Unveiling the Mysterious World of Animal Dreams

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Often deemed a black box resistant to scientific examination, the human mind challenges empirical inquiry—particularly in subjective experiences like dreams. However, objective empirical measures can indeed be applied to such phenomena. While there has been notable progress in understanding human dreams, the domain of sleep and dreams in non-human animals remains less explored. This review paper addresses whether animals experience dreams and, if so, the nature of these dreams. To this end, it evaluates various research methodologies, including monitoring neural activity, replaying new memories, and analyzing dream-like behaviors. It also identifies crucial sleep patterns, such as Rapid Eye Movement (REM), Slow-wave (SW) sleep, and unihemispheric sleep, that play significant roles in dreaming. Furthermore, this study proposes a novel approach for deciphering animal dream content, specifically by investigating dreaming in octopuses. The paper concludes by examining atypical sleep patterns and deviations from everyday dream experiences.

Keywords: Behavioral and Social Sciences; Dreaming; Neuroscience; REM sleep; Slow-Wave Sleep

Introduction

Sleep, far from being a mere restorative process, plays a pivotal role in brain development and plasticity. It is a fundamental aspect of life, influencing brain maturation from early stages and shaping learning and memory in adulthood[1,2]. Our brains cycle through two primary sleep stages: rapid eye movement (REM) and slow-wave sleep (SWS).

Since the Carboniferous period, research has shown that all observed animals engage in slow-wave sleep (SWS), characterized by minimal activity and sensory-motor downscaling[3]. During this sleep phase, brain activity is prominent in the hippocampus, which plays a crucial role in memory consolidation and retrieval, and the neocortex, which is responsible for processing sensory perceptions, emotions, and cognitive functions[4,5]. Thus, SWS enhances learning and memory consolidation across species.

REM sleep has evolved in animals with more complex learning requirements. Reptiles, for instance, with more straightforward needs for survival, often do not exhibit REM sleep[6]. In contrast, during REM sleep in other species, the forebrain is as active as during waking. This hyperactivity promotes cognitive flexibility and abstract reasoning with the increased strength of memory associations and restructuring[7]. It is, therefore, believed that this state is strongly associated with dreaming. Dreaming is evidenced in humans as a common byproduct of sleep through verbal feedback and self-reports. However, while animals exhibit similar sleep stages, the question remains whether dreaming is independent of these stages[8]. Hence, the following review aims to explore the following questions: First, is there evidence to support that animals experience dreaming? Second, what is the potential function of dreaming in animals? Before addressing these questions, it is necessary to understand the general definition of dreaming. Subsequent sections will investigate different methods of measuring neural activity during animal sleep and assess whether these indicate dreaming. The discussion will also consider the distinctive sleep patterns observed in cetaceans and rock hyraxes to broaden our understanding of sleep's evolutionary trajectory.

What are Dreams?

Early research on dreams, most notably Freud's work, describes them as a form of 'wish fulfillment' involving two intertwined mental processes: unconscious forces constructing a wish and a censoring mechanism distorting this wish within the dream narrative[9]. Contrasting this view, modern scientific inquiry often characterizes dreams as the consequence of random neural activity and stochastic deep brain inputs that merge memory fragments[10]. Such a description accounts for the seemingly random and diverse nature of dreams. Nonetheless, the thematic consistency observed in the dreams of individuals with trauma or post-traumatic stress disorder challenges the idea that dreams lack specific content or purpose, pointing to a more complex interplay of psychological and neurobiological factors in dream formation[11].

As a result, this article defines dreaming as a dynamic process of memory reverberation that entails the reorganization and dissemination of memories. It posits that this reverberation aids learning by forging new memories and creatively repurposing fragments into novel scenarios, serving as a 'rehearsal mechanism' for future challenges. Dreams, characterized by hyper-associativity, connect characters, places, and actions in bizarre ways, exhibiting a spectrum of intensity, from faint impressions to complex, vivid narratives [12]. They engage all senses, including auditory, olfactory, tactile, gustatory, motor, vestibular, and linguistic modalities, forming vivid memories that can often be articulated upon waking [13]. However, due to the subjective nature of these psychological states, direct measurement is impractical. To address this challenge, the following section will explore innovative techniques researchers have devised to measure dream phenomena objectively, thus overcoming the limitations imposed by subjective self-reporting.

Neuronal and Behavioral Signatures of Dreaming

Traditionally, studies on sleep have relied heavily on verbal self-reports as the primary evidence of dreaming. Moreover, some skeptics argue that spontaneous behaviors exhibited during REM sleep may not directly correspond to dreaming. Yet, recent findings present a more nuanced perspective, strongly suggesting that dream states exhibit distinct patterns that can be observed without solely relying on verbal feedback [14]. In REM sleep behavior disorder (RBD) cases, where muscle atonia is incomplete, patients physically act out their dreams, ranging from simple movements to complex actions like speaking or gesturing [15]. These actions often reflect the content of their dreams, particularly when they involve perceived threats or attacks. The alignment between reported dream content and observed behaviors upon waking—a phenomenon known as isomorphism—provides strong evidence that these motor actions are enactments of the dream experience rather than random sleep-time movements [16,17].

Memory Recall

During waking, our brain forms specific neural patterns that recur in sleep due to memory propagation, commonly called "replay." This replay is crucial for learning, as dreamers often require fewer repetitions to learn tasks than those who do not. Historically, this was demonstrated in a seminal study by Skaggs and McNaughton (1996), where they recorded the activity of rats' hippocampal place cells using electrophysiological methods. Their findings revealed that rats running through a maze activated the same hippocampal place cells during subsequent REM sleep phases, implying that the day's experiences were being replayed and thus consolidated in memory [18]. A recent study by Xu et al. also observed that nonhuman primates exhibit a similar replay during sleep [19]. The study used sophisticated neural recording techniques to monitor the primary motor cortex, finding that sequences of neural activity observed during waking states were replayed during SWS and REM sleep states. This discovery in primates parallels previous observations in rodents. It suggests that replay may be a common neurological mechanism for memory consolidation across species, reinforcing the hypothesis that non-human animals may share a similar function of memory replay during sleep as humans do.

Moreover, the study by Melnattur and colleagues (2015) on honeybees adds a fascinating layer to our understanding, showing that even invertebrates exhibit behaviors indicative of memory consolidation during sleep [20]. In their research, honeybees exposed to context odors while awake and then again during deep sleep stages showed superior memory retention, similar to the replay observed in mammals. This finding parallels dream-like experiences in humans during non-REM sleep, expanding the scope of replay to include a variety of species, and underscores the possibility that experiencing dreams or dream-like states as a tool for learning and memory is a widespread trait in the animal kingdom. This cross-species comparison highlights a potential universal neurobiological mechanism for memory processing during sleep.

Dream Enactment

Animals might be acting out their dreams during sleep. For instance, Michel Jouvet's cat study captures oneiric behavior—actions that, performed during sleep, seem influenced by dreams— a phenomenon observed in numerous mammalian species [21]. Jouvet observed cats that would stand and move around their enclosure as though chasing prey and, at other times, bit randomly, without any apparent objective, even when toy mice were placed in front of them. These behaviors appeared to lack the intentional, goal-directed nature in their wakeful activities. For instance, when researchers placed a piece of paper on a cat's fur, a stimulus that would normally provoke a cat to groom itself while awake, the cat did not engage in this behavior during sleep. This absence of goal-directed response during sleep suggests that these animals are not simply moving but possibly reliving their natural behaviors in dreams.

Alternatively, some propose that animal dream enactment behaviors during sleep may result from processes like motor memory consolidation or sensory processing [22]. While these behaviors may resemble dreaming, motor memory consolidation primarily reinforces learned motor skills, distinct from the conscious mental imagery and narrative content associated with dreaming. Thus, while behaviors during sleep may seem like dreaming, they likely involve different neural processes and serve distinct features.

However, Sanford et al.'s study on rats provides compelling evidence that neural replay occurs in the hippocampus and the visual cortex, suggesting a direct connection to the perceptual imagery experienced during dream states [23–25]. Furthermore, when rats replay neural firing patterns during SWS, these patterns are not always exact replicas of the original ones. Dreaming involves the creation of patterns that have never been experienced before, occurring in the absence of environmental stimulation[26]. The novel changes in neural patterns during replay, which are not elicited by specific environmental stimulation previously encountered in waking experiences, may mirror the sleeping experience of the animal. While basic brain functions might influence animals' sleep behaviors, there's also evidence they could be dreaming.

While initially observed in mammalian studies, this evidence of dreaming extends beyond this class of animals. Indeed, creatures as diverse as octopuses demonstrate behaviors during sleep that suggest a form of dreaming. Octopuses are a fascinating example. Sleeping octopuses at times may rapidly twitch their eyes, suckers, or arms, exhibit increased ventilation rates, tightly curled arms, or show rapid changes in body patterns unrelated to the surrounding environment during sleep[27]. Unlike other animal models and humans, octopuses do not suppress the muscle atonia accompanying REM sleep. As suggested by Malinowski and colleagues (2021), this allows for potential dream content to be revealed through their dream enactment without putting the animal at risk[28]. By observing changes in body patterns unique to each behavior, such as hunting, contesting, or mating, we can better understand the dream content experienced by the octopus naturally without requiring advanced technology.

Another example is the study on cuttlefish, which also display a wide range of changes in chromatophore patterns in the skin[29]. The results revealed that the expression of individual chromatic components and whole-body patterns was always highly transitory in the REM-like state and usually different from how they are expressed in awake cuttlefish. The chronic pattern of a typical camouflage such as 'mottle' was maintained for many minutes or hours while awake. However, in a sleeping state, it was briefly shown for seconds in a disorganized manner. Thus, it is crucial to consider that these rapid chromatophore pattern changes will likely interfere with successful camouflage and may be costly in predation risk.

Why Do Animals Dream?

Having established that species, such as mammals and cephalopods, may experience dream content, the question arises as to why they dream. Our brain enhances cognitive flexibility during REM sleep by actively refining and molding memories gathered while awake, creating generalized assumptions about reality. Thus, familiar faces and locations appear within complex and confusing narratives in our dreams. The threat simulation theory suggests that our brain constructs these scenarios to facilitate the rehearsal of reactions, optimizing our responses during waking life with fewer repetitions[30]. Furthermore, decreased prefrontal cortex activity during REM sleep, a region associated with critical thinking and decision-making, is crucial for enhancing learning processes[31,32]. This reduction in activity facilitates the brain's ability to form genuine, unfiltered reactions to dream scenarios, which might not occur under the influence of the fully active prefrontal cortex during waking hours. This mechanism supports the theory that dreams allow for rehearsing responses to various situations without the constraints of logical reasoning, enabling more instinctual and emotional processing. By experiencing a range of scenarios in a dream state, individuals can prepare for real-life situations with broader responses, enhancing adaptability and problem-solving skills in waking life.

In addition, dreams potentially serve as a mechanism for future predictions by selectively encoding and simulating relevant phenomena within specific contexts while de-emphasizing irrelevant information[33]. This process, known as prospective coding during REM sleep, may explain the bizarreness of dreams as a method of identifying and representing significant patterns from past experiences as sensorimotor images[34]. When these dream-generated images are activated as predictive codes during wakefulness, they could improve cognitive efficiency by ensuring sensory inputs are quickly and accurately matched with suitable actions. This concept suggests that dreams simulate potential actions leading to desirable outcomes and help avoid actions associated with negative consequences, as seen in nightmares.

In numerous animal species studied so far, juveniles tend to rely heavily on REM sleep compared to adults. Active sleep constitutes about 50% of total sleep at birth and decreases roughly 20% to 25% over the first two years[35]. This finding reflects the fact that inexperienced individuals require more frequent simulation-based learning processes to survive in environments that are deemed unpredictable and dangerous. Nevertheless, other species evolved in ways that can be described as atypical when it comes to sleeping.

Unique Patterns of Sleep

Most circadian rhythms are divided between wake and sleep, but certain species have found a unique solution by combining the two. Unihemispheric sleep is a state in which one cerebral hemisphere sleeps while the other remains awake, so the saying "sleeping with one eye closed and one open" is quite literal for these species. Among mammals, unihemispheric sleep is restricted to aquatic species such as cetaceans, eared seals, and manatees. On the other hand, uni-hemispheric sleep is typical among birds and potentially in reptiles. In marine mammals, it allows them to surface to breathe, while in birds, it helps with predator detection[36]. Unihemispheric sleep occurs exclusively during slow-wave sleep, as alert wakefulness and deep slow-wave sleep fall at the opposite spectrum[37].

Interestingly, some species, such as birds, eared seals, and manatees, display unihemispheric and bihemispheric sleep (where both parts of the brain sleep). Humans also have the potential to obtain this trait. Fundamentally, the mammalian brain is not constrained in its ability to develop unihemispheric sleep since it has adopted this state on at least three occasions: Cetacea, Pinnipedia, and Sirenia. Plus, even terrestrial mammals like rats and humans display minor interhemispheric asymmetries in EEG activity during sleep.

Earlier sections established that the brain typically goes through two stages during sleep: SW and REM. However, what if there is a third one? Somnus innominatus (SI) is a sleep state showing mixed characteristics of SW and REM sleep. This additional sleep characteristic is observed in rock hyrax[38]. Rock hyraxes, also known as dassies, are small, furry mammals native to Africa and the Middle East. Because they have both sleep stages, this suggests that they experience dreams during their sleep.

Interestingly, some research indicates that SI may lead to a more vivid and narrative dream than SW dreams but less so than REM dreams[39]. Rock hyraxes may have various dream experiences depending on their sleep patterns. SI in the rock hyrax makes it attractive to investigate the neural correlates of dreaming using the techniques currently developed in humans[40].

Methodology

This paper undertook a rigorous and comprehensive literature search, utilizing databases such as Google Scholar, the National Institutes of Health, and JSTOR. We used keywords related to "sleep behaviors," "dream enactment," and "dreaming in non-human animals" with filters for the English language and peer-reviewed articles published between January 2000 and December 2023. Occasionally, we referenced older articles for historical examples. We based our selection on empirical focus, transparent methodology, and significant contribution to dream research. We carried out data extraction on publication details, methodology, and principal findings independently to minimize bias. We then followed this with a narrative synthesis to organize the conclusions thematically. We assessed the quality of the included studies using CONSORT and COREQ checklists, as well as the Cochrane Risk of Bias and ROBINS-I tools, to ensure the synthesis incorporated high-quality and reliable evidence.

Discussion

This paper delves into a less-explored realm, specifically the occurrences of dreams in non-human animals. It substantiates the claims that animals may dream, backed by measurements of their neural signatures and dream enactment. For instance, rats demonstrate dreaming by recalling neural signatures formed during waking, such as navigating a maze and creating novel neural signatures during sleep. Similarly, animals like cats exhibit dream behavior by enacting their dreams, such as cycling their legs in the air or engaging in behavioral routines that are not goal-oriented. The study addresses potential counterarguments, such as these behaviors attributed to spontaneous neural activations and motor memory consolidation. It draws on evidence from studies on patients with REM sleep behavior disorder (RBD) to propose that oneiric behavior during sleep is strongly linked to dreams rather than being random. Moreover, activating specific brain regions during sleep, such as the visual cortex and hippocampus, further bolsters the notion that the brain consolidates memory during sleep to create novel scenarios.

Moreover, the paper briefly explores sleep patterns in other species, such as honeybees, rock hyraxes, octopuses, and cetaceans. It paves the way for future avenues in animal research involving methods that investigate dreams without compromising the animals' safety. For instance, octopuses do not suppress the muscle atonia accompanying REM sleep, unlike other animals. This unique characteristic opens up the possibility of revealing potential dream content by observing behavior, such as changes in body patterns. This potential for future research expands our understanding of animal sleep and holds promise for uncovering more about the intriguing world of animal dreams.

This paper also discusses potential reasons behind animal dreaming, such as the threat simulation theory and future guessing. Sleep was first developed to improve learning through memory propagation, making newly acquired memories independent of the hippocampus. REM sleep enhanced this feature in particular species like mammals and birds. During REM sleep, dreams are more vivid and follow a continuous narrative. These simulations inspired the threat simulation theory, which suggests that dream content serves as a "rehearsal mechanism," allowing animals to practice their behavioral procedures related to survival with fewer repetitions in the waking. In addition, dreaming in animals could also serve other functions, such as emotional regulation, problem-solving, and creativity. These potential functions of animal dreaming require further exploration and could be the focus of future research.

Furthermore, these simulations appear more frequently in juveniles, indicating that naive and inexperienced individuals rely more heavily on this feature. In summary, dreaming is an evolutionary trait shared by many species. Although each animal has a unique dreaming pattern, they all serve similar functions, such as memory consolidation and behavioral practices linked to survival. These differences are crucial, especially in animals with uncommon sleeping patterns, such as rock hyraxes, which warrant further studies. The significant neural signatures of dreaming underscore the importance of not relying solely on verbal feedback in dream investigations, as different brain regions control various aspects of the sleep experience. For instance, two distinct brain regions control dream experience and recall. These findings not only encourage but also necessitate future research on animal sleep behavior and unique neural patterns associated with dreams, offering a fascinating and enlightening avenue for further exploration.

Conclusion

In conclusion, while this paper has contributed to the understanding of dreaming in non-human animals and proposed exciting directions for future research, it is imperative to acknowledge the methodological and interpretative challenges that lie ahead.

Potential Limitations

While based on robust studies, this paper's conclusions have certain limitations. The practice of inferring dream experiences in non-human animals from neural signatures and behaviors presents a risk of oversimplification, as these may not aptly reflect the range of dream experiences across different species. This interpretation often hinges on parallels with human sleep, potentially overlooking the unique complexities of each species' dreaming process.

There is also a crucial need to avoid anthropomorphizing animal behaviors, recognizing the fine line between empirical observation and human-like attribution. Extending findings from specific species to others requires cautious justification, considering distinct differences in sleep patterns and cognitive capacities across species. Ethical concerns necessitate the shift toward more humane, non-invasive methods in the study of animal dreaming. Furthermore, observations of dream behaviors must be approached with rigorous scientific methods to prevent misleading conclusions rooted in human biases. The exploration of dream-like states in octopuses and unihemispheric sleep remains speculative, demanding a wealth of empirical data to support or refute these intriguing notions.

In sum, the paper contributes valuable insights to the study of animal dreaming but highlights the need for methodological rigor and careful interpretation. As we progress, it is critical to maintain an iterative research approach, continually seeking empirical validation and refining our hypotheses with interdisciplinary studies. This will enhance our understanding of dreaming across the animal kingdom, grounded in empirical evidence and respect for the diversity of animal cognition.

Future Directions

Future research should prioritize exploring the neural underpinnings of dream processes in various species, particularly those with unusual sleep patterns, such as octopuses and rock hyraxes. These investigations are essential for filling existing knowledge gaps regarding the evolutionary breadth of dreaming and its possible roles in cognitive functions like memory, learning, and adaptive behaviors. Additionally, there is an intriguing opportunity to study unihemispheric sleep's potential in humans, which may yield new insights into sleep pathologies and methods for enhancing rest quality.

Advancing this domain mandates a careful balance between research's scientific value and animal subjects' welfare. It is imperative to ensure that the anticipated benefits of this research outweigh any risks posed to the animals involved. This ethical consideration becomes particularly significant when delving into non-human subjects' cognitive and emotional realms. Prioritizing non-invasive methodologies will minimize the impact on the subjects and maximize the ethical integrity of the research.

It is crucial to develop and improve noninvasive methods for studying dream content. Such advancements will enable researchers to interpret the cognitive and emotional facets of dreams in nonhuman animals with greater accuracy. Controlled experimental setups that facilitate the observation of dream enactment behaviors could illuminate the complexities of dreams beyond what is currently understood, thereby enriching our understanding of consciousness and cognition across species.

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About the Author

Alina Turaliyeva is a Year 12 student at Haileybury Almaty, Kazakhstan. She is deeply passionate about neural psychology and international relations. Her intrigue was further ignited by an article on sleep and dreams, enhancing her exploration into neural psychology's complexities. Her recent projects delve into psycho-analytics within big data and its implications on marketing strategies, especially concerning democratic societies and digital political campaigning. Committed to blending her interests in psychology and international relations, Alina seeks to unravel the intricate connections between psychological concepts and global issues, aiming to broaden the understanding of human behavior and contribute significantly to both domains.

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