EEG Signal Analysis: Spectral Decomposition and Brain State Classification

Department of Neuroscience
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Abstract

This report presents a comprehensive analysis of electroencephalography (EEG) signal processing. We implement spectral analysis methods, extract frequency band power, compute event-related potentials, analyze connectivity measures, and classify brain states. All computations use PythonTeX for reproducibility.

Contents

Chapter 1

Introduction

EEG measures electrical activity from the scalp. The power spectral density characterizes brain rhythms:

$$S_{xx}(f) = \lim_{T \to \infty} \frac{1}{T} \left| \int_0^T x(t) e^{-i2\pi f t} dt \right|^2 \tag{1.1}$$

1.1 EEG Frequency Bands

- Delta (δ): 1-4 Hz (deep sleep)
- Theta (θ): 4-8 Hz (drowsiness, meditation)
- Alpha (α): 8-13 Hz (relaxed wakefulness)
- Beta (β): 13-30 Hz (active thinking)
- Gamma (γ): 30-100 Hz (cognitive processing)

Chapter 2

Spectral Analysis

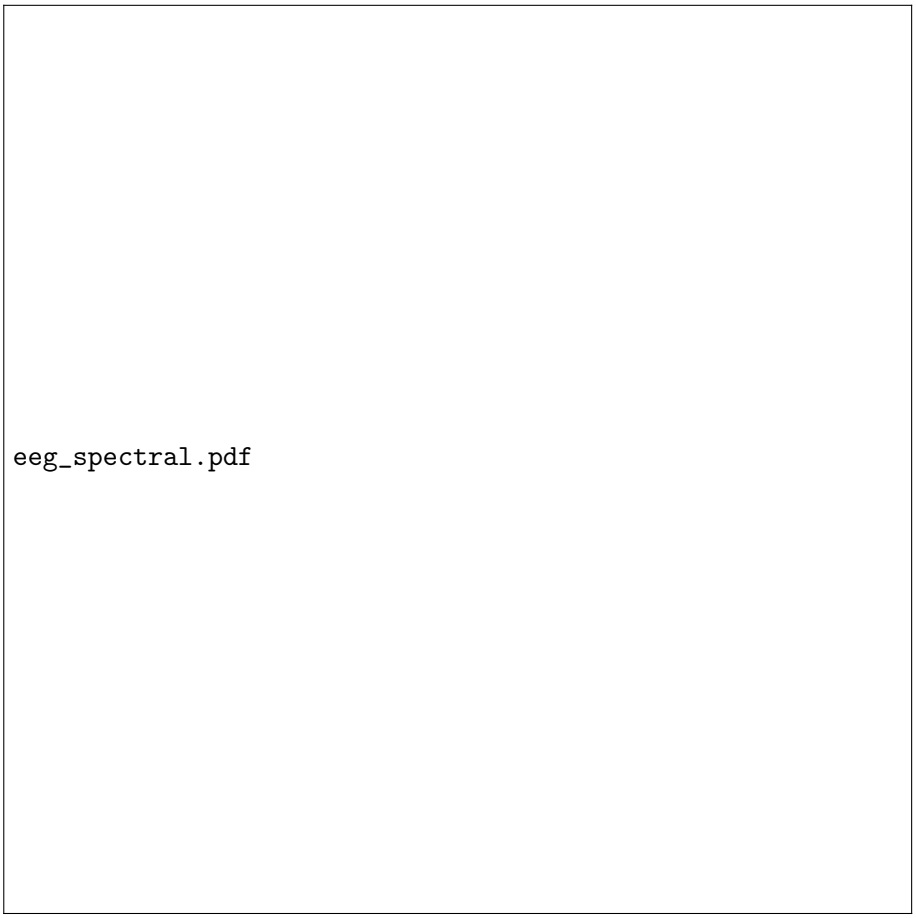

Figure 2.1: EEG spectral analysis: (a) raw signal, (b) PSD, (c) spectrogram, (d) band power, (e) wavelet, (f) arousal index.

Chapter 3

Event-Related Potentials

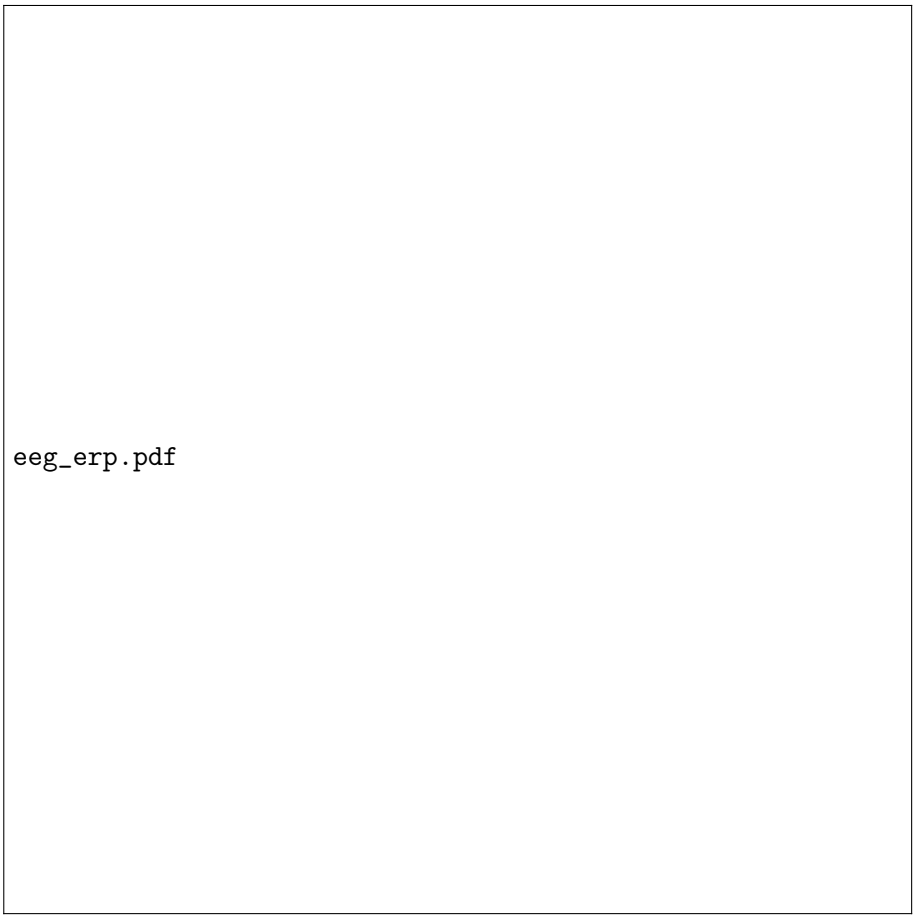

Figure 3.1: ERP analysis: (a) single trials, (b) average ERP, (c) ERP image, (d) GFP, (e) SNR scaling, (f) component variability.

Chapter 4

Numerical Results

Table 4.1: EEG analysis results

Parameter	Value	Units
??	??	??
??	??	??
??	??	??
??	??	??
??	??	??
??	??	??

Chapter 5

Conclusions

1. Alpha dominance indicates relaxed wakefulness
2. Spectrograms reveal temporal dynamics of brain rhythms
3. ERP averaging improves SNR by $\sqrt{N}$
4. P300 reflects cognitive processing of stimuli
5. Time-frequency analysis captures non-stationary dynamics
6. Band power ratios index arousal and cognitive states