Original Paper

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Constitutive Reactivity of VPA as a Bioenergetic Basis for Human Cooperation: The Syntelic Ape Hypothesis and Its Application to AI

Reiji Kikuchi

mk9tmk9tmk9t@yahoo.co.jp

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Summary

This paper discusses the possibility that the fundamental drive separating the human lineage is not the traditional individual "autotelic" challenge, but rather a "syntelic" challenge—sharing goals and overcoming risks with others—which we term the "Challenging Cooperation Propensity."

Falcone et al. demonstrated that Varicose Projection Astrocytes (VPAs) represent a reactive phenotype appearing only under stress in other species [Falcone 25]. This paper proposes the "Constitutive Reactivity Hypothesis of VPA," suggesting that humans physiologically normalized (constituted) this high-metabolic cellular state and exapted it to boost cognitive functions.

Furthermore, this paper hierarchically discusses how this physiological basis may have enabled syntelic behavior. Ultimately, it explores the potential of "Syntelic AI" as an "energy-constrained synchronous prediction model" and a cognitive load distribution algorithm in HRI, aiming to engineeringly reproduce and support this mechanism.

1. Introduction: From Autotelic to Syntelic

What makes humans human? Tomasello's Shared Intentionality explains the cognitive capacity for human collaboration but not the underlying drive [Tomasello 19].

We propose that this drive may lie in the Challenging Cooperation Propensity. While Csikszentmihalyi referred to the state of immersion in self-contained activities as "autotelic" [Csikszentmihalyi 90], the true singularity of humans arguably lies in achieving stronger immersion and pleasure in a "syntelic" (goal-sharing, interdependent) state, as proposed by Walker [Walker 10].

However, the act of "synchronizing with others" imposes an extremely high computational load on the brain compared to solitary action. This paper considers how this high-cost behavioral strategy became biologically possible and how it might be supplemented by modern AI technology.

2. Hardware: Exaptation of "Constitutive Reactivity" by VPA

2.1 Exaptation from Pathology to Function

Falcone's research suggests that VPA-like morphology in mice is a transient response induced by inflammatory cytokines [Falcone 25]. Normally, this reactive astrogliosis is a high-energy state for tissue repair, which carries the risk of neurotoxicity if prolonged.

However, human VPAs appear to physiologically maintain only the complex morphology and high metabolic activity characteristic of this "reactivity" without accompanying cell death or toxicity. This suggests that during human evolution, mutations in the gene expression regulation of astrocytes may have allowed them to acquire "Constitutive Reactivity," avoiding pathological inflammation while normalizing only its high functionality. Indeed, experiments transplanting human glial cells into mice have shown significant improvements in learning ability and plasticity [Han 13], indicating that this state provides functional benefits.

2.2 Astrocytes as Body Budget Managers

Why did humans need a fuel-inefficient brain consuming more than twice the energy of chimpanzees [Herculano-Houzel 12]?

Lisa Feldman Barrett defined the primary function of the brain as managing the "Body Budget" (Allostasis) [Barrett 17]. In complex social environments, predicting others' intentions (mentalizing) and dealing with uncertainty are considered the largest expenditure items for the body budget.

The "Aerobic Glycolysis" demonstrated by Goyal et al. [Goyal 14] might imply that VPAs are running a continuous operation, constantly supplying immediate fuel (lactate) for these predictive computations [Magistretti 15]. VPAs may function as body budget managers to enable the luxury

investment of syntelic cooperation.

3. Software: Neurochemical Selective Pressures and Evolutionary Timeline

3.1 The Metabolic Revolution at 7 Ma and Brain Expansion at 2 Ma

We consider the possibility that VPA-ization was not the result of brain expansion but a "pre-adaptation." It is speculated that because a metabolic infrastructure via VPAs was established at the early hominin stage 7 million years ago, the subsequent explosive brain volume expansion accompanying increased caloric intake (meat-eating and cooking [Wrangham 09]) and the acquisition of more advanced sociality in the genus Homo became possible.

3.2 Sapiens vs. Neanderthals: Differences in Scalability

How did Sapiens achieve their unique evolution on this VPA infrastructure? Pereira-Sanchez et al. showed that modern humans carrying Neanderthal genes have lower dopamine synthesis capacity [Pereira-Sanchez 21], suggesting that Neanderthals' exploratory drive might not have been as excessive as that of Sapiens.

Furthermore, according to Pearce and Dunbar, the group size of Neanderthals is estimated to have remained small (10-20 individuals) [Pearce 13]. In contrast, Sapiens might have acquired the scalability to form large-scale "collective brains" by post-natally updating their brain hardware through epigenetic regulation by serotonin (VPA-Serotonin Loop) [Sardar 23].

4. Behavioral Strategy: Social Flow and the Supreme Reward

4.1 Reinterpreting the Lovejoy Hypothesis

The male provisioning in early hominins [Lovejoy 09] can be interpreted as the first practice of challenging cooperation, involving dangerous transportation (challenge) and appetite suppression (cooperation).

4.2 Molecular Mechanisms of Social Flow

Dölen et al. proved that in social interactions, the activation of oxytocin receptors in the nucleus accumbens triggers serotonin release, which generates social reward (pleasure) [Dölen 13].

Furthermore, Keeler et al. reported that in group improvisational singing (a state of social flow), oxytocin levels significantly increase and correlate with the quality of the flow experience [Keeler 15]. This reward system may have provided the motivation to execute cooperation even at the risk of the high-cost VPA system (body budget deficit).

5. Engineering Implementation: Prospects for Syntelic AI

5.1 Mental Illness as an Evolutionary Trade-off

The "constitutive reactivity" by VPA is highly likely a double-edged sword. Sekar et al. elucidated that the schizophrenia risk gene (C4) triggers excessive synaptic pruning mediated by microglia and astrocytes [Sekar 16]. This suggests that human-specific mental illnesses may originate from a breakdown in body budget management (increased prediction errors and metabolic failure) caused by VPA.

5.2 Energy-Constrained Synchronous Prediction Models

The complexity of modern society is beginning to exceed the processing capacity of the human VPA. To solve this problem, the implementation of "Syntelic AI" that engineeringly supports human challenging cooperation, rather than mere efficiency (Autotelic AI), is required.

The engineering requirements would likely converge on the following two points:

1. Energy-Constrained Synchronous Prediction Model:

Current AI often assumes infinite resources, but human intelligence is optimized within the energy constraints of VPA. By incorporating a metabolic cost function into the model as an artificial VPA and adopting an architecture that intentionally increases "fluctuations" (constitutive reactivity) during resource shortages, it may be possible to enhance adaptability to unpredictable situations.

2. Cognitive Load Distribution Algorithm in HRI:

This involves implementing an algorithm where AI monitors the state of the human body budget (fatigue or emotional arousal) in real-time and dynamically offloads cognitive tasks to the AI before the VPA exceeds its metabolic threshold. This would allow the entire human-AI hybrid system to maintain a syntelic state continuously.

6. Experimental Proposals for Hypothesis Verification

To verify this hypothesis, we propose the following three experimental approaches. The common marmoset is optimal as an animal model because it engages in cooperative breeding and has established genetic modification techniques [Sasaki 09][Burkart 14].

• Paleo-biology (Reconstruction of ancient astrocytes): Estimating astrocyte-related genes of early hominins from 7 million years ago and reproducing them in iPS cells to verify the timing of acquiring constitutive reactivity without pathological inflammation.

• Identifying mutation dates via molecular clocks: Calculating the mutation dates of genes related to astrocyte morphological regulation to verify if they coincide with the onset of bipedalism (7 million years ago).

• Introduction of human VPA factors into marmosets: Observing whether marmosets introduced with human-specific VPA regulatory genes exhibit increased cooperative behavior under risk (challenging cooperation).

7. Conclusion

Humans are speculated to be biological entities that use the "constitutive reactivity" of VPA as a physiological basis, thereby enabling high-cost syntelic behavior. The ultimate goal of AI technology should not be to replace this biological instinct, but perhaps to engineeringly complement the energetic vulnerability our brains harbor, rebuilding a social infrastructure where we can challenge together once again.

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