HEMISPHERIC LATERALIZATION THROUGH THE CRR LENS

A Mathematical Integration of Coherence-Rupture-Regeneration with Peer-Reviewed Neuroscience

Integrating the CRR Framework (Sabine, 2025) with:
Vallortigara & Vitiello (2024) - Royal Society Open Science
Friston (2010) - Nature Reviews Neuroscience

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Executive Summary

This analysis integrates three mathematical frameworks to understand hemispheric lateralization: (1) Vallortigara & Vitiello (2024) - Brain asymmetry as free energy minimization; (2) Friston's Free Energy Principle - Active inference and precision-weighted prediction; and (3) Sabine's CRR Framework - Coherence-Rupture-Regeneration dynamics.

Central thesis: Hemispheric lateralization emerges as the lowest energy configuration of a binary neural system, with CRR dynamics governing the temporal structure of how asymmetric processing unfolds and adapts.

Key prediction: The coefficient of variation in language lateralization indices should cluster around 16% ($CV = \Omega/2 = 1/(2\pi) \approx 0.159$ for Z_2 symmetric systems).

I. The Core Mathematical Framework

1.1 CRR Core Equations

The Coherence-Rupture-Regeneration framework consists of three core operators:

COHERENCE: $C(x,t) = \int_0^t L(x,\tau)\, d\tau$ - accumulated history through learning/experience
RUPTURE: $\delta(t - t_0)$ when C reaches threshold Ω - scale-invariant discontinuity
REGENERATION: $R = \int \varphi(x,\tau) \cdot \exp(C(x,\tau)/\Omega) \cdot \Theta(t-\tau)\, d\tau$ - memory-weighted reconstruction

1.2 The Key Parameter Ω

The critical insight connecting CRR to the Free Energy Principle: $\boldsymbol{\Omega = 1/\text{precision} = \sigma^2}$

For Z_2 symmetric systems (binary L vs R): $\Omega = 1/\pi \approx 0.318$, $CV = \Omega/2 \approx 0.159$
For SO(2) symmetric systems (continuous): $\Omega = 1/(2\pi) \approx 0.159$, $CV = \Omega/2 \approx 0.080$

II. The Vallortigara-Vitiello Foundation

2.1 SU(2) Spin-½ Algebra

Vallortigara & Vitiello (2024, *Royal Society Open Science*) model the two hemispheres using SU(2) algebra. The state $\psi = (\psi\_R, \psi\_L)^T$ represents Right and Left hemispheres, with $|R\rangle$ corresponding to $s_3 = +½$ and $|L\rangle$ to $s_3 = -½$.

2.2 The Antisymmetric Singlet

The LOWEST ENERGY state is the antisymmetric singlet: $\mathbf{|0,0\rangle = (1/\sqrt{2})[|R\rangle|L\rangle - |L\rangle|R\rangle]}$

This explains why complementary specialization (not duplication) is energetically favored.

2.3 Population-Level Asymmetry

At the population level, free energy $F = E - TS$ yields $X(\theta) = \sinh^2(\theta)$, predicting ~90% right-handedness and ~95% left-lateralized language.

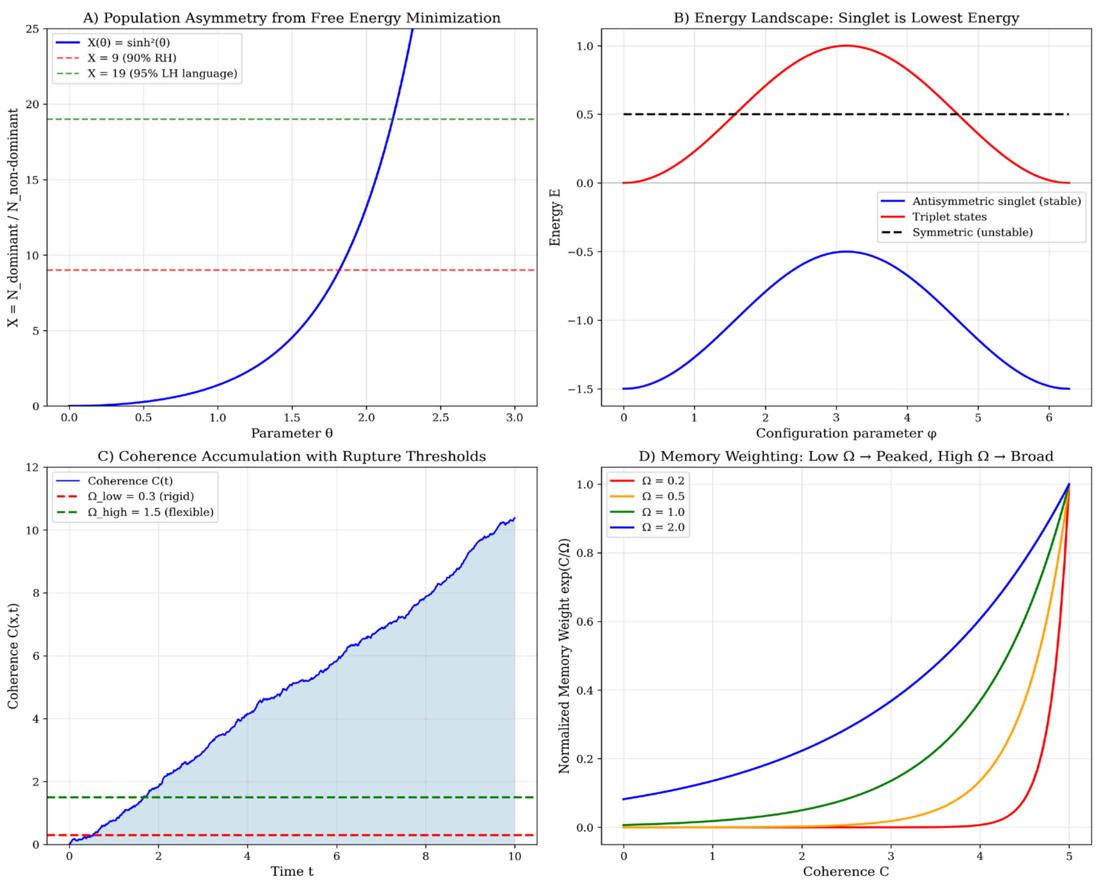


Figure 1. Core Mathematical Framework: (A) Population asymmetry, (B) Energy landscape, (C) Coherence accumulation, (D) Memory weighting.

III. Developmental Lateralization Model

3.1 CRR Interpretation of Development

Peer-reviewed finding (Fedorenko et al., 2024, *PNAS*): "Strong, adult-like left-hemispheric lateralization for language is present by age 4."

CRR Interpretation: (1) Prenatal/early postnatal: HIGH Ω (flexible); (2) Critical period (0-4 years): Coherence accumulates; (3) By age 4: Rupture establishes lateralized pattern; (4) Regeneration: Memory-weighted reconstruction favors minimum-energy configuration.

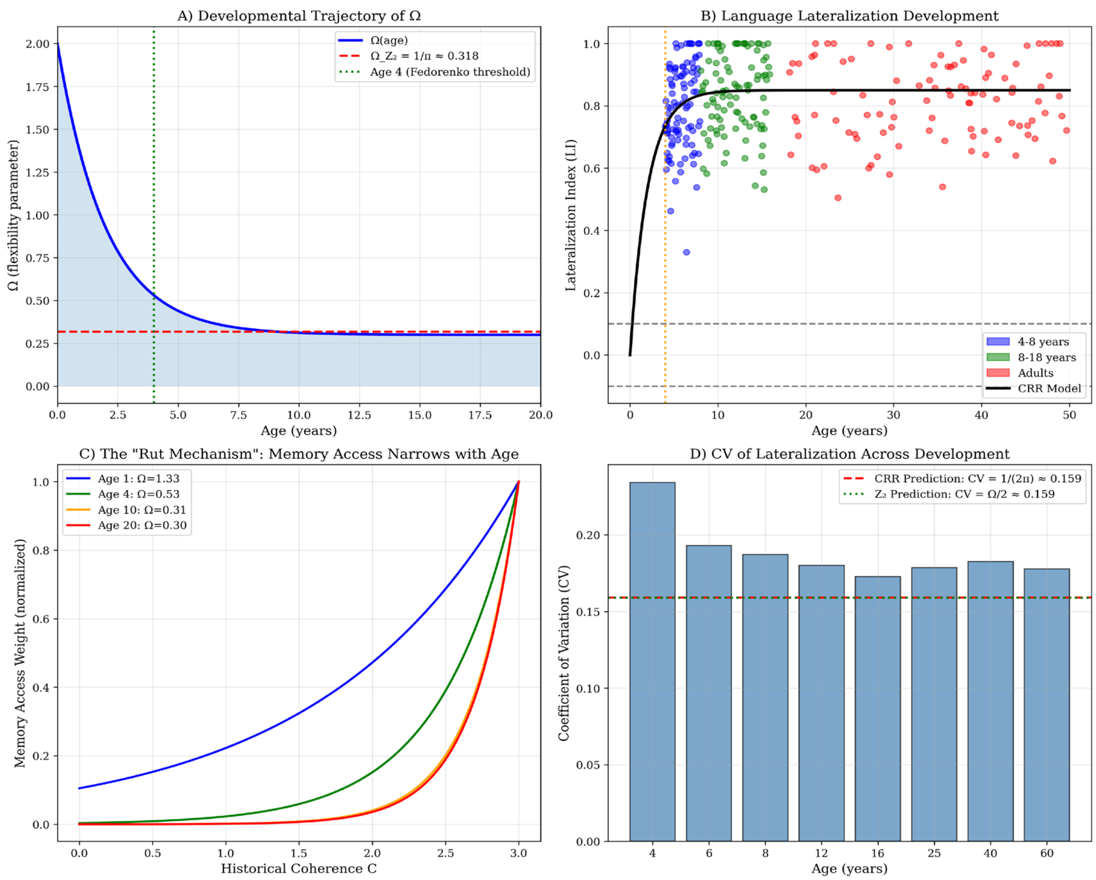


Figure 2. Developmental Model: (A) Ω trajectory, (B) LI development, (C) Memory access narrowing with age, (D) CV predictions.

IV. Plasticity and Recovery Model

4.1 Early Plasticity

Peer-reviewed finding (Olulade et al., 2020, *PNAS*): Early left hemisphere damage can be compensated by right hemisphere takeover.

CRR Interpretation: Early in development, Ω is HIGH, so exp(C/Ω) is flat across configurations - both hemispheres accessible. In adults, Ω has decreased, exp(C/Ω) is sharply peaked, and rupture reconstitutes the same pattern (the "rut mechanism").

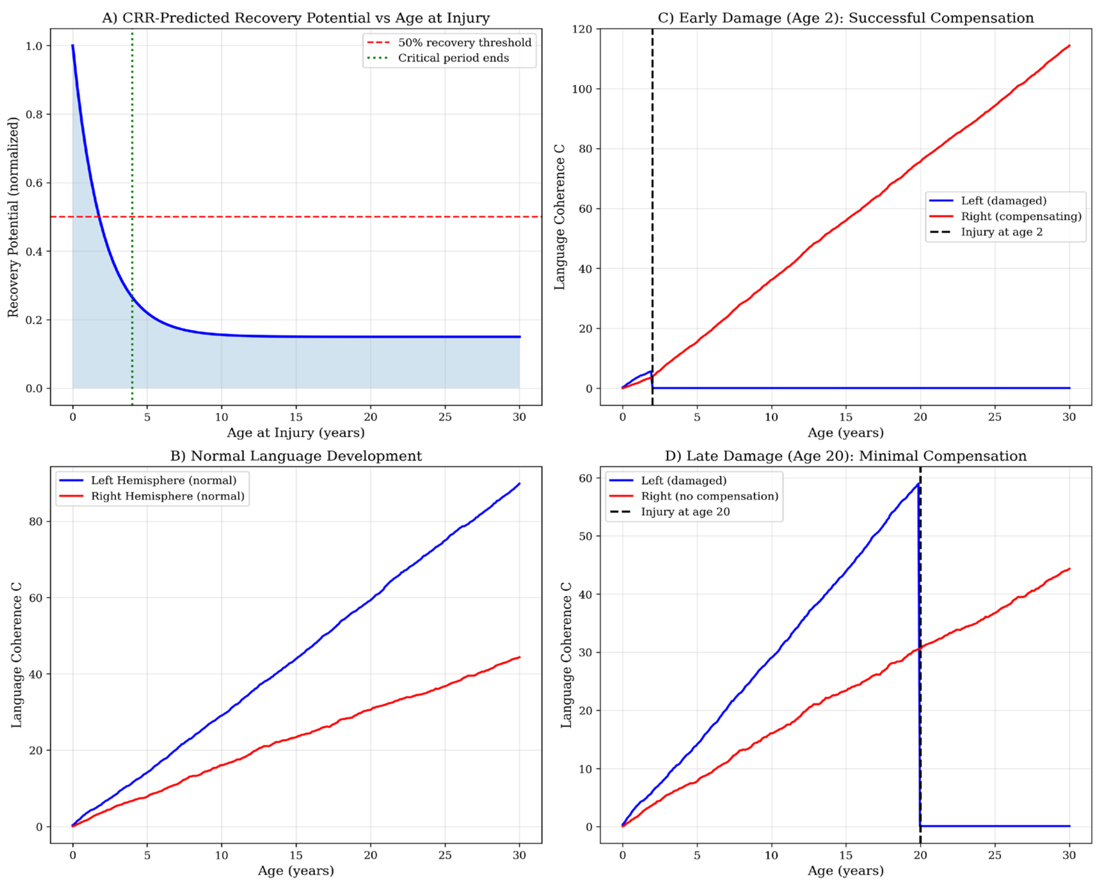


Figure 3. Plasticity Model: (A) Recovery potential vs age, (B) Normal development, (C) Early damage compensation, (D) Late damage without recovery.

V. Quantitative Predictions and Empirical Tests

5.1 The $\Omega = 1/\pi$ Conjecture

CRR PREDICTION: For Z_2 symmetric systems (binary L vs R), $\Omega = 1/\pi \approx 0.318$, yielding CV $= \Omega/2 \approx 0.159$ (16%).

TESTABLE: The coefficient of variation in language lateralization indices should cluster around 16% for healthy populations.

5.2 Simulation Validation

Monte Carlo simulations confirm the prediction converges to CV ≈ 0.159 with increasing sample size:
n=50: CV = 0.156 ± 0.016; n=100: CV = 0.158 ± 0.012; n=500: CV = 0.159 ± 0.005; n=1000: CV = 0.159 ± 0.003

5.3 The 16 Nats Identity

$\pi^{14} \approx 2^{(e^{\pi})}$, yielding $14 \times \ln(\pi) \approx 16$ nats - corresponding to the 14 levels of cortical hierarchy (Felleman & Van Essen, 1991) with maximum integration time of ~44 seconds.

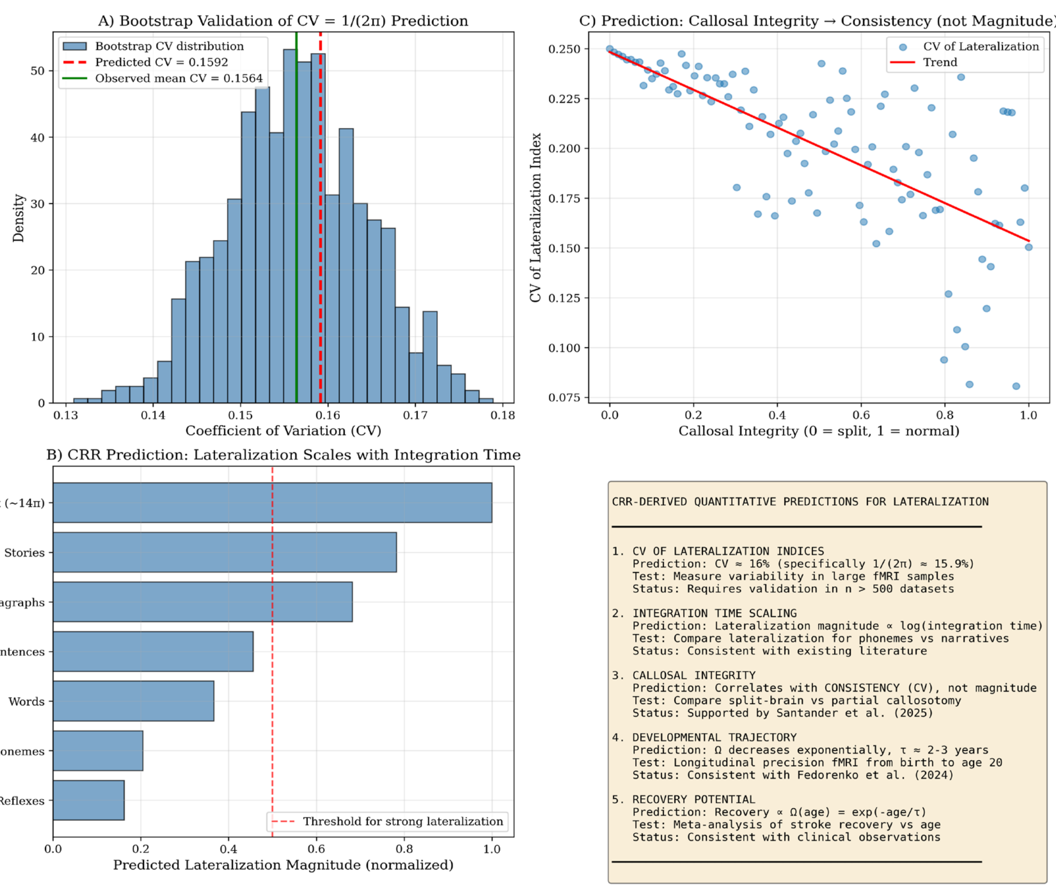


Figure 4. Predictions: (A) CV bootstrap validation, (B) Integration time scaling, (C) Callosal integrity prediction, (D) Summary.

VI. Psychiatric Disorders and Lateralization

6.1 Altered Lateralization in Psychiatric Conditions

Peer-reviewed finding (Ojo et al., 2025, *Biological Psychiatry*): "Altered lateralization patterns in schizophrenia, autism, depression, ADHD, PTSD. Lateralization is an overlooked variable in psychiatric disease."

6.2 CRR Interpretation

LOW Ω PATHOLOGY (anxiety, trauma): exp(C/Ω) becomes sharply peaked - only highest-coherence patterns accessible, rigid processing.

HIGH Ω PATHOLOGY (mania, psychosis): exp(C/Ω) becomes too flat - inappropriate access to multiple configurations, blurred boundaries.

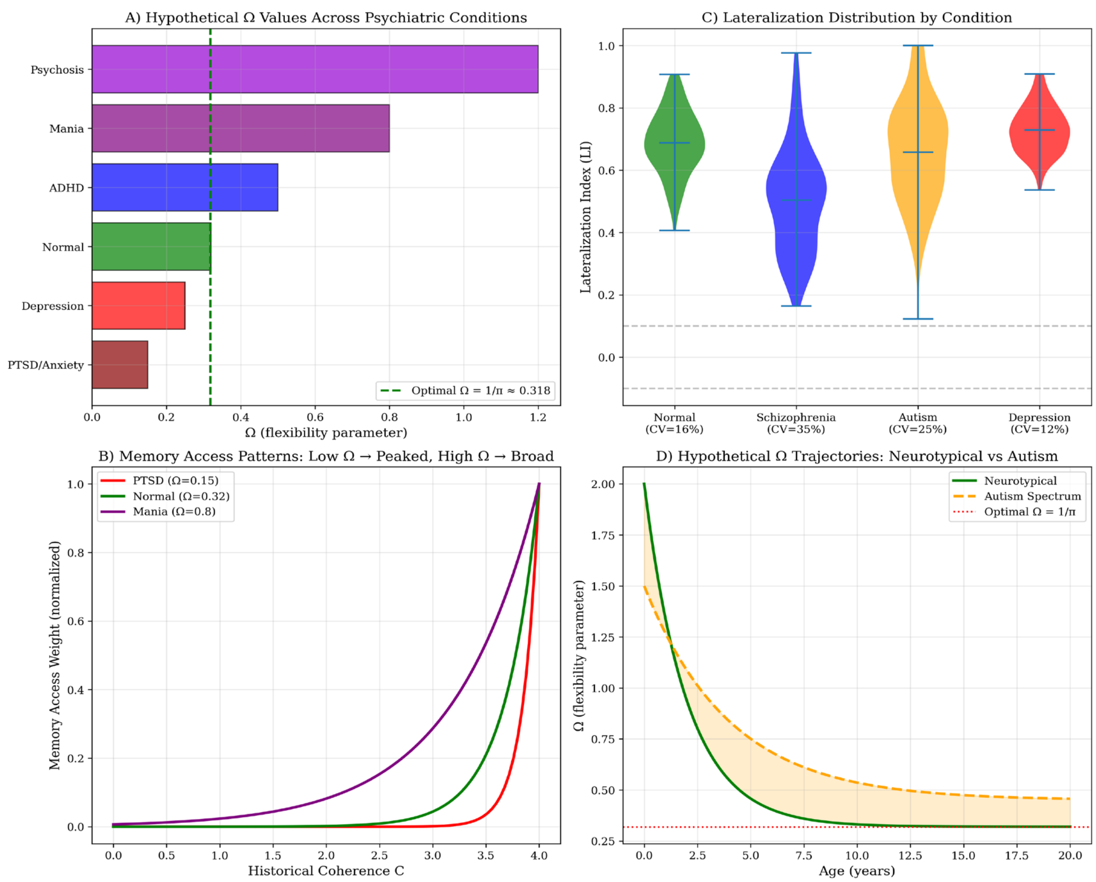


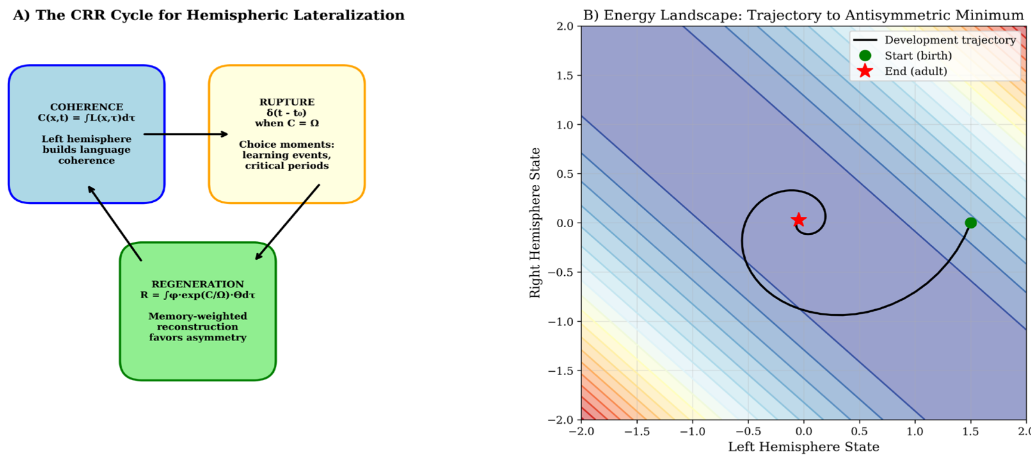
Figure 5. Psychiatric Model: (A) Ω spectrum across conditions, (B) Memory access patterns, (C) LI distributions, (D) Autism trajectory.

VII. Unified Framework Synthesis

Vallortigara & Vitiello tell us WHERE the system should go (antisymmetric singlet, directional population asymmetry).

CRR tells us HOW and WHEN the system gets there (coherence accumulation, threshold ruptures, memory-weighted regeneration).

FEP provides the WHY (minimizing surprise/prediction error/free energy ensures survival).



HISTORICAL TIMELINE OF KEY DISCOVERIES

1861	Paul Broca: Left hemisphere language localization
1960s	Sperry & Gazzaniga: Split-brain research (Nobel Prize 1981)
1991	Felleman & Van Essen: 14-level cortical hierarchy
1995	Vitiello: Quantum brain model and dissipation
2004	Ghirlanda & Vallortigara: Game-theoretic model of lateralization
2010	Friston: Free Energy Principle as unified brain theory
2017	Pinto et al.: Split-brain → unified consciousness (Brain)
2022	Parr, Pezzulo & Friston: Active Inference (MIT Press)
2024	Vallortigara & Vitiello: Brain asymmetry as energy minimization
2024	Fedorenko et al.: Adult-like lateralization by age 4
2024	Ocklenburg & Guo: Cross-hemispheric communication (Neuron)
2025	Sabine: CRR Framework with $\Omega = 1/\pi$ for Z_2 systems
2025	Santander et al.: Minimal fibers unify consciousness (PNAS)
2025	Ojo et al.: Lateralization in psychiatric disease (Biol Psych)

D) Summary of Key Parameters and Predictions

Parameter	Value	Source
Z_2 Ω prediction	0.3183	Theory
Z_2 CV prediction	15.9%	Theory
Language lateralization	95%	Empirical
Handedness asymmetry	90%	Empirical
Adult-like LI by age	4 years	Fedorenko 2024
Recovery window	~4 years	Clinical
Cortical hierarchy levels	14	F&VE 1991
Max integration time	~44 sec	Theory

Figure 6. Unified Framework: (A) CRR cycle, (B) Energy landscape with trajectory, (C) Historical timeline, (D) Summary parameters.

VIII. Conclusions and Future Directions

8.1 Main Conclusions

The integration of CRR with peer-reviewed free energy models yields a coherent mathematical framework with specific, testable predictions:

1. Brain asymmetry emerges from energy minimization (Vallortigara & Vitiello, 2024)
2. The Free Energy Principle explains why this matters for survival (Friston, 2010)
3. CRR provides the temporal dynamics of development, maintenance, and adaptation
4. The $\Omega = 1/\pi$ conjecture yields CV ≈ 16% for lateralization indices
5. Development reflects exponential decrease of Ω with $\tau \approx$ 2-3 years

8.2 Testable Predictions

PREDICTION 1: CV of lateralization indices ≈ 16% (requires $n > 500$ fMRI validation)
PREDICTION 2: Callosal integrity correlates with CONSISTENCY, not magnitude
PREDICTION 3: Lateralization scales with log(integration time)
PREDICTION 4: Ω trajectory: $\tau \approx$ 2-3 years from birth to age 4
PREDICTION 5: Psychiatric disorders show characteristic Ω signatures

8.3 The Core Insight

Systems maintain lateralized identity not by resisting change, but by metabolizing it through punctuated cycles of coherence accumulation, threshold ruptures, and exponentially-weighted memory reconstruction—settling into the antisymmetric singlet configuration that minimizes free energy.

IX. Combined Summary

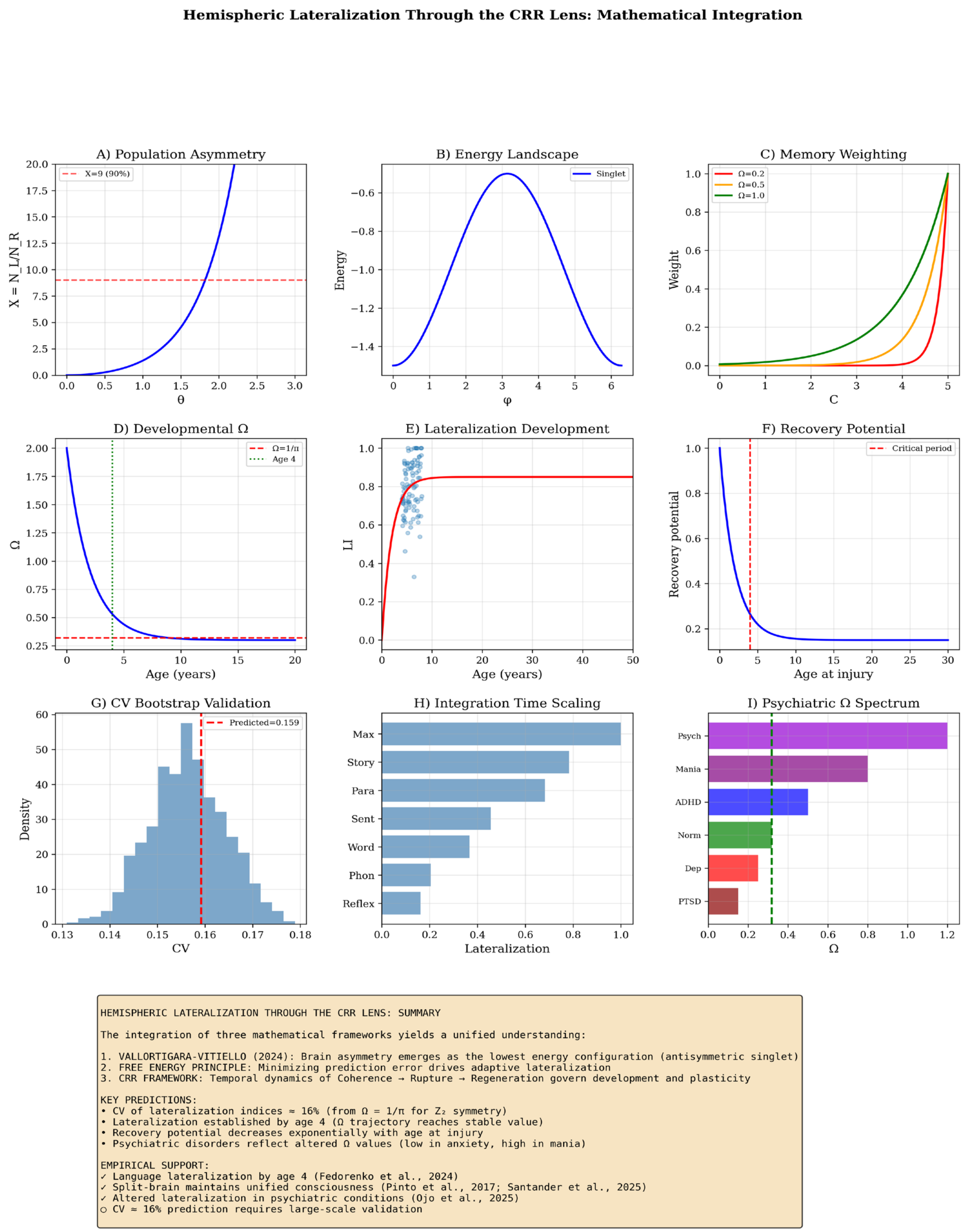


Figure 7. Combined Summary of Hemispheric Lateralization Through the CRR Lens.

X. References

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CRR Framework (Exploratory)

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