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General Activity in Baboons Measured With a Computerized, Lightweight Piezoelectric Motion Sensor: Effects of Drugs

ROBERT D. HIENZ,*†[1] JAYLAN S. TURKKAN,* DEBRA J. SPEAR,*
CHRISTINE A. SANNERUD,‡ BARBARA J. KAMINSKI* AND RICHARD P. ALLEN§

**Division of Behavioral Biology, Department of Psychiatry*
†Center for Hearing Sciences
The Johns Hopkins University School of Medicine, Baltimore, MD 21224
‡The Addiction Research Center, National Institute on Drug Abuse
§The Sleep Disorders Clinic
The Francis Scott Key Medical Center, Baltimore, MD 21224

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HIENZ, R. D., J. S. TURKKAN, D. J. SPEAR, C. A. SANNERUD, B. J. KAMINSKI AND R. P. ALLEN. *General activity in baboons measured with a computerized, lightweight piezoelectric motion sensor: Effects of drugs.* PHARMACOL BIOCHEM BEHAV **42**(3) 497–507, 1992.—A small, 1-oz activity-monitoring device is described for measuring motor activity continuously for periods of up to 42 days. The monitor employs a piezoelectric sensor that detects extremely small accelerations induced by movements. The monitor can be placed on collars or harnesses (e.g., for rabbits, cats, dogs, nonhuman primates, etc.). The use of the monitor is described within numerous laboratories studying the behavioral pharmacology of drugs in individually caged laboratory baboons. Patterns of daily activity were reliably recorded over periods of several months, and reflected the normal activity patterns of animals. The activity monitor recorded reliable, drug-induced changes in general activity that paralleled the known effects of the same drugs on learned behaviors. Low doses of the stimulants cocaine and *d*-amphetamine both increased general activity. Marked reductions in general activity were observed following both the administration of Δ-9-tetrahydrocannabinol and an antihypertensive drug combination of diuretic and verapamil.

Motor activity Drugs *d*-amphetamine Cocaine Δ-9 THC Verapamil Hydrochlorothiazide Baboon Nonhuman primates

THE measurement of general activity is of major importance for many areas of human and animal biomedical research. Studies abound on changes in activity produced by toxic substances, therapeutic medications, work/rest schedules, and other manipulations [e.g., (9,20,23)]. General activity measurements have also been used in the clinical diagnosis of panic disorders (29) and sleep disturbances (2). A number of activity-monitoring systems have been developed for specific use in the animal laboratory. Primary approaches to the measurement of activity in animals have included the use of photobeams, running wheels, field detectors based upon ultrasonic (Doppler) or capacitance circuits, open-field and other complex visual notations from videotaped images, and mechanical transducers such as force platforms and jiggle cages (8).

Disadvantages of current devices in animal research are several and have been discussed extensively (8,9,11,22,23). For example, some telemetry systems are invasive in that they must be subcutaneously implanted; further, the recorded activity levels in some of these systems can vary according to the proximity of the animal to an overhead electronic interface (22). Other devices, such as force platforms and jiggle cages, require that animals be placed in a restricted environment for detection of movement, which may not allow for 24-h monitoring and detection of circadian and ultradian (>1 cycle per day) rhythms. Running wheels do not measure activity when an animal is not in the wheel, even though an animal may be engaged in other activities. Many automated monitors such as Minimitters® do not have sufficient memory for extended recording of activity over long periods of time. Finally, sepa-

[1] Requests for reprints should be addressed to Robert D. Hienz, Ph.D., Division of Behavioral Biology, Behavioral Biology Research Center, Hopkins Bayview Research Campus, 5510 Nathan Shock Drive, Suite 3000, Baltimore, MD 21224.

rate activity-testing environments can produce differing durations and levels of adaptation, which can interact unpredictably with experimental manipulations.

The vast majority of current activity-measurement systems have been developed and tested in rodents. In research with nonhuman primates, some studies have directly employed activity-monitoring devices developed for rodents (3), while others have developed methods specifically for use with nonhuman primates. These latter methods include, for example, a tethering system connected to an overhead potentiometer (27); a photocell methodology refined for use particularly with small primates such as squirrel monkeys (*Saimiri sciureus*) (15); and an ultrasonic motion sensor used with squirrel monkeys (13). A variety of notation systems and ethograms have also been used, primarily to assess the behavior of larger primates such as baboons. These latter methods require extensive technical support, however, either for real-time visual observations [e.g., (4,24,25)] or for later coded transcriptions from videotapes (26). Although specific behavioral categories can be characterized with such notation schemes, an overall measure of the degree of general activity cannot be easily derived. Counting the number of movements, for example, depends upon a somewhat arbitrary definition of when one movement ends and another begins.

In our laboratories, the need for continuous measurement of general activity in nonhuman primates arose from several different research projects in a variety of experimental settings. These projects ranged from acute and long-term studies of the effects of cocaine, *d*-amphetamine, marijuana, and other psychoactive drugs; to the chronic biobehavioral studies of the effects of antihypertensive agents. Theoretical and practical considerations prompted a search for an unobtrusive activity monitoring device that would: a) be well tolerated by adult male baboons, b) require low staff involvement, c) not interfere with psychological well-being of these primates, and d) meet rigorous technical criteria including validity and reliability. We describe here a self-contained, nonrestrictive activity-monitoring device based upon piezoelectric technology that has the potential to widen the range of methodological options for the measurement of activity in nonhuman primates and other large animals. This small, 1-oz unit [Personal Activity Monitor (PAM), Individual Monitoring Systems, Baltimore, MD] has been adapted from a similar unit developed at NIH (5). The PAM unit has been used in human studies of sleep disorders (1) and in studies on the effects of medication on children with attention deficit hyperactivity disorder (21).

The following report describes activity recorded with the PAM unit in such a variety of laboratory settings within the Division of Behavioral Biology over a 2-year period, and includes descriptions of activity changes following the administration of numerous pharmacological compounds. These compounds included cocaine, *d*-amphetamine, Δ-9-tetrahydrocannabinol (THC), and an antihypertensive drug combination consisting of hydrochlorothiazide and verapamil. The general activity of a large number of baboons was monitored individually as activity occurred naturally within the laboratory, as well as during food-reinforced operant behavioral sessions.

METHOD

Subjects

Subjects were drug-naive and drug-experienced dog-faced baboons (both *Papio anubis* and *Papio cynocephalus* subtypes, supplied by Primate Imports) weighing between 18–26 kg. A total of approximately 19 adult, male baboons from the Self-Administration, Drug-Dependence, Animal Psychophysics, and Cardiovascular Laboratories within the Division of Behavioral Biology have worn the activity device. Data for a subset of these subjects have been analyzed for presentation here. All baboons were individually housed in large-primate cages equipped with seating benches, and had free access to water. Baboons were maintained on a restricted feeding schedule; supplemental monkey chow was provided for baboons not receiving their entire food intake during operant sessions. The feeding schedules permitted progressive weight gain, although at 5–10% below ad lib weights. Fresh fruit was provided daily.

Apparatus

The monitoring device is a compactly designed (LWH = 5.5 × 3.3 × 1.5 cm) unit enclosed in a plastic case, with no external wires, as shown in Fig. 1A. Movement of the monitor triggers an internal piezoelectric sensor. The monitor is sensitive to accelerations exceeding 1/10 of a g force, and has a frequency response of 0.25–6.0 Hz. When the monitor is placed on a desktop, for example, it will register accelerations induced by pencil taps on the desktop. For these near-threshold accelerations, the monitor is sensitive to movements in all directions except along the length of the monitor. Normal movements produced by humans and/or experimental animals, however, are almost never only in one plane. Further, such movements typically greatly exceed this low-threshold criterion for the other planes detected by the monitor. For all practical purposes, then, the monitor is sensitive to almost any movement in any direction.

The monitor's internal microprocessor records activity over 1,024 time intervals. Each interval is further divided into 4,096 equal sample time units. The number of sample time units during which any activity produces acceleration above threshold is counted. This results in a sum ("activity count") ranging from 0–4,096 for each of the 1,024 time intervals. The software provided by the manufacturer reduces this activity scale further by dividing each activity count by 16, thus producing an activity count range of 0–256. Alternatively, each count may be divided by 4,096, which would give the proportion of sample time units during which the activity threshold was exceeded for each of the 1,024 time intervals. This latter measure is referred to as "activity density," and ranges from 0–1. The length of each of the 1,024 time intervals can be preset by the manufacturer to measure activity for periods ranging from 0.0137–0.88 s (see Table 1), thus providing high resolution for any activities exceeding a few seconds in duration. Selecting among these ranges also allows one to record activity for overall periods as short as 16 h and as long as 42 days and 16 h. The activity monitor can also be calibrated by the manufacturer for different sensitivities; for activity data of the present report, sensitivity was set so that activity greater than 1/10 *g* force triggered each count. The monitor is powered by two 3-V lithium batteries mounted on an internal board (Fig. 1A). The batteries are easily obtainable at low cost (Matsushita Electronics, #BR-2325-1HG, about $40.00), last for about 9–10 months, and can be installed by a trained technician.

Although the monitor can withstand vigorous body movement, strong blows may damage the piezoelectric transducer. For this reason, when placed on our adult baboons, the monitor was further protected in a padded metal case (see Fig. 1). For most baboons, the monitor and protective metal container

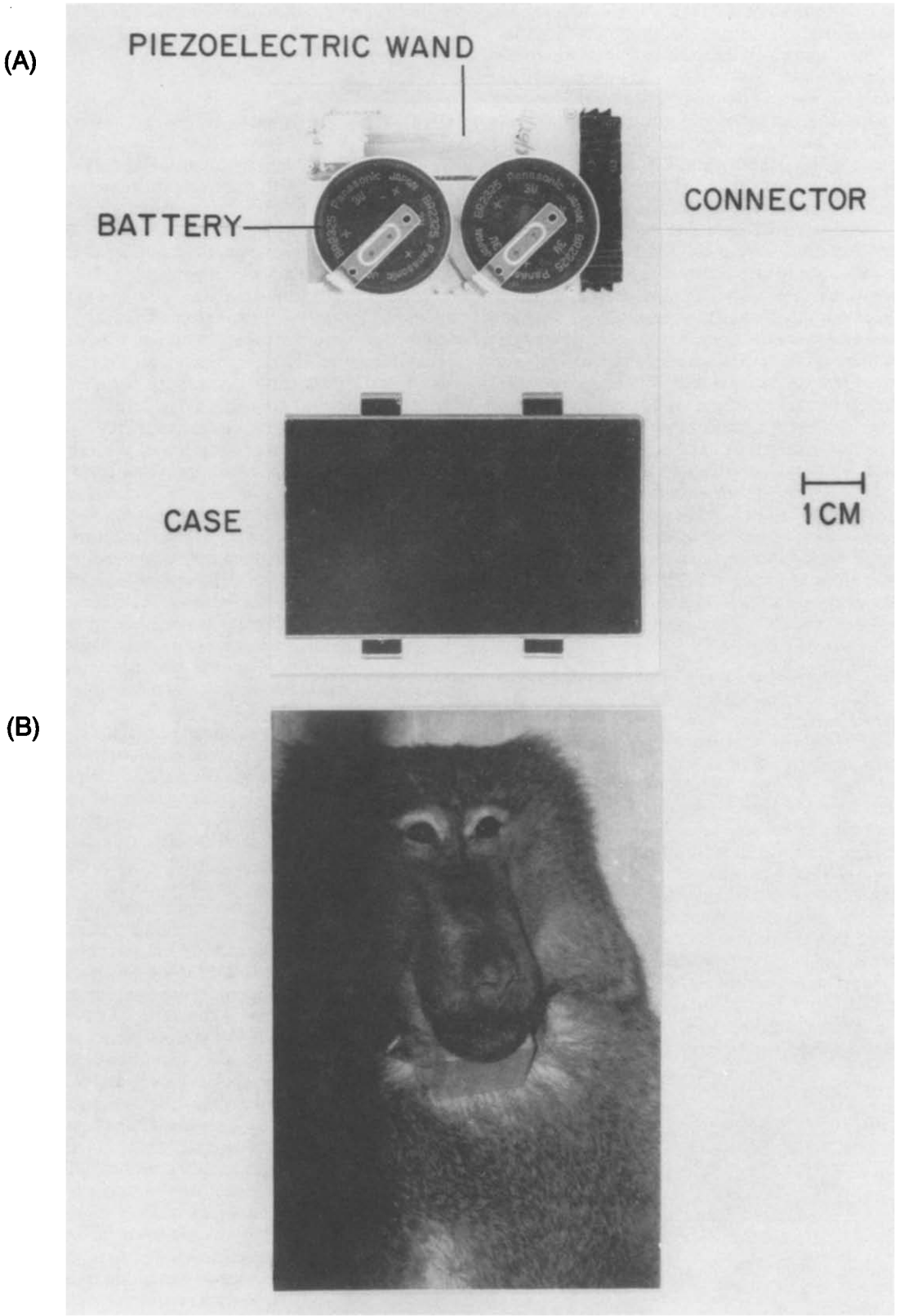

FIG. 1. (A) Actual-size photograph of the PAM unit, showing the piezoelectric wand, 3-V lithium batteries, connector, and protective case. (B) Photograph of a monitor attached to a 1-in. wide leather collar on an adult male baboon.

were mounted on a soft leather neck collar and rested directly under the chin, as shown in Fig. 1B (31). For baboons used in chronic drug administration studies, the monitor and protective container were mounted on the outer casing of a polyethylene plastic backplate that protected an intragastric catheter [see (16) and (24) for further details]. Orientation for both placements situated the long axis of the activity monitor lengthwise across the animal. Both types of placement have been well tolerated by all baboons and did not interfere with eating or restrict body movements.

Activity monitors record activity continuously. When the memory is full (e.g., after 42 days and 16 h for a monitor with a 1-h interval period), the data "wraps around" in the internal memory and begins to write over the first day's activity record. An option in the software allows for reading such data accurately so that one obtains, for example, 42 days and 16 h of continuous activity data time-locked to the point when the monitor is removed and the data are read into a computer. Data are extracted and the internal memory cleared and reset via a proprietary computer interface, which is controlled by the software provided by the manufacturer. The PAM software runs on Macintosh computers and has been designed for flexibility in data analysis. The software also has tabular data displays and includes graphic displays such as simple bar graphs of both raw or averaged activity and raster plots. In addition, the data can be exported as a text file (in ASCII format) for further analysis by spreadsheet programs, and the graphic displays can be exported to other applications as well (e.g., to drawing programs via PICT files).

Drug Administrations

In the Animal Psychophysics and Cardiovascular Laboratories of the Division of Behavioral Biology, drugs were routinely administered either orally or via IM injections into the gluteal region of an animal. Cocaine hydrochloride was administered intramuscularly. On nondrug days, an equal volume of vehicle (saline) was similarly administered. For chronic cocaine administration, the drug was administered at approximately the same time every day in a single injection, with injection site varied daily to avoid tissue damage. Reliable self-ingestion of Δ-9-THC was obtained by injecting the drug (dissolved in ethanol) into an orange slice and watching the animal consume the slice. On control days, the drug vehicle alone was injected into the orange slice and consumed by the animal. Both the diuretic hydrochlorothiazide and the calcium antagonist verapamil were also given orally by sprinkling powdered forms of the appropriate doses of these drugs inside banana slices and watching baboons consume the bananas. Rejection of these foods was never observed. In the Drug-Dependence Laboratories within the Division, *d*-amphetamine sulfate (dissolved in saline) was administered intramuscularly.

TABLE 1

ACTIVITY MONITOR TIMING CHARACTERISTICS

Time Interval Width	Within-Interval Sample Time Unit Width	Total Recording Period
60 min	0.879 s	42 days, 16 h
30 min	0.439 s	21 days, 8 h
15 min	0.220 s	10 days, 16 h
7.5 min	0.110 s	5 days, 8 h
3.75 min	0.055 s	2 days, 16 h
1.875 min	0.027 s	1 day, 8 h
0.938 min	0.014 s	16 h

RESULTS

General Activity Patterns

Figure 2 shows activity counts plotted as a function of time for baboon PW, with each column representing the activity count for a 30-min time interval. A sample of 5 days of continuous activity is shown in the top panel, with an expanded view of one of these days shown in the bottom panel. Both of these graphs represent data as shown by the PAM software, which allows for immediate visual display of the data in this format. (Any portion of the data may be examined in more detail by using the computer mouse to draw a rectangular selection window around the desired portion.) From Fig. 2 (top), one can readily distinguish the activity patterns during daytime hours vs. the near-zero activity patterns observed overnight. Peaks in the activity records at about 7:00 a.m. correspond to the laboratory lights-on time (marked with asterisks). The lower panel in Fig. 2 is from one 24-h period of activity and illustrates activity in more detail following the laboratory events of morning lights on (point A), followed by a drug vehicle injection (point B), an auscultatory blood pressure measurement (point C), and the beginning of the operant test session (point D). Two additional indices often used for assessment of changes in activity/inactivity in human sleep studies are also indicated in the lower panel of Fig. 2: a) single periods of inactivity and b) consecutive periods of inactivity. Alternatively, a total 24-h activity measure may be taken by averaging or summing activity counts over each 24-h period.

Figure 3 shows two examples of the different levels of resolution available with the monitor. Activity counts are shown as a function of time for two separate monitors worn simultaneously by one of the experimenters on the right wrist for 6 h. One monitor (top panel) was preset to record activity in 1-h intervals, while the second monitor (middle panel) recorded activity in 1-min intervals. While general changes in activity may be viewed with the 1-h recording interval (Fig. 3, top), a more detailed, fine-grained representation of activity can be obtained with the use of the 1-min recording interval (Fig. 3, middle). An alternative method for comparing the resolution of these two monitors is to simply collapse the activity counts of the 1-min interval monitor into 1-h bins and then compare the average hourly activity counts for the two monitors. This comparison is shown in the bottom panel of Fig. 3. Note the similarities in activity changes from one hour to the next for the two monitors when the data are examined in this manner. The actual activity count values did not, however, closely approximate one another. This is primarily due to the manner in which activity counts are recorded. For the 1-h recording interval, for example, a single suprathreshold movement occurring within a sample time unit of 0.88 s would result in an activity count. For the 1-min interval, however, that single movement might register in only a few of the 60 sample time units extending across the same 0.88-s time span.

Figure 4 shows the sensitivity of the monitor to various types of hand movements maintained for equal time periods when the monitor was worn around the wrist of one of the experimenters. The monitor not only easily registered back-and-forth movements or shaking of the wrist (the monotonic arm movements at various speeds), but also responded to key-

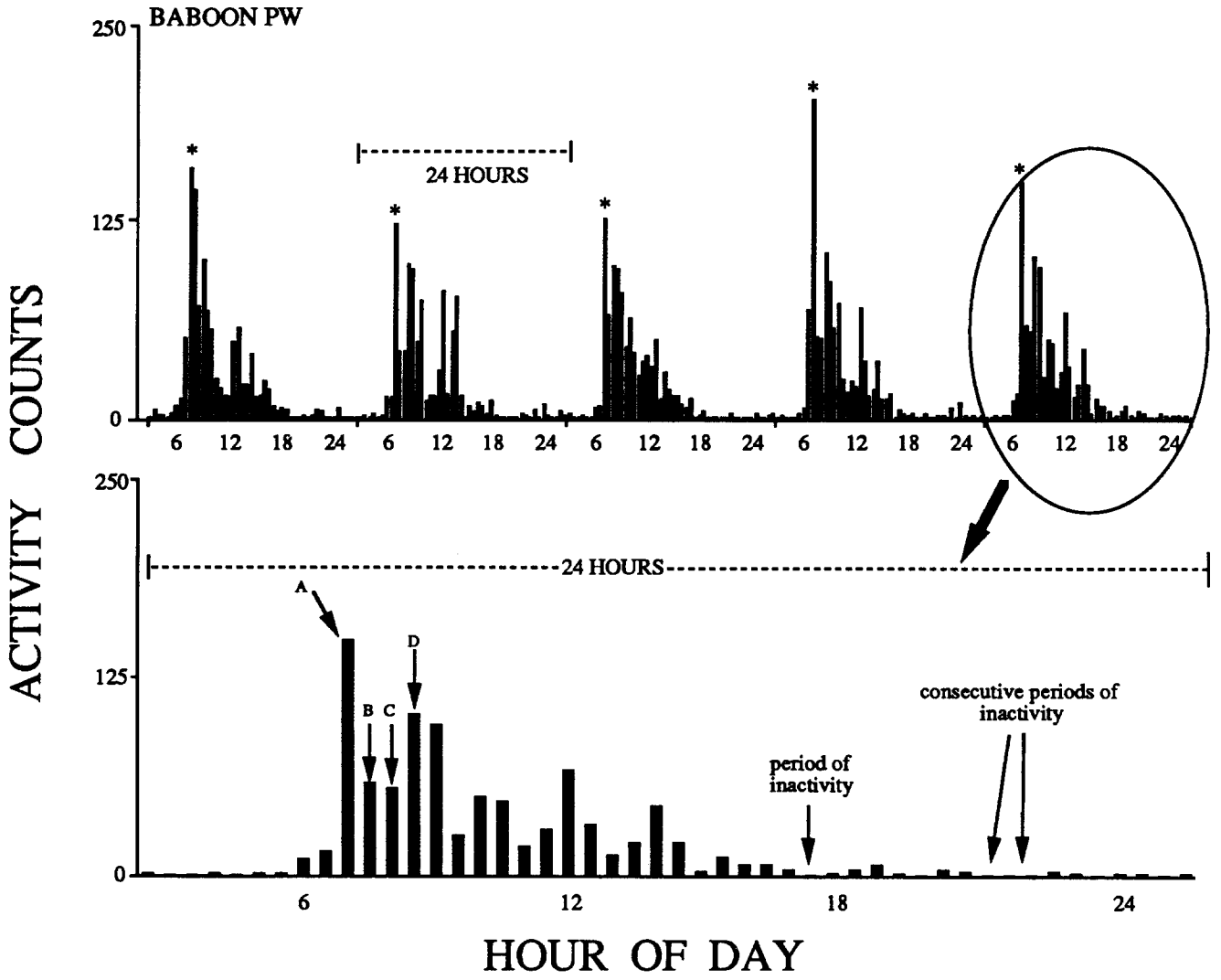

FIG. 2. Activity counts as a function of time for one baboon for 5 consecutive days (upper panel), with the fifth day enlarged (lower panel) for added detail. Each column represents the activity count recorded over a 30-min interval from a monitor attached to a collar. Hours of the day are indicated for 6 a.m., noon, 6 p.m., and midnight for each day. Asterisks indicate times of laboratory lights being turned on each morning (hour 7). In the lower graph, the following events are indicated: lights on (point A), daily drug vehicle injection (point B), daily ausculatory blood pressure measurement (point C), and start of the daily operant test session (point D). Single and multiple periods of inactivity are indicated by arrows in the lower panel. These two graphs represent actual data displays taken from the PAM software provided by the manufacturer.

board typing movements, which involved minimal motion of the whole arm.

Effects of Drugs on Activity

Figure 5 shows the effects of the stimulant cocaine on 24-h activity counts recorded from two baboons wearing monitors on neck collars. The top graph shows activity for 30-min intervals for nonsession days (weekends), weekdays (when the baboon was given saline and then performed an operant task), and a single day during which 0.32 mg/kg cocaine hydrochloride was injected immediately prior to the experimental session. Peaks in activity between the hours of 10 and 12 under all conditions coincided with daily activities within the laboratory (e.g., cage cleaning, watering, etc.). During weekdays, this baboon's weekday operant testing sessions began at about hour 12 (starting at Point A). A second activity peak (about hour 15) coincided with increased activity during feeding times. Following the single injection of cocaine, however, clear elevations in activity counts occurred that peaked at 3 h postinjection (hour 15) and persisted for up to 10 h postinjection. While stimulants are known for their ability to increase activity, at high doses stimulants can have the opposite effect of suppressing behavior (7,28). The effects of a high dose of cocaine on activity are shown in the bottom graph of Fig. 5. In this instance, 1.8 mg/kg cocaine was administered daily for 21 consecutive days, and 1-h intervals of activity averaged across this 3-week period are shown in the graph, as well as averaged activity following saline injections both before and after the cocaine dosing regime. Injections were given immediately after the baboon entered a test chamber for his daily operant task (indicated at A in the graph for all functions).

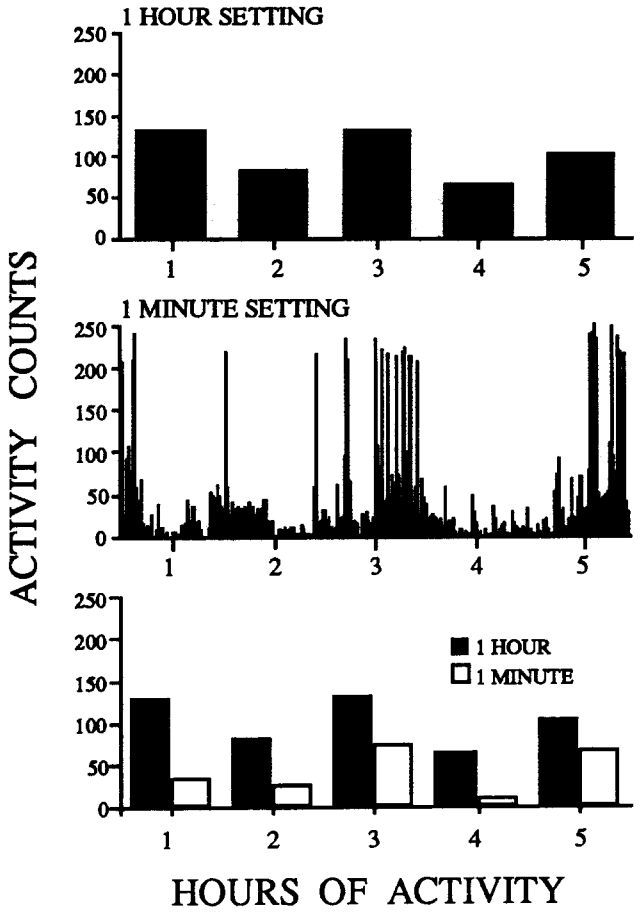

FIG. 3. Activity counts as a function of time for one monitor preset to record activity in 1-h increments (top) and a second minitor simultaneously recording activity in 1-min increments (middle). Both monitors were worn simultaneously on the right wrist of one of the experimenters. The bottom pannel shows comparisons of activity counts over time for both monitors, with activity counts for the 1-min monitor averaged over 1-h intervals.

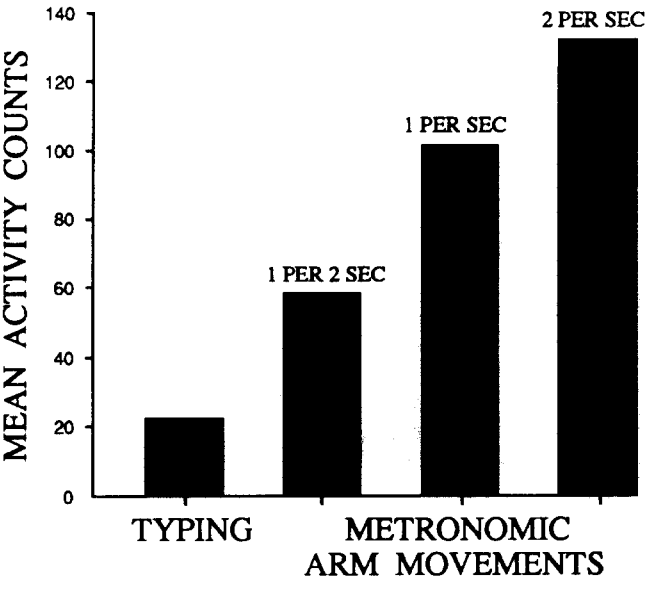

FIG. 4. Average activity for different types of human hand movements recorded with a monitor set for 1-min resolution. The monitor was worn around the right wrist of one of the experimenters who then engaged in the indicated movements for equal time durations.

This high dose of cocaine produced a sharp drop in activity for the 2 h following injection, following which the animal began to perform the operant task (indicated at B in the graph).

Figure 6 shows examples of how daily activity patterns can be altered by another stimulant, *d*-amphetamine. The left panels of Fig. 6 show the activity counts recorded from a monitor attached to a harness backplate for a 24-h period following a single IM administration of drug vehicle in baboon AR. A food-reinforced operant task was performed four times daily by the baboon and is easily distinguished in the activity record by the four regularly spaced peaks in activity (marked with asterisks). General activity was considerably reduced when the task was not being performed. The left-middle graph of Fig. 6 shows activity counts for a 24-h period following administration of 0.32 mg/kg *d*-amphetamine. Drug administration markedly reduced activity during the first two operant task periods, when activity in the absence of drug was normally high. In contrast, nonsession activity was augmented following *d*-amphetamine, compared to the nondrug condition. Administration of a higher *d*-amphetamine dose, 1.0 mg/kg, resulted in almost complete suppression of general activity for hours 12–24 (Fig. 6, left-bottom).

The rate-dependent changes in activity described above can be graphically represented by comparing changes in the activity count distributions over the 24-h periods for drug vs. nondrug conditions. This was accomplished by computing percentiles for a frequency distribution of activity counts for each condition (ignoring the time when the activity occurred). The activity counts following drug at each percentile point were then plotted as a function of the activity counts following vehicle for that same percentile point. By looking at percentiles across the entire activity count distribution, one can look at how different parts of the activity distribution (e.g., the relative frequency of low, medium, and high activity) change following drug manipulations. The top-right panel of Fig. 6 shows such a scatter plot for the data in the left panels of Fig. 6. The diagonal line represents equality. If, for example, the fiftieth percentile point (i.e., the median of the distribution) following vehicle is the same as the fiftieth percentile point following drug, then that point would fall on the diagonal. Points are ordered on the graph from left to right and represent the following percentiles: 1, 2, 3, 4, 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 95, 96, 97, 98, and 99. After 0.32 mg/kg *d*-amphetamine, activity was increased compared to vehicle for the low percentile points, indicating that the lower end of the activity distribution was elevated following this low dose of *d*-amphetamine. At the same time, activity at the high end of the distribution was reduced. Thus, this dose of *d*-amphetamine acted to increase lower-active periods and decrease higher-active periods. The 1.0-mg/kg *d*-amphetamine dose reduced activity at all levels to below that produced by the 0.32-mg/kg *d*-amphetamine dose.

Orderly dose effects were quite evident for a second ba-

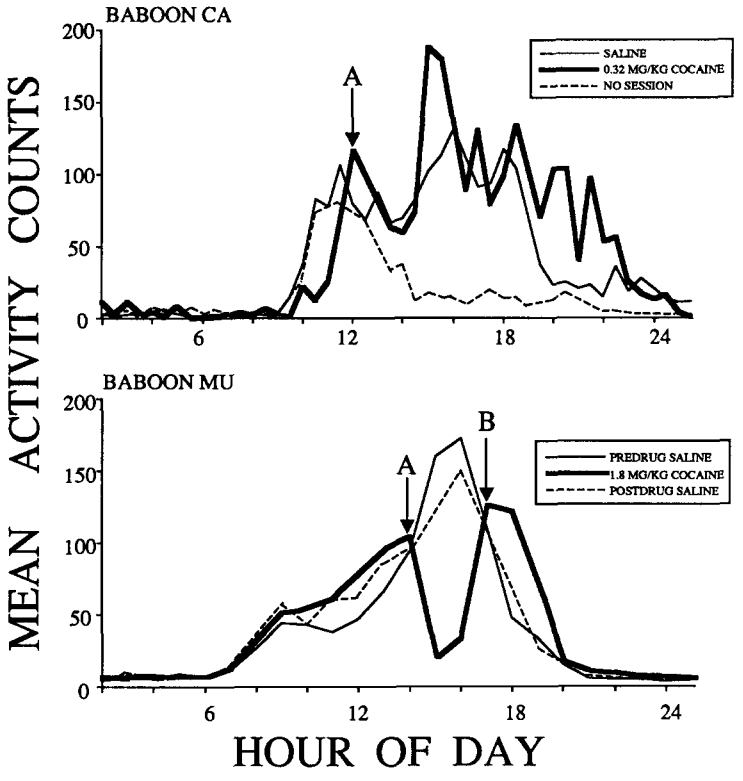

FIG. 5. Twenty-four-hour activity following cocaine administration for two baboons wearing monitors on neck collars. Upper graph: Activity recorded with 30-min interval resolution, showing averaged activity for days with no test sessions (broken line), days when saline was given prior to test sessions (thin solid line), and for a single day when 0.32 mg/kg cocaine was administered (heavy solid line). The drug was given at the start of baboon CA's operant test session (at point A). Lower graph: Activity recorded with 1-h interval resolution, showing averaged activity for before (thin solid line), during (heavy solid line), and after (broken line) the 21 days of daily dosing with 1.8 mg/kg cocaine. Saline injections were given on all nondrug days. All injections were given immediately after the baboon entered the test chamber for his daily operant task (at point marked A). During the drug administration regime, this baboon typically did not respond in the operant task until 2–3 h postinjection (start of responding indicated at point marked B). Hours of the day are indicated for 6 a.m., noon, 6 p.m., and midnight.

boon, GI, given *d*-amphetamine doses of 0.32, 1.0, and 1.8 mg/kg, as shown in the lower-right percentile plot of Fig. 6. The data from this subject showed a clearly monotonic dose-effect relationship, with higher doses of *d*-amphetamine resulting in greater reductions for higher-activity periods.

Routine observations of animals' cage activities by our laboratory technicians noted inactivity following administration of drugs known to have sedative-like effects (e.g., alcohol, marijuana). Such drugs failed, however, to produce performance changes during food-reinforced test sessions. The activity monitor has been successfully employed to obtain data documenting such activity changes. Figure 7 (top) shows the resultant changes in activity following administration of an antihypertensive drug combination commonly used to treat hypertensive patients. Two baboons were given a combination of a diuretic (hydrochlorothiazide, 1.0 mg/kg/day) and a calcium antagonist (verapamil, 3.2 mg/kg/day) daily for a 3-week period. Average activity patterns are shown in Fig. 7 (top) for 1 week prior to any drug administration and for the second week of daily dosing with the drug combination. The 24-h activity pattern during vehicle was dominated by peak activity periods corresponding to the performance of an operant task designed to test the effects of the drugs on learning (point marked A). Following drug, however, these peaks in the activity pattern were clearly suppressed, while there was little change in activity at other periods in the day [cf also (31)]. This decreased activity was not correlated with decreased food consumption, but was accompanied by increased errors during the operant discrimination task [a color matching-to-sample procedure; (32)].

Decreased activity has also been observed following administration of Δ-9-THC, the active constituent in marijuana. Figure 7 (bottom) shows 24-h activity patterns averaged across 5 successive days of predrug, 21 days of daily administration of 3.2 mg/kg Δ-9-THC, and 5 days of postdrug vehicle administration. Drug was administered orally (injected into an orange slice) immediately prior to the baboon's daily testing session (at the point marked A). Activity clearly decreased following the daily Δ-9-THC administrations, and persisted throughout much of the day, even though the baboon contin-

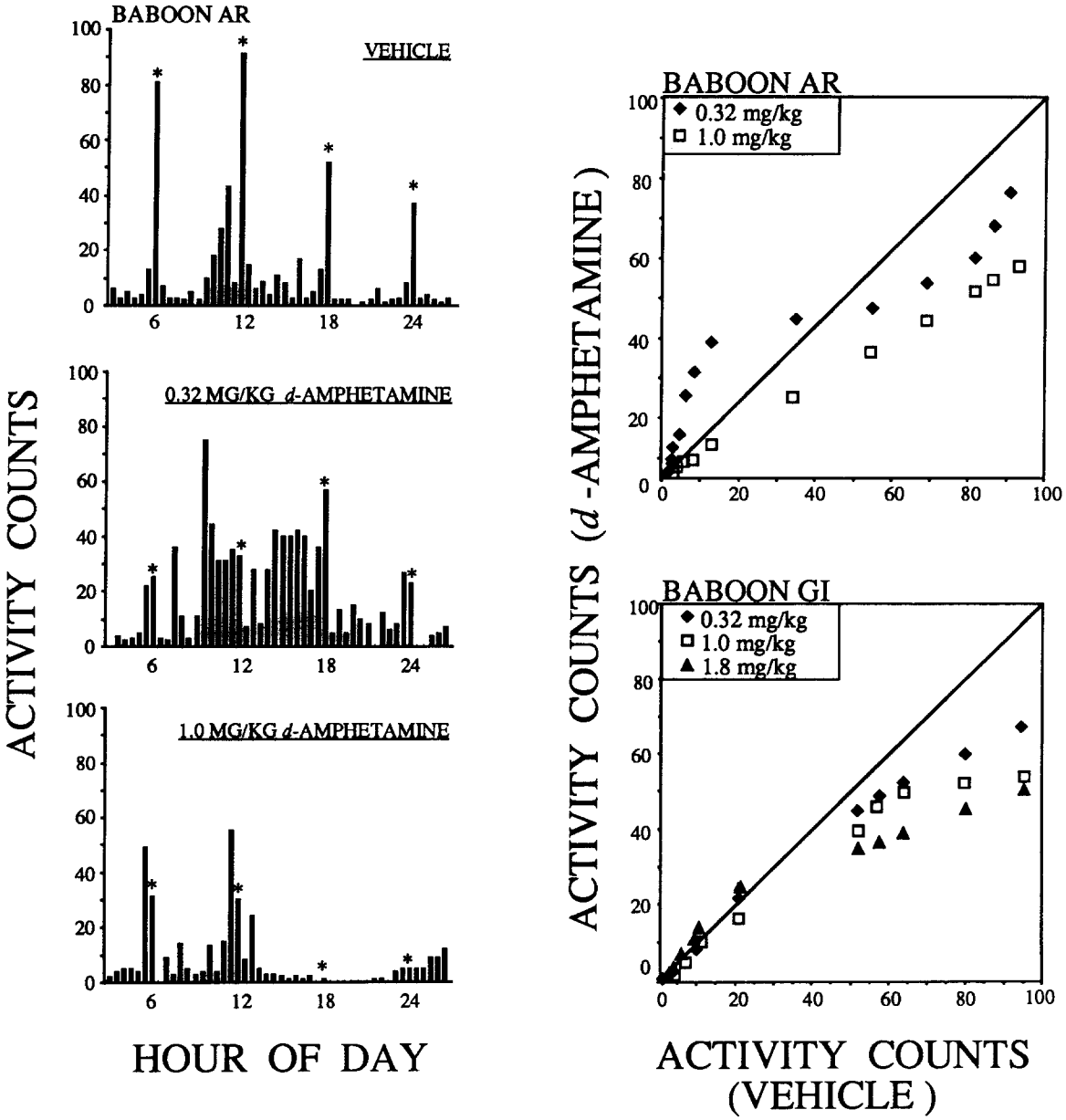

FIG. 6. Left panels: Activity counts for 30-min intervals plotted as a function of time for a monitor attached to a harness backplate of baboon AR. The baboon performed an operant task four times daily (indicated by an asterisk). Each graph is for a single 24-h period, with the top, middle, and bottom graphs for periods following IM administration of drug vehicle (saline), 0.32 mg/kg *d*-amphetamine, and 1.0 mg/kg *d*-amphetamine, respectively. Hours of the day are indicated for 6 a.m., noon, 6 p.m., and midnight. Right panels: Activity counts at 19 different percentile points within the activity count distributions following *d*-amphetamine plotted as a function of the corresponding percentile points following vehicle administration. Points are ordered on the graph from left to right, and represent the following percentiles: 1, 2, 3, 4, 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 95, 96, 97, 98, and 99. The diagonal represents equal activity for both drug and nondrug conditions. Upper graph shows data for baboon AR following 0.32 and 1.0 mg/kg *d*-amphetamine (same data as left panels). Bottom graph shows similar data for baboon GI following IM injections of 0.32, 1.0, and 1.8 mg/kg *d*-amphetamine plotted as a function of the corresponding percentile points following vehicle administration.

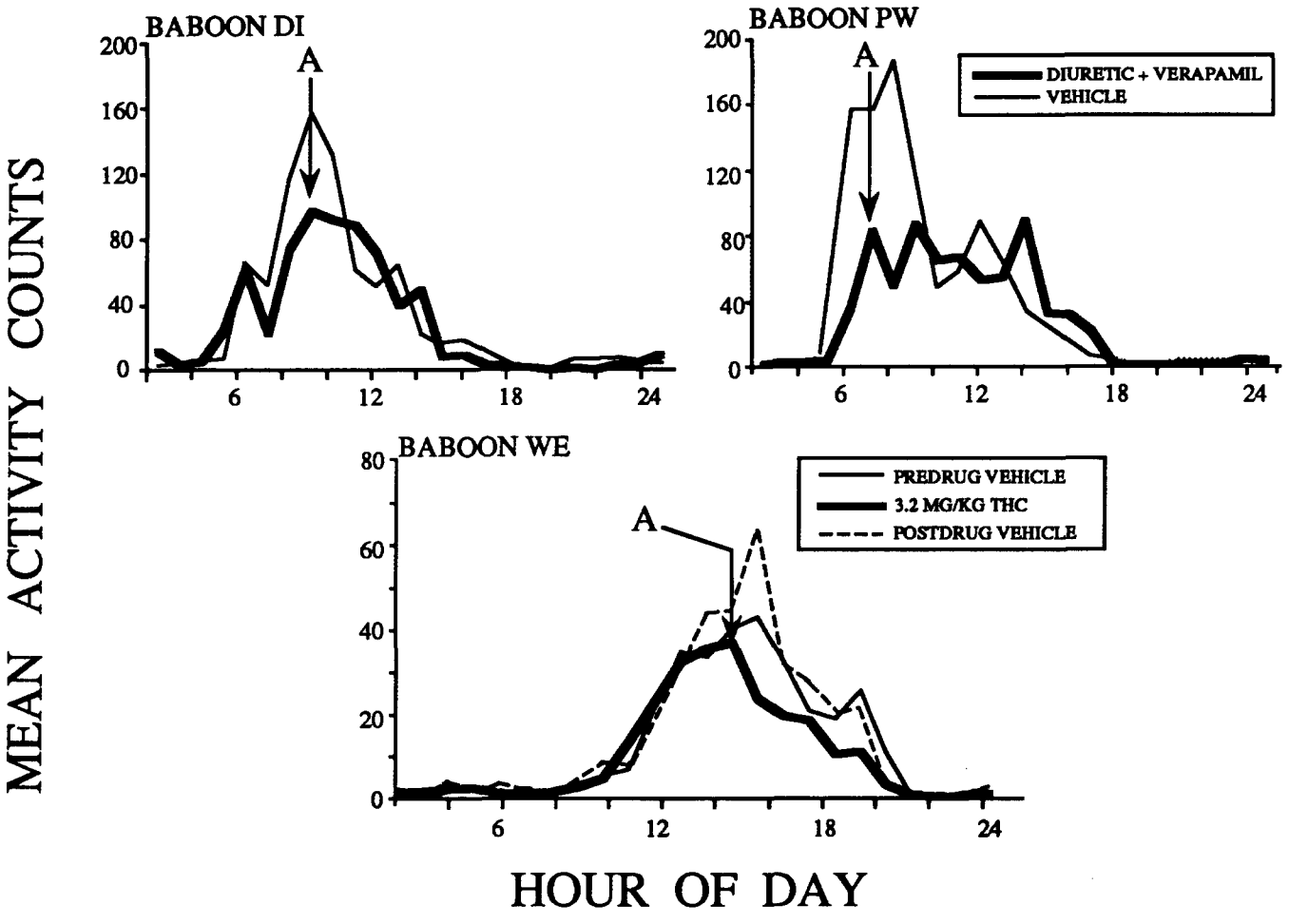

FIG. 7. Average 24-h activity patterns following administration of an antihypertensive drug combination to two baboons (upper graphs) and Δ-9-THC to one baboon (lower graph). All monitors were attached to collors and recorded activity over 1-h intervals. The start of operant test sessions are indicated by the points marked A. Upper graphs: 5-day average activity patterns for the week prior to any drug administration (thin line) and for the second week of daily drug dosing (heavy line) with a combination of the diuretic hydroclorothiazide (1.0 mg/kg/day) and the calcium antagonist verapamil (3.2 mg/kg/day). Lower graph: average activity patterns for predrug (thin line), drug (heavy line), and postdrug (broken line) conditions following 21 days of daily administration of 3.2 mg/kg Δ-9-THC. Drug or vehicle was administered orally immediately prior to the baboon's daily testing session (at point A). Hours of the day are indicated for 6 a.m., noon, 6 p.m., and midnight.

ued to perform the operant task immediately following drug administration.

DISCUSSION

The PAM is a small, lightweight, compact activity monitor that can consistently measure general activity continuously for periods of up to 42 days. The device is particularly suitable for use with humans and many experimental animals for numerous reasons. First, the recording of activity need not be restricted to any particular environment, as is the case with jiggle cages or infrared motion detectors. Second, relatively complete freedom of movement is provided when the monitor is attached to a collar or harness. A third advantage of the monitor is that activity can be continuously recorded for long time periods. Finally, the unit's sensitivity and temporal resolution can be adjusted to meet differing needs of either clinical or basic research protocols.

As used in the Behavioral Pharmacology Research Laboratories of the Division of Behavioral Biology, the activity monitor has been a useful adjunct to ongoing studies of the effects of drugs on behavior. General activity was recorded for periods of up to 42 days, and patterns of daily activity for individual baboons were reliably recorded over periods of several months. The temporal patterns of activity recorded by the monitor reflected the normal activity patterns of baboons (e.g., day-night cycles), and also reliably indicated preprogrammed activities (e.g., operant test sessions). Further, general activity was recorded in different environments (e.g., home cage vs. test chamber) with the same monitor. Finally, use of the monitor required only minimal technician time while yielding a wealth of data. This is in sharp contrast to observational methods that require extensive investments of observer time [e.g., the bar code scoring system of Forney et al. (10)].

The activity monitor recorded reliable, drug-induced changes in general activity that paralleled the known effects of the same drugs on learned behaviors. The stimulant cocaine produced increases in activity at low doses. A higher cocaine dose decreased general activity, similar to the decrease in re-

sponse rates often observed following higher cocaine doses in squirrel monkeys (12). Low doses of the stimulant *d*-amphetamine also increased activity. Similar increases in motor activity have been reported following amphetamine administration in squirrel monkeys (13) and rats (14,18). Further, *d*-amphetamine selectively changed the distribution of activity by elevating the low end of the distribution and reducing activity at the high end of the distribution. This result parallels the well-known rate-dependent effects of *d*-amphetamine (i.e., increasing low rates of responding and decreasing high rates of responding under operant schedules of reinforcement (7)]. Finally, *d*-amphetamine affected general activity in a dose-dependent fashion such that high-frequency activities were further suppressed with increasing drug doses.

Other drug effects demonstrated with the monitor included the marked reduction in general activity following administration of antihypertensive compounds and a similar reduction in activity following ingestion of the active constituent in marijuana, Δ-9-THC. Other studies have reported reduced activity for Δ-9-THC (6,17). Antihypertensive agents also have been shown in hypertensive patients to decrease self-reported activity and arousal (19,30). The present data on general activity are thus consistent with such findings and also demonstrate the ability of the present activity monitor to detect such changes as well. In sum, numerous changes in general activity, including dose-related changes, were observed with the monitor following administration of a number of well-known pharmacological compounds.

Knowledge of the effects of drugs on general activity is essential for a complete analysis of drug action on behavior. General activity is a frequently employed dependent measure in the study of drug actions in rodents, with specific changes in activity being part of a drug's profile (11). This is not often the case when drugs are studied in larger animals such as primates, and may be due in part to the lack of easily employed or readily available activity-measurement techniques. Further, there have been relatively few investigations into the role of circadian rhythms in influencing a drug's effect on behavior (8). The PAM activity unit may provide the necessary measurement technique for carrying out these types of studies.

Current disadvantages of the monitor are that: a) Timing and sensitivity adjustments must be made by the manufacturer; b) the maximum recording time is 42 days and 16 h; and c) infrequently, an animal may not adapt well to wearing a collar with the monitor attached. Regarding the first two points, it should be noted that newer versions of the PAM monitor will extend the recording time for up to 60–90 days. In addition, the manufacturer is developing new models that will allow adjustment of both the timing and sensitivity of the units in the laboratory. Regarding the adaptability of the device to our baboons, we found that an occasional animal will engage in frequent pulling on the collar when it is first worn. When such behavior results in chronic skin irritations, use of the monitor is discontinued with that animal. Only one baboon, however, failed to adapt to wearing a collar with a monitor. No such problems have developed with the chronically catheterized baboons, as the 1-oz monitor was likely not noticeable when attached to the backplate of their harness system.

An obvious drawback of the monitor is that it does not differentiate types of movements or differing spatial patterns that may similarly trigger the transducer. In the case of drug-induced activity effects, for example, a drug could differentially affect specific behaviors such that one behavior decreased in frequency while another increased in frequency, with the result that little or no change in general activity might be detected. Another possibility is that the monitor may not record certain stereotypic movements if, for example, movements were restricted to an animal's extremities only. Given the relative lack of studies on drug effects on activity in larger animals such as nonhuman primates, however, it appears that the present type of activity monitor could still be a useful adjunct in such studies.

Other limitations of the device involve its inherent size, the method of retrieving the data, and field calibration of the unit. While the monitor's relatively small size makes it ideal for use with humans and many other animals, it is clearly not readily adaptable for use with small, rodent-size animals. This is currently an important limitation due to the widespread use of rodents in experimental research. Future advances in miniaturization may, however, obviate this problem. Problems with the method of data retrieval can arise because the monitor must be removed from an animal and directly attached to a computer interface for data retrieval. Large primates such as baboons, however, cannot be directly handled, which currently necessitates that these animals be mildly sedated for monitor retrieval. Thus, for long-term studies beyond the total recording period of the monitor interruptions in experimental protocols for data retrieval may be required. A related problem concerns the synchronizing of the monitor's recording intervals with experimental events. If, for example, a 1-h interval monitor is reset at 10:30, then subsequent activity is recorded over 1-h intervals starting at each half-hour. If a subsequent drug injection (or other laboratory event) occurs on the hour, however, an accurate measure of activity immediately following the injection is unavailable due to the combining of activity counts for 30 min prior to and after drug injection. This is not a problem inherent in the monitor, but an issue that experimenters should carefully consider when designing studies. Finally, while monitor calibration is done by the manufacturer no procedures currently exist for calibrating the monitor in the experimental laboratory. For any study requiring precise control or adjustment of the activity-measuring device, this would be a disadvantage. We have not, however, observed any noticeable changes in sensitivity of the monitors over time. The manufacturer also reports little drift in sensitivity, and is currently developing field methods of calibrating the monitor.

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