INSTRUMENTATION & TECHNIQUES

Recording horizontal rotations of head and eyes in spontaneous shifts of gaze[1]

COLWYN TREVARTHEN[2] *and* BERNARD TURSKY,
DEPARTMENT OF PSYCHIATRY, HARVARD UNIVERSITY MEDICAL SCHOOL, Boston, Massachusetts 62115

In this paper, a method is described for simultaneous recording of horizontal rotation of the eyes in the head and rotation of the head about its natural vertical axis. Angular positions of eyes and head are obtained as proportionate dc voltages that are summed to obtain a record of the horizontal direction of gaze sensitive to 1-deg saccades and accurate to within ±2 deg for at least the central 90 deg of the visual field. The apparatus is so light that it is hardly felt by the S, who, while seated, is free to move in any way he chooses and to perform any task. In addition, the angular position of a target rotating around the head may also be recorded for observation of visual-pursuit behavior.

The electro-oculogram (EOG) has often been used in the psychology and physiology laboratory to record eye movements and eye position (Marg, 1951; Young, 1963). The complication of differentiating between head movements and eye movements has usually been solved by using a restraining device to fix the position of the S's head. The effect of this procedure on experimental behavior can only be surmised. In our effort to study the spontaneous head-eye coordination in infants, it bec essential that a method be devised to record ind dently the movement of the head, the eye, and the target. This recording technique had to produce negligible S discomfort and to impose no restraint or interference even during large and erratic displacements and rotations of the head. We found no apparatus described in the literature that would satisfy our requirements.

The method described here has proven to be extremely comfortable for the S, who senses only that he is wearing a light hat and has three small electrodes attached to his face. He becomes quickly adapted to these attachments. The apparatus has been found highly suitable for studies with adult Ss as well as with infants. It is easy to employ and is accurate and reliable for studies of natural shifts in the horizontal direction of gaze.

MEASUREMENT OF HEAD ROTATION

Various optical and electromagnetic methods were considered as possible means of inertialess recording. These were rejected because of their complexity or inaccuracy; finally, a counterweighted mechanical coupling was designed[3] that provided an elegant and accurate solution (Fig. 1).

In this mechanism, a low-torque potentiometer[4] is linked to a hat-like harness designed for comfort and easy attachment. A band of vinyl plastic material provides a nonskid grip on the skin of the forehead. It is continued by an elastic band under the back of the head and the hat is held firm by an adjustable adhesive connection of Velcro tape. An elastic band over the top of the head carries patches of Velcro tape for the attachment of the coupling to the potentiometer. The microtorque potentiometer is connected as one arm of a Wheatstone bridge, the output of

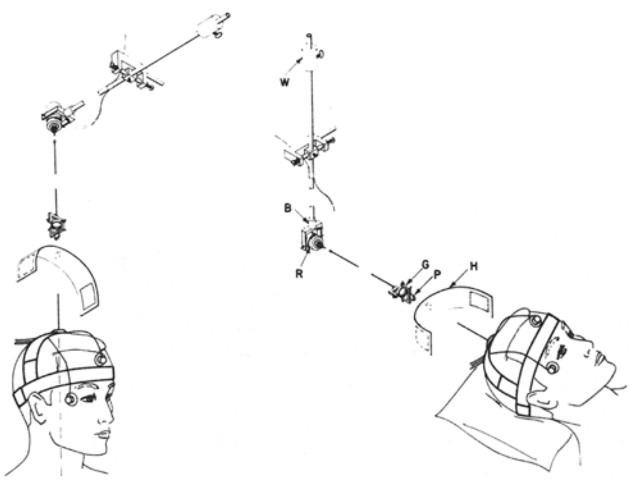

Fig. 1. Apparatus for measuring head rotations. A pivoted arm of aluminum tubing is mounted horizontally or vertically. The weight of the potentiometer (R), which is suspended within a gimbal attached to the arm by a precision ball-bearing (B), is balanced by the adjustable weight (W). A 0.05-in.-diam hard stainless-steel tubing, no less than 18 in. long, connects the potentiometer through a ring coupling (G) made of aluminum to a moulded hat-band (H) of 1/16-in.-thick plastic. The connection is by a plug (P). The S wears a light hat, described in the text, and the EOG electrodes.

which is recorded on one dc channel of a polygraph.

An upright adult maintains his head in balance between gravitation tending to pull the head forward and a muscular pull in the opposite direction from the back of the skull. The balanced head is rotated around an axis that is behind the center of gravity of the head. This axis remains fixed relative to the head, while the inclination of the head on the shoulders is changed by tilting or bending the head forward or backward.

When the potentiometer is attached, as shown in Fig. 1, the rotations of the head to turn it to the left or right are measured accurately, even when the head is tilted somewhat out of the normal balanced position. With a seated S, the normal head inclinations do not introduce an error of more than 1-2 deg in the measure of horizontal head rotation. The largest inclinations are commonly in a forward direction to lower the gaze for inspection in planes nearby and below eye level. The eyes usually remain within ±20 deg of the position that they assume when the gaze is on the horizon and the head is held comfortably upright.

When there is an angle between the axis of rotation of the head and the shaft of the potentiometer, the transmission through the coupling, G, is nonlinear. For an angle of 20 deg between these axes, errors varying between ±5%, depending upon the rotary position of the coupling, will be introduced. It is a simple

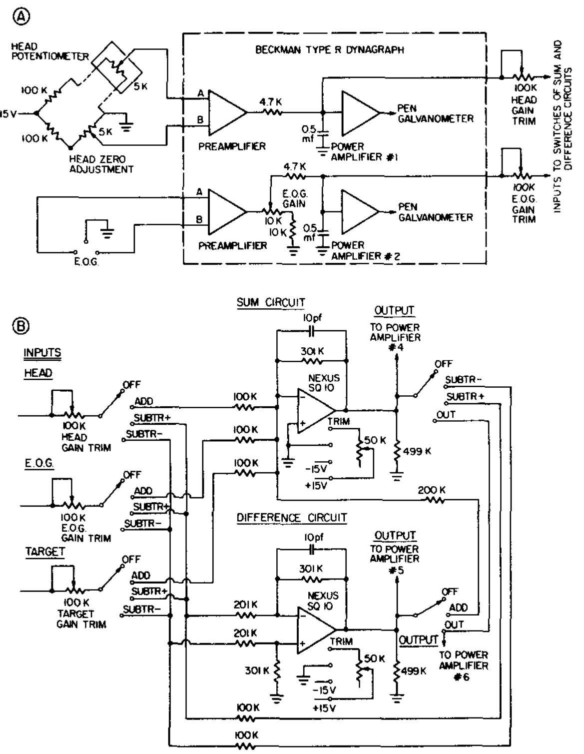

Fig. 2A. Recording circuits for head rotation and EOG. A bridge circuit, identical with that for the head rotation, is used to record rotation of a target about an axis in line with the vertical axis of the head.

Fig. 2B. The sum and difference amplifiers and switching circuits.

matter to remove these errors by presenting the S with a visual field in which the information he is interested in lies close to the horizontal plane through the eyes.

Normal head rotations, even the most rapid, are highly dampened; therefore, the lightweight mechanism attached to the head does not produce an inertial force large enough to be sensed by the S. Even the erratic movements of a 3-month-old infant do not appear to be modified by the apparatus. As is shown in Fig. 1, the apparatus may be positioned to record from a prone S.

MEASUREMENT OF HORIZONTAL EYE MOVEMENT

Modified silver-silver chloride electrodes (O'Connell & Tursky, 1960) are employed to record horizontal eye movements. These highly stable, nonpolarized electrodes are mounted in small, light plastic holders to fit the size requirements of experimentation with infants. Two electrodes are directly connected to a dc channel of the recorder (Fig. 2A).

The following steps are made in preparation for recording: The electrodes are stabilized for no less than 1 h in contact with a volume of Sanford Redux paste. Stabilization is carried out with the electrodes filled with paste and in close contact, face to face, to ensure against evaporation from the enclosed paste. The electrodes are attached to the S after the hat-band for the head-rotation measurement is in place. The skin is first cleaned with alcohol or simply wiped with a damp cloth and then dried. It is not generally necessary to abrade the skin. The spot of skin that will be under the electrode should be moistened with a drop of paste that is rubbed in gently for a second or two. The electrode must be attached immediately after this, and the paste inside it must be sealed from the air and without bubbles. The electrode resistance must be below 5,000 ohms.

With these electrodes, it is possible to obtain drift-free dc recordings of eye rotations. A noise compounded of effects from EEG, EMG, and the recording equipment, and equivalent to approximately 1 deg of eye movement, is inevitable. High-frequency components (above 60 Hz) may be filtered out, and appropriate RC filter circuits are included in Fig. 2A following the preamplifiers to do this. Blink artifacts and galvanic skin potential changes are also recorded, but both may be recognized and are not troublesome with most Ss. With infants under 1 month of age, and with drowsy or frightened individuals, less controllable artifacts may appear.[5] Crying, talking, chewing, and the like produce myographic and electrode-movement artifacts.

In visual-tracking tests, the target is mounted on an arm that has the same axis of rotation as does the head potentiometer. Rotation of the target is recorded from a 5,000-ohm potentiometer that is connected as one arm of a Wheatstone bridge similar to that described for recording head movements. The output of this bridge is obtained on a third dc channel of the recorder.

DERIVATION OF THE DIRECTION OF GAZE AND TRACKING ERROR

The amplitude of the direct eye-movement potentials is adjusted by proper setting of the Beckman preamplifier controls and the supplementary continuous-gain controls shown in Fig. 2A. The output of the head-movement and target bridges are similarly adjusted to give equal amplitude signals for equal arcs of rotation.

The head channel is first accurately calibrated to produce a known signal for 10 deg of head rotation with respect to the room in which the apparatus is suspended. With both infants and adults, the eye-rotation signals may then be standardized against the head rotations with the aid of automatic compensatory reactions of the S while he is making spontaneous reorientations with head and eyes. Alternatively, head rotations are imposed while the S is maintaining fixation on a point in the room. The

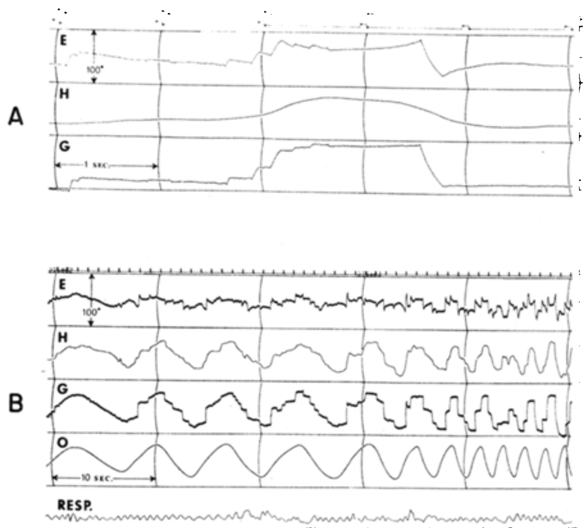

Fig. 3A. Sample recordings (adult). Large saccades coupling head and eyes in visual exploration of an extensive array.

Fig. 3B. Sample recordings (9-week-old infant). Tracking a 1½-deg target rotating at 36 in. from the head axis. E = EOG; H = head rotation; G = angular direction of gaze = E + H; O = angular direction of target object; RESP = respiration. The time marker records seconds.

latter is a more convenient method with adult Ss, who may also be asked to fixate points of known location in the room while keeping the head immobile.

Because of the early maturation of accurate compensatory adjustments,[6] a record of 1 or 2 min of spontaneous visual exploration of a stationary array, occupying at least 90 deg of the field, is generally sufficient for accurate matching of head and eye signals with an attentive S over the age of 2 months. When this adjustment is correctly made, the summed record of gaze displacement shows almost complete compensation for head rotations in both directions, and the portions of the trace between eye saccades are flat (Fig. 3). Consistent deviations indicate that the gain for the EOG is too high or too low.

The outputs of the amplifiers for the EOG and for both bridges are connected through an appropriate switching circuit to an electronic sum and difference circuit.[7] The switching at the input to these analog devices is arranged so that any of the signals can be added to or subtracted from any other signal or from any combination of signals (Fig. 2B). The output of these networks is displayed on separate channels of the polygraph. Thus, the angle of the direction of gaze in the horizontal plane is the sum of the head and eye voltage, and the difference between this sum and the target voltage is the tracking error (Fig. 3).

DIRECTION-OF-GAZE SWITCH FOR THE CONTROL OF VISUAL EXPLORATION

The dc "line-of-sight" signal has been employed to regulate a stimulus. An angle of visual space is designated, and the stimulus may be made to appear only when the S is looking outside it. Electronic level detectors have been used to delineate the width of the field, the boundaries of which may be adjusted independently to obtain an "on" or "off" zone of any width in any part of the field. In other words, it is possible to arrange for a stimulus to appear only at a designated locus in the visual field or in a large or small part of the field.

We have applied this method for verification of fixation while testing peripheral vision and in the study of infant vision.

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NOTES

1. Support for this work was obtained from the National Institute of Child Health and Development, Grant R01-HD-03049. The apparatus described was developed for research with infants while the senior author was a Research Fellow at the Center for Cognitive Studies of Harvard University. The study of the early development of visual orientation was carried out in collaboration with Dr. J. S. Bruner, with whom the needs of the recording mechanism were determined.

2. Now at the Biology Division, California Institute of Technology, Pasadena, California 91109.

3. We wish to thank Mr. Ralph Gerbrands for his design and fabrication of this exquisite piece of equipment.

4. Giannini Controls Corporation; Microtorque Potentiometer, Model 85111, resistance of 5,000 ohms.

5. Other considerations applying specially to work with young infants will be discussed in a forthcoming publication.

6. Trevarthen, C. 000 000 000 000 000 000 000 000 000, in preparation.

7. Mr. James Campbell of the Electrical Engineering Department, Caltech, has helped us in improving the recording circuits.

A titration procedure for generating escape behavior

JAMSHID KHALILI,[1] MARVIN F. DALEY, *and* CARL D. CHENEY, *UTAH STATE UNIVERSITY, Logan, Utah 84321*

In a grid-shock escape paradigm using time-out as reinforcement, both fixed-ratio and variable-interval performances were established directly from a continuous reinforcement schedule with rats and guinea pigs. A procedure was developed that employed a stepwise decrease in reinforcement time for all responses except the terminal response. Acquisition and long-term maintenance data were obtained from Ss trained on this titrated negative-reinforcement procedure.

By far the largest proportion of research on the control and modification of behavior has been accomplished using positive-reinforcement (reward) procedures; i.e., studies using food, intercranial stimulation, or water have predominated. Researchers and theoreticians have realized, however, that much animal behavior in natural as well as in experimental environments is under the control of aversive contingencies. There is an extensive literature on the use of shock to control behavior, although few successful methods for the acquisition and maintenance of extended schedules of escape behavior using grid-delivered electric shock have been devised.

Recently, a technique was reported for developing performance on a ratio schedule using ICS for positive reinforcement (Huston, 1968). It was proposed that fixed-ratio performance could be established directly from a continuous reinforcement regimen by a gradual reduction of the ICS train duration, contingent on all but the terminal response in the ratio.

In light of the difficulties reported in the acquisition and maintenance of grid-escape behavior (Dinsmoor, 1967), we adapted Huston's procedure to escape training, and experiments were conducted to show its reliability, species generalization, and long-term maintenance properties.

In a fixed-ratio (FR) schedule of negative reinforcement, the organism is required to emit a certain number of responses before the final response can produce a time-out or escape from the aversive stimuli. Using rats with subcutaneously implanted electrodes, Es have been unable to obtain or to maintain responding even on small fixed-ratio escape schedules (Hendry & Hendry, 1963). They reported that ratio requirements as low as 4 showed straining. Winograd (1965) reports a need to stay at FR 1 for as long as 16 sessions before the ratio could be slightly increased. He also found it necessary to shave the bodies of the rats when grid-shock was employed. In spite of these precautions, Winograd observed disruption of behavior during the first few sessions at ratios higher than FR 1 and, in fact, the shock level had to be doubled for one of the Ss in order to maintain any responding. Disorderly records were also obtained using a procedure in which the terminal response of an FR run yielded a