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Sophisticated sleep improves our brains

Our advanced cognitive and social skills might derive from the evolution of improved sleep quality; today, sleep therapy could help with mental health issues and learning

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In the past decades, sleep researchers have been quietly accumulating knowledge about the physiology of sleep. Without any real health application for this knowledge, however, the public and the press have slept blissfully through most of their breakthroughs. Yet, recent findings about the evolution of sleep in humans and the effects of sleep disruption on human health seem to have finally woken the public up. A recent paper from David Samson and Charles Nunn, evolutionary anthropologists from Duke University in the USA, puts forward the hypothesis that humans have evolved more efficient sleep patterns than other primates and that this is because "[e]arly humans experienced selective pressure to fulfill sleep needs in the shortest time possible" [1]. This efficient slumber, the authors argue, might have contributed to setting our ancestors on the evolutionary path toward human civilization. *The New York Times*, among other newspapers, covered the publication, which follows in the wake of research indicating that human sleep patterns have stayed largely stable during the course of human evolution, from hunter-gatherers to modern city dwellers [2]. Both of these insights provide evolutionary context for the health impact of too little sleep, with both epidemiological and clinical research showing that sleep disruption has a negative effect on health and well-being. More recently, however, there is evidence that sleep has distinctly positive therapeutic potential to treat a variety of phobias and other psychotic conditions.

The evolutionary study that attracted media attention raises interesting questions about the co-evolution of sleep and human cognitive faculties. Samson and Nunn suggest that sleep became subject to strong selective pressures—"including increased predation risk [...] threats from intergroup conflict, and benefits arising from increased social interaction" [1]—when our ancestors moved down from the trees and onto the savannah. As a result, the authors find that "humans are more efficient in their sleep patterns than are other primates, and that human sleep is shorter, deeper, and exhibits a higher proportion of REM than expected". In other words, by sleeping deeply for around 7 hours a night, early humans had more time for productive and social tasks during the waking period and could develop and sustain more advanced cognitive and manipulative abilities.

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"Deeper stage sleep is associated with cognitive benefits such as memory consolidation and processing of emotional valence (judgement or attitude), but at the [cost] of being vulnerable to one's sleep environment", Samson explained. "This vulnerability would have been life threatening in the wild, if not for early humans living in larger groups, controlling fire, [...] as well as sleeping consistently on stable, terrestrial sleeping surfaces. All these elements working together could have removed previous barriers in attaining the kind of high-quality sleep humans are characterized by today".

Sleep in most warm-blooded vertebrates occurs in two principal distinct phases: REM (rapid eye movement) sleep and non-REM (NREM) sleep that are distinguished in a number of ways including changes in cortical electrical activity. Based on an analysis of sleep patterns and the timing of REM sleep in many mammalian species, Samson and Nunn conclude that evolution appears to have taken multiple directions as far as sleep patterns are concerned. "There is incredible variation in sleep ecology and sleep architecture across mammals", Samson said. "For example, giraffes only sleep 4.6 hours a night, and the platypus has more absolute REM per night than humans. I believe this illustrates the importance of controlling for phylogeny (evolutionary relationships) and other variables that are known to influence sleep and keeping analyses limited to the phylogenetic order in question, in this case, primates". Within primates, sleep duration tends to correlate with two key measures: overall physical size and interbirth interval, according to Samson. Mouse lemurs, for example, sleep for 17 hours a day, whereas a chimpanzee sleeps just under 10 hours. Similarly, animals with a larger interbirth interval tend to sleep less: When predation pressure is high, animals cannot afford to sleep so long.

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It seems that humans have broken these rules. As Samson noted, humans sleep far

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less than their size would predict; in fact, the average of 7 hours for humans is less than for any other primate species. The changes that allowed sleep duration to be reduced so much in humans probably include an increased proportion of REM sleep, although Samson commented that the precise benefits REM remain an open question. "I think there is more evidence to support REM's role as important to human cognition than there is to reject it", he said, acknowledging that there is evidence both for and against the importance of REM. "To be clear, a test that would convince me that REM is not as important as we think to cognition would be a meta-analysis that showed the distribution of studies that either support or reject the idea that REM is a critical factor".

There has also been a great deal of interest in whether sleep patterns have changed in the modern era, stoked by concerns that the stresses of modern life and artificial lighting are disrupting sleep patterns with a detrimental impact on health and quality of life. A team of American and South African researchers set out to test this hypothesis by investigating the sleep patterns of 94 individuals from three contemporary hunter-gatherer populations: the Hadza of Tanzania, the San of Namibia, and the Tsimane of Bolivia [2]. These groups were selected for being geographically and genetically distinct, while still living much as their ancestors had done for thousands of years.

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Based on 1165 days of data, the authors found that, despite differences in detail, all three groups had sleep patterns similar to one another and, importantly, to those of people in developed countries, at least in duration. They did note, however, that there was less incidence of insomnia—and probably other sleep disorders—along with greater seasonal variation in sleep duration such that the hunter-gatherers got about an hour more sleep during the winter. "The surprising finding was not that they slept less, but rather that they clearly did not sleep much more than we do", said Jerome Siegel, joint lead author and Director of the Centre for Sleep Research at UCLA in the USA. "Some had speculated that electricity had greatly decreased sleep time and that we evolved to sleep when it was dark. However, on average hunter-gatherers went to sleep 3.3 hours after sunset and none of them went to sleep when it got dark. In most, but not all, cases they also awakened before sunrise".

Siegel highlighted the link between sleep and environmental temperature as the most important finding: "Hunter gatherers slept through the coldest portion of the night and awakened at the temperature nadir around dawn". The team found that strong vasoconstriction occurred at the onset of waking in both summer and winter and concluded that this acted to stimulate thermogenesis in raising the brain and core temperature. The study also confirmed the circadian aspect of sleep linked to the day/night cycle, since virtually all sleep occurred during darkness, but that this rhythm is somewhat overridden by seasonal variations owing to temperature, rather than light. This supports the theory that sleep may be linked to conservation of energy to reduce thermogenesis at the coolest times of night.

Another notable finding was that the hunter-gatherers organize their daily activities to get maximum exposure to light in the morning, rather than at noon when the sun is strongest, which is also consistent with the idea that behavioral thermoregulation operates to avoid the heat of the day. The authors speculated that this might explain the greater effectiveness of morning light in treating clinical depression, since it would restore the evolved pattern of human exposure to light.

There is mounting epidemiological support that prolonged disruption of the sleep cycle is detrimental to health. In humans, the evidence to date is largely correlational, in so far that people who regularly work night shifts appear more prone to a variety of conditions, including cancers, obesity, and type-2 diabetes. One of the biggest studies to look at this link followed almost 75,000 registered US nurses over 22 years and was published early last year [3]. It found that mortality especially from cardiovascular diseases (CVD) was 11% higher for women who had worked more than 5 years of rotating night shifts compared with the general population. The risks increased with time: CVD mortality rose to 19% among those who had worked rotating shifts for 6–14 years and to 23% after 15 years or more. Nurses who had done shift work for 15 or more years also had a 25% higher risk of lung cancer, but no elevated risk for other cancers. "Given that it is correlational evidence, however, one cannot exclude an unknown co-varying factor that is truly causal", said Michael Hastings, joint head of Neurobiology at the UK's Medical Research Council of Molecular Biology in Cambridge. "With that caveat, the data is pretty strong and well supported by shorter-term experimental studies in mice and humans". Hastings cited a recent study by a team in the Netherlands as experimental proof that circadian or body clock disruption can accelerate the development of breast cancer in mice [4].

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The key insight from the Dutch study is that rotational shift work constantly disrupts the balance between different circadian clocks in the body, according to Gijsbertus van der Horst from the University Medical Center in Rotterdam, the Netherlands, and corresponding author of the paper. "The central circadian clock in the suprachiasmatic nuclei (SCN) in the brain is kept in phase with the light-dark cycle by light, or photo-entrainment, and in turn synchronizes peripheral clocks in virtually all other cells and tissues", van der Horst explained. "In the case of shift work, we deliberately choose to remain awake and stay active at times of the day when our body clock tells us to sleep", he continued. "During shift work, in contrast with a jet lag situation, the light-dark cycle remains unaltered, and as light is the most important Zeitgeber [external cue] for entrainment, the central SCN clock does not shift. On the other hand, as peripheral clocks, but not the central SCN clock, can be entrained by food, the altered eating times during shift work are likely to shift the peripheral clocks and cause a jet lag-like situation in peripheral tissues".

But van der Horst also noted recent work [5] that suggests that the impact of rotating shifts can be reduced if they run forward rather than backward, because the human internal clock runs at around 25 hours per day. He added that more work on animal models is needed to resolve the long-term health impacts of shift work, taking account of individual factors such as chronotype.

Whatever the negative health impacts of lack of quality sleep, the positive benefits of good sleep could be used therapeutically to help people heal. Because sleep plays a crucial role in consolidating memories of various types, it could be used in the treatment of mental disorders, in particular anxieties, phobias, or post-traumatic stress disorder (PTSD).

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During sleep, memories are reactivated in the hippocampus, the medial region of the brain that plays a crucial role in the consolidation of memories from short- to long-term storage. This has inspired recent research into whether memory consolidation during sleep can be manipulated by providing cues, such as sounds or smells, related to the events that initiated the memories. This is known as targeted memory reactivation (TMR), in which subjects memorize something while awake in association with a sound cue, which is replayed during subsequent NREM sleep.

Behavioral neurobiologist Jan Born, from the University of Tübingen in Germany, conducted one of the first comprehensive studies into this possibility. Born compared memory cueing during wakefulness, NREM sleep and REM sleep for declarative long-term memories that store facts, words, and events, and procedural memory that enables tasks or actions that require coordination and involve sequences of movements or manipulations [6]. As a cue, Born's team issued an odor while the subjects were performing the tasks or receiving the facts to be memorized. Later, the subjects were again exposed to the odor during wakefulness, REM, and NREM sleep. Born's team found that re-exposure to the odor improved the retention of declarative memories, but not of procedural memories, and only during NREM sleep. The study confirmed the role of the hippocampus in this process, as earlier FMRI (functional magnetic resonance imaging) studies had shown that odor re-exposure during NREM sleep causes a significant activation in the hippocampus, correlating with the consolidation of declarative memories.

"Sleep can also protect newly formed memories from "interference" by other activities."

Born's study has since been followed by others, and he himself is involved in a recent paper suggesting that sleep can have a profound impact on retaining spatial memories in children. This kind of sub-category of declarative memory becomes more sophisticated during brain development to enable ever more complex feats of navigation such as map reading, following directions and remembering how to get to a place previously visited. Born thinks that spatial memory in children is predominantly egocentric—that objects are encoded with reference to the person's own position—while most adults have developed allocentric memory, in which object locations are remembered with reference to each other. "Our hypothesis is that children tend to organize space around their own movement", he said. "But we have evidence, as yet unpublished, that after sleep, children are able to organize space in a more allocentric way, which is the normal adult way". Such findings could have interesting implications for learning and possibly treating people with a spatial memory deficit.

Another crucial point from the earlier FMRI studies and confirmed by recent work is that different neural networks are activated during memory consolidation when people are sleeping compared to when they are awake and that this varies between memory categories. "In declarative memory, sleep helps involve neural networks outside the hippocampal area", Born explained. This is known as system conjugation: bringing together different areas of the brain to consolidate declarative memories without physical strengthening of individual syntactical connections, but more through the establishment or recruitment of existing neural network regions. According to Susanne Diekelmann, also from the University of Tübingen, these processes enable sleep to do more than just consolidate memories that have just been learned; they also prepare the brain for subsequent cognitive activity and learning, which is perhaps why "power napping" can work well in some people. Sleep can also protect newly formed memories from "interference" by other activities [7]. As Diekelmann commented, the insight that newly formed memories are more susceptible to loss or disruption from other cognitive tasks before sleep than afterward further reinforces the idea that sleep stabilizes memories.

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These insights could have therapeutic potential in various ways. "Basically all treatments that are related to any kind of new learning might benefit from sleep, for example motor rehabilitation after stroke", Diekelmann said. "Different forms of psychotherapy might particularly benefit from sleep interventions, considering that psychotherapeutic treatments often include a re-learning of non-adaptive behavior or changing maladaptive traumatic memories". Diekelmann said that this approach seems to work particularly well for treating arachnophobia by exposure therapy reinforced by sleep. She highlighted a recent successful study in which 40 arachnophobes were subjected to a session of virtual reality exposure to large spiders with some then sleeping for 90 minutes and others kept awake [8]. The sleep group reported significantly reduced fear when approaching a live spider a week later. The authors conclude that sleep could increase psychotherapeutic effectiveness, possibly by strengthening new non-fearful memory traces.

Such findings suggest that sleep also plays an important role in mediating fears and anxieties, quite apart from other cognitive and memory-related activities. Future research may elucidate more clearly the roles of different forms of sleep for all these activities, but it is already clear that the sleep/wake cycle is not a binary experience, but that each state contains shades of the other. Moreover, there is plenty of evidence from very different fields of research that sleep is crucial for both mental and physical health. Given the stresses of modern life, a stronger focus on understanding the role of sleep and improving its quality should have a dramatic impact on health and maintaining a healthy work/life balance.

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