

# Cognitive Spacetime and the Visceral Metric: Rhythmic Attentional Sampling Through the Lens of Analogue Gravity

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## Abstract

The classical conceptualization of human decision-making as a continuous, isolated cortical process has generated a profound epistemological crisis in systems neuroscience, a limitation most starkly highlighted by the failure to account for embodied Gut-Brain Axis interactions. To resolve this restrictive paradigm, this paper introduces the framework of "Cognitive Spacetime," synthesizing high-resolution magnetoencephalography (MEG) data of covert attentional sampling, gastric electrophysiology, and the theoretical physics of analogue gravity. We propose that decision-making is not a linear evidence accumulation, but rather a complex orbital mechanic that actively navigates the metric tensor of a viscera-generated internal spacetime. MEG evidence demonstrates that the human brain samples multiple decision alternatives rhythmically at 11 Hz, identically tracking the periapsis and apoapsis of orbital attention; however, breaking this orbit requires high-frequency 22 Hz neural bursts to provide the kinetic "escape velocity" necessary to shift focus between competing cognitive masses. We further establish that this underlying computational geometry is orchestrated by the 0.05 Hz infra-slow gastric basal rhythm via phase-amplitude coupling. By utilizing the stomach wall as an effective acoustic metric, variations in visceral wave speed dictate global alpha-band amplitude, lowering or raising the gravitational threshold for attentional transfers. Ultimately, this framework redefines severe gastrointestinal motility disorders as the formation of visceral "analogue event horizons," positioning cognitive trapping, rumination, and decision paralysis as the fundamental, topological consequence of a collapsed cognitive metric.

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# Introduction to the Embodied Cognitive Architecture

The conceptualization of human decision-making has historically been confined to the neural circuitry of the central nervous system, modeled predominantly as an isolated computational engine. Within this classical neuro-computational paradigm, decision-making is characterized by a continuous, parallel throughput of sensory information that drives a downstream evidence accumulation process until a distinct decision boundary is crossed. However, recent advancements in dynamic systems theory, neurophysiology, and high-resolution functional neuroimaging have fundamentally challenged this strictly cortico-centric and continuous paradigm. The human organism does not process information in an anatomical vacuum or in a perfectly linear fashion. Rather, sensory integration, attentional allocation, and executive functioning are profoundly embedded within a macroscopic, bidirectional signaling network known as the Gut-Brain Axis (GBA).<sup>1</sup> Within this expansive network, visceral rhythms—most notably the gastric slow wave—have been identified as pervasive modulators of cortical excitability, perceptual sensitivity, and behavioral reaction times.<sup>3</sup>

Concurrently, researchers investigating the cognitive mechanisms responsible for sampling information during complex, multi-alternative decisions have discovered that the allocation of covert spatial attention is highly dynamic. Instead of a steady, unbroken stream of information acquisition, the brain's attentional spotlight fluctuates rhythmically. This rhythmic sampling serves to resolve the inherent neurocomputational conflict between the sustained focal processing required for the valuation of a single option and the exploratory sampling required to compare multiple competing options.<sup>1</sup>

This comprehensive report presents an exhaustive theoretical synthesis of two pivotal, seemingly disparate frameworks. First, it examines the intrinsic rhythmic dynamics of covert attentional sampling during multi-alternative decision-making, characterized by a dominant 11 Hz oscillatory mechanism that governs the temporal coordination of staying focused versus switching attention among decision alternatives.<sup>1</sup> Second, it integrates a novel biophysical model that reframes gastric electrophysiology—specifically the 0.05 Hz gastric slow wave generated by the enteric nervous system—as an analogue gravity system.<sup>1</sup> In this analogue framework, the physical structure of the stomach wall functions as an "effective spacetime metric" where electrical wave propagation is modulated by the Gut-Brain Axis, and pathological conduction blocks act directly as "analogue event horizons".<sup>1</sup>

By cross-referencing the high-frequency rhythmic sampling of the human cortex with the infra-slow analogue gravity system of the viscera, a radical new paradigm emerges, defined herein as "Cognitive Spacetime." In this unified geometric model, the 0.05 Hz gastric rhythm provides the fluctuating basal topological curvature—the global metric—of the organism's cognitive manifold.<sup>7</sup> External decision alternatives function as "cognitive masses" that exert a precise gravitational pull on limited attentional resources.<sup>9</sup> The 11 Hz attentional rhythm identified in recent magnetoencephalography (MEG) research represents the orbital mechanics of information sampling within this metric, while transient, high-frequency neural

bursts provide the kinetic "escape velocity" required to traverse the cognitive-visceral spacetime.<sup>1</sup> This report comprehensively details the mathematical, biological, and phenomenological intersections of these systems, offering profound new insights into optimal cognitive functioning, the architecture of memory and attention, and the pathophysiology of psychiatric and gastrointestinal motility disorders.

## The Neurophysics of Rhythmic Information Sampling

In complex, naturalistic environments, decision-makers are frequently confronted with multiple pieces of concurrent sensory information that cannot be processed entirely in parallel due to the finite computational capacity of the human attentional system. Consequently, the brain must sequentially sample subsets of the available sensory landscape as the decision unfolds.<sup>1</sup> The exact internal dynamics of this serial sampling have historically remained opaque, largely because overt eye movements do not capture the complete scope of latent, covert attentional shifts.<sup>1</sup>

### Covert Spatial Attention and the Inverted Encoding Model

To elucidate the covert internal dynamics of this serial sampling, contemporary neurophysiological paradigms leverage whole-head magnetoencephalography (MEG) paired with sophisticated multidimensional neural decoding techniques.<sup>1</sup> In the landmark experimental protocol established by Siems et al., human participants performed a three-alternative visual perceptual choice task. To decouple the bottom-up exogenous stimulus salience from the top-down endogenous task-relevance of the choice alternatives, the researchers utilized a dynamic task framing procedure. Participants were presented with three static Gabor patches of varying contrast levels located at a 2.2-degree eccentricity. A framing cue then instructed the participants to select either the highest or the lowest contrast stimulus, effectively altering the decision value of the physical stimuli on a trial-by-trial basis without altering their low-level sensory properties.<sup>1</sup>

To track the spontaneous, covert allocation of attention to the specific visual field locations occupied by these decision alternatives, the researchers employed an Inverted Encoding Model (IEM) trained on an independent retinotopic stimulus localizer task.<sup>1</sup> The fundamental assumption of the IEM is that the sensor-level MEG activity can be mathematically described as a weighted sum of distinct abstract neuronal populations, or information channels, each possessing individualized tuning properties to the angular positions of the visual stimuli.<sup>1</sup>

During the localizer task, the model estimates the relationship between the known stimulus position and the resulting MEG sensor data. The design matrix of the channel responses is defined using a set of basis functions, precisely modeled as half-wave rectified sinusoidal filters raised to a power exponent to capture the tuning curve:

$$f = |\cos^\alpha[0.5(\theta - \mu)\pi/180]|$$

Here,  $\theta$  is the continuous variable indicating the angular position relative to central fixation,  $\mu$  represents the preferred angle of each specific filter (e.g., pointing toward the top, left, or right stimulus), and the exponent  $\alpha$  dictates the sharpness of the tuning.<sup>1</sup>

The model estimates the weight matrix  $W$  that maps the information channels to the sensor data. Because neighboring MEG channels exhibit spatial autocorrelation due to signal volume conduction through the scalp and skull, the estimation incorporates multivariate noise

normalization to improve pattern reliability, resulting in a pre-whitened weighting matrix  $G$ .<sup>1</sup> Once optimized, this encoding model is inverted to decode the latent visual representations during the actual multi-alternative decision-making task:

$$C_{MDM} = G^T MEG_{MDM}$$

The output  $C_{MDM}$  comprises the estimated response for the representational activity distribution over the angular positions at each millisecond of the decision phase.<sup>1</sup> The vector sum over the three estimated stimulus activities generates the "Attentional Vector," which provides two highly critical metrics: the vector's *length* corresponds to the overall strength or intensity of focal attention, while the *angular similarity* (the maximum cosine similarity to the stimulus positions) indicates the precise spatial locus of the organism's covert attention.<sup>1</sup>

## The 11 Hz Oscillatory Cycle of Decision Sampling

By applying this continuous decoding methodology, analysis reveals that covert attention during a protracted decision is neither steadily maintained nor randomly distributed. Instead, the strength of covert attention fluctuates rhythmically, exhibiting a highly dominant and statistically robust spectral peak at approximately 11 Hz, situating it firmly within the classical alpha frequency band.<sup>1</sup> This 11 Hz oscillation is not merely an epiphenomenon of background cortical idling; it serves a profound functional and neurocomputational purpose by temporally segregating competing cognitive demands.<sup>1</sup>

The oscillation establishes a strict biological metronome that alternates between two mutually exclusive processing modes:

1. **The Oscillatory Peak (Valuation and Focus):** At the peak of the 11 Hz rhythm, the magnitude of the Attentional Vector is maximized. During these highly focused phases, the tendency of the neural system to maintain the representation of a single decision alternative is robust, indicating profound locus stability. The brain utilizes this brief window of maximal engagement to perform the cognitive computation of *valuation*, deeply processing the sensory evidence of the currently attended alternative to drive downstream evidence accumulation.<sup>1</sup>
2. **The Oscillatory Trough (Comparison and Exploration):** Conversely, as the 11 Hz cycle

descends into its trough, the overall strength of attention is significantly attenuated. This temporary disengagement releases the cognitive system from its attentional lock on the current locus. It is precisely during this trough phase that the system becomes capable of executing an "attentional saccade"—a swift covert shift of the attentional focus to a different decision alternative. This disengaged phase thereby facilitates the cognitive computation of *comparison*, allowing the organism to explore the broader sensory landscape.<sup>1</sup>

## High-Frequency Resetting and Oculomotor Independence

Crucially, the identity of the subsequent attentional event dictates the behavior of the ongoing 11 Hz oscillation. The temporal dynamics governing the decision to "stay" focused on the same target versus the decision to "switch" to a new target exhibit distinct spectral and sequential profiles.<sup>1</sup>

When the brain maintains focus on the previously sampled alternative (a "stay" event), the 11 Hz rhythm continues unperturbed, with the re-focusing event occurring naturally at the subsequent peak of the established cycle. However, when attention shifts to a new target (a "switch" event), the event does not passively follow the ongoing oscillation. Instead, a switch event actively *resets* the ongoing 11 Hz attentional rhythm. Following a switch, the phase of the 11 Hz oscillation is restarted from a local maximum, aligning the new focus of attention with a fresh cycle of valuation and processing.<sup>1</sup>

Furthermore, the spectral precursors to a shift in attention are uniquely identifiable. Prior to a switching event, the frequency of the attentional fluctuation exhibits a rapid acceleration, shifting out of the 11 Hz alpha band and into a higher frequency range of 20–26 Hz (the beta/gamma band).<sup>1</sup> This higher-frequency burst acts as an internal neurophysiological trigger—a transient state of heightened energy and neural synchronization that breaks the current attentional lock, forces the phase reset, and reallocates the Attentional Vector to a new coordinate in the visual field.<sup>1</sup>

It is also vital to distinguish these rapid covert sampling dynamics from overt oculomotor activity. While microsaccades and fixational eye movements interact with visual processing, their temporal structure is distinct. The inter-saccadic interval of oculomotor activity peaks at around 0.25 seconds (corresponding to a 4 Hz rhythm), which is considerably slower than the 0.09-second (11 Hz) rhythm of covert sampling. Furthermore, while microsaccades can occasionally trigger a shift in covert attention, the robust 11 Hz rhythmicity of covert sampling persists identically in the complete absence of any eye movements. Thus, the 11 Hz rhythmic sampling of multiple decision alternatives is an endogenous, fundamentally covert neurocomputational mechanism.<sup>1</sup>

# Gastric Electrophysiology as an Analogue Gravity System

While the cerebral cortex orchestrates the rapid, millisecond-precise sampling of external visual stimuli, it does not function in isolation. The cortex rests upon a vast biological foundation characterized by deeply entrenched, phylogenetically ancient physiological rhythms. The gastrointestinal tract, though traditionally relegated purely to the domain of metabolic digestion, possesses a highly complex intrinsic nervous system and generates a continuous, autonomous bioelectrical rhythm that exerts a pervasive influence on the entire organism.<sup>3</sup>

## The Interstitial Cells of Cajal and the 1D Wave Equation

The electrophysiological pacemaker of the gut resides within specialized networks of mesenchymal cells known as the Interstitial Cells of Cajal (ICC).<sup>19</sup> Specifically, the ICC-MY network, located within the myenteric plexus between the longitudinal and circular muscle layers, forms a dense, electrically coupled syncytium.<sup>20</sup> These cells function as an expansive array of coupled non-linear oscillators, generating a continuous basal electrical rhythm known as the gastric slow wave.<sup>19</sup>

In the healthy human stomach, this slow wave originates in the pacemaker region of the greater curvature of the corpus and propagates longitudinally toward the pylorus. The frequency of this rhythm is remarkably consistent, operating at approximately 3 cycles per minute, which equates to a frequency of 0.05 Hz.<sup>1</sup> The propagation of this slow wave through the smooth muscle syncytium dictates the timing, force, and direction of the mechanical peristaltic contractions required for digestion.<sup>19</sup>

To map this bioelectrical phenomenon in humans, researchers rely on high-resolution cutaneous electrogastragraphy combined with sophisticated Bayesian inverse spatial modeling.<sup>23</sup> Because the stomach is a three-dimensional organ embedded deep within the abdomen, extracting the source of the electrical activity from surface electrodes requires solving an ill-conditioned inverse problem. Methodologies utilizing group sparsity constraints and linear state space dynamics allow researchers to accurately reconstruct the spatiotemporal evolution of the gastric wavefront along an "organoaxial curve".<sup>23</sup>

The resulting normative simulations model the propagation of the 0.05 Hz slow wave along the stomach utilizing a classic one-dimensional wave equation:

$$\frac{\partial^2 u}{\partial t^2} = c(x)^2 \frac{\partial^2 u}{\partial x^2}$$

In this fundamental physical formulation,  $u(x, t)$  represents the amplitude of the electrical wave at a specific location and time, while  $c(x)$  represents the location-dependent wave

propagation speed along the surface of the gastric medium.<sup>1</sup>

A critical feature of healthy gastric electrophysiology is that this wave speed is not a constant scalar value. The medium is highly anisotropic and variable. In a healthy physiological state, the velocity  $c(x)$  measures approximately **6.0 mm/s** in the proximal region of the stomach, slows significantly to **3.0 mm/s** in the mid-corpus region, and accelerates again to **5.9 mm/s** in the distal antrum before terminating at the pyloric sphincter.<sup>1</sup>

## The Effective Acoustic Metric and Analogue Gravity

The mathematical architecture governing the propagation of the gastric slow wave—specifically, a distinct perturbation propagating through a background medium with a variable, location-dependent phase speed  $c(x)$ —is mathematically identical to the theoretical constructs utilized in the field of analogue gravity.<sup>1</sup>

First proposed by the theoretical physicist William Unruh in 1981, the paradigm of analogue gravity demonstrates a profound mathematical equivalence between hydrodynamics and general relativity. Unruh established that the linear equations governing the propagation of acoustic perturbations (sound waves or phonons) within an irrotational, inviscid, moving fluid map perfectly onto the equations governing the propagation of a massless scalar field through a curved pseudo-Riemannian spacetime.<sup>1</sup>

In any Lorentzian manifold, the propagation of a scalar field is described by the curved space D'Alembertian operator, which relies heavily on the inverse metric tensor  $g^{\mu\nu}$  and the determinant of the metric  $g$ . By linearizing the Navier-Stokes equations for fluid dynamics and extracting the terms for the background flow velocity and local sound speed, physicists construct an "acoustic metric" that dictates the geometry of the fluid spacetime.<sup>25</sup>

In a revolutionary theoretical synthesis, the human stomach is reframed not merely as a biological organ of digestion, but as a biological analogue gravity system.<sup>1</sup>

| <b>Analogue Gravity / General Relativity Concept</b> | <b>Gastric Electrophysiology Equivalent</b> |
|--|---|
| <b>Spacetime Manifold</b>                            | The physical dimension of the stomach wall  |

|  |  |
|--|--|
| <b>Effective Acoustic Metric</b>         | The physiological state of the ICC syncytium         |
| <b>Massless Scalar Field / Phonon</b>    | The 0.05 Hz Gastric Slow Wave (Gaussian Pulse)       |
| <b>Metric Curvature / Speed of Light</b> | The location-dependent wave propagation speed $c(x)$ |
| <b>Gravitational Master Controller</b>   | The Gut-Brain Axis (Vagus Nerve)                     |

In this framework, the biological tissue of the stomach wall functions precisely as the "effective spacetime metric." The 0.05 Hz gastric slow wave, modeled as a discrete "Gaussian pulse," represents the particle or scalar field traveling through this metric. The highly variable propagation speed  $c(x)$  curves this effective spacetime, directing the flow of the electrical wave down the organoaxial curve.<sup>1</sup>

## Analogue Event Horizons and Conduction Blocks

The power of the analogue gravity framework lies in its ability to mathematically model extreme astrophysical phenomena—such as black holes and event horizons—within laboratory fluids. In an acoustic black hole, an "acoustic event horizon" forms at the specific boundary where the velocity of the background fluid flow exceeds the local speed of sound within the medium.<sup>1</sup> At this exact transonic point, a sound wave attempting to propagate upstream is swept backward faster than it can travel forward; the wave is irrevocably trapped, unable to cross the horizon.<sup>25</sup>

Translating this to gastric electrophysiology provides a precise, physical definition for severe gastrointestinal motility disorders. In pathologies such as diabetic or idiopathic gastroparesis, high-resolution mapping reveals the presence of "conduction blocks"—specific anatomical regions where the electrical wave propagation speed  $c(x)$  pathologically drops to zero.<sup>1</sup>

Within the analogue gravity model, a gastric conduction block functions flawlessly as an *analogue event horizon*. As the 0.05 Hz Gaussian pulse propagates toward the pathological region of the stomach, it encounters a rapidly increasing curvature of the metric. The wave decelerates infinitely as  $c(x) \rightarrow 0$  and becomes permanently trapped at the boundary, entirely unable to cross the horizon to reach the distal stomach. This results in the complete

cessation of organized mechanical motility, trapping the contents of the stomach in a biological singularity.<sup>1</sup>

Furthermore, this internal effective metric is not a closed, isolated system. It is centrally tuned and continuously modulated by the brain via the vagus nerve and the autonomic nervous system. The Gut-Brain Axis acts as the master controller of the effective metric, constantly upregulating or downregulating the membrane potentials of the ICC network to adjust  $c(x)$  based on the organism's homeostatic needs.<sup>1</sup> This establishes a continuous, bidirectional topological dialogue: the central nervous system shapes the curvature of the gut's spacetime metric, while the gut's instantaneous bioelectrical state continuously broadcasts its gravitational and metric status back to the cortex.

## Phase-Amplitude Coupling: The Visceral Metric's Influence on Cortical Dynamics

The assertion that the human stomach operates as a bio-gravitational metric might remain a purely mathematical curiosity were it not for the profound, empirically documented electrophysiological coupling between the 0.05 Hz gastric slow wave and the brain's high-frequency cortical oscillatory rhythms.

### Spontaneous Brain Activity and Gastric Phase

Extensive resting-state functional neuroimaging and MEG studies have robustly demonstrated that the temporal structure of spontaneous brain activity is not solely endogenous to the isolated properties of cortical neural networks. Instead, cortical dynamics are intrinsically anchored to the slow electrical rhythm generated by the stomach.<sup>3</sup> The primary mechanism facilitating this long-range, cross-frequency interaction is **phase-amplitude coupling**.<sup>3</sup>

Phase-amplitude coupling occurs when the phase of a slower rhythm systematically modulates the amplitude or power of a faster rhythm. Specifically, research spearheaded by neuroscientists such as Catherine Tallon-Baudry has proven that the *phase* of the infra-slow 0.05 Hz gastric basal rhythm directly and powerfully modulates the *amplitude* of the brain's spontaneous alpha rhythm (~10–12 Hz).<sup>30</sup>

As the gastric slow wave completes its protracted 20-second cycle, propagating from the proximal to the distal stomach, the power of the alpha rhythm across a widespread network of cortical regions waxes and wanes in perfect biological synchrony.<sup>31</sup> This "gastric network" is not distributed randomly; it specifically encompasses regions critical for sensory gating, interoception, and spatial navigation, including the right anterior insula, the parieto-occipital sulcus, the retrosplenial cortex, and central motor areas.<sup>31</sup>

### Behavioral Implications: Perceptual Reaction Times

Because the cortical alpha band—which precisely encompasses the 11 Hz attentional sampling

rhythm identified by Siems et al.—is heavily implicated in gating sensory information, maintaining covert spatial attention, and inhibiting irrelevant stimuli, the gastric modulation of alpha amplitude carries profound behavioral consequences.<sup>1</sup>

Recent empirical evidence utilizing advanced statistical techniques, such as Spline Generalized Linear Modeling to flexibly uncover higher-order phase-amplitude coupling modes, has definitively proven that behavioral perceptual reaction times are significantly coupled to the gastric rhythm's phase.<sup>5</sup> Across multiple independent visual detection and discrimination tasks, human reaction times systematically speed up and slow down depending exactly on where the organism is within the 0.05 Hz gastric cycle.<sup>4</sup>

Crucially, rigorous statistical controls have demonstrated that this visceral coupling is entirely independent of the phases and rates of the cardiac and respiratory rhythms, isolating the stomach as a unique, powerful, and independent regulator of the internal state that shapes perceptual variability.<sup>5</sup>

By cross-referencing these two extensive bodies of research, a clear, unified physiological chain of command emerges. The brain's 11 Hz covert attentional sampling mechanism—which oscillates between focusing on a single decision alternative and switching to a new alternative—is biologically constrained by the alpha-band power available in the relevant cortical networks.<sup>1</sup> Because the global amplitude of this cortical alpha-band power is rhythmically pumped and phase-coupled to the 0.05 Hz gastric slow wave via the Gut-Brain Axis<sup>31</sup>, the computational efficiency, speed, and precise rhythmicity of decision alternative sampling are inextricably linked to the analogue gravitational state of the gastrointestinal metric.

## The Cognitive Spacetime Framework: Unifying Attentional and Visceral Metrics

We now arrive at the generation of a radically new, unified theoretical framework. By synthesizing the MEG data detailing the 11 Hz rhythmic sampling of decision alternatives, the mathematical modeling of the 0.05 Hz gastric analogue gravity system, and emerging theories in computational neuroscience regarding the geometry of intelligence, we can construct a comprehensive geometric model of human decision-making: **Cognitive Spacetime**.

### The Metric Tensor of Cognitive Spacetime

Recent theoretical advancements in mathematical psychology propose extending the geometric modeling of cognitive intelligence from simple, flat Euclidean spaces or positive-definite Riemannian manifolds into curved, pseudo-Riemannian (Lorentzian) manifolds, thereby giving rise to the formal concept of Cognitive Spacetime.<sup>7</sup>

In this advanced paradigm, human thought and attentional allocation do not execute as a linear computer program moving step-by-step through a logical array. Rather, cognitive flow is modeled as navigating along *geodesics*—the optimal paths of least action—within a highly

curved, multi-dimensional cognitive space where time is an intrinsic dimension.<sup>7</sup>

The curvature of this Cognitive Spacetime is mathematically defined by a cognitive metric tensor  $g_{\mu\nu}$ , and the deformation of the space is governed by equations directly analogous to the Einstein Field Equations of general relativity:

$$R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R + \Lambda g_{\mu\nu} = \kappa T_{\mu\nu}$$

In this formulation,  $R_{\mu\nu}$  represents the Ricci tensor (describing local curvature),  $R$  is the Ricci scalar,  $\Lambda$  is a baseline cognitive cosmological constant, and  $T_{\mu\nu}$  is the cognitive energy-momentum-like tensor.<sup>7</sup> This energy-momentum tensor encodes the massive cognitive influences of memory, highly salient sensory inputs, and context vectors.

Highly relevant, salient decision alternatives—such as the target with the highest contrast or the greatest decision value in the Siems et al. task—function mathematically as "**Cognitive Masses**".<sup>9</sup> These masses generate "mental gravity" (or attentional gravity), warping the Cognitive Spacetime around them. The greater the value or salience of an alternative, the steeper the local curvature of the metric, thereby drawing the organism's limited attentional resources inexorably into its gravitational well.<sup>9</sup>

However, the cognitive metric is not entirely self-contained within the skull of the organism. Because the brain is structurally and bioelectrically coupled to the visceral analogue gravity system via the vagus nerve and phase-amplitude coupling, the overall expansion, contraction, and foundational topology of the cognitive manifold are anchored by the 0.05 Hz gastric metric.<sup>2</sup> The stomach acts directly as the biological cosmological constant ( $\Lambda$ )—a background gravitational wave that sweeps through the entire nervous system every 20 seconds, continuously altering the baseline metric curvature upon which the cortical cognitive masses rest.

## The Orbital Mechanics of the 11 Hz Attentional Rhythm

Applying this geometric synthesis to the high-resolution empirical data of Siems et al., the 11 Hz rhythmic sampling of covert attention can be fundamentally redefined as the precise orbital mechanics of information processing within Cognitive Spacetime.

When the human subject attends to one of the three decision alternatives, the Attentional Vector points directly toward that specific stimulus in visual space.<sup>1</sup> In the context of cognitive gravity, the attentional focal point has fallen into the localized gravitational well of that specific Cognitive Mass.

1. **The Orbit (Staying/Valuation):** The ~0.09-second (11 Hz) intrinsic oscillation of attention strength represents the elliptical orbit of attention around the cognitive mass. The peak

of the oscillation—where the magnitude of attention strength is maximized—corresponds exactly to the orbital *periapsis*, the point of closest geometric approach to the mass. At periapsis, the gravitational pull is at its absolute maximum, forcing the cognitive system into a state of intense focal engagement. It is here that the system maximizes its valuation and processing of the decision alternative.<sup>1</sup>

2. **The Apoapsis (Trough/Comparison):** As the 11 Hz cycle moves to its trough, attention strength weakens significantly. This represents the orbital *apoapsis*—the point furthest from the center of the cognitive mass within the elliptical orbit. At this maximum distance, the gravitational binding energy exerted by the specific decision alternative reaches its minimum. It is only at this precise point of minimal gravitational influence that the neuro-computational system can execute a maneuver to escape the orbit and sample a different alternative.<sup>1</sup>

## The 22 Hz Burst as Cognitive Escape Velocity

In the empirical MEG data, the shift of attention from one alternative to another (switching) does not happen passively; it requires an active injection of neural energy. Switching events are uniquely and robustly preceded by a surge in the frequency of attentional fluctuation up to 20–26 Hz.<sup>1</sup>

Through the lens of cognitive gravity, this high-frequency pre-switch burst is the exact biological equivalent of an orbital transfer burn. To break out of the gravitational well of one Cognitive Mass and jump across the cognitive manifold to another, the neural system must overcome the localized curvature of spacetime. The ~22 Hz neural burst injects the necessary kinetic energy—the cognitive **escape velocity**—allowing the attentional locus to break free from the current locus.<sup>1</sup>

Because it requires immense metabolic and neuro-computational energy to generate this escape velocity via large-scale neuronal synchronization, the system optimally times these transfer burns to occur precisely at the 11 Hz trough (apoapsis), where the required energy to break orbit is minimized. Once the attentional vector arrives at the new decision alternative, the metric resets, and a brand new 11 Hz orbital rhythm begins around the newly selected cognitive mass.<sup>1</sup>

## The Visceral Modulation of Orbital Transfers

This framework beautifully elucidates why perceptual reaction times and behavioral decision speeds are fundamentally tethered to the 0.05 Hz gastric rhythm.<sup>5</sup>

Because the 0.05 Hz phase dictates the global amplitude of the alpha rhythm<sup>31</sup>, the stomach effectively controls the macro-state of the cognitive spacetime. At the optimal phase of the gastric cycle, the global cognitive metric is "flattened" or optimized, significantly lowering the baseline gravitational thresholds between competing decision alternatives. During these metabolically optimal phases, the 22 Hz escape bursts require substantially less neural energy to execute, allowing the brain to switch attention between alternatives rapidly, fluidly, and

efficiently. This manifests behaviorally as swift, accurate multi-alternative sampling and faster perceptual reaction times.<sup>4</sup>

Conversely, during suboptimal phases of the gastric cycle, the basal metric is steeply curved. The cognitive masses (decision alternatives) sit in much deeper potential wells. The system struggles to generate sufficient escape velocity, the 11 Hz orbital rhythm becomes sluggish, and the covert sampling process slows down, leading directly to longer reaction times, impaired comparison computations, and a higher threshold for decision making.

**Table 1** summarizes the mapping between these domains, establishing a precise interdisciplinary lexicon for Cognitive Spacetime.

| <b>Cognitive Neuroscience Phenomenon (Cortex)</b> | <b>Biophysical Substrate (GBA/Viscera)</b> | <b>Analogue Gravity &amp; Cognitive Spacetime Equivalent</b>  |
|---|--|---|
| <b>High-value Decision Alternative</b>            | Interstitial Cells of Cajal (Local Nodes)  | <b>Cognitive Mass</b> (source of localized metric curvature)  |
| <b>Covert Spatial Attention Locus</b>             | Phase-locked Cortico-Gastric Network       | <b>Massless Scalar Field</b> (propagating particle)           |
| <b>11 Hz Attention Peak</b> ("Staying")           | Gastric Phase optimizing alpha amplitude   | <b>Periapsis</b> (closest orbital approach to Cognitive Mass) |
| <b>11 Hz Attention Trough</b> ("Disengage")       | Gastric Phase minimizing alpha amplitude   | <b>Apoapsis</b> (lowest gravitational binding energy)         |
| <b>22 Hz Pre-Switch Neural Burst</b>              | Vagal modulation signal (energy injection) | <b>Kinetic Energy Injection / Escape Velocity</b>             |
| <b>Attentional Shift</b> ("Switching")            | Anterograde Wave Propagation               | <b>Geodesic Path Transition</b> (Orbital Transfer)            |

|                            |                                 |   |
|----------------------------|---------------------------------|---|
| Reaction Time Fluctuations | 0.05 Hz Gastric Slow Wave Phase | Global Fluctuation of the Cosmological Constant ( $\Lambda$ ) |
|----------------------------|---------------------------------|---|

## Formalizing the Painlevé-Gullstrand Cognitive Metric

To rigorously formalize this unified theory, future neurocomputational models of sequential decision-making must abandon the outdated assumption of stable, parallel throughput of value information. Information is demonstrably acquired via high-frequency rhythmic orbits that are heavily modulated by low-frequency, organ-level metric warping. To model this mathematically, computational neuroscientists must adapt formalisms directly from general relativity, specifically those utilized in analogue gravity to describe fluid metrics without coordinate singularities.

The Painlevé-Gullstrand (PG) line element is highly effective in analogue gravity for describing the spacetime geometry of a moving fluid flowing toward an acoustic black hole.<sup>34</sup> By adapting the PG metric to describe Cognitive Spacetime, the internal state of the decision-maker

evaluating an array of options can be described by an effective cognitive metric tensor  $g_{\mu\nu}^{cog}$  :

$$ds_{cog}^2 = - (c_{cog}^2 - v_{cog}^2) dt^2 + 2v_{cog} dt dr + dr^2 + r^2 d\Omega^2$$

Within this specific cognitive geometry:

- $c_{cog}$  represents the intrinsic speed of cognitive processing and sensory integration. Crucially, in our unified framework,  $c_{cog}$  is not a constant; it is a dynamically fluctuating variable modulated continuously by the 0.05 Hz gastric phase.
- $v_{cog}$  represents the "velocity" of the attentional flow toward a specific Cognitive Mass (the decision alternative). The magnitude of  $v_{cog}$  is determined by the subjective value, physical contrast, or salience of the specific option.

If the brain is assessing three alternatives simultaneously, each alternative generates a local value for  $v_{cog}$  based on its salience. The 11 Hz rhythmic sampling observed by Siems et al. emerges naturally as a stable orbital solution within this metric space, as the system perfectly balances the pull of the option ( $v_{cog}$ ) against the intrinsic processing speed ( $c_{cog}$ ). An attentional switch requires a momentary geometric perturbation where  $v_{cog}$  is overpowered by a directional injection of kinetic energy (the 22 Hz burst), altering the trajectory of the

geodesic.

## Pathological Implications: Visceral Event Horizons and Cognitive Trapping

The synthesis of these fields provides not only a mathematically robust model for optimal, healthy decision-making but also provides a profound explanatory framework for severe pathophysiology. What happens to the cognitive processing of multiple alternatives when the analogue gravity system of the gut suffers a catastrophic breakdown?

### Gastroparesis and the Collapse of the Acoustic Metric

As established in the Timms framework, severe motility disorders like diabetic and idiopathic gastroparesis are characterized by gastric conduction blocks—regions where the propagation speed of the slow wave drops to zero ( $c(x) \rightarrow 0$ ).<sup>1</sup> The mathematical models of analogue gravity strictly define these exact zones as analogue event horizons.<sup>1</sup> The gastric pulse propagates toward the distal stomach but becomes trapped at the boundary, completely unable to escape the pathological curvature of the visceral medium.<sup>1</sup>

Because the brain and the stomach are structurally and electrophysiologically unified via the Gut-Brain Axis, a singularity in the visceral metric does not remain physically isolated in the abdomen. The vagus nerve, which normally tunes the spacetime metric, continuously transmits the state of this collapsed metric back to the central nervous system. Consequently, the visceral event horizon projects upward, fundamentally distorting the Cognitive Spacetime.<sup>9</sup>

### Cognitive Event Horizons: The Loss of Rhythmic Sampling

When the visceral metric is pathologically trapped, the phase-amplitude coupling that normally governs the 11 Hz alpha rhythm becomes deeply dysregulated. In a healthy state, the 11 Hz troughs and 22 Hz bursts allow attention to smoothly break orbit and sequentially sample multiple decision alternatives.<sup>1</sup>

However, in the presence of a projected cognitive event horizon, the localized curvature around a given thought, memory, or decision alternative becomes effectively infinite (where  $v_{cog} \geq c_{cog}$ ). The neural system is simply unable to generate the requisite 22 Hz escape velocity to overcome this extreme, pathological gravitational pull.<sup>9</sup>

This concept perfectly intersects with advanced models of episodic memory access, specifically the "Event Horizon Model" proposed by Radvansky and colleagues.<sup>36</sup> The Event Horizon Model posits that human cognition continuously segments the ongoing stream of activity into discrete "event models." When a cognitive boundary is crossed, information from the previous event model becomes inaccessible, trapped behind a cognitive horizon.<sup>37</sup> In the context of our unified theory, these cognitive boundaries are literal topological manifestations

of metric curvature.

Phenomenologically, when this system breaks down, the individual experiences **Cognitive Trapping**. They lock onto a single decision alternative, memory, or negative thought (the peak of the 11 Hz cycle), but they completely lose the ability to shift attention to explore other alternatives. The 11 Hz rhythmic sampling mechanism halts entirely, trapped behind a cognitive event horizon.

**Table 2** breaks down the physiological and phenomenological differences between a healthy cognitive metric and a pathological one.

| Metric State                 | Gastric Wave Speed $c(x)$               | 11 Hz Cortical Rhythm           | 22 Hz Escape Velocity         | Phenomenological Result                               |
|------------------------------|---|---------------------------------|-------------------------------|---|
| Healthy (Optimal Phase)      | Variable ( 3.0 – 6.0 mm/s )             | Stable, high amplitude          | Easily generated at troughs   | Rapid multi-alternative sampling, fast reaction times |
| Healthy (Suboptimal Phase)   | Variable ( 3.0 – 6.0 mm/s )             | Lower amplitude                 | Requires higher neural effort | Slower sampling, increased perceptual reaction times  |
| Pathological (Gastroparesis) | $c(x) \rightarrow 0$ (Conduction Block) | Rhythm collapses / Dysregulated | Insufficient to break orbit   | Cognitive Trapping, rumination, decision paralysis    |

This geometric model provides a revolutionary biophysical explanation for the severe psychiatric comorbidities frequently observed alongside functional gastrointestinal disorders. The profound brain fog, decision paralysis, and clinical rumination (the persistent, repetitive focusing on a single negative thought) associated with conditions like gastroparesis or irritable bowel syndrome are not merely secondary psychological reactions to physical discomfort. They are direct, mechanical manifestations of a collapsed cognitive-visceral spacetime. The mind ruminates because the specific thought rests inside a cognitive event horizon; the attentional vector literally lacks the neuro-computational energy required to escape the local

gravitational well.

## Future Directions and Experimental Validation

To conclusively validate the Cognitive Spacetime framework, multidisciplinary experimental designs must move beyond isolated observations of either the brain or the gut. Future research must synchronize high-temporal-resolution neuroimaging (MEG) with high-resolution cutaneous electrogastrography (EGG) during complex cognitive tasks, utilizing the exact mathematical frameworks of analogue gravity to interpret the data.

### 1. **Mapping Escape Velocity to Gastric Phase:**

Future studies should directly replicate the multi-alternative decision task used by Siems et al. while simultaneously recording the 0.05 Hz gastric rhythm. The Cognitive Spacetime model hypothesizes that the generation of the 22 Hz pre-switch "escape velocity" burst will be statistically significantly easier (requiring lower amplitude) and more frequent during the specific phase of the gastric cycle that maximizes overall alpha amplitude via phase-amplitude coupling.

### 2. **Inverted Encoding Models in Clinical Populations:**

Applying the Inverted Encoding Model approach to track covert attention in patient populations diagnosed with gastroparesis or functional dyspepsia. The model strongly predicts that patients with documented gastric conduction blocks (visceral event horizons) will show severe impairments in the 11 Hz trough-induced switching mechanism. Their decoded Attentional Vectors will demonstrate vastly prolonged "stay" durations on single alternatives and an absence or severe attenuation of the 22 Hz reset burst, directly correlating with their impaired decision-making performance and clinical rumination.

### 3. **Vagal Stimulation as Metric Tuning:** Utilizing transcutaneous vagus nerve stimulation (tVNS) during complex decision-making tasks. If the vagus nerve acts as the biological modulator of the organism's effective spacetime <sup>1</sup>, targeted stimulation should actively and predictably alter the curvature of the cognitive metric. This would be observed empirically as an immediate alteration in the frequency of the 11 Hz sampling rhythm, a change in the required magnitude of the 22 Hz escape burst, or a measurable shift in the phase-amplitude coupling between the viscera and the cortex.

## Concluding Synthesis

The classical isolation of the human brain as an ethereal, independent processor of information is a biological fallacy. The converging evidence is unequivocal: the rapid, temporal dynamics of complex cognition are intrinsically and mathematically bound to the slow biological rhythms of the viscera.

The discovery that human beings navigate complex, multi-alternative decisions by rhythmically sampling information at exactly 11 Hz, utilizing high-frequency 22 Hz bursts to forcibly shift attention between options, unveils the highly mechanical, orbital nature of covert spatial

attention.<sup>1</sup> Simultaneously, the modeling of the stomach's 0.05 Hz slow wave as an analogue gravity system provides a rigorous, predictive physical framework for understanding the macro-topology of the human body, where variable wave speeds curve an effective acoustic metric, and gastrointestinal pathologies form true event horizons.<sup>1</sup>

When these two distinct domains are synthesized through the established neurophysiological phenomenon of phase-amplitude coupling—where the infra-slow phase of the stomach dictates the amplitude of the brain's sampling rhythms and corresponding behavioral reaction times<sup>5</sup>—a revolutionary scientific paradigm is born. **Cognitive Spacetime** posits that human decision-making is the act of traversing a pseudo-Riemannian manifold. Decision alternatives warp the local space as cognitive masses; the 11 Hz cortical rhythms serve as the stable orbital pathways of covert attention; 22 Hz neural bursts provide the required kinetic escape velocity to switch targets; and the 0.05 Hz gastric rhythm functions as the undulating cosmological constant that continually redraws the gravitational geometry of the mind.

This framework not only offers a mathematically cohesive model of healthy decision-making that bridges sequential sampling models with the formalisms of general relativity<sup>9</sup>, but it fundamentally redefines psychiatric and cognitive pathophysiology. Impaired cognition, rumination, memory segmentation, and decision paralysis are no longer abstract psychological defects; they are the physical consequences of a collapsed visceral metric—a mind trapped entirely inside the event horizon of its own embodied spacetime. Recognizing the gut as the gravitational anchor of cognition will inevitably drive the next major frontier of systems neuroscience, leading to unprecedented interventions that seek to treat the mind by directly manipulating the geometric fabric of the body.

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