JOURNAL OF THE TENNESSEE ACADEMY OF SCIENCE 72(1–2):42–44 JANUARY–APRIL 1997

INDUCED ATMOSPHERIC PRESSURE CHANGES ELICIT SPONTANEOUS RESPONSES IN BATS

MICHAEL G. SCOTT AND GERALD L. VAUGHAN

Department of Ecology and Evolutionary Biology, Hesler 501, The University of Tennessee, Knoxville, TN 37996

ABSTRACT—Individuals of three insectivorous species of bats (*Eptesicus fuscus, Myotis velifer,* and *Tadarida brasiliensis*) were observed for spontaneous responses to induced atmospheric pressure changes. Visual observations of ventilation rate were compared between control periods and periods in which atmospheric pressure was increased or decreased 4.2 kPa over 3 min, a rate typical of altitude changes in flight. Bats of each species responded to the induced pressure changes. Therefore, the bats displayed a critical component of a functional pressure altimeter, the ability to detect pressure changes.

Correlations of behavioral activities with atmospheric pressure have been reported for a variety of animals. For example, daily cycles in atmospheric pressure appear to synchronize behaviors in marine mollusks (Brown et al., 1956), house mice (*Mus musculus*; Truchan and Boyer, 1972), and pocket mice (*Perognathus longimembris*; Hayden and Lindberg, 1969). As an indicator of favorable weather conditions, atmospheric pressure may induce reproductive activity in the tree frog (*Hyla crucifera*; Martoff, 1960) and bird migration events (Lehner and Dennis, 1971; Alerstam, 1981). Insect abundance is correlated with atmospheric pressure (Harker, 1958) as is foraging activity of the leopard frog (*Rana pipiens*; Robertson, 1978).

For flying animals (birds and bats) atmospheric pressure is a potential source of information that might be used as the basis of a pressure altimeter, navigation by patterns of atmospheric pressure and meteorological forecasting (Lehner and Dennis, 1971; Kreithen and Keeton, 1974). Bats may use atmospheric pressure to monitor weather conditions from caves which are isolated from weather fluctuations (Nagel and Nagel, 1994), predict local insect abundance (Paige et al., 1989), or avoid inclement flying weather (Scott, 1994).

The prominent properties of variation in atmospheric pressure are absolute magnitude and rate of pressure change. Absolute pressure magnitude is a reliable indicator of altitude while pressure change can be separated into two types: rapid changes associated with altitude changes in flight; relatively slow changes associated with meteorological events (Lutgens and Tarbuck, 1989). Hypotheses linking animal activity with atmospheric pressure include the assumption that the animal in question can detect the type of atmospheric pressure conditions involved. The ability to detect atmospheric pressure has been experimentally demonstrated in only two species of birds (Lehner and Dennis, 1971; Kreithen and Keeton, 1974). It has been reported that some bats have a middle ear organ that may be an atmospheric pressure detector (von Bartheld, 1990). Therefore, the purpose of this study was to investigate whether bats can detect and respond to atmospheric pressure changes typical of those they encounter during flight.

MATERIALS AND METHODS

Three species of insectivorous bats were used for this study. Fourteen *Eptesicus fuscus* were captured by hand in day roosts in eastern Tennessee, while 18 *Myotis velifer* and 18 *Tadarida brasiliensis* were captured by hand net as they exited roosts in Mason Co., Texas. All bats were determined to be adult based on the degree of ossification of the metacarpal-phalangeal joint (Anthony, 1988). After testing, bats were marked with dye (1% Eosin Y) and released near the capture site within 24 h. Recaptured bats were not retested.

A steel pressure chamber, 37 cm in length by 39 cm in diameter, was constructed to evaluate the response of bats to pressure changes. Ports provided for air inflow, air outflow, manometer attachment, and a pressure-release valve. The chamber, except for an observation port, was lined with eggshell foam to dampen sound. Air inflow and outflow were driven by an air-vacuum pump isolated in an adjacent room. Modulating air outflow (0.6 or 1.2 l/min) while maintaining a set air inflow (0.9 l/min) produced pressure changes of ±1.4 kPa/min. Pressure changes, initiated from ambient atmospheric pressure and measured by means of a water-filled U-tube manometer, were repeatable (±2.6%) and linear with respect to time (R^2 = 0.999). Air flow in the chamber did not produce detectable sound between 0.1 and 165.0 kHz (Radio Shack® microphone 33-2001 and an Ultrasound Advice Mini 2 tunable bat detector). Temperature inside the chamber matched room temperature (ca. 20°C).

Movement of bats within the pressure chamber was restricted to a 15- by 13- by 7-cm Plexiglas and wire-mesh enclosure attached to the observation port at one end of the chamber. The rate of rhythmic movement of the posterior dorsal surface of bats, enhanced by reflective foil, was used as an index of a spontaneous response to induced pressure changes. This rhythmic movement has been considered to be a measure of ventilation rate (Constantine, 1986) but is not significantly different from heart rate (pers. obser.). Behavior and responses of bats were recorded on videotape.

The apparatus was established in a quiet room with illumination from a diffused 15-watt, incandescent light. Between 1800

TABLE 1. Statistics from paired-difference *t*-tests used to test the mean response (expressed as percentage of control) during pressure decreases and increases for *Tadarida brasiliensis, Myotis velifer,* and *Eptesicus fuscus.*

Species	Pressure change	*n*	Mean difference	*SE*	*d.f.*	*t*-value	*P*-value
T. brasiliensis	Decrease	18	13.2	4.1	17	2.9	0.009
	Increase	18	9.4	9.9	17	0.9	0.360
M. velifer	Decrease	18	19.3	4.6	17	4.2	0.001
	Increase	18	9.8	3.6	17	2.6	0.020
E. fuscus	Decrease	14	12.8	2.1	13	2.1	0.060
	Increase	14	16.3	3.2	13	3.2	0.010

and 0400 h, a single bat with four reflective foil strips attached to its posterior dorsal surface was placed in the enclosure and, then, sealed in the pressure chamber. Each bat was allowed to acclimate to the apparatus for 30 min before testing while being exposed to airflow with the pressure release valve open so the bat was at ambient pressure. Bats that did not settle to a resting position within 30 min were not tested. Each bat was observed during a pressure increase and a pressure decrease (±1.4 kPa/min for 3 min; equivalent to 140-m change in altitude over 1 min). Each pressure increase or decrease was paired with a control period of the same duration and air flow rate, respectively, but no change in atmospheric pressure, in order to determine a resting rate for comparison with test sessions. Pressure increases and decreases were presented to each bat in random order with test and control sessions randomized within pairs. Accumulated pressure was released over 30–60 sec at the end of each test, and air outflow changed as necessary for the subsequent session. Sessions were separated by 5 min. The spontaneous response index was assessed during each 15-sec interval of the 3-min sessions from video records. Rates from test sessions were expressed as a percentage of the paired control session. The response index during both control sessions for each bat was compared within species to evaluate the effectiveness of the interspersed waiting periods. The response index during paired control and test sessions was compared to evaluate the influence of induced pressure changes. Comparisons were made using paired difference *t*-tests with a significance criterion of 0.05.

RESULTS

The mean response index was not different between the two control sessions for *T. brasiliensis* (n = 18, difference = 6.1, SE = 5.5, P = 0.3), *M. velifer* (n = 18, difference = 0.3, SE = 7.8, P = 0.97), or *E. fuscus* (n = 14, difference = 6.5, SE = 8.2, P = 0.44). The mean response index during control sessions was 154/min (SE = 9.7) for *T. brasiliensis,* 223/min (SE = 6.7) for *M. velifer,* and 130/min (SE = 7.5) for *E. fuscus.* The mean response index during test sessions (expressed as percentage of control) was greater than during the control in all cases except during the pressure increase for *T. brasiliensis* and pressure decrease for *E. fuscus* (Table 1). For *T. brasiliensis,* the first significant increase in response index occurred in interval 9 with decreasing pressure and interval 2 with increasing pressure (Table 2). For *M. velifer,* the first significant increase in response index occurred in interval 1 with decreasing pressure and interval 3 with increasing pressure (Table 2). For *E. fuscus,* no significant increase in response index was observed with pressure decrease but occurred in interval 1 with an increase in pressure (Table 2).

DISCUSSION

Because no difference in the response index was observed between control sessions, the responses during test sessions were not an artifact of a shifting baseline. All three species of bats appeared to be able to detect and respond to atmospheric pressure

TABLE 2. Statistics from paired-difference *t*-tests used to find the first time interval in which a significant increase in the response index (expressed as a percentage of control) occurred for *Tadarida brasiliensis, Myotis velifer,* and *Eptesicus fuscus.*

Species	Pressure change	Interval	*n*	Mean difference	*SE*	*d.f.*	*t*-value	*P*-value
T. brasiliensis	Decrease	9	18	25.1	10.5	17	2.3	0.03
	Increase	2	18	32.3	13.6	17	2.4	0.03
M. velifer	Decrease	1	18	12.5	5.2	17	2.3	0.03
	Increase	3	18	15.7	7.4	17	2.1	0.05
E. fuscus	Decrease[1]							
	Increase	1	14	29.9	11.3	13	2.7	0.02

[1] No significant increase in response index was observed.

changes typical of those they might encounter during flight. Individuals of all three species of bats responded to decreasing or increasing pressures.

The sensitivity of bats to pressure change was demonstrated by the rapidity of their response to pressure change, often within the first time interval after the pressure change was initiated (change of 0.35 kPa; equivalent to a 35-m change in altitude over 15 sec). All three species of bats were more sensitive to pressure change than are humans, the only other mammalian species that has been tested (Rockley and Hawke, 1992). Bats were not as sensitive as trained homing pigeons that can detect pressure changes as small as 0.1 kPa (Kreithen and Keeton, 1974).

The response to small atmospheric pressure changes in this study indicates that some bats have the ability to sense atmospheric pressure changes of the magnitude normally encountered during altitude changes in flight. Therefore, these bats possess a critical component of a functional pressure altimeter, a pressure detector. The magnitude and rate of pressure changes induced in this study, however, were not representative of pressure changes associated with weather patterns that might be used for meteorological forecasting. Whether bats can detect such pressure changes or even use pressure change as an indicator of altitude change has not been demonstrated.

Literature Cited

ALERSTAM, T. 1981. The course and timing of bird migration. Pp. 201–232 *in* Animal migration (D. J. Aidley, ed.). Cambridge Univ. Press, Cambridge.

ANTHONY, E. L. P. 1988. Age determination in bats. Pp. 47–59 *in* Ecological and behavioral methods for the study of bats (T. H. Kunz, ed.). Smithsonian Inst. Press, Washington, DC.

BROWN, F. A., JR., M. F. BENNETT, H. M. WEBB, AND C. L. RALPH. 1956. Persistent daily, monthly, and 27-day cycles of activity in the oyster and quahog. J. Exp. Zool., 131:235–262.

CONSTANTINE, D. G. 1986. Insectivorous bats. Pp. 650–655 *in* Zoo and wild animal medicine (M. E. Fowler, ed.). W. B. Saunders, Philadelphia.

HARKER, J. 1958. Diurnal rhythms in the animal kingdom. Biol. Rev., 33:1–52.

HAYDEN, P., AND R. G. LINDBERG. 1969. Circadian rhythm in mammalian body temperature entrained by cyclic pressure changes. Science, 164:1288–1289.

KREITHEN, M. L., AND W. T. KEETON. 1974. Detection of changes in atmospheric pressure by the homing pigeon, *Columbia liva.* J. Comp. Physiol., 89:73–82.

LEHNER, P. N. AND D. S. DENNIS. 1971. Preliminary research on the ability of ducks to discriminate atmospheric pressure changes. Ann. New York Acad. Sci., 188:98–109.

LUTGENS, F. K., AND E. J. TARBUCK. 1989. The atmosphere. Prentice Hall, Englewood Cliffs, New Jersey.

MARTOFF, B. S. 1960. Autumnal breeding of *Hyla crucifera.* Copeia, 1960:56–57.

NAGEL, A., AND R. NAGEL. 1994. Activity of hibernating bats in their natural habitat recorded by automatic data logging. Bat Res. News, 35:37.

PAIGE, K. N., K. TYRELL, T. JUENGER, AND G. FULLER. 1989. Tracking insect prey from the roost: bats and barometric pressure. Bat Res. News, 30:58.

ROBERTSON, D. R. 1978. The light dark cycle and a nonlinear analysis of lunar perturbations and barometric pressure associated with the annual locomotor activity of the frog, *Rana pipiens.* Biol. Bull., 154:302–321.

ROCKLEY, T. J., AND W. M. HAWK. 1992. The middle ear as a baroreceptor. Acta Otolaryngology, 112:816–823.

SCOTT, M. G. 1994. Environmental correlates of insectivorous bat foraging activity. Bat Res. News, 35:114.

TRUCHAN, L. C., AND S. D. BOYER. 1972. Barometric pressure correlations with spontaneous motor activity of albino mice *Mus musculus.* Phys. Zool., 45:204–214.

VON BARTHELD, C. S. 1990. Development and innervation of the paratympanic organ in chick embryos. Brain Behav. Evol., 35:1–15.