The Vortex of Consciousness: The Physical Origin of Subjective Experience

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Abstract

How neural activity generates subjective experience—the "hard problem" of consciousness—remains unresolved [1]. This paper proposes the Consciousness Flow Vortex Model Hypothesis (CFVM-H), positing that subjective experience arises from vortex dynamics formed by closed recursive structures in the thalamocortical loop. This vortex exhibits three core characteristics: closed-loop circulation, vortex core focusing, and global synchronization. These features directly map to three fundamental elements of subjective experience: self-boundary, first-person perspective, and a unified field of sensation. CFVM-H provides a testable, physics-based framework for the "hard problem" of consciousness, defining subjective experience as an inevitable product of vortex structure rather than a mysterious emergent property.
Keywords: Hard problem of consciousness; Subjective experience; Consciousness vortex model; Central thalamic nucleus; Neural dynamics; Vortex theory

1 Introduction

The "hard problem" of consciousness—how neural activity gives rise to subjective experience—remains unsolved [1]. Global workspace theory and integrated information theory describe consciousness from the perspective of information processing but fail to specify the specific physical structures and their dynamic mechanisms that generate subjective experience [2-5]. A key clue is that minor damage (<1 cm^3) to the midline thalamic nuclei can lead to loss of consciousness, whereas extensive cortical damage may not [6,7], suggesting that the core substrate of consciousness resides deep within the thalamus. Fang et al. [8] found that the centromedian/parafascicular (CM/Pf) thalamic nuclei initiate activity prior to the prefrontal cortex during conscious perception and drive global synchronization via theta oscillations. However, why does this temporal precedence and global synchronization produce subjective experience? This paper proposes the Consciousness Flow Vortex Model Hypothesis (CFVM-H), positing that subjective experience is the physical outcome of vortex-like dynamic phenomena formed by closed recurrent structures in thalamocortical loops (Fig 1).
Fig 1. Schematic of neural information flow dynamics in the consciousness vortex.

2 Current Theoretical Challenges

Current theories of consciousness primarily focus on the study of "recursive closed loops" at the level of information logic recursion. This recursive approach has fundamental limitations and cannot generate subjective experience.

2.1 Lack of Physical Entity

Information logic recursion occurs at an abstract cognitive level—where symbols refer to symbols, and thoughts point to thoughts—without involving real physical entities, energy flows, or spatial fields. It is essentially a "description" of the objective world, not "existence" itself.

2.2 Lack of a Focal Center

Information logic recursion forms discrete loops with no clear dynamic focal center. All information processing involves stepwise discrete transitions. The core of subjective experience is a singular, focused perceptual center—the "first-person self." Discrete logical loops cannot integrate into such a unified subject.

2.3 Lack of Information Fusion

Information logic recursion processes information in a fragmented manner, with sensory and multidimensional information remaining separated. In contrast, subjective experience is a continuous, unified whole—for example, when seeing an apple, the sensations of color, shape, and taste merge into a holistic experience.

2.4 Lack of Kinetic Characteristics

Information logic recursion lacks kinetic characteristics such as energy, flow, intensity, contraction, and diffusion, being a static symbolic operation. Subjective experience, however, is a dynamic and continuous process—such as the fluctuation of emotions, the focusing and dispersion of attention.

In short, information logic recursion is the repetition and direction of information, while subjective experience is a real physical process, belonging to different dimensions. This is the core reason why current theories struggle to break through. The breakthrough lies in shifting from information logic to physical dynamics.

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3 The Consciousness Vortex Model Hypothesis (CFVM-H)

This section borrows the mathematical formalism of fluid mechanics to describe neural field dynamics. It is important to clarify that the term "vortex" here does not refer to fluid motion at the biophysical level, but rather to phase singularities and limit cycle attractors existing in high-dimensional neural state spaces. This structural isomorphism in mathematics allows us to use vector field analysis to describe the physical process of consciousness integration.

3.1 Vortex Phenomena Are Widespread in the Nervous System

Vortices are real physical phenomena in the nervous system. Spiral waves with phase singularities as their core exist in the human cerebral cortex, covering the entire cortical surface, propagating around the center through rotation, coordinating cross-network information flow, and directly participating in cognitive processing[9]. Spiral waves are not unique to humans; they have been reported in neural circuits ranging from insects to mammals[10,11]. Closed recursive loops—a necessary condition for vortex formation—are a common structural feature of the nervous system.

3.2 Core Definition

This paper proposes**the Consciousness Flow Vortex Model Hypothesis (CFVM-H)**, with the core proposition:**Subjective experience is an inevitable physical outcome of vortex**

dynamics formed by neural information flow in closed recursive loops.

The model predicts: With the central medial thalamic nucleus (CM) as the dynamic vortex core, surrounded by a series of approximately circular neural structures, a bilaterally symmetric, multi-layered nested information flow network is formed. Neural signals originate from the vortex core, creating closed rotating loops. The loops in the left and right hemispheres achieve strong coupling and phase synchronization through cross-hemispheric structures such as the massa intermedia of the thalamus and the corpus callosum, collectively constituting a unified dynamic flow field.

Terminology Explanation: "Vortex" is the core metaphor of this theory, referring to the three dynamic characteristics of information flow in the thalamocortical loop: **recursive convergence, vortex core focusing, and global synchronization**. This term is not a simple appropriation of fluid mechanics concepts but an original designation for specific patterns of neural dynamics.

3.3 Three Core Dynamic Features

CFVM-H proposes that the consciousness vortex possesses three core dynamic features, all of which are quantifiable and verifiable physical attributes:

(1) Closed Cyclicity: The information flow starts from the vortex core, travels through output channels along neural networks, and ultimately returns to the input channels at the other end of the core, forming a closed rotating loop. This structure exhibits recursive robustness: when one side of the loop is damaged, the other side can maintain the basic flow field through unidirectional recursion.

(2) Vortex Core Focusing: The flow field exhibits centripetal rotational characteristics, with multimodal sensory information (visual, auditory, tactile, etc.) converging toward the vortex core (thalamic core regions), forming a singular focal center.

(3) Global Synchronization: The rotation of the flow field features global synchronization, where neural activities across different brain regions are entrained into the same dynamic flow field. Bilateral circuits achieve synchronization through structures like the thalamic intermedullary mass, enabling the simultaneous integration of multidimensional information.

3.4 Direct Mapping from Vortex Dynamics to Subjective Experience

The core theoretical contribution of CFVM-H is the establishment of a **direct mapping** between the characteristics of vortex dynamics and the elements of subjective experience. This mapping does not require additional assumptions but is derived from the physical structure of the vortex.

Closed Loop → Self-Boundary: The closed loop of information flow forms a clear dynamical boundary between the interior of the flow field and the external objective world. This boundary distinguishes "self" from "external world," generating the "perception of self-existence"—the primary prerequisite for subjective experience.

Vortex Core Focusing → First-Person Perspective: The centripetal focusing of the vortex causes all multimodal neural signals to converge toward the vortex core, forming a singular perceptual focal point. This hypothesis posits that this focal point is the first-person "I" of subjective experience. The uniqueness of the vortex core explains the unified subjectivity of experience, avoiding the fragmented experience of "multiple selves." The focusing intensity of the vortex core is negatively correlated with its radius: when attention is concentrated, the vortex core contracts, making the first-person perspective more distinct; when attention is

dispersed, the vortex core expands, and the perspective becomes more blurred.

Global Synchronization → Continuous Unified Perceptual Field : The global synchronized rotation of the vortex draws fragmented neural signals such as vision, hearing, touch, and emotions into the same dynamic flow field, achieving seamless integration of multi-dimensional information. The continuity of rotation ensures subjective experience without interruption; the synchronization of rotation allows sensations from different senses to merge into a unified whole.

3.5 Quantitative Expression of Subjective Experience

CFVM-H proposes that the intensity (richness and clarity) of subjective experience can be described by the core physical parameters of the flow field. The cross-species quantitative relationship can be expressed as (Fig 2):

$$E \propto (\Gamma / r_0) \cdot \sigma \cdot C$$

Where:

- **E** : Consciousness energy, reflecting the wakefulness intensity, integration strength, and stability of consciousness;
- **Γ** : Initial vorticity of awareness, the initial dynamic force of awareness generated by the thalamus;
- r_0 : Vortex core radius, positively correlated with the directedness of experience;
- **σ** : Information integration force, the ability to gather, categorize, and unify perceptual information toward the core;
- **C** : Consciousness exclusivity, the ability to isolate "non-self" information.

This relationship indicates that differences in subjective experience can be attributed to variations in the physical structure of the vortex. This provides a foundation for quantitative testing. Currently, this expression is proposed as a heuristic framework, and the specific measurement schemes for each parameter require future research combined with high-density neural recordings for calibration.

Fig 2. Schematic diagram of quantitative parameters of the consciousness vortex neural information flow field.

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4 Empirical Evaluation: Centromedian Thalamic Nucleus as the Vortex Core

CFVM-H The most critical focal point is the anchoring of the vortex core: the centromedian thalamic nucleus serves as the vortex core, and this inference is supported by numerous empirical data.

4.1 Anatomical Basis: CM Possesses the Structural Conditions of a Vortex Core

CM is located at the geometric center of the internal medullary lamina of the thalamus, surrounded by all key thalamic nuclei such as the ventral anterior nucleus, ventral posterior nucleus, medial dorsal nucleus, and parafascicular nucleus [12]. From a whole-brain scale, CM is situated deep along the midline of the cerebral hemisphere, serving as the convergence hub of the brainstem-thalamus-cortex tripartite structure.

The microstructure of CM supports its function as the vortex core. Its volume is approximately

310 mm^3, with a neuronal density of about 2200 neurons/mm^3, totaling approximately 664,000 neurons [12]. It is predominantly composed of large and medium-sized projection neurons, with extensive axonal branching, providing the structural capability to simultaneously send synchronized signals to multiple regions such as the entire cerebral cortex and basal ganglia.

The Critical Role of the Internal Medullary Lamina : CM is completely enveloped by dense fibers of the internal medullary lamina. The internal medullary lamina consists of highly myelinated large-diameter axons (conduction velocity 30-50 m/s), enabling bidirectional direct communication between CM and all thalamic nuclei.

4.2 Core Activation Precedes Peripheral Regions—Electrophysiological Evidence

Fang et al. [8] directly examined the temporal relationship between CM/Pf and the cortex using sEEG in human subjects. Key findings:

- **Temporal Lead** : In a conscious perception task, neural activity in CM/Pf emerged approximately 200-300 milliseconds after stimulus presentation, **significantly earlier than** the activity in the prefrontal cortex.
- **Phase Driving** : The theta wave phase of CM/Pf directly drives the gamma wave amplitude in the prefrontal cortex, indicating that the direction of information flow is from the thalamus to the cortex.
- **Causal Directionality**: Phase transfer entropy analysis confirmed that the direction of information flow is **CM/Pf → prefrontal cortex**, not the reverse ($p = 5.55\times10^{-7}$).

The study conclusion explicitly states: "Higher-order thalamic nuclei serve as the gating hub for conscious perception, achieved through the thalamo-prefrontal circuit" [8]. Furthermore, CM neurons exhibit significant high-frequency activity in the gamma band (30-100 Hz), which can synchronously drive coherence activity in bilateral cerebral cortices**[13,25]**.

4.3 Core Lesions Eliminate Consciousness—Clinical Lesion Evidence

CM Microlesions Cause Loss of Consciousness: Plum and Posner[6] first systematically described the relationship between midline thalamic lesions and consciousness disorders in their seminal monograph. Subsequent studies confirmed that occlusion of the Percheron artery, which supplies the bilateral paramedian thalamic regions (including CM), can lead to bilateral thalamic infarction. Patients present with fluctuating consciousness levels, persistent drowsiness, or even coma, with severity directly correlated to the extent of CM nucleus damage**[20]**.

Abnormal CM in Patients with Impaired Consciousness : fMRI studies of patients with chronic disorders of consciousness show significantly reduced functional connectivity in the CM nuclei, and the strength of their connections with the prefrontal and parietal cortices is directly correlated with the patient's level of consciousness [15]. The "neuronal index" constructed based on CM neuronal activity shows a significant positive correlation with the Coma Recovery Scale-Revised (CRS-R) scores, enabling precise differentiation of consciousness levels and prediction of rehabilitation outcomes **[19]**.

Lesion Localization in Self-Perception Disorders : Diseases with self-perception abnormalities as core symptoms exhibit lesions concentrated in the thalamo-limbic pathways:

- Capgras syndrome (delusion of imposters): Lesions involve the prefrontal-thalamic-amygdala pathway [21]
- Cotard syndrome (delusion of being dead): Lesions often affect the thalamus, cingulate gyrus, and prefrontal cortex [22]

- Self-perception disturbances in schizophrenia: Pathological studies confirm abnormal connectivity in the thalamocortical circuits [23]
- **Counterevidence from Locked-In Syndrome** : Patients with locked-in syndrome, due to damage to the lower pons causing paralysis and mutism, retain intact function in the thalamic-midbrain core regions, maintaining full consciousness and intact subjective experience [6,24]. This indicates that as long as the core regions housing the CM remain functional, the "vortex of consciousness" can persist, further supporting the localization of CM as the core of this vortex.

4.4 Core Activities Correlated with Consciousness Clarity — Imaging Evidence

High-Field fMRI Evidence: Multiple independent 3T/7T fMRI studies consistently demonstrate:

- In the awake state, the CM exhibits centralized localized bright activation, with 7T-fMRI showing a sharply defined activation focus significantly higher than surrounding nuclei, bilaterally highly symmetrical [14,16].
- CM activation displays 360° global symmetry, radiating outward from the vortex center in a radial-circular pattern. Functional connectivity analysis indicates uniform radial projections from the CM to the entire brain**[15,16]**.
- Under anesthesia, sleep, and states of impaired consciousness, the BOLD signal of the CM significantly attenuates; signal restoration occurs upon consciousness recovery [14,15].

4.5 Causal Evidence: DBS Stimulation of CM Restores Consciousness

The most direct causal evidence comes from deep brain stimulation (DBS) studies:

- Schiff et al. [17] reported a case of a patient who remained in a minimally conscious state for 6 years following traumatic brain injury. After receiving bilateral CM-Pf complex DBS, the patient's consciousness level significantly improved, restoring abilities such as following commands, uttering words, and watching movies.
- A meta-analysis including 49 patients with chronic disorders of consciousness showed that 7 patients experienced significant recovery of consciousness after DBS treatment, with marked improvement in Coma Recovery Scale-Revised (CRS-R) scores**[16]**.
- Lupi et al.**[18]** demonstrated in an anesthetized animal model that electrical stimulation of the central thalamus directly restores coordinated cortical activity, proving that CM plays a dominant regulatory role in driving whole-brain synchronization.
- Whole-brain synchrony and resting-state functional connectivity confirmed that CM is a key hub of the whole-brain network, exhibiting the strongest functional connectivity strength and phase synchrony among thalamic regions**[14]**. Inhibition of CM under anesthesia directly leads to the collapse of cortical synchronization, whereas electrical stimulation of the central thalamus restores coordinated cortical activity[14,18].

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5 Conclusion

This paper proposes the Consciousness Flow Vortex Model Hypothesis (CFVM-H), with the core proposition that subjective experience is an inevitable physical outcome of neural information flow forming vortex dynamics within closed recursive loops. The three core

dynamic features of this vortex directly map to the three fundamental elements of subjective experience. This mapping requires no additional assumptions but is derived from the physical structure of the vortex itself.

CFVM-H is complementary rather than opposed to existing mainstream theories (GWT, IIT)**[2-5]**. GWT and IIT describe the informational structural features of consciousness, while CFVM-H explains why these informational structures are accompanied by subjective experiences—because information processing occurs within a physical flow field characterized by vortex dynamics.

CFVM-H provides a testable, physics-dynamics-based framework for the "hard problem" of consciousness. If further validated, it would redefine subjective experience from a mysterious "emergent property" to an inevitable product of vortex physical structures, offering a new structured pathway for consciousness research to transition from speculation to empirical investigation.

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