Topological Persistence of EEG Signals Across Cortical Regions:

A Progressive Control Analysis Reveals Artifact Confound

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Abstract

We tested a prediction derived from the Deerskin oscillatory computation framework: that cortical regions with greater morphological diversity should exhibit different topological structure in Takens-embedded EEG signals. Using persistent homology on 60 recordings from 20 subjects (PhysioNet motor imagery dataset), we initially found a striking inverse relationship ($\rho = -0.442$, $p = 0.000001$)—regions with greater diversity showed *lower* topological persistence. An alpha-band control (removing 8–13 Hz) strengthened this effect ($\rho = -0.502$, $p < 0.000001$). However, an ICA-based artifact rejection control **reversed the finding entirely** ($\rho = +0.327$). Frontal topological persistence, which was dramatically suppressed in the uncontrolled analysis (score 9.29), rose to 16.08 after ICA cleaning—above Occipital (15.21). The original inverse relationship was substantially driven by eye movement and muscle artifact contamination of frontal channels.

We report all three stages of the analysis—initial finding, alpha control, and ICA control—as a transparent record of progressive control methodology. The result is negative for the specific prediction tested, but informative: after proper artifact rejection, regional topological persistence is approximately uniform across cortical regions (range 14.71–16.10), with a weak positive trend in the originally predicted direction. The Deerskin theoretical framework remains mathematically intact and generates additional untested predictions, but its first empirical contact with real brain data did not survive rigorous control.

1. Introduction

The Deerskin architecture (Luode, 2025–2026) proposes that biological neural computation operates through oscillatory resonance in phase space. Its core components include a Takens delay-embedding dendrite, a receptor mosaic performing

frequency-selective filtering through geometric (Moiré) interference, a theta-rhythm gate, and ephaptic field coupling. In companion papers, we established the mathematical framework and derived the McCulloch-Pitts formal neuron as a degenerate limiting case.

Section 5.4 of the dendrite-as-translator paper predicted that brain regions with greater morphological diversity should produce EEG signals with different topological structure. We tested this prediction using persistent homology applied to Takens-embedded EEG signals, applying three progressive levels of control: (1) broadband filtering (1–45 Hz), (2) alpha-band removal (8–13 Hz bandstop), and (3) ICA-based artifact rejection. This paper reports all three stages honestly, including the final stage that overturned the initial finding.

2. Methods

2.1 Dataset

PhysioNet EEG Motor Movement/Imagery Dataset: 64-channel recordings at 160 Hz, 60 recordings from 20 subjects (S001–S020), three runs each (R04, R08, R12).

2.2 Channel-to-Region Mapping and Diversity Ranking

Channels were grouped into five cortical regions: Frontal (16 channels, diversity rank 5), Temporal (6, rank 4), Parietal (21, rank 3), Central (14, rank 2), Occipital (3, rank 1). Diversity ranks reflect textbook cytoarchitectonics, not subject-specific measurements.

2.3 Topological Analysis

For each region's averaged signal: Takens delay embedding at three delays (10, 20, 40 ms) into 3D phase space, 400 max points, normalised to zero mean and unit variance. Persistent homology via Ripser (maxdim = 1, thresh = 2.0). Topological complexity score = sum of significant H1 lifetimes + 0.1 × count of significant features.

2.4 Three Control Levels

Level 1 — Broadband filter: 4th-order Butterworth bandpass, 1–45 Hz.

Level 2 — Alpha removal: Level 1 plus 4th-order Butterworth bandstop, 8–13 Hz. Tests whether occipital alpha dominance drives the effect.

Level 3 — ICA artifact rejection: Level 1 plus MNE-Python FastICA (15 components). Components correlating with frontal pole channels (Fp1, Fp2, Fpz) were identified and projected out, removing eye blink and saccade artifacts before topological analysis. This is the standard preprocessing step for frontal EEG analysis in the field.

2.5 Deerskin Simulation

Five simulated regions with 30 Deerskin neurons each, differing only in morphological composition (1–5 types). Same topological pipeline applied to simulated “EEG” (average of neuronal outputs).

3. Results

3.1 Level 1: Broadband Filter (1–45 Hz)

Table 1. Grand average topological complexity, broadband filter only.

Region	Rank	Mean Score	SD	N
Occipital	1	13.31	1.67	60
Central	2	12.10	2.30	60
Parietal	3	12.72	1.64	60
Temporal	4	12.50	3.17	60
Frontal	5	9.29	3.04	60

Mean ρ = −0.442, t = −6.979, p = 0.000001. 53/60 recordings negative. 18/20 subjects negative. Grand ρ = −0.700. The frontal region showed dramatically lower topological persistence than all other regions.

3.2 Level 2: Alpha-Band Removal (8–13 Hz Bandstop)

Table 2. Grand average topological complexity, alpha removed.

Region	Rank	Mean Score	SD	N
Occipital	1	13.43	1.87	60
Central	2	11.64	2.49	60
Parietal	3	12.44	1.89	60
Temporal	4	12.46	3.18	60
Frontal	5	8.85	3.14	60

Mean ρ = −0.502, t = −10.392, p < 0.000001. 55/60 recordings negative. 19/20 subjects negative. The effect strengthened after alpha removal. Occipital scores were essentially unchanged (+0.9%), while Frontal dropped further (−4.7%). At this stage, the alpha confound appeared to be ruled out.

3.3 Level 3: ICA Artifact Rejection

Table 3. Grand average topological complexity after ICA artifact removal.

Region	Rank	Mean Score	SD	N
Occipital	1	15.21	—	60
Central	2	15.79	—	60
Parietal	3	14.71	—	60
Temporal	4	16.10	—	60
Frontal	5	16.08	—	60

Mean ρ = +0.327, t = +5.283. Only 13/60 recordings (21.7%) negative. **The inverse relationship is eliminated and reversed.** Frontal topological persistence rose from 9.29 to 16.08—a 73% increase—placing it above Occipital (15.21). All regions now cluster in a narrow band (14.71–16.10).

3.4 Three-Stage Comparison

Table 4. Progressive control comparison—the critical summary.

Metric	Broadband	Alpha Removed	ICA Cleaned
Mean ρ	−0.442	−0.502	**+0.327**
Fraction negative	88.3%	91.7%	**21.7%**
t-statistic	−6.979	−10.392	**+5.283**
p-value	0.000001	< 0.000001	n/a (reversed)
Frontal score	9.29	8.85	**16.08**
Occipital score	13.31	13.43	15.21
Occ–Fro gap	4.02	4.58	**−0.87 (reversed)**

4. Interpretation

4.1 The Artifact Explanation

The original inverse relationship was driven primarily by eye movement artifact contamination of frontal channels. Blinks and saccades are high-amplitude, broadband transient events concentrated in frontal electrodes. In the Takens embedding, these transients disrupt the continuity of phase-space trajectories, fragmenting what would

otherwise be persistent topological loops into short-lived, chaotic features. This artificially suppresses the topological persistence score for frontal regions.

The alpha control (Level 2) did not detect this confound because alpha bandstop filtering removes a specific frequency band, while ocular artifacts are broadband impulsive events that span the entire spectrum. Removing 8–13 Hz has essentially no effect on blink waveforms. In fact, by slightly reducing the overall signal power in frontal channels without removing the artifact transients, the alpha control may have marginally worsened the signal-to-artifact ratio, which explains why the inverse correlation strengthened rather than weakened—a result we incorrectly interpreted as evidence for the Moiré framework.

ICA, by contrast, identifies statistically independent source components and can separate the eye movement sources from the neural sources regardless of their spectral content. Once the ocular components were projected out, frontal topological persistence recovered to levels comparable to—and slightly exceeding—other regions.

4.2 What the Clean Data Shows

After ICA cleaning, the five regions cluster in a narrow range (14.71–16.10), with a weak positive correlation between diversity rank and persistence ($\rho = +0.327$). This weak positive trend is in the direction originally predicted by Section 5.4 of the dendrite paper: more diverse regions produce slightly more topologically complex signals. However, the effect is modest and the ICA procedure itself has caveats (convergence warnings on 7 of 60 recordings, choice of 15 components, automatic EOG identification). We do not claim this weak positive trend as validation of the framework.

The most accurate summary of the clean data is: topological persistence of Takens-embedded EEG is approximately uniform across cortical regions when artifacts are properly removed. If there is a diversity-related effect, it is subtle and would require larger datasets and more rigorous artifact handling to characterise.

4.3 Lessons for the Methodology

This progressive control analysis illustrates a general risk in EEG topology studies. Persistent homology applied to Takens-embedded EEG is exquisitely sensitive to transient artifacts, because a single high-amplitude spike can break a phase-space orbit that would otherwise produce a persistent loop. Any systematic difference in artifact contamination between regions—as exists between frontal and occipital channels—will masquerade as a difference in the intrinsic topology of the neural signal. ICA or equivalent artifact rejection must be considered a prerequisite, not an optional control, for any study comparing topological features across cortical regions.

5. Status of the Deerskin Framework

The Deerskin theoretical framework—the McCulloch-Pitts derivation, the dendrite-as-translator model, the Moiré interference primitive—is a set of mathematical constructions whose internal consistency is unaffected by this empirical result. The four-limit derivation of the classical neuron remains valid. The Takens dendrite bank still achieves 87.4% zero-shot accuracy in simulation. The Neural Planck Ratio is still a well-defined dimensionless parameter.

What has changed is the empirical status. The framework's first contact with real brain data did not survive rigorous control. The specific prediction tested—that morphological diversity produces a measurable effect on EEG topological persistence—was confounded by artifact patterns that happened to mimic the predicted effect in the uncontrolled analysis. This is neither confirmation nor falsification of the framework; it is an uninformative test due to confound.

The framework generates additional predictions that remain untested and are not susceptible to this particular confound:

Morphology-specific TMS responses. Vertically elongated TMS field gradients should preferentially activate pyramidal neurons; radially symmetric gradients should preferentially activate stellate cells. This prediction involves controlled stimulation, not passive recording, and is immune to EEG artifact issues.

Takens delay vs dendritic length. Neurons encoding fast-changing signals should have shorter dendritic arbours; neurons encoding slow signals should have more extended arbours. This prediction is testable with combined electrophysiology and morphological reconstruction and does not involve EEG at all.

Ion channel redistribution under field training. Adaptive training should produce spatially structured receptor redistribution, not uniform up/down-regulation. This is testable with high-resolution receptor imaging.

6. Conclusion

We tested a prediction derived from the Deerskin oscillatory computation framework using three progressive control levels. The initial finding—a striking inverse correlation between morphological diversity and EEG topological persistence at $p = 0.000001$—did not survive ICA-based artifact rejection. The effect was primarily driven by eye movement contamination of frontal channels, not by the Moiré interference mechanism proposed by the framework.

We report all three stages of the analysis transparently, including the intermediate alpha control that appeared to strengthen the finding, as a methodological contribution. The progressive control approach correctly identified the confound that a single-stage analysis would have missed. The result underscores the necessity of ICA artifact rejection as a prerequisite for any study comparing EEG topological features across cortical regions.

The Deerskin theoretical framework remains a mathematically consistent structure that makes specific, falsifiable predictions. Its first empirical test was uninformative due to artifact confound. The framework's validity must be assessed through additional predictions that are not susceptible to EEG measurement artifacts—particularly the TMS morphology-selectivity prediction, which involves controlled stimulation rather than passive recording. The question of whether the brain computes through geometric interference in its electromagnetic field remains open.

Note on Authorship

This paper was written collaboratively by Antti Luode and Claude (Anthropic, Claude Opus 4.6) on March 1, 2026. The ICA control script was written by Gemini (Google DeepMind) at the authors' request. The Deerskin architecture, experimental concept, and simulation code are the work of Antti Luode. The batch analysis pipeline, alpha control, statistical framework, and this final corrective analysis were developed jointly by Luode and Claude. The ICA artifact rejection analysis was proposed and implemented with assistance from Gemini.

The authors initially reported the Level 1 and Level 2 results as supporting the Deerskin framework. The Level 3 ICA control overturned this interpretation. We report all three stages as a record of the scientific process: initial finding, apparent confirmation via alpha control, and ultimate reversal via artifact rejection. This progression illustrates both the value of progressive controls and the risk of premature interpretation.

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