Alpha-Band Entropy Suppression Tracks Cortical State Transitions During High Arousal

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Introduction

- Brain waves are patterns of electrical activity generated by populations of neurons, and they can be divided into five main frequency ranges ('bands'). Each is associated with different functional states. In particular, alpha waves correspond to cognitive inhibition and disengagement from external input [1].
- The Entropic Brain Hypothesis theorizes that functional states and processing flexibility are dependent on the diversity of cortical signaling [2].
- Lempel-Ziv Complexity (LZC) is one mathematical, frequency band-constrained measure of entropy that can be applied to EEG data [3].
- High arousal states tend to decrease spontaneous neural activity, instead increasing cortical responsiveness to salient input.
- Few studies investigate the role of high arousal states in alpha entropy dynamics, though alpha band activity is highly relevant to regulation of response to emotional salience [4].

Frequency Band	Frequency	Associated with:
Gamma (γ)	35 Hz +	Perceptual and computational precision, local circuit synchrony
Beta (β)	12–35 Hz	Task-set maintenance, sensorimotor control
Alpha (α)	8–12 Hz	Cognitive inhibition and gating, internal focus
Theta (θ)	4–8 Hz	Drowsiness, cognitive control (region-specific)
Delta (δ)	0.5–4 Hz	Deep sleep

Table 1: Frequency bands [1]

Hypothesis

Arousal will result in the suppression of alpha band Lempel-Ziv complexity, resulting in a more constrained cortical state associated with heightened salience processing.

Methods

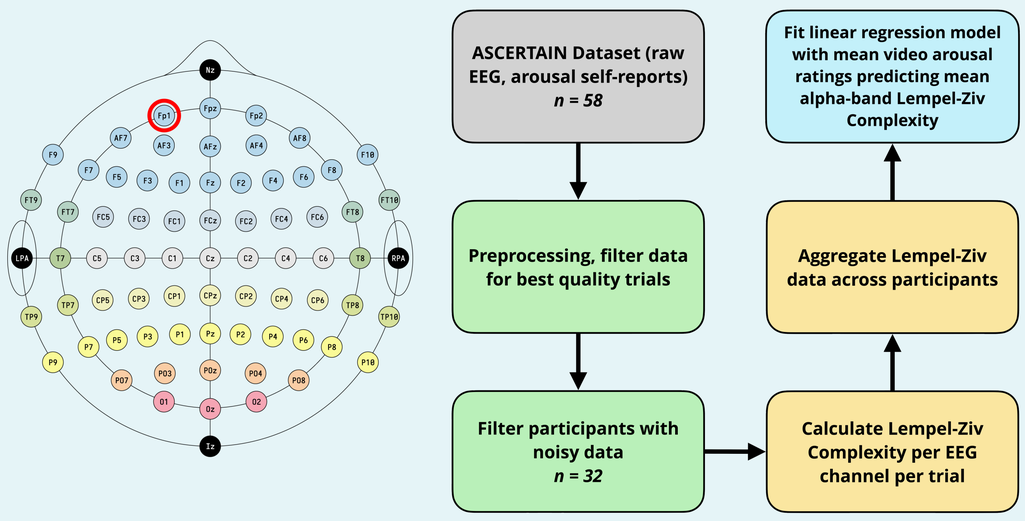


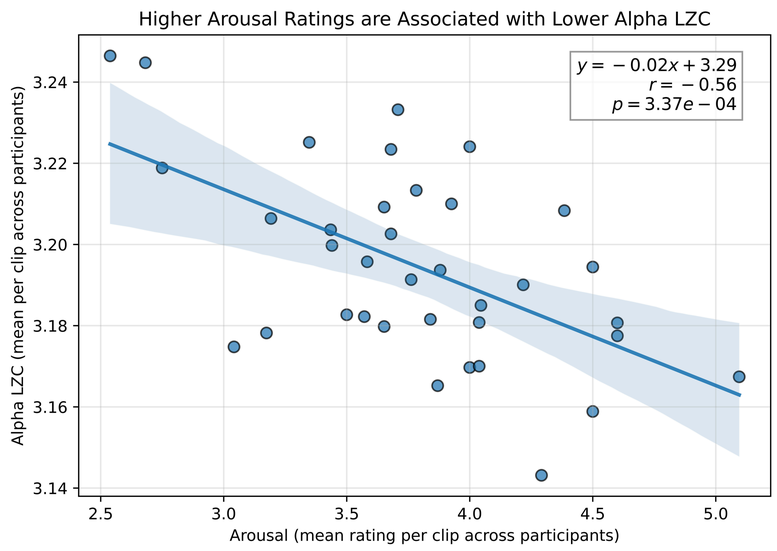
Figure 1: Frequency bands [6]

The ASCERTAIN dataset recorded arousal self reports and Fp1 single-electrode temporal EEG data using a commercial NeuroSky sensor from 58 participants while viewing affective movie clips [5].

Results

1. Video clips rated high in emotional arousal were associated with lower alpha-band Lempel-Ziv complexity measured in the frontal cortical region, consistent with elevated sympathetic nervous system activation

2. When fitting a trial-by-trial mixed-effects model that controlled for participant and video-specific baselines, we found no significant correlation between Lempel-Ziv Complexity in any frequency band and arousal ratings



$$L\bar{Z}C_{\alpha,v} = \beta_0 + \beta_1 \bar{A}_v + \varepsilon_v$$

Frequency Band	Coefficient	SE	P-value
Gamma (γ)	0.283	0.312	0.365
Beta (β)	0.200	0.267	0.455
Alpha (α)	0.085	0.259	0.744
Theta (θ)	-0.095	0.172	0.583
Delta (δ)	0.018	0.096	0.852

Discussion

1. Our results suggest that alpha-band entropy reflects a dynamic, adaptive shift in cortical processing: when arousal increases, cortical systems transition toward a more constrained and externally responsive state. This aligns with models in which alpha power facilitates rapid sensory gating and readiness for salient input.

2. Trait-level differences exerted neglibible influence on band-specific entropy in high arousal settings. Instead, we found that participants suppressed alpha complexity with high consistency across personality types, indicating a predominantly state-driven effect.

3. Given alpha entropy's demonstrated reliability in indicating stress, future studies may extend the work to examine alpha LZC as a potential biomarker for stress-related affective dysregulation.

Limitations & Future Directions

- There may be limited ecological validity of the stimuli used due to passive viewing. A central component of alpha waves and higher-frequency bands is information processing and decision making. Using valenced videos, there is no active 'response' merited, cutting out the later behavior of circuits that would be involved in high-arousal decisionmaking. Future studies should utilize endogenous sources of arousal.

- High frequency bands are more vulnerable to artifacts, which may have reduced our sensitivity in detection of entropy dynamics in higher bands (beta, gamma).

- Future work could apply a multimodal (EEG, ECG, GSR) deep-learning model to improve prediction of affective traits by learning non-linear features across modalities that traditional models do not capture.

References, More Information & Acknowledgements

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