Penguins snatch seconds-long microsleeps

Christian D. Harding[1] and Vladyslav V. Vyazovskiy[2,3,4]

1. Division of Pulmonary, Critical Care, Sleep Medicine and Physiology, Department of Medicine, University of California San Diego, La Jolla, CA, USA.

2. Department of Physiology, Anatomy and Genetics, University of Oxford, Oxford, UK.

3. Sir Jules Thorn Sleep and Circadian Neuroscience Institute, University of Oxford, Oxford, UK.

4. The Kavli Institute for Nanoscience Discovery, University of Oxford, Oxford, UK.

Email: vladyslav.vyazovskiy@dpag.ox.ac.uk

Considerable research efforts have been committed to understanding the fundamental biology of sleep. Yet, this knowledge is mostly derived from lab-oratory studies undertaken in a handful of model organisms, such as mice, rats, and fruit flies, and in conditions that are vastly different from those where sleep evolved. Studies of nonmodel organisms in natura may help elucidate functions of sleep but this is still largely unchartered territory and presents numerous challenges—from unconventional anatomy and physiology to distinct ecological specialization and environmental influences. On page XXX of this issue, Libourel et al. (1) report an unusual pattern of frequent short bouts of sleep in wild chinstrap penguins (Pygoscelis antarcticus), which calls into question not only the current understanding of how sleep architecture is regulated but also the extent to which it can be altered before the benefits of sleep are lost.

Sleep seems to be ubiquitous in the animal kingdom and is defined by features such as lack of movement and relative loss of ability to sense and respond to the environment (2). Although the environment thus plays a critical role in the very definition of sleep, it has traditionally been considered relevant only because it can be standardized to enable studies into endogenous mechanisms or "drives" for sleep—which are thought to reflect primary biological need—unspoiled by noisy environments. The limitations of this approach are made clear when species are studied in naturalistic conditions. Predation risk, lighting conditions, seasons, reproduction, food availability, temperature, and social environment all influence the diurnal dynamics and architecture of sleep both across species and across time within an individual (3–10).

Libourel et al., implanted electrodes for recording electrical activity in the brain [electroencephalogram (EEG)] and neck muscles [electromyogram] as well as an accelerometer to capture position information in freely roaming and nesting chinstrap penguins in the Antarctic. They also used noninvasive sensors to monitor location and ambient temperature. Combined with continuous video monitoring and direct observations over multiple days, the authors were able to identify periods of sleep in penguins that showed a number of notable peculiarities. Bouts of sleep were defined primarily as transient increases in EEG slow-wave activity, occurring both bilaterally and unilaterally. The latter was weakly correlated with contralateral eye closure, as has previously been described in birds (8). Penguins nesting at the periphery of the colony slept in a more consolidated manner and engaged in what the authors referred to as a deeper sleep. Notably, contrary to the conventional understanding of sleep, penguins did not engage in prolonged, consolidated periods of sleeping. Instead, the birds were observed to nod off frequently, accumulating more than 11 hours of sleep per day in thousands of brief epochs that lasted only 4 s on average and are therefore called "microsleeps."

The data reported by Libourel et al. could be one of the most extreme examples of the incremental nature by which the benefits of sleep can accrue. Although sleep bout duration is sensitive to many variables and differs widely among species, the seconds-long microsleeps of chinstrap penguins are markedly brief. Proving that sleeping in this way comes at no cost to the penguin would challenge the current interpretation of fragmentation as inherently detrimental to sleep quality.

The findings also provide strong evidence for the adaptation of sleep architecture to extreme environments. Penguins sleep in large, noisy colonies, where they are constantly bombarded by stimulation from movement and sounds produced by coresidents. They are also under surveillance by brown skua (Stercorarius antarcticus)—predatory birds that feed on the eggs and chicks of penguins. Sleep is, by definition, incompatible with the vigilance required to protect the nests. If it can be determined that penguins are less responsive to environmental stimuli during microsleeps, as normally occurs during sleep, then the constant switching between wake and sleep may be a strategy that penguins have evolved to balance sleep and vigilance requirements. An alternative interpretation for this switching is that the birds are experiencing interrupted sleep—an unintended and perhaps unwanted consequence of their boisterous social surroundings. Sleep within a colony is therefore likely to occur in a piecemeal fashion, where, at any given moment, some birds are asleep and others awake so that the entire colony is always half-awake and half-asleep—similar to the idea of “corporate vigilance” in doves (11).

That Libourel et al. observed longer bouts and deeper sleep in birds on the periphery of the colony argues against the hypothesis that locally increased predation risk results in less consolidated sleep. This interpretation of the data is contingent on a number of factors. Although brown skuas are assumed to be the main threat to the penguins, some dangers, or simply disturbance, might arise from inside the colony—for ex-ample, noise or risk of theft of nest material by other penguins. It should be added that “sleep depth” is a widely used but somewhat questionable metaphor because objective and subjective measures of sleep depth can be dissociated, and the relationship of sleep depth with brain activity is not straightforward (12). Another interpretation is that birds at the periphery do need to be extra vigilant, resulting in their awake state being of higher “intensity,” which in turn requires more-intense recovery sleep (13).

With the advent of modern techniques that dissect the contribution of specific brain circuits to sleep oscillations and local and global control of sleep, elucidating the neurophysiological substrate of sleep has become a focus of sleep research. However, most of the progress made in this area has come from mammals, and knowledge of sleep-wake–controlling circuitry in birds remains in its infancy. Given the distinctive structure of the brain in birds, the basic organization of arousal- and sleep-promoting networks is likely to be fundamentally different. Therefore, the frequent alternation of wake and sleep observed in chinstrap penguins has important implications for the understanding of sleep control in general. For example, instability of sleep-wake states in mice has been linked with malfunction of the orexinergic system, such as in narcolepsy (14), and in humans, conditions that fragment sleep, such as sleep apnea, may have major consequences for cognitive function and possibly even precipitate the development of neurodegenerative disease (15). Thus, what is abnormal in humans could be perfectly normal in birds or other animals, at least under certain conditions.

Any observations made regarding sleep will reflect not only hard-wired species-specific genetically determined features, but also the immediate role of the environment and other ecological and physiological needs. Therefore, not considering context will bias interpretation. For example, microsleeps in penguins may be an extension of previously observed seasonal changes in sleep duration among birds (8), present only when penguins are nesting and caring for their young. The wider and crucially important implication of this role of context is that data on molecular or neurophysiological substrates of sleep derived from a typical laboratory experiment may not be reproducible if repeated in other, nonstandard conditions, such as at thermoneutrality, in a more naturalistic social setting, or simply when the animals can choose their environment. Studies like that of Libourel et al. reveal underappreciated flexibility in sleep phenotypes, which can, in turn, inform traditional laboratory studies.

Climate change and human activities are applying increasing pressure on natural habitats, thereby altering ecosystems, and light pollution and noise are affecting the amount and the quality of sleep in wild animals. Therefore, sleep studies in the wild are also crucially important in the context of conservation. Although there will always be ethical and ecological concerns associated with research in wild animals, conscientious and well-constructed studies, such as that of Libourel et al., are the best way to exploit opportunities to study sleep in wild animals free from human influence while it is still possible.

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