

Behavioral sleep in captive sea otters

Oleg I. Lyamin, Alexander I. Oleksenko, Vladimir F. Sevostiyarov,
Evgeni A. Nazarenko and Lev M. Mukhametov

Severtsov Institute of Ecology and Evolution, Russian Academy of Sciences, 33 Leninsky prospekt, Moscow, 117071, Russia

Abstract

We observed the behavior of two captive sea otters (*Enhydra lutris*) in water and on land at the Utrish Marine Station of the Russian Academy of Sciences. The behavior of otters was divided into 4 distinct stages: active wakefulness (40.5–50.5% of 24 h), quiet wakefulness (21.5–30.8%), quiet sleep (23.9–35.0%), and paradoxical sleep (1.1–2.5%). During quiet sleep in water, otters floated on the back at the surface in the typical posture with both eyes closed. Paradoxical sleep was recorded both in water and on land and was characterized by jerks and twitches of the head, paws and whole body and evident muscle tone hypotonia. The main sleep period (quiet and paradoxical sleep) occurred in otters during the night when they usually slept on land. During the day otters slept only in water.

Key words: sea otter, sleep, slow-wave sleep, paradoxical sleep, resting behavior, pinnipeds, cetaceans.

Introduction

Sleep in most terrestrial mammals is subdivided into two distinct stages—slow-wave sleep and paradoxical (or rapid eye movement) sleep. Slow-wave sleep is characterized by high-amplitude synchronized activity in the electroencephalogram, absence of eye movement, and decreased (compared to wakefulness) skeletal muscle tone. In most animals paradoxical sleep is identified by desynchronized, low-amplitude electroencephalogram activity (similar to waking), rapid eye movements, muscle jerks, and postural atonia. These two stages of sleep are found in all terrestrial mammals, including placental mammals, marsupials, and recently in monotremes (Zepelin, 1994; Siegel, 1999).

The pattern of sleep in dolphins and seals differs significantly from that in terrestrial mammals and was described elsewhere (Mukhametov *et al.*, 1977; Mukhametov *et al.*, 1984; Lyamin, 1993; Lyamin &

Chetyrbock, 1992; Castellini *et al.*, 1994). The sea otter (*Enhydra lutris*) is the only representatives of Carnivora adapted for constant living in the aquatic environment (Barabash-Nikiforov *et al.*, 1968). Several publications described in detail the different types of activity in these animals (feeding, grooming, traveling, interacting etc.), but provide a little information concerning their rest stages (Packard & Ribic, 1982; Ralls & Siniff, 1990; Ralls *et al.*, 1995). Therefore, the primary aim of this study was to characterize behavioral sleep in sea otters in water and on land.

Materials and Methods

We had an opportunity to observe the behavior of two young sea otters (a male and a female, 6–8 month old) at the Utrish Marine Station of the Russian Academy of Sciences (near the city Novorossiysk). During observations, the otters were kept in pools filled with sea water up to a depth of 1 m, which had wooden platforms positioned above the surface. During the first three weeks the sea otters were kept together and then the male was taken to another facility where it was no longer available for observations. Preliminary observations of the male and female were performed during the daytime (2–4 h per day) throughout a two-week period. The purpose of these observations was to formulate behavioral criteria for discrimination of behavioral stages in sea otters and to train the observers to identify the behavior of the otters in the same way. Then, 5 series of visual observations were performed while sea otters were observed continuously for 36–72 h. In series I (05/25), which lasted for 36 h, both otters were kept together in a spacious round pool (12 m in dia, 3 m deep). In this series, we observed and documented the behavior of both animals for 15 sec at the end of every 5 min interval throughout 36 h. In series II–V, we observed the female for 3 continuous days per series. In series II (06/03–06/05) and III (06/11–06/13), the female was alone in the same pool. Several

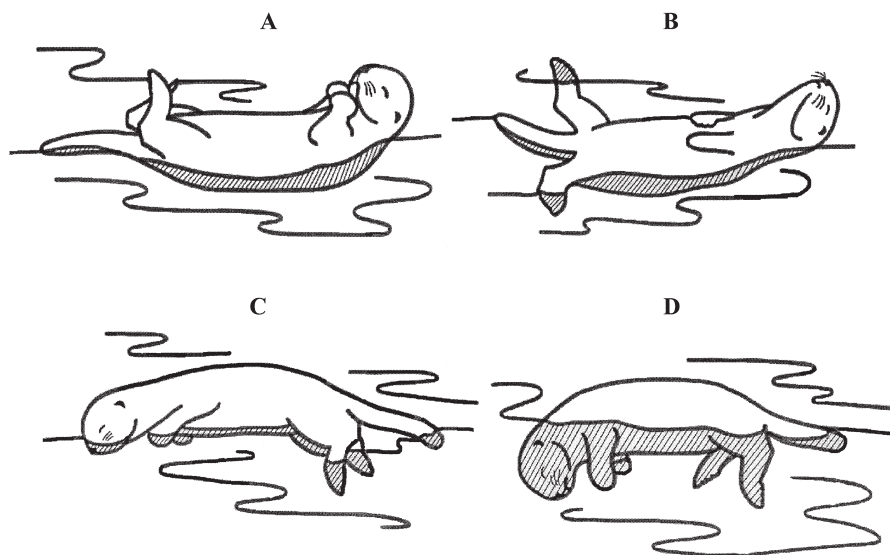


Figure 1. Typical sleep postures in the sea otter. A—quiet sleep, B—transition from quiet sleep to paradoxical sleep, C and D—paradoxical sleep.

days after series III had been completed the female was moved to a rectangular pool ($9 \times 4.5 \times 1.3$ m). In series IV (07/03–07/05) and V (08/15–09/17), the female was observed in this pool. In series II–V, we used a PC-computer and a program of our own design to document the behavior of the female by pressing keyboard keys, which were previously assigned to behavioral events (grooming, respiratory acts, jerks of the eyes, head or body, etc.) and any changes in the activity pattern of the animal (swimming, feeding, floating on the surface etc.). The time and codes of events were stored in a computer for quantitative analysis. During the study the observers worked in 3–4 h shifts. Two observers who had previously participated in similar studies of sleeping behavior in seals performed visual observations at night and during the afternoon, when the sea otters slept most of the time. The distance between the observer and the otter varied between 3 and 10 m. While the animal was asleep, we used binoculars to detect behavioral features of sleep.

The pools were located outdoors and were under natural illumination (daylight hours were between 0600–0700h and 1900–2000h). During the nighttime, we turned on one 150 W aerial lamp placed 3 m above the water surface to provide additional illumination for observations. The otters were fed 3 times a day (0800–1000h, 1200–1300h and 2000–2100h), but they were never deliberately awakened for this if they were asleep. The food (mollusk, squid, and small fish) was thrown on the bottom of the pool, and the animals could pick it up at any

time. The pools were cleaned and filled with fresh sea water daily between 0800 and 1000h.

Results

The behavior of sea otters was subdivided into 4 distinct stages: active wakefulness (AW), quiet wakefulness (QW), quiet sleep (QS), and paradoxical sleep (PS).

AW was scored when the sea otter was swimming (usually looking for a food or foraging), eating food (fish or mollusks), lying on the water surface, or grooming vigorously while rolling near the surface. All the time spent on cleaning of pools (1 to 2 h per day between 0800 and 1000h) also was considered AW. QW was scored when the otter floated belly-up on the surface or lay on the platform with its eyes opened most of the time. Grooming behavior such as rubbing of the body, nibbling or licking of paws, belly or tail also was included in QW if it was not accompanied by rolling in water. AW and QW episodes were scored when they lasted for at least 20 sec.

QS was scored when the otter floated on its back at the surface, in the typical posture or lay motionless on the platform (usually curled up) with its eyes closed for at least 20 sec. While sleeping in water, sea otters put their forepaws on the chest. The rear feet lay on the surface of the water or on the belly. The tail always lay on the water surface and infrequently moved (Fig. 1a). Sea otters were not completely immobile in this state. Sometimes they moved their bodies, presumably to balance and to

Table 1. Characteristics of sleep and activity stages in sea otters (n=number of days).

Parameters	Series I (n=1) male	Series I (n=1) female	Series II–III (n=6) female	Series IV (n=3) female	Series V (n=3) female
Total amount of (% of 24-h):					
Active wakefulness	32.3	40.3	45.9 ± 1.6	64.8 ± 2.6	67.7 ± 2.0
Quiet wakefulness	36.1	31.6	25.3 ± 1.0	14.4 ± 3.9	7.0 ± 1.0
Quiet sleep	31.6*	28.1*	27.0 ± 1.6	20.1 ± 1.4	23.2 ± 1.4
Paradoxical sleep	—	—	1.8 ± 0.2	0.7 ± 0.2	2.1 ± 0.1
Characteristics of paradoxical sleep episodes:					
Duration of episode (sec)	—	—	153 ± 27	70 ± 4	131 ± 16
Number of episodes (per day)	—	—	11 ± 2	9 ± 2	14 ± 2

*Paradoxical sleep was not scored in series I.

keep the posture. Occasionally, they rocked on their sides, but as soon as their nostrils touched the water animals returned to the typical posture, frequently without any sign of behavioral arousal.

Episodes of PS were characterized by easily recognized behavioral signs of this stage of sleep in terrestrial mammals (Zepelin, 1994), including single and serial jerks and twitches of the head, paws and whole body, and also disruption of the typical QS posture. In water, episodes of PS started either with jerks or slow movement of the head toward the water surface (Fig. 1b). Frequently, the head submerged and the animal rocked on its side or onto a belly-down position, staying up to 1 min with all paws and head submerged (Fig. 1c, d). On land (in this case, the platform), the onset of PS also accompanied by evident visual signs of skeletal muscle hypotonia—the neck and sometimes paws stretched out along the platform. We defined the start of the episode as the time when the first jerks or the previously described postural changes occurred. We considered an episode finished when the animal went back to the belly-up position, displayed any signs of behavioral arousal (e.g., eyes opening) or when jerks were not observed for more than 60 sec.

In series I, when both sea otters were being continuously observed for 36 h, the total sleep times (QS and PS) in the male and female were very similar (Table 1; PS was not scored in this series). In series II and III, when only the female was observed, AW time as a percentage of 24-h varied between 40.5% and 50.5%; QW—between 21.5% and 30.8%; QS—between 23.9% and 35.0%; and PS—between 1.1% and 2.5%. In the female, about 90% of all swimming was accompanied by grooming. Forty percent of the female's QW on land and 79% in water also contained different elements of grooming behavior. From 6 to 16 episodes of PS were recorded in the female per day. Thirty six

percent of all episodes of PS recorded in series II and 50% in series III occurred in water. The duration of episodes varied between 5 and 314 sec. The longest episodes of PS were recorded on land; however, we did not find a significant difference between the mean duration of PS in water and on land (e.g., on the second day of series III the mean duration of PS episodes in water was 90 ± 33 sec, $n=6$ and on land 95 ± 51 sec, $n=7$).

Of all respiratory pauses in sea otters, 90% were shorter than 15 sec. In AW, pauses longer than 30 sec were recorded only when animals dove looking for food. In series II and III, the mean respiratory pause in the female during AW in water when it was not diving was equal 12.2 ± 1.0 sec ($n=140$). In QS the mean pauses were 6.4 ± 0.2 sec ($n=363$) during QS in water and on land 5.6 ± 0.2 sec ($n=524$). Pauses longer than 30 sec were recorded in both sea otters during PS in water when the otter's head sank under the surface and the animal rocked on its side or onto a belly-down position. The longest pause during PS lasted 70 sec.

The 24-h sleep profile (QS and PS) in the otters was bimodal in series I, II and III. The main sleep period occurred during the nighttime. On different days, it started at 2000–2200h and ended at 0600–0900h in the morning. During this time, otters rested both in water and on the platform. The second period occurred between 1200h and 2000h, when animals slept only in water. QS episodes in this time were shorter than during the nighttime and more frequently interrupted by episodes of AW and QW. The 24-h sleep profile in the female in series II–V is shown in Figure 2.

When the female was moved to a smaller pool where it could observe its surroundings (series IV), its behavior changed markedly (Table 1). The daily amount of AW increased and the amount of QW, QS, and PS decreased. Locomotion in series IV constituted a stereotyped swimming around the

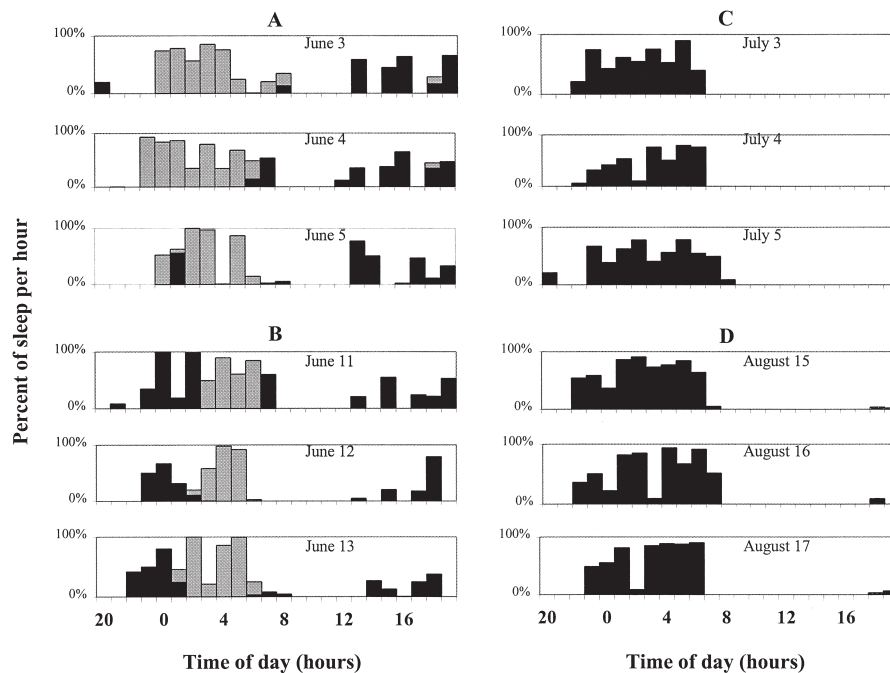


Figure 2. 24-h sleep profile in a sea otter female in captivity. Quiet sleep and paradoxical sleep episodes are included together. A-series II, B-series III, C-series IV, D-series V. Bars represent percents of each hour. Black bars represent sleep in water, gray bars indicate sleep on land.

pool. In addition, the daytime sleep period disappeared, and the otter stopped going onto the platform for rest, even during the nighttime (Fig. 2). One and a half months later (series V) the amount of QS and PS, and the mean duration of PS episodes increased, approaching the corresponding values in the series II and III. Only after two and a half months following the move the female started to sleep during the daytime in water. Only after three and a half months it started to sleep on the platform during the nighttime.

Discussion

Our observations showed that behavioral sleep in sea otters can be subdivided into two stages. QS scored in our study apparently represented mostly episodes of slow-wave sleep; however, we can not exclude that a small portion of QW was included in this stage too. Behavioral features of PS in sea otters meet the criteria for this stage of sleep in terrestrial mammals (Zepelin, 1994). We emphasize that the rest stage as it was scored in several zoological studies (e.g., Ralls & Siniff, 1990; Ralls et al., 1995) actually was composed of different functional states, such as QW, slow-wave sleep and PS. For instance, in our previous study we showed that the amount of PS in fur seals on land was

estimated electrophysiologically as $3.6 \pm 0.3\%$ ($n=7$), but visually only as $2.5 \pm 0.8\%$ ($n=3$) (Lyamin *et al.*, 1996). Therefore, both PS and slow-wave sleep can be precisely revealed in mammals only on the basis of recording of the electroencephalogram, electromyogram and electrooculogram. During our observations, the behavioral sleep in sea otters occupied in total 25–37% of 24-h. Of course, additional observations need to be done and our present estimation of the time budget in captive sea otters is preliminary.

It is important that PS was observed in sea otters both in water and on land. Until now PS, accompanied by typical behavior and electrographic features, was recorded in water in only three species of phocid seals (Mukhametov *et al.*, 1984; Lyamin, 1993; Castellini *et al.*, 1994). In fur seals, which belong to Otariidae, rare episodes of PS in the water were very brief, usually less than 10 sec (Lyamin *et al.*, 1996). In dolphins PS, has never been recorded in electrophysiological studies and characteristic jerks were only observed in well adapted captive animals (e.g., Mukhametov & Lyamin, 1994; Lyamin *et al.*, 1998).

Though sea otters show a bimodal pattern of activity in the wild, this pattern could be affected by many factors (e.g., Ralls & Siniff, 1990). It is reasonable to suggest that two periods of activity in

otters in our experimental conditions were enforced by human activity (cleaning of pools, feeding). In the wild in some places sea otters rest on land mostly during the night and in water during the day (Barabash-Nikiforov *et al.*, 1968), while in other locations they commonly haul out during daylight hours (Reidman & Estes, 1990). In our conditions sea otters also slept only in water during the daytime while during the nighttime they slept both in water and on land. The otters began to haul out and sleep on the platform only when they became more familiar with the environment. It suggests that, in spite of the fact that sea otters can sleep both on water and on land, they consider the aquatic environment a safer place to sleep than on land.

The most important common feature of sleeping behavior in sea otters and fur seals appears to be the lack of complete immobility during sleep in water. A significant electrographic peculiarity of the Otariidae sleep is the interhemispheric electrocorticogram asymmetry during slow-wave sleep (Mukhametov *et al.*, 1985; Lyamin & Chetyrbok, 1992), which is similar to 'unihemispheric slow-wave sleep' in dolphins (Mukhametov *et al.*, 1977). Based on the behavioral similarities between sea otters and fur seals, we suggest that sea otters, like Otariidae seals and dolphins might have the same amazing sleep pattern.

Acknowledgments

The study was supported by Utrish Dolphinarium Ltd. The authors thank Drs. M. Castellini, M. Eiland and R. Jameson for comments on the manuscript.

Literature Cited

- Barabash-Nikiforov, I. I., Marakov, S. V. & Nikolaev, A. M. (1968) *The Kalan or Sea Otter*. Nauka, Leningrad (Transl. from Russian by A. L. Peabody. U.S. Department of Commerce. NOAA. Nat. Mar. Fish. Serv., Off. Int. Fish., Language Services Div. Washington. D.C.).
- Castellini, M. A., Milsom, W. K., Berger, R. J., Costa, D. P., Jones, D. R., Castellini, J. M., Rea, L. D., Bharma, S. & Harris, M. (1994) Patterns of respiration and heart rate during wakefulness and sleep in elephant seal pups. *American Journal of Physiology*. **266**, R863–R869.
- Lyamin, O. I. (1993) Sleep in the harp seal (*Pagophilus groenlandica*). Comparison of sleep on land and in water. *Journal of Sleep Research*. **2**, 170–174.
- Lyamin, O. I. & Chetyrbok, I. S. (1992) Unilateral EEG activation during sleep in the cape fur seal, *Arctocephalus pusillus*. *Neuroscience Letters*. **143**, 263–266.
- Lyamin, O. I., Oleksenko, A. I., Polyakova, I. G. & Mukhametov L. M. (1996) Paradoxical sleep in northern fur seal in water and on land. *Journal of Sleep Research*. **5** (supplement 1), 130.
- Lyamin, O. I., Shpak, O. V., Nazarenko, E. A. & Mukhametov, L. M. (1998) The behavioral signs of paradoxical sleep in the beluga whale. *Journal of Sleep Research*. **7** (supplement 2), 166.
- Mukhametov, L. M. & Lyamin, O. I. (1994) Rest and active states in bottlenose dolphins (*Tursiops truncatus*). *Journal of Sleep Research*. **3** (supplement 3), 174.
- Mukhametov, L. M., Supin, A. Y. & Polyakova, I. G. (1977) Interhemispheric asymmetry of the electroencephalographic sleep patterns in dolphins. *Brain Research*. **134**, 581–584.
- Mukhametov, L. M., Lyamin, O. I. & Polyakova, I. G. (1985) Interhemispheric asynchrony of the sleep EEG in northern fur seals. *Experientia*. **41**, 1034–1035.
- Mukhametov, L. M., Supin, A. Y. & Polyakova, I. G. (1984) Sleep in caspian seals (*Phoca caspica*). *Journal of High Nervous Activity*. **34**, 259–264 (in Russian).
- Packard, J. M. & Ribic, C. A. (1982) Classification of the behavior of sea otters (*Enhydra lutris*). *Canadian Journal of Zoology*. **60**, 1362–1373.
- Ralls, K. & Siniff, D. B. (1990) Time budget and activity patterns in California sea otters. *Journal of Wildlife Management*. **54**, 251–259.
- Ralls, K., Hatfield, B. B. & Siniff, D. B. (1995) Foraging patterns of California sea otters as indicated by telemetry. *Canadian Journal of Zoology*. **73**, 523–531.
- Riedman, M. L. & Estes J. A. (1990) The sea otter (*Enhydra lutris*): behavior, ecology, and natural history. *U.S. Fish and Wildlife Service Biological Rep.* **90** (14). pp. 126
- Siegel, J. M. (1999) The evolution of REM sleep. In: R. Lydic, R and H. A. Baghdoyan (eds.). *Handbook of Behavioral State Control*. Pp. 87–100. CRC Press: Boca Raton.
- Zepelin, A. (1994) Mammalian sleep. In: M. H. Kryger, T. Roth & W. C. Dement (eds.). *Principle and Practice of Sleep Medicine*. Pp. 69–80. Saunders Company, Philadelphia.