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Evaluation of the Ability of Northern Fur Seals to Perceive and Visually Discriminate Images under the Conditions of Sleep Loss

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INTRODUCTION

Reduced sleep time impairs cognitive functions, such as attention, sensory perception, decision making, learning and memory as shown in humans and most studied terrestrial animals [1, 2]. This data is considered to support the popular hypothesis that sleep is crucial to maintain cognitive processes. At the same time, marine mammals (cetaceans, pinnipeds) annually migrate long distances. During this time the patterns of their activity and sleep change while the time spent asleep appears to shorten [3-5]. It is not known whether sleep deficit has any negative impact on cognitive functions in marine mammals.

The objective of this study was to evaluate the capabilities of northern fur seals (members of the otariidae seals, pinnipeds) to perceive and analyze information under the conditions of almost complete absence of sleep.

The study was conducted at the Utrish marine Station of A.N. Severtsov Institute of Ecology and Evolution of RAS. The subjects were 2 adult female fur seals (age 4–10 years old). They were housed in separate outdoor pools with sea water. Both seals were trained to determine the larger of two white plastic circles presented on a dark screen above the water. The animals indicated their choices while pushing with the tip of their jars the targets located beneath the circles. The diameter of circles was 17, 18, 19, 19.5 and 20 cm. The 20 cm diameter circle was paired with one of 4 other circles of smaller diameter. The circles were presented at a distance of 1 m from the start position assumed by animals. The distance between the centers of circles was 40 cm. The correct choice was rewarded with fish. Training and test sessions were performed twice a day: in the morning (between 7 and 9 h) and in the evening (18–20 h). Each pair (20–17 cm, 20–18 cm, 20–19 cm and 19.5–20 cm) was presented 20 times per session. The position of the smaller and larger circles (from the left or right side) was varied randomly. The pairs were presented in a series in which the

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[1]The article was translated by the authors.

difference in size between circle diameters was decreased, that increasing the task difficulty. Each session consisted of 60 (first 3 pairs) or 80 (all 4 pairs) pair presentations.

After the seals had learned the task (less than 5 errors for 20 presentations for the pair 20–17 cm over 4 consecutive experiments) their ability to perform the test was evaluated for 3 or 4 pairs of circles in the conditions of: (1) normal housing (the seals were not disturbed except for the tests; "baseline"); (2) total sleep deprivation for a period of 108 hr ("sleep deprivation"); (3) recovery (same conditions as during baseline). During the baseline and recovery periods the seals had access to the platform which was positioned above the water. They always slept on land under these conditions. During sleep deprivation they were not allowed to haul out, that is they were kept afloat all the time. When in water fur seals sleep at the surface on their sides [3-5]. The seals were deprived from sleep by disturbing them every time they attempted to assume the characteristic sleep posture. An experimenter approached the pool whenever the seal tried to assume the posture. During the first 2–3 deprivation day this was sufficient to disturb the animal which resumed active swimming or grooming. On the last day of deprivation an experimenter often had to slap on the water surface to make the seal became active. The behavior of animals was monitored and videotaped continuously. The duration of time spent in active and rest behaviors was scored based on the prior established criteria [3, 4]. The performance of seals was evaluated when reviewing videos and measuring the latency of correct response (time lapse, accuracy of 35 ms) and calculating the percentage of errors for each pair. A total of 3 sleep deprivation experiments were conducted in seal no. 1 and one experiment was conducted in seal no. 2. The main data were collected during 2 experiments when the animals were presented with 4 pairs of circles. The results of these studies are presented in this report.

As expected, the percent of errors both seals made while discriminating two circles was dependent on the difference in their diameters (one way repeated measures ANOVA, $p < 0.001$ for both seals; $F [3, 12] = 63.993$ and $F [3, 12] = 16.874$ for seal m and seal no. 2). Under baseline conditions both seals made almost no errors while discriminating the larger circle for pair 20–17 cm and 20–18 cm (Figs. 1A, 1B). Under the baseline conditions the mean number of errors did not exceed 5% (Figs. 2A, 2D). For pair 20–19 cm the number of errors was greater when compared to the first two pairs: on average $18.5 \pm 5.6\%$ in seal no. 1 (ranging between 10 and 25% during different tests; Figs. 1A, 2A) and $26.3 \pm 3.0\%$ in seal no. 2 (15–45%; Figs. 1B, 2D; paired comparison $p < 0.02$). Moreover, in seal no. 2 percent of errors was comparable with the probability of random selection (Fig. 2D). Both seals failed to discriminate the larger circle for the pair 20–19.5 cm. In most individual tests (Figs. 1A, 1B) and when averaged for all baseline tests (Fig. 2A, 2D) the percent of errors was greater than the probability of random choice. The difference between pair 20–19.5 and 20–19 cm was significant in seal no. 1 ($p < 0.001$) but not in seal no. 2 ($p = 0.173$).

In seal no. 1 under the baseline conditions, the average response time varied between 0.68 and 1.02 s (Fig. 1B). The speed of response did not depend on the pair (difficulty of task) irrespective of the side (to the right or left side from the animal) on which the larger circle was presented ($p > 0.05$, Figs. 2B, 2C). In seal no. 2 the response speed was slower: on average between 0.83 and 1.25 s for different baseline tests (Fig. 1D). For the larger circle presented on the right side the response latency progressively decreased as the difference

between the circles became smaller (Figs. 2E, $p = 0.016$, F3.12 = 5.216). The difference was significant for the pairs 20–17 cm and 20–19.5 cm ($p = 0.01$). For the larger circle presented on the left side the response latency in seal no. 2 did not depend on the pair of circles ($p > 0.05$ for all 4 pairs). Therefore, a more challenging discrimination task did not affect the latency of response (seal no. 1 and seal no. 2 for the larger circle from the left side) or even decrease it (seal no. 2, the larger circle from the right side). The latency decrease can be explained by making the decision by choosing to go the same target regardless of the positions of smaller and larger circles.

There were only a few attempts to assume sleep posture during the first and second days of sleep deprivation in fur seals. On the third and fourth deprivation days the number of attempts increased. Under the sleep deprivation conditions the total rest time In seal no. 1 decreased to 1/80th of the baseline level (on average 306 min per day during the baseline days or 21.2% of 24-h; on average 4 min per day or 0.3% of 24-h during deprivation). Under the same deprivation conditions, the rest time in seal no. 2 decreased to 1/68th of the baseline level (193 min per day or 13.3% of 24-h in baseline; on average 3 min or 0.2% of 24-h during deprivation). On the first recovery day the amount of rest time sharply increased in both seals accounting for 1096 min per day in seal no. 1 (76% of 24-h or 359% of the baseline value) and 823 min per day in seal no. 2 (57 and 430%, respectively).

Under the sleep deprivation conditions the mean percent of errors in seal no. 1 decreased for all pairs of circles when compared to the baseline (for instance, greater than 1.5 fold for pairs 20–17 and 20–18 cm and less than 20% for two others, Fig. 2A). Under the same conditions, the number of errors in seal no. 2 notably decreased (by 50% when compared to baseline) only for pair 20–18 cm (Fig. 2D). During recovery seal no. 1 made about the same number of errors as during deprivation while seal no. 2 performed even slightly better. Statistical analysis revealed that all described differences were not significant ($p = 0.07$–0.80). Therefore, the percent of errors did not differ between the deprivation and baseline conditions in both seals.

In seal no. 1 the latency increased when compared between baseline and deprivation conditions for pairs 20–17 cm and 20–18 cm (on average by 100 ms, $p < 0.05$, post hoc test after ANOVA). However, it did not change for pairs 20–19 or 20–19.5 cm ($p > 0,05$; Figs. 2B, 2C). In seal no. 2 the latency tended to decrease for all pairs on deprivation days in comparison with the baseline. However, the difference was significant only for pair 20–19 cm (the larger circle was to the right side from the seal; Fig. 2E) and for pair 20–19.5 cm (the larger circle was to the left side from the seal; Fig. 2F). Therefore, under the conditions of sleep deprivation the response latency tended to change in different directions in the studied fur seals when compared to the baseline conditions.

Electrophysiological studies revealed that slow wave sleep in fur seals in water occurs at the surface in a characteristic posture when on their sides. When in this posture EEG slow waves (a measure of sleep intensity) occur and then progressively reach maximum expression. Paradoxical sleep in fur seals while in water often disappears for several days or even weeks [3, 4]. The rest of time fur seals are engaged in active wakefulness while swimming or grooming. In our study the fur seals were disturbed every time they attempted to assume the

sleep posture. We can hypothesize that during the last 2 deprivation days EEG slow waves in fur seals developed much faster when in this posture compared to the baseline conditions. However, even in this case, the total duration of such episodes of light sleep should not exceed 20 s. In addition, the number of attempts to assume sleep posture progressively increased in both seals over the course of deprivation ("sleep pressure" was building up) and the "rebound" phenomena was recorded on the first recovery day (a compensatory 3.4 and 4.4 fold increase of the rest time). Based on the following evidence we believe that over the course of a 108-h sleep deprivation periods of quite wakefulness and rest (and sleep) were almost entirely eliminated in both fur seals.

Some birds are capable of substantial reducing sleep time during migratory and breeding seasons. Reduced sleep time does not appear to cause any consistent effect on their ability to learn or on the success of their performance [6, 7]. In the current study, for the first time cognitive functions in animals were evaluated under the conditions of virtually no rest (and sleep) over the course of several (4.5) days. Regardless of the enormous sleep deficit, the ability of fur seals to perceive and analyze visual information did not deteriorate compared to the baseline period. The data collected during this study differ from that obtained in the majority of human [8], as well in rodents [9, 10] and in primates [11] studies showing that cognitive performance started to degrade after one night of wakefulness or even partial sleep reduction in all of these subjects. We suggest that marine mammals (and most likely other marine mammals), unlike the majority of studied terrestrial animals and humans, are capable of tolerating greatly reduced sleep time while preserving cognitive processes underlining analytical brain processes and vital behaviors (navigation, feeding, breeding, escaping of predators, etc.). Further research in marine mammals is required to evaluate (1) the impact of sleep loss on cognitive functions of different levels and hierarchy, and (2) how the reduction in sleep time is compensated by concomitant changes of sleep composition and active behaviors in this group of animals.

Acknowledgments

REFERENCES

1. Killgore DS, Progr. Brain Res, 2010, vol. 185, pp. 105–129.

2. McCoy JG and Strecker RE, Neurobiol. Learning Memory, 2011, vol. 96, pp. 564–582.

3. Lyamin OI and Mukhametov LM, in Severnyi morskoi kotik. Sistematika, morfologiya, ekologiya, povedenie (Northern Fur Seal: Systematics, Morphology, Ecology, and Behavior), Moscow: Nauka, 1998, pp. 280–302.

4. Lyamin OI, Lapierre JL, and Mukhametov LM, in The Encyclopedia of Sleep, Waltham (MA): Academic, 2013, vol. 1, pp. 57–62.

5. Trites AW, Lestenkof P, Battaile B, North Pacific Research Board: Project 636: Final Report, Vancouver: Univ. British Columbia, 2009, pp. 1–31.

6. Rattenborg NC, Mandt BC, Obermeyer WH, Winsauer PJ, Huber R, Wikelski M, and Benca RM, PLoS Biol., 2004, vol. 2, pp. 924–936.

7. Lesku JA, Rattenborg NC, Valcu M, Vyssotski AL, Kuhn S, Kuemmeth F, Heidrich W, and Kempenaers B, Science, 2012, vol. 337, pp. 1654–1658. [PubMed: 22878501]

8. Jackson ML, Croft RJ, Kennedy GA, Owens K, and Howard ME, Accident Anal. & Prevention, 2013, vol. 50, pp. 438–444.

9. Colavito V, Fabene PF, Grassi-Zucconi G, Pifferi F, Lamberty Y, Bentivoglio M, and Bertini G, Front. Syst. Neurosci, 2013, vol. 7, pp. 1–17. [PubMed: 23420631]

10. van Enkhuizen J, Acheson D, Risbrough V, Drummond S, Geyer MA, and Young JW, Behav. Brain Res, 2014, vol. 261, pp. 40–48. [PubMed: 24333377]

11. Deadwyler SA, Porrino L, Siegel JM, and Hampson RE, J. Neurosci, 2007, vol. 27, pp. 14239–14247. [PubMed: 18160631]
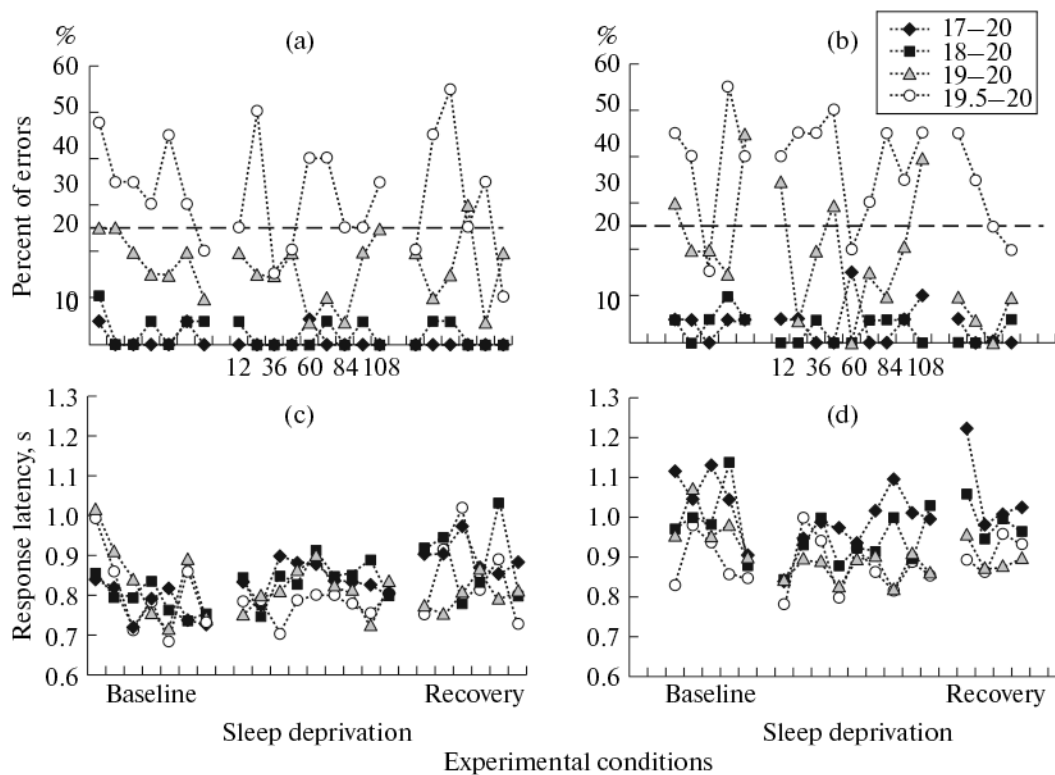
Fig. 1.
Percent of errors and response latency in fur seals when discriminating the larger of two circles under the baseline conditions, 108-h sleep deprivation and during recovery. A and B—seal no. 1, B and C—seal no. 2. Different markers signify an average for the given pair of circles (20–17, 20–18, 20–19 and 20–19.5 cm) in consecutive tests. Duration of sleep deprivation is shown in hours. The dotted line on the diagrams of the top row marks the error value of random response (25%, more than 5 errors out of 20 trails, binomial test—$p > 0.05$). The response latencies are given for the tests in which the larger circle was located to the right side from the seal.
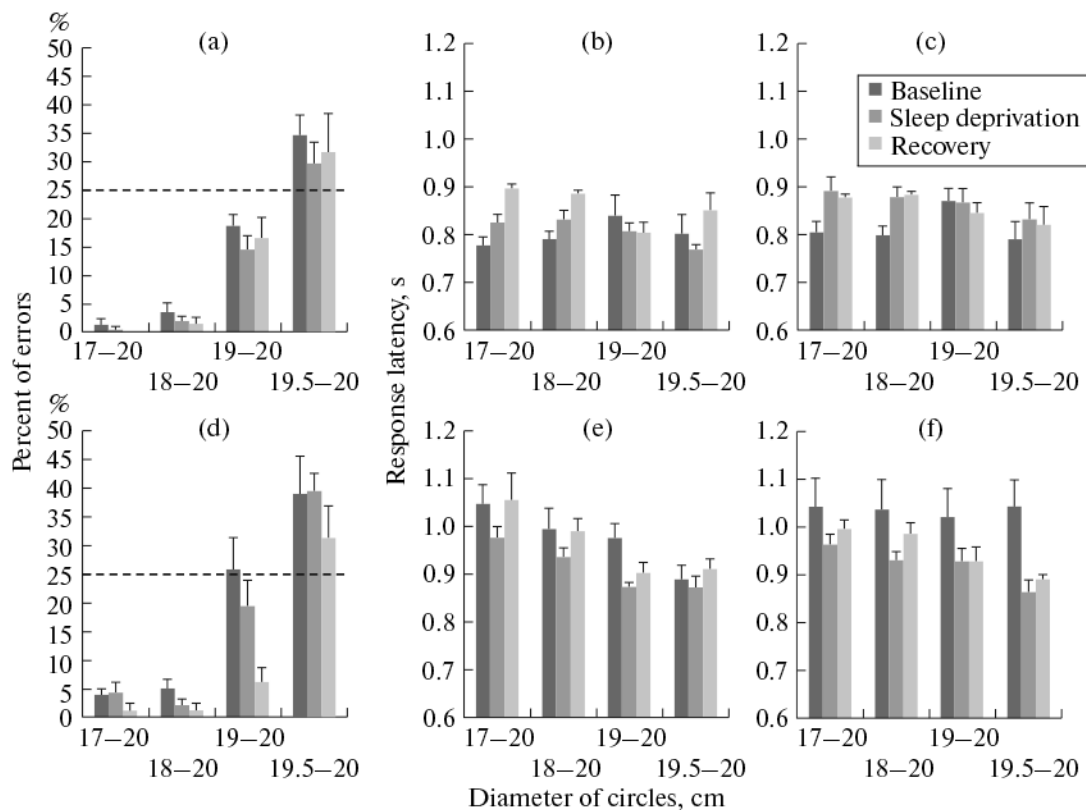
Fig. 2.
Mean percent of errors and response latency in two fur seals when discriminating the larger of two circles under the baseline conditions, 108-h sleep deprivation and during recovery. A, B and C—seal no. 1, D, E, and F—seal no. 2. The latency values are given separately for the tests when the larger circle was positioned to the right side (B and E) or left side (C and F) to the seals. The data are presented as mean $M \pm m$ standard error for each pair of circles for all tests under the baseline conditions, sleep deprivation and recovery. The dotted line marks the error value of random response.