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The Syntelic Ape Hypothesis: The Evolution of Sleep and Metabolism Accompanying Bipedalism and the Use of Fire, and a Novel Verification Protocol for the VPA Supercompensation Model Using Next-Generation Image Analysis

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Summary

This paper attempts to reconsider the evolution of human-specific prolonged Rapid Eye Movement (REM) sleep and Varicose Projection Astrocytes (VPA) from an ecological perspective, developing the author's proposed "Syntelic Ape Hypothesis." It explores how the stamina gained through bipedalism was functionally exapted into social "Sustained Challenging Cooperation," and further discusses the risk of "brain asphyxiation" that its evolutionary mismatch might bring to modern society.

Furthermore, focusing on the "colocalization" of neuronal growth and local astrocyte dynamics during sleep, this paper proposes a novel verification protocol integrating next-generation image analysis algorithms (e.g., AQuA), along with specific falsification criteria to ensure its robustness as a scientific theory.

1. Sleep Structure of Primates and Human Specificity

When considering the foundation of human higher cognitive functions, comparing sleep structures with closely related primates is extremely useful.

First, as established findings in comparative cognitive science, the following sleep data can be cited. The total sleep time of rhesus macaques is about 11–13 hours with a REM sleep ratio of about 15–18% (Capellini et al., 2008), and the total sleep time of chimpanzees is about 9.7 hours with a REM sleep ratio of about 11–15% (Videan et al., 2001).

On the other hand, although modern humans have one of the shortest total sleep times among primates at about 7.1 hours, their REM sleep ratio is at an unusually high level of about 22–25% (Samson & Nunn, 2015).

From these comparisons, it can be reasonably inferred that human-specific metabolic and environmental adaptations brought about this extreme shift in sleep structure. In recent years, interlaminar astrocytes (such as VPAs) have attracted attention as a basis for human-specific brain functions (Falcone et al., 2025). As one possibility, this paper proposes a working hypothesis that the evolution of this VPA and the specific increase in REM sleep acted complementarily in the development of human social intelligence.

Note that human evolution is a process in which multiple factors, such as language, culture, social structure, frontal lobe expansion, and dietary changes, are intricately intertwined. This paper does not explain human evolution by a single factor, but rather examines the role played by VPAs within this multi-factor model as a single testable hypothesis.

2. Reconstruction of the Metabolic Foundation Brought by Bipedalism and the Use of Fire

As the reason for the increased proportion of REM sleep in modern humans, a scenario in which the following two evolutionary adaptations acted in combination can be considered.

First is the acquisition of stamina and the ability to travel across vast lands through bipedalism. One prominent evolutionary interpretation in evolutionary anthropology is that the ecological shift enabling prolonged aerobic exercise prepared the developmental foundation for the monoamine neurotransmitter system (such as dopamine and serotonin) in the brain.

A reasonable inference derived from this is that when highly coordinated group action became essential for humans to survive the harsh savanna, they may have functionally exapted

their "physical stamina" for relentlessly tracking prey into "cognitive stamina" for maintaining complex human relationships. In other words, the hypothesis is that they acquired "Sustained Challenging Cooperation"—the ability to withstand the immense cognitive load of suppressing selfish impulses and continuously reading the intentions of others.

While this sustained social overload can become a pathology that causes neuroinflammation and network atrophy (Slavich & Irwin, 2014; Setiawan et al., 2015), as a bold hypothesis, this paper proposes that human VPAs functionally utilized this high load (Kondev et al., 2026) and constructed a unique system to accumulate the biomass (metabolic building blocks) necessary for nighttime supercompensation during the day through aerobic glycolysis (Pellerin & Magistretti, 1994).

Second is the conservation of digestive energy and the securing of safety through the acquisition of fire. The fact that humans routinely used fire and acquired safe terrestrial camps, thereby reducing predation risk and obtaining an environmental foundation to improve sleep efficiency, is a widely supported finding in archaeology and anthropology (Wrangham, 2009; Samson & Nunn, 2015).

Furthermore, cooking significantly reduced the biological burden of food digestion. Taking a step further, this paper deduces a scenario in which the need for deep non-REM sleep, previously devoted to physical repair, relatively decreased, and the reduced sleep time budget may have been reallocated to REM sleep (supercompensation of the brain) accompanied by the maintenance of highly advanced social networks.

3. Hypothesis of Local Wiring Based on Neuronal Growth and D-Serine Release Mechanisms

To examine the micro-physiological validity of this hypothesis, the findings, inferences, and hypotheses are organized at the molecular and cellular levels.

First, long-term in vivo imaging has proven that sleep directly promotes the physical formation (structural plasticity) of dendritic spines in neurons after learning (Yang et al., 2014), and it is an established finding in modern neuroscience that the release of D-serine and other substances from astrocytes is essential for this synaptic growth (long-term potentiation) (Henneberger et al., 2010).

Furthermore, regarding calcium (Ca2+) activity in astrocytes, there are macro-level calcium waves spreading across the entire cell and local microdomains (calcium sparks) occurring at the tips of extremely fine processes. While macroscopic activity decreases during sleep, localized sparks in microdomains continue to occur actively in conjunction with specific synaptic activities (Ingiosi et al., 2020). Based on this fact, it is believed that synaptic selection during sleep is precisely controlled through the activation of localized microdomains without uniformly exciting the entire brain.

Based on these points, this paper presents the following working hypothesis as a possibility. Normal astrocytes also possess existing mechanisms to release D-serine, but human-specific VPAs may have significantly expanded this existing mechanism. In other words, by utilizing their characteristic long varicose projections, they may have evolved into a "multiplex local integration system" capable of simultaneously triggering synchronized microdomain sparks at multiple distant synapses and pinpoint-dropping D-serine into specific, complex social cognitive circuits, without causing whole-cell waves. If this mechanism exists, humans may have acquired the ability to supercompensate and optimize their enlarged and complex brain networks during the night without causing interference.

4. Proposal of a Novel Experimental Verification Model Using Next-Generation Image Analysis

To demonstrate the aforementioned hierarchical hypothesis, a verification protocol centered on the next-generation image analysis algorithm "AQuA (Astrocyte Quantitative Analysis)" (Wang et al., 2019) is proposed.

4.1 Key Quantitative Metrics

Using AQuA, the following three metrics will be heavily quantified:

① Spatial Extent: Measure the volume over which a single spark spreads to verify whether human VPAs function as a mechanism synchronizing distant local events.

② Duration: If the spark duration of VPAs is significantly longer than that of mice, it can serve as collateral evidence that they secure longer working times to physically fixate extensive networks.

③ Morphological Complexity and Network Integration: When random firing activities caused by PGO waves (Pontine-Geniculo-Occipital waves) occur, highly synchronized firing (Co-activation) among distant varicosities is predicted to be observed. Furthermore, by introducing analyses of functional connectivity and network modularity based on graph theory, going beyond mere simultaneous activity, we will quantitatively verify whether VPAs selectively pick and integrate meaningful multiple connections.

4.2 Mapping of Colocalization via an Integrated Analysis Pipeline

To confirm that persistent local sparks are occurring during

REM sleep, dual-wavelength simultaneous two-photon calcium imaging will be used to map the spatial overlap between neuronal activity (red) and VPA activity (green).

The spatiotemporal dynamics of VPAs will be extracted using AQuA, and neuronal firing will be extracted using dedicated algorithms such as Suite2p (Pachitariu et al., 2016). We will then employ a method that strictly analyzes pixel-level colocalization using a custom pipeline integrating both datasets.

4.3 Construction of a Comparative Verification Model

Using the above metrics and analysis pipeline, data from wild-type mice (Phase 1) and humanized chimeric mice (Han et al., 2013) (Phase 2) will be directly compared.

4.4 Falsifiability and Rejection Conditions of This Hypothesis

In order for this hypothesis (the Syntelic Ape Hypothesis and VPA Supercompensation Model) to maintain its robustness as a scientific theory, if any of the following experimental results are obtained, this hypothesis shall be defined as partially or fundamentally rejected (falsified):

① Non-detection of Significant Differences in VPA Spatiotemporal Dynamics (Fundamental Rejection): If the activity of Ca2+ microdomains in VPAs (spatial extent, duration, and functional connectivity between distant processes) in humanized chimeric mice shows no statistically significant scale expansion or synchrony during REM sleep compared to normal astrocytes in wild-type mice.

② Lack of Correlation Between Local D-Serine Release and Structural Plasticity (Partial Rejection): If, in dual-wavelength simultaneous imaging, no statistically significant spatial and temporal correlation is observed between the sites of VPA local sparks, the structural plasticity of neurons (formation of new spines), and the local colocalization of D-serine.

③ Divergence Between Social Overload and VPA Metabolic Signals (Rejection of the Hypothesis Model): In a model animal subjected to a cognitive load simulating sustained challenging cooperation (social interaction task), if the process of daytime aerobic glycolysis enhancement and subsequent nighttime supercompensation (synaptic optimization and cognitive function recovery) shows no significant difference between a group with inhibited VPA Ca2+ activity/metabolic control and a normal group.

5. Considerations for Modern Society: Evolutionary Mismatch and "Brain Asphyxiation"

Finally, the pathologies of modern society are considered from the perspective of evolutionary medicine.

The phenomenon where a lack of exercise accompanying technological development disrupts humanity's original metabolic balance and induces various modern diseases is an already established finding as a typical example of Evolutionary Mismatch. Based on this finding, this paper presents a bold working hypothesis in the realm of social cognition.

If humanity evolutionarily acquired "Sustained Challenging Cooperation," its immense cognitive load (the gritty social friction of daytime interactions) may have acted as a trigger for the accumulation of metabolic biomass in VPAs. However, in the modern "frictionless society" where friction with others and cognitive loads are eliminated to the extreme limit, opportunities for cognitive challenging cooperation during the day are drastically decreasing.

If this hypothesis is correct, VPAs may consequently run the risk of losing both the trigger and the building blocks necessary to integrate networks during REM sleep. We hope that this verification protocol will contribute to elucidating the mechanism of this critical situation of "brain asphyxiation," where a convenient, frictionless social environment paradoxically causes the malfunction of the social brain's supercompensation mechanism—humanity's greatest invention.

6. Conclusion

In this paper, we proposed an evolutionary scenario in which humanity shifted its metabolic budget of sleep from the body to the brain through the acquisition of stamina via bipedalism and the use of fire. Based on this scenario, the supercompensation mechanism during REM sleep by VPAs may have evolved as an adaptation to "Sustained Challenging Cooperation" to maintain advanced sociality, and its reality could be scientifically verified through quantitative comparisons using a next-generation image analysis pipeline.

At the same time, by undergoing an empirical process based on the specific rejection conditions (falsifiability) presented in this paper, this hypothesis will be evaluated for its validity as a testable scientific theory, rather than remaining a mere evolutionary scenario. We must also face head-on the hypothetical risk that this exquisite sleep mechanism is on the

verge of "asphyxiation" due to modern environmental changes through multifaceted empirical research.

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