IS THE BRAIN A STATISTICIAN?

Work in progress with Aline Duarte, Guilherme Ost,
Antonio Galves, Ricardo Fraiman
MaClinC NeuroMat

The idea that the brain continuously makes predictions about the world is becoming prevalent

Vargas, Rangel and Galves, 2014
http://arxiv.org/abs/1409.6744

Edweard Muybridge, 1887

PREDICTING MEANS
ANTICIPATING OUTCOMES

Efferent copy: Von Helmholtz (1821 – 1894)

- **Causal relationships between actions and their consequences**
- **Dynamic simulation of our body and of the context**
- **Reduction of movement-produced uncertainties**
- **Learning**
- **Probabilistic estimation**

The Helmholtz' heritage

Kawato et al., 1987; Jordan and Rumelhart, 1992; Jordan, 1995;
Wolpert et al., 1995; Miall and Wolpert, 1996; Wolpert,1997;

Mumford, Shadmehr, Friston, Dehaene and many others

…BUT HOW TO TACKLE THIS PROBLEM?

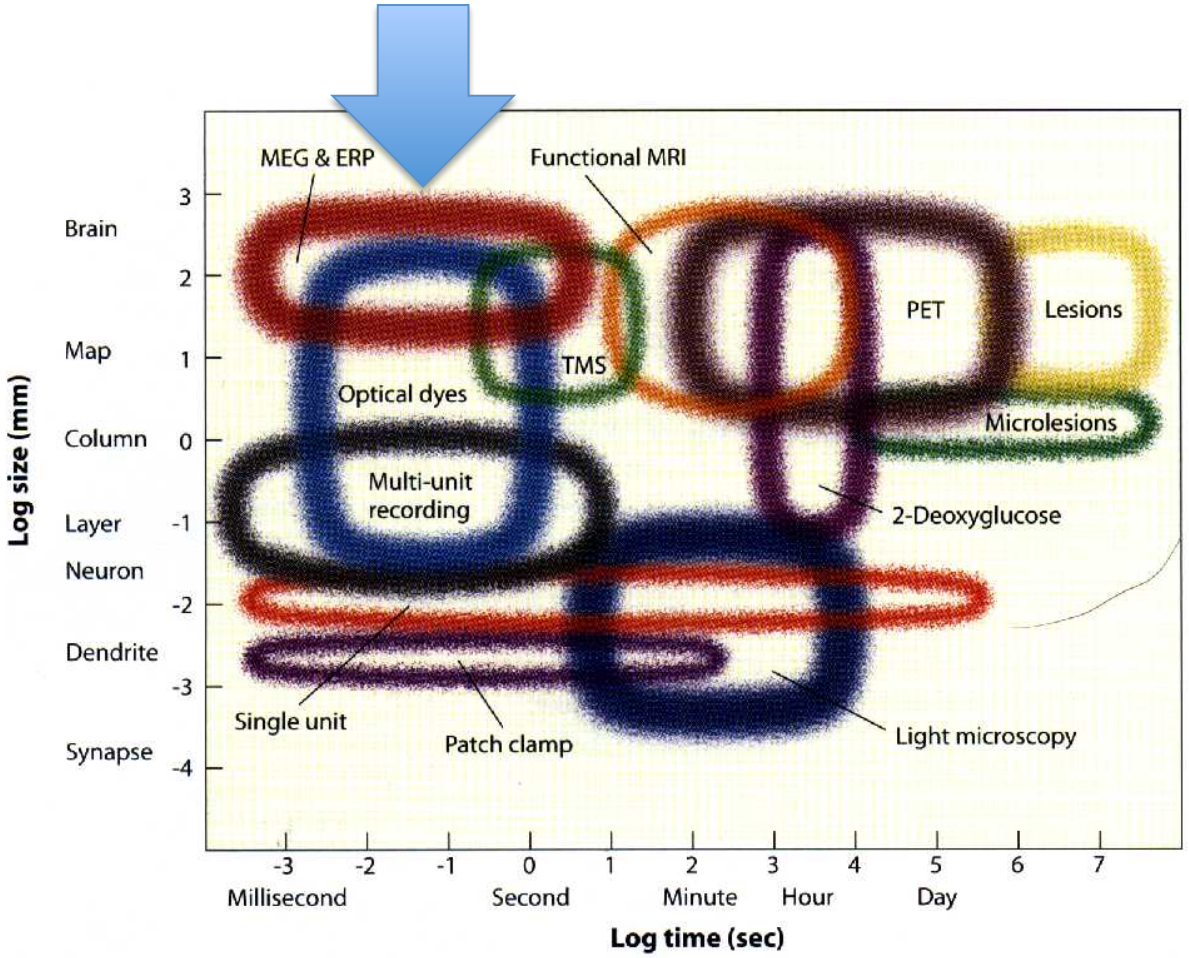
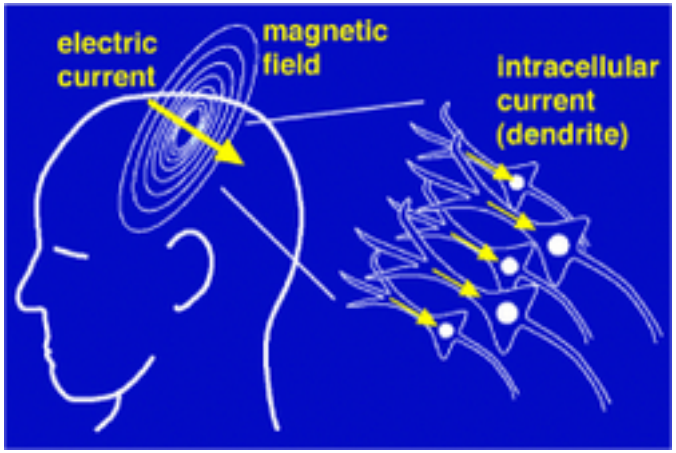


Figure 3.40 Spatial and temporal resolution of the prominent methods used in cognitive neuroscience. Temporal sensitivity, plotted on the x axis, refers to the time scale over which a particular measurement is obtained. It can range from the millisecond activity of single cells to the behavioral changes observed over years in patients who have had strokes. Spatial sensitivity, plotted on the y axis, refers to the localization capability of the methods. Light microscopy allows activity at individual synapses to be observed. Naturally occurring lesions damage large regions of the cortex.

MAGNETOENCEPHALOGRAPHY



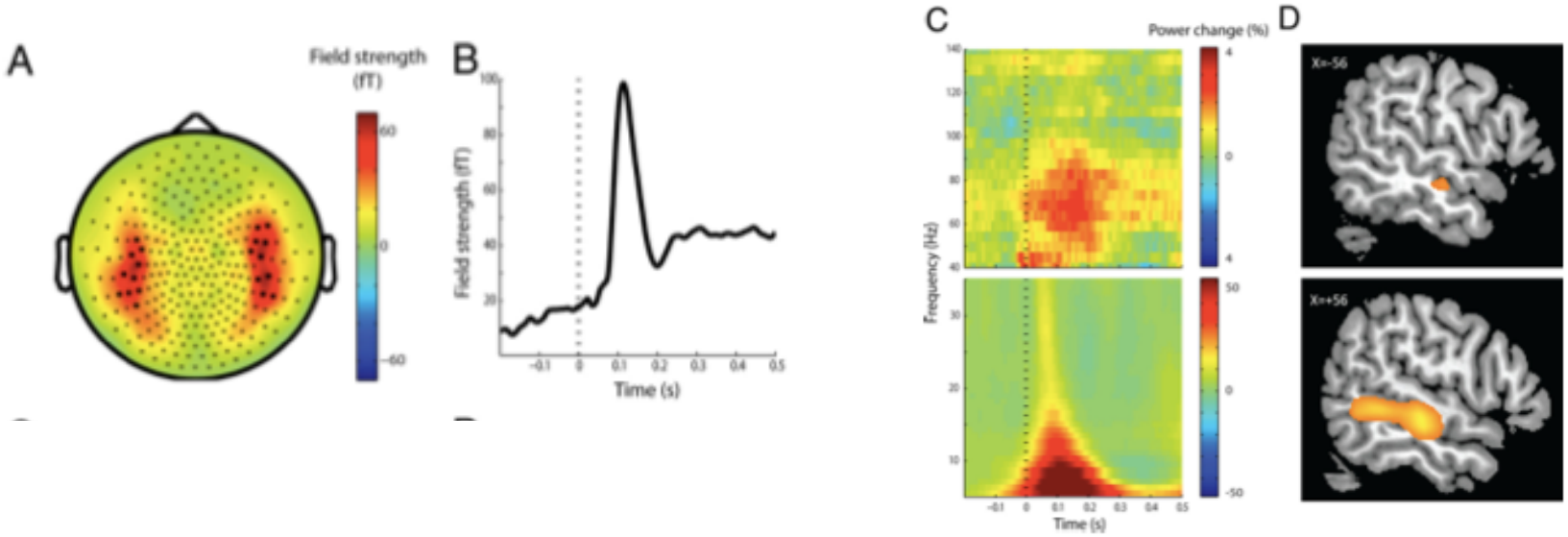
http://en.wikipedia.org/wiki/Magnetoencephalography

9118 • The Journal of Neuroscience. June 22. 2011 • 31(25):9118 –9123

Behavioral/Systems/Cognitive

Prior Expectation Mediates Neural Adaptation to Repeated Sounds in the Auditory Cortex: An MEG Study

Ana Todorovic, Freek van Ede, Eric Maris, and Floris P. de Lange
Donders Institute for Brain, Cognition, and Behaviour, Radboud University Nijmegen, 6500 HB Nijmegen, The Netherlands



Activity yielded by a tone presentation

Localization of auditory activation: temporal cortex

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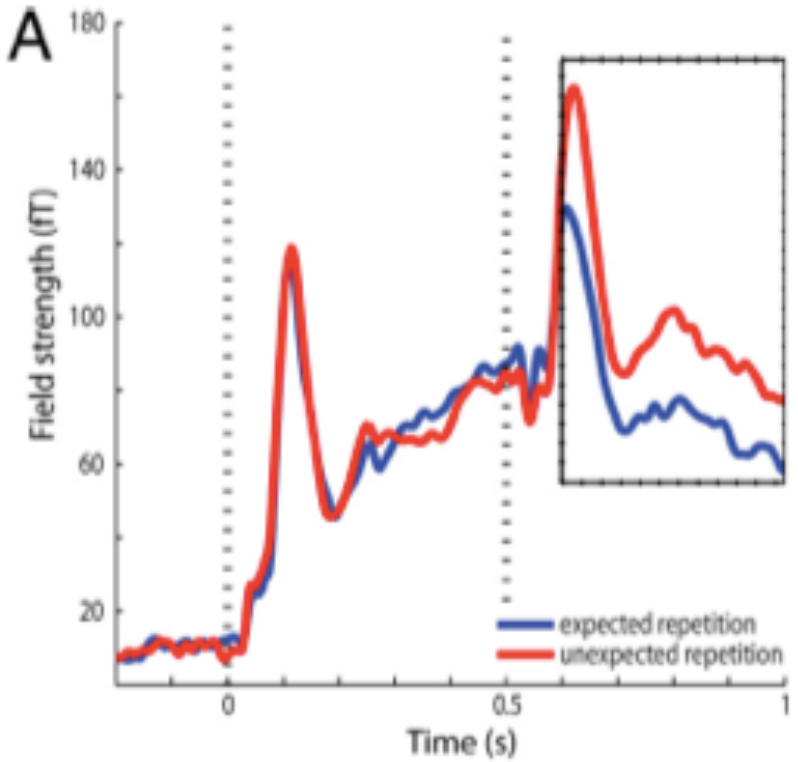
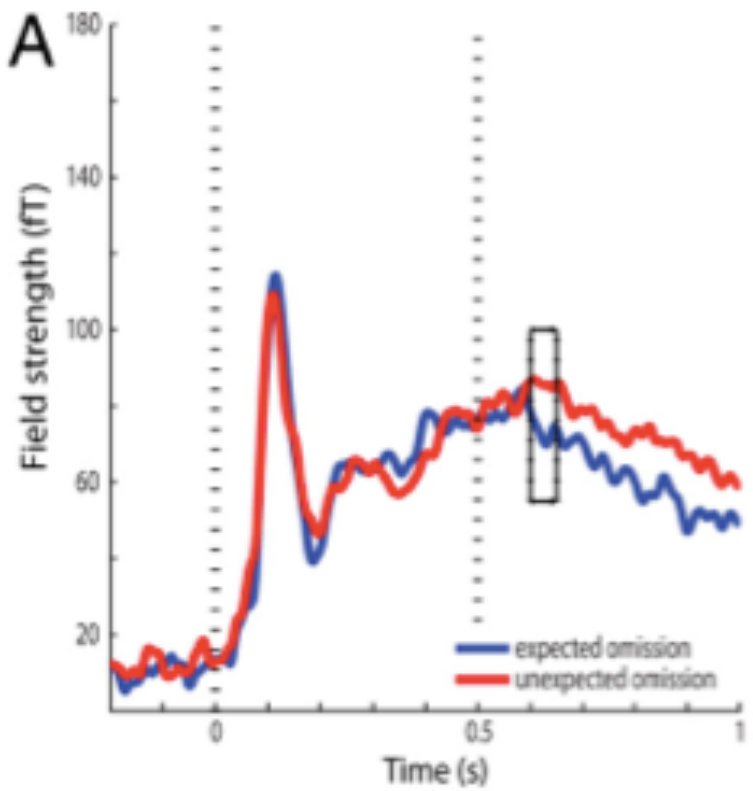
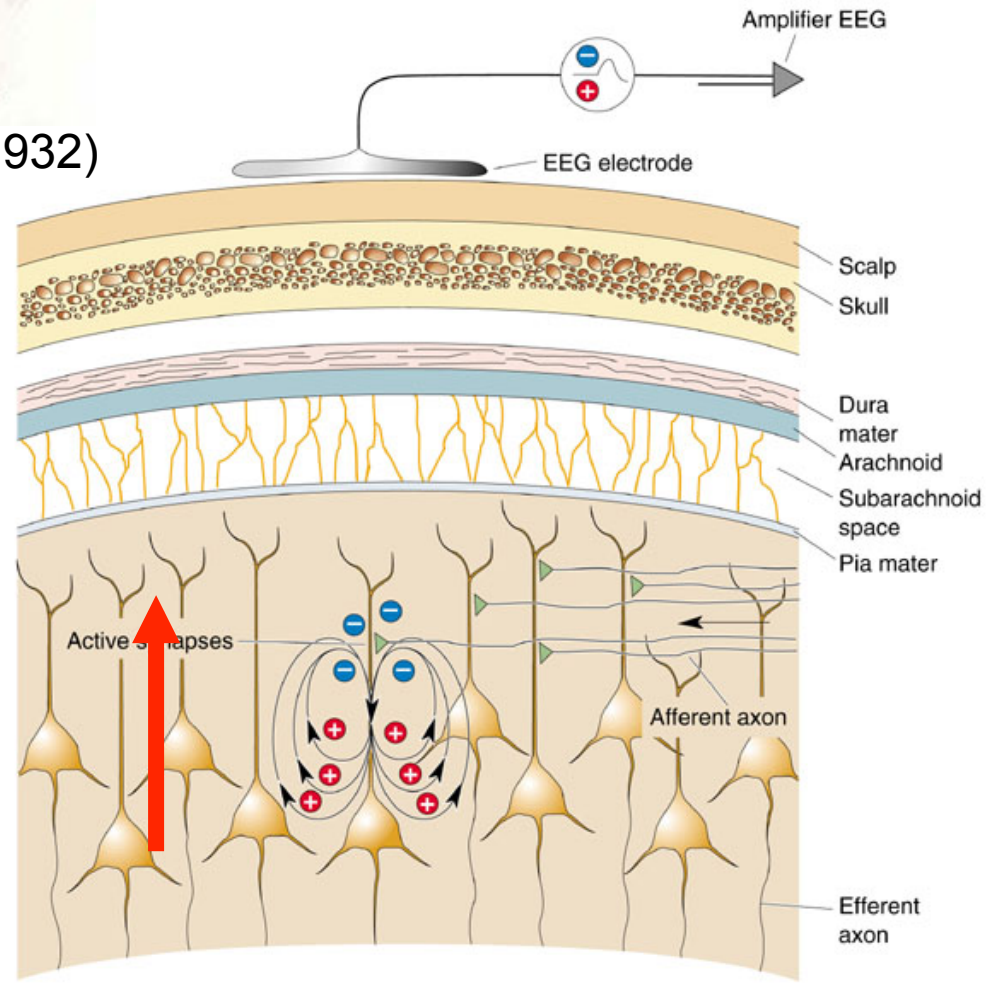




ELETROENCEFALOGRAPHY

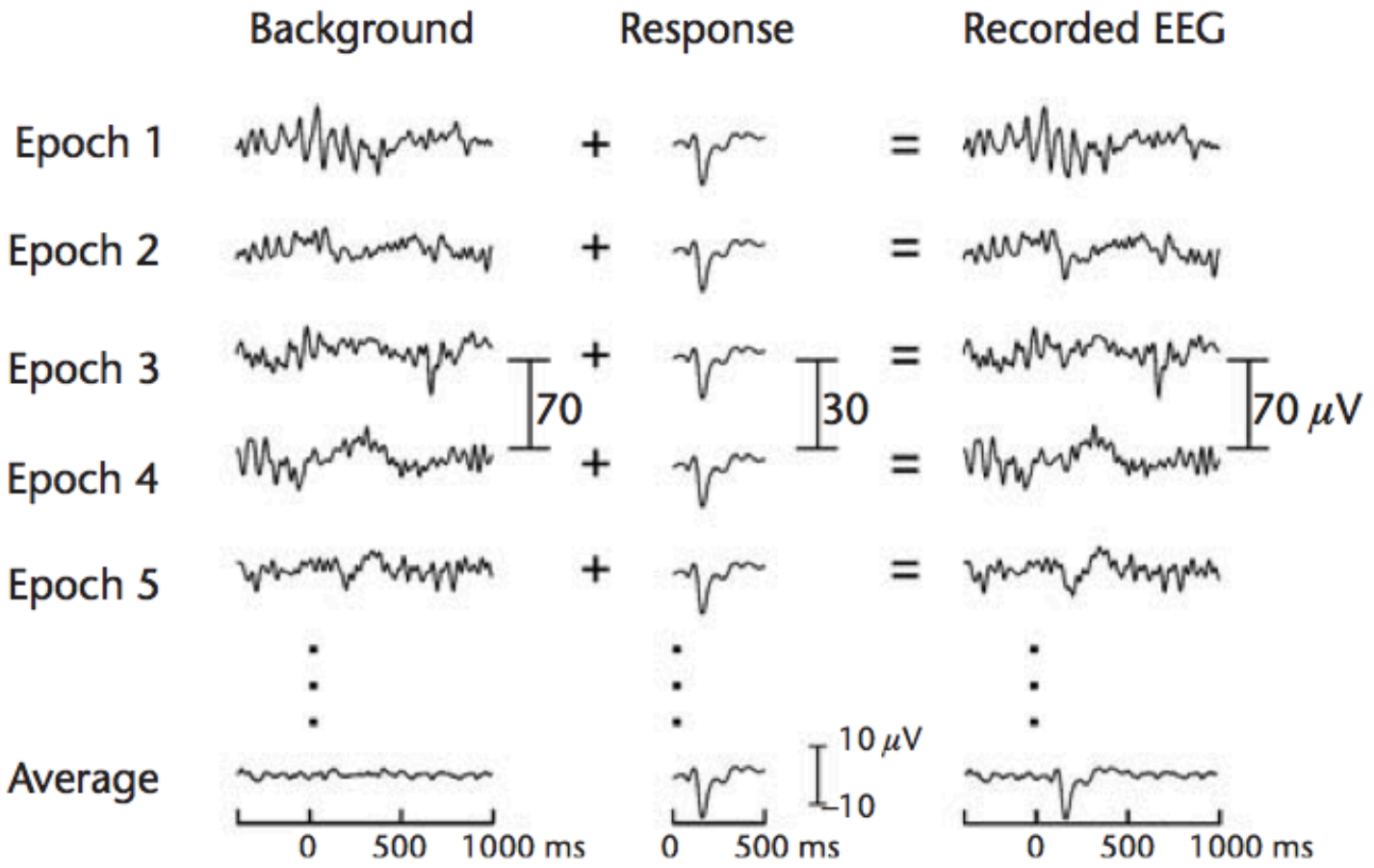
(Hans Berg, 1932)



Extracellular Current flow

http://en.wikipedia.org/wiki/Electroencephalography

EVENT RELATED POTENTIALS (in the 60's)

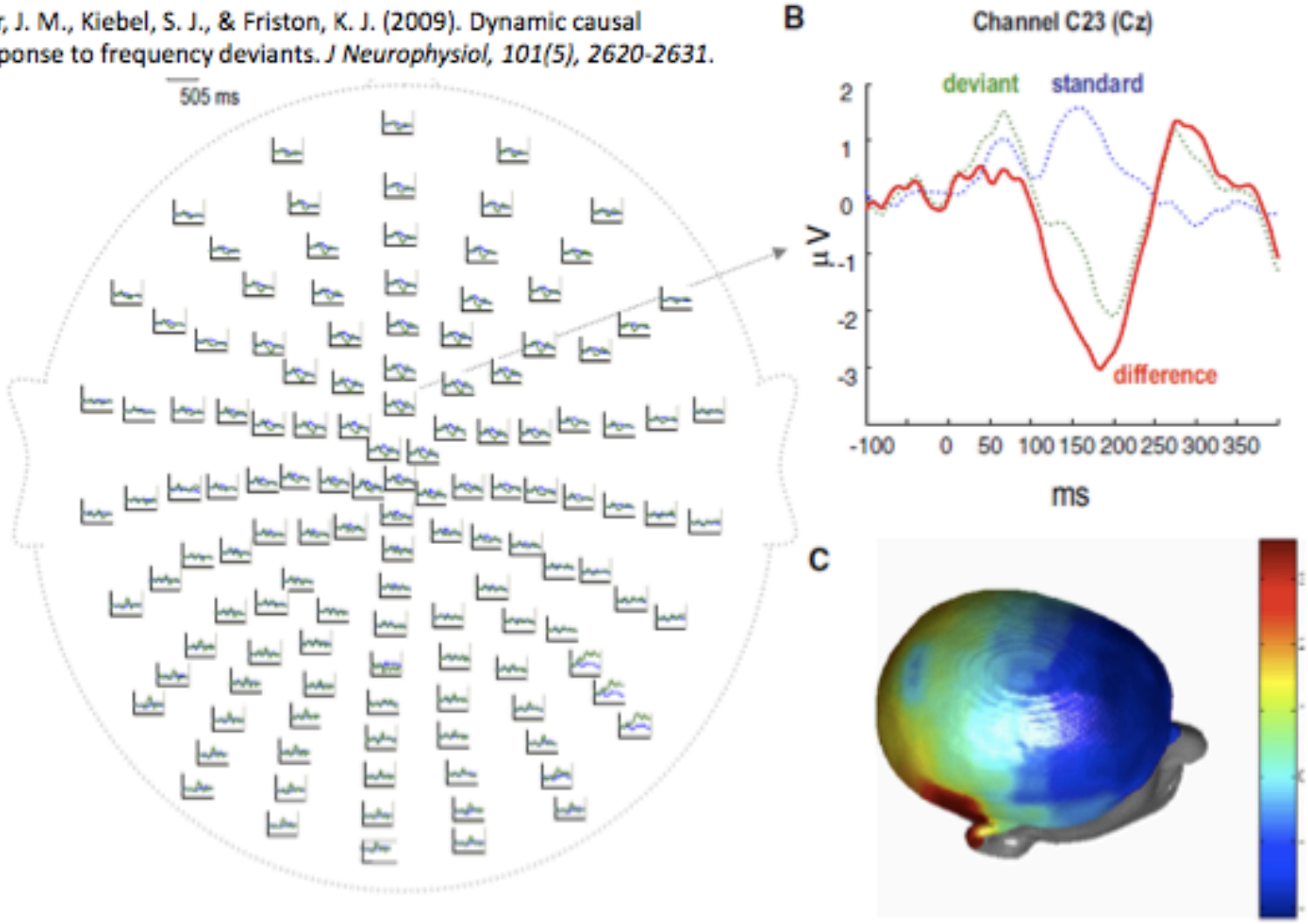


IN: Quantitative EEG Analysis Methods and Clinical Applications

Ed. By Martin L. Yarmush, Christopher J. James (2009).

- *"Mismatch negativity"*: after several repetitions, the hearing of an unexpected deviant frequency triggers a brain response to the novel stimulus.

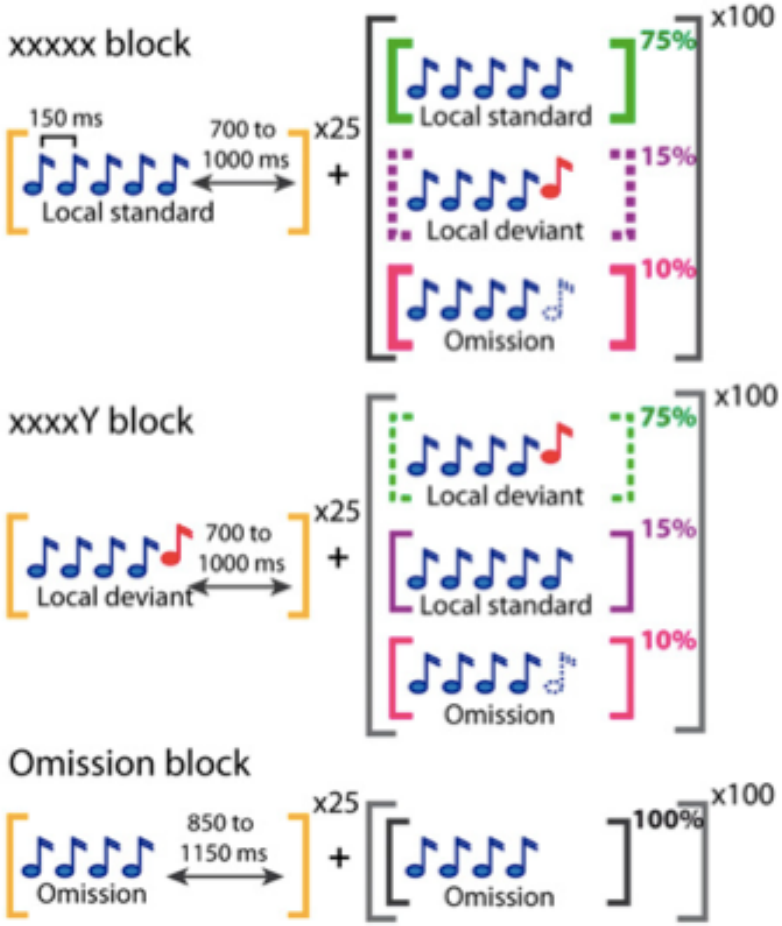
Garrido, M. I., Kilner, J. M., Kiebel, S. J., & Friston, K. J. (2009). Dynamic causal modeling of the response to frequency deviants. *J Neurophysiol, 101(5), 2620-2631.*

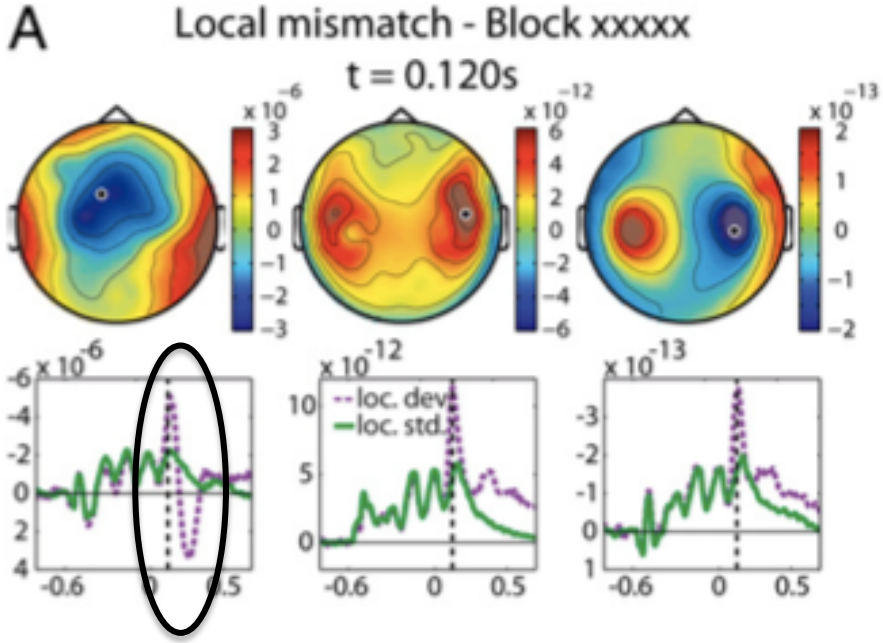


S. Deahene Lectures, college de france, 2012

Evidence for a hierarchy of predictions and prediction errors in human cortex

Catherine Wacongne[a,b,c,1,2], Etienne Labyt[a,b,c,1], Virginie van Wassenhove[a,b,c], Tristan Bekinschtein[d], Lionel Naccache[e,f], and Stanislas Dehaene[a,b,c,g,2]



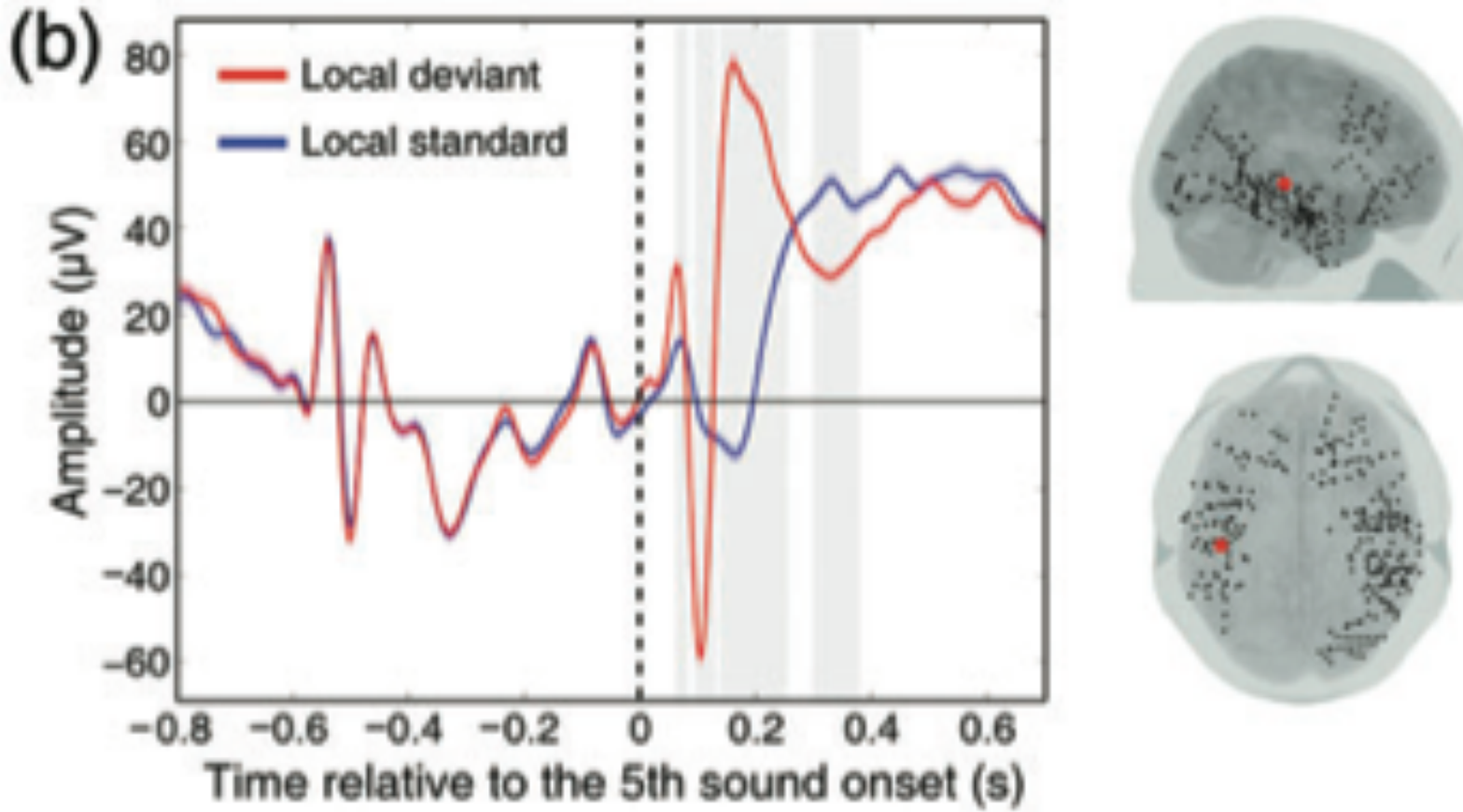


Cerebral Cortex Advance Access published June 26, 2014

Cerebral Cortex
doi:10.1093/cercor/bhu143

Event-Related Potential, Time-frequency, and Functional Connectivity Facets of Local and Global Auditory Novelty Processing: An Intracranial Study in Humans

Imen El Karoui[1], Jean-Remi King[1,2,3], Jacobo Sitt[1,2,3], Florent Meyniel[1], Simon Van Gaal[1,2,3], Dominique Hasboun[1,4], Claude Adam[5], Vincent Navarro[1,2,5], Michel Baulac[5], Stanislas Dehaene[2,3,6,7], Laurent Cohen[1,5] and Lionel Naccache[1,4,5]



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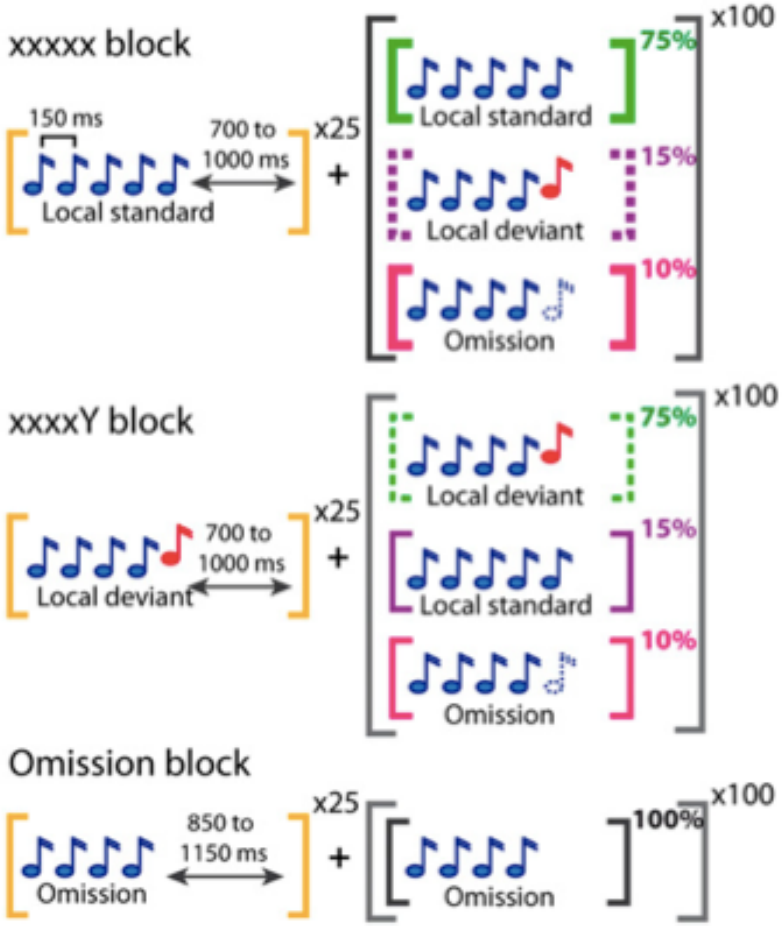
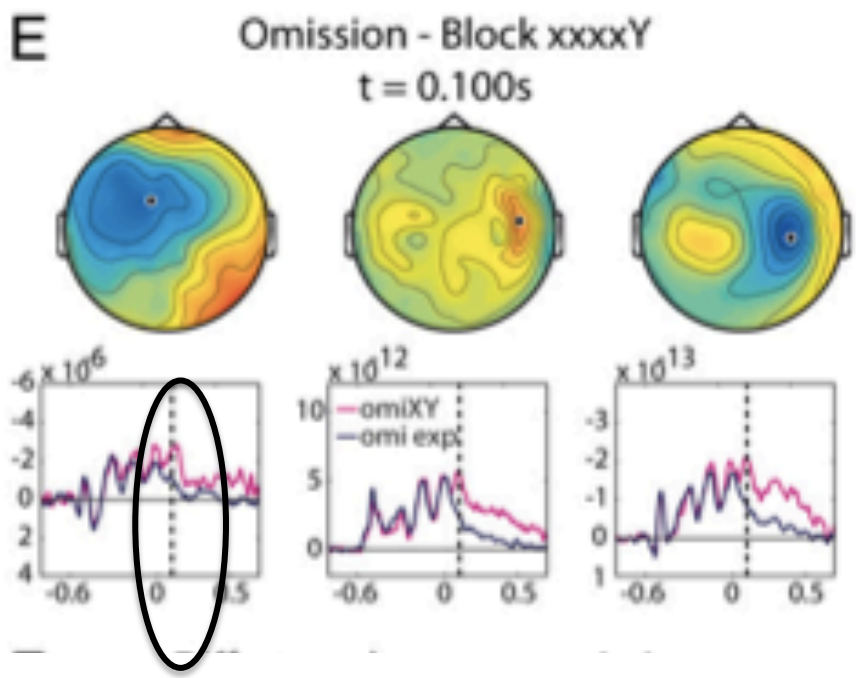




Omission response

THE BRAIN DETECTS MISSING EVENTS
(i.e. THOSE THAT WERE EXPECTED)

AND

REACTS STRONGLY TO UNEXPECTED EVENTS

A NEW EXPERIMENTAL APPROACH…

RETRIEVING THE STRUCTURE OF THE SOURCE

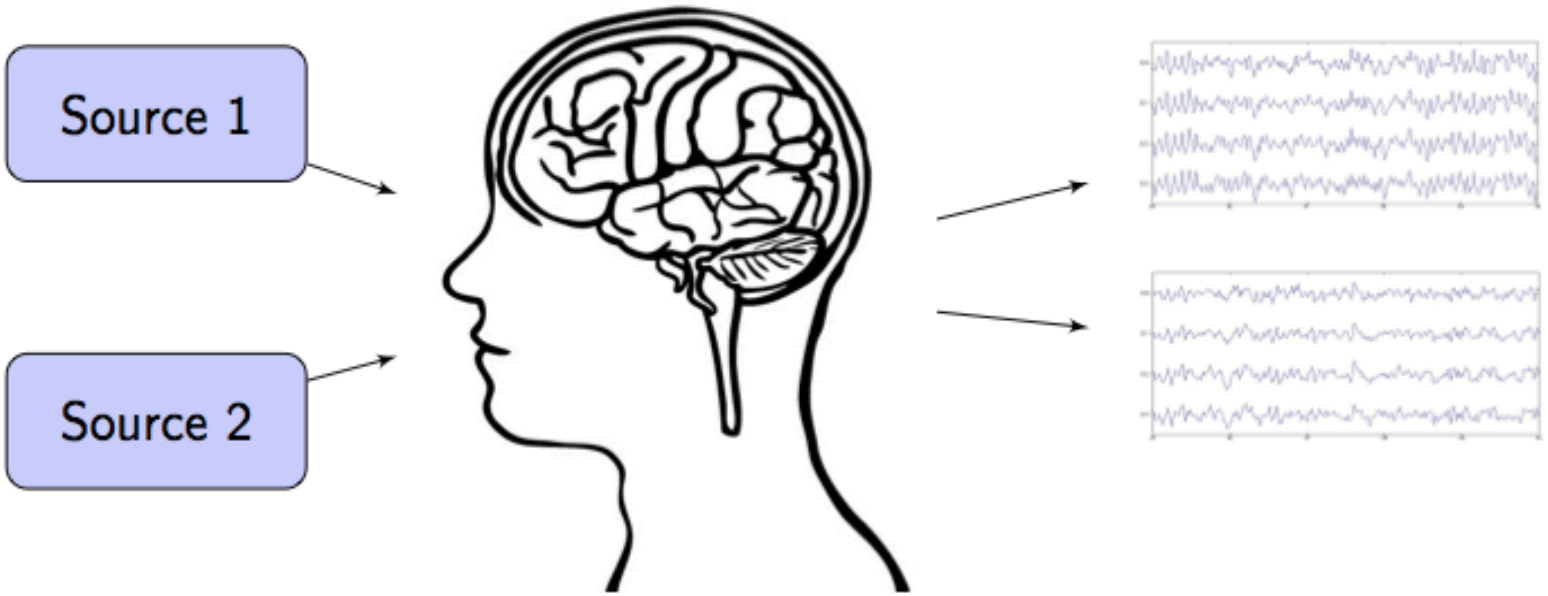
HAND CLAP SEQUENCES ORGANIZED IN

TERNARY (waltz)
QUATERNARY (samba)
INDEFINITE

Work in progress with Aline Duarte, Guilherme Ost, Antonio Galves, Ricardo Fraiman

MaCLinC NeuroMat

RETRIEVING THE STRUCTURE OF THE SOURCE



- The stimuli consist of independent samples produced by different stochastic rhythmic sources.
- Each sample is a sequence of strong beats, weak beats and silent units generated by a probabilistic source

- First rhythm: Waltz.
- 
- Symbols
  - 2 - strong beat.
  - 1 - weak beat.
  - 0 - silence unit.
- Chain generation:
  - start with a deterministic sequence $(x_n)_{n\in\mathbb{Z}}$

    $$\cdots \mathbf{2}\ 1\ 1\ \mathbf{2}\ 1\ 1\ \mathbf{2}\ 1\ 1\ \mathbf{2}\cdots$$

  - replace in a iid way each symbol 1 by 0 with probability ϵ.

- Second rhythm: simplified Samba.
- 
- Symbols

  - 2 - strong beat.
  - 1 - weak beat.
  - 0 - constitutive silence unit or omitted weak beat.
- Chain generation:
  - start with a deterministic sequence $(x_n)_{n\in\mathbb{Z}}$

$$\cdots \mathbf{2}\ 1\ \mathbf{0}\ 1\ \mathbf{2}\ 1\ \mathbf{0}\ 1\ \mathbf{2}\ 1\ \mathbf{0}\ 1\ \mathbf{2}\cdots$$

  - replace in a iid way each symbol 1 by 0 with probability ϵ.

- Third rhythm: Independent rhythmic units.
- 
- Symbols
  - 2 - strong beat.
  - 1 - weak beat.
  - 0 - silence unit.
- Chain generation:
  - choose any symbol in a iid way with probability 1/3.

We mark each stimulus onset:

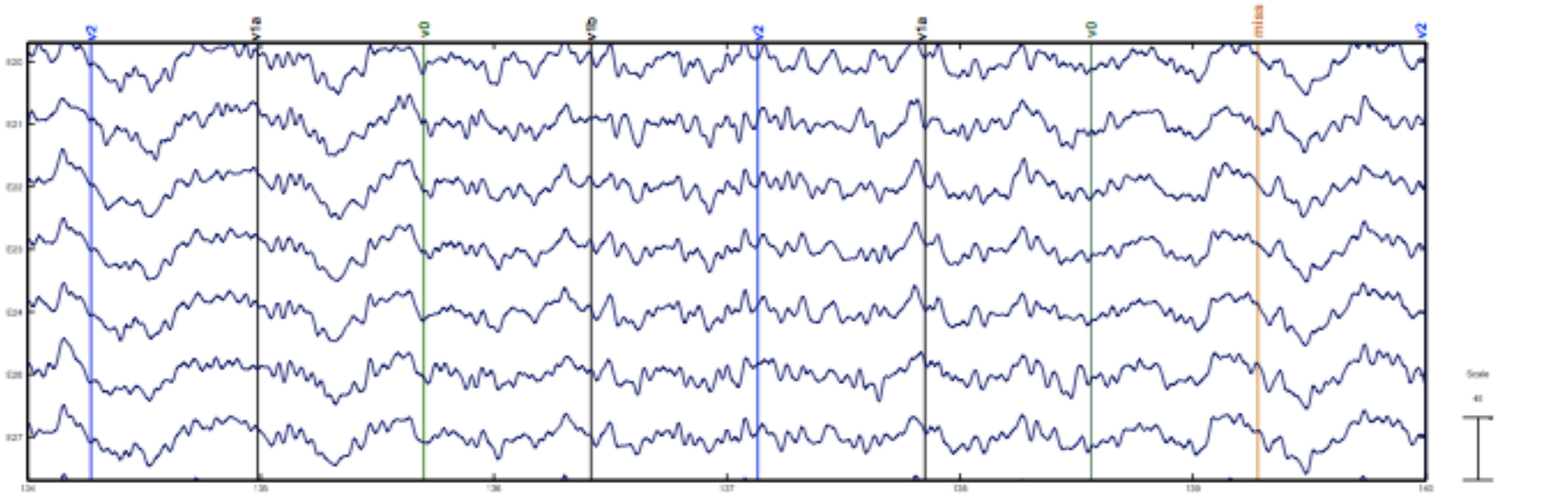
Constitutive silence unit $\longrightarrow V_0$

Weak beat $\longrightarrow V_1$

Strong beat $\longrightarrow V_2$

Omitted weak beat $\longrightarrow$ Miss

Has the EEG data anything to say about the *structure* of the source?



- We can segment the EEG data into several pieces so that each individual stimulus corresponds to a specific event.
- Both Miss and V_0 time intervals correspond to silence units.
- However, from a structural point of view Miss and V_0 are entirely different.

Remember:

- Miss is an omitted weak beat.
- V_0 is a constitutive silence unit.

Do the EEG data say anything about the structure of the source?