Reports

Photoelectric Technique for Measuring Eye Movements

Abstract. By the system described, the movement of a stimulus and the correlated tracking movements of the eye are recorded simultaneously. The technique for measuring the eye movements consists of detecting and amplifying by photomultiplication the total amount of light passing through a small slit upon which is imaged a small portion of the light-dark field represented by the iris and sclera of the eye. This total amount of light varies directly with the angular position of the eye.

The two standard methods for measuring eye movements, the corneal-reflex method and its numerous variations, and the electric method which is based upon measuring the difference in potential between the front and back of the eye, have been and are useful for many purposes. These methods, however, have certain disadvantages, one of which is the difficulty of coupling them easily with a system for generating a variety of stimuli whose structural attributes, velocity, and magnitude of displacement can be varied systematically and related directly with the tracking motions of the eye (*1*).

A more general disadvantage of these methods is their lack of efficiency in generating data. The present method overcomes these disadvantages and has, in addition, certain specific advantages (*2*).

The principle of the technique is based upon detecting the difference in reflectance between the iris and sclera of the eye in such a way that this difference can be expressed as proportional to the angular rotation of the eye. Figure 1 illustrates the principle. A portion of the eye as seen about 45 degrees laterally to an observer's direct line of sight is imaged on a surface containing a slit whose dimensions are approximately 1 mm wide by 1 cm long. The slit is parallel to the horizontal meridian of the eye. As the eye moves laterally right or left, more or less of the image of the iris falls upon the slit; hence more or less of the total light incident upon the surface containing the slit passes through the slit. Immediately behind the slit is the photocathode of a photomultiplier tube. The output of the tube thus becomes a signal whose magnitude is in known proportion (through calibration) to the lateral rotation of the eye.

The output of the photomultiplier tube (*3*) is coupled to an electronic switch (*4*) through an impedence-transforming amplifier. A variable high-voltage power supply (0 to 1000 volts d-c) with gas-tube regulation is provided for the photomultiplier tube. The amplifier is of a difference configuration type with high d-c stability and moderate voltage gain (20 to 1).

The entire detector assembly consists of the photomultiplier tube, a simple lens system (triplet) which focuses the desired portion of the eye on the slit which is located directly in line with and just in front of the photocathode of the tube, the adjustment mechanism for positioning the detector with respect to the eye, a mounting arm, and a headpiece to which the entire detector assembly is attached (*5*). The detector is counterweighted, and the observer is provided with a bite-board and a chin rest.

Moving targets which can be varied in velocity, acceleration, extent of displacement, as well as in intensity, form, and duration of exposure before and after movement are generated by an apparatus which projects 2-by-2-inch slides on a rotating mirror. The rotation of the mirror is controlled electromechanically in order to produce the desired pattern of movement, which is observed by the subject.

An electric signal proportional to the angular rotation of the mirror and hence to the angular position of the stimulus is obtained by mounting a pair of coils external to and above the mirror. A small third pickup coil attached to the back of the mirror extends up into the alternating magnetic field produced by the field coils. The field coils are driven at a resonant frequency of 8.5 kcy/sec by an audio generator. The output of the pickup coil is thus an amplitude-modulated signal which is calibrated in terms of the known limits of travel of the mirror.

The amplified d-c signal from the photomultiplier tube and the a-c signal from the pickup coil on the mirror are input signals to an electronic switch. By means of this switch both signals are displayed on an oscilloscope, and the display is recorded photographically by a camera with a Polaroid adapter.

Figure 2 shows a typical recording of the tracking motion of an observer's right eye and the associated movement of the stimulus. The point at which the "envelope" opens in the upper trace represents the beginning of movement

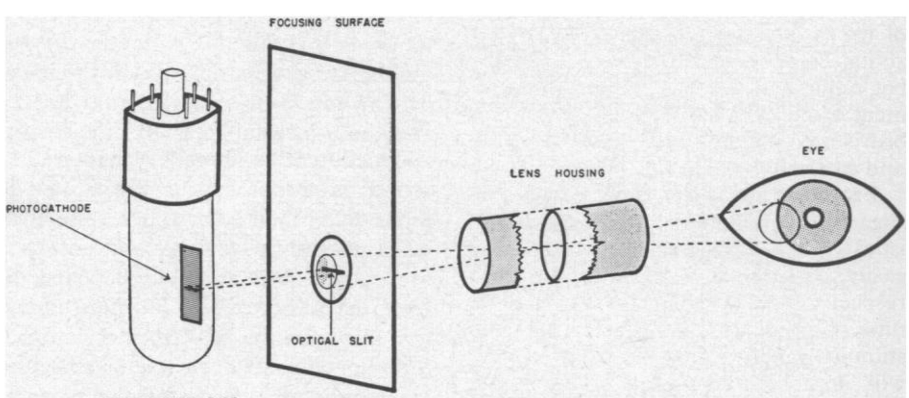

Fig. 1. The principle of measurement in schematic form. The lens casts an image of a portion of the iris and sclera on a focusing surface containing a slit. Behind the slit is the photocathode of a photomultiplier tube. As the eye moves laterally, more or less of the iris is imaged on the slit, and hence more or less total light strikes the photocathode. Variation in total energy thus can be correlated with eye position.

Instructions for preparing reports. Begin the report with an abstract of from 45 to 55 words. The abstract should *not* repeat phrases employed in the title. It should work with the title to give the reader a summary of the results presented in the report proper.

Type manuscripts double-spaced and submit one ribbon copy and one carbon copy.

Limit the report proper to the equivalent of 1200 words. This space includes that occupied by illustrative material as well as by the references and notes.

Limit illustrative material to *one* 2-column figure (that is, a figure whose width equals two columns of text) or to *one* 2-column table or to *two* 1-column illustrations, which may consist of two figures or two tables or one of each.

For further details see "Suggestions to Contributors" [*Science* **125**, 16 (1957)].

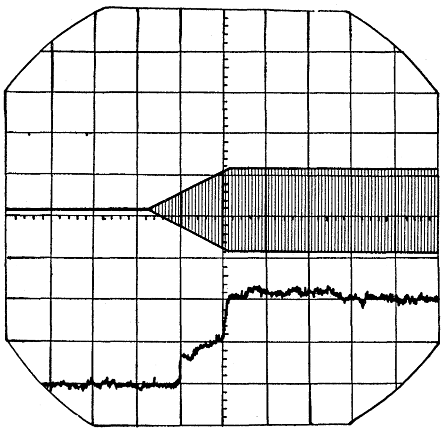

Fig. 2. Oscilloscopic record of stimulus movement (upper trace) and the corresponding tracking movement of the eye (lower trace). Velocity of stimulus movement constant at 21.5 deg/sec. Extent of movement, 8 deg, left to right. Horizontal sweep time, 200 msec/cm. Change in angular position of eye is linearly related to voltage change. Voltage scale, 5 volt/cm (vertical).

of the target, which consisted of a dark vertical hairline and which moved 8 deg from right to left at a constant velocity. The constant velocity is indicated by the linear sides of the envelope. Cessation of motion of the stimulus is indicated by the point where the sides of the envelope become parallel.

The eye-movement record (lower trace) in Fig. 2 shows a reaction time of approximately 160 msec and a pattern of an initial and final saccadic movement with a brief intermediate smooth pursuit movement of duration approximately 200 msec. A slight overshoot is evident for about 600 msec after cessation of the movement of the stimulus. When this record was made, the stimulus was visible in a fixed position both before and after movement. Eye fixations at these stages of the display are indicated by the horizontal components of the record at the beginning and the end of the eye-movement trace. The noise level in the record is a combination of electronic noise and physiological nystagmus.

From records such as that shown in Fig. 2, reaction time and rate characteristics of eye movement are determined easily, as well as lag-lead errors with respect to the stimulus at any point in time. Considering the flexibility of the stimulus-generating system described, it will now be possible to obtain systematic and extensive data on the eye as a tracking mechanism, and correlated with these data, the perceptual data for moving stimuli. Moreover, the principle of measurement used in conjunction with a miniaturized detector which can be worn by the observer without external support will make possible for the first time eye-movement measurement with free head movement. The miniaturization of the detector and the use of the present principle of measurement in recording vertical motions of the eye are currently being developed.

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References and Notes

1. G. Westheimer, *A.M.A. Arch. Ophthalmol.* **52**, 932 (1954).
2. Research on design and development of this technique for measuring eye movements has been supported by the National Science Foundation. We acknowledge the valuable assistance rendered by Theodore Marton of Princeton University.
3. RCA 931-A or RCA 1P-21. The latter is a "selected" tube; for a given noise level it has greater sensitivity than the former.
4. Dumont model 185-A, modified to provide electronic regulation of the anode voltage supply within the switch.
5. A headpiece for each observer is made from fast-setting plaster bandage. The detector is attached to the headpiece by screws and a metal base imbedded in the plaster.

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Electrolyte-Solvent Interactions: Effect of Electrolytes on Vibrational Spectrum of Methanol

Abstract. The addition of quaternary ammonium halides to dilute solutions of methanol in benzene shifts the equilibrium

Associated MeOH $\rightleftarrows$ unassociated MeOH

to the left. For several tetrabutylammonium salts, the order of increasing effectiveness in causing the shift is: picrate $<$nitrate $<$bromide $<$chloride. The results provide evidence for the solvation of electrolytes by polar molecules.

There has been considerable interest in spectral studies of electrolyte-solvent interactions in recent years. Most of these have involved metallic ions and a study of their ultraviolet or visible spectra in various solvents. The results of these studies have been interpreted in terms of charge-transfer complexes.

Another question is whether the extent of electrolyte association—for example, ion-pair formation—affects these spectra. Quite recently Popov and Humphrey (*1*) have shown that when anion-cation interaction is purely electrostatic, as in the quaternary ammonium salts, the extent of ion-pair formation has no effect on the ultraviolet and visible spectra.

No corresponding work has been done in the infrared. In this region of vibrational spectra it is conceivable that the interaction of electrolytes with polar molecules would modify the spectra of the latter—for example, by solvation.

We report here what is, as far as we know, the first observation of such an interaction—the influence of electrolytes on the equilibrium between associated and nonassociated methanol when both are dissolved in benzene.

It is well known that the O–H stretching vibration for methanol occurs at 2.75 μ and that the (self)-association peak occurs at 3.0 μ in pure liquid methanol (*2*). In a moderately dilute solution ($>25 \times 10^{-3}M$) of methanol in a nonabsorbing, nonpolar solvent (benzene), both peaks are present, their intensity ratio depending on the total concentration. In a very dilute solution the associated peak is absent. A plot of absorbancy versus total concentration for both peaks is shown in Fig. 1. The addition of an electrolyte tends to enhance the associated peak at the expense of the nonassociated one. A plot of the concentration ratio of the two forms as a function of total concentration is shown for various concentrations (molar concentrations are used throughout this report) of the electrolyte — tetrabutylammonium bromide (Bu_4NBr). The cationic charge is buried in a paraffin ball in this salt, and in the environment most of the electrolyte exists in the form of electrostatically associated ion pairs and quadrupoles, with the free-ion concentration rather low. However, in spite of what are probably rather weak electrostatic ion-dipole interactions, the effect of the salt in enhancing the associated methanol concentration is considerable, increases in the two concentrations being roughly equal to each other.

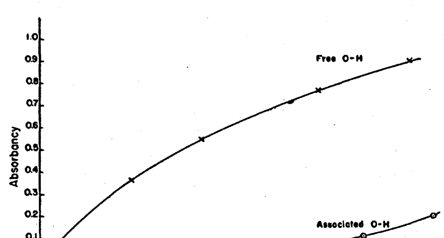

Fig. 1. Absorbancy of the free O–H (2.75 μ) and associated O–H (3.0 μ) peak as a function of total concentration in benzene.