Behavior Research Methods & Instrumentation
1974, Vol. 6 (4), 399-402

INSTRUMENTATION & TECHNIQUES

A simple turntable for vestibular stimulation of cats by acceleration through a fixed angle with description of a head restraint

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An inexpensive turntable for producing uniform angular accelerations for use in vestibular research is described. The table provides semicircular canal stimulation for cats or smaller animals at moderate accelerations above 3 deg sec^{-2}. A head restraint suitable for use on the table and designed for chronically implanted cats is also described.

Turntables capable of producing a uniform angular acceleration as a stimulus for the semicircular canals are necessary for some types of experiments on the vestibular system. Unfortunately, the complexity and high cost of electronically controlled units such as described by McCabe and Gillingham (1964) preclude their use in many laboratories. We describe here a turntable, driven by a falling weight, which provides an extremely inexpensive means of conducting experiments on animals as large as cats. A description of a new type of head restraint, designed for use with chronically implanted cats, is included. Gleisner and Henriksson (1963) used a similar drive, but only for smaller animals. The more inexpensive motor drives, such as the one described by Clark (1969), are limited to high angular accelerations and animals with weights under 300 g.

THEORY

The physics of a falling-weight turntable is relatively simple. The motion of the table can be described by the equation

$$r \times ma = I\alpha \text{ (r, a, and } \alpha \text{ are vectors),}$$

where r is a vector representing the distance from the center of the turntable to the point at which force is applied, I is the moment of inertia of the system, and α is the resultant angular acceleration. The force is derived from the mass of the falling object, m, and the acceleration due to gravity, a. In a frictionless system, the force is constant and linearly related to angular acceleration, which therefore should also remain constant. Herein lies the major disadvantage of the system. With a constant force, there is no compensation for opposing frictional forces, as there would be in a system employing feedback control. Thus, a given acceleration is accurate only on the average and is not strictly repeatable from trial to trial. The variability is quantified in the calibration section of this paper and is not a serious problem provided the E is aware of it.

TURNTABLE

Figure 1 shows the general plan of the turntable. The bed of the table was laminated from three large disks of particle board. Before assembly, the wood was sealed and coated with polyurethane varnish to prevent absorbtion of moisture. The table was purposely made massive so that the high moment of inertia could aid in overcoming minor variations in acceleration due to friction. The laminated structure forms a deep groove around the circumference in which the rope lies after being attached to the falling weight. The components of the table are bolted together to allow easy assembly and mounting of restraints or other experimental equipment.

The table turns on a set of roller bearings from the rear axle of a truck. As these bearings do not have mounting flanges, a mounting plate was machined from aluminum[1] and the race press fitted into it. The plate was then bolted to a firm support. The journal (rotating part of the bearing) was similarly fitted to a wooden plug and screwed to the bottom of the turntable proper. Light machine oil was applied to the bearing to insure smooth, noiseless operation. The small diameter of this type of bearing necessitates the use of counterweights placed on the surface of the table to offset the mass of the animal and restraining equipment. A precision roller bearing is required for reliable operation and to prevent the tangential force of the falling weight from pulling the bearing out of its race. Originally, a large-diameter

*Early development of this project was funded in part by USPHS Research Grant 1 R01 EY00979-01 EXP from the National Eye Institute to Wayne Hershberger. The authors thank Dr. Hershberger for his encouragement and suggestions during construction of the apparatus.

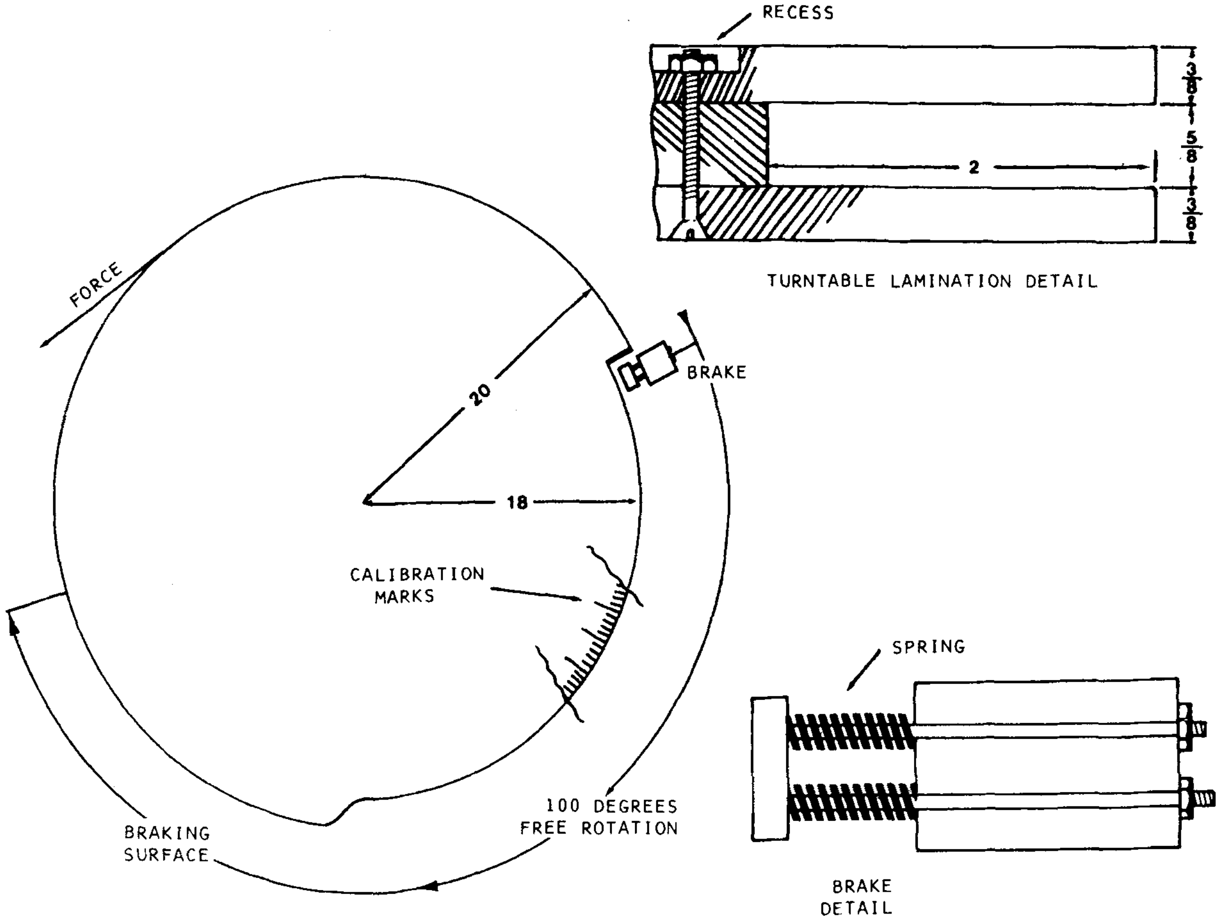

Fig. 1. Major dimensions of the turntable and relationship of turntable movement and brake. Restraining devices of different types can be mounted anywhere on the surface.

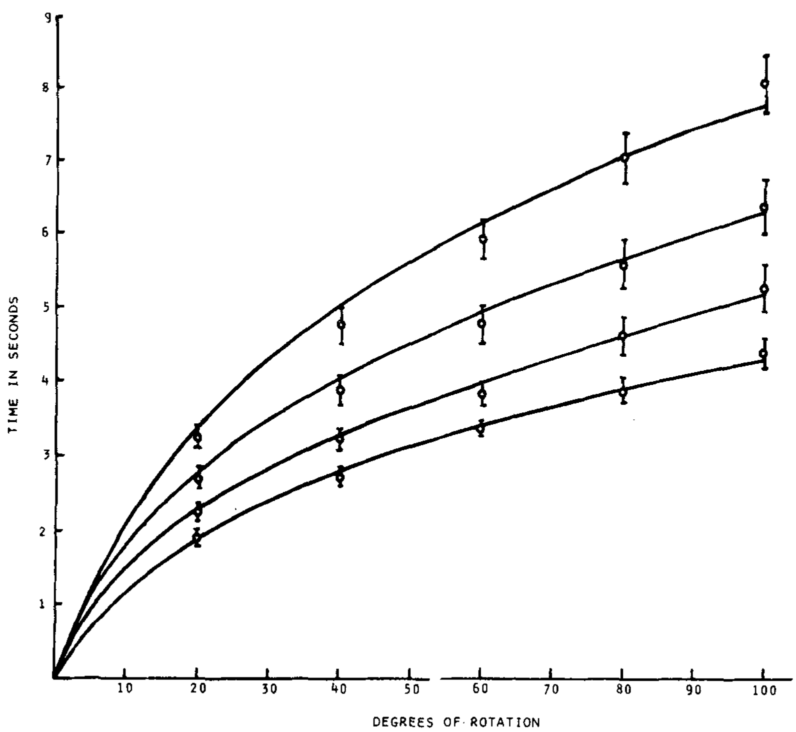

Fig. 2. Calibration curves for four angular accelerations. Curves represent (top to bottom) 3.36, 5.15, 7.45, and 10.75 deg sec^{-2}. Error bars enclose ±1 standard deviation in seconds. Solid lines represent theoretical curve.

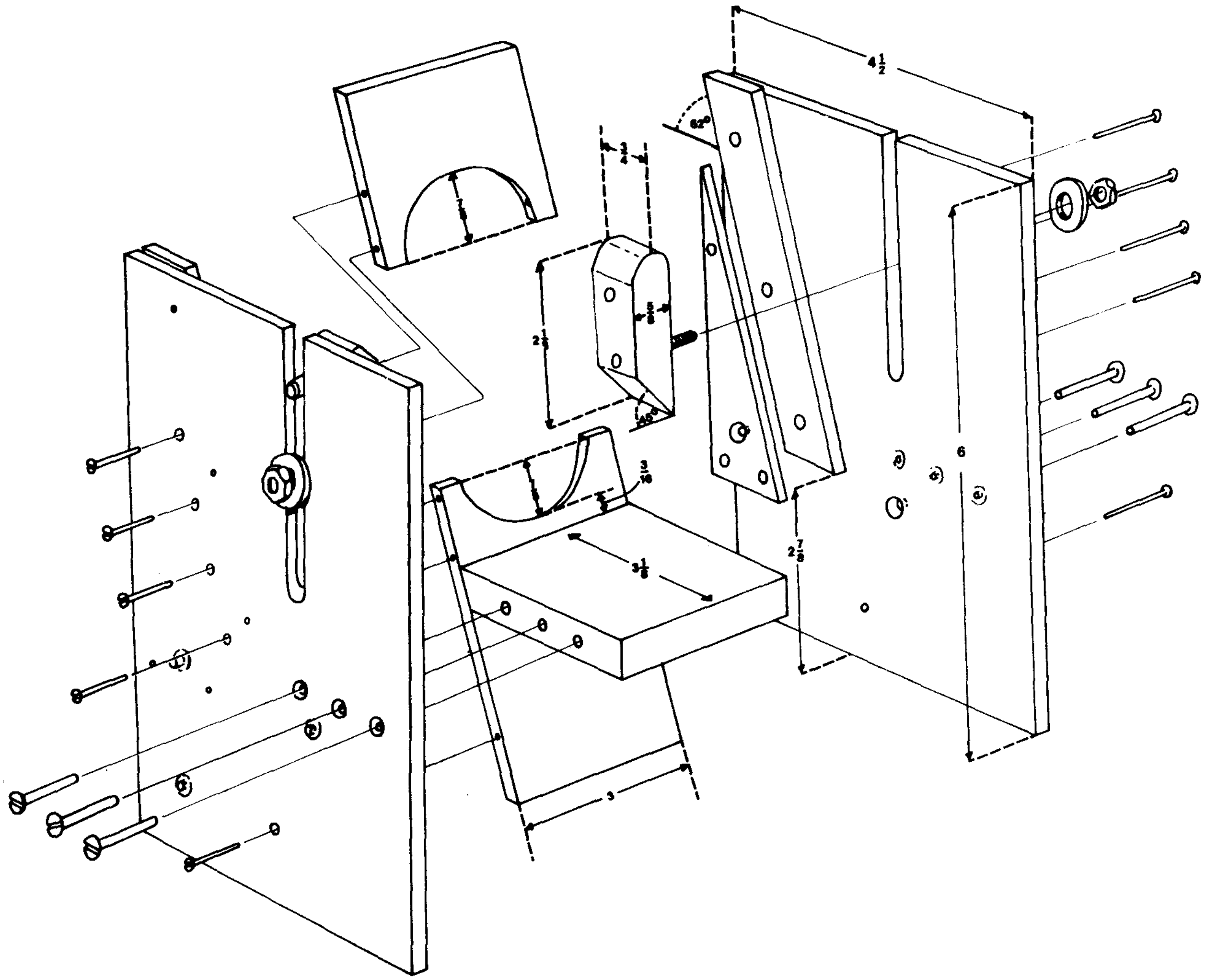

Fig. 3. Exploded view of head restraint for chronic cats. Dimensions will vary with age and sex of the cat.

"lazy susan" bearing was used, because its construction provided a stable platform without the use of counterweights. While inexpensive, tests indicated that this type of bearing was susceptible to friction and was excessively noisy in operation.

The falling weight is a plastic bottle which can be filled with sufficient water to give the required angular acceleration. The bottle is connected to the edge of the turntable by ¼-in.-diam braided nylon cord, which passes through a pulley system to an overhead suspension point that provides a clear drop of several feet. Nylon pulleys were used to further reduce system noise. Duration of the acceleration for a given mass is limited by the distance the weight can drop.

The study for which the turntable was designed requires an acceleration through only 100 deg. For shorter periods of acceleration, the turntable can be released from points closer to the end of the free rotation sector. Various release points can be defined by stops on the underside of the table. Skavenski and Robinson (1973) also describe experiments requiring fractional rotations. To stop the rotation following this period, a passive brake is employed. The outer disks of the turntable were cut back for 2 in. along the 100-deg sector of free rotation. A spring-loaded brake shoe, fixed with respect to the center of rotation, contacts the edge of the table only when the free sector has passed. Deceleration of the turntable is regulated by tension on the springs or by changing the distance between the brake and the edge of the table. Although not investigated in detail, deceleration appears nearly linear if its magnitude is small. Larger decelerations (< 60 deg sec^{-2} tend to stop rotation rather abruptly with a concomitant increase in afternystagmous.

CALIBRATION

Testing and calibration of the turntable were carried out on-line with a general-purpose laboratory computer. Similar techniques are used to monitor rotation during experiments.

The procedures described here can easily be modified for use with the more conventional laboratory counters and timers. The monitoring procedure currently in use employs a lamp and photocell to sense white-on-black ticks placed at 1-deg intervals around the circumference of the table. This method yields position as a function of time, which can be used to calculate velocity or

Fig. 4. EOG of vestibular nystagmous recorded from an electrode placed at the outer canthus of the left eye of a cat. The stimulus was a counterclockwise angular acceleration of 7.5 deg sec^{-2}. Slow phase (arrow) indicates a deviation of the eye to the left.

acceleration. An alternative and commonly used method employs a small dc motor coupled to the edge of the turntable. The motor acts like a generator and produces a voltage proportional to velocity. This signal can be electronically integrated to yield position or differentiated to yield acceleration.

To determine the suitability of the turntable for use in various experiments, two questions were asked: Does the turntable produce uniform angular acceleration, and is the acceleration reliable (i.e., repeatable from trial to trial)? To answer these questions, 10 consecutive runs were made at each of four different accelerations. Data from individual runs were collected in the form of degrees of rotation as a function of time from the beginning of the run, and averaged for each acceleration. Each average was then fit to the following equation, where t is the time required to turn Θ degrees by using a least-squares method to estimate the angular acceleration:

$$\Theta = \tfrac{1}{2}\alpha t^2.$$

The results of these calculations are displayed in Fig. 2. Goodness of fit increases with the magnitude of acceleration, there being a tendency toward flatness at the lowest accelerations. There was no indication of drift across the 10 runs. For a given acceleration, the variability, as measured by the standard deviation of arrival times, increases with the duration of the acceleration. The variability in time translates into standard deviations of 0.3 to 0.5 deg sec^{-2}. This indicates that the primary source of variability is kinetic rather than static friction. In all calibration runs, the cables connecting the animal to the recording apparatus were not passed through a commutator but were suspended loosely from the ceiling. The contribution of this method of attachment to variability was found to be negligible.

HEAD RESTRAINT

Figure 3 shows the head restraint designed for use on the turntable. It is constructed of ¼-in. Plexiglas, except for the chinrest of 5/8-in. material which forms the main structural element. All edges and corners are rounded and all screw heads countersunk to prevent injury to the cat. A guillotine-type slide encircles the neck and is screwed in place once the cat's head has been inserted. The slide is angled to give maximum contact with the rear of the skull when the animal is erect. Two rigid plastic pieces placed laterally along the posterior portion of the head also make contact with the caudal aspect of the temporal bones for additional support. Two other anterior clamping pieces slide in place from the top to provide downward and opposing lateral force just forward of the ears. This leaves the top of the head free for electrode placement.

In use, the cat is first bound by rolling it up in a cloth "straight jacket." It is then laid in the restraint with the body level and slightly below the chinrest. (Once bound and subjected to several periods of habituation, most cats do not struggle while the head restraint is being secured and remain quiet for at least 1 h of recording.) If slight traction is applied to the cat's neck (being careful not to choke the animal), movement can be more severely restricted. Otherwise, the cat is able to move his head forward, and slight rotation of the head about the horizontal axis may result. Figure 4 shows vestibular nystagmus recorded using the apparatus just described.

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NOTE

1. The authors express their thanks to Duane McClure for donating the bearing and helping with calibration. Bob Jensen and Len Nenja also aided in calibration and eye-movement recordings. Since local availability will influence the exact choice of bearing, no detailed drawing of the mounting was provided. The authors will send sketches and suggestions for mounting roller bearings to any interested investigator.

(Received for publication April 5, 1974; revision received May 20, 1974.)