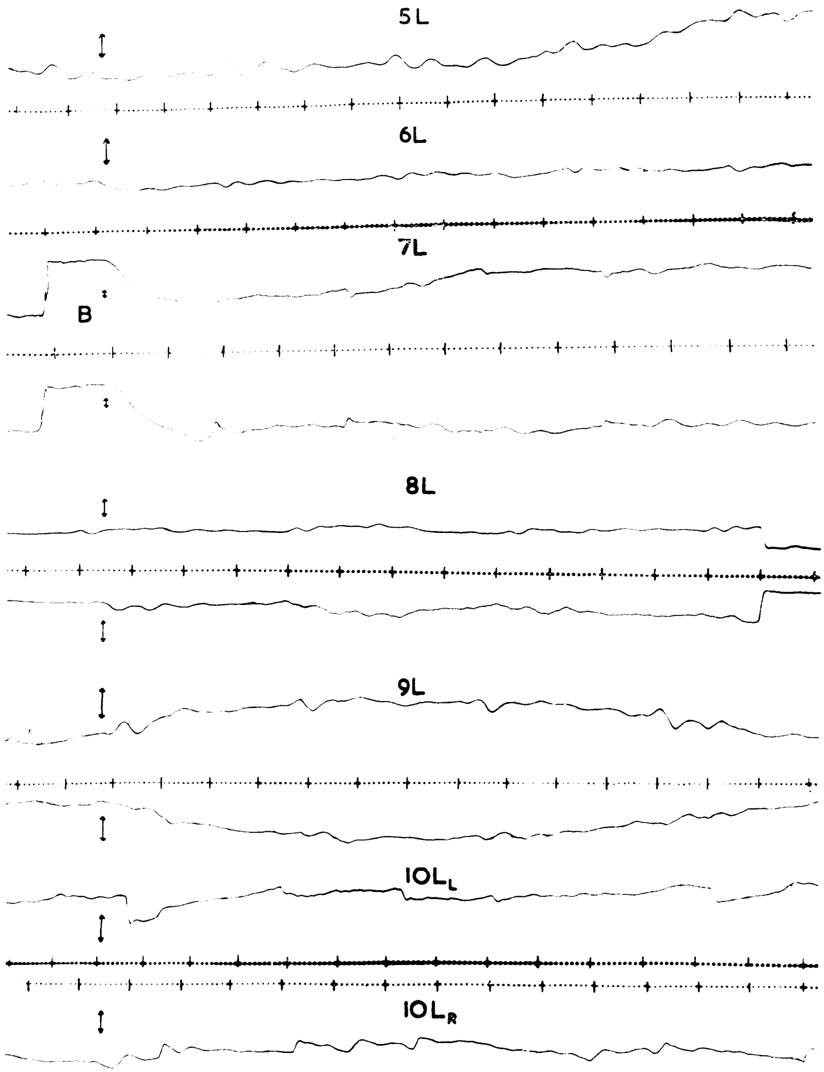


FIG. 5.—Head movements (W.D.W.)

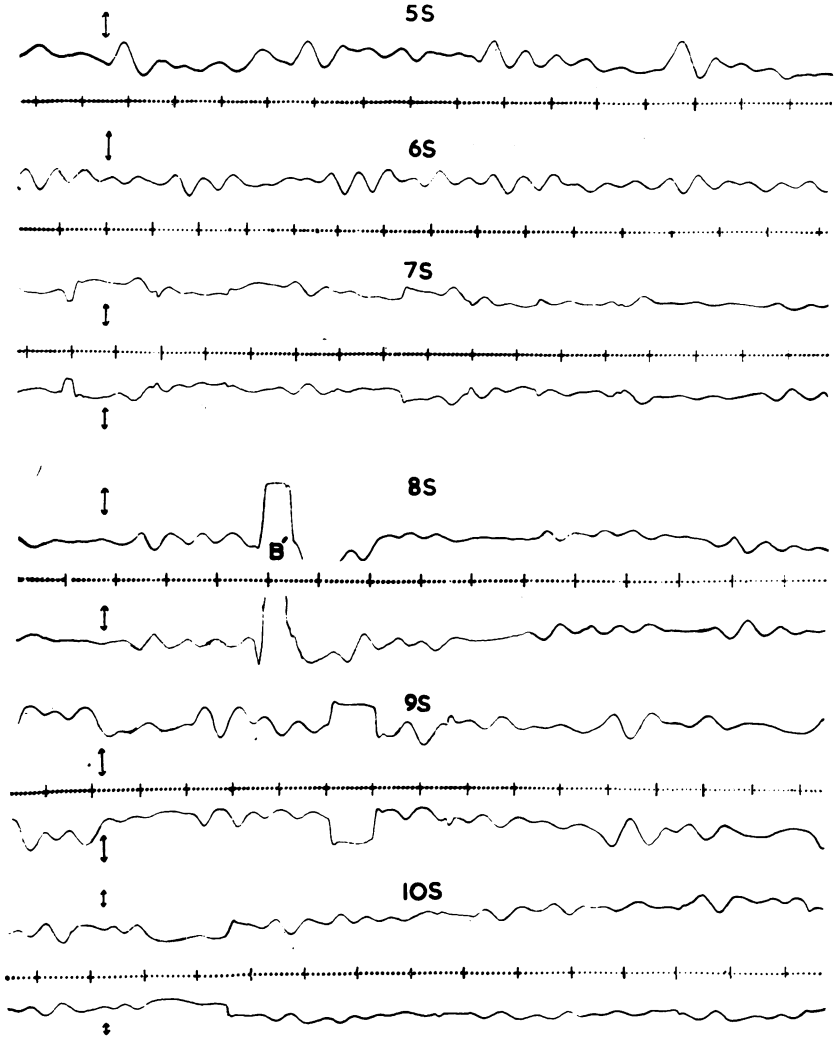
FIG. 6.—Head movements (R.S.L.)

FIG. 7.—Eye records (W.D.W.)

FIG. 8.—Eye records (R.S.L.)

FIG. 9.—Eye records (L.C.T.)

FIG. 10.—Eye records (R.W.G.H.)



NOTES:—

Time (increasing to the right) | . . . . | ≡ 0.2 sec.

L = up and down—upwards towards time line

S = side to side—left towards time line

Left-eye records above, and right-eye records below the time line

Amplitude shown at side ; height of arrowed line represents a rotation of 20 minutes, assuming the separation of the centre of curvature of the cornea and the centre of rotation of the eye is 5.3 mm.

R.S.L. (the only two subjects with suitable teeth for the experiment) are shown in Figs 5 and 6 respectively ; the movements are very similar to those recorded with the subject sitting up but not fixating (Lord, 1950). The average value of the maximum (sideways) periodic displacement is 0.035 mm. for W.D.W. and 0.024 mm. for R.S.L. Day-to-day variations are again found in the amplitude of the head movement pattern.

Figs 7 to 10 show eye records for subjects W.D.W., R.S.L., L.C.T., and R.W.G.H. respectively, for binocular fixation of a bright disk, angular diameter 1 minute, distance from the subject $5\frac{1}{2}$ ft. The records have many features in common with those for monocular fixation with the subject sitting up (Lord, 1950a). The head-movement pattern can again be picked out in almost all records, and its magnitude shows day-to-day variations. The average maximum value of the periodic head movements, as deduced from the side-to-side eye records of W.D.W. and R.S.L., is 0.026 mm. for each subject. This value agrees with that deduced from the artificial cornea records for R.S.L. with or without binocular fixation (Lord, 1950a) and with the value deduced from the artificial cornea records for W.D.W. without fixation ; it is, however, appreciably lower than the average value for both subjects deduced from their monocular fixation eye records, and that for W.D.W. deduced from the artificial cornea records with binocular fixation. It would thus appear likely that any effect of fixation on head movements is masked by day-to-day variations. The average maximum value of the periodic head movements of all subjects, 0.033 mm. agrees with the average value of 0.036 mm. obtained from the monocular fixation records of the same four subjects. An interesting feature of the up-and-down records is that periodic head movements deduced from the left- and right-eye records are out of phase ; this presumably indicates that some head movement occurs about a horizontal axis perpendicular to the front of the subject. The phenomenon is illustrated in figures 7L, 8L, and 9L, for W.D.W., R.S.L. and L.C.T. respectively.

It appears from the records that the eyes rotate at the same time, in the same direction and, in general, by the same amount. For all subjects, flicks starting in the downward direction are hardly ever found (Lord, 1950a ; Lord and Wright, 1948) ; flicks starting to the right are about twice as frequent as those starting to the left, except for subject W.D.W., for whom they occur with about equal frequency. The value of the average interval between flicks, as deduced from the binocular fixation records are 0.76, 0.89, 10, and 10 seconds for W.D.W., R.W.G.H., L.C.T. and R.S.L. respectively. The value for R.W.G.H. is in fair agreement with the monocular value of 0.86 seconds for both supine and upright positions. For

W.D.W., the binocular value is intermediate between the monocular values obtained for the upright (Lord, 1950a) and supine (Lord and Wright, 1948) positions. For R.S.L., the binocular average is somewhat smaller, and for L.C.T. somewhat larger, than the corresponding monocular average ; these variations may not be significant, because, on account of their slow flicking speed, averages for R.S.L. and L.C.T. are based on comparatively few values.

With all subjects, the recording of both eyes simultaneously was found easier in the side-to-side than in the up-and-down direction. In the case of R.W.G.H., no satisfactory record of both eyes simultaneously has yet been obtained in the up-and-down direction : Figs $10L_L$ and $10L_R$ show up-and-down records made on separate occasions for the left and right eyes respectively ; for the side-to-side direction, however, satisfactory recording has been accomplished of both eyes simultaneously (Fig. 10S).

The duration and magnitude of the flicks remain at 0.02 to 0.03 seconds and from 2 to 25 minutes of the arc respectively. The gaps at B and B^1 in records 7L and 8S respectively are due to blinks.

Discussion

In order to deduce the movement of the retina, relative to the image of a fixation object formed by the eye, from the results of any existing method of investigating eye movements, some assumptions must be made about the behaviour of the eye (Lord, 1950c). The validity of theories of the visual mechanisms, based on retinal scanning (Marshall and Talbot, 1942 ; Jones and Higgins, 1947) therefore depends on the validity of the assumptions, and the reliability (Lord, 1950c ; Lord and Wright, 1950) of the eye-movement data employed. The data used are based on the results of an investigation by Adler and Fliegelman (1934) who reported that the normal eye is perpetually making high-frequency rotations, magnitude about 2 minutes of the arc, with larger, slower frequency excursions, superimposed. As far as is known, the existence of the high-frequency movement has not been confirmed by other investigators. In the dynamic (retinal scan) theory of depth perception (Marshall and Talbot, 1942), it is further postulated that the scanning movements of the two retinæ are asynchronous ; it seems unlikely that this supposition will derive support from the results described in this paper.

In the clinical field, the application of the photo-electric corneal reflex method to the investigation of the effect of a posture change on head and monocular fixation eye movements may be of significance (Lord, 1950a). Moreover, the photo-electric apparatus appears to be well suited to the investigation of nystagmus of small amplitude (Lord, 1950b) and further work with it on nystagmus and other pathological cases might, therefore, be of value.

Summary

The application of the photo-electric corneal reflex method to the measurement of binocular eye movements of subjects in the sitting position is described. To facilitate the positioning of the subject, a mouthpiece holder of novel design has been evolved ; variations in the inter-pupillary distance are compensated for by altering the separation between the left- and right-eye optical systems. Studies of binocular-fixation eye records of four subjects indicate that rotations of the eyes occur simultaneously, move in the same direction, and are, in general, of the same amplitude ; hardly any movements starting in the downward direction have been found. The records are similar to the monocular fixation eye records obtained with the subject sitting up ; some variation in the average flicking rate has, however, been found.

I am very grateful to Dr. W. D. Wright for suggesting the problem, for helpful discussions and criticisms, and for acting as subject. I also wish to thank the other subjects : Drs. L. C. Thomson and R. S. Longhurst, and Mr. R. W. G. Hunt, with all of whom I have had many stimulating discussions. I am glad to acknowledge the help given by many members of the Physics Department Staff at Imperial College, especially Messrs. A. E. Davis and F. W. Martin. I also wish to express my thanks to Mr. F. D. Perkins of Philips Electrical Ltd. for supplying a double-tubed cathode ray oscillograph to my specification.

I am glad to acknowledge the continued financial support of the Medical Research Council.

REFERENCES

ADLER, F. H., and FLIEGELMAN, M. (1934). *Arch. Ophthal., Chicago*, **12**, 475.
JONES, L. A., and HIGGINS, G. C. (1947). *J. opt. Soc. Amer.*, **37**, 217.
LORD, M. P. (1948). *Proc. phys. Soc., Lond.*, **61**, 489.
——— (1949). *Sci. J. R. Coll. Sci.*, **19**, 116.
——— (1950a). *Nature, Lond.*, **166**, 349.
——— (1950b). *Ibid.*, **166**, 1036.
——— (1950c). *Brit. J. physiol. Optics*, **7**, 150.
——— and WRIGHT, W. D. (1948). *Nature, Lond.*, **162**, 25.
——— ——— (1949). *Ibid.*, **163**, 803.
——— ——— (1950). *Rep. Progr. Phys.*, **13**, 1.
MARSHALL, W. H., and TALBOT, S. A. (1942). " Visual Mechanisms " *in* Biological Symposia, vol. 7, p. 117. Cattell Press, Lancaster, Pa., U.S.A.