Sleep quantitation in common marmoset, cotton top tamarin and squirrel monkey by non-invasive actigraphy

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Abstract

Sleep quantitation data on the Neotropical primate species, apart from the squirrel monkey, are still sparse. As such, we have quantitated sleep in the common marmosets (*Callithrix jacchus*), cotton top tamarins (*Saguinus oedipus*) and squirrel monkeys (*Saimiri sciureus*) reared in one primate facility simultaneously, by non-invasive actigraphy. The range in total sleep time/24 h measured for male adult common marmosets, cotton top tamarins and squirrel monkeys were 713–793 min ($n=4$), 707–889 min ($n=4$) and 459–475 min ($n=2$) respectively. The range in sleep episode length /12 h dark phase for marmosets, tamarins and squirrel monkeys were 21–52 min ($n=3$), 10–28 min ($n=4$) and 9–15 min ($n=2$) respectively. Since vigilance is a critical evolutionary adaptive feature of predator avoidance among Callitrichid monkeys and squirrel monkeys, the shorter ranges in sleep episode length recorded, even under captivity, in this study could be interpreted as probable indicators of such vigilance behavior during the rest phase. We hypothesize that the vigilance behavior when it exists during a primate's active phase should also prevail when it is at rest (sleep). This hypothesis deserves additional testing in female Callitrichid monkeys.
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1. Introduction

It is hardly debatable that simultaneously conducted comparative biochemical studies in multiple non-human primate species provide dividends in characterizing the phylogenetic links among evolutionary kins (Welsh and Walker, 1972, 1973; McGeachin and Akin, 1982; Roger et al., 1993; Croll et al., 1993; Fukuhara and Kageyama, 2005). However, due to restraints in space, time, funds and biased concerns of activists espousing animal rights, conducting comparative, prospective physiological studies simultaneously in more than one species of primates is becoming less feasible to plan and execute. Despite such a bottleneck, curiosity and need to quantitate the yet unknown details on the sleep behavior of three prominently used laboratory primates belonging to Cebidae family prompted us to initiate this study at our primate facility in Inuyama, Japan.

Sleep behavior in mammals, according to Zepelin (1989), can be defined by two criteria: (1) sustained quiescence in a species-specific posture accompanied by reduced responsiveness to external stimuli, and (2) quick reversibility to the wakeful condition, which distinguishes sleep from coma and hypothermic states such as hibernation and torpor. In addition, a third criterion representing characteristic changes in the electroencephalogram (EEG) is also considered as a useful validatory component of sleep. Of all the behaviors exhibited by the non-human primates (hereafter, referred to as primates), sleep behavior is rather difficult to quantitate (Siegel, 2005), especially the validation by EEG under acceptable standards of scientific rigor.

As of now, sleep behavior has been quantitated in only around 5% of the 234 extant primate species (Campbell and Tobler, 1984; Zepelin, 1989). Paucity of sleep quantitation data in the primate field studies is understandable. Absence of natural light during the sleep phase of primates is a prime hindrance for observation. To further compound the issue, artificial light disturbs the sleep behavior of the focal animals. The fatigue factor of the human observer in nights which leads

to sub-par and erroneous data collection cannot be overlooked. One should also not underestimate the inherent danger from other poisonous and predatory animals in the milieu which may affect the concentration of the researcher. Thus, sleep behavior studies have to depend more on primates reared in captivity.

Common marmosets (*Callithrix jacchus*) and cotton top tamarins (*Saguinus oedipus*), among the New World monkeys belonging to Callitrichidae, have gained prominence as cost-effective and lab-worthy primates for experimental use in captivity (Stellar, 1960; Poole et al., 1999). While common marmosets are endemic to Brazil, the cotton top tamarins are endemic to Colombia. Though still widespread in the Pernambuco region of Brazil, the wild *C. jacchus* populations have been suffering from severe depletion and decline due to habitat destruction (Rylands, 1993; Norconk et al., 1996). As a cumulated consequence of habitat loss, hunting and illegal capture for pet trade, a harsher vulnerable-threatened fate is now faced by wild *S. oedipus* populations in its native north western Colombian habitat, bordering the Caribbean Sea — between the eastern bank of Atrato river and western banks of Cauca and lower Magdalena rivers (Mast et al., 1993; Defler, 2004). The extent of the spread of *S. oedipus* to the south is believed to be 1500 m altitudinal limit into the Andean foothills (Mast et al., 1993).

Past field studies on *C. jacchus* and *S. oedipus* monkeys and their rather unique ecological role among the anthropoid primates have been reviewed (Sussman and Kinzey, 1984; Rylands, 1993; Defler, 2004). However, there is paucity of information on the sleep behavior of *Callithrix* and *Saguinus* genera living in the wild, and what is available were based on quasi-quantitative, opportunistic and/or naturalistic observations (Hershkovitz, 1977; Dawson, 1979; Heymann, 1995; Day and Elwood, 1999). The squirrel monkey (*Saimiri sciureus*), a New World monkey belonging to Cebidae, also continues to be one of the popular primate species for studies in neuroscience and pharmacology, since its introduction into aerospace medical research and animal space flight in 1958 (Beischer, 1968). As such polysomnography-derived data on sleep–wake cycles and biorhythm of squirrel monkeys have been published from a few laboratories (Adams and Barratt, 1974; Wexler and Moore-Ede, 1984, 1985, 1986; Erny et al., 1985; Breton et al., 1986; Edgar et al., 1993; Klerman et al., 1999, 2000). A couple of the early studies on sleep quantitation using polysomnography in squirrel monkeys (Adams and Barratt, 1974; Breton et al., 1986) were limited to 10–12 h.

Though polysomnography still remains as the 'gold standard' for sleep quantitation measurements, it is a highly invasive technique. Using brain and muscle electrodes in primates, seated in a restraint chair, has come under serious criticism as well since 1980s. The inability to sustain the recording for days is another demerit for polysomnography. Thus, quantitative sleep data recorded by non-invasive methods such as actigraphy have gained acceptance lately in understanding the sleep architecture of different primate species, including humans (Zhdanova et al., 2002; Ancoli-Israel et al., 2003; Sri Kantha and Suzuki, in press). As such, our objectives were two fold: (1) to quantitate sleep in the common marmosets

and cotton top tamarins reared in our primate facility simultaneously, by non-invasive actigraphy, to fill the currently existing void on sleep literature of *C. jacchus* and *S. oedipus* populations, and (2) to calibrate the actigraphy sleep measurement in *S. sciureus* monkey with the previously reported polysomnographic sleep measurement for this species.

2. Materials and methods

2.1. Animals and housing

The age composition and masses of study subjects reared at the Primate Research Institute facility and used in the experiments are provided in Table 1. Male members of common marmosets (*C. jacchus*, $n=5$), cotton top tamarins (*S. oedipus*, $n=4$) and squirrel monkeys (*S. sciureus*, $n=2$) were used in this study. As indicated in Table 1, excluding one tamarin (So 105), all five marmosets and three tamarins were pair-housed with either a female mating partner or sibling/half-sibling or parent/offspring, in metal cages of dimension, $70 \, cm \times 70 \, cm \times 150 \, cm$. The two squirrel monkeys shared a stainless group cage ($1.2 \, m \times 1.2 \, m \times 2.1 \, m$) with two adult females and a young male. This group cage had access to a sun-room with adequate vertical space ($24 \, m \times 28.5 \, m \times 77.5 \, m$) incorporated with diverse small vegetation including vines, small water facility and enrichment accessories like ropes and wood planks as multiple level perches. Mention should be made that when squirrel monkeys were studied in May 2005, the natural daylight extended to 14 h, and as such, the

Table 1
Basic details of the male study subjects and the duration of sleep quantitation

Monkey ID	Age at experiment [a] (years)	Weight (g)	Duration of sleep quantitation (days)
Common marmoset [b]			
Cj 62	10	412	7
Cj 98	8	440	7
Cj 123	6	363	7
Cj 133	6	277	7
Cj 174	0.8	266	7
Cotton top tamarin [c]			
So 105	14	425	8
So 133	11	500	8
So 165	7	473	8
So 173	6	533	8
Squirrel monkey [d]			
Ss 114	13	927	3
Ss 115	13	954	3

[a] All monkeys were born in captivity.
[b] Cj 62 and Cj 98 are half-siblings sharing the same cage. Cj 123 was pair-housed with a mating partner. Cj 133 and Cj 174 are parent and male offspring, sharing the same cage.
[c] So 105, being senile, was housed in a single cage. So 133 was pair-housed with a mating partner and their baby offspring. So 165 and So 173 are siblings sharing the same cage.
[d] Ss 114 and Ss115 shared a group cage with two females and another male, age ranging from 5 to 10 years.

complete dark phase during the study period was shortened to 10 h.

While cotton top tamarins and squirrel monkeys occupied the same room, the cages of common marmosets were in a separate room. Thus, the light intensity of the two rooms varied. Alternating 12 h light (6:00 h–18:00 h) and 12 h dark (18:00 h–6:00 h) phases prevailed in the housing facility. The light intensities at the bottom of the cages, 1 m above the ground during the light phase were as follows; 60–150 lux (marmosets), 800–1250 lux (tamarins) and 440–460 lux (squirrel monkeys), as routinely checked by an illuminance meter (TopCon IM-5, Tokyo).

The pair-housing cages of marmosets and tamarins were designed in such a way that though visual contacts among the conspecifics occupying separate cages were impermissible, unrestricted vocal contacts could be heard by the conspecifics around the clock. All monkey cages were provided with commercial food pellets for New World Monkeys (25.1 g protein and 10.6 g lipid/100 g diet) and water ad libitum. In addition, monkeys also received sliced fruit portions and insects as additional food supplements on a daily basis. The room temperature and relative humidity were maintained by automatic controls at 25 ± 1 °C and 50–60% respectively.

2.2. Experiments and measurements

Activity–sleep patterns of the monkeys were monitored via actigraphy [Actiwatch AW 64 model-MINIMITTER, Mini Mitter Company, Bend, Oregon, USA; containing 64KB of on-board memory] as described previously (Sri Kantha and Suzuki, in press). Briefly, the actiwatch (weighing 17 g), pre-set to collect activity–rest data of individual monkey with a sampling rate of 32 Hz and a sampling epoch of 1 min, was suspended in a ribbon, and positioned on monkey's back following anesthesia with ketamine HCl (10 mg/kg body weight; Sankyo, Tokyo). For each experimental subject, longitudinal data on activity–rest behavior, daily total sleep time (TST) and sleep episode length (SEL) were collected before removal of actiwatch from monkey's neck. Data collection periods for marmosets, tamarins and squirrel monkeys were 7 days, 8 days and 3 days respectively. Accumulated data were transferred to the computer, via Mini Mitter Actiwatch Reader through an RS-232 Serial Port and Activity Sleep® Activity Monitoring Software, version 3.3 [Mini Mitter Company].

As per the operational definition of sleep in actigraphy, in the absence of any force made by the subject, which exceed 10 mg
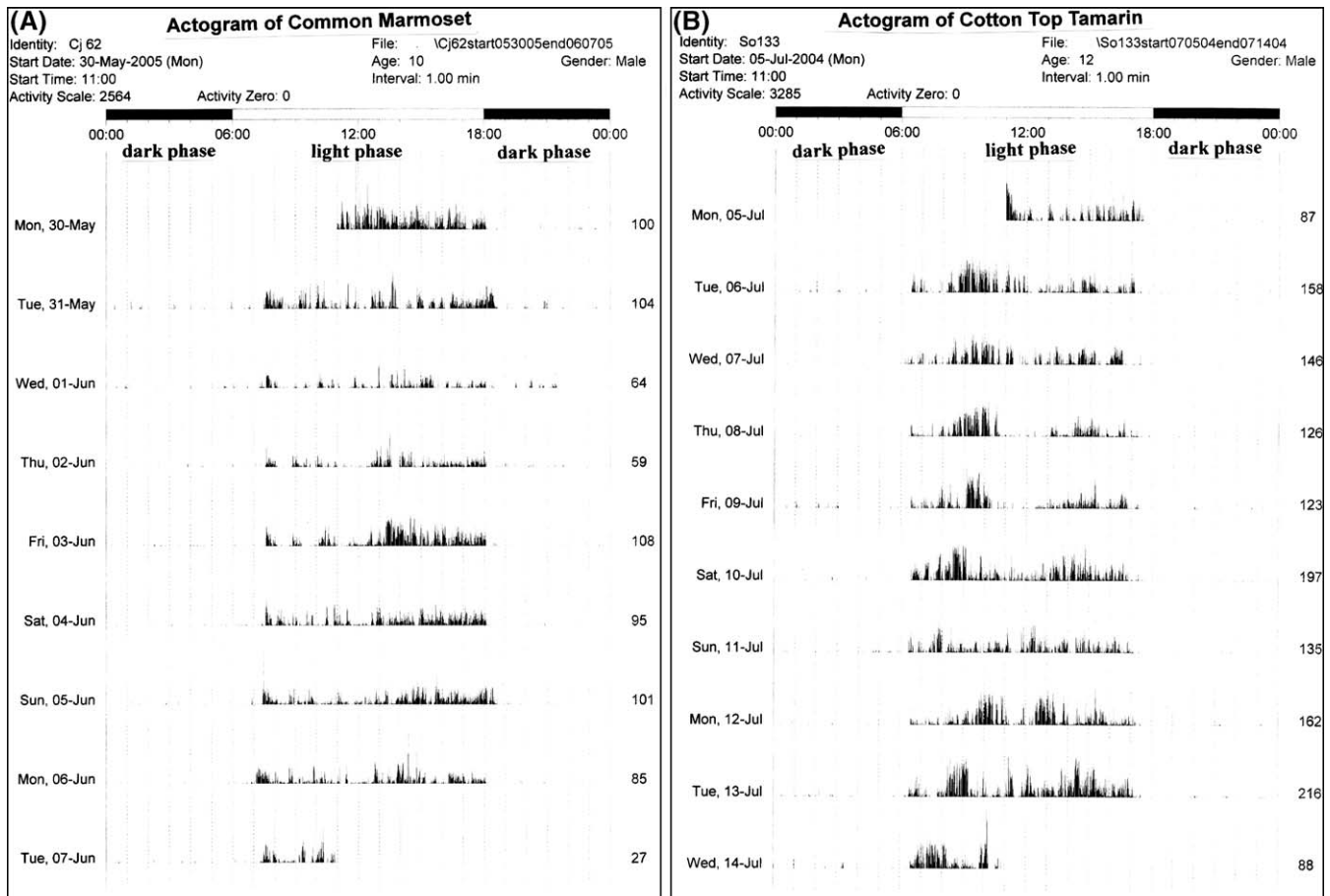

Fig. 1. Representative actograms of two Callitrichid monkeys studied under captive condition. (A) A male common marmoset (*Callithrix jachchus*), aged 10 years; (B) a male cotton top tamarin (*Saguinus oedipus*), aged 12 years. The number indicated in each row of the right end of both panels refers to mean Actiwatch activity counts per a 24-h period. The almost-blank spaces recorded during the dark phase (18:00 h–06:00 h) equates to the recurrent rest (sleep) cycle.

in any direction during the measuring period (counted as epoch of 1-min duration), the animal was assumed to be at rest — i.e., sustained quiescence in a species specific posture, and thus equated to sleep in somnology studies (Campbell and Tobler, 1984). The activity–rest phases of the animal were quantitated in an arbitrary unit called Actiwatch (AW) activity count, where any omnidirectional motion by the animal with a minimal resultant force of 10 mg was quantitated by the instrument with reference to degree and speed of motion. These parameters are converted to produce an electrical current that varied in magnitude. This derived algorithm is referred to as activity count, which is instrument specific.

During the experimental period, female cage mates of the experimental monkeys of all three species were also tagged with Actiwatches for experimental rigor. All experiments were carried out following approval from the Research Committee of the Primate Research Institute, and according to this
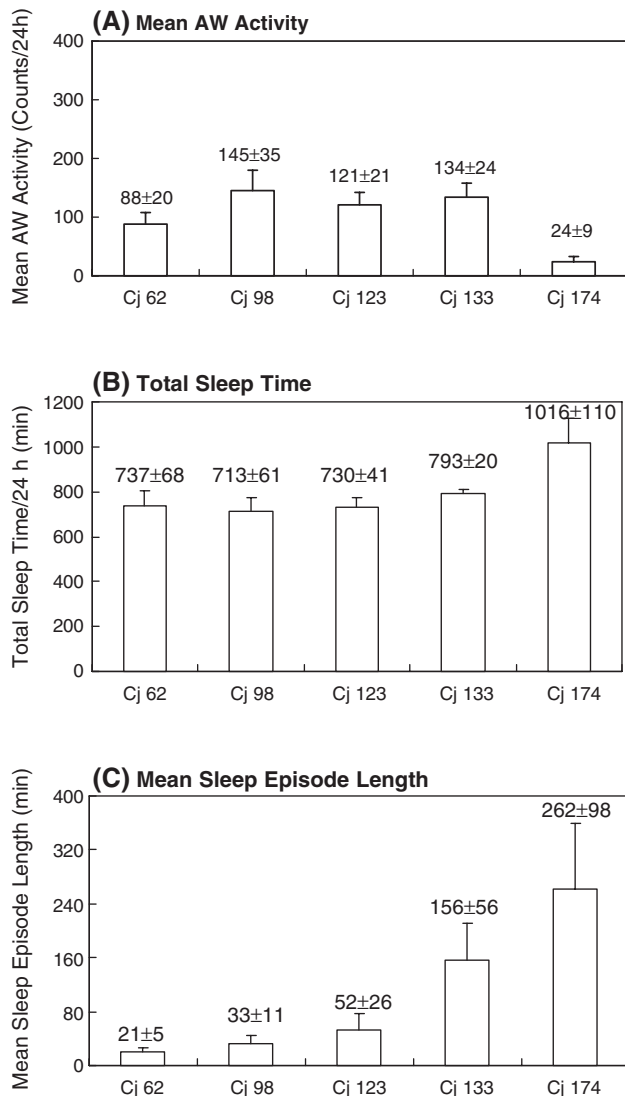

Fig. 2. Sleep Quantitation in male common marmosets. (A) Daily activity, (B) daily total sleep time, (C) sleep episode length during the dark phase. Results are also indicated in numbers (mean±SD) above each histogram.
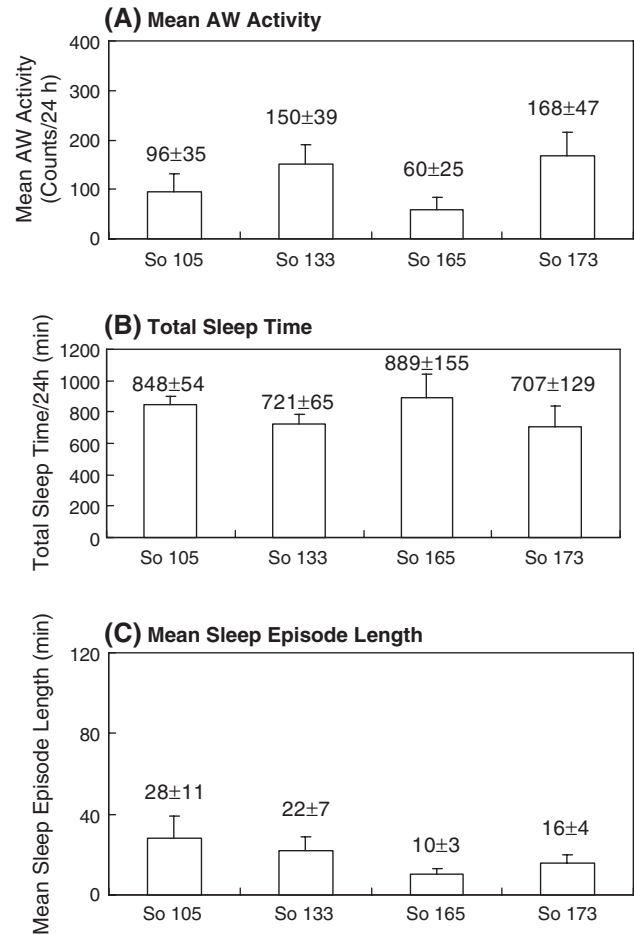

Fig. 3. Sleep Quantitation in male cotton top tamarins. (A) Daily activity, (B) daily total sleep time, (C) sleep episode length during the dark phase. Results are also indicated in numbers (mean±SD) above each histogram.

Institute's Guidelines for the Care and Use of Laboratory Primates. Data collection began in April 2004 and ended in June 2005.

3. Results

3.1. Activity

Representative actograms of common marmoset (Cj 62, aged 10 years) and cotton top tamarin (So 122, aged 12 years) are presented in panels A and B of Fig. 1 respectively. The number indicated at the right end of each row of both panels refers to Actiwatch (AW) mean activity counts per a 24-h period. The almost-blank spaces recorded during the dark phase (18:00 h–06:00 h) indicate the recurrent rest (sleep) cycle. The daily activity levels, measured as mean AW activity counts, of marmosets, tamarins and squirrel monkeys are shown in the panel A of Figs. 2–4 respectively. The mean values of activity counts for four adult marmosets ranged between 88 and 145 (Fig. 2A). However the activity value (mean±SD) of 24±9 recorded for the 10-month-old juvenile marmoset (Cj 174) was 5.6-fold lower to the activity value (134±24) of its 6-year-old parent sharing the same cage; this
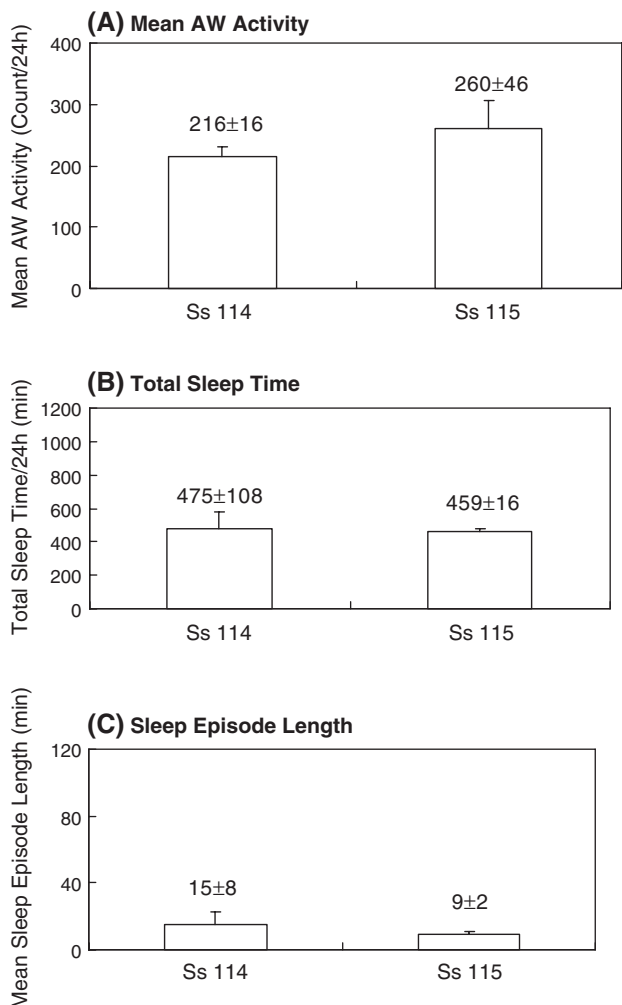
Fig. 4. Sleep Quantitation in male squirrel monkeys. (A) Daily activity, (B) daily total sleep time, (C) sleep episode length during the dark phase. Results are also indicated in numbers (mean±SD) above each histogram.

result, indicating the developmental immaturity of the juvenile marmoset was not unusual. The mean values of activity counts for four adult tamarins, with a range from 60 to 168 (Fig. 3A) more or less overlapped with the range determined for the adult marmosets. Compared to the activity counts recorded for both marmosets and tamarins, the mean daily activity count of 238 for two squirrel monkeys was markedly higher. This result is also reasonably convincing in terms of the difference in physical stature, body weight and athletic capabilities between the two Callitrichid monkeys and the squirrel monkey.

3.2. TST

The quantitated daily TST of marmosets, tamarins and squirrel monkeys are presented in the panel B of Figs. 2–4 respectively. While the daily TST of four adult marmosets ranged between 713 and 793 min (Fig. 2B), the daily TST of four adult tamarins ranged between 707 and 889 min (Fig. 3B). Though the TST range of tamarins was broader by 102 min, and the mean (±SD) TST values for marmosets and tamarins were 743±35 min and 791±91 min respectively, the overlap in daily

sleep time between these two species is markedly obvious. Fig. 2B also indicates that the daily TST of juvenile marmoset (Cj 174) exceeded that of its parent (Cj 133) sharing the same cage by 223 min; and this was again an expected phenomenon, considering the physical immaturity and lower activity profile of the juvenile monkey. However, the mean TST values of 467 min recorded for the two squirrel monkeys (Fig. 4B) was 4–5 h lower in comparison to the mean TST values of adult marmosets and tamarins.

3.3. SEL

The quantitated SEL during the dark phase (18:00 h–06:00 h) of marmosets, tamarins and squirrel monkeys are shown in the panel C of Figs. 2–4 respectively. The mean SEL of four adult marmosets showed an unusually long range, from 21 min to 156 min (Fig. 2C), though this range when revised to accommodate the numbers obtained for three monkeys (namely Cj 62, Cj 98 and Cj 123) would become narrower between 21 min and 52 min. This revision is rather reasonable, because Cj 133 monkey – as per the experimental design – shared the cage with its juvenile offspring Cj 174, whose SEL was an unusual 262 min. In contrast to the marmosets, as Figs. 3C and 4C indicate, the SEL ranges of four tamarins (10–28 min) and two squirrel monkeys (9–15 min) were markedly shorter. As a sleep parameter, SEL appears to be species specific and probably less influenced by the immediate external environment, in comparison to TST.

4. Discussion

The representative activity–rest pattern of common marmoset, presented in Fig. 1 (panel A) in this study, corroborates well with the previous data figures of Erkert et al. (1986) and Menezes et al. (1993), on the circadian activity rhythms of common marmoset, obtained under comparable experimental protocols. However, we were unable to locate any previous reports with figures on the activity–rest pattern of captive cotton top tamarins, to corroborate the data presented in Fig. 1 (panel B).

To our knowledge, the present study appears to be the only attempt so far, to quantitate two sleep parameters (TST and SEL) of three New World monkey species captively-reared in the same facility, using the same instrument, for a period of ≥ 3 days. Among the New World monkeys, while sleep quantitation by polysomnography in squirrel monkey has been reported in the past (Table 2), sleep data of Callitrichid monkey species obtained by any objective method, excluding that of Crofts et al. (2001), have been lacking. Even in the squirrel monkeys, the experimental designs of the past polysomnography studies leave much to be desired. In almost all these studies due to experimental constraints, monkeys were restricted to sound-attenuated, individual cages during sleep quantitation. This type of artificial environment is at variant from the natural milieu in which squirrel monkeys rest, occasionally in huddle positions with their conspecifics

(Kaplan, 1977; Mendoza, 1999). As such, sleep quantitation of captive squirrel monkeys living in a simulated natural milieu became a relevant objective for us.

In Table 2 we provide a summary of past sleep quantitation data for common marmosets and squirrel monkeys and have added the results obtained in the present study for these two species as well as cotton top tamarins. In the present study, we have quantitated the daily mean TST and SEL in these three species. Though the natural, wild milieu prevailing in the Neotropical rain forests could not be duplicated, we have attempted to quantitate TST and SEL of the common marmosets, cotton top tamarins and squirrel monkeys under conditions that are mildly reflective of the wild state. Either the breeding pairs/parents and offspring or the siblings were grouped together in cages for marmosets and tamarins. The sleep in two squirrel monkeys was measured in an unrestrained set up, where they were living with three conspecifics in a group cage which had access to a sun-room with adequate vertical space.

It is evident from Table 2 that the TST values of common marmosets (743 ± 35 min) obtained in the present study using actigraphy aligns favorably with the early reports Fitzgerald (1935) and Stellar (1960), based on subjective counting. But the

TST values measured by radio telemetry (Crofts et al., 2001) were nearly 3 h lower than that of the present study. Nevertheless, the SEL range of 40–50 min for marmosets reported by Crofts et al. (2001) is in agreement with the SEL range of 21–52 min obtained in the present study for three adult marmosets, namely Cj 62, Cj 98 and Cj 123. Since the present study appears to be the first report on the sleep quantitation in cotton top tamarins, the mean TST (791 ± 91 min) and the SEL range (10–28 min) for this species awaits further confirmation. However, indirect confirmatory support for the validity of TST values obtained in the present study is available. The daily TST values obtained by us for *C. jacchus* (12 h 23 min, mean of 4 adults) and *S. oedipus* (13 h 11 min, mean of 4 adults) are in harmony with the previous determinations of active phase duration in these two species, living in the wild. Castro et al. (2003) have reported that free-ranging *C. jacchus* members living at the Experimental Forestry Station in Northeastern Brazil showed an average duration of the active phase of $11:37$ h ±13.8 min. Dawson (1979) had determined that for *S. oedipus* members inhabiting the Pacific slope of Panama Canal Zone, the total daily activity time averaged 11 h.16 min ±62 min. The durations of daily activity time reported by Castro et al. (2003) and Dawson (1979) for *C. jacchus* and *S. oedipus* respectively, when subtracted from 24 h provide the duration of rest phase for these two species and the derived numbers tally perfectly with the TST values obtained in the present study for *C. jacchus* and *S. oedipus*.

As for the squirrel monkey, the average TST value of 467 min obtained in the present study by actigraphy lies in between the lower (329 ± 32 min) and upper extremes (672 ± 12 min) of TST values reported by four previous groups using polysomnography (Table 2). But the SEL range for squirrel monkeys have not been recorded in these reports (Adams and Barratt, 1974; Wexler and Moore-Ede, 1985; Breton et al., 1986; Edgar et al., 1993). As such, the validity of the shorter SEL range of 9–15 min for squirrel monkey reported in this study deserves confirmation, under identical experimental set up. Under the experimental set up used in this study where squirrel monkeys were provided with a sun-room and when measurements were made the natural daylight was extended to 14 h, the resulting effect of such shortened dark phase on the diminished TST (in comparison to previous reports by Adams and Barratt, 1974; Wexler and Moore-Ede, 1985; Edgar et al., 1993) and SEL deserve additional attention.

A positive correlation of SEL to the brain weight and encephalization of mammalian species has been suggested (Zepelin, 1989); i.e., mammals with smaller brains have a shorter SEL (for example, house mouse: 11 min, laboratory rat: 11 min, dog: 20 min, and cat: 25 min) than the mammals with larger brains (for example, baboon: 40 min, chimpanzee: 85 min, and human: 90 min). However, since only meager information is currently available on the SEL of different primate species the validity of an exclusive correlation between SEL and brain weight needs further scrutiny. Apart from the brain weight and encephalization process, we believe that SEL is further influenced by parameters such as age, group composition in the surrounding milieu, ovarian cycle in

Table 2
Summary of sleep quantitation in three species of New World monkeys

Method	Number and sex [a]	Body weight (g)	Mean TST (min)	SEL range (min)	Authors [b]
Common marmoset					
[Unspecified] [c]	11?	n.r.	780–840	n.r.	1
[Unspecified] [c]	25?	n.r.	∼840	n.r.	2
Radio telemetry	4♂+♀	n.r.	569±8	40–50	3
Actigraphy	4♂	277–440	743±35	21–156	This study
	1♂ [d]	266	1016	262	This study
Cotton top tamarin					
Actigraphy	4♂	425–500	791±91	10–28	This study
Squirrel monkey					
Polysomnography	3♂	560–700	593±62	n.r.	4
Polysomnography	4♂	∼900	672±12	n.r.	5
Polysomnography	11♂+♀	600–800	329±32	n.r.	6
Polysomnography	5♂	1100–1150	534±40	n.r.	7
Actigraphy	2♂	927–954	467	9–15	This study

TST—total sleep time (mean±SD); SEL—sleep episode length (mean±SD); n.r.—not recorded.

[a] All monkeys of three species, excluding one *C. jacchus* juvenile used in this study, were adults.

[b] Authors: 1—Fitzgerald, 1935; 2—Stellar, 1960; 3—Crofts et al., 2001; 4—Adams and Barratt, 1974 (12 h recording only); 5—Wexler and Moore-Ede, 1985; 6—Breton et al., 1986 (10 h recording only); 7—Edgar et al., 1993.

[c] Most probably subjective counting; the exact number and sex of marmosets observed for sleep quantitation not clearly specified, since these were early attempts on breeding this species under captivity.

[d] The juvenile (Cj 174), aged 10 months, used in this study for the purpose of checking age-related difference in sleep in comparison to its male parent (Cj 133), sharing the same cage.

Table 3
Comparison of sleep measurement methods for non-human primates

Parameter	Polysomnography	Videography	Actigraphy
(1) Validity:	High; due to differential merit in distinguishing non-REM and REM sleep phases	Medium; sleep phases cannot be differentiated	Medium; sleep phases cannot be differentiated
(2) Convenience:	Low; need for surgery, delay from post-surgical recovery, potential for interference of wires and electrodes by dexterous primate	Low; need for post hoc reviewing and data tabulation from tape, camera positioning need alteration as per primate movement	High
(3) Extended recording:	Feasible only for one to few days	Feasible for weeks	Feasible for weeks
(4) Chair/Gadget restraint:	Needed, and rather sub-natural	Not needed	Not needed
(5) Inter-experimenter reliability:	Medium; because of the need for surgery and its restraints	High; no surgery needed	High; no surgery needed

non-REM—non-rapid eye movement sleep; REM—rapid eye movement sleep.

females, parenting status of the primate and last but not the least, inherent evolutionary adaptiveness of the primate against predation pressure. In the present study, the SEL data obtained for parent–offspring marmoset pair (Cj 133 and Cj 174) living in the same cage demonstrates the influence of age and parenting status on SEL. Though Cj 133 is an adult male, its markedly higher SEL (156 ± 56 min) in comparison to the SEL range (21–52 min) of its conspecifics cohabiting with adults in their respective cages deserves notice.

Vigilance, a critical evolutionary adaptive feature of predator avoidance, is exhibited by Callitrichid monkeys (Caine, 1986, 1987; Ferrari and Ferrari, 1990; Price et al., 1991) and squirrel monkeys (Biben et al., 1989) during their active phases, even if they live under captive conditions. Vigilance has been generally defined as a behavioral 'state of readiness [in animals] to detect specific unpredictable events in the environment' (Harre and Lamb, 1986). According to Treves (2000), the definitions of vigilance contributed by primate behavioral scientists are rather non-uniform because 'many primate studies use idiosyncratic sampling rules'. We also concur with Treves (2000) that vigilance measurement is further compounded by the limitations in methodology to simultaneously detect exhibited multiple modes of vigilance by primates, representing the visual, auditory and olfactory senses. As such, within the boundaries of our recording technique used in this study, the shorter SEL ranges recorded for the cotton top tamarins (10–28 min) and squirrel monkeys (9–15 min) in this study could be interpreted as linked to inherited vigilance behavior. We hypothesize that the vigilance behavior when it exists during a primate's active phase should also prevail when it is at rest (sleep) and the shorter SEL ranges are probable indicators of such vigilance behavior. This hypothesis deserves additional testing in Callitrichid monkeys of female sex as well.

The use of actigraphy as a viable method of sleep quantitation in non-human primates deserves scrutiny. While polysomnography is still considered as the 'gold standard' for sleep quantitation measurements, its many drawbacks also deserve recognition (Table 3). These drawbacks contribute much to the loss of rigor in the gathered data, especially in case of highly intelligent, dexterous non-human primates. Absence of accurate stereotaxic brain atlases further add to the difficulty in measuring the sleep of marmoset and tamarin monkeys via polysomnography. To the best of our knowledge, a stereotaxic brain atlas for cotton top tamarin is still unavailable. Even the available stereotaxic brain atlas for common marmoset by Stephan et al. (1980) was based on the observations made on only 5 adult male marmosets, and carries a disclaimer stating, "This stereotaxic atlas should not be considered as a comprehensive presentation and classification of the cyto and myeloarchitectonics of the brain of the common marmoset monkey. Although a great effort was exerted to identify completely the cellular aggregates which are visible on the plates several grey masses could not be labeled with certainty." As such, until the availability of reliable stereotaxic brain atlases of common marmoset and cotton top tamarin, accurate sleep measurements using polysomnography appear impractical.

To conclude, in order to determine normative values on sleep parameters, in this study we have quantitated TST and SEL for males of common marmosets, cotton top tamarins and squirrel monkeys. These data add to our recent findings on the sleep parameters of owl monkey, Aotus species (Sri Kantha and Suzuki, in press). Taken together, these results may be of value (a) to evaluate the functions of sleep among Neotropical primates in phylogenetic and interspecies context (Siegel, 2005), and (b) to aid the protocols of the conservation programs targeted towards marmosets and tamarins in the wild (Kleiman, 1977; Rylands, 1993, Defler, 2004). Data obtained in a companion study in which we have quantitated the TST and SEL for females of common marmosets and cotton top tamarins will be presented separately.

Acknowledgments

References

Adams, P.M., Barratt, E.S., 1974. Nocturnal sleep in squirrel monkeys. Electroencephalogr. Clin. Neurophysiol. 36, 201–204.
Ancoli-Israel, S., Cole, R., Alessi, C., Chambers, M., Moorcroft, W., Pollak, C.P., 2003. The role of actigraphy in the study of sleep and circadian rhythms. Sleep 26, 342–392.

Beischer, D.E., 1968. The squirrel monkey in aerospace medical research. In: Rosenblum, L.A., Cooper, R.W. (Eds.), The Squirrel Monkey. Academic Press, New York, pp. 347–364.

Biben, M., Symmes, D., Bernhards, D., 1989. Vigilance during play in squirrel monkeys. Am. J. Primatol. 17, 41–49.

Breton, P., Gourmelon, P., Court, L., 1986. New findings on sleep stage organization in squirrel monkeys. Electroencephalogr. Clin. Neurophysiol. 64, 563–567.

Caine, N.G., 1986. Visual monitoring of threatening objects by captive tamarins (Saguinus labiatus). Am. J. Primatol. 10, 1–8.

Caine, N.G., 1987. Vigilance, vocalizations, and cryptic behavior at retirement in captive groups of red-bellied tamarins Saguinus labiatus. Am. J. Primatol. 12, 241–250.

Campbell, S.S., Tobler, I., 1984. Animal sleep: a review of sleep duration across phylogeny. Neurosci. Biobehav. Rev. 8, 269–300.

Castro, C.S.de., Menezes, A.L.de., Moreira, L.F.deS., 2003. Locomotor activity rhythm in free-ranging common marmosets (Callithrix jacchus). Biol. Rhythm Res. 34, 23–30.

Crofts, H.S., Wilson, S., Muggleton, N.G., Nutt, D.J., Scott, E.A.M., Pearce, P.C., 2001. Investigation of the sleep electrocorticogram of the common marmoset (Callithrix jacchus) using radiotelemetry. Clin. Neurophysiol. 112, 2265–2273.

Croll, D.H., Ausman, L.M., Nicolosi, R.J., 1993. Cholesterol metabolism in New World primates: comparative studies in two tamarin species (Saguinus oedipus and Saguinus fuscicollis) and the squirrel monkey (Saimiri sciureus). Comp. Biochem. Physiol. B 106, 845–853.

Dawson, G.A., 1979. The use of time and space by the Panamanian tamarin, Saguinus oedipus. Folia Primatol. 31, 253–284.

Day, R.T., Elwood, R.W., 1999. Sleeping site selection by the Golden-handed tamarin Saguinus midas midas: the role of predation risk, proximity to feeding sites, and territorial defence. Ethology 105, 1035–1051.

Defler, T.R., 2004. Primates of Colombia. Conservation International, Bogota, Colombia, pp. 188–201.

Edgar, D.M., Dement, W.C., Fuller, C.A., 1993. Effect of SCN lesions on sleep in squirrel monkeys: evidence for opponent processes in sleep–wake regulation. J. Neurosci. 13, 1065–1079.

Erkert, H.G., Nagel, B., Stephani, I., 1986. Light and social effects on the free-running circadian activity rhythm in common marmosets (Callithrix jacchus; Primates): social masking, pseudo-splitting and relative coordination. Behav. Ecol. Sociobiol. 18, 443–452.

Erny, B.C., Wexler, D.B., Moore-Ede, M.C., 1985. Circadian sleep–wake cycle organization in squirrel monkeys. Am. J. Physiol. 248, R353–R362.

Ferrari, S.F., Ferrari, M.A.L., 1990. Predator avoidance behaviour in the buffy-headed marmoset, Callithrix flaviceps. Primates 31, 323–338.

Fitzgerald, A., 1935. Rearing marmosets in captivity. J. Mammal. 16, 181–188.

Fukuhara, R., Kageyama, T., 2005. Structure, gene expression and evolution of primate glutathione peroxidases. Comp. Biochem. Physiol. Part B Biochem. Mol. Biol. 141, 428–436.

Harre, R., Lamb, R. (Eds.), 1986. The Dictionary of Ethology and Animal Learning. Blackwell Reference, Oxford, p. 163.

Hershkovitz, P., 1977. Living New World Monkeys (Platyrrhini), vol. 1. University of Chicago Press, Chicago, pp. 564–565.

Heymann, E.W., 1995. Sleeping habits of tamarins, Saguinus mystax and Saguinus fuscicollis (Mammalia; Primates; Callitrichidae) in north-eastern Peru. J. Zool., Lond. 237, 211–226.

Kaplan, J.N., 1977. Breeding and rearing squirrel monkeys (Saimiri sciureus) in captivity. Lab. Anim. Sci. 27, 557–567.

Kleiman, D.G. (Ed.), 1977. The Biology and Conservation of the Callitrichidae. Smithsonian Institution Press, Washington, DC.

Klerman, E.B., Boulos, Z., Edgar, D.M., Mistlberger, R.E., Moore-Ede, M.C., 1999. Circadian and homeostatic influences on sleep in the squirrel monkey: sleep after sleep deprivation. Sleep 22, 45–59.

Klerman, E.B., Boulos, Z., Edgar, D.M., Mistlberger, R.E., Moore-Ede, M.C., 2000. EEG delta activity during undisturbed sleep in the squirrel monkey. Sleep Res. Online 3, 113–119.

Mast, E.B., Rodriguez, J.V., Mittermeier, R.A., 1993. The Colombian cotton top tamarin in the wild. In: Clapp, N.K. (Ed.), A Primate Model for the Study of Colitis and Colonic Carcinoma—The Cotton top Tamarin (Saguinus oedipus). CRC Press, Boca Raton, FL, pp. 3–43.

McGeachin, R.L., Akin, J.R., 1982. Amylase levels in the tissues and body fluids of several primate species. Comp. Biochem. Physiol. A 72, 267–269.

Mendoza, S.P., 1999. Squirrel monkeys, In: Poole, T. (Ed.), The UFAW Handbook on the Care and Management of Laboratory Animals, 7th ed. Terrestrial Vertebrates, vol. 1. Blackwell Science, Oxford, pp. 591–600.

Menezes, A.A.L., Moreira, L.F.S., Azvedo, C.V.M., Costa, S.F., Castro, C.S.S., 1993. Behavioral rhythms in the captive common marmoset (Callithrix jacchus) under natural environmental conditions. Braz. J. Med. Biol. Res. 26, 741–745.

Norconk, M.A., Rosenberger, A.L., Garber, P.A. (Eds.), 1996. Adaptive Radiations of Neotropical Primates. Plenum Press, New York.

Poole, T., Hubrecht, R., Kirkwood, J.K., 1999. Marmosets and tamarins, In: Poole, T. (Ed.), The UFAW Handbook on the Care and Management of Laboratory Animals, 7th ed. Terrestrial Vertebrates, vol. 1. Blackwell Science, Oxford, pp. 559–573.

Price, E.C., McGivern, A.M., Ashmore, L., 1991. Vigilance in a group of free-ranging cotton top tamarins Saguinus oedipus. Dodo J. Jersey Wildl. Preserv. Trust 27, 41–49.

Roger, E.J., Sabrah, T., Hebert, J.R., Ausman, L.M., Hegsted, D.M., Nicolosi, R.J., 1993. A comparison of serum retinol concentration between human and different species of normo and hypercholesterolemic nonhuman primates fed semi-purified diets with defined amounts of vitamin A. Comp. Biochem. Physiol. A 106, 749–754.

Rylands, A.B. (Ed.), 1993. Marmosets and Tamarins; Systematics, Behaviour and Ecology. Oxford University Press, Oxford.

Siegel, J.M., 2005. Clues to the functions of mammalian sleep. Nature 437, 1264–1271.

Sri Kantha, S., Suzuki, J., in press. Sleep profile and longevity in three generations of a family of captive Aotus colony of Bolivian origin. Int. J. Primatol., 27.

Stellar, E., 1960. The marmoset as a laboratory animal; maintenance, general observations of behavior, and simple learning. J. Comp. Physiol. Psychol. 53, 1–10.

Stephan, H., Baron, G., Schwerdtfeger, W.K., 1980. The Brain of the Common Marmoset (Callithrix jacchus) A Stereotaxic Atlas. Springer-Verlag, Berlin.

Sussman, R.W., Kinzey, W.G., 1984. The ecological role of the Callitrichidae; a review. Am. J. Phys. Anthropol. 64, 419–449.

Treves, A., 2000. Theory and method in studies of vigilance and aggregation. Anim. Behav. 60, 711–722.

Welsh, J.D., Walker Jr., A.W., 1972. Intestinal disaccharidase activity of non-human primates: I. Tupaiidae, Cebidae and Cercopithecidae. Comp. Biochem. Physiol. A 41, 719–726.

Welsh, J.D., Walker Jr., A.W., 1973. Intestinal disaccharidase activity of non-human primates: II. Lorisidae, Hapalidae, Cebidae. Comp. Biochem. Physiol. A 46, 549–557.

Wexler, D.B., Moore-Ede, M.C., 1984. Effects of a muramyl dipeptide on the temperature and sleep–wake cycles of the squirrel monkey. Am. J. Physiol. 247, R672–R680.

Wexler, D.B., Moore-Ede, M.C., 1985. Circadian sleep–wake cycle organization in squirrel monkeys. Am. J. Physiol. 248, R353–R362.

Wexler, D.B., Moore-Ede, M.C., 1986. Resynchronization of circadian sleep–wake and temperature cycles in the squirrel monkey following phase shifts of the environmental light–dark cycle. Aviat. Space Environ. Med. 57, 1144–1149.

Zepelin, H., 1989. Mammalian sleep. In: Kryger, M.H., Roth, T., Dement, W.C. (Eds.), Principles and Practice of Sleep Medicine. W.B.Saunders Company, Philadelphia, pp. 30–49.

Zhdanova, I.V., Geiger, D.A., Schwagerl, A.L., Leclair, O.U., Killiany, R., Taylor, J.A., Rosene, D.L., Moss, M.B., Madras, B.K., 2002. Melatonin promotes sleep in three species of diurnal nonhuman primates. Physiol. Behav. 75, 523–529.