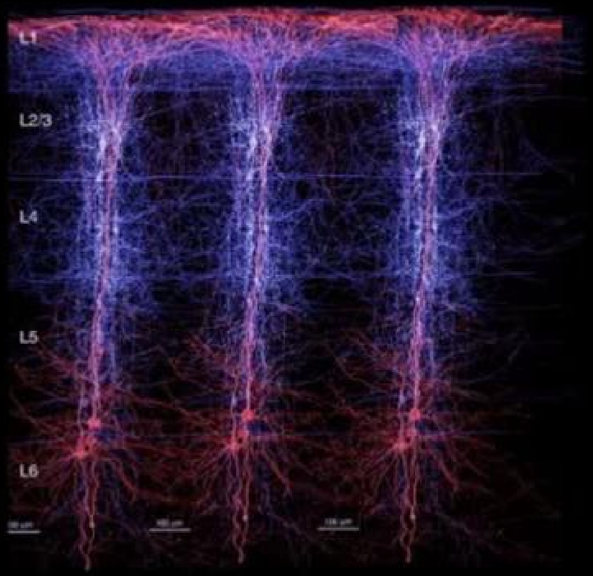
Lecture 13. Bridging Distributional Semantics and Neuroscience



Pyramidal neurons are spatially aligned perpendicular to the cortical surface.

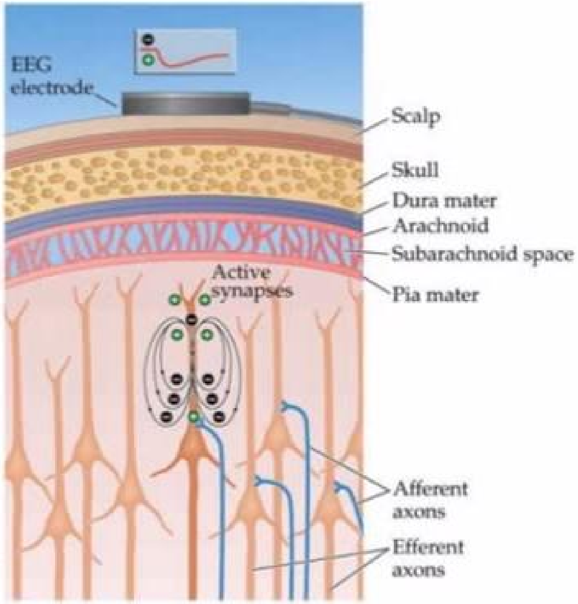
Creates a dipole layer or dipole sheet in the cortex.

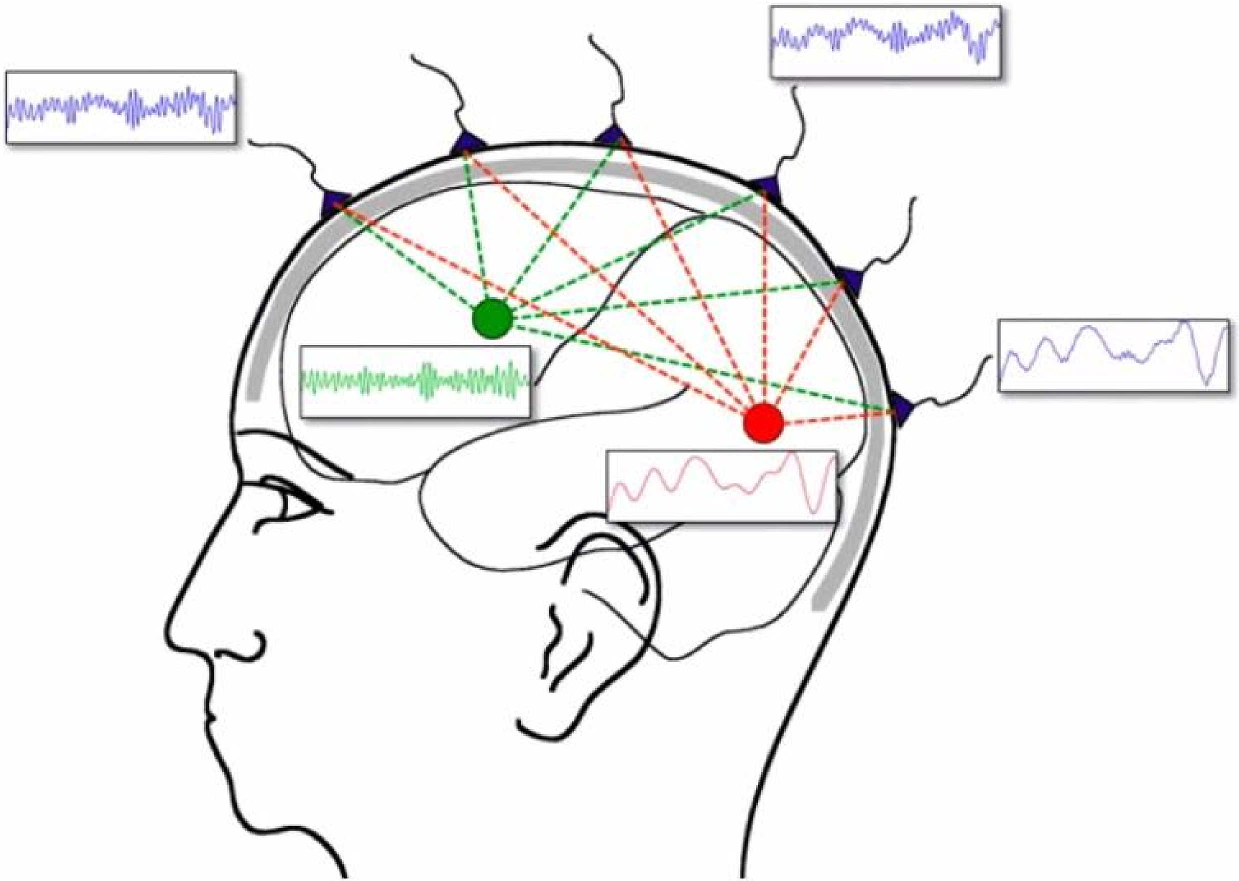
Thus, EEG represents mainly the postsynaptic potentials of pyramidal neurons close to the recording electrode.

- EEG results from the *combined* activity of a *large* numbers of *similarly oriented* pyramidal neurons.

- Requires *synchronous* activity across groups of cells.

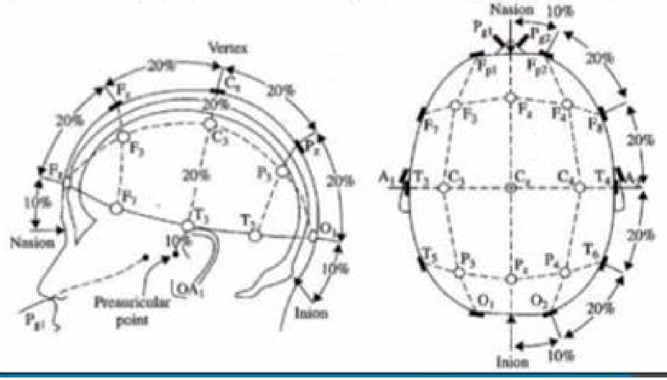
- EEG reflects *summed* post synaptic activity of large cell ensembles.

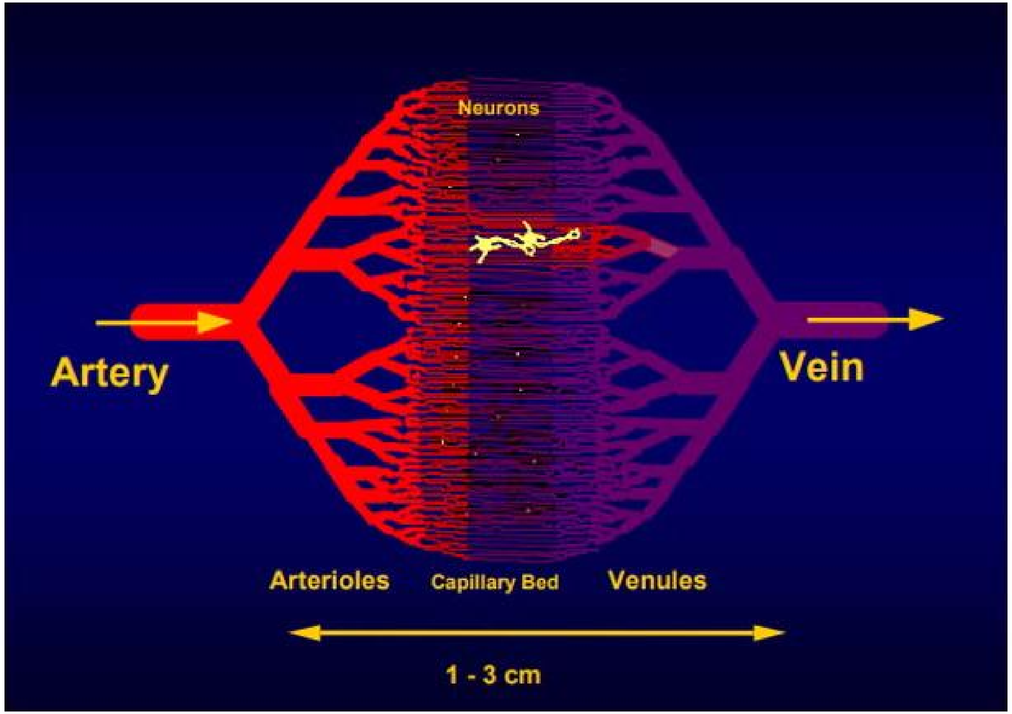




Surface recordings

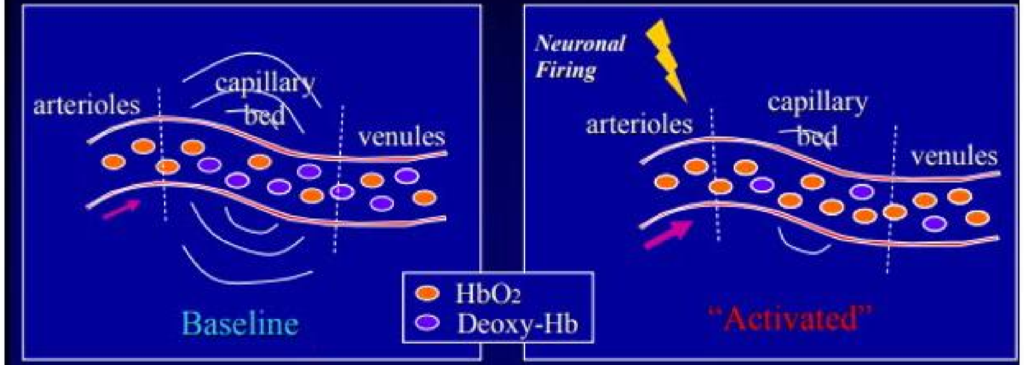
- EEG is recoded from electrodes placed on the surface of the scalp.
- The 10-20 position system ensures consistent placement of electrodes across the surface of the scalp independent of head size and shape.
- Uses anatomical landmarks to determine specific distances across the head.
- Places electrodes at regular intervals based on these distances.



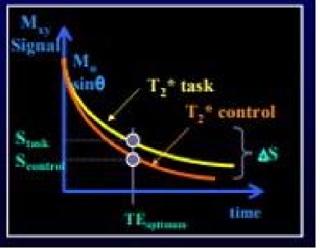


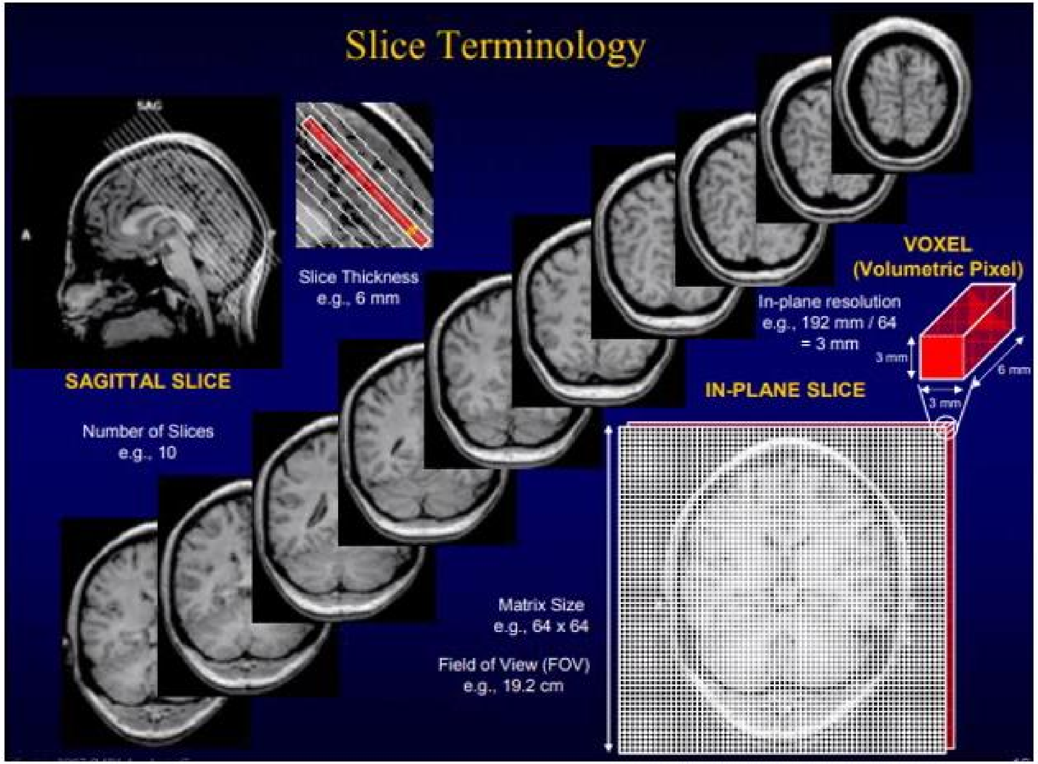
Neurons
Artery
Vein
Arterioles
Capillary Bed
Venules
1 - 3 cm

Blood Oxygen Level Dependent (BOLD)



- Neural activity increases
- Blood flow increases ("reactive hyperemia")
- Deoxyhemoglobin concentration decreases
- Magnetic field homogeneity increases
- Gradient echo EPI signal increases




Slice Terminology
SAG
A
SAGITTAL SLICE
Slice Thickness
e.g., 6 mm
Number of Slices
e.g., 10
VOXEL
(Volumetric Pixel)
In-plane resolution
e.g., 192 mm / 64
= 3 mm
3 mm
6 mm
3 mm
IN-PLANE SLICE
Matrix Size
e.g., 64 x 64
Field of View (FOV)
e.g., 19.2 cm

Основной принцип подходов для изучения ЭЭГ-ФМРТ сцепления (*Mulert C., 2010*)

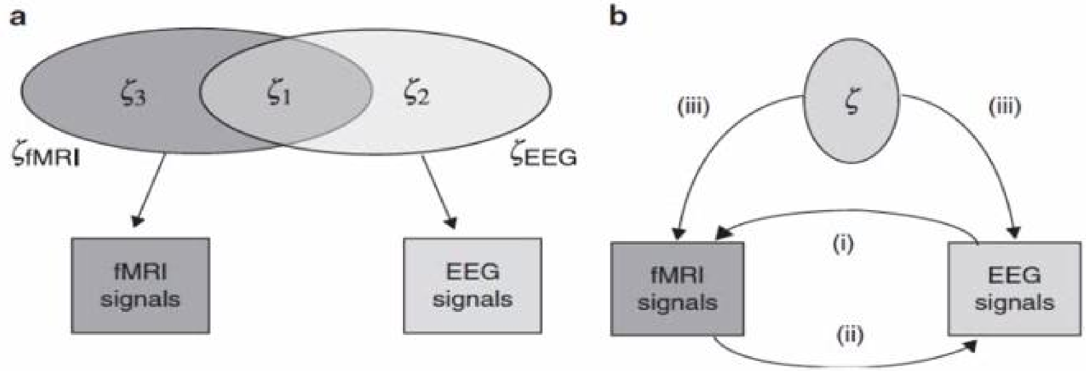
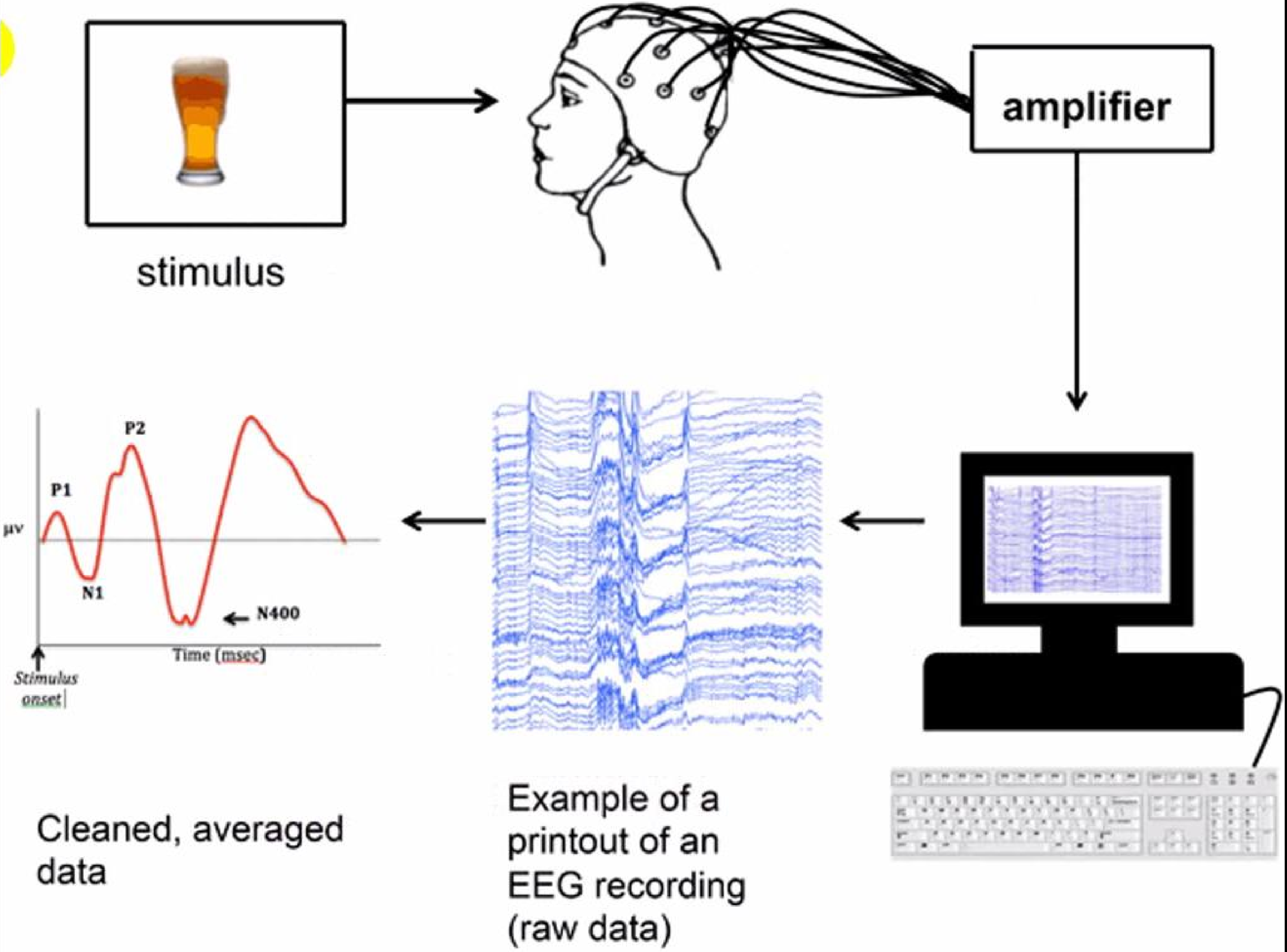
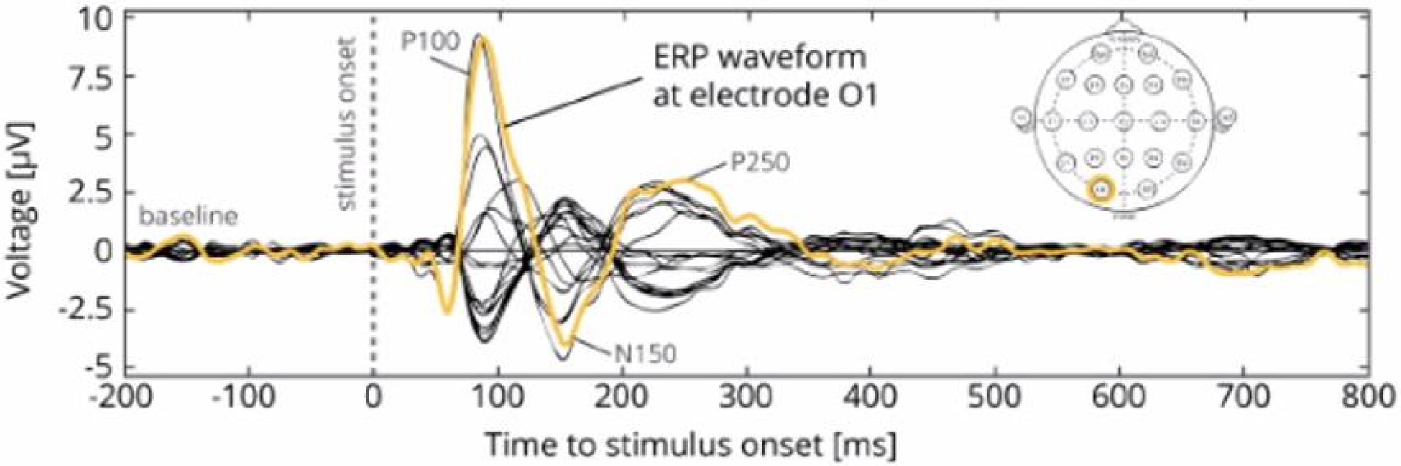


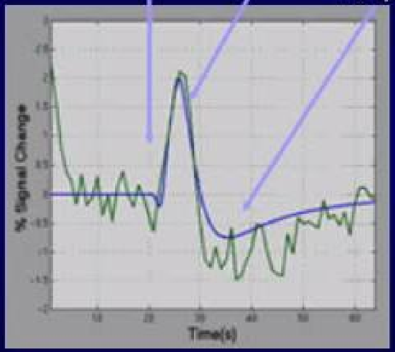
Fig. 1a–b Formalisation of the EEG–fMRI coupling–uncoupling (**a**) and EEG–fMRI fusion approaches (**b**) (adapted from Daunizeau et al. 2007 and Kilner et al. 2005). Any multimodal information fusion approach will be beneficial for inferring common neuronal states, ζ_1. This means that asymmetrical EEG–fMRI approaches systematically bias their estimate of ζ_1 by introducing information from ζ_{EEG} [(*i*): EEG to fMRI approaches, i.e. integration through prediction] or ζ_{fMRI} [(*ii*): fMRI to EEG approaches, i.e. integration through constraints]. In contrast, symmetrical EEG–fMRI fusion approaches rely on a joint EEG–fMRI generative model, which allows the estimation of ζ_1 to be derived from an optimal balance between EEG- and fMRI-derived information [(*iii*): integration through forward models]


stimulus
amplifier
P2
P1
μv
N1
N400
Time (msec)
Stimulus onset
Example of a printout of an EEG recording (raw data)
Cleaned, averaged data



Time-Course Response in fMRI

- Brief neuronal events can elicit a (positive) blood flow and oxygenation response.
- Reponses to events as brief as 50 ms have been recorded.



Functional MRI response to a visual stimulus of duration 2s

EEG

- N400 (400 milliseconds after stimuli were presented) the most important one for a linguist, because it is associated with a comprehension of semantic information
- N1-moment (80-120 milliseconds after stimuli) is also essential as it reports the earliest reaction of human brain

N400

Using Language Models and Latent Semantic Analysis to Characterise the N400m Neural Response

Mehdi Parviz, Mark Johnson **Blake Johnson, Jon Brock**

Language, Cognition and Neuroscience

ISSN: 2327-3798 (Print) 2327-3801 (Online) Journal homepage: https://www.tandfonline.com/loi/plcp21

Word predictability and semantic similarity show distinct patterns of brain activity during language comprehension

Stefan L. Frank & Roel M. Willems

- frequency
- Predictability

- Surprisal vs semantic distance

- fundamental assumption of fMRI-research is that when an individual perform two tasks simultaneously, BOLDresponse is added linearly, what means scaling (multiplying by a number) for each chosen process and their summation.

- People are different and lot of processes pass at the same time
- Statistical averaging

- Neurolinguistics investigate questions connected with brain reaction not on real world objects, but rather with organization and access to mental representation of word’s meaning. processes of word and object recognition are not at all equivalent

Learning to Identify POS from Brain Image Data*

Arshit Gupta Tom Mitchell

- # Bayes, 88%, part-of-speech

Localization/intensity

- # Semantic vs syntax

- weighted sum of semantic values of a given word

Neuropsychologia

Volume 42, Issue 1, 2004, Pages 62-70

Processing concrete words: fMRI evidence against a specific right-hemisphere involvement

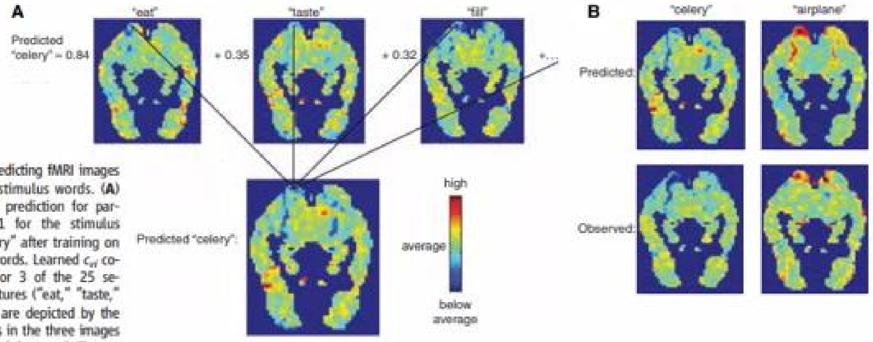
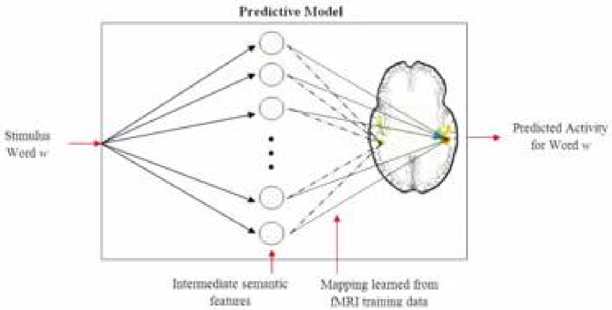


Fig. 2. Predicting fMRI images for given stimulus words. (**A**) Forming a prediction for participant P1 for the stimulus word "celery" after training on 58 other words. Learned c_{vi} coefficients for 3 of the 25 semantic features ("eat," "taste," and "fill") are depicted by the voxel colors in the three images at the top of the panel. The co-occurrence value for each of these features for the stimulus word "celery" is shown to the left of their respective images [e.g., the value for "eat (celery)" is 0.84]. The predicted activation for the stimulus word [shown at the bottom of (A)] is a linear combination of the 25 semantic fMRI signatures, weighted by their co-occurrence values. This figure shows just one horizontal slice [$z = -12$ mm in Montreal Neurological Institute (MNI) space] of the predicted three-dimensional image. (**B**) Predicted and observed fMRI images for "celery" and "airplane" after training that uses 58 other words. The two long red and blue vertical streaks near the top (posterior region) of the predicted and observed images are the left and right fusiform gyri.

Predicting Human Brain Activity Associated with the Meanings of Nouns

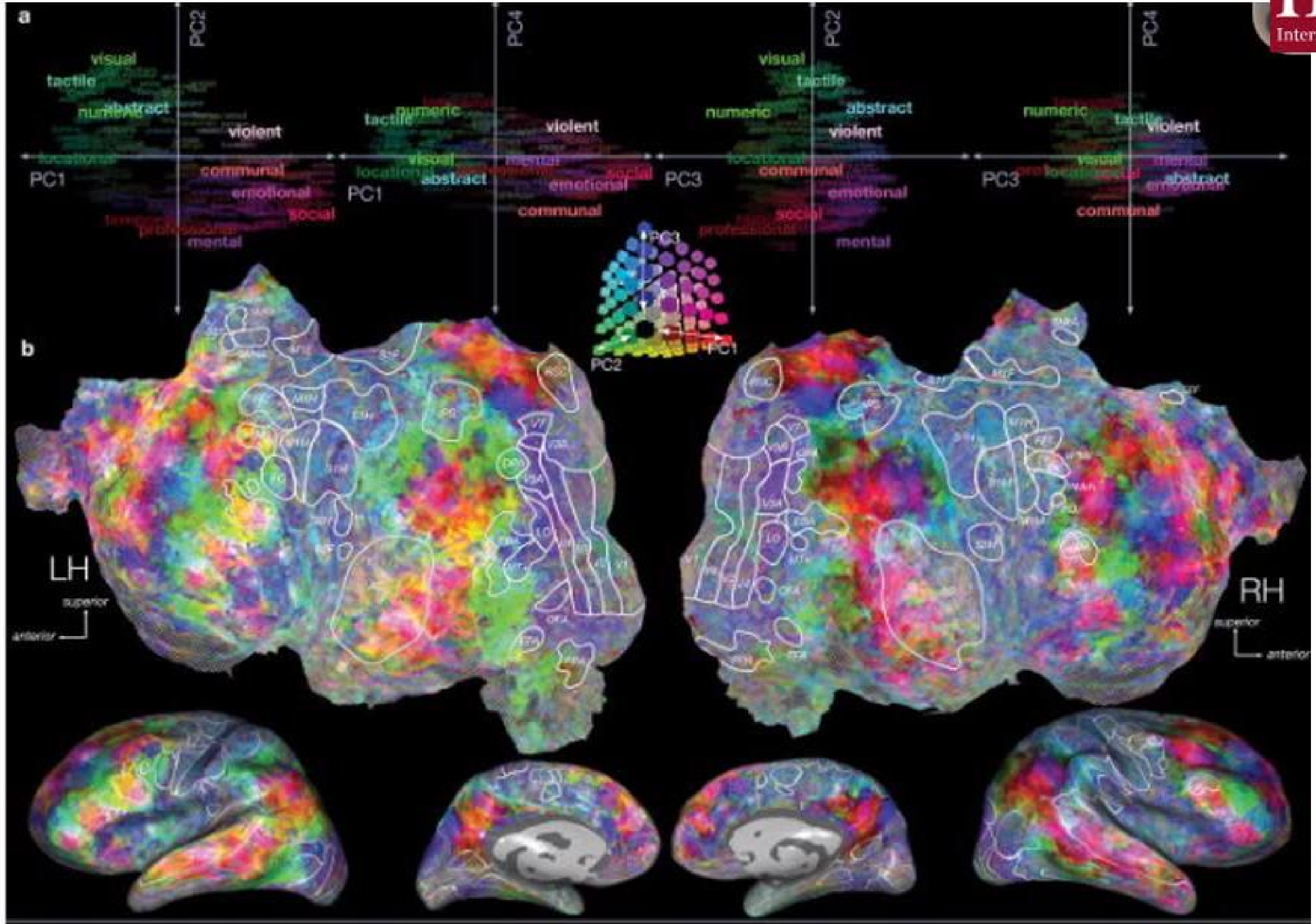
Tom M. Mitchell,[1*] Svetlana V. Shinkareva,[2] Andrew Carlson,[1] Kai-Min Chang,[3,4]



Natural speech reveals the semantic maps that tile human cerebral cortex

Alexander G. Huth,[a] Wendy A. de Heer,[b] Thomas L. Griffiths,[a,b] Frédéric E. Theunissen,[a,b] and Jack L. Gallant[a,b]

nature
International journal of science

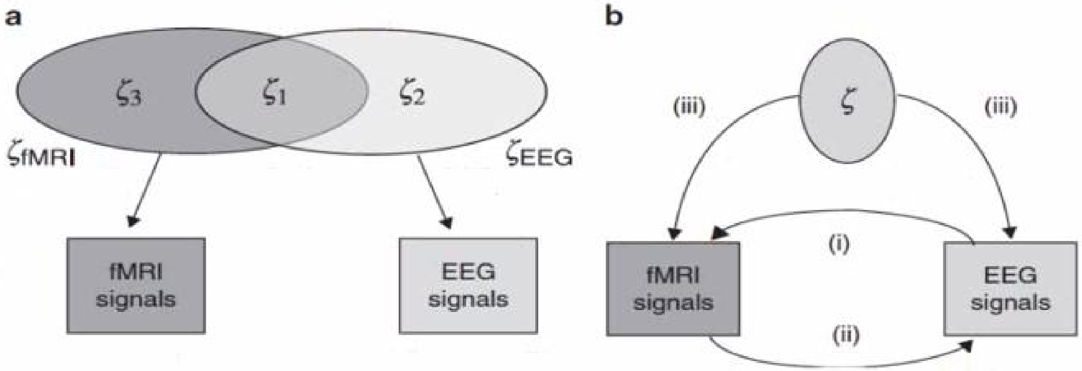


7person
x 2 hour

- semantic center (brain parts responsible for processing semantic information) is more or less common across the participants in terms of its localization in a brain, and the reaction of each individual in response to the given stimuli doesn’t differ significantly from the reaction of other participants.

EEG+fMRI

Основной принцип подходов для изучения ЭЭГ-ФМРТ сцепления (*Mulert C., 2010*)



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- The first approach is the fMRI-informed EEG method, which aims to guide electromagnetic source estimation using results obtained from fMRI images with superior spatial resolution, thereby improving EEG source localization (Heinze et al., 1994, Huster et al., 2011).

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ФМРТ-зависимые ЭЭГ-подходы: EEG Finger Print (*Meir-Hasson Y., 2013*)

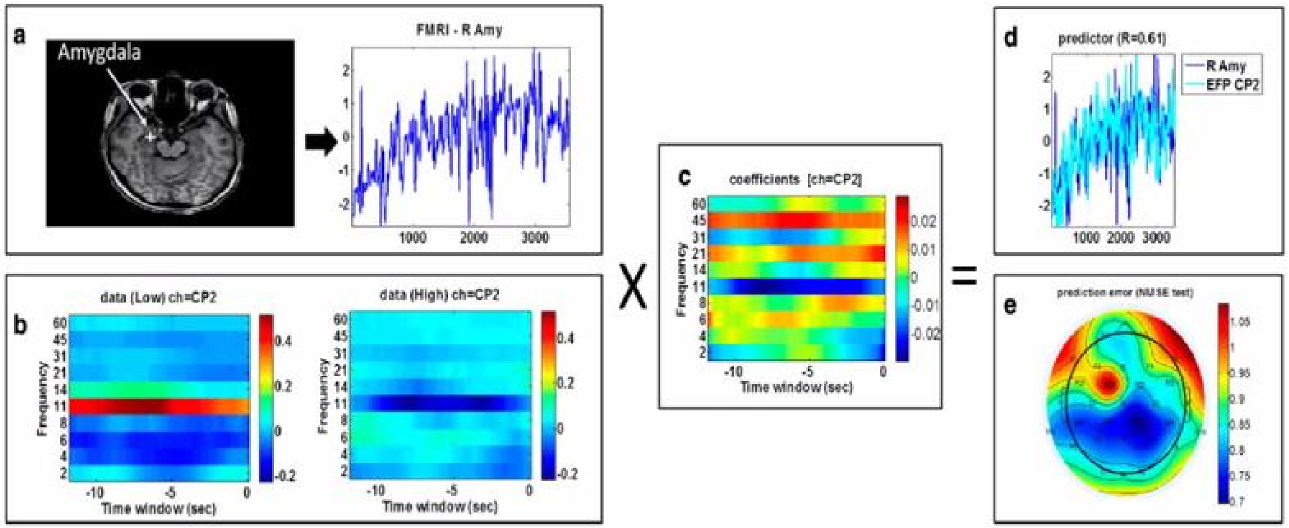
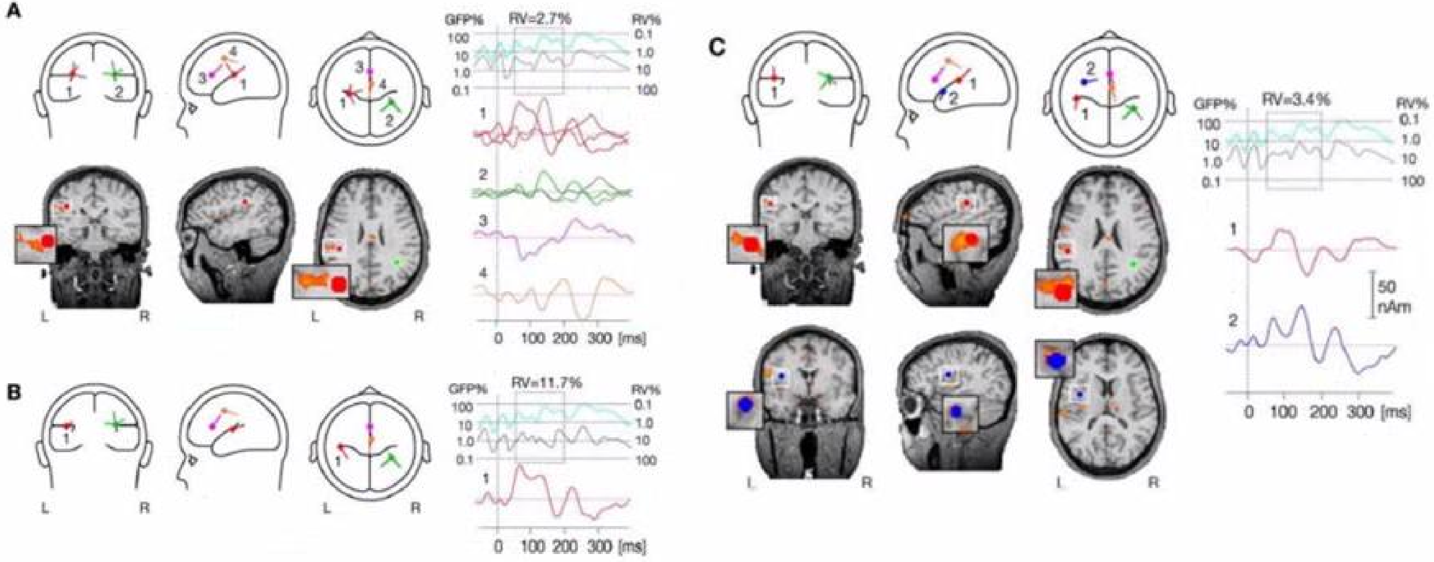


Fig. 3. Prediction input and output. a) Processed ROI signal and b) processed EEG data of a specific electrode. Two matrices are demonstrated. The left one is an average matrix of the entire EEG data related to lower 25% values of the ROI signal and the right one is an average matrix of the entire EEG data related to upper 25% values of the ROI. c) The EFP derived by the prediction model. Increased activity in the fMRI signal can be indicated by strong red coefficients which relate to increased activity in that time-frequency range or strong blue coefficients which relate to decreased activity in that time-frequency range. d) The predictor generated using the coefficients found. This predictor contains the same information as the ROI signal but it was produced using EEG, so it is sensitive to changes in the EEG that occur in higher temporal resolution than the original fMRI signal. e) Map of the prediction error using each one of the electrodes. This map indicates which electrodes were more useful in the prediction of the specific ROI.

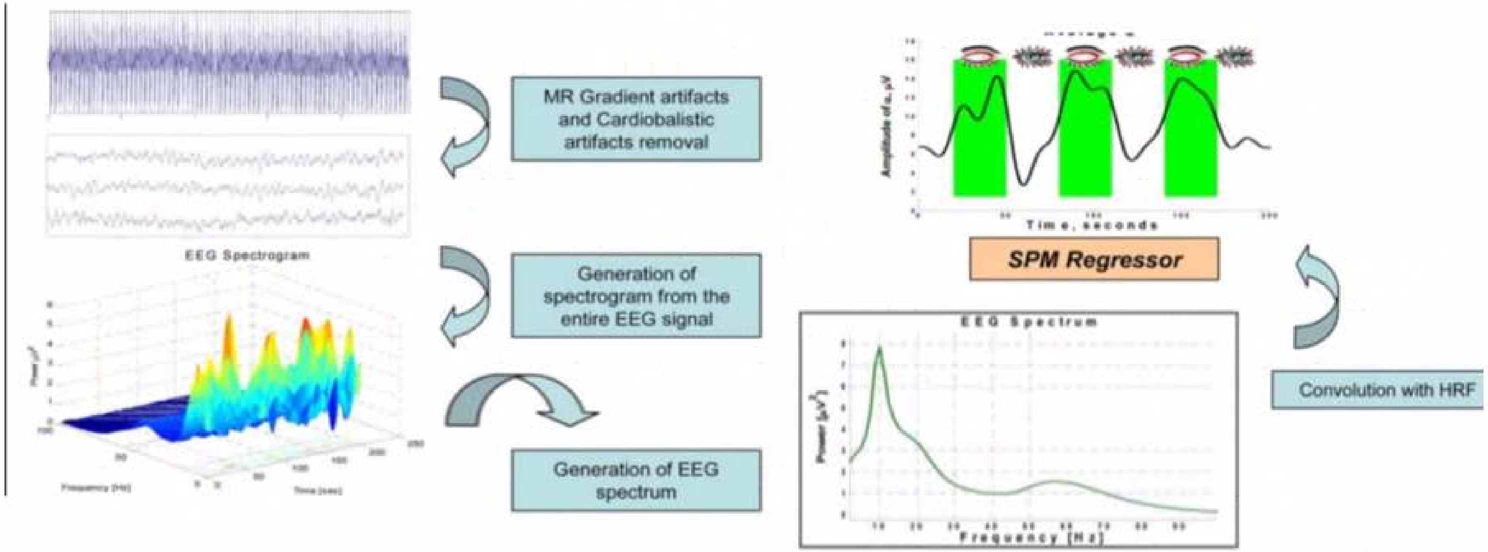
Y. Meir-Hasson et al. / NeuroImage 102 (2014) 128–141

Интеграция через ограничение: локализация диполей (*Stancak A., 2005*)



- The second method for handling multimodal neuroimaging data is EEG-informed fMRI, which considers the direct correlation between EEG and fMRI. In this method, we first could detect specific EEG features of interest, such as ERP amplitude (Debener et al., 2005), EEG synchronization (Mizuhara et al., 2005), and power within specific frequency bands (Laufs et al., 2003, Scheeringa et al., 2009) over time. Next, we investigate the association between fluctuations of these features over time, as well as fMRI signal fluctuation during the experiment.

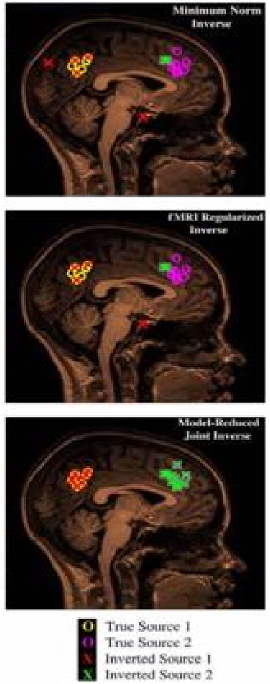
Интеграция через предсказание: ЭЭГ-зависимые фМРТ-подходы (*Ben-Simon E., 2008*)



Индуцированный альфа-ритм – левые боковые височные регионы, гиппокамп;

Спонтанный альфа-ритм – префронтальные регионы мозга, таламус.

Симметричные фМРТ-ЭЭГ-подходы: ICA и реалистичные BOLD-модели (*Brookings T., 2009*)



Две модели:

1. Регуляризация решения обратной задачи ЭЭГ;

$$\vec{S} = L^{-}\vec{E} + N_L\vec{\alpha}$$

$$\sigma_{\vec{E}} = ||LL^{-}\vec{E} - \vec{E}|| \qquad \sigma_{\vec{B}} = \min_{\{\lambda,\kappa,\vec{\alpha}\}} |||L^{-}\vec{E} + N_L\vec{\alpha}| - \lambda\vec{B} - \kappa||$$

2. Набор нелинейных дифференциальных уравнений с начальными условиями, описывающими нейрональную активность (физические трансформации в сосудах, изменения содержания кислорода в крови) и дающие на выходе измеряемый фМРТ-сигнал.

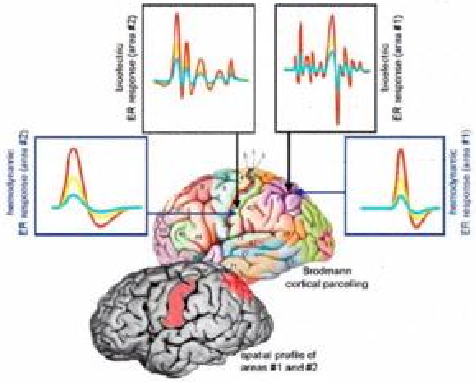
Использовался PCA и ICA-метод для подгонки базисного сигнала к данным

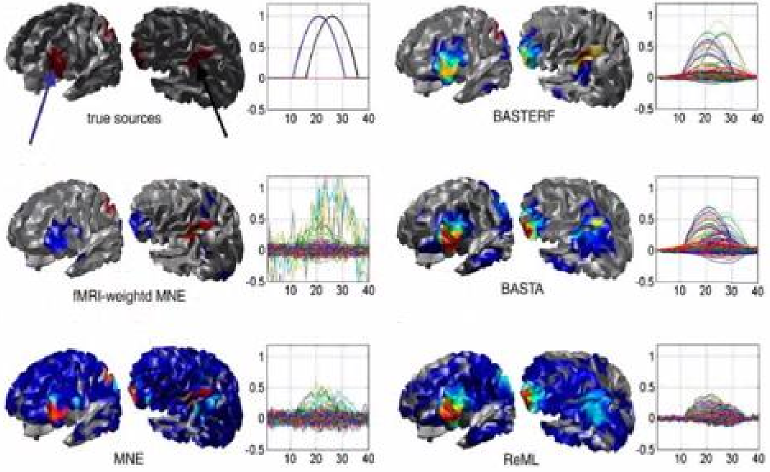
Симметричные фМРТ-ЭЭГ-подходы: исследование ERP (*Daunizeau J., 2007*)

Нейронная активность: набор динамических процессов, характеризующих узлы сетей мозга, вовлеченной в те или иные события. Обе активности имеют некий общий пространственный источник, для идентификации которого использовалось вариационное Байесовское обучение.

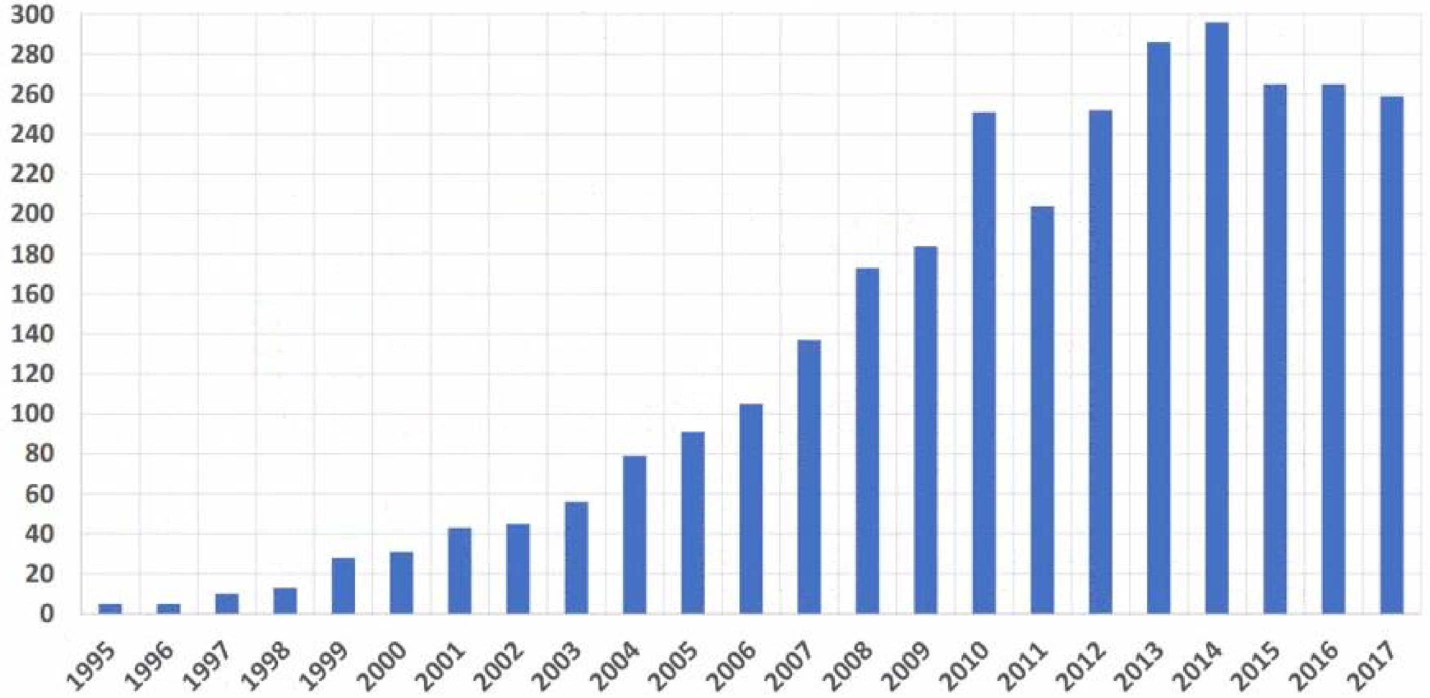
$$\mathbf{M} = \mathbf{GJ} + \mathbf{E} \qquad \mathbf{Y} = \mathbf{Bh} + \mathbf{F}.$$

$$\mathbf{J} = \mathrm{Diag}(\mathbf{w}^{\mathrm{EEG}})\mathbf{CX} + \mathbf{R} \qquad \mathbf{h} = \mathbf{ZC}^{\mathrm{T}}\mathrm{Diag}(\mathbf{w}^{\mathrm{fMRI}}) + \mathbf{L}$$

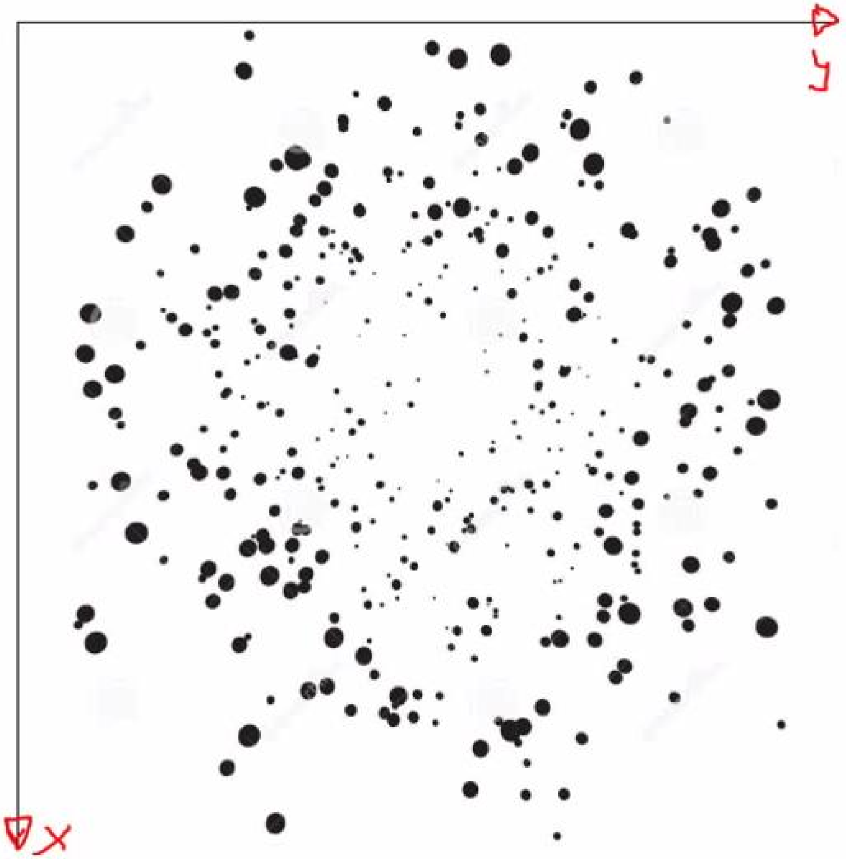




Scopus (fmri and eeg - TITLE, ABS, KEY)

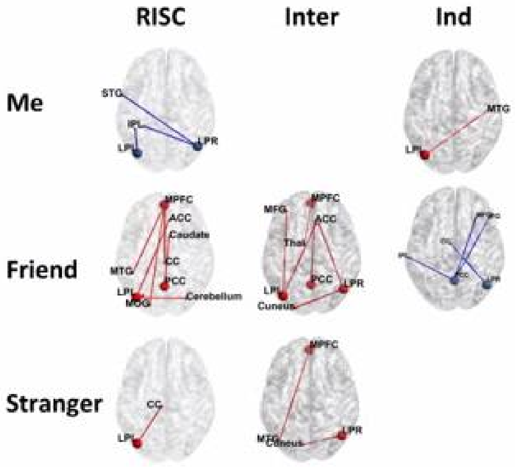


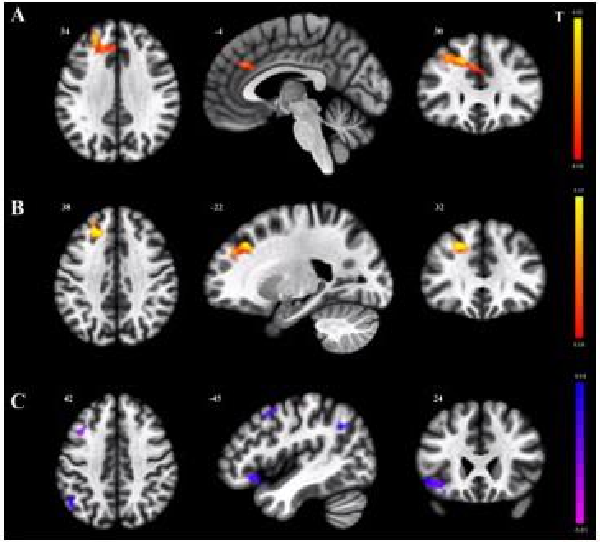
- 50 persons (25m/25f) x 1 hour
- 1h= 25 words, adjective (1/3 positive, 1/3 neutral, 1/3 negative) x 4 times each
- MRI|fMRI 3T + EEG 100 channel with map



y
x

- Me&Friend>Stranger&Enemy





- N400, predictability
- Word semantic maps

10x