Supplementary Material S2

Data Outputs and Validation Protocols (SAIM Engine v9.3)

Takafumi Shiga et al.

1 S2.1 Output Data Structure

The SAIM Engine v9.3 generates standardized CSV files for every subject to ensure transparency, reproducibility, and third-party auditability.

1.1 S2.1.1 Full Time-Series Data (`SAIM_FullData_*.csv`)

This file contains the raw computed metrics for every 10-second sliding window throughout the experiment.

Column Name	Definition & Physiological Interpretation
`Phase`	Experimental phase label (e.g., "I: Pre", "IV: PostRest").
`NCI`	**Neural Complexity Index (0.0-1.0).** The primary outcome measure. Higher values indicate a highly integrated, low-error state.
`NCI_Vol`	**NCI Volatility.** Standard deviation of NCI. High volatility indicates state lability or ongoing reorganization.
`F`	**Free Energy Proxy.** Lower values indicate an optimized system state (Minimization of Free Energy).
`PE`	**Prediction Error.** Derived from EEG Alpha instability. Represents the "cost" of processing sensory mismatch.
`HEMO`	**Neurovascular Flexibility.** Derived from fNIRS HbO variance. Represents the available metabolic resource capacity.
`FSI`	**Frontal Stability Index.** EEG Gamma/Delta ratio. Higher values indicate cognitive binding and alertness.
`SOM`	**Micro-kinematic Stability.** Inverse of body sway/acceleration.
`AUT`	**Autonomic Flexibility.** Entropy of Heart Rate.

1.2 S2.1.2 Statistical Report (`SAIM_Stats_Blind_*.csv`)

Contains the results of the bootstrap analysis comparing Baseline vs. Post-Rest phases.

- **Blind_ID:** A random hash assigned to the dataset to prevent analyzer bias during review.
- **Mean_Diff:** The effect size (Post - Pre). Positive values in NCI/HEMO indicate improvement.
- **CI_Lower / CI_Upper:** 95% Confidence Interval boundaries.
- **Significant:** Marked as TRUE if the CI excludes zero.

2 S2.2 Visualization & Validation Protocols

2.1 S2.2.1 Phase Space Trajectory (The "Reorganization Loop")

The trajectory plot (`Trajectory_*.png`) visualizes the system's dynamics in the PE (x-axis) vs. NCI (y-axis) plane. We classify the response into three types:

1. **Type A (Reorganization / Success):** A distinct loop or "V-shape" trajectory.
   - *Dynamics:* Start → High Error/Low NCI (Destabilization) → High NCI (Re-integration).
   - *Example:* Subject S07 (Week 2).
2. **Type B (Refractory / Saturation):** High initial NCI with minimal movement or negative shift.
   - *Dynamics:* Start (High NCI) → Increased Error → Return to similar or slightly lower NCI.
   - *Interpretation:* Homeostatic maintenance of a previously optimized state.
   - *Example:* Subject S00 (Week 3).
3. **Type C (Non-Responder):** Random walk or stagnation without resource mobilization (Low HEMO change).

2.2 S2.2.2 Distribution Analysis (Boxplots)

The boxplots (`SAIM_Result_*.png`, bottom panel) display the robust distribution of states.

- **Validation Criteria:** A successful intervention is characterized by a significant rightward shift (positive Z-score) in HEMO and NCI distributions in Phase IV (PostRest) compared to Phase I (Pre), accompanied by a narrowing of the Interquartile Range (IQR) indicating state stabilization.