INSTRUMENTATION & TECHNIQUES

Transduction of the rabbit's nictitating membrane response

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Gormezano, Schneiderman, Deaux, and Fuentes (1962) introduced the rabbit nictitating membrane response (NMR) preparation and the use of a minitorque rotary potentiometer and hook and thread for NM coupling that, over the ensuing years, has remained the almost universally employed method of NMR measurement (see Gormezano, Prokasy, & Thompson, 1987). However, in recent years, our laboratory has been employing a photoresistive Polaroid transducer and ball-joint NM coupler that, in our judgment, has many advantages over any extant method of NMR measurement. The present paper provides a description of the design and functional properties of the transducer and coupler.

The purpose of the present paper is to provide a description of the design and properties of a photoresistive Polaroid transducer and ball-joint coupler for recording the rabbit's nictitating membrane response (NMR). The system has substantial advantages over the rotary potentiometer and string coupler introduced more than 25 years ago (Gormezano, Schneiderman, Deaux, & Fuentes, 1962). Moreover, it has a number of properties not uniformly shared by any extant method of NM measurement. Accordingly, the purpose of this paper is to provide a characterization of the principles governing the operation of the photoresistive transducer and ball-joint coupler.

A puff of air or paraorbital shock to the rabbit's cornea results in eyelid closure, eyeball retraction, and a lateral extension of the nictitating membrane from the inner canthus of the eye across the surface of the cornea. In early conditioning studies, virtually identical acquisition functions were reported for the eyelid (Schneiderman, Fuentes, & Gormezano, 1962), nictitating membrane (Gormezano et al., 1962), and eyeball retraction response (Deaux & Gormezano, 1963). Although the NMR is a passive response mediated by eyeball retraction, it is far easier to record than eyeball retraction. Moreover, the NMR has an exceedingly stable baseline and, for purposes of neural analysis, a far less complex motor control system than the eyelid. Accordingly, over the last 25 years the measurement of paraorbital reflexes in this laboratory has been almost exclusively restricted to the NMR.

Rotary Potentiometer and NM Thread Coupler

At least 25 rabbit NMR laboratories have been established in this country and around the world; with few exceptions, they measure the NMR with a rotary potentiometer and thread-and-hook coupler (see Gormezano, 1966). Briefly, for NM movement to be recorded, the eyelids are retracted with tailor hooks fastened to the ends of velcro strips. The hooks are inserted under the lids and the strips passed around the top of the head and fastened together. A muzzle-like headmount containing the transducer assembly is positioned and secured on the animal's head. (When electrode or cannula implants are employed, the transducer assembly may be attached to a Plexiglas block secured to an Amphenol connector assembly, to a cannula housing, or directly to a bolt cemented to the animal's skull.) A small hook, secured to a length of thread, is attached to a loop sutured in the NM, and the other end of the thread is secured around the long arm of an L-shaped 19-g lever rod. The short arm of the lever is mechanically coupled to a bushing on the shaft of a minitorque Giannini rotary potentiometer. To preclude any slack in the thread, a small counterweight or counter-torque provided by a balance wheel is applied to the short arm. The Giannini potentiometer we employed (Model 85153) was lightweight, of exceedingly low torque (0.004 cm-g), and relatively inexpensive (\$65 each). However, the company ceased its production, and minitorque potentiometers available from other manufacturers (e.g., Conrac Corporation, Litton Industries) are exceedingly expensive (\$600-\$700).

Some alternative methods for NMR measurement include the recording of corneoretinal potential (Powell, Lipkin, & Milligan, 1974), strain gauge measurement (Yehle, 1968), and photosensitive transduction of light reflected from the cornea (Van Dercar, Swadlow, Elster,

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& Schneiderman, 1969). However, we favored the development of a photoresistive transducer system with a direct mechanical coupling because, in part, the system is relatively inexpensive to construct, it is durable, and it assures the secure recording of NMRs from a relatively stable reference point (baseline). Moreover, the system has the greater potential for reliably and accurately transducing NMR topography and the extracted dependent variable measures.

A Photoresistive Polaroid Transducer

We initially developed a photoresistive transducer with a small LED and photosensitive diode separated by a flag on an axle attached to the NM by a thread and hook. Movements of the NM rotated the flag and allowed varying amounts of light to fall on the diode. Unfortunately, the light variation produced by flag rotation produced a modest nonlinear output that proved intractable to simple transformations. Accordingly, we developed the photoresistive Polaroid transducer and ball-joint NM coupler seen on the rabbit's headmount in Figure 1.¹ The transducer components are primarily housed in an opaque casing fashioned from a .028-m length of 2.54-cm-diam

black acrylic rod whose open end is anchored to an aluminum bracket.² The top of the bracket serves to mount an Amphenol connector and cable, and its slotted and angled base secures the entire system to the rabbit's headmount (or head bolt, Amphenol assembly, or cannula secured to the animal's skull). Inside the transducer housing, a Teflon bushing on the short arm of an L-shaped lever supports a disk of polarized film (Edmund Scientific, No. 71939) that is positioned between a constant-intensity LED (Litronix, Model RLC-201) and a photocell (Vac-tec, Model VT-212L). The photocell is covered by a fixed plate of polarized film. Movement of the NM, translated mechanically to the lever, rotates the disk of polarized film, producing changes in the level of illumination reaching the photocell through the fixed polarized plate. The accompanying variations in the voltage across the photocell are amplified and recorded.

Figure 2 presents the circuit diagram for the transducer. The input voltage to the circuit may be provided by any well-regulated power supply producing ± 2 to ± 8 V dc. The value of the balance resistor wired in series with the photocell, depicted as $1\text{ M}\Omega$, will determine the sensitivity, or gain, of the transducer. Specifically, transducer sensitivity is inversely proportional to the absolute value of the difference between the balance resistance and the resting resistance of the photocell. In the present configuration, the resting resistance of the photocell is approximately 140 K, and a 1-mm excursion of the transducer armature, as measured at a radius of 50 mm, produces a dc potential change in excess of 100 mV. A capacitor is included in the circuit to filter any possible 60-Hz noise in the transducer signal attributable to a shock (US) source. The value of the capacitor may be varied to produce any desired low-pass filtering characteristic or, alternatively, it may be excluded from the circuit.

Ball-joint coupler. Coupling the NM to the transducer is a horizontal, 22-g hypodermic tube that passes through a hole drilled in an aluminum casing positioned at the end of the long arm of the 19-g L-shaped lever. Within the aluminum casing is a ball bearing fitted into a socket. One end of a length of piano wire is spot welded in a hole drilled in the ball bearing, and the other end of the wire is shaped to form an S. The aluminum casing and its components are then secured to the armature by press-fitting the S-shaped wire into the orifice of the 19-g armature. A knurled screw at the base of the aluminum casing allows for the lateral adjustment of the length of the 22-g coupler tube between the NM loop and armature and then the securing of the tube into place. Housed within the coupler tube is a length of piano wire, one end of which is fashioned into a hook with the open C-portion of the hook resting just inside the tube. The other end of the wire is fastened to a spring-loaded plunger that when squeezed extends and exposes the open C-portion of the hook for fastening to the NM loop. On release of the spring, the hook returns to its resting position on the inside circumference of the tube and clamps onto a portion of the loop.

Figure 1. Restrained rabbit with close-up view of headmount, transducer housing, armature, and ball-joint coupler between NM loop and armature.

Figure 2. Photoresistive bridge circuit.

The adjustment of the long arm of the lever to the "zero" (vertical) position is then achieved by a lateral adjustment of the coupler tube.

Conclusions

The photoresistive Polaroid transducer and ball-joint NM coupler have a number of properties not uniformly shared by any extant method of NM measurement. First, the transducer is light, durable, stable, virtually maintenance free, and inexpensive to construct. Second, the signal from the transducer is of sufficient magnitude to preclude the need for preamplification. Third, the transducer provides a linear output for a range of movement far exceeding any NM extension. Moreover, the ball-joint coupler represents a substantial improvement over our previous (see Gormezano, 1966) and almost universally employed NM string coupler (see Gormezano, Prokasy, & Thompson, 1987). First, the direct NM-transducer coupling eliminates the need for a counterweight or counter-torque. The ball-joint coupler assembly, secured to the end of the transducer's armature, can be conceptualized as functioning in a manner analogous to the bob of a simple pendulum. The total mass of the coupler assembly is relatively light. Accordingly, little torque is required to displace the armature ("pendulum"), and its restoring force is exceedingly small. Second, the ball joint allows the coupler arm to rotate in the Z-plane, and, irrespective of the armature's rotational arc, the coupler arm moves through a fixed horizontal plane. Accordingly, the ball joint permits accurate transduction of the NM's curvilinear movement across the globe of the eye and, hence, a very faithful transduction of NMR topography in real time. Accordingly, one major consequence is that the ball-joint coupler augments the transducer's precision of measurement of the onset latency as well as the peak latency

(i.e., the latency at which maximum amplitude is attained) of unconditioned and conditioned responses. Third, the manner in which the coupler clamps onto the circumference of the NM loop precludes slippage in the measurement of NM extension and slack in recording NM retraction. In sum, the resistive Polaroid transducer and ball-joint NM coupler constitute a configuration for NM measurement that is markedly superior to our previous methods and has advantages over any extant method. The photoresistive transducer assembly has been in use in our laboratories for almost a decade and the ball joint NM coupler for more than 5 years. These devices have more than met our expectations in the quality of data produced and their robustness over long-term usage.

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NOTES

1. The photoresistive Polaroid transducer and ball-joint NM coupler are available for \$90 and \$40, respectively, from the Iowa Scientific Division, The University of Iowa Research Foundation, Iowa City, IA 52242 (Attention: H. William Trease).

2. A parts list for the photoresistive Polaroid transducer is: (1) LED, Litronix Model RLC201 (red light, constant intensity under an operating range of 4-16 V); (2) photocell, Vactec Model VT-212L (2 fc, resistance = 6 K Ω , maximum dark resistance = 5 M Ω); (3) polarized film (#71939, Edmund Scientific, Barrington, NJ); and (4) transducer housing machined from #2025 "black round acrylic rod 'cast'" (Cope Plastics, Cedar Rapids, IA).

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