From Giants to Jellyfish: The Evolution of Sleep Across Species

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AGAINST ALL ODDS

The basis of evolution is rooted in trial and error. "Survival of the fittest" is a well-documented phenomenon in which individuals of a species exhibiting more advantageous traits are more likely to survive and reproduce than those exhibiting weaker traits. And yet, this hardly seems to explain a massive anomaly in biological behavior, sleep. If evolution relies on exterminating traits that hinder survival, then it leaves many scratching their heads when we apply it to our most defenseless state.[1,2]

There have been advances in sleep science in recent years, but many of its functions still remain a mystery. Although there has been a recent uptick in our understanding of it—including the stages of sleep and how they link to cognition—the nature of sleep initially seems to go against all logic.[1,2] Sleep forces us to enter a state of complete vulnerability to predation or natural exposure, and it inhibits us from otherwise productive acts that would benefit our survival. It would then seem that after many millennia of evolution, we would have outgrown this seemingly detrimental trait. After all, it seems absurd to spend one-third of our life in this unresponsive state. Yet, we see sleep in every single lifeform, from worms to whales to elephants.[1,2,3]

Though scientists still have yet to fully understand sleep, its prevalence across species points to some fundamental need. As we probe into this need, the architecture, as well as the similarities and differences between species' patterns of sleep, comes into focus.

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IF IT WALKS LIKE A DUCK AND SLEEPS LIKE A DUCK

To say that every living thing sleeps is a bold claim, as naturally, some species do not seem to fit the bill. How do marine mammals sleep if they must constantly come up for air? What does an insect's sleep even look like?

With current technology, it is easy to discern when a *human* is asleep or awake—and even how *deeply* they are sleeping. In laboratories, sleep scientists subject humans to polysomnography (or PSGs), which measure brain activity, eye movement, and muscle tone.[1,3]

However, non-human animals are not always the easiest laboratory subjects, as in the case of insects. Instead of measuring their physiological traits, sleep scientists rely on observing insects' behavioral states in order to identify if an animal is asleep or not. Though sleep varies across all species, it is possible to confidently claim that an animal is sleeping by recognizing a series of criteria. First and foremost, an animal will be immobile. Secondly, their responsiveness to stimuli is suppressed. Thirdly, and most importantly, with enough external stimuli, this behavioral state of unresponsiveness will be reversed. This last criterion is crucial because it is what separates sleep from death.[2] Some sleep scientists use far more criteria to discern whether an animal is asleep, as seen in Figure 1.

Setting the standards for what counts as sleep allows scientists to more easily delineate the evolution of this behavioral state. To find out why we all sleep, it is important to figure out what counts as sleep—as well as when and where it originated. As Stanford neurobiologist Dr. Philippe Mourrain says, "As we define more and more what sleep is, we

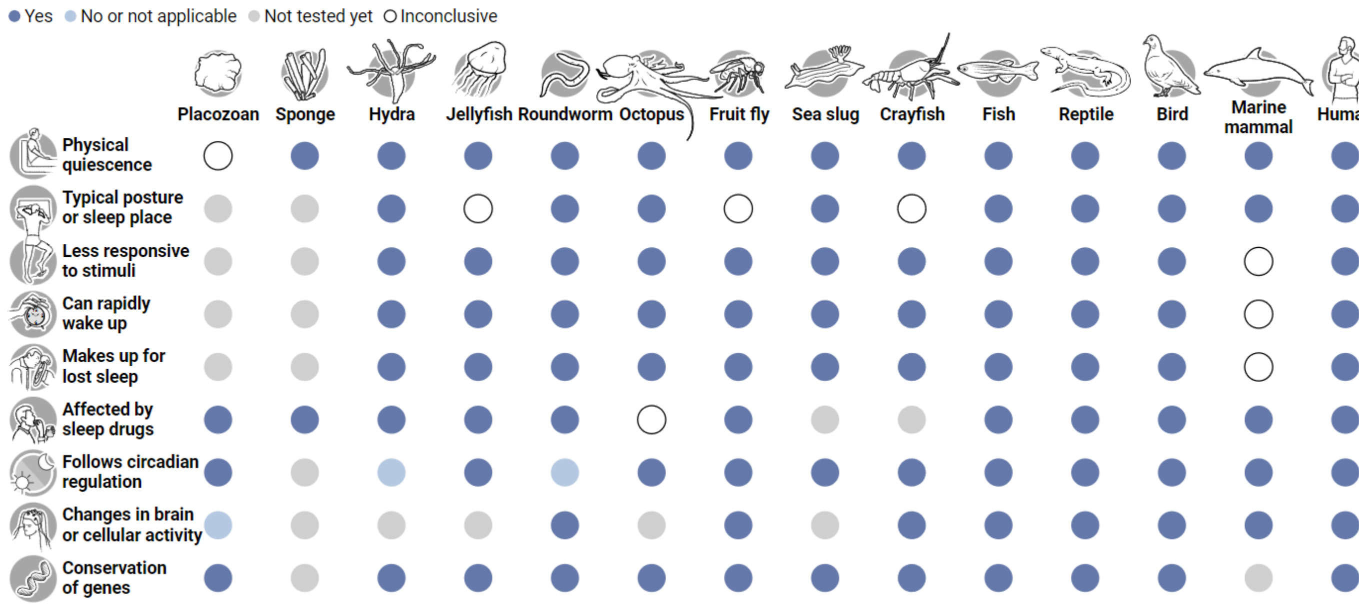

Figure 1: Characteristics of Sleep Among Species. Scientists can get very specific in their criteria to classify an organism as sleeping.

will have an idea of its function."[3]

WHEN THE WORLD WENT TO SLEEP

Worms do not sleep exactly like humans. In fact, they only do so at specific stages in their development, entering each sleep-like state as they transition from one larval stage to another.[4] But even with this remarkably different form of sleep, the fact is that worms become immobile, their responsiveness to stimuli is suppressed, and this non-responsive state is reversible. Worms, like all other lifeforms, sleep.

Emerging at least 500 million years ago, worms predate all vertebrate life.[1] Some sleep scientists use these animals as our earliest point of reference for sleep in evolutionary trees. Adopting this perspective, we can conclude that sleep, at its latest, emerged from worms about half a billion years ago.

However, this is simply one outlook on the origins of sleep, one that zeroes in on early lifeforms *with* a central nervous system. Among the growing sleep research in animals, sleep has even been observed in animals without a central nervous system, such as jellyfish.[5,6] Researchers at the University of California, Berkeley and California Institute of Technology have found that jellyfish display "sleep-like" behaviors, including slowed movement at night and the ability to be roused from this state with some effort.[5] This new information recontextualizes sleep entirely, dating it back almost 1 billion years. It also brings into question what benefit sleep serves a lifeform without a brain. Researchers hypothesized that perhaps sleep has a metabolic component enabling certain biochemical reactions crucial for life to take place that otherwise could not occur during wakefulness, highlighting the significance of sleep itself.[2,5]

This knowledge poses another crucial question as to what came first: sleep or the brain? An ongoing hypothesis in sleep science is that sleep was actually animals' original state of being, and wakefulness—alongside the brain—emerged later in the evolutionary tree.[1,2]

NOT ALL SLEEP IS CREATED EQUAL

As seen in the case of jellyfish and worms, the form in which sleep manifests varies across all animals. In fact, it even varies radically between mammals. While humans, on average, require eight hours of sleep per night, elephants only need four. Compare that to bats, who are only awake for five hours a day. Even within the rodent family, each species has varying sleeping habits.[1]

Sleep scientists have long attempted to identify a logical pattern explaining the variations in sleep, aiming to determine some rule that explains why one organism requires more sleep than another. One hypothesis is that the more complex the brain is relative to body size, the longer an animal will sleep, but this is inconsistent with present data. For example, rats and opossums weigh around the same, and yet opossums sleep around 50% more than rats.[1]

As it stands, we can assume that sleep habits depend on a wide variety of factors, such as diet, the number of predators and prey

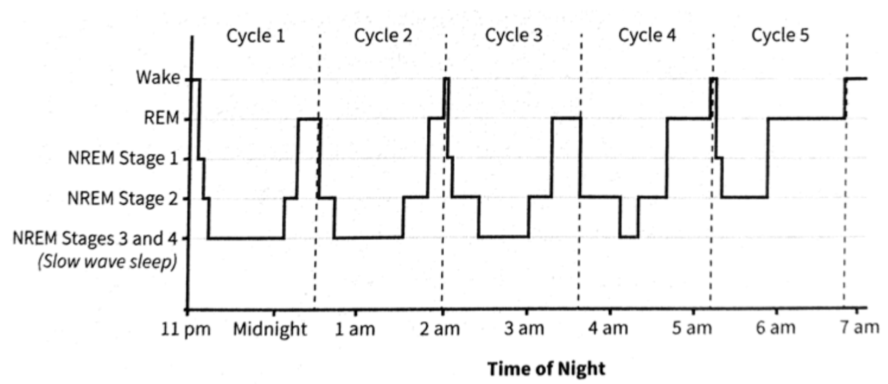

Figure 2: The Architecture of Sleep. Humans go through different stages of sleep throughout the night, ranging from REM to stages 1 through 4, and even with some scattered waking moments. The higher the stage is, the "deeper" the sleep. These stages cycle through each other in periods of about 90 minutes.

in a habitat, metabolic and nervous systems, and more. An experiment underscored the influence of diet on sleep by comparing the sleep patterns of ducks who naturally foraged and ducks who were provisioned food. The ducks that did not have to forage slept less, suggesting that foraging increases sleep need.[2] This is one way in which ecological factors shape sleep, stressing the likelihood that evolution has whittled down the forms of sleep in species to best serve them and their unique needs.[1,2]

Because each human has different needs, sleep may appear unique from person to person—or even from night to night. In the past half-century, there has been a surge in our understanding of sleep, including the discovery of sleep *stages*. There are five sleep stages that can be observed physiologically using polysomnography, which involves measuring electrical activity in the brain, eye movements, and muscle movements. One stage of sleep is called rapid eye movement, or REM sleep; in this stage, the eyes make sharp horizontal movements. Then, stages 1 through 4 are generally known as NREM or non-rapid eye movement.[1,2]

REM sleep is a rather peculiar stage during which brain activity closely resembles wakefulness. However, the body becomes paralyzed, presumably because this is also the stage when dreaming primarily occurs—and our brain does not want us acting out our dreams.[1]

There is substantial evidence that REM sleep is critical in humans for the consolidation of memories, where they are assimilated and stored into an established network of knowledge (though NREM also helps in processing memory). REM sleep may also serve a large role in our ability to abstract patterns and reveal solutions to situations previously unsolved.[7] It seems there is merit in the idea that you should sleep on a problem.

However, as crucial as REM sleep is to humans' cognition, it is interesting to see where REM sleep appears in other species. The only classes proven to exhibit REM sleep are mammals and birds. However, these two classes evolved separately from one another, proving that REM sleep has independently manifested twice throughout evolutionary history.[1,8]

Furthermore, with its links to higher cognition in humans, this evolutionary model potentially frames REM sleep as a key to more efficient mechanisms in animals with highly complex brains.[8]

SLEEP'S EVOLUTIONARY TRAJECTORY

Narrowing in on the evolution of sleep within humans, there are clear indicators that our habits have been molded by our physical and social environments. From modernization alone, our sleep behavior has become vastly different from what it was in pre-industrialized periods.

Scientists observed sleep habits across the Hadza, San, and Tsimané groups: three pre-industrialized societies that did not have access to artificial lighting and were completely dependent on hunting and gathering for food. Observations gleaned from their lifestyles point to how industrialized societies have forced us to depart from our more natural behaviors—behaviors that remained intact in these societies.[9]

For instance, the San and Tsimané groups live far enough from the equator to have varying durations of sunlight during different seasons. In both groups, the participants slept nearly an hour longer in the winter than they did in the summer. Another crucial difference seen in these tribes was the fact that they regularly napped in the middle of the day. We all naturally experience a dip in alertness during the midafternoon, which is hypothesized to be when humans are biologically wired to have a short period of sleep. These pre-industrialized societies reassert this claim, leading us towards the conclusion that modernized societies simply pressure humans to suppress this natural urge to nap.[9]

These behaviors indicate that pre-industrialized societies' sleep patterns are far more natural to humans. It is reasonable then that there is not even a word for "insomnia" among these tribes. Once the concept was explained to them, scientists found that the proportion of tribal people who experienced insomnia was far lower than the 10–30% chronic insomnia rate reported in industrial societies.[9]

The differences between these tribes and our modern societies reveal our evolutionary trajectory. As we introduce new environmental factors and promote different sleep behaviors, humans continue down a path of reshaping our sleep patterns. Although the differences in sleep patterns among animals are vast, the similarities underscore the importance of sleep.

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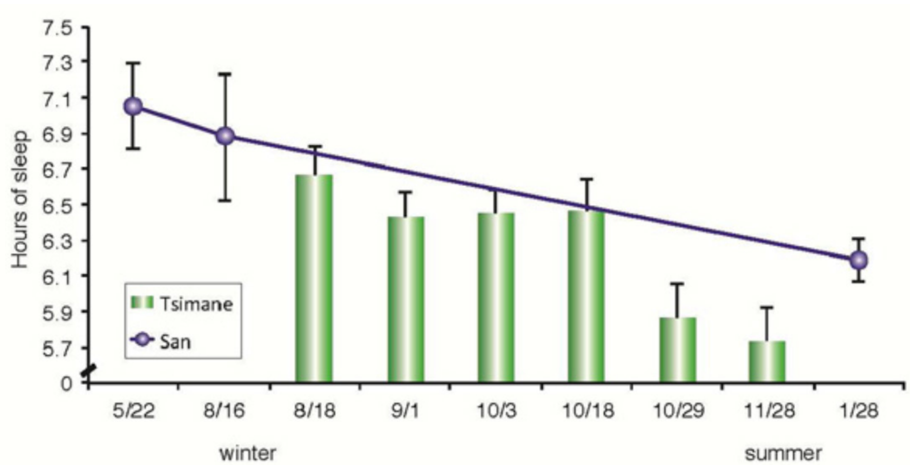

Figure 3: Duration of Tribespeople's Sleep Across Seasons. This graph shows the amount of sleep the tribespeople averaged overnight in different seasons. In the winter months, they slept longer than they did in the summer months, highlighting their dependence on sunlight to determine the length of their sleep.

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IMAGE REFERENCES

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