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Motor Activity of Squirrel Monkeys Measured With an Ultrasonic Motion Sensor

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HOLTZMAN, S. G. AND C. W. YOUNG. *Motor activity of squirrel monkeys measured with an ultrasonic motion sensor.* PHARMACOL BIOCHEM BEHAV **38**(3) 633–637, 1991.—We describe an ultrasonic motion sensing system for measuring the motor activity of individual squirrel monkeys in their home cage. The system utilizes an inexpensive Commodore 64 microcomputer for data collection and can distinguish between movements of short (i.e., <1.0 s) and longer (i.e., ≥1.0 s) duration, and between number of movements and time spent in motion. The diurnal pattern of spontaneous activity is illustrated along with the dose-dependent effects of *d*-amphetamine (0.025–1.6 mg/kg) and haloperidol (0.025–0.4 mg/kg).

Motor activity Ultrasonic motion detector Squirrel monkey Diurnal activity *d*-Amphetamine Haloperidol

LOCOMOTOR activity provides a simple and convenient measure of the behavioral state of an animal. It has been used widely and successfully to characterize and quantify behavioral effects of drugs from a broad range of pharmacological classes. Most drug studies have been performed on rodents and a number of different types of monitoring devices and methodologies are available for this purpose (2,3). Devices commonly used to measure the locomotor activity of rodents, such as the photocell activity monitor, have been adapted for the measurement of activity of small primates (4). However, the measurement of motor activity in larger animals, such as primates, has been reported infrequently, due in part to the lack of an appropriate selection of automated systems from commercial sources.

We have developed an ultrasonic motion sensing system for monitoring the activity of small primates in an enclosed space. The system utilizes an inexpensive Commodore 64 microcomputer for data collection and has the additional advantage of being able to monitor the activity of the subject in its home cage. This report describes the system and its application for measuring the spontaneous motor activity of squirrel monkeys. It also illustrates the potential utility of the system for measuring drug effects. Dose-response curves were determined for *d*-amphetamine, a prototypic behavioral stimulant, and for haloperidol, a prototypic behavioral depressant.

METHOD

Subject

The subjects were adult male squirrel monkeys (*Saimiri sciureus*), weighing 700–1000 g. Between experimental sessions the monkeys were housed one per cage in a vivarium that was illuminated between 0600 and 1800 hours. The home cage was a commercially available stainless-steel unit, measuring 45 cm wide × 45 cm deep × 60 cm high (Hoeltge, Inc., Cincinnati, OH). Water and food (high protein monkey chow No. 5045; Purina Mills, Inc., St. Louis, MO) were present in the home cage at all times, including experimental sessions.

Apparatus

The principal components of the ultrasonic motor activity monitoring system consisted of the following: ultrasonic head, data processor, Commodore 64 computer, disk drive, video display monitor, and dot matrix printer. The ultrasonic head was mounted on an inside wall of a wooden test enclosure, measuring 85 cm wide × 70 cm deep × 75 cm high, that was ventilated and sound-attenuating. A camera with a wide-angle low-light lens also was mounted on the wall of the test enclosure and connected to a video monitor for visual surveillance of an animal during a test session. A diagram of the activity monitoring system is shown in Fig. 1.

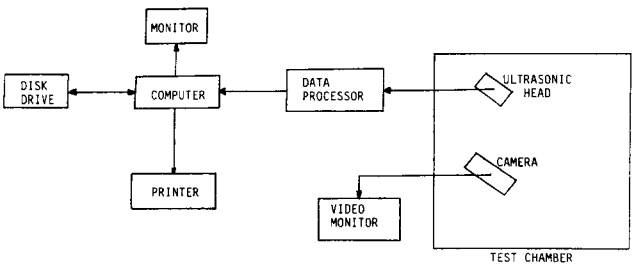

FIG. 1. Schematic diagram of ultrasonic motion sensing system.

DATE ___/___/___ TIME ___:___

MONKEY _____

DRUG _____ AMOUNT _____

RUN TIME ___:___:___

RUN	LG-T	LG-N	SM-T	SM-N	TN-N	TN-T
#11:	809	58	2673	708	838	3482
#12:	411	29	1674	502	531	2085
#13:	11	1	507	175	176	518
#14:	60	4	432	131	135	492
#15:	309	18	879	242	260	1188

FIG. 2. Example of computer printout of data from an activity recording session. Run time is the interval at which data are reported during a session, and can be set in hours, minutes, and seconds. Data in this example were reported in "runs" of 30-min intervals. Columns are: time (seconds) spent in large movements (LG-T), number of large movements (LG-N), time (seconds) spent in small movements (SM-T), number of small movements (SM-N), total number of movements (TN-N), total time (seconds) spent in motion (TN-T). The last digit of each time value represents tenths of a second.

The ultrasonic head contained the transmitter and receiver transducer [each one a model TR-89/B, Type 40 transducer (i.e., 40 kHz); Massa Products Corp., Hingham, MA]. The transmitted signal was reflected from the walls of the test enclosure to the receiver transducer. Changes in the position of a subject produced

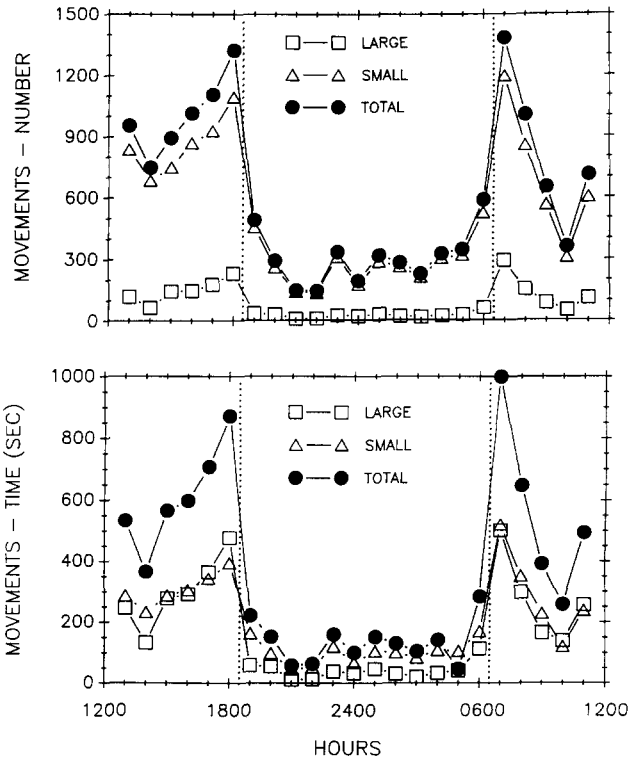

FIG. 3. Diurnal spontaneous activity of squirrel monkeys. The light in the test chamber was off during the interval between the two dotted vertical lines. Each point is a mean of one observation in each of six monkeys.

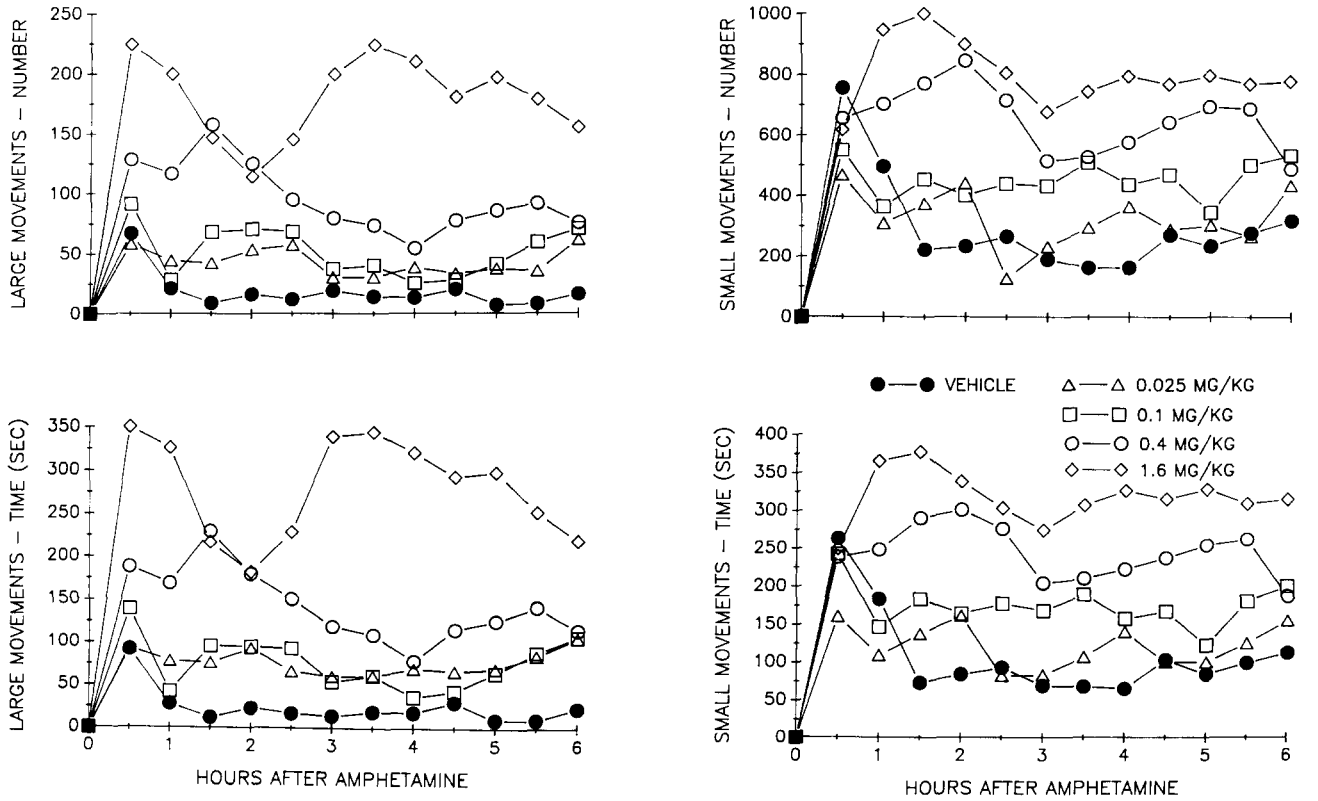

FIG. 4. Time course of the effects of vehicle or *d*-amphetamine (0.025–1.6 mg/kg) on the motor activity of squirrel monkeys. Each point is a mean of one observation in each of five monkeys.

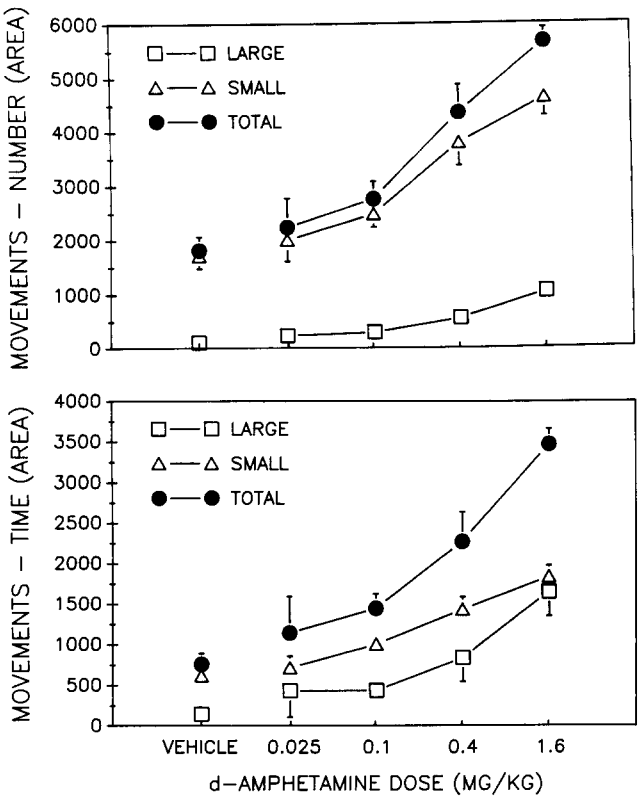

FIG. 5. Dose-response curves for *d*-amphetamine on the motor activity of squirrel monkeys. These curves were derived from the area under the 6-h time-course curves in Fig. 4. Each point is a mean; vertical lines are one S.E.M., and are absent if the S.E.M. is less than the radius of the point.

varying signals that were mixed with the stationary returning signals and represented the motion of the subject. These signals were amplified and transmitted to a pulse-stretcher circuit in the data processor, which produced a TTL DC level signal for as long as the subject was in motion. The length of the signal was stored on counters, which were connected to the computer by parallel output. The ultrasonic head developed an interrupt request, which was serviced by the computer. The computer read the data and then generated a reset pulse to the ultrasonic head and counting circuit; the ultrasonic head was then ready to transmit subsequent signals from the receiver transducer to the data processor.

The data processor measured units of time of motion. It was contained in a small cabinet with a numeric display, which facilitated the correlating of activity-input signals with the subject display on the video monitor. The data processor housed the pulse stretcher, timing circuits and counters, as well as "housekeeping" circuits for interrupts, read and resets. It also contained a calibration adjustment that could be used to set the minimum size of movement that would be detected. The sensitivity of the device was first adjusted to detect a small swinging pendulum that had been placed in an elevated position in the center of the test chamber. With a subject in the test chamber the calibration was readjusted to a setting that ensured detection of movement throughout the cage. Periodic tests with the swinging pendulum over the course of the study confirmed that the sensitivity setting remained stable and further adjustment was not required.

The computer program, written in BASIC, kept track of the kinds of motion specified, and issued an output to the printer at the indicated interval of time, which could range from seconds to hours. The computer program separated movements into small and large, defined for purposes of this study as an episode of continuous motion lasting less than 1.0 s (small) or 1.0 s or longer (large). The data collected were: number of large movements, number of small movements, total number of movements (large + small), time (s) spent in large movements, time spent in small movements, total time in motion. Figure 2 illustrates a representative computer printout for part of an actual experimental session.

Testing Procedure

On the day of a test, the monkey was removed from its home cage and weighed. It then was either returned immediately to its home cage or was placed in a Plexiglas primate restraining chair where it was injected with a dose of *d*-amphetamine or haloperidol and then returned to its home cage. The monkey cage was placed on a dolly and moved a short distance through a hallway to the laboratory where activity was measured. For the measurement of diurnal activity, the cage containing the monkey was placed in the sound-attenuating enclosure at 1130–1145 h; beginning at 1200 h, activity was recorded for 23 h in blocks of 1 h. For the measurement of drug effects, activity recording began immediately after the cage was placed in the sound-attenuating enclosure, approximately 5 min after the injection. Activity was recorded for 6 h in blocks of 30 min; experiments were conducted between 0900 and 1600 hours. Each of the monkeys was tested not more frequently than once per week, and was exposed to the handling procedures and testing environment at least two times before being used in an actual experiment.

Drugs

d-Amphetamine sulfate (Sigma Chemical Co., St. Louis, MO) was dissolved in 0.9% saline solution; doses are expressed as the free base. Haloperidol base (McNeil Pharmaceutical, Springhouse, PA) was dissolved in three parts of 8.5% lactic acid and two parts of 1.0 normal sodium hydroxide. Drugs were injected into a thigh muscle in a volume of 1.0 ml/kg of body weight. The various doses of a drug and the drug vehicle were administered to each monkey in a random sequence.

Data Analysis

Time-course data for each of the six dependent measures were analyzed separately for each drug, using a two-factor analysis of variance with repeated measures on both factors (time, dose). Area under each of the time-effect curves was determined by the trapezoidal rule (7) and used to construct dose-response curves. Areas of activity for each of the six dependent measures were then analyzed separately for each drug, using a one-factor analysis of variance with repeated measures, followed by a Dunnett's *t*-test (two-tailed) for multiple comparisons of a control mean with treatment means. In all cases, a p value of ≤ 0.05 was considered to be statistically significant.

RESULTS

Diurnal Activity

Throughout the period when lights were on in the test chamber, the number of small movements ($\leq$1.0 s) exceeded the number of large movements ($\geq$1.0 s) by 5–10-fold (Fig. 3). However, the amount of time spent in small and large movements was approximately equal. Activity fell precipitously when the houselight

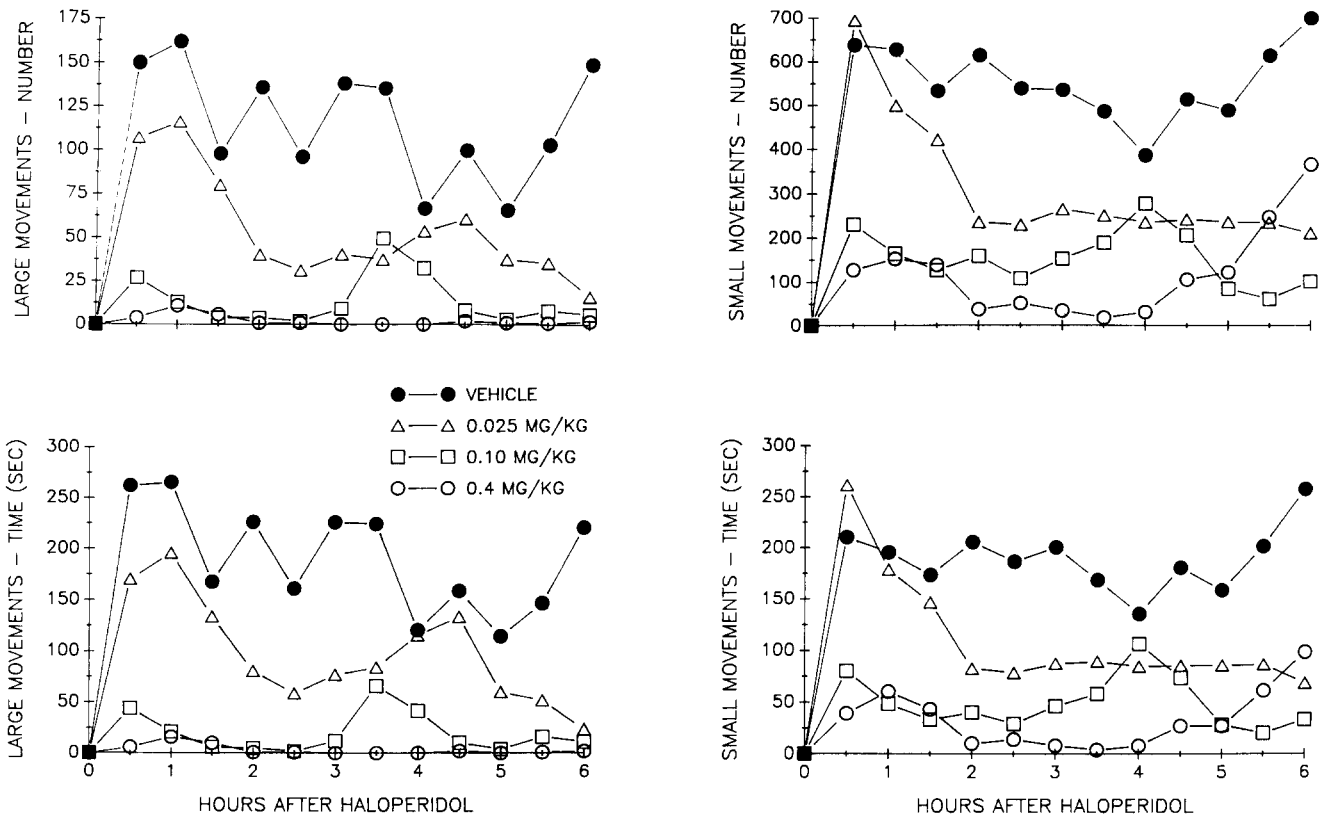

FIG. 6. Time course of the effects of vehicle or haloperidol (0.025–0.4 mg/kg) on the motor activity of squirrel monkeys (n = 6).

was extinguished, and remained low until the light was turned on again the next morning (Fig. 3). Small movements accounted for almost all of the activity recorded during the dark period.

d-Amphetamine

As little as 0.025 mg/kg of *d*-amphetamine increased the average amount of large activity (number of movements and time in motion) in most of the 30-min intervals of the session (Fig. 4). The next higher dose, 0.1 mg/kg, consistently increased small as well as large activity. The highest dose, 1.6 mg/kg, produced an approximately 10-fold increase in number of large movements and time spent in large movements and increased both parameters of small activity by approximately 5-fold. Stereotyped head movements were observed in all monkeys throughout the session, beginning 30–60 min after injection. At all doses, small and large activity tended to remain elevated over the course of the 6-h session. All of the two-factor analyses of variance showed a significant effect of dose, $F(4,16) \geq 5.34$, with $p < 0.01$ for each comparison, but no significant effect of time and no significant interaction of dose by time. Dose-response curves derived from the area under the time-course curves are shown in Fig. 5.

Haloperidol

All measures of motor activity were reduced substantially by 0.025 mg/kg of haloperidol, the lowest dose tested (Fig. 6). The onset of drug action was gradual. Peak behavioral depression occurred in the fourth 30-min interval and, generally, persisted for the remainder of the session. The highest dose tested, 0.4 mg/kg, virtually eliminated large activity and reduced small activity (number and time) markedly (Fig. 6). All of the two-factor analyses of variance showed a significant effect of dose, $F(3,15) \geq 3.83$, with $p < 0.05$ for each comparison, and a significant effect of time for time spent in large movements, $F(11,55) = 2.05$, $p < 0.05$, and in small movements, $F(11,55) = 1.96$, $p < 0.05$. In addition, there was a significant interaction of dose by time for the measure of time spent in small movements, $F(33,165) = 1.56$, $p < 0.05$. Dose-response curves determined from area under the time-course are shown in Fig. 7.

DISCUSSION

The ultrasonic motion sensing system appears to be a suitable means of measuring the motor activity of squirrel monkeys. Changes in spontaneous activity as a function of the illumination cycle were readily detected. In addition, orderly increases and decreases in activity, respectively, were recorded over the range of doses of *d*-amphetamine and haloperidol. The sensitivity of the activity measure to the effects of these drugs compares favorably with the sensitivity of operant procedures. The rate of operant responding of squirrel monkeys usually is increased by 0.03–0.1 mg/kg of *d*-amphetamine, depending upon the particular schedule of reinforcement (1), and decreased reliably by haloperidol at doses on the order of 0.01 mg/kg (6). Periodic observation of the monkeys via the closed-circuit video system indicated that the activity data being recorded under baseline conditions and after drug administration did correspond appropriately to the movements of the animals.

This motion detection system has several features that may be advantageous for quantifying the motor activity of small primates. A monkey can be tested in its home cage, if it is housed individ-

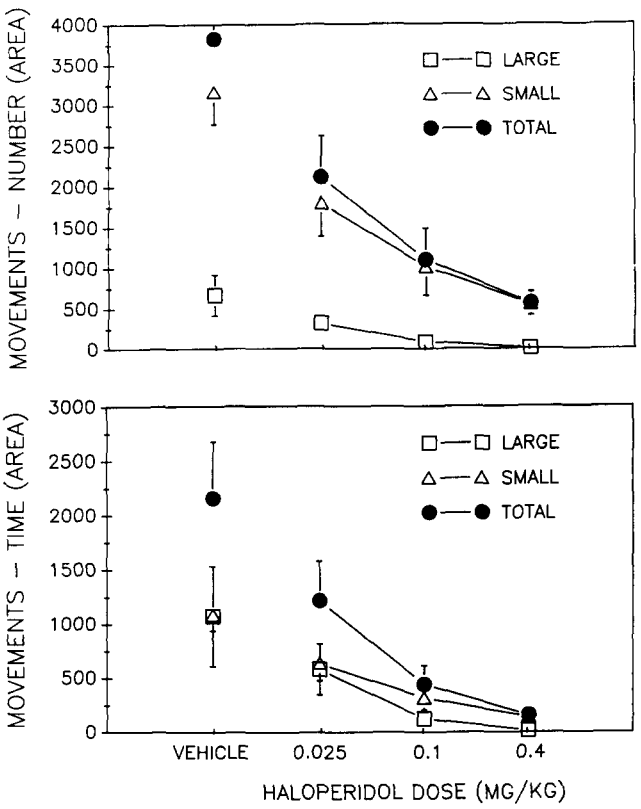

FIG. 7. Dose-response curves for haloperidol on the motor activity of squirrel monkeys. The curves were derived from the area under the 6-h time-course curves in Fig. 6. Each point is a mean and one S.E.M.

ually. This minimizes the need to habituate the subject to a novel testing environment. It also eliminates the potentially confounding influence of previous animals in the testing space. Furthermore, this arrangement should facilitate around-the-clock or other forms of relatively long-term monitoring. We placed the home cage in a sound-attenuating enclosure during activity measurements. However, if the presence of other animals or personnel is not a major concern, there is no reason why the ultrasonic head could not be placed in the vivarium for continuous monitoring over days or weeks.

The ultrasonic sensor detects activity in all plains, as is required in the case of a primate. In addition, the device can distinguish between two sizes of movement, "small" and "large," which can be defined by the user. It also can distinguish between number of movements and time spent in motion. With the definition of small movement that we used (i.e., duration <1.0 s), all six activity measures appeared to be equally sensitive to the drugs that were tested. However, these activity measures might well be affected differentially with a different demarcation between small and large movements and/or with other drugs. Distinctions between types of movement were more apparent in the case of spontaneous nocturnal activity. The value of multiple concurrent measures of activity has been emphasized (3,5).

The ultrasonic motion sensing system provides substantial power and flexibility at a modest cost: approximately $1,000 for a discount-priced Commodore 64, disk drive, video monitor, printer, and the components of the ultrasonic head and data processor. Power and flexibility could be increased further by using a computer with an RS-232 serial interface. With this type of arrangement, timing and counting functions could be specified by the software. The data processor would require fewer components and the number of activity parameters that could be followed, such as length of movement epoch, would increase. The system should be adaptable for many types of small primates.

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REFERENCES

1. Barrett, J. E.; Katz, J. L. Drug effects on behaviors maintained by different events. In: Thompson, T.; Dews, P. B.; McKim, W. A., eds. Advances in behavioral pharmacology, vol. 3. New York: Academic Press; 1981:119–168.
2. Dourish, C. T. Effects of drugs on spontaneous motor activity. In: Greenshaw, A. J.; Dourish, C. T., eds. Experimental psychopharmacology. Clifton: Humana Press; 1987:153–211.
3. Geyer, M. Approaches to the characterization of drug effects on locomotor activity in rodents. In: Adler, M. W.; Cowan, A., eds. Testing and evaluation of drugs of abuse. New York: Wiley-Liss, Inc.; 1990: 81–99.
4. Jones, D. L.; Dill, R. E. An inexpensive automatic activity monitor for small primates. J. Pharmacol. Methods 7:47–55; 1982.
5. Schaefer, G. J.; Bonsall, R. W.; Michael, R. P. An automatic device for measuring speed of movement and time spent at rest: Its application to testing dopaminergic drugs. Physiol. Behav. 37:181–186; 1986.
6. Spealman, R. D.; Kelleher, R. T.; Goldberg, S. R.; DeWeese, J.; Goldberg, D. M. Behavioral effects of clozapine: Comparison with thioridazine, chlorpromazine, haloperidol and chlordiazepoxide in squirrel monkeys. J. Pharmacol. Exp. Ther. 224:127–134; 1983.
7. Tallarida, R. J.; Murray, R. B. Manual of pharmacologic calculations with computer programs. 2nd ed. New York: Springer-Verlag; 1987.