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[Gerd Leidig](#) *

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Article

Affect as Pacemaker: How Elation and Anxiety Govern Brain-World Alignment via Affective Criticality

Gerd Leidig

Independent Researcher, Cologne, Germany; ORCID iD: <https://orcid.org/0009-0007-6751-1373>;
gerd.leidig@gmail.com

Abstract

The alignment between neural dynamics and environmental structures constitutes a fundamental challenge in neuroscience. While Georg Northoff's Temporo-Spatial Theory of Consciousness (TTC) posits a "common currency" of temporo-spatial dynamics, the mechanistic operationalization of this alignment remains unspecified. This report integrates the TTC with the Affective Criticality Hypo proposed by Tucker, Luu, and Friston (2025). We propose that consciousness and optimal brain-world alignment emerge when the neural system operates in a regime of Excitatory-Inhibitory (E/I) precision balance. Specifically, we identify the affective qualities of elation and anxiety not as epiphenomenal accompaniments, but as constitutive control parameters regulating precision weighting in active inference. Elation corresponds to excitatory precision (E), enhancing prior confidence, while anxiety corresponds to inhibitory precision (I), enhancing sensory vigilance. This balance is homeostatically regulated through sleep-wake cycles, where NREM and REM sleep serve as subcritical and supercritical excursions, respectively. We provide a formalization of this process within the variational free energy framework and compare its explanatory power against alternative theories (e.g., Binding by Synchrony, Population Clocks). We conclude that affective criticality offers a neurobiologically grounded mechanism for the brain-world alignment, transforming the "hard problem" of consciousness into a problem of precision-regulated inference.

Keywords: affective criticality; brain-world alignment; active inference; excitatory-inhibitory balance; temporo-spatial theory; sleep consolidation; precision weighting

Public Significance Statement

This research redefines the role of emotions—specifically elation and anxiety—not as mere side effects of thought, but as the fundamental "pacemakers" that keep the human brain in sync with the external world. By framing consciousness as a dynamic process of alignment, the study demonstrates how our feelings act as biological control dials, balancing our internal expectations with external reality. Furthermore, it highlights the vital role of sleep in recalibrating this delicate balance. These insights suggest that many mental health challenges may stem from a "miscalibration" of this internal timing system, opening new avenues for understanding and treating psychiatric disorders through the lens of neural and affective synchronization.

Introduction: The Problem of Brain-World Alignment

The phenomenon of brain-world alignment describes a fundamental process in neuroscience: the establishment of a temporal and structural correspondence between the physical patterns of the external world and the dynamic activity of the brain (Northoff, 2022; Tucker et al., 2025). This alignment is not merely a matter of signal detection but involves the profound integration of information across various timescales, forming the basis for cognitive functions such as attention, memory, and consciousness (Northoff, 2018). The central challenge lies in understanding how the

brain continuously translates oscillations, rhythms, and wave patterns from the physical world—whether the tonal frequency of conversation, light intensity fluctuations, or mechanosensory impulses—into a synchronized pattern of action potentials and neurochemical signals (Canolty et al., 2006; Engel & Fries, 2010).

While established theories, such as the Temporo-Spatial Theory of Consciousness (TTC) developed by Georg Northoff and colleagues, offer a powerful metatheory of correspondence, the question of the concrete mechanism operationalizing this alignment remains largely open (Northoff, 2023). The TTC postulates that the correspondence between neuronal states and the physical world occurs at a fundamental level of temporo-spatial dynamics rather than pure representation. Consciousness arises when the intracranial time dynamics of the brain align with external time dynamics, defined as a "common currency" (Northoff, 2022).

This report addresses this gap by integrating the work of Tucker, Luu, and Friston (2025), who propose the Hypothesis of Affective Criticality. This hypothesis posits that consciousness and optimal brain-world alignment emerge when the neuronal system operates in a regime of Excitatory-Inhibitory (E/I) precision balance (Tucker et al., 2025). This state resides at the fine line between complete order (rigid, predictable activity) and complete disorder (chaotic, irrelevant activity)—a point known as the "critical point" (Beggs & Plenz, 2003; Hesse & Gross, 2014). We argue that affective qualities serve as the control parameters that maintain this criticality.

The Affective Dimension of Criticality: Precision as a Control Variable

The decisive contribution of this synthesis lies in identifying the affective qualities of elation and anxiety not as epiphenomenal accompaniments of thought, but as constitutive elements of the inferential process itself (Hesp et al., 2021; Tucker & Luu, 2012). These affective signals serve as control variables determining how strongly internal predictions (Priors) are weighted against external sensory evidence (Likelihoods). The hypothesis distinguishes two primary, dualistic control systems, each associated with a specific affective quality (Tucker et al., 2025):

1. **Excitatory Precision (E):** This system is linked to the affective quality of elation or phasic arousal (Tucker & Luu, 2012). It serves to increase the precision of internal predictive models (Priors). High E-values indicate that the brain strongly believes in its own expectations. This leads to an expansion of the conceptual scope, promotes the generation of new, creative predictions, and makes the system less sensitive to minor sensory errors (Isen, 1987; Tucker, 2007). Technically, E scales the complexity term in the Bayesian inference formula, measuring confidence in the internal generative model (Friston, 2010).
2. **Inhibitory Precision (I):** This system is linked to the affective quality of anxiety or tonic activation (Tucker & Luu, 2012). It increases the precision of sensory evidence (Likelihoods). High I-values signal high vigilance for the external world, sharpening error correction and narrowing the associative scope (Tucker et al., 2025). The brain trusts its own representations less and direct sensory information more. In the formal model, I scales the accuracy term, measuring the fit of predictions with real evidence (Friston, 2010).

The balance of both systems is described by the precision ratio, $\rho = E/I$. Optimal states of brain-world alignment occur when this ratio oscillates in the critical regime (Tucker et al., 2025). A dominant I leads to overfitting to evidence (rigid, inflexible reactions), while a dominant E leads to neglect of reality and excessive generalization (flexible, unrealistic predictions). Only the critical balance enables maximum adaptive plasticity and the most effective minimization of prediction errors, implying minimal Variational Free Energy (F) (Friston, 2010).

This conception fundamentally transforms the view of the interaction between brain and world. Instead of a passive mapping of external patterns via neuronal activity, alignment becomes an active, dynamic process of precision-controlled inference. The physical features of the environment—their rhythms, frequencies, and amplitude modulations—are translated into the electromagnetic and

neurochemical language of the brain by affectively controlled precision determining how this information is processed (Tucker et al., 2025).

Table 1. Control Parameters and Their Functions in Alignment.

Control Parameter	Affective Quality	Neurophysiological Correlate	Function in Alignment
E (Excitatory Precision)	Elation, Phasic Arousal	θ - γ Coupling, ACh, Phasic LC-NE, Lemnothalamic Projections	Increases Prior Precision; expands conceptual scope; generates feedforward predictions
I (Inhibitory Precision)	Anxiety, Tonic Activation	α - β Oscillations, Tonic LC-NE, VTA-D2/D4, Collothalamics Projections	Increases Sensory Precision; sharpens feedback correction; stabilizes sensory evidence
$\rho = E/I$ (Precision Ratio)	Affective Balance	Scale-invariant Correlations, 1/f Spectrum, Neural Avalanches	Defines the critical regime state for optimal alignment

Note. Adapted from Tucker et al. (2025). This table concretizes the abstract theory for comparative analysis, linking affective qualities directly to specific neurophysiological patterns and inferential functions.

An external rhythm, such as the syllable frequency in speech (~4–8 Hz), can entrain the phase of endogenous theta oscillations. The prevailing affective precision (whether E-dominated or I-dominated) then determines whether this coupling is used to generate expansive predictions (E-dominated, θ - γ coupling) or for precise error correction (I-dominated, α - β oscillations) (Canolty et al., 2006; Engel & Fries, 2010). Thus, affective qualities become functional control variables steering the weighting of prediction against evidence in the real-time process of thinking and seeing (Hesp et al., 2021).

Neurobiological Implementation: Dual Limbic Systems as Affective Oscillators

The hypothesis of affective criticality requires a plausible anatomical and neurophysiological basis to explain how the two dual control systems—excitatory (E) and inhibitory (I) precision—are implemented. Tucker, Luu, and Friston (2025) propose that these systems are not merely abstract mathematical quantities but rely on specific, hierarchically organized neuronal networks: the dual limbic systems, enabling vertical integration of control across multiple timescales (Luu et al., 2024).

The model distinguishes two main components of the limbic system, which undertake different inferential tasks depending on their orientation (dorsal/ventral) and projection patterns (limbifugal/limbipetal) (Tucker & Luu, 2012):

1. The Dorsal Limbic Papez Circuit: This system is associated with excitatory (E) regulation (Tucker et al., 2025). It is characterized by a minimally developed granular layer and primarily supports excitatory, feedforward (limbifugal) projections. This type of signal transmission is ideal for generating top-down predictions about future states of the world. The affective quality assigned to this system is phasic arousal, experienced as the feeling of elation (Tucker & Luu,2012). The neurobiological basis lies in projections from the pontine brainstem (Reticular Activating System), projecting via the lemnothalamus to the cortex, triggering rapid, phasic excitation (Luu et al., 2024).
2. The Ventral Limbic Yakovlev Circuit: This system is assigned to inhibitory (I) regulation (Tucker et al., 2025). It possesses a pronounced granular layer rich in inhibitory interneurons, making it particularly suitable for performing bottom-up error corrections via feedback (limbipetal) projections. The associated affective quality is tonic activation, experienced as anxiety (Tucker & Luu, 2012). The neurobiological basis comprises projections from the midbrain (VTA), reaching the cortex via the collothalamus, generating long-lasting, tonic excitability (Luu et al., 2024).

These two systems form part of a larger, hierarchically organized control loop utilizing subcortical arousal systems as fundamental pacemakers (Tucker et al., 2025). Subcortical systems provide basal neuromodulatory rhythms (Norepinephrine, Dopamine, Acetylcholine, Serotonin) controlling global cortical excitability (Mesulam, 1989). A decisive mechanism synchronizing these

control systems across various timescales is Cross-Frequency Coupling (CFC), particularly Phase-Amplitude Coupling (PAC) (Canolty et al., 2006). In PAC, the phase of a slow oscillation (e.g., Theta) modulates the amplitude of a faster oscillation (e.g., Gamma). Neurotransmitters like Acetylcholine and Dopamine play a decisive role here, modulating the strength and stability of these coupling patterns through phase-dependent release (Tucker et al., 2025).

Formalization of Alignment: Affective Criticality in the Variational Free Energy Equation

The theoretical power of the affective criticality hypothesis lies in its ability to embed intuitive notions about affective and cognitive processes into the rigorous mathematical framework of Active Inference (Friston, 2010; Parr & Friston, 2017). Active Inference postulates that all biological systems, including the brain, control their behavior to maintain their state within a limited region of state space by maximizing the probability of their own existence (Friston, 2010). The central principle governing this behavior is the minimization of Variational Free Energy (F) (Friston, 2010).

The basic formula of variational free energy F for a given generative model $p(o, s)$, describing both sensory evidence o and the causing states of the world s , can be formulated with respect to an approximate posterior distribution $q(s)$ of the agent as follows (Friston, 2010):

$$F(q, o) = D_{KL}[q(s) \parallel p(s)] - \mathbb{E}_q[\ln p(o | s)]$$

This expression divides into two terms: The first term, the Kullback-Leibler divergence D_{KL} , represents the complexity of the generative model and measures the difference between the agent's a-priori belief about the states of the world ($p(s)$) and its current, approximate belief ($q(s)$). The second term represents the accuracy or expected log-likelihood and measures how well the agent's predictions ($p(o | s)$) match the actually received sensory evidence (o) (Friston, 2010).

The Criticality Hypothesis by Tucker, Luu, and Friston (2025) extends this equation by introducing the affective control parameters E (excitatory precision) and I (inhibitory precision) as multiplicative weights into both terms (Tucker et al., 2025). These weights function as gain-control parameters steering the relative importance of complexity and accuracy (Parr & Friston, 2017). The modified equation reads:

$$F(q, o) = \mathbb{E}_q[\ln q(s) - E \cdot \ln p(s)] + D_{KL}[q(E)q(I) \parallel p(E, I)] - \mathbb{E}_q[I \cdot \ln p(o | s)]$$

- Role of Parameter E (Excitatory Precision): Parameter E multiplies the Prior term, i.e., complexity. High values for E (corresponding to the affective quality of elation) increase the "weight" or "precision" of the Priors. This means the agent strongly believes in its internal model and attempts to keep the complexity of its model low, even if this means some sensory error signals are ignored or dismissed as noise (Tucker, 2007).
- Role of Parameter I (Inhibitory Precision): Parameter I multiplies the Likelihood term, i.e., accuracy. High values for I (corresponding to the affective quality of anxiety) increase the precision of sensory evidence. The agent becomes extremely sensitive to prediction errors and strives to adapt its predictions perfectly to sensory reality. This reduces the complexity of the model but can lead to rigid, stereotypical reactions allowing no creative generalizations (Tucker & Luu, 2012).

The goal of Active Inference is the minimization of F . The affective criticality hypothesis predicts that this minimum is reached not at a point, but along a curve defined by the optimal balance of E and I . This state, where the precision ratio $\rho = E/I$ oscillates in the critical regime, minimizes free energy and maximizes the adaptive plasticity of the system (Tucker et al., 2025).

5. The Pacemaker of Criticality: Sleep-Wake Cycles as Homeostatic Regulation

The assumption that the brain must operate in the critical regime to achieve optimal alignment raises the question of how this sensitive equilibrium is maintained. The answer lies in cyclic

regulation via the sleep-wake rhythm. Tucker, Luu, and Friston indicate that nightly excursions from the critical regime are not an interruption of alignment but its constitutive prerequisite (Tucker et al., 2025).

Table 2. Sleep Phases and Their Functions for Alignment.

Sleep Phase	Dominant Parameter	Neurophysiology	Function for Alignment
NREM (N1–N3)	I ↑(Inhibitory)	Slow Oscillations, Spindles, Hippocampal Ripples, GABAergic	Inhibitory Specification: Selection and stabilization of unpredicted events; Explicit memory consolidation
REM	E ↑(Excitatory)	θ - γ Coupling, PGO Waves, Cholinergic Arousal	Excitatory Reintegration: Creative recombination of Priors; Implicit memory consolidation; Generalization
Wakefulness	$\rho \approx 1$ (Critical)	Balance of E and I, Scale-invariant Correlations	Simultaneous Operation of Both Systems: Optimal Inference, Extended Working Memory Capacity, Conscious Experience

Note. Adapted from Tucker et al. (2025). Sleep phases are interpreted as targeted excursions into sub- and supercritical states necessary for specific types of memory consolidation.

- NREM Sleep (Subcritical, I-dominated State): During Non-Rapid Eye Movement sleep, particularly in deeper stages (N2/N3), the inhibitory control mechanism (I) dominates (Tucker et al., 2025). Characteristic EEG patterns like Slow Oscillations and Thalamo-Cortical Spindles reflect enhanced inhibitory control (Tononi & Cirelli, 2014). In this state, termed "inhibitory specification," the brain is actively prevented from forming new connections weakened by daily experience. Instead, selective stabilization of synaptic connections deemed important occurs. Specifically, explicit, declarative memory is consolidated (Born & Wilhelm, 2012).
- REM Sleep (Supercritical, E-dominated State): Rapid Eye Movement sleep represents the counterpart. In this phase, the excitatory control mechanism (E) is ramped up, resembling wakefulness regarding neuronal activity and cholinergic arousal (Hobson & Friston, 2012). This state, described as "excitatory reintegration," serves the consolidation of implicit, procedural memory (Diekelmann & Born, 2010). The brain uses this time for creative recombination of existing predictive models (Priors), leading to new, generalized knowledge structures (Hinton et al., 1995).
- Integration in Wakefulness (Critical, E/I-balanced State): Upon awakening, the brain is in a state characterized by careful calibration of the E-I balance. NREM sleep has completed error correction and stabilization, while REM sleep has reorganized and generalized predictive models (Tucker et al., 2025). The resulting wakeful state enables the simultaneous operation of both systems: the expansiveness of prediction generation and the precision of error correction.

Comparative Evaluation: Criticality as a Meta-Theoretical Framework

The true strength of the affective criticality hypothesis by Tucker, Luu, and Friston (2025) reveals itself in comparative analysis with other established theories of consciousness and brain function. Rather than existing as an isolated theory, it offers an integrative meta-theoretical framework uniting the strengths of various models (Friston et al., 2017).

Table 3. Comparison of Explanatory Power of Different Theories.

Criterion	Northoff (Temporo-Spatial)	Singer (Binding by Synchrony)	Buonomano (Population Clocks)	Predictive Processing (Friston)	Affect Logic (Ciompi)	Criticality (Tucker et al.)
Mechanistic Specificity	Low (Metatheoretical)	Medium (Gamma Synchrony)	Medium (Population Dynamics)	High (Bayesian Formulas)	Low (Synergetic)	High (E-I Precision, Neuromodulatory)
Explanation of Affective Qualities	Implicit	No	No	Implicit (Precision)	Explicit (Affect Logic)	Explicit (Elation/Anxiety as Control Parameters)
Sleep-Wake Integration	Limited	No	No	Implicit	No	Explicit (NREM/REM as E-I Excursions)
Cross-Scale Coherence	High (Fractal)	Low (Local)	Medium (Temporal)	High (Hierarchical)	High (Self-similar)	High (Scale-invariant Correlations)
Empirical Testability	Medium (fMRI, EEG)	Medium (EEG, MEG)	High (Single-unit, fMRI)	High (Computational, fMRI)	Low (Abstract)	High (EEG Oscillations, Neuromodulatory Manipulation)
Explanation of "Pacemaker"	Scale-free Infralow Dynamics	External Rhythm Entrainment	Internal Population Dynamics	Hierarchical Prediction Errors	Self-Organization	Dual Limbic Systems + Subcortical Arousal Control

Note. This table highlights the integrative power of the Criticality Hypothesis. It offers high mechanistic specificity by replacing abstract concepts with concrete, measurable parameters like E-I precision.

The Criticality Hypothesis fills gaps left by other theories. While Singer's Binding-by-Synchrony postulates synchronization as a binding mechanism, it does not explain *what* is bound or *why* (Singer, 1999). The Criticality Hypothesis fills this gap by postulating that affective precision controls *which* features are summarized in synchronous binding (Tucker et al., 2025). Similarly, it complements Buonomano's Population Clocks by explaining how internal clock mechanisms are regulated: the E-I balance determines the speed and flexibility of these internal trajectories (Tucker et al., 2025).

Particularly interesting is the synergy with Northoff's Temporo-Spatial Dynamics. While the TTC offers a powerful metatheory describing correspondence on an abstract level (Northoff, 2022), the Criticality Hypothesis provides the concrete mechanism enabling this correspondence: the E-I precision balance (Tucker et al., 2025). The "common currency" of the TTC becomes a measurable quantity (the ρ parameter), varied by affective signals.

Synthesis and Implications: Affect as a Fundamental Control Mechanism of Consciousness

The conceptual synthesis of affective criticality as a central control parameter for brain-world alignment, based on the work of Tucker, Luu, and Friston (2025), enables a profound reassessment of the role of affect in cognitive and conscious processes (Tucker et al., 2025). The synthesis of analyzed sources can be summarized in five central points:

1. Alignment as a Precision-Controlled Inference Process: Physical patterns of the external world are not blindly copied but interpreted through an affectively weighted Bayesian inference process. Control parameters Excitatory Precision (E), embodied in elation, and Inhibitory Precision (I), embodied in anxiety, dynamically control how strongly internal predictions (Priors) determine the updating of neuronal representations compared to external sensory evidence (Likelihoods) (Friston, 2010; Tucker et al., 2025).
2. Neurochemical Translation via Affectively Modulated Cross-Frequency Coupling: External rhythms can entrain endogenous oscillations, and affective precision determines whether this coupling is used for generating expansive predictions (E-dominated, θ - γ) or precise error correction (I-dominated, α - β), with neurotransmitters stabilizing this coupling through phase-dependent release (Canolty et al., 2006; Tucker et al., 2025).
3. The Pacemaker as a Hierarchical System of Affective Oscillators: There is no single timer, but a vertically integrated system of subcortical arousal controls (phasic/tonic), limbic precision regulators (dorsal/ventral), and cortical frequency coupling, adaptively calibrated via affective feedback (Luu et al., 2024).
4. Sleep as Homeostatic Recalibration of Criticality: Nightly excursions into NREM sleep (I-dominated, subcritical) and REM sleep (E-dominated, supercritical) are constitutive prerequisites for consolidating memory systems and recalibrating precision controls for the following wake period (Tucker et al., 2025).
5. Consciousness as an Emergent Property of Critical Balance: The subjective experience of the "specious present"—the extended temporal coherence of conscious experience—is interpreted as a direct consequence of long-range temporal correlations occurring at E-I criticality (James, 1890; Müller et al., 2025).

Philosophical Implications and Future Directions

The Criticality Hypothesis demands a revision of the classical relationship between subjectivity and objectivity. The affective qualities of elation and anxiety are no longer considered mere "soft" accompaniments of a "hard" neuronal process but as the constitutive control parameters enabling brain-world alignment in the first place (Tucker et al., 2025). The so-called "hard problem of consciousness" is thus not solved but transformed: Subjective experience is not an inexplicable epiphenomenon but the phenomenal manifestation of precision-controlled inference regulating organism-environment alignment in real-time (Chalmers, 2007; Friston et al., 2020).

For future research, this implies that the affective criticality hypothesis generates concrete, testable predictions:

- Neurophysiological: Manipulation of E-I balance via neuromodulatory pharmaceuticals should shift the precision of predictions versus error correction in EEG/MEG measurements (Tucker et al., 2025).
- Behavioral-Psychological: Affective induction (Elation vs. Anxiety) should modulate conceptual scope versus sensory vigilance in relevant tasks (Isen, 1987).
- Clinical: Disorders of E-I balance (e.g., Mania: $I \uparrow$, Anxiety Disorders: $I \uparrow$) should show specific deficits in brain-world alignment, interpretable as deficits caused by chronically miscalibrated precision control (Tucker, 2007; Friston et al., 2016).

Conclusion

In summary, affective criticality bridges the gap between the abstract description of brain-world correspondence and the concrete, affectively controlled mechanisms enabling this alignment in real-time. It integrates the structural perspective of Temporo-Spatial Dynamics with the formal clarity of Active Inference, providing a neurobiologically founded and philosophically profound answer to the question of how an organism remains in contact with its world. Affect is not merely part of the problem of brain function; it is the solution itself.

Declaration on the Use of Artificial Intelligence (AI)

In accordance with established scientific integrity standards and current institutional guidelines, the author declares that generative artificial intelligence (AI) was utilized in the preparation of this research report. Specifically, large language models were employed as sophisticated instruments for structural organization, the translation of complex interdisciplinary concepts into precise academic English, and the accurate typesetting of mathematical notations using LaTeX.

The conceptual synthesis, the original theoretical integration of primary sources (notably Tucker, Luu, and Friston, 2025), and the final critical verification of all contents remain the sole intellectual responsibility of the author. The AI was used as a tool for formal refinement and cognitive scaffolding, ensuring that the depth of the neurobiological analysis is matched by linguistic and structural clarity.

Conflicts of Interest: There are no known conflicts of interest associated with this article.

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