A method for measuring horizontal and vertical eye movement chronically in the monkey

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FUCHS, ALBERT F., AND DAVID A. ROBINSON. A method for measuring horizontal and vertical eye movement chronically in the monkey. J. Appl. Physiol. 21: 1068-1070. 1966.—Eye movements are measured chronically in the monkey by surgically implanting a coil of fine wire upon the eyeball beneath the bulbar conjunctiva and recti insertions. The ends of the coil are led to a connector mounted on the monkey's head. When the animal is exposed to two alternating magnetic fields in spatial and phase quadrature, signals generated in the coil on the eye may be phase detected to produce two voltages proportional to horizontal and vertical eye position with an accuracy of 15 min of arc. This technique makes it possible to record eye movements conveniently and accurately in the experimental animal in long- or short-term experiments on oculomotor functions as well as enabling the experimenter to control eye movements by training the animal in visual tracking tasks.

Vertical alternating magnetic fields. A voltage is induced in the coil which is a function of the angle between the eye position and the magnetic field. This voltage is phase detected against both horizontal and vertical reference voltages, resulting in two d-c voltages proportional to the horizontal and vertical deflection angles. For human experiments the coil is embedded in a scleral contact lens which is held onto the topically anesthetized eye by suction.

In the monkey, however, the coil may be permanently implanted, approximately in the coronal plane, under the four rectus muscles beneath the bulbar conjunctiva. The two coil leads are led behind the lateral fornix and under the skin to terminate in a female connector fastened to the skull.

Since the technique measures the orientation of the eye in space, one may know at what the monkey is looking independently of his head position, facilitating the training of the monkey in performing visual tracking. Due to the homogeneity of the magnetic fields in the vicinity of the animal's head, the measure of eye rotation is independent of head position when the monkey is loosely restrained in a primate chair. If desired, head position is easily measured by a second coil implanted in or pasted on the animal's head, permitting the measurement of eye rotation with reference to the unrestrained head. Thus eye movements may be recorded at the convenience of the experimenter in the lightly restrained, unanesthetized monkey.

The method has a resolution of 1.5 min of arc, linear within 6% of a full scale of ±20°, and possesses a system bandwidth of 1,000 cycles/sec. As with all quantitative techniques, it is necessary to establish a base line and gain calibration for each animal. Each monkey is trained to perform a visual discrimination task on objects located at some arbitrary zero position in his visual field and at ±10° horizontally and/or vertically from zero. When he simultaneously fixes his head by pulling on a spring-loaded bite bar and looks at the target for, say, 5 sec, he receives a liquid reward through the hollow center of the bar. The eye movements, therefore, can be measured only within the accuracy of this calibration.

Methods

The monkey is anesthetized by the intravenous administration of sodium pentobarbital. Instead of the conventional eye speculum, which impairs ocular mobility in the monkey, the eye is exposed with a pair of threads through the upper and lower lids. The eye is depressed and a cut is made in the superior lateral quadrant down to the sclera. A muscle hook is inserted into the cut, directed under the superior rectus and brought out through an eye drilled in the muscle hook tip, and the hook is withdrawn leaving the thread under the tendon of insertion of the lateral rectus.
MEASURING MONKEY EYE MOVEMENTS

Fig. 1. Detail of monkey's eye showing the placement of incisions and the suture under the superior rectus insertion.

Throughout the operation the eye is periodically irrigated with a saline wash to which 0.05 mg/ml of adrenaline chloride has been added to retard the conjunctival swelling.

In a similar manner, threads may be located under the remaining rectus muscles. With the help of the threads the muscle hook may be reinserted beneath any muscle, threaded with wire and withdrawn, placing the wire beneath the tendon. In order to combine the best features of biological inertness, flexibility, and strength, a stranded stainless steel conductor (7 strands of no. 44 wire; International Wire Products, Midland Park, N. J.) was coated with Teflon (Hi Temp Wires Co., Westbury, N. Y.), resulting in a finished diameter of .008 inch. The wire is wound under each succeeding muscle insertion and beneath the bulbar conjunctiva until three full turns lie upon the globe in a plane approximately perpendicular to the optic axis. Within 2 weeks after the operation the wires are encapsulated by a cylinder of scar tissue, firmly anchoring them to the sclera.

After the wires leave the eye they must not be allowed to intercept the magnetic fields and so induce a spurious voltage which would be interpreted as a signal from the eye coils. Therefore the wires are tightly twisted upon each other as soon as they leave the sclera. The wires must now pass from the freely rotating globe to the fixed orbital socket. A pocket is blunt dissected between Tenon's capsule and the lowest conjunctival layers backward behind the lateral fornix from the cut in the inferior lateral quadrant. An incision is now made over the zygomatic process of the frontal bone and the twisted wire pair is passed, by means of a half-circle cutting needle, from the depths of the pocket behind the lateral fornix to emerge from the zygomatic incision. It is necessary that the wire slide easily in and out of the pocket as the eye turns so that the wire does not tether the eye. Therefore, the wires are carefully bent to leave the globe tangentially. Finally, the wires are stitched to the deep fascia at the bottom of the zygomatic incision to prevent any subsequent accidental tension on the eye. With a hypodermic needle as a conduit, the wires are passed sub-dermally to a point on the skull near the intended pedestal location. The conjunctiva is closed, an antibacterial ophthalmic ointment applied, and the lids sutured together.

The pedestal and its mounting procedure are modifications of those successfully employed by Sheatz (6). The connection between the coil leads in the female pedestal and a male plug from the amplifiers presents another coil area to the magnetic fields. Therefore, precautions are taken in the pedestal design to magnetically shield the connection to prevent the generation of a spurious voltage. Figure 2 shows the pedestal as a hollow nylon cylinder with a larger concave base into which has been screwed a threaded steel sleeve. The pair of twisted wires enters the pedestal through a hole in its base and are soldered (Eutectic Welding Alloys Corp., Flushing, N. Y.) to female transistor socket leads which have been force into a screw plug. With the screw plug held by a slot scored in its head, the pedestal is screwed up onto the plug. Since the male connector has a similar sleeve designed to overlap its female counterpart, the connection is made in an enclosure free from magnetic flux.

Fig. 2. Detail drawing (A) of the magnetically shielded female pedestal. Insert (B) shows method of securing the pedestal to the skull.

Fig. 3. A typical recording of the saccadic eye movement of a monkey trained for visual tracking. Top trace: vertical eye movement; middle trace: horizontal eye movement; lower trace: horizontal target movement.
A skin flap is reflected to expose the calvarium into which a \( \frac{3}{16} \) inch hole is trephined. Three short radial defects are nibbled out with a narrow jawed mastoid ronguer so that nylon screws may be lowered head first down the center hole to the dura and slid gently out along the channels. The screws are positioned to allow their projecting threads to emerge through slots in the pedestal base. Dental cement (Grip-Caulk Co., Milford, Del.) is poured into the central defect and worked around the screws. The electrical connections described in the previous paragraph are completed, the pedestal is lowered onto the screws, secured by nylon nuts, and the base of the assembly is covered with dental cement. A circular hole is cut in the skin flap to accommodate the projecting pedestal, and the wound is closed. The monkey receives daily doses of systemic antibiotics for a period of 1 week after the operation after which the lids are freed.

RESULTS

Under visual examination the conjunctiva of the lateral fornix appears slightly inflamed, and the operated eye exhibits a medial deviation and an impairment of abduction which we feel to be an incomitant strabismus involving the lateral rectus. These conditions improve markedly over an additional week's recovery period although the deviation may never completely disappear.

However, the eye movement recordings reveal no impairment to the mobility of the operated eye. A monkey will spontaneously abduct as often as he makes movements in other directions. Furthermore, these eye movements reveal no essential differences from movements recorded by other techniques on humans (2) so that we believe the monkey's ocular mobility to be normal. Figure 3 shows the saccadic response of the eye to a temporal target displacement of 10°. The monkey, with the coil placed in the right eye, exhibits a central latency of 198 msec and a saccade duration of 28 msec in making a 9.5° following movement.

Although the monkey probably suffers from diplopia, he is able to perform visual discrimination tasks well and prefers to always observe the target with the same eye. Because of the diplopia introduced, this technique is not recommended for studying disjunctive eye movements, except for accommodation convergence, although the method is successful in studying the version movements involved in monocular tasks.

Finally, two major sources of difficulty in technique should be emphasized. The type of dental cement is critical since bone erosion under and around the pedestal occurs with some cements. Second, the most critical part of the coil placement is directing the wire behind the lateral fornix in a manner that avoids undue wire flexure at one point, leading to eventual wire breakage.

In a total of 14 implanted monkeys, the wires broke in 4, all after an implantation period of 2 weeks or less. The break usually occurred where the wires started twisting, immediately upon leaving the globe. The remaining implants remained continuous for periods averaging 7 weeks, after which they were removed for various other reasons.

REFERENCES