Learning cognitive features from multiway EEG data using tensor decomposition

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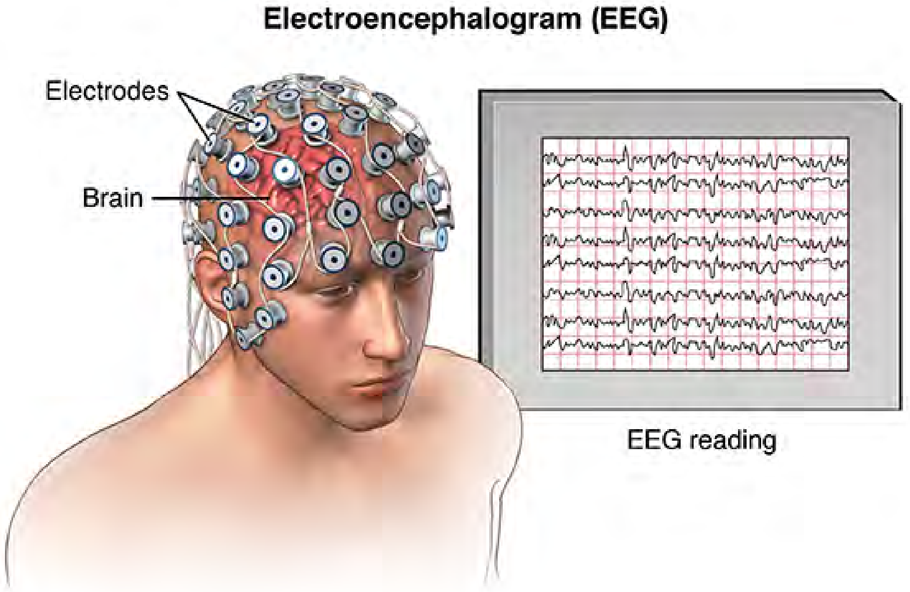
Part 1

Tensor Representation of EEG Data

EEG Data

Electroencephalography (EEG) is an electrophysiological monitoring method to record electrical activity of the brain.

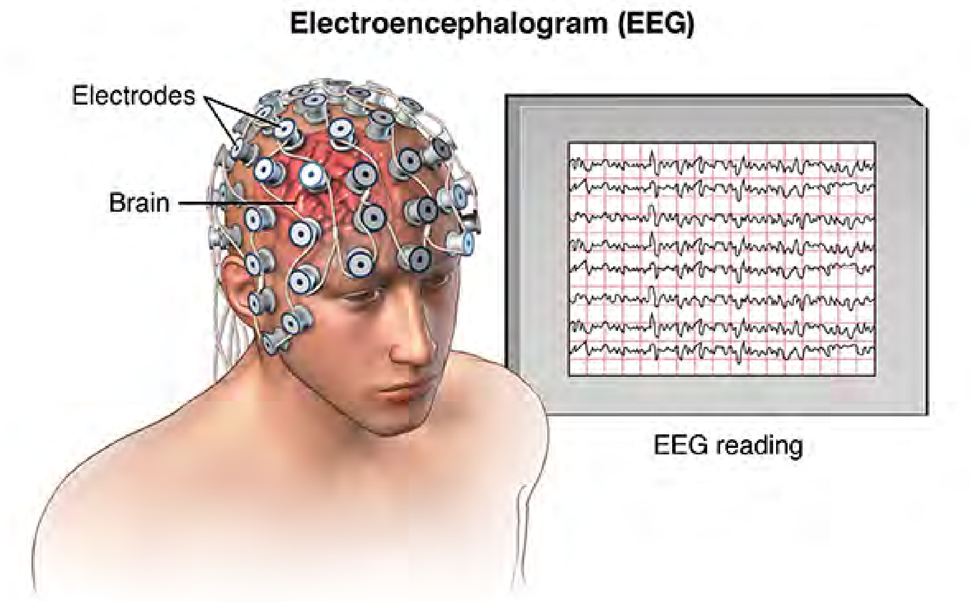


Three categories of EEG data [2]:

1. **Spontaneous EEG:** no external stimulus
2. **Event-related potentials (ERP):** repeated stimulus
3. **Ongoing EEG:** naturalistic and continuous stimulus

[1]. https://hvmn.com/biohacker-guide/cognition/eeg-measures-of-cognition
[2]. Cong, F., Ristaniemi, T., & Lyytinen, H. Advanced signal processing on brain event-related potentials. World Scientific, 2015.

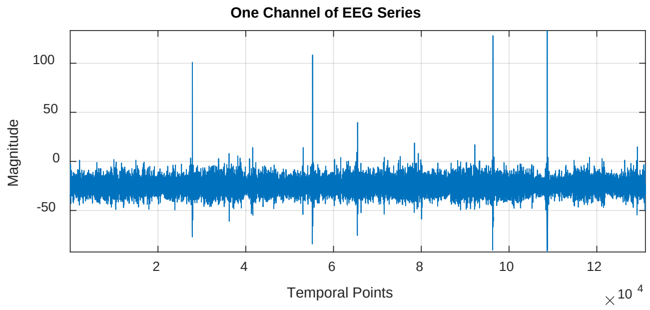
EEG Data



Matrix (two-way data):
Channel × Time

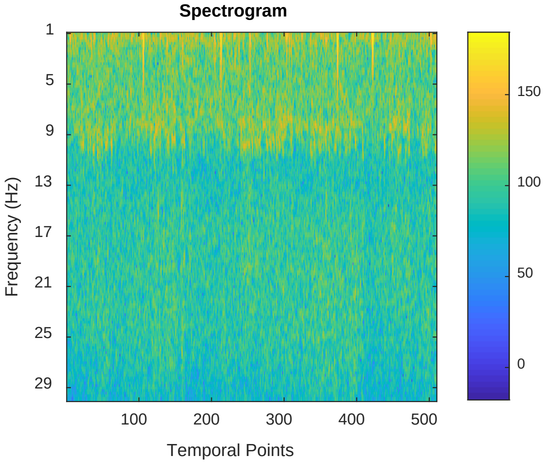
Frequency ?

Tensor Representation of Ongoing EEG Data

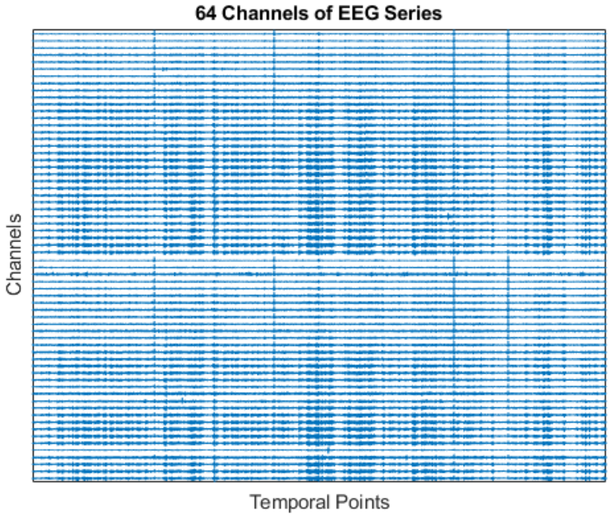


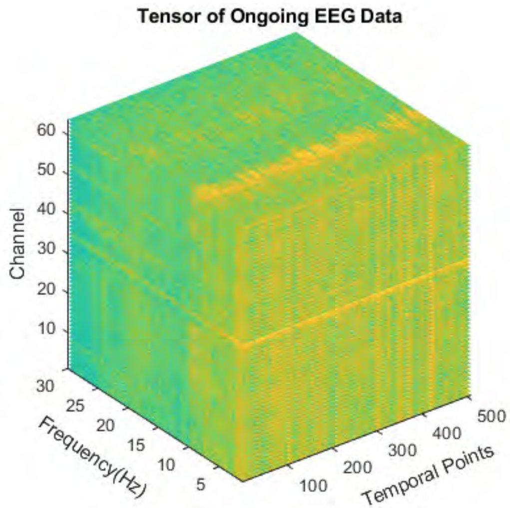
(8.5 minutes)

Short-Time Fourier Transform (STFT)



Frequency × Time

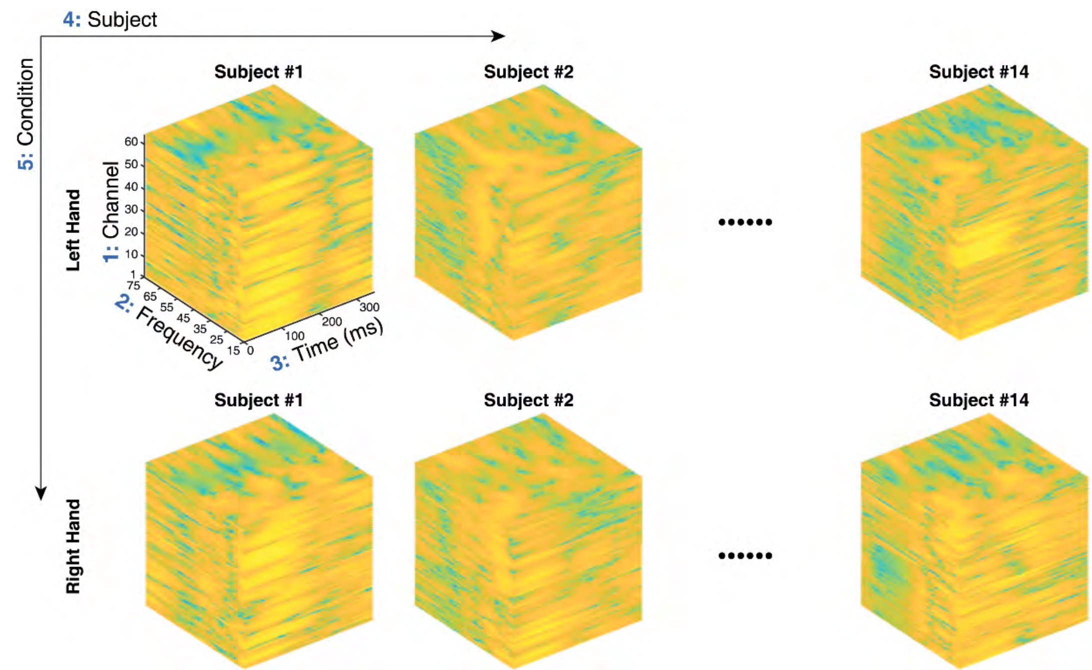




Channel × Frequency × Time

Fifth-order ERP Tensor

Channel × Frequency × Time × Subject × Condition



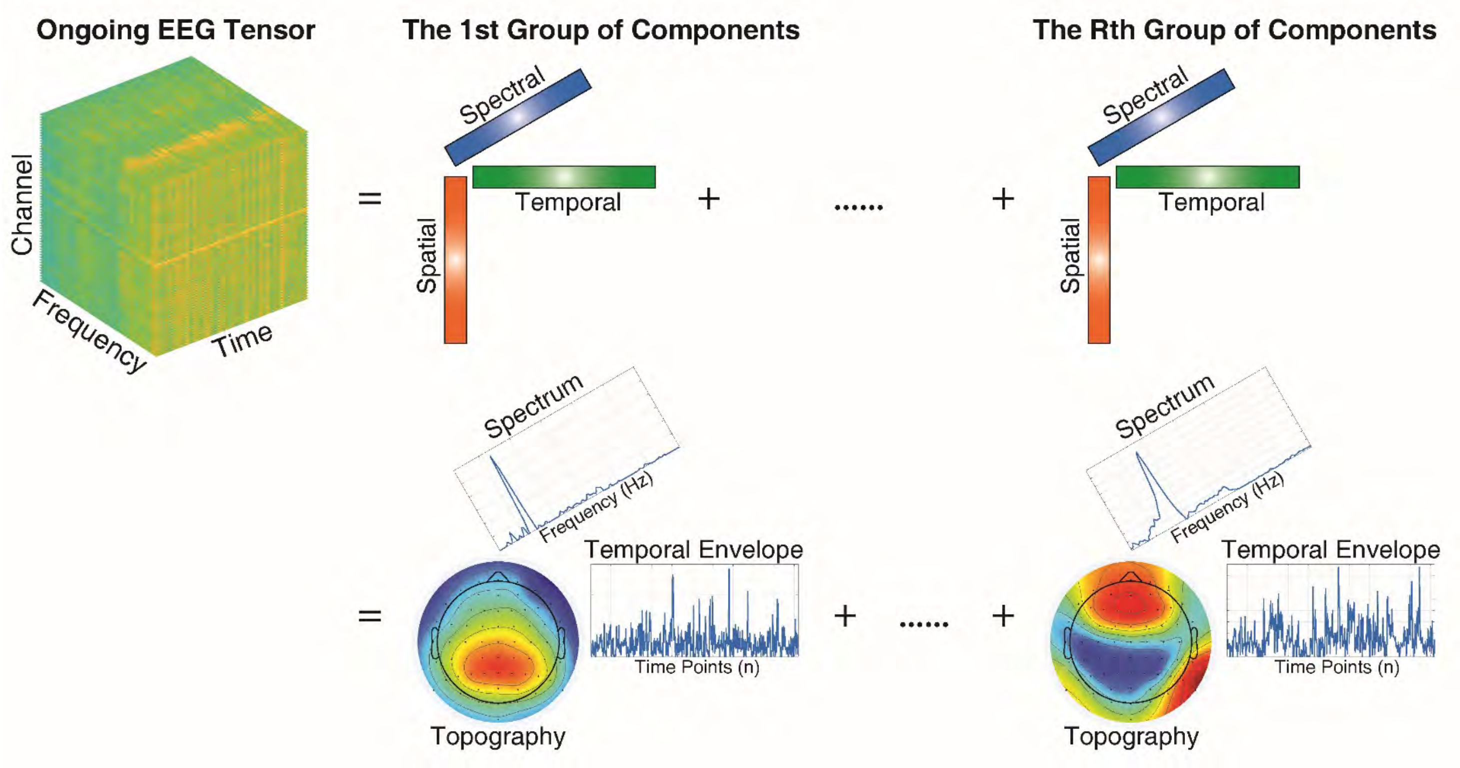
EEG Data Analysis Methods:

Conventional Methods:
Time, Frequency, Time-Frequency Domain

Matrix Decomposition (two-way):
PCA, ICA, NMF

Advanced Method:
Tensor Decomposition
(multiway method)

EEG Tensor Decomposition



Advantage:
the interaction information among different modes (channel, frequency, time) of EEG data is retained.

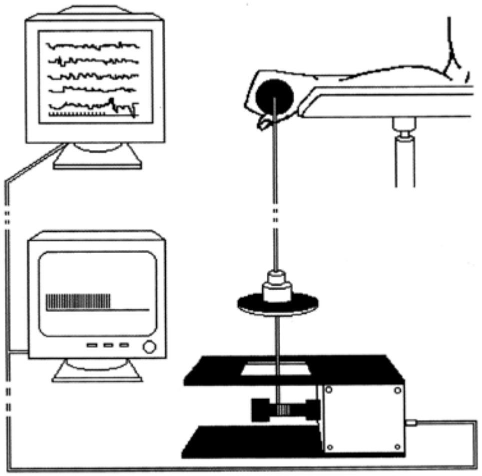
Part 2

Real-world EEG Tensor Applications

Real-world EEG Application I

Fifth-order ERP tensor analysis: proprioceptive stimulus

Tensor Size: 64 × 61 × 72 × 14 × 2
(Channel × Frequency × Time × Subjects × Condition)

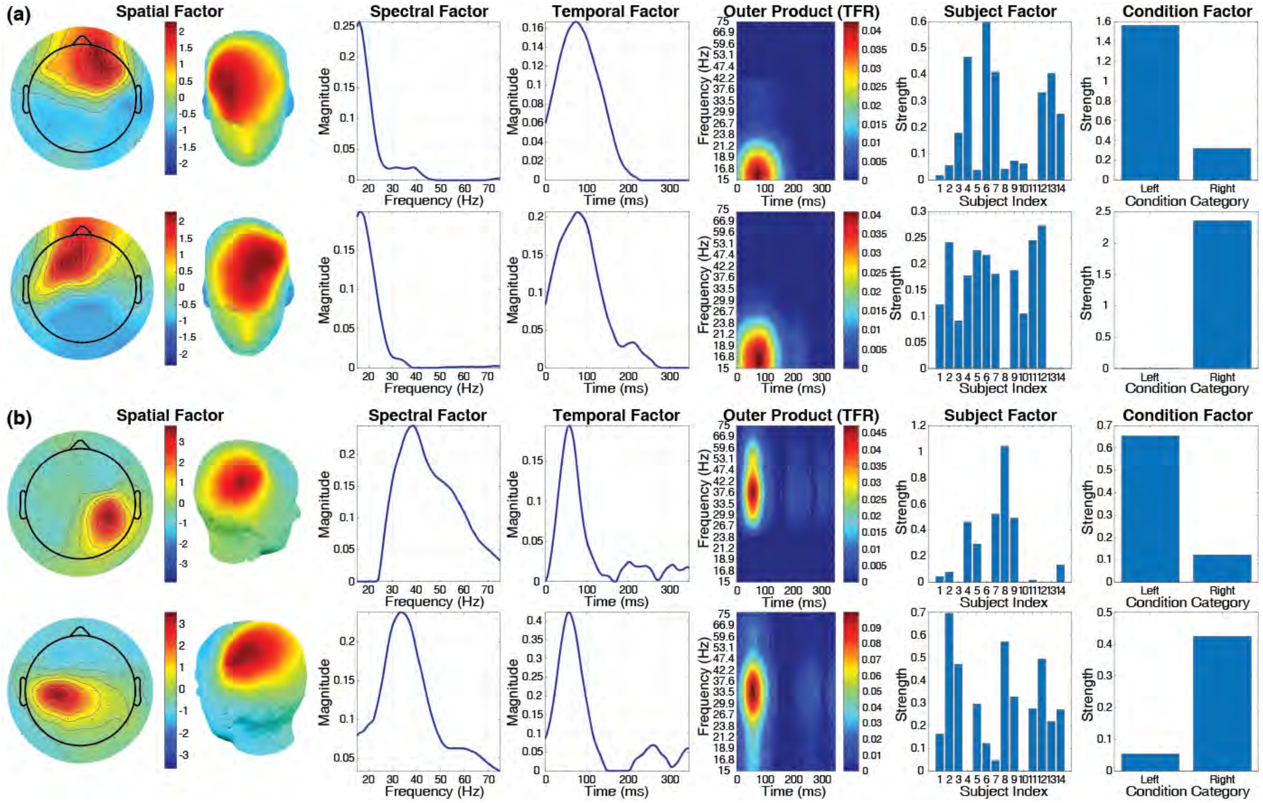


Stimulus on left and right hand.

[1]. Arnfred, Sidse, et al. "Proprioceptive evoked potentials in man: cerebral responses to changing weight loads on the hand." *Neuroscience letters* 288.2 (2000): 111-114.
[2]. Mørup, Morten, Lars Kai Hansen, Josef Parnas, and Sidse M. Arnfred. "Decomposing the time-frequency representation of EEG using non-negative matrix and multi-way factorization." *Technical University of Denmark Technical Report* (2006).

Real-world EEG Application I

Fifth-order ERP tensor analysis: proprioceptive stimulus



Deqing Wang, Yongjie Zhu, Tapani Ristaniemi, et al. *Extracting multi-mode ERP features using fifth-order nonnegative tensor decomposition*, Journal of Neuroscience Methods. Volume 308, 2018. p.240-247.

Real-world EEG Application II

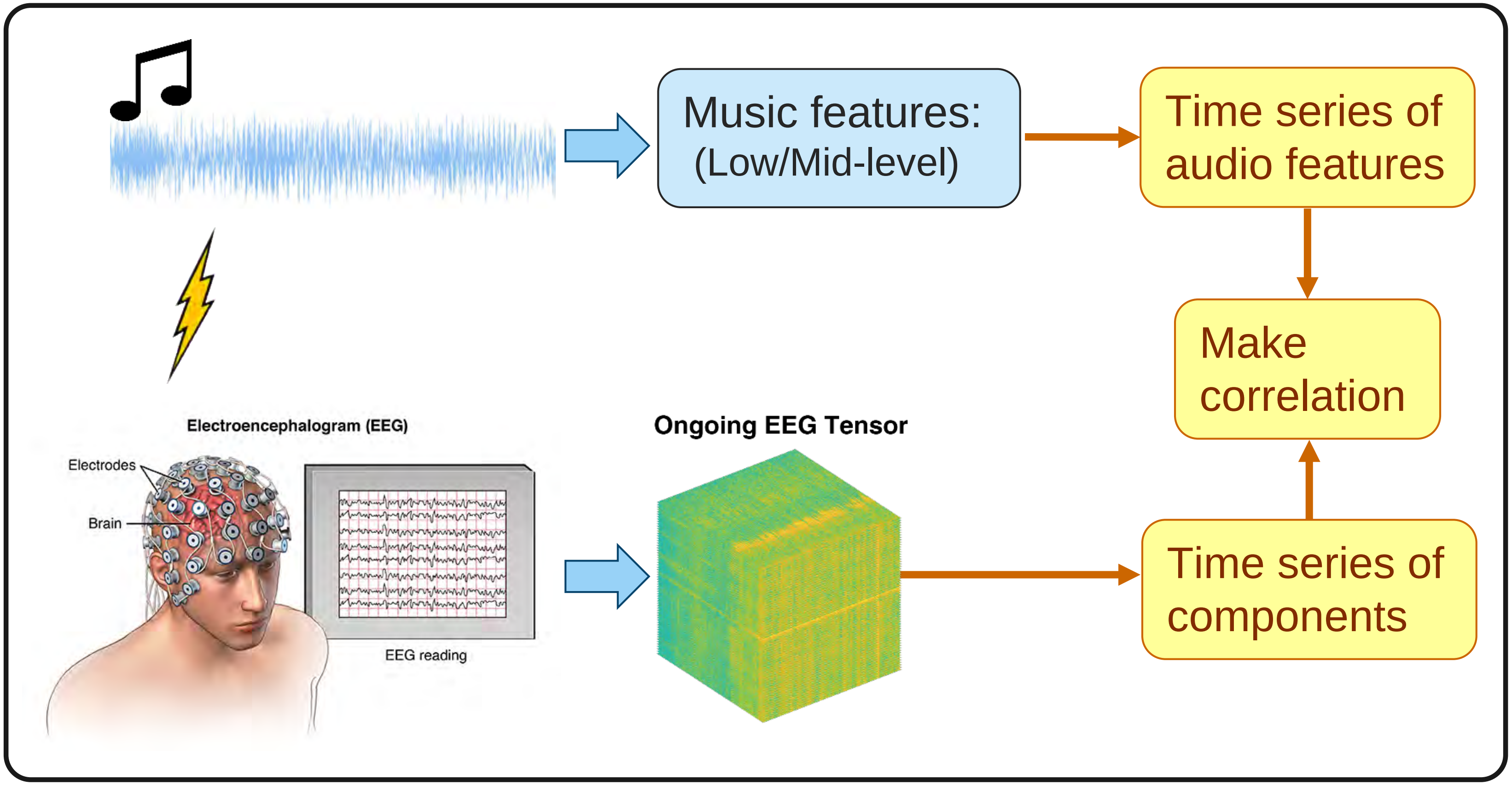
Ongoing EEG Data analysis: naturalistic music stimulus

Uncovering the neural underpinnings of **music processing** has become a central theme in **cognitive neuroscience** in the past decade.

[1]. Janata P., Cognitive Neuroscience of Music, in The Oxford Handbook of Cognitive Neuroscience, Volume 1: Core Topics. 2013, Oxford University Press: New York. p. 111-134.

Real-world EEG Application II

Ongoing EEG Data analysis: naturalistic music stimulus



Research Framework

Real-world EEG Application II

Ongoing EEG Data analysis: naturalistic music stimulus

Tensor Data:

Stimulus: continuous and naturalistic modern tango music stimulus.

Tensor Size: (one subject) time×frequency×channel = 510×146×64

Five music features:

Tonal features (Mode, Key Clarity)

Rhythmic features (Pulse Clarity, Fluctuation Centroid, Fluctuation Entropy)

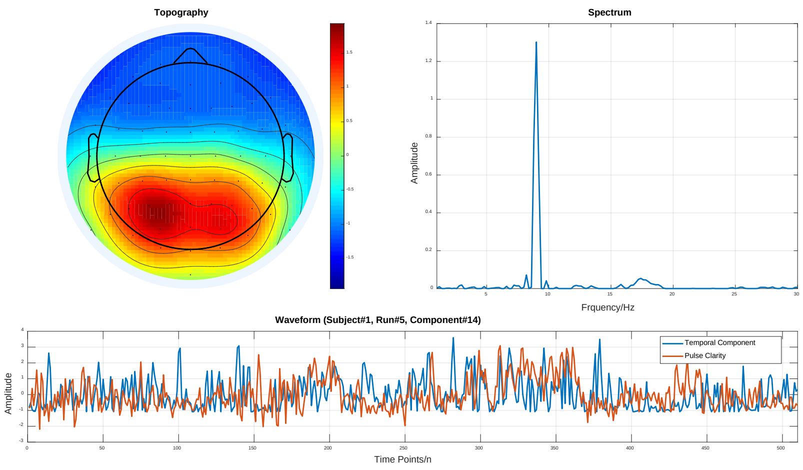


Fig. 1. Components correlated with **pulse clarity** feature

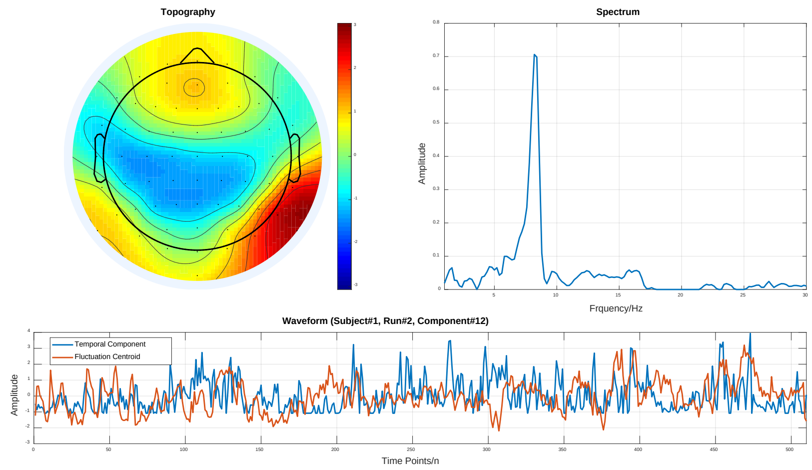


Fig. 2. Components correlated with **fluctuation centroid** feature

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References:

Deqing Wang, Yongjie Zhu, Tapani Ristaniemi, et al. Extracting multi-mode ERP features using fifth-order nonnegative tensor decomposition, Journal of Neuroscience Methods. Volume 308, 2018. p.240-247.

Deqing Wang, Xiaoyu Wang, Yongjie Zhu, et al. Increasing stability of EEG Components Extraction Using Sparsity Regularized Tensor Decomposition, in Advances in Neural Networks – ISNN 2018, T. Huang, et al., Editors. 2018, Springer International Publishing. p. 789-799.

Deqing Wang, *Extracting Meaningful EEG Features Using Constrained Tensor Decomposition*, Ph.D. Thesis, University of Jyväskylä, Finland. December 2019.

(The demonstrations and codes of EEG tensor decomposition are available on the author’s website, http://deqing.me/)