Atomic Decomposition of EEG for Mapping Cortical Activation

Roman Rosipal, Leonardo Jose Trejo, Eran Zaidel

Introduction

To improve the measurement and differentiation of normal and abnormal brain function we are developing new methods to decompose multichannel EEG into elemental components or "atoms." We estimate EEG atoms using multiway analysis, specifically parallel factor analysis or PARAFAC for modeling. Activation sequences of EEG atoms can identify functional brain networks dynamically, with much finer time resolution than fMRI. Guided by the score values of the identified atoms we inferred the volumetric brain sources of the selected networks using the sLORETA pseudoinverse algorithm. To confirm network identities, we compared 2-D and 3-D functional network maps derived from EEG atoms to known functional neuroanatomy of the networks. We find that multichannel EEGs in most individuals can be accounted for by a set of five to six standard atoms, which parallel classical EEG bands, and have unique power spectra, scalp and cortical topographies.

Methods

Data acquisition and preprocessing: We analyzed 64-channel EEG data recorded from fourteen UCLA students in a study consisting of resting state conditions (EO - eyes-open, EC - eyes-closed), neurofeedback training (BFB, seven C3 beta trained subject, seven sham), continuous performance test (CPT) and the lateralized attention network test (LANT) [1]. The EEGs were down sampled to 128 Hz. Data were re-referenced using the average reference method and were segmented into 1-s long windows with no overlap. For each segment the positive logarithmic power spectral density was computed using the fast Fourier method with Hann windowing. Frequencies in the range of 0 to 64 Hz were used considered.

PARAFAC: A three-way PARAFAC model was applied to data [2]. Three loading matrices, **A**, **B** , and **C** with elements a_{if}, b_{jf}, and c_{kf} defines the model

$$x_{ijk} = \sum_{f=1}^{F} a_{if} b_{jf} c_{kf} + \epsilon_{ijk} \ ,$$

where ϵ_{ijk} are the residual elements. The loadings elements are found by minimizing the sum of squares of the residuals ϵ_{ijk}

$$min_{a_{if} b_{jf} c_{kf}} \| x_{ijk} - \sum_{f=1}^{F} a_{if} b_{jf} c_{kf} \|^2$$

sLORETA: An estimate of cortical activation corresponding to the scalp EEG was carried out with sLORETA [3]. sLORETA estimates an image of cortical activation (inferred by current-source density estimates) for every sample time-point. To separate EEG into segments of specific spatial and frequency based scalp activation patterns we used multi-way atomic decomposition of EEG and we defined segments of EEG based on the atomic score values. This allowed us to combine different atomic activations and to study the linked cortical patterns.

References

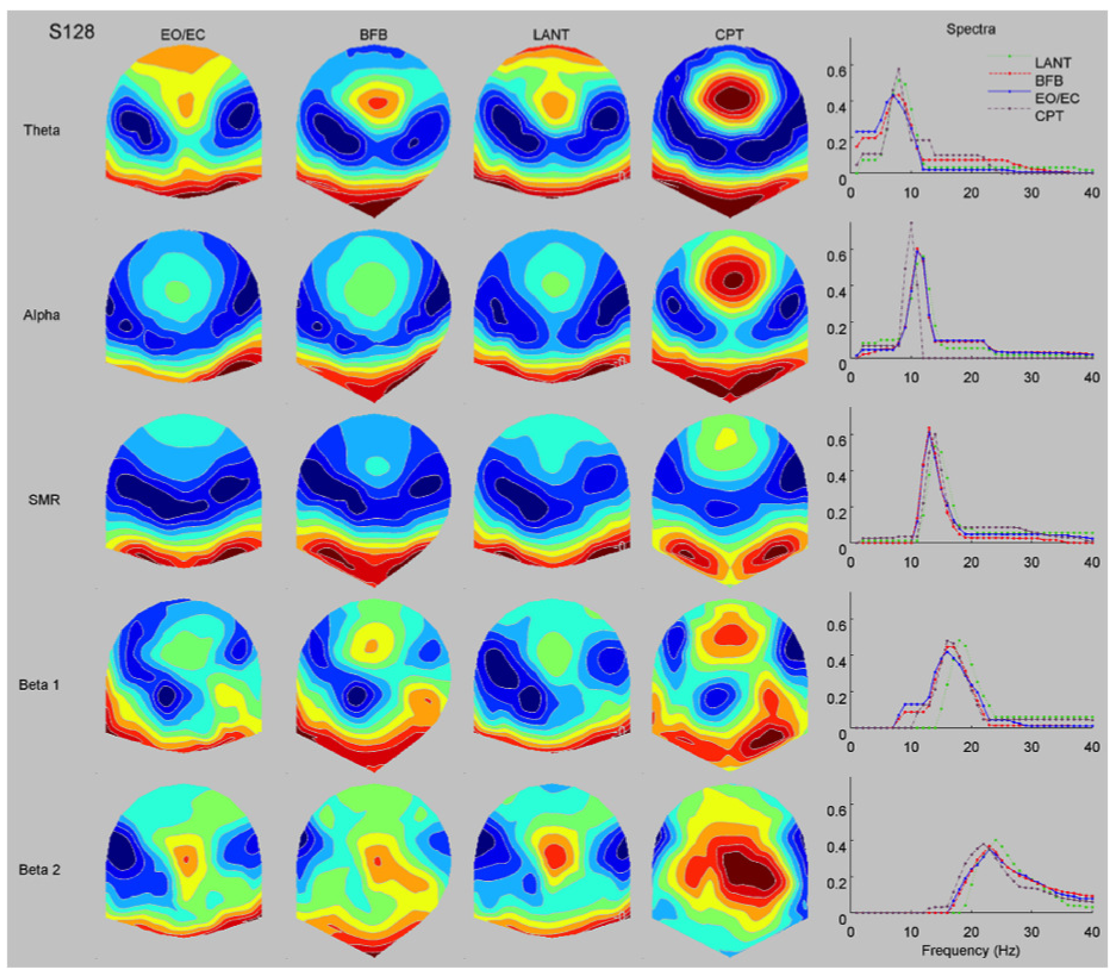
[1] Greene, D.J., et. al.: Measuring attention in the hemispheres: the lateralized attention network test (LANT). *Brain and Cog.*, 66, 21–31, 2008.

[2] Bro, R.: PARAFAC. Tutorial and applications. *Chem. and Int. Lab. Syst.*, 38, 149–171, 1997.

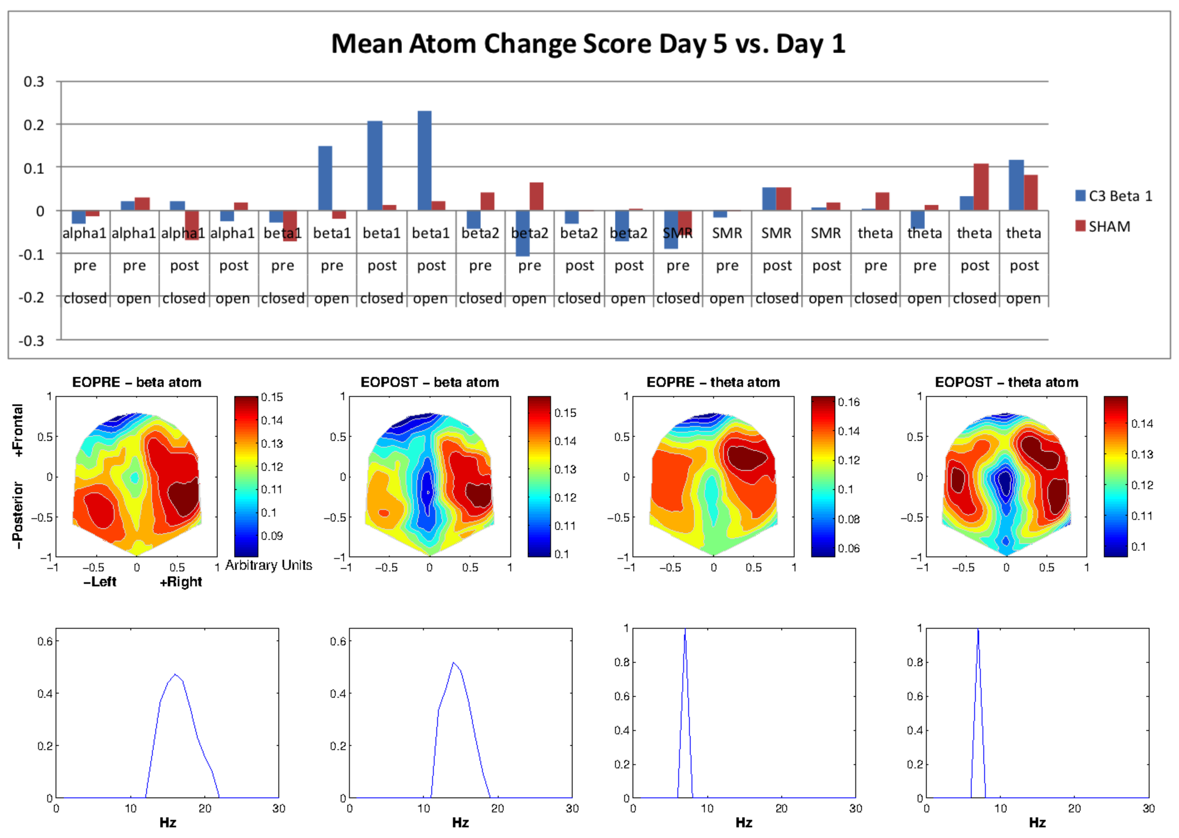
[3] Pascual-Marqui, R.D.: Standardized low-resolution brain electromagnetic tomography (sLORETA): technical details. *Methods Find. Exp. Clin. Phar.*, 24, 5–12, 2002.

[4] Nichols. T.E. & Holmes, A.P.: Nonparametric Permutation Tests for Functional Neuroimaging *Hum. Brain Map.*, 15, 1–25, 2001.

PARAFAC atoms



Reliability of EEG atom measurement. Five standard atoms estimated during four experimental conditions.

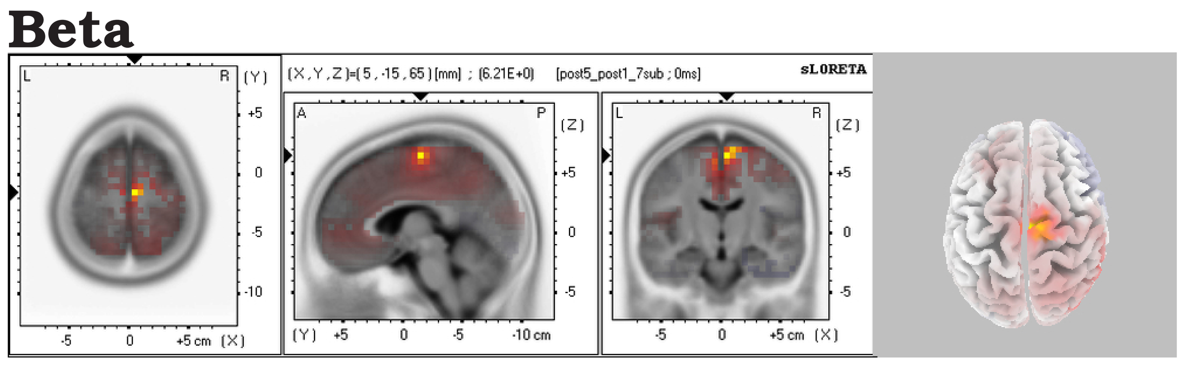


Top: Atom score changes after 3 BFB training sessions.
Botton: Extracted beta and theta PARAFAC atoms from EO resting periods recorded prior (EOPRE) and after (EOPST) BFB training sessions.

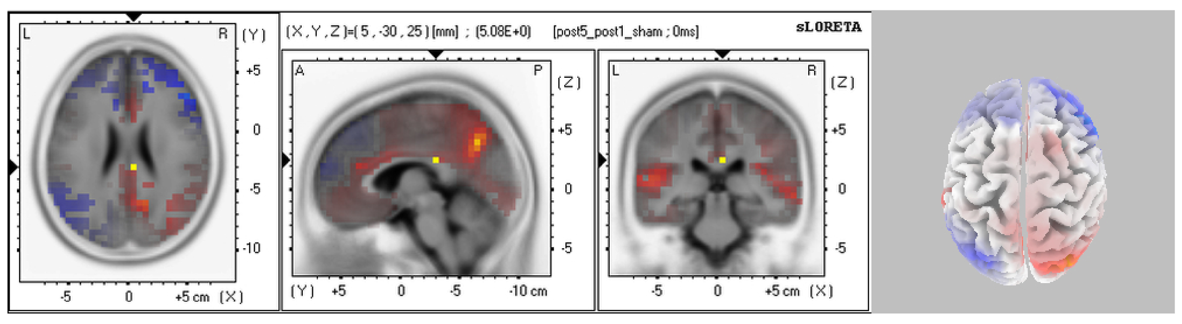
sLORETA - BFB training effect, Eyes-open resting, Day5 vs Day1

It is impossible to know for sure where EEG sources come from using scalp electrodes, but we can make reasonable educated guesses with pseudo-inverse methods like sLORETA. We selected segments of EEG corresponding to high score values (85th percentile) of the extracted PARAFAC beta and theta atoms. Nonparametric paired permutation t-test [4] was used to compare BFB effects in EO resting post-training condition (Day5 vs Day1).

Beta

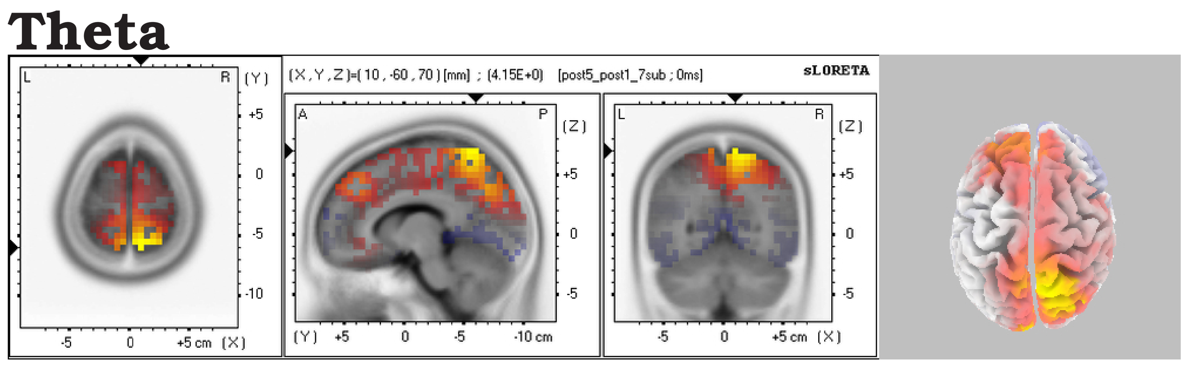


C3 beta: The max. t-statistic t=6.2 (p=0.08), Brodmann area 6, medial frontal gyrus.

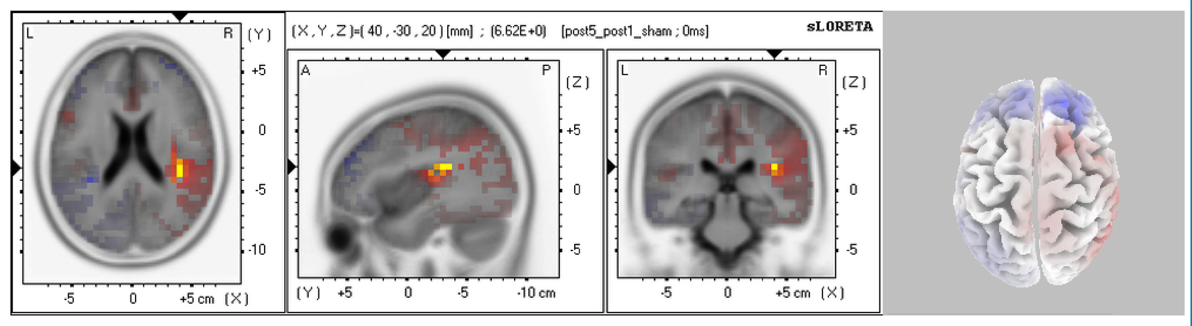


Sham: The max. t-statistic t=5.1 (p=0.32), Brodmann area 23, posterior cingulate.

Theta



C3 beta: The max. t-statistic t=4.2 (p=0.32), Brodmann area 7, postcentral gyrus.



Sham: The max. t-statistic t=6.6 (p=0.08), Brodmann area 13, insula.

Conclusions

We are presenting a new approach of combining multi-way atomic decomposition of EEG with cortical activation mapping. This is a novel way of studying the association between scalp EEG and the underlying cortical sources. Although this initial report describes very interesting results, a thorough detailed analysis and statistical evaluation of the methodology and results is required and is currently underway.

Funding

This work was supported by the U.S. Army Research Laboratory Contract No. W911NF-11-C-0081. R.R. was partially supported by the MZ 2012/56-SAV-6, VEGA 2/0043/13 and VEGA 1/0503/13 grants.