Can Fractal and Complexity Measures of Electrophysiological Signals Be Used to Study Subjective Experience?

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Keywords — Complexity, Criticality, Consciousness

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- complexity, critialicy and related approaches looking for system dynamics and variability are gaining traction in neurosicence
- Biomarkers based on it are succesful in discrimating states of consciousness, whiile effort was directed toward styding the content
- conscious experience is rich and has high dimensional structure [1], which is set the problem suitable for next set of tool arising from statistical physics and complexity science

Quantifying information during conscious experience

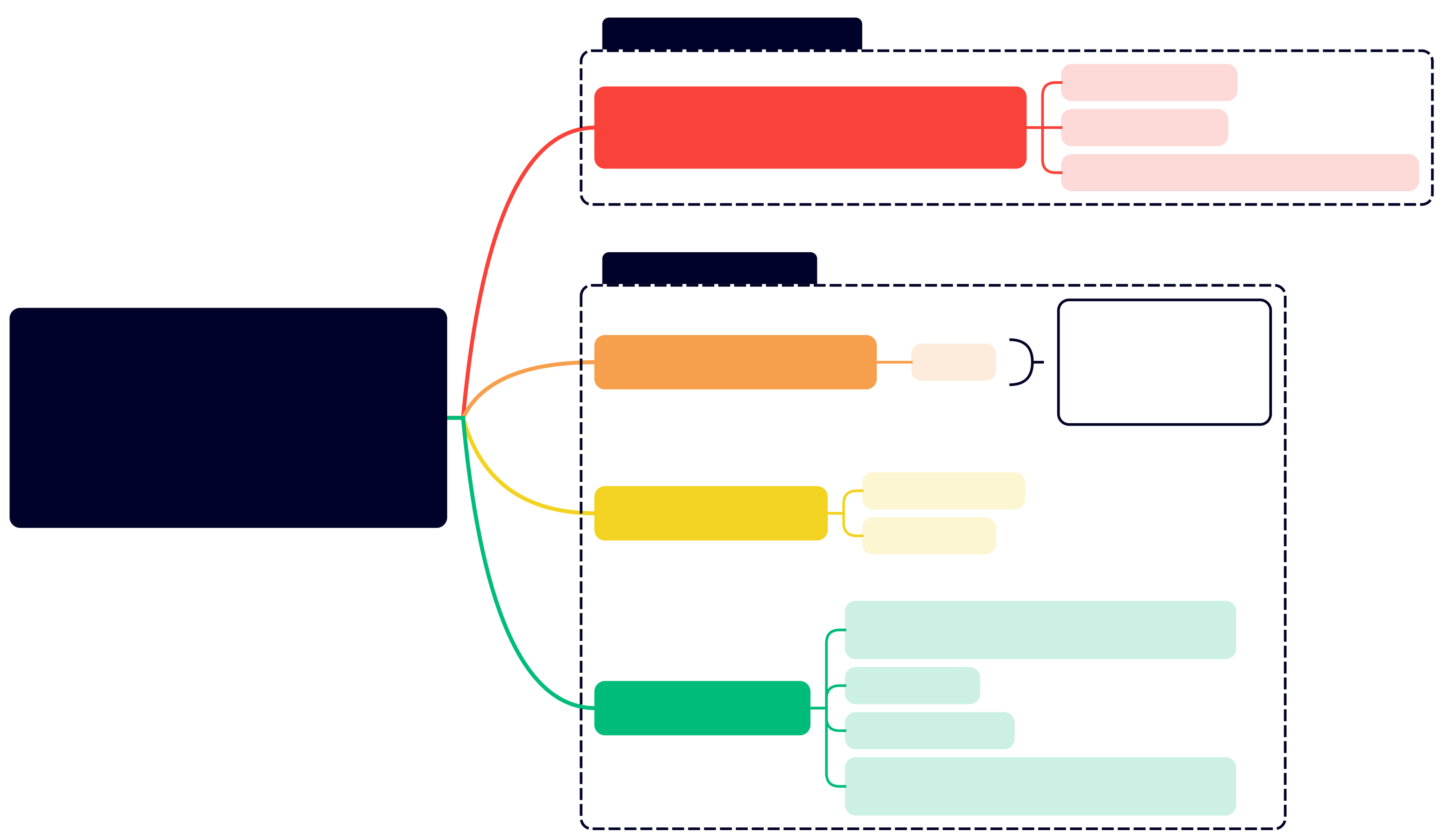

Figure 1

Richness of conscious experience pose a question to the neuroscience
::: # Brain criticality
Criticality is the singular state of complex systems poised at the brink of a phase transition between order and randomness.

Power laws and 1/f noise

X. Ji, E. Elmoznino, G. Deane, A. Constant, G. Dumas, G. Lajoie, J. Simon, and Y. Bengio [1]

Consciousness measures and Complexity

- Repertoire of states
- Integration and unity
- Effects of psycholics on complexity

Add graph about 1/f aperiodic term

- add tables with differnt measures explained
- add soort of SCHEMES
- START FROM WRITING MESSAGES
- autopoiesis as reference?? self organisation of life

graph of different frameworks - how we could combine it with neurophenomenology?

- flexibility in relation to environment?
- complexity of signal reflects structure of the generators?
- microstates
- complexity of brain signal will reflect inner processes but also envirobmnet
- meditation vs effort

-richness of experience - Information theory - dynamical systems

This poster presents a perspective on bridging quantitative measures of neural dynamics with phenomenal consciousness. The connection between self-organizing systems and spectral 1/f phenomena predates the recent surge in studies. Currently, these measures are being used to differentiate states of consciousness (e.g., distinguishing between minimally conscious and vegetative states, identifying sleep phases) and are also applied in research on psychedelics (e.g., the "entropic brain" hypothesis, where stimulants increase the complexity and richness of neuronal communication).

Complexity measures for EEG

Method	Domain	Key Characteristics	Strengths	Limitations
Auto-correlation decay time	Time	Measures how quickly signal decorrelates with itself	Correlates with knee frequency; relationship with age persists after accounting for exponent	—
Hurst Exponent	Time	Quantifies long-term memory of time series	Measures statistical dependence between distant points	More influenced by oscillations
DFA (Detrended Fluctuation Analysis)	Time	Examines how fluctuations scale with window size	Removes overall trends first	—
Fractal Dimension metrics (Higuchi, Katz, Petrosian)	Time	Measure signal complexity and self-similarity	Katz fractal dimension less affected by oscillations	—
Lempel-Ziv Complexity	Time	Counts unique patterns in binarized signal	Less affected by oscillations	—
Entropy measures (ApEn, SampEn, PE, WPE)	Time	Quantify signal unpredictability	Sample entropy less affected by oscillations	Permutation entropy strongly influenced by oscillations
Spectral Parameterization (SpecParam/ FOOOF)	Frequency	Models both periodic and aperiodic components	Handles knees and broad peaks well; directly separates oscillations from background	More complex modeling approach
IRASA	Frequency	Separates components through resampling	Directly separates oscillations from background	Less effective with knees or non-scale-free signals

Increased entropy or fractal dimension often correlates with positive affective states (e.g., psychedelics) and cognitive flexibility, whereas reduced complexity is observed in conditions such as depression. These patterns frequently involve NMDA receptors modulation (excitation-inhibition framework), providing a mechanistic link to various conditions that alter subjective experience, including schizophrenia and ADHD. Additionally, age-related changes in spectral slope correlate with cognitive reserve capacity, suggesting that variations in brain dynamics may # fundamentally shape phenomenological experience across the lifespan.

Summary

Despite its promise, there is not yet a coherent framework linking everyday subjective experience with these quantitative measures of neural dynamics. This poster synthesizes primary research directions and highlights potential underlying biological mechanisms while also pointing to the imitations.

Possible studies ideas

- Ideas put figure about increased number of papers(qualitative experinec + aperiodic + complexity)

Bibliography

[1] X. Ji *et al.*, "Sources of Richness and Ineffability for Phenomenally Conscious States," *Neuroscience of Consciousness*, vol. 2024, no. 1, p. niae1, May 2024, doi: 10.1093/nc/niae001.