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Sleep: Giving it up to get it on

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A new study presents evidence of sex-related sleep reduction in males of two marsupial mice species but not in females. The growing experimental data suggest that seasonal sleep reduction, linked to migrations and reproductive periods, is common among animals.

Sleep, or sleep-like states, have been proposed to be present in all animal species, from simple organisms to placental mammals[1]. An extensive amount of data suggests that sleep is important for various processes at the molecular, cellular, and systemic levels[2]. Several theories suggest that sleep has a restorative purpose[3], but no persuasive evidence for any such universal function

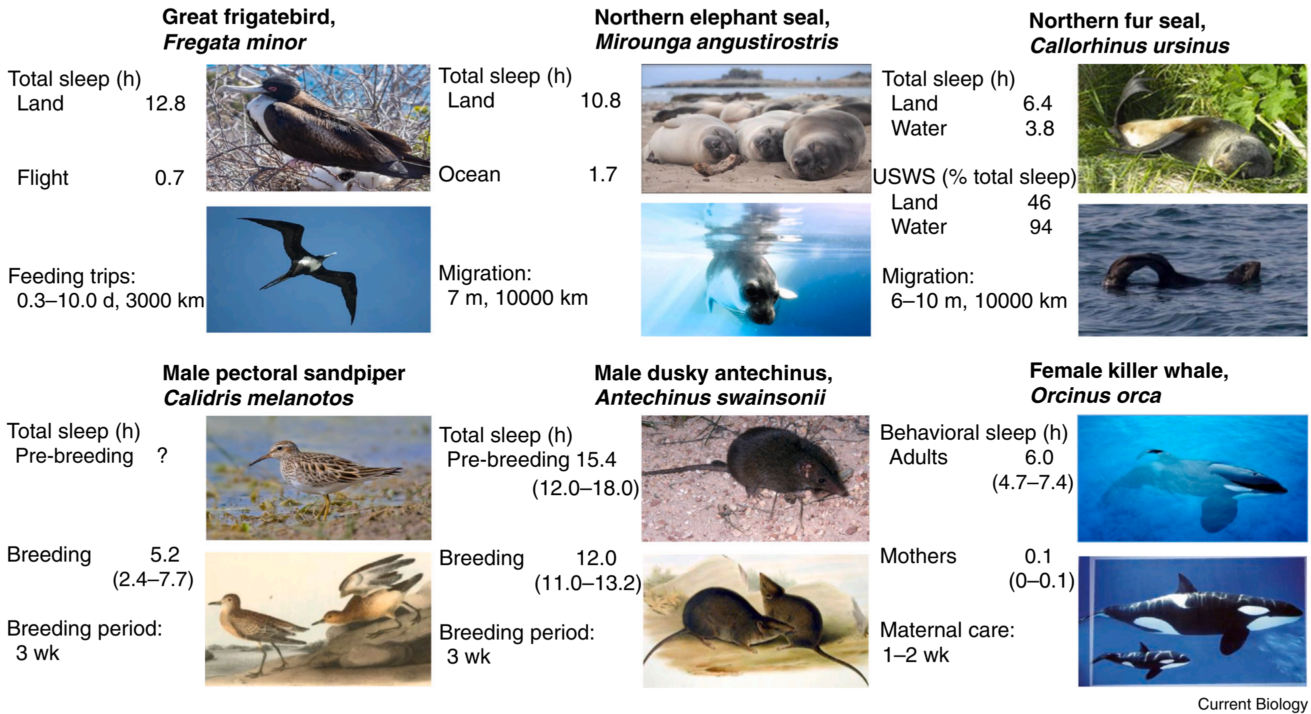

Figure 1. Sleep loss in animals.
Shown here are animals that exhibit adaptive sleep reduction or even loss during migrations and reproduction periods. Total sleep time is either average or median data, and the range for individual animals. Unihemispheric sleep (USWS) is percentage of slow-wave sleep. Additional details can be found in publications[6,8–10,16,19,20]. Image credits: great frigatebird in tree, © Nicolas Völcker/Wikimedia Commons (CC BY-SA 4.0 Deed); great frigatebird in flight, Tom Tarrant/Wikimedia Commons (CC BY 3.0 Deed); male pectoral sandpiper, Andreas Trepte/Wikimedia Commons (CC BY-SA 2.5 Deed); pair of pectoral sandpipers, J.J. Audobon (in public domain); northern elephant seals (beach), with permission from J. Kendall-Bar; northern elephant seals (ocean), with permission from J. Kendall-Bar; male dusky antechinus, I.R. McCann, Museum Victoria (CC BY 4.0 Deed); pair of dusky antechinus, M. Rawlinson, C. Accurso and K. Walker © Museum Victoria; northern fur seal (land), with permission from S. Korneva; northern fur seal (ocean), with permission from S. Artem'eva; killer whale (resting at surface), O. Lyamin; killer whales (pair), O. Lyamin.

has been reported[4]. A different view proposes that sleep is rather a state of adaptive inactivity that allows for a high level of responsiveness. Sleep reduces energy expenditure until changing conditions favor extended wakefulness. This view helps to explain the wide variability in the amount and patterns of sleep between species[4,5].

Recent advances in technology, such as portable recorders of electrophysiological parameters (electroencephalogram, electromyogram, electrooculogram, electrocardiogram), and motor activity (acceleration), offer the opportunity to study animal sleep under natural conditions. Three prior studies revealed remarkable examples of seasonal sleep reduction in wild animals (Figure 1). Male pectoral sandpipers (*Calidris melanotos*) remain active up to 95% of the time during the 3-week breeding period to compete for access to fertile females, resulting in more offspring for those who sleep less[6,7]. Great frigatebirds (*Fregata minor*) exhibit a pronounced over 15-fold reduction of sleep during nonstop flights over the ocean (of up to 10 days), averaging just 0.7 hours of sleep daily compared to 13 hours in their nests[8]. Northern elephant seals (*Mirounga angustirostris*) reduce sleep on average to one-fifth of baseline while in the ocean, managing only 2 hours per day over their 7-month migrations compared with 10 hours on land[9]. In all cases, the sleep reduction was followed by a modest increase in the amount of sleep or in the depth of slow-wave sleep. These studies demonstrate that certain species can seasonally reduce their sleep without any noticeable impact on their behavior or overall well-being.

In a recent issue of *Current Biology*, Zaid and colleagues[10] report on a sex-specific reduction in sleep during the breeding season in two endemic Australian marsupial mice: dusky and agile antechinuses (*Antechinus swainsonii* and *A. agilis*). Characterized by semelparity (having a single reproductive episode before death), their reproductive system, unusual among mammals, involves a brief 3-week breeding period. During this time, males engage in protracted copulations with multiple females. Males refrain from eating and subsequently face a high mortality rate. Females are intent on copulating with many fertile males during their short reproductive season and may give birth several times during their lives. Females bear 6–10 cubs sheltered in a skin fold for 3 months. The timed mating in Antechinuses ensures offspring weaning when abundant food, primarily insects, is available[11,12].

Using accelerometry, Zaid and colleagues measured the activity of male dusky antechinuses during the first 4 days of the reproductive period compared to the last 4 days of the pre-breeding stage. The animals were housed individually in a naturalistic environment. They found that reproductive males increased their activity during the breeding period, while female activity remained unchanged. The magnitude of the response in males correlated with the rise in testosterone. The authors speculated that activity in male dusky antechinuses activity may be affected by the lunar phase.

To determine whether increased activity in reproductive males reflects less sleep, the authors conducted an additional study using electroencephalography and accelerometry in a laboratory setup. They determined that the transition from waking to sleep in dusky antechinuses occurs very rapidly, typically within seconds, making the absence of movement a reliable criterion for sleep. Considering prior collected accelerometry data, the authors concluded that male dusky antechinuses reduce sleep during the breeding period (Figure 1).

Finally, the authors found a decline in oxalic acid levels over the breeding season in wild male agile antechinuses, but not in females. Based on the assumption that oxalic acid is a potential biomarker for sleep loss in mammals[13], it was concluded that in the wild, males of both antechinus species experience sleep deprivation during the breeding season.

This study of Zaid and colleagues represents another effort to learn more about sleep in the wild. The authors provide direct evidence of seasonal, sex-related sleep restriction linked to reproductive periods in a mammal, maximizing male performance.

In most mammalian species, the reproductive potential of males persists for multiple seasons. Marsupial mice of the genus *Antechinus* attracted attention because of their unusual reproductive cycle. The physiological costs of such a strategy are seemingly excessive, because of the high male mortality rate. However, it is unlikely that the reduced sleep duration in reproductive males of two antechinus species is unique because of their semelparity. During the breeding season, males of most animal species prioritize mating behaviors over other activities[14,15]. This cannot occur without a reduction in sleep duration and depth, with the extent of these changes varying due to the species' biological cycle and environmental factors. There is no doubt that this applies not only to males but also to females. Major sex-related behavioral features of sleep reduction are observed in cetacean mothers, which greatly reduce or eliminate preferred sleep behavior for weeks after giving birth to calves (Figure 1)[16,17].

The primary findings in male dusky antechinuses and in pectoral sandpipers[6] exhibit notable similarities. However, the extent of sleep reduction in breeding marsupial mice was considerably less, with the remaining sleep, as estimated by activity level, ranging between 45 and 55% of a 24-hour period. The lesser effect in marsupial mice could be attributed to male separation, differences in reproductive strategies between mammals and birds, environmental factors, or the analysis procedure.

According to the homeostatic theory of sleep regulation, a decrease in sleep time should be followed by a subsequent compensatory increase[18]. In male dusky antechinuses a high activity level continued after the reproductive period ended, suggesting no evidence for 'sleep rebound'. It is possible that the reduction in sleep in breeding male dusky antechinuses was compensated for by an increase in sleep depth, similar to the case of male pectoral sandpipers. Among these birds, individuals that slept the least exhibited deeper sleep, as indicated by electrical brain activity[6]. However, such changes could not be determined in dusky antechinuses based on accelerometry measurements. An additional factor contributing to the reported sustained activity in the male dusky antechinuses could be the lack of clear boundaries between the analyzed periods.

An interesting finding of this study is that only 2 out of 10 studied males of dusky antechinuses died at the end of the breading period, and they were not the ones that experienced the greatest loss of sleep. As correctly pointed out by the authors, the males' deteriorating condition seemed to be triggered by factors beyond the reduction of sleep duration. This serves as a good example where the temporal alignment of events does not imply a causal connection between them, as may occur during sleep deprivation experiments with frequent awakenings of subjects leading to negative consequences for the animals' health and waking performance[5].

The sleep reduction in breeding male Antechinuses and pectoral sandpipers was generally less pronounced compared to that observed in migrating frigatebirds and in northern elephant seals. Another notable example of sleep reduction associated with feeding behavior is northern fur seals (*Callorhinus ursinus*). Their migration trips are comparable to those of elephant seals, both in terms of duration and distance traveled. In the water, northern fur seals exhibit unihemispheric sleep[19,20], so the sleep time in each hemisphere throughout the entire migration period may be half as much as on land (Figure 1). Thus, in these studied species, the magnitude of sleep reduction associated with migratory behavior was markedly greater than that associated with reproductive behavior.

The current data suggest that seasonal sleep reductions, associated with periods of migrations and reproduction, are widespread among animals. From an evolutionary perspective, such sleep reductions are advantageous. Extended and more efficient feeding builds vital reserves and improves overall fitness and health, while increased activity correlates with reproductive success. Balancing the evidence that supports the need for sleep with the growing experimental data on adaptive sleep loss is an exciting challenge. It is particularly interesting to understand the mechanisms that enable animals to sustain reduced sleep and uphold waking performance.

DECLARATION OF INTERESTS

The authors declare no competing interests.

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