International Journal of Primatology, Vol. 27, No. 3, June 2006 (© 2006)
DOI: 10.1007/s10764-006-9047-y

Sleep Profile and Longevity in Three Generations of a Family of Captive Bolivian *Aotus*

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Received July 16, 2004; revision December 8, 2004; accepted May 31, 2005; Published Online July 25, 2006

The daily total sleep time (TST) of the only nocturnal simian primate, Aotus spp., remains little studied under controlled conditions. We conducted 3 experiments in 4 owl monkeys (Aotus sp.), aged 1–27+ yr, to determine the daily TST. We housed 3 their—a nuclear family—in 1 cage and the remaining senescent female in an adjacent separate cage. We monitored their activity-sleep pattern longitudinally for 15–20 d via actigraphy: by tagging an acclerometer-type miniature transmitter (Actiwatch-MINIMITTER) sensitive to omnidirectional movement, to the owl monkey's neck. The TST (9.5–12.5 h) was ca. *4.5–7 h less than the 17 h Perachio reported for owl monkeys in 1971 by polysomnography, under similar 12-h-light; 12-h dark conditions. Our finding corroborates well with the TST for other nonhuman primates. Four members of the Aotus colony at our facility reached 20 yr in captivity; the oldest (wild-born female) is still living at >27 yr, and the second oldest (captive-born male), is 23 years now.*

KEY WORDS: actigraphy; longevity; nocturnality; parental care; total sleep time.

INTRODUCTION

Primatologists have shown considerable interest in the uniqueness of owl monkeys (*Aotus* spp.) as nocturnal simians (Baer *et al.*, 1994; Martin, 1987; Wright, 1989). Because of their special status among extant primates, field primatologists from Perú, Paraguay, Argentina, and

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Bolivia have described its sleeping sites such as tree holes and platforms in lodge trees (Aquino and Encarnacion, 1986; Garcia and Braza, 1993; Hershkovitz, 1983; Rathbun and Gache, 1980; Wright, 1978, 1983;). Wright (1983, 1994) observed that owl monkeys in the wild Chaco environment of Paraguay, rather than strictly adhering to their nocturnal routine, also stay active in diurnal hours including noon and opt for random sleep tree choice instead of habitual sleep trees. Fernandez-Duque and Rotundo (2003) confirmed similar diurnal behavior in *Aotus azarai* inhabiting Eastern Formosa, Argentina. However, quantitating the daily total sleep time (TST) of owl monkeys showing such cathemeral activity (Tattersall, 1987) in their natural habitats had remained a challenge.

The purpose and need for sleep in primates, including humans, remain unsolved (Dement and Vaughan, 1999; Hairston and Knight, 2004). To comprehend the primary function of sleep in humans, quantitating the daily TST of primate species is a vital first step. Despite input from many laboratories, researchers have achieved sleep quantitation in only <10% of extant primate species (Campbell and Tobler, 1984; Zepelin, 1989) under captive conditions, and peers still need to experimentally check and confirm previous reports via identical or less invasive, alternative methods. A stimulus for our study was that researchers have not quantitated sleep in owl monkeys, with the exception of 2 brief reports of Perachio (1971, 1977) via polysomnography under heavily restrained conditions. The Primate Research Institute, Inuyama, Japan established an *Aotus* colony of Bolivian origin in the mid-1970s. Three founding members (At 23 female, At 24 male, and At 25 female; Fig. 1), have lived >20 yr in captivity. Kawamura *et al.* (2002) previously reported the Y-chromosomal red-green opsin genes of 9 members of the breeding colony (including At 23 and At 24). We had 2 specific objectives: to quantify the sleep parameters in owl monkeys by actigraphy and to report on the longevity record of captive owl monkeys at our facility, where At 23 (Fig. 2) has exceeded the currently available record on captive longevity for *Aotus*.

MATERIALS AND METHODS

While noting that the specific taxonomy of *Aotus* is still in a state of fluidity since the 1980s (De Boer, 1982; Ford, 1994; Groves, 2001; Hershkovitz, 1983), we presume that, based on their Bolivian origin, the owl monkeys at our facility are *Aotus azarae*, though karyotype analysis is needed to confirm this. Because the arrival of the owl monkeys in our colony predated the revision of *Aotus* from a single species *A. trivirgatus* into 7–9 species (Ford, 1994; Groves, 2001; Hershkovitz, 1983), for continuity and convenience only, we denote the owl monkeys at our facility with

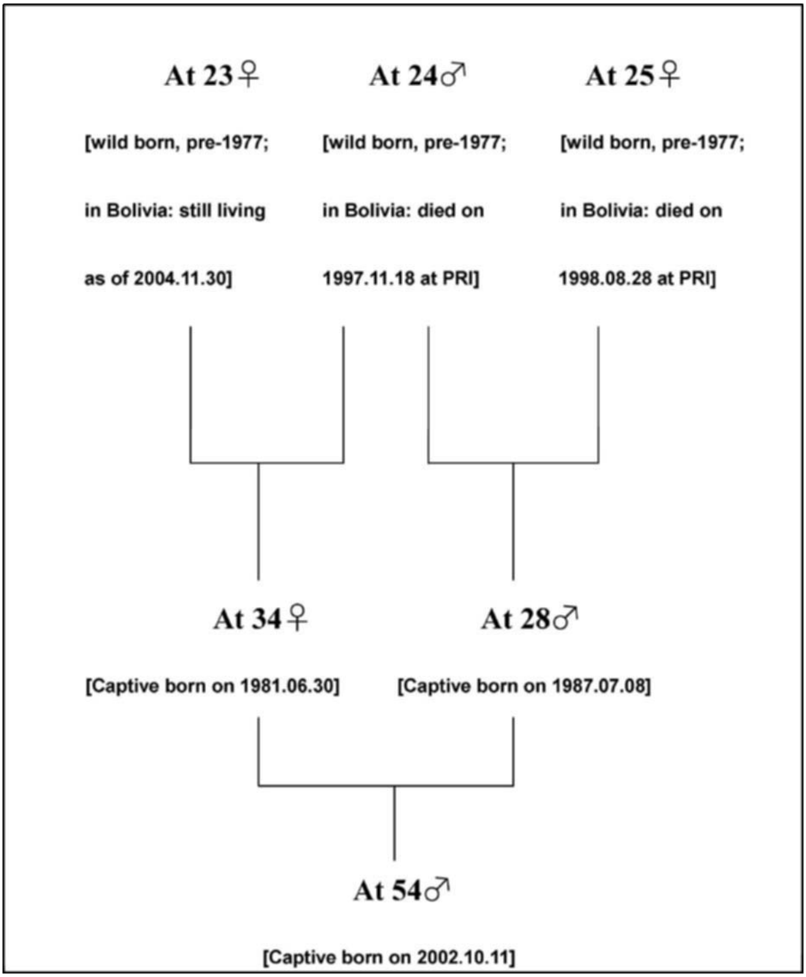

Fig. 1. Genealogy of a 3-generational owl monkey family at the Primate Research Institute (PRI), Inuyama, facility. [At 28 and At 34 are step-siblings, sharing the same male parent. At 54, the only progeny of At 28 and At 34 used for total sleep time (TST) determination is indicated, while its elder and younger siblings are excluded.]

the marker prefix At. We used 4 owl monkeys comprising a 3-generational family (Fig. 1, excluding At 24 and At 25, which died in 1997 and 1998, respectively) in the determination of TST. We housed 3 (a breeding pair comprising At 28 male, At 34 female, and the male offspring At 54) in 1 stainless steel cage (100 × 70 × 60 cm), and the remaining senescent At 23 female in an adjacent separate cage. The body masses of At 23, At 28, At 34,

Fig. 2. At 23♀ (wild-born), aged >27 yr, in September 2004. Note the marked ventrally drooping vocal sac. (Photograph by Minoru Kinoshita.)

and At 54 during the experimental period (July 2003–June 2004) were 1490, 1116, 1270, and 883 g, respectively. We maintained the *Aotus* colony room on a shifted, alternating 12-h light (2300–1100 h; 200 lux) –12-h dark (11:00–23:00 h; 0.01–0.5 lux) cycle (Erkert, 1989). We routinely checked lighting of the room via an illuminance meter (TopCon IM-5, Tokyo). The owl monkeys had food and water *ad libitum*, and we supplemented the pellet diet daily with fresh fruits and twice weekly with meal worms.

We monitored activity-sleep patterns of the owl monkeys via actigraphy, by tagging an acclerometer-type miniature transmitter (Actiwatch AW 64 model-MINIMITTER, Mini Mitter, Bend, OR, containing 64 KB of onboard memory) sensitive to omnidirectional movement to the individual's neck. The actiwatch is capable of sensing any omnidirectional movement with a minimal resultant force of 10 mg. We preset each actiwatch (weighing 17 g) to collect activity-rest data of individual owl monkeys with a sampling rate of 32 Hz and a sampling epoch of 1 min, suspended in an elastic band, and positioned it on the individual's neck after anesthesia with ketamine-HCl (10 mg/kg body wt; Sankyo, Tokyo). We accumulated longitudinal data on daily TST for up to 20 d before removal of actiwatch from the individual's neck. We retrieved accumulated data into the computer, via Mini Mitter Actiwatch Reader through an RS-232 Serial Port and Activity Sleep® Activity Monitoring, version 3.3 (Mini Mitter). The communication link between the actiwatch and the actiwatch reader is short-range telemetric.

We conducted 3 experiments between August 2003 and June 2004, and studied 2 (mating pairs At 28 and At 34) of the 4 owl monkeys, repetitively.

Experiment 1

From August 6 to 27, 2003, we tagged actiwatches to At 28 and At 34 (mating pair) sharing the same cage with their offspring, At 54.

Experiment 2

From January 9 to 28, 2004, we tagged actiwatches to At 28, At 34, and At 54, sharing the same cage, and At 23 in the adjacent cage. Our goals were to confirm the findings of Expt. 1 and to evaluate whether the offspring (At 54) of the mating pair exhibits a varying sleep profile compared to that of its parents (At 28 and At 34).

Experiment 3

The mating pair (At 28 and At 34) gave birth to an offspring (At 56) on April 15, 2004. Subsequently, from June 7 to 22, 2004, we tagged actiwatches individually to At 28, At 34, and their elder offspring At 54 sharing the same cage. For most of the experiment, the male parent At 28 carried the 7–8-wk-old baby dorsally (Dixson, 1982, 1983). We aimed to assess whether baby carriage influenced the sleep profile of the male parent.

In the first 2 experiments, At 28 rejected the actiwatch placed on his neck, after the first 2 d. However, when we tagged it again, he did not reject it. In Expt. 3, such a rejection did not recur. Thus, sleep profile data were missing for At 28 between d 3 and 5 in the first 2 experiments.

The Primate Research Institute's ethics committee on experiments approved our experiments, which complied with ethical standards in the treatment of primates.

RESULTS

A distinguishing physical feature in At 23 is the prominently visible, drooping vocal sac (Fig. 2), which Hill (1964, p. 160) described as "extending caudally behind clavicles and laterally deep to sternomastoids; partially subdivided in median line by septum formed by projection of infrahyoid muscles dorsal to sac; sac communicating with interior of larynx by paired openings in thyrohyoid membrane." Also, because of advancing senescence, both eyes have well-developed cataracts, which mildly hampered At 23's movements within the cage.

Experiment 1

The fluctuations in daily TST for 20 d of continuous monitoring for At 28 and At 34 sharing the same cage are in Fig. 3A. The mean (+SD) values of daily TST for At 28 and At 34 are 658 (+ 64) and 665 (+ 92) min, respectively. Thus, on average the TST is *ca.* 11 h in the mating pair of owl monkeys. The abrupt interruption in sleep record in the actogram of At 28 (Fig. 3A) between d 4 and 6 was caused by his rejection of the actiwatch during the first weekend of the experiment.

Experiment 2

The fluctuations in daily TST recorded for 19 d of continuous monitoring in 4 owl monkeys are in Fig. 3B. The mean (+ SD) value of daily TST, 747 (+138) min is maximum for At 23. The TST for the other 3 owl monkeys, sharing same cage, are 711 (+85) min for At 28, 588 (+91) min for At 34, and 598 (+44) min for At 54. The daily TST of the youngest owl monkey, aged 1 yr and 3 mo, did not differ markedly from that of its parents (At 28 and At 34). However, the daily TST of the oldest, At 23, appeared longest (almost 12.5 h), though without markedly differing from that of the other 3 owl monkeys.

Experiment 3

The fluctuations in daily TST, recorded for 15 d of continuous monitoring, in 3 owl monkeys are in Fig. 3C. At the start of the experiment, the mating pair's new offspring was 7 wk old and the male parent (At 28) carried him on his back most of the time. Presumably because of the physiological burden, the mean (± SD) value of daily TST, 820 (± 71) min, is markedly higher than the corresponding values for At 28 in Expt. 1 and 2 (Table I). Conversely, the mean (± SD) value of daily TST, 612 (± 85) min for At 34, is in a similar range of the corresponding values for the subject in Expt. 1 and 2 (Table I). The daily TST values for progeny At 54 resembled the pattern of the female parent At 34.

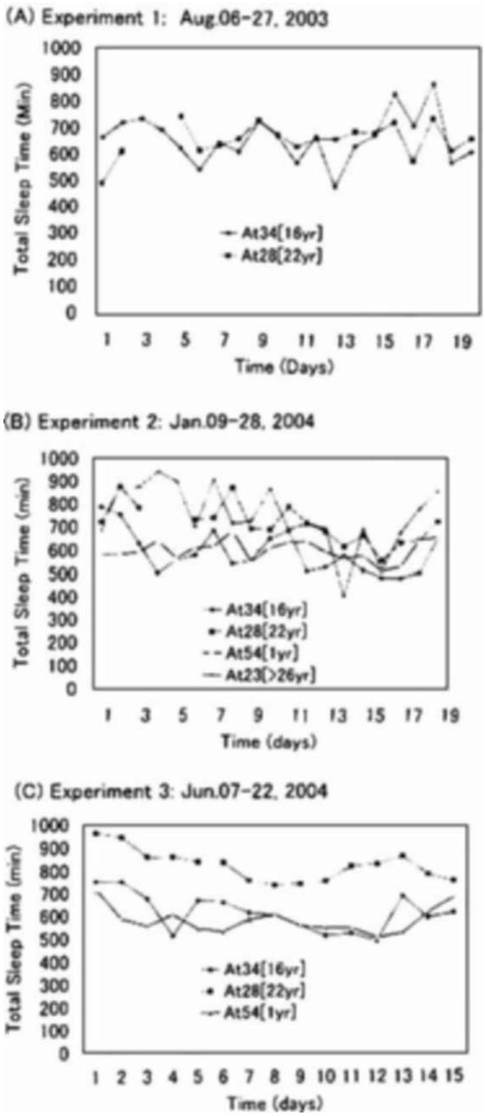

Fig. 3. Daily total sleep time (TST) determinations in owl monkeys. (A) Expt. 1 (August 6–27, 2003)—At 28♂ and At 34♀; Expt. 2 (January 9–28, 2004)—At 23♀, At 28♂, At 34♀, and At 54♂; Expt. 3 (June 7–22, 2004)—At 28♂, At 34♀, and At 54♂. In all 3 experiments, mating pairs At 28♂, At 34♀, and their 1-yr-old offspring At 54♂ shared the same cage. During Expt. 3, At 28♂ also carried a new offspring, born on April 4, 2004.

Table I. Summary of 3 experiments on the quantitation of daily total sleep time (TST) in 3 generations of a family of owl monkeys

Owl monkeys[a]	Daily mean TST (min)[b]		
	Expt. 1	Expt. 2	Expt. 3[c]
At 23♀		747 ± 138	
At 28♂	658 ± 64	711 ± 85	820 ± 71
At 34♀	665 ± 92	588 ± 91	612 ± 85
At 54♂		598 ± 44	578 ± 59

[a]At 28, At 34 and At 54 occupied the same cage during the period covered in 3 experiments.
[b]Expressed as mean ± SD.
[c]An infant (At 56) born to the mating pair (At 28 and At 34) on April 15, 2004, also occupied the same cage during the experimental period.

DISCUSSION

The only other sleep-related data on owl monkeys are those of Perachio (1971, 1977), who used polysomnography to quantitate sleep in 3 adults, exact ages not reported. Perachio (1971) reported a mean total of 16 h and 56 min sleep for 24 h, under 12-h light (108 lux) and 12 dark (6.5 lux). Our data from Expt. 2 show that the TST for 2 senile monkeys (At 23 and At 28) average 12 h and 9 min for 24 h. The TST for adult At 34 and prepubescent At 54 average 9 h 48 min and 9 h 58 min, respectively, which are within the range (8–12 h) for other nonhuman primates (Campbell and Tobler, 1984; Zepelin, 1989) and also nearly 4–6 hours less than those that Perachio (1971) reported. A caveat by Perachio (1971, P.58), stating that "Since there was some difficulty in developing a reliable scoring procedure for quantification, no analysis of the data will be presented," suggests that the nearly 17-h TST for owl monkey he reported may be an overestimate, owing to excessive restraint and resulting tiredness of the monkeys. Thus, it is reasonable to infer that the daily TST range for owl monkey is 9.5–12.5 h, as in Fig. 3 and Table I.

The highest mean TST of 13 h and 40 min Expt. 3 for At 28, in comparison to TST durations in Expt. 1 and 2 for the same individual, could be caused by the parental burden of dorsal carriage of the 7–8-wk-old offspring (weighing *ca.* 250 g) most of the time. Though sharing the same cage with its mating partner (At 34) and an older progeny (At 54), the taxing performance of carrying an infant on its back by a male parent (At 28) results in a marked increase of nearly 2 h of daily sleep (Fig. 3C Vs. Fig. 3A and B). In place of polysomnography to quantitate total sleep time, we used actigraphy, which is a reliable, noninvasive, convenient,

Table II. Longevity records for owl monkeys in captivity

Location	Maximum longevity in captivity (yr)	Reference
London Zoo	12.0–12.7	Jones (1962); Hill (1964)
San Diego Zoo	~15	Bowden and Jones (1979)
San Diego Zoo	18.5	Jones (1982)
London[a]	12–20?	Hearn and Dixson (1984)
(unidentified)[b]	18	Scott (1992)
California Institute of Technology[c]	>20	Baer (1994)
University of Tubingen	>20	Rappold and Erkert (1994)
Lincoln Park Zoo, Chicago[c]	~25	Margulis (2004)[d]
(unidentified)[b]	~26—27	Allman *et al.* (1998)
University of Tubingen	>25	Erkert (1999)
(unidentified)[b]	25.3	Carey and Judge (2000)
Kyoto University, Inuyama[e]	>27	Present study (2004)

[a]Location not specifically indicated; appears to be composite information. The question mark following the numbers is as in the original.
[b]Cites the source as M. L. Jones (1980).
[c]Unpublished data.
[d]Personal correspondence from Sue Margulis (Primates Curator, Lincoln Park Zoo, e-mail, November 18, 2004).
[e]At the Primate Research Institute colony; refers to At 23, oldest owl monkey (wild born), and introduced in 1977 as an adult. That a second owl monkey, At 28 (captive born), had reached 23 yr is also of interest.

objective, and longitudinal method to quantitate sleep in primates, including humans (Ancoli-Israel *et al.*, 2003; Kushida *et al.*, 2001; Sadeh *et al.*, 1995; Zhdanova *et al.*, 2002). The underlying premise of actigraphy measurement is that, in the absence of any detected activity, i.e., below the measurement threshold set for the instrument, the subject is in complete rest, which equates to sleep.

The relevance of quantitating sleep in owl monkeys can be explained in terms of its special evolutionary adaptation as the only nocturnally active simian primate. In evolutionary terms, the intrusion of humans into primarily nocturnal frontier (as shift workers in production, health, entertainment, and service industries) opened up only from the 1880s when mass production of light bulbs and electrical accessories became a reality (Melbin, 1978). Thus, owl monkeys—as the nearest evolutionary kin of humans and a predecessor of nocturnal living—provide a unique model to comprehend the sleep behavior and its accompanying health problems of nocturnally active humans.

Table II is a literature summary of owl monkey longevity records in captivity, since 1962. At 23, >27 yr of age, has become one of the longest living captive *Aotus*. Captive born At 28 also has completed 23 yr in June 2004. Schultz (1969) and Bowden and Jones (1979), among others, have anticipated increasing longevity of captive primates in general. Easily available balanced diet, veterinary care, absence of predators in the milieu, and reduction in physiological overexertion are leading factors that contribute to increasing longevity among captive primates. Two of our *Aotus* subjects exceeded 23 yr in captivity. The presence of a prominently visible vocal sac of long-lived At 23 (Fig. 2) is of some degree of curiosity, though reported previously (Giles *et al.*, 1974; Hayama, 1970; Hewitt *et al.*, 2002). According to Hill (1972), a vocal sac reinforces vocalization, in addition to serving a respiratory function. However, among the 15-member owl monkey colony in the room, At 23 now appears to be the least vocalizing member because of senescence. The current chronological age of At 23 can only be speculated to *ca.* 30 yr because subadults disperse in the wild at *ca.* 3 yr and At 23 became a captive member of our facility in 1977. Despite her old age, she still retains vigor, possesses good reflexes, and is healthy.

ACKNOWLEDGMENTS

We thank Nobuko Matsubayashi of the Center for Human Evolutionary Modeling Research for providing expert technical assistance and Minoru Kinoshita for photography. Two anonymous referees provided much helpful criticism to improve an earlier version of the manuscript.

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