

EEG/MEG 1: Basics and Pre-Processing

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Timing Is Essential

... so here is a bit of history:

Ancient Egypt, 2750 BC:

Electric Fish (“Thunderer of the Nile”)
Some Roman writers mention electric shocks as an ailment for headaches (~ 0 AC)...



Ancient Greece, 600 BC:

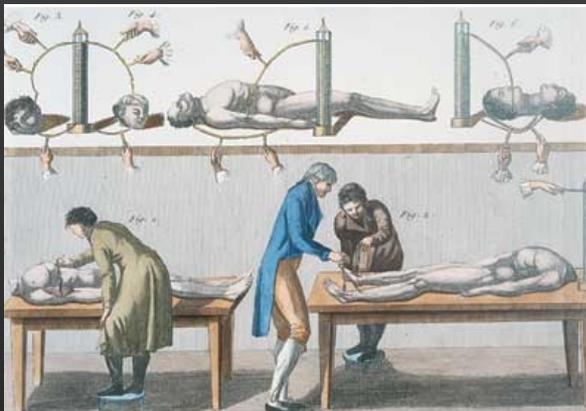
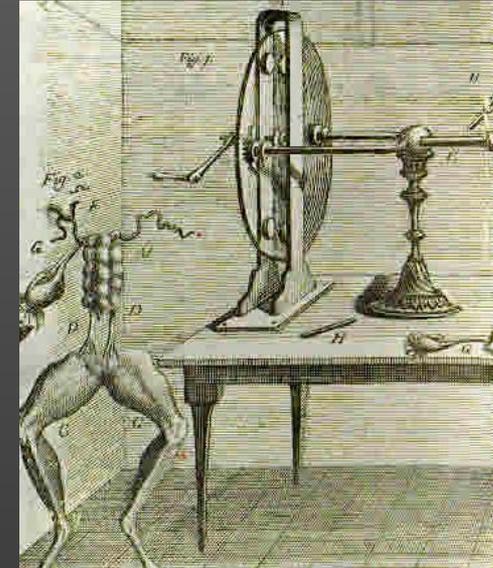
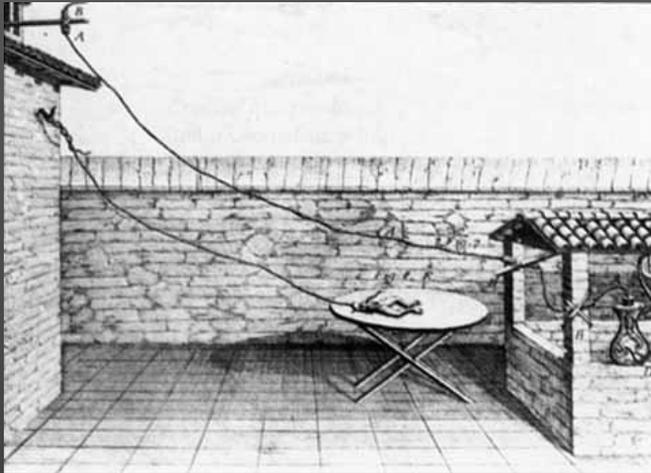
Thales describes static electricity
“electron”



Early Science

1771

Luigi Galvani, Bologna, “animal electricity”



In 1803:

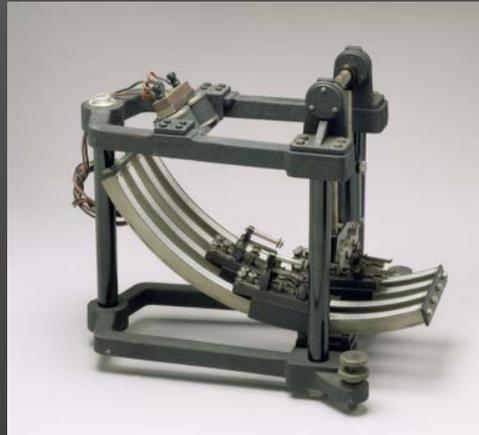
“On the first application of the process to the face, the jaws of the deceased criminal began to quiver, and the adjoining muscles were horribly contorted, and one eye was actually opened. ...

Mr Pass, the beadle of the Surgeons' Company, who was officially present during this experiment, was so alarmed that he died of fright soon after his return home.”

<http://www.executedtoday.com/2009/01/18/1803-george-foster-giovanni-aldini-galvanic-reanimation/>

Early Electrophysiology

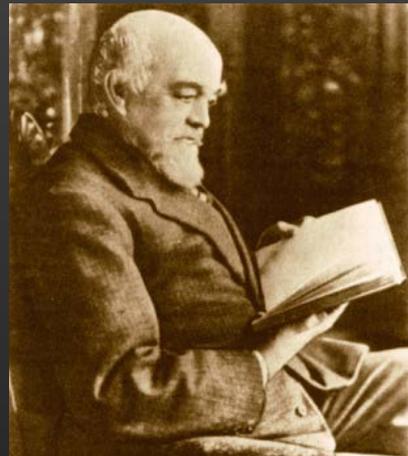
1842: Du Bois-Reymond, Berlin
nerve action potentials
neurons



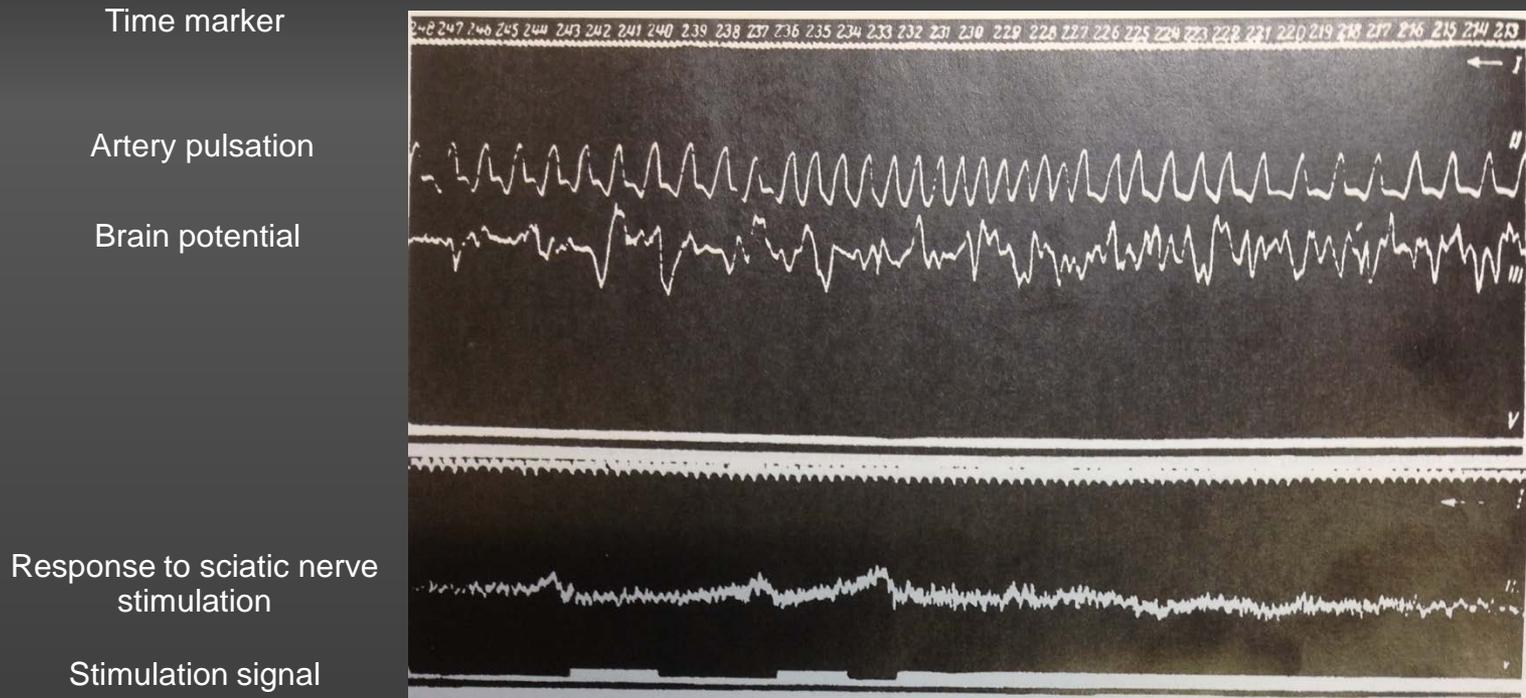
1852: Helmholtz, Berlin
speed of action potentials in frogs
neurons



1875: Richard Caton, Liverpool
first “ECoG” from animals



Early EEG



“Danilevsky (1852-1939) ... finished his thesis entitled “Investigations into the Physiology of the Brain (1877). ... He published an extensive textbook of human physiology in 1915. ... He saw his high hopes unfulfilled as far as the spontaneous electrical activity of the brain was concerned. ... He was not the only EEG researcher with shattered hopes in the field of psychophysiology”.

From: Niedermeyer and Schomer, 2011

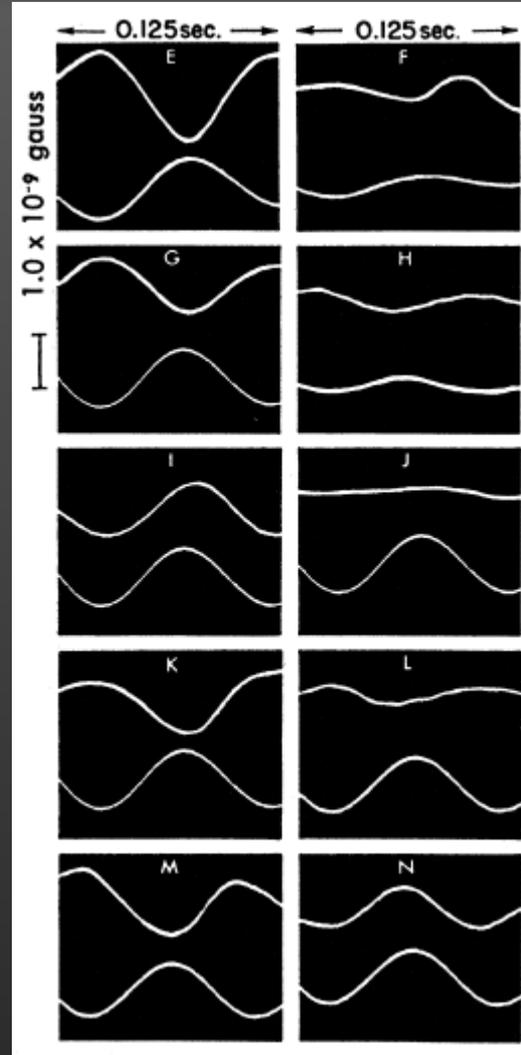
But now we've got MEG!

First MEG: Pre-SQUID age

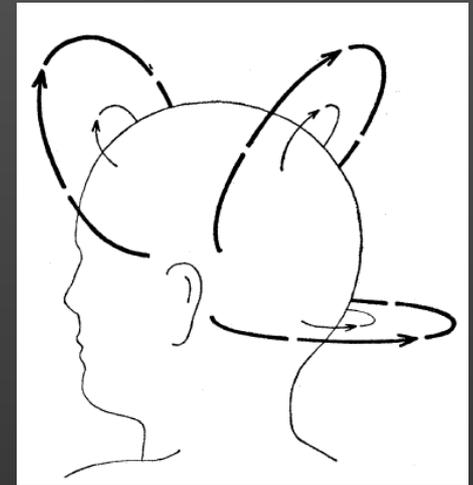
MEG pioneers
MIT



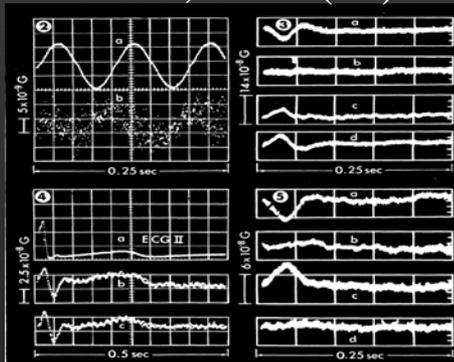
MEG, 1968



Alpha Rhythm



MCG, 1967/(63)



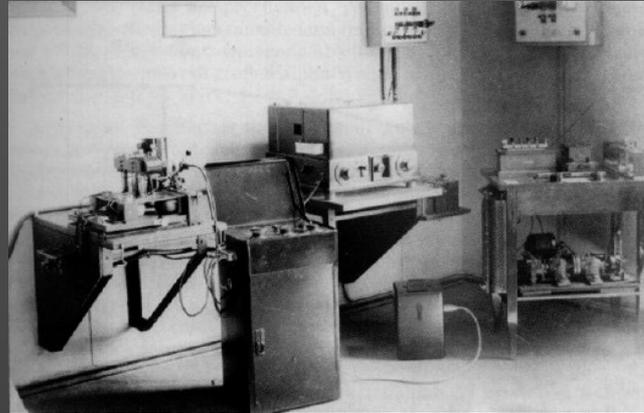
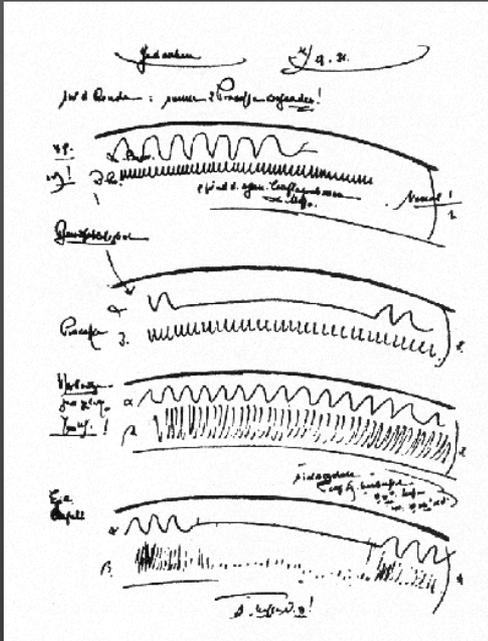
Cohen, Science 1967

Cohen, Science 1968

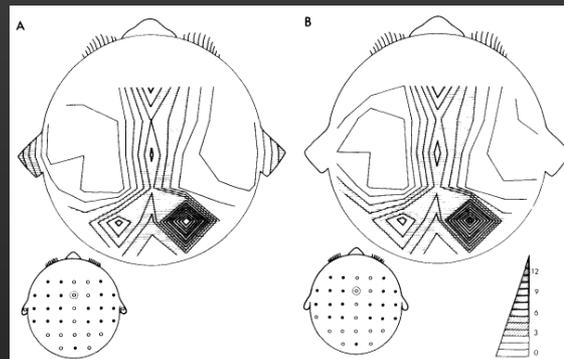
Early EEG

Hans Berger, Jena 1924

First Fourier Analysis of EEG: Berger&Dietsch 1931



1969/70: 32/48-channel EEG, "generators"



Lehmann, 1971

Early ERPs

A summation technique for detecting small signals in a large irregular background. By G. D. DAWSON. *Neurological Research Unit, Medical Research Council, National Hospital, Queen Square, London, W.C. 1*

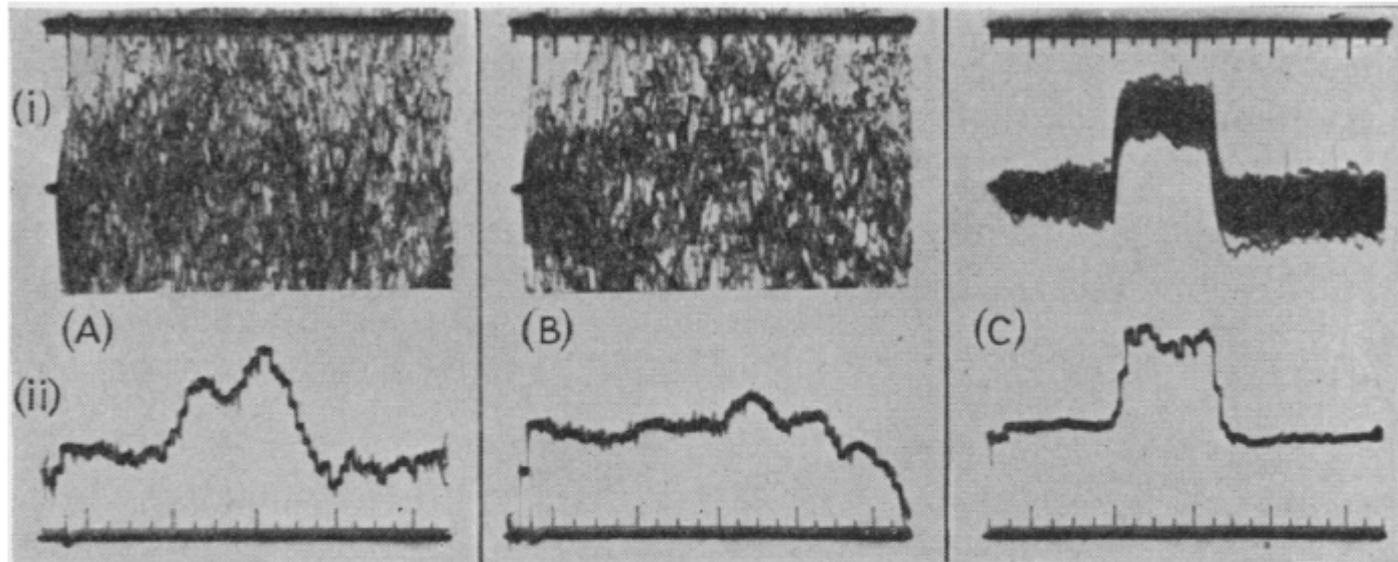


Fig. 1. An experiment to detect cerebral responses when the left ulnar nerve was stimulated at the wrist once per second. The upper line of traces shows sets of 55 records superimposed and the lower line the averages of these given by the machine. In A, from the contralateral scalp, there was one electrode on the midline and one over the right central sulcus. In B, from the ipsilateral scalp, the record was taken from the same midline electrode and one over the left central sulcus. In C is shown the result of making the electrode over the central sulcus positive to that on the midline by $5 \mu\text{V}$. The largest spikes in the time scales show intervals of 20 msec., and the stimulus was applied 5 msec. after the start of each sweep.

Example: The Curse of Automaticity

There is ample evidence that we cannot suppress task irrelevant information:

red blue green yellow brown white ... (Stroop, 1935/92)

Masked semantic priming

(e.g. Neely/Kahan 2001; but see Kinoshita/Quinn 2008)

Semantic effects on lexical decision and naming (e.g.

Chumbley/Balota 1984; Woollams 2005)

But word frequency (and other) effects are strongly modulated by task

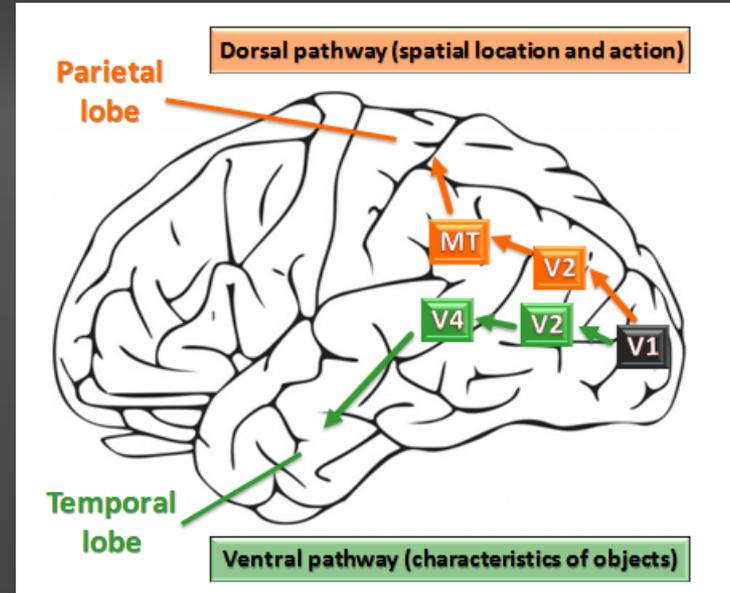
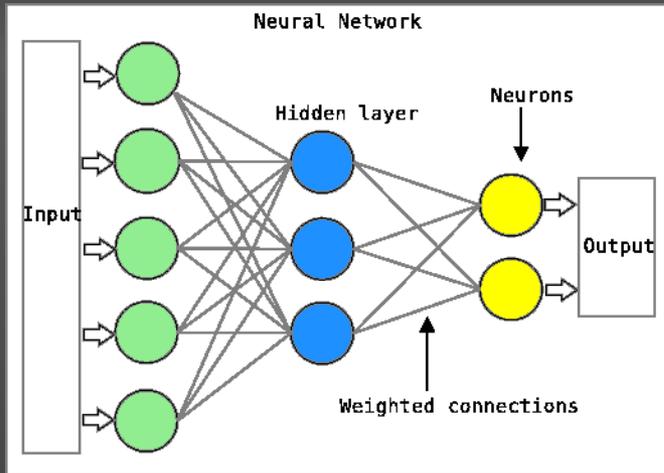
(e.g. Balota/Yapp 2006; Norris 2006)

Is visual word recognition “automatic”

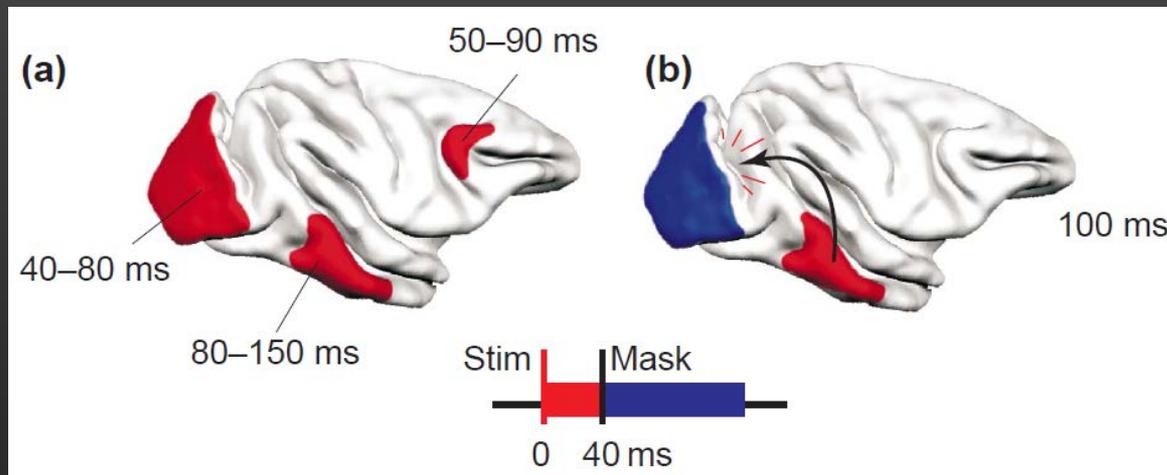
i.e.

Does information retrieval change depending on task demands?

Fast Hierarchical Processing



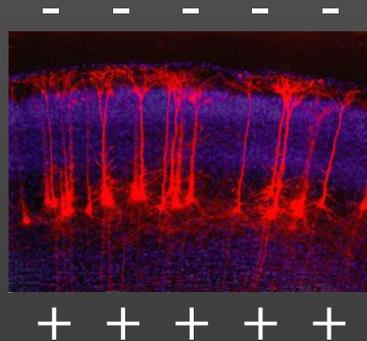
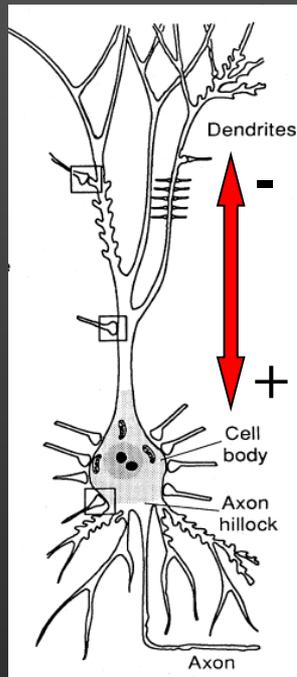
<http://www.intechopen.com/books/visual-cortex-current-status-and-perspectives/adaptation-and-neuronal-network-in-visual-cortex>



Lamme & Roelfsema, TINS 2000

Main Generators of Electrical Activity in the Brain

- Apical dendrites of pyramidal cells
- NOT action potentials
- **EEG/MEG: same generators, different sensitivity**

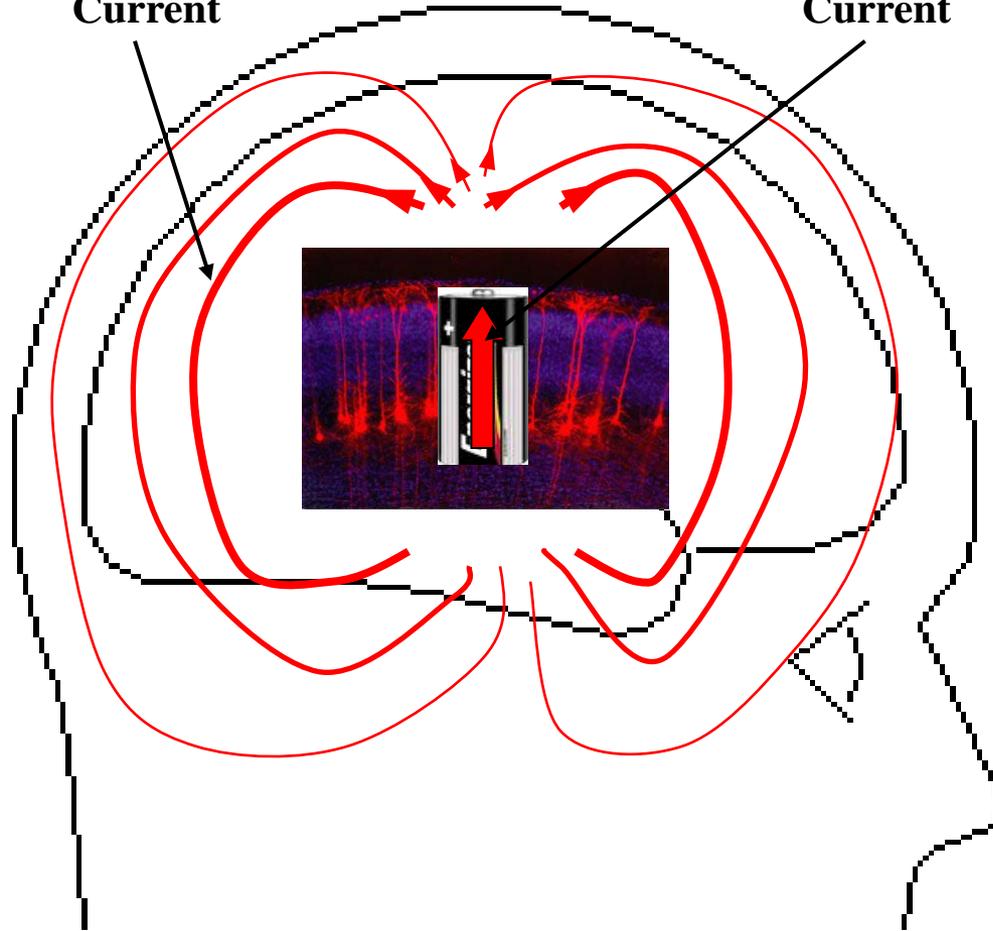


- ~ 1 Million synapses needed to activate simultaneously
 - Luckily: ~10000 cells per mm^2 , ~ 1000 synapses per cell
- => several mm^2 can produce measurable signal

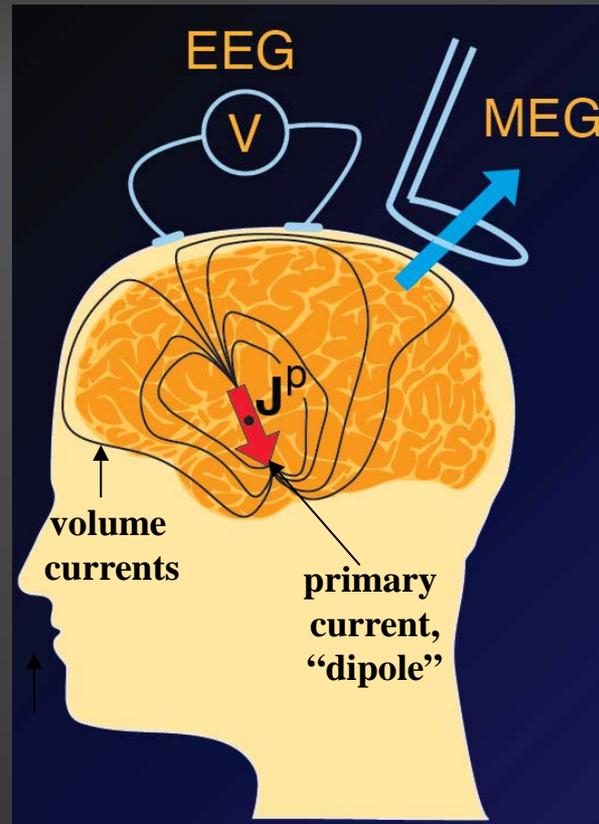
Current Flow in the Head

**“Volume”/“Passive”
Current**

**“Primary”/“Impressed”
Current**



EEG/MEG Measurements

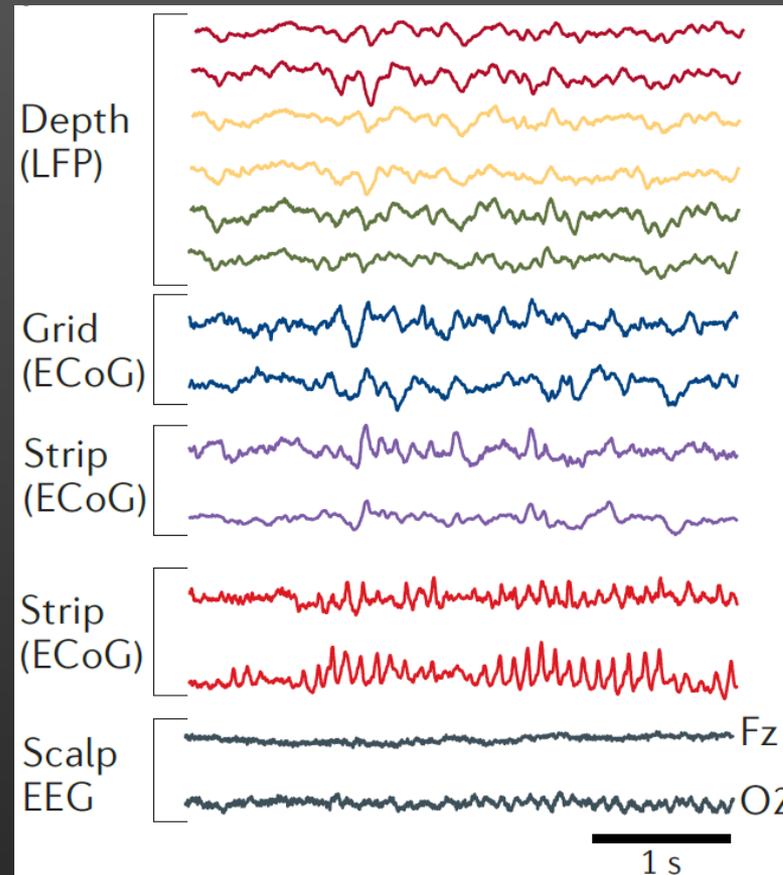


Volume currents affect both EEG and MEG –
but EEG more than MEG

Neurophysiological basis of EEG/MEG

EEG/MEG are assumed to be a “spatiotemporally smoothed version of the local field potential (LFP)”, which in turn correlates with firing rates.

However, the evidence for this is indirect.



Electro- and Magnetoencephalography



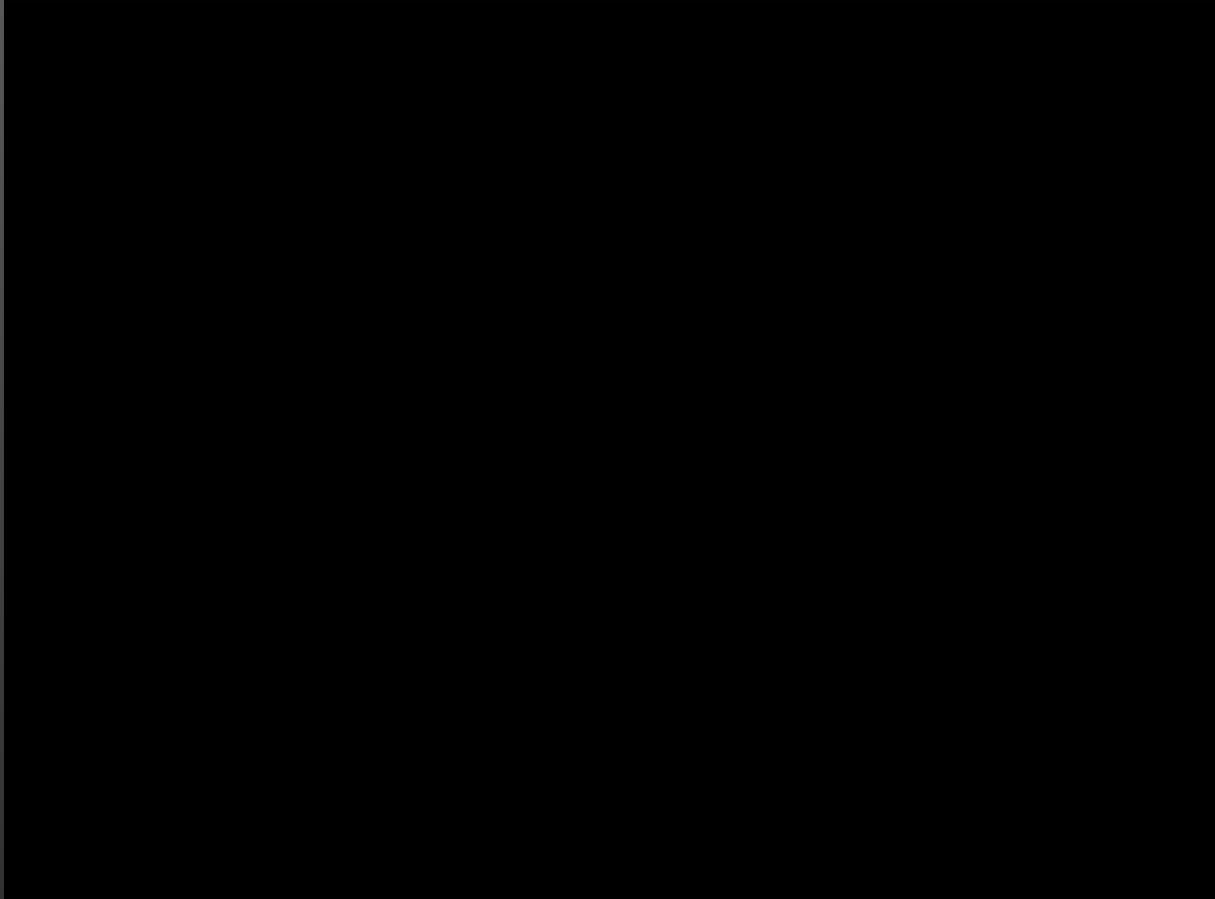
MEG



EEG



Word Recognition is Fast

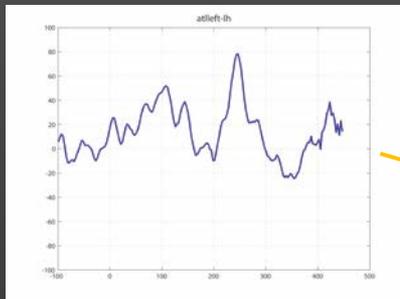


Spatio-temporal dynamics of brain activation

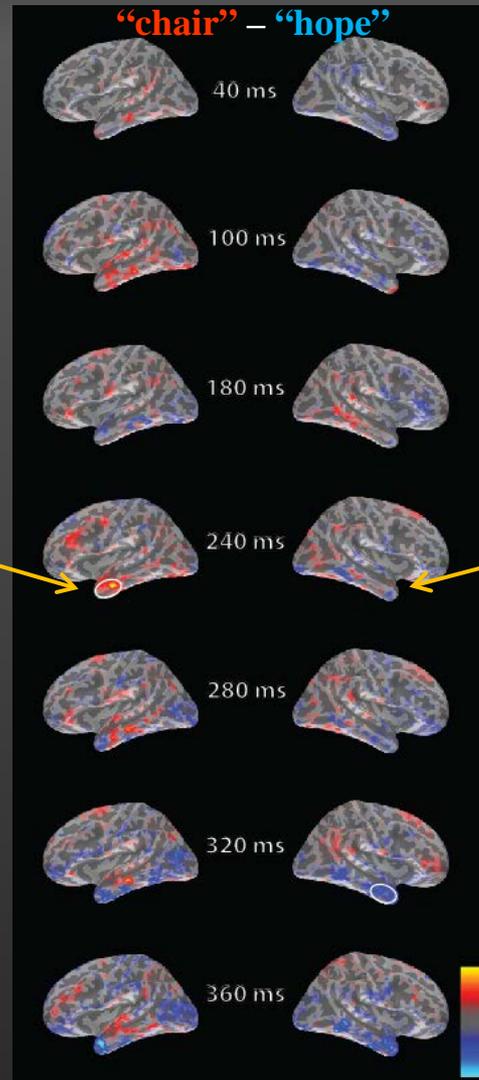
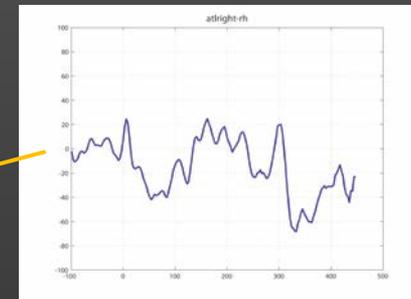
Concrete – Abstract

“chair” – “hope”

Left ATL

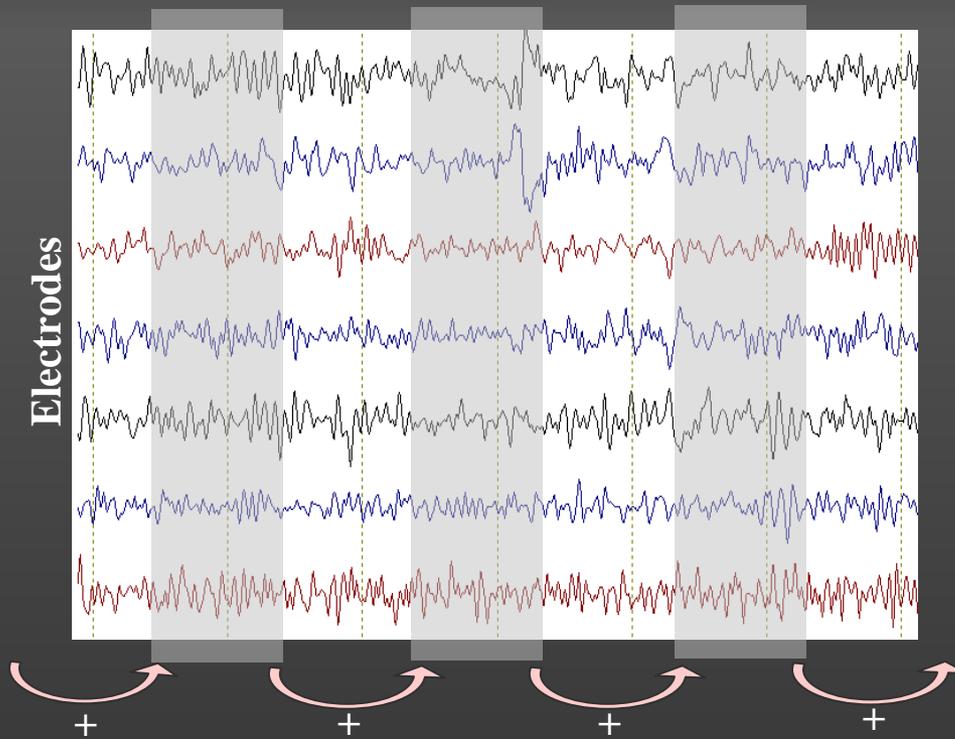


Right ATL

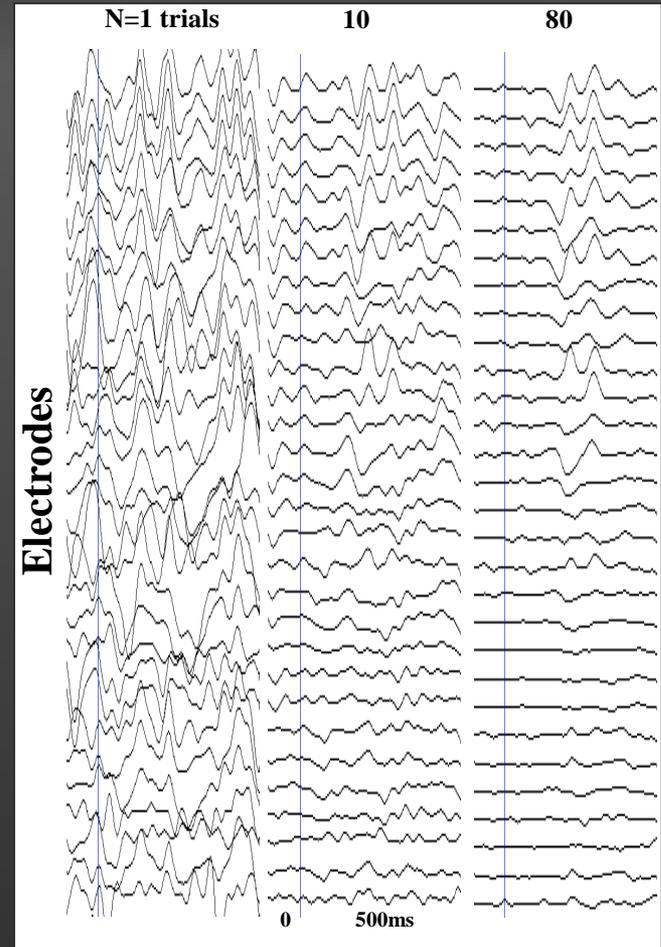


Data Averaging

Continuous “raw” data:



Averaged data:



Artefacts and Noise Reduction

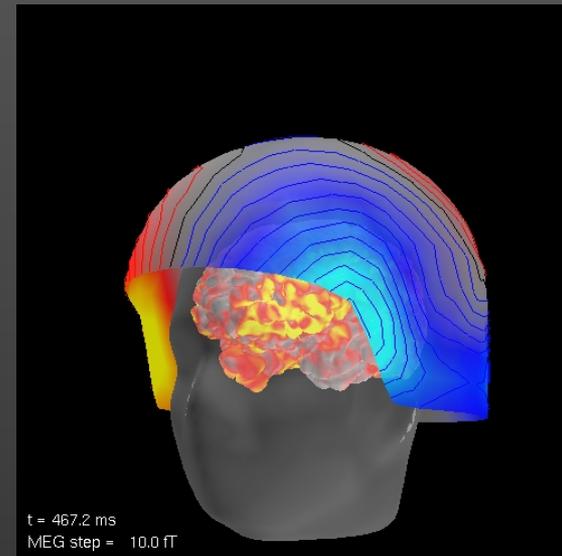
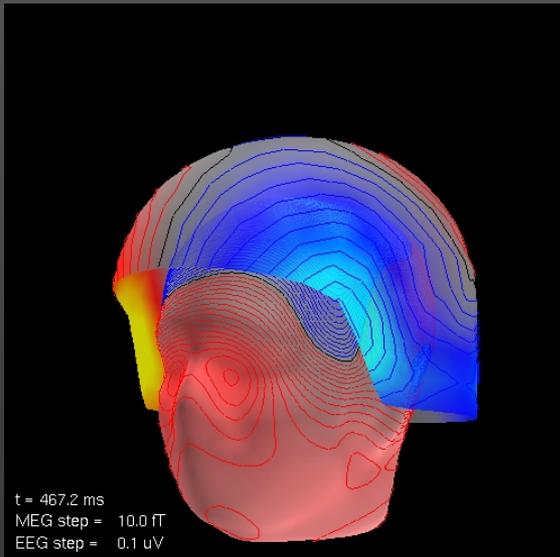
- The importance of particular artefacts depends on the type of analysis:
 - Muscle activity and micro-saccades produce predominantly high-frequency (>30 Hz) activity
 - Eye blinks $\sim < 10$ Hz
 - Eye blinks (or heart rate, respiration) may vary systematically with stimulus presentation

- Common procedures:
 - Visual inspection for faulty channels, frequent artefacts etc. (subjective)
 - “Min/max” rejection criteria during epoching
 - Maxfilter, ICA, eye artefact correction

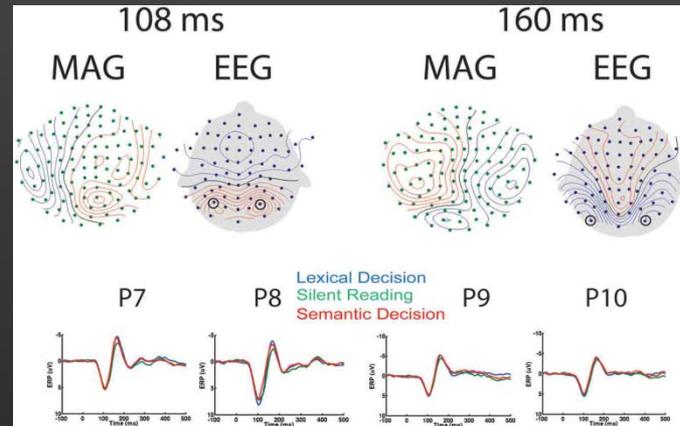
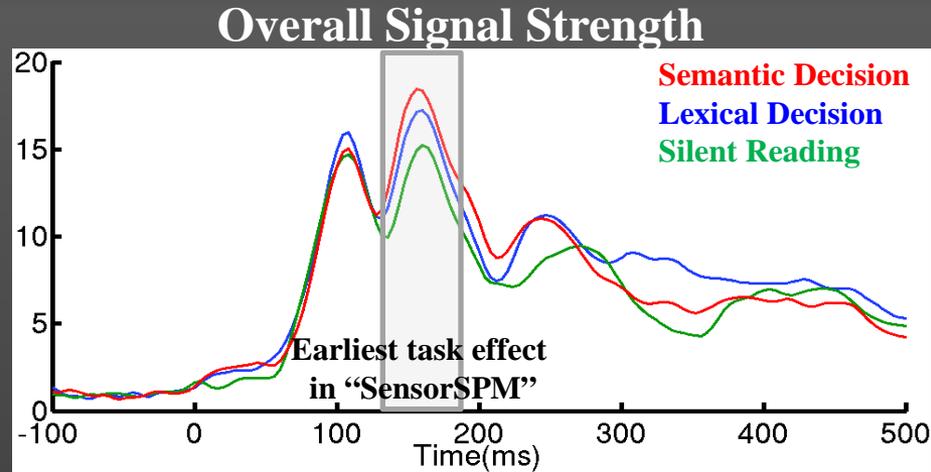
careful when artefacts/residuals are systematic:
check averaged EOG/ECG channels, movement parameters etc.

- Guidelines:
 - Picton et al., “Guidelines for using human event-related potentials to study cognition: recording standards and publication criteria”, Psychophysiology 2000
 - Gross et al., “Good practice for conducting and reporting MEG research”, Neuroimage 2012

Eye Blink Artefacts in EEG and MEG

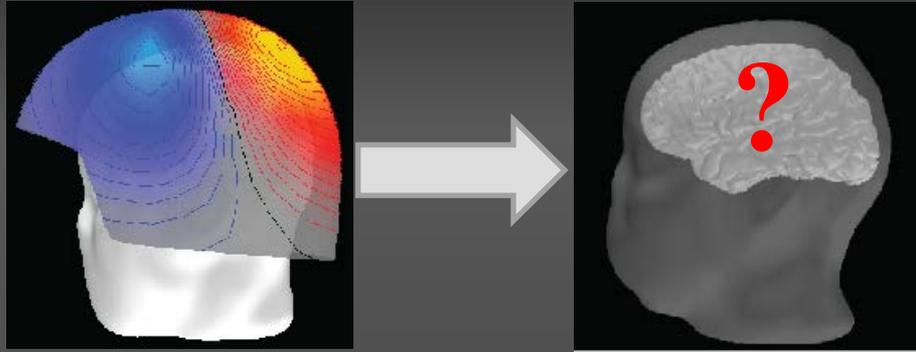


Top-Down Modulation of Brain Activation

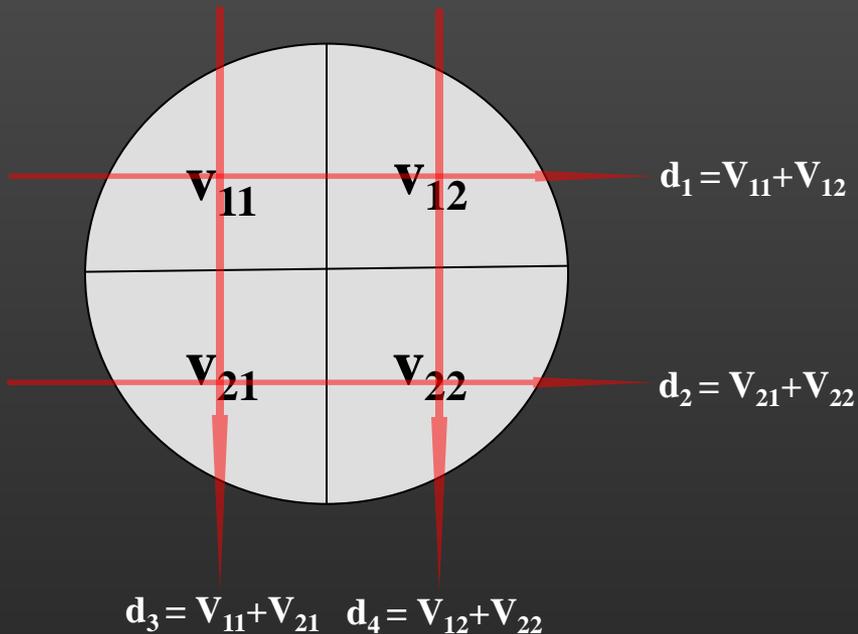


Task modulation around 150 ms => evidence for early “filtering”

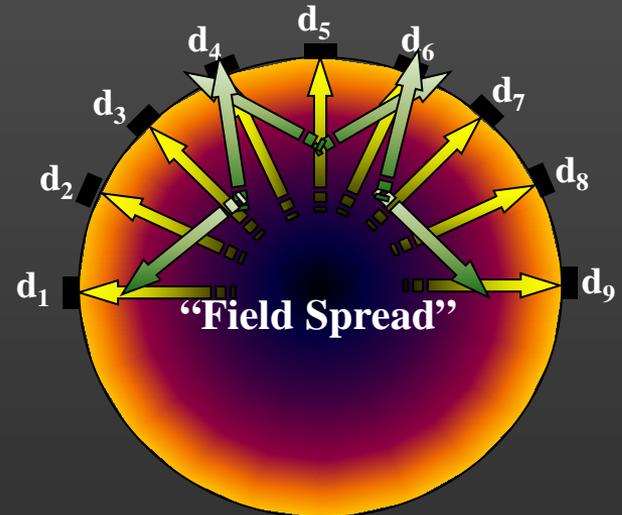
Where Are the Sources? The Inverse Problem



Tomography
(CT, fMRI...)



EEG/MEG



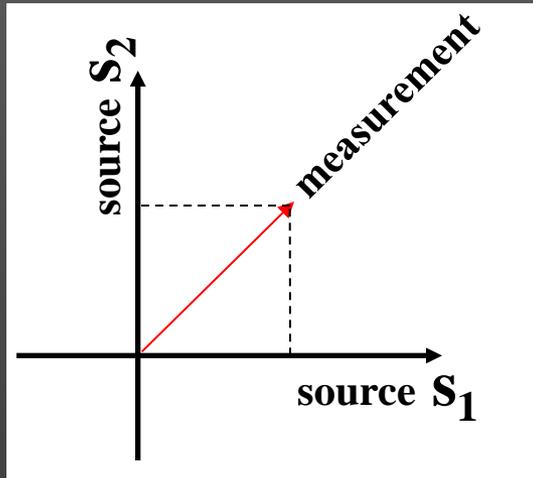
Information is lost during measurement

Cannot be retrieved by mathematics

Inherently limits spatial resolution

Why Inverse "Problem"?

Reconstructing information
from an incomplete projection:



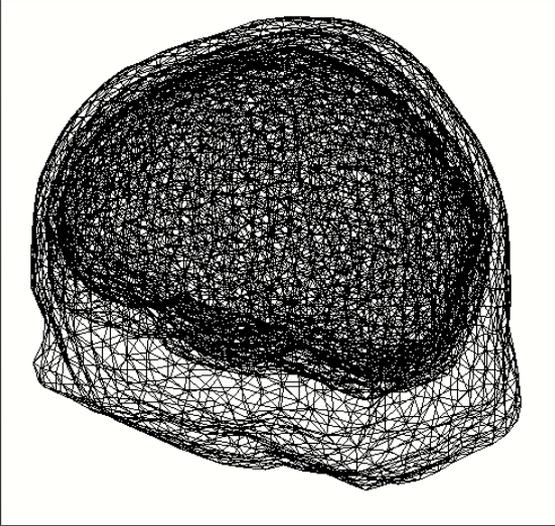
We only see a faint shadow of the real distribution of brain activity.

If you are not shocked by the EEG/MEG inverse problem...
... then you haven't understood it yet.

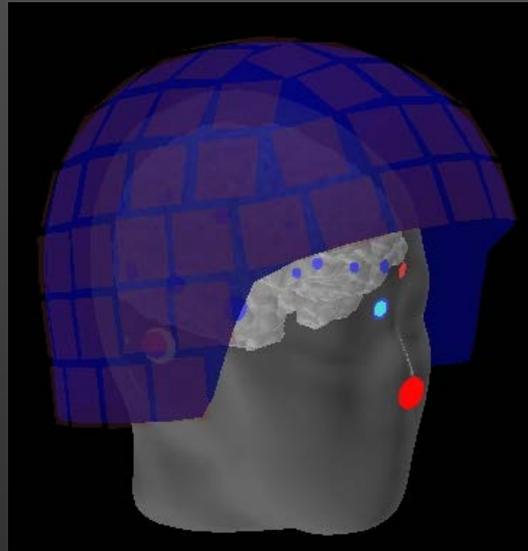
(freely adapted from Niels Bohr)

Ingredients for Source Estimation

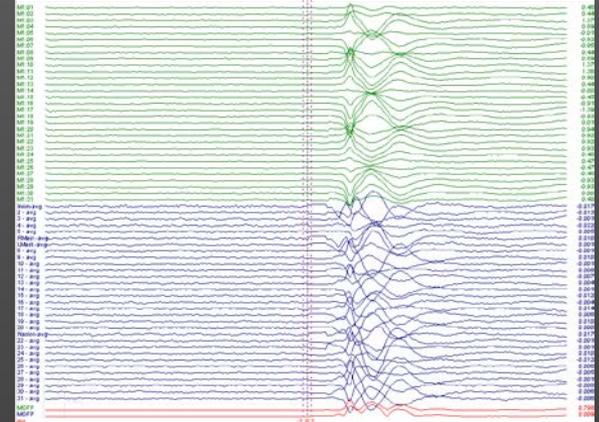
Volume Conductor/
Head Model



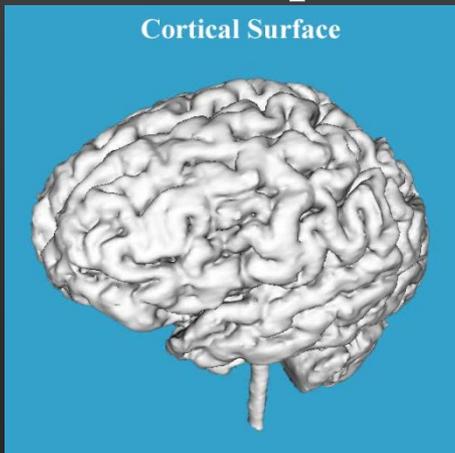
Coordinate
Transformation



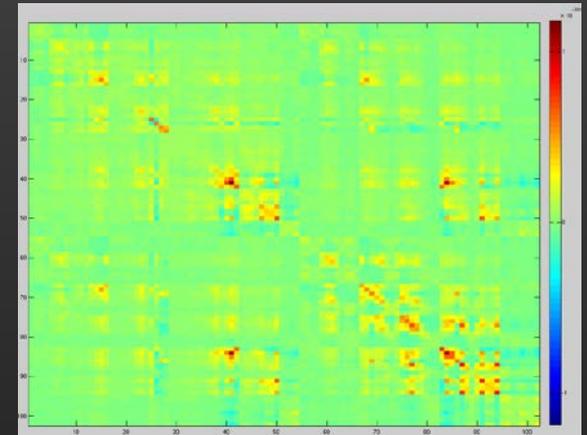
MEG data



Source Space

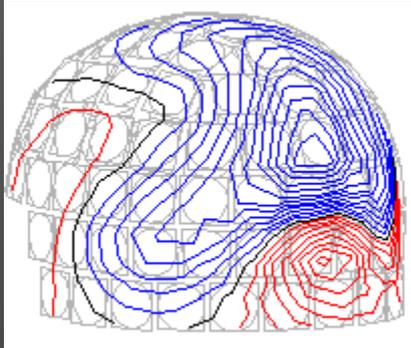


Noise/Covariance Matrix

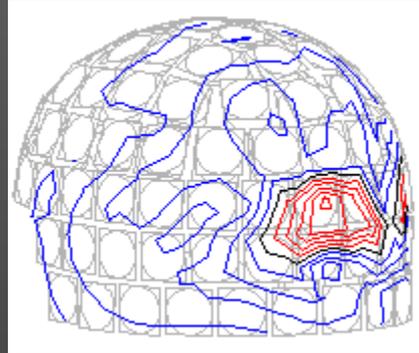


Topographies

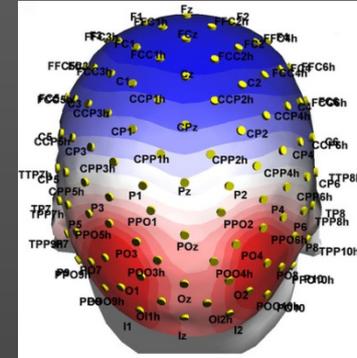
Visually Evoked Fields ~100 ms



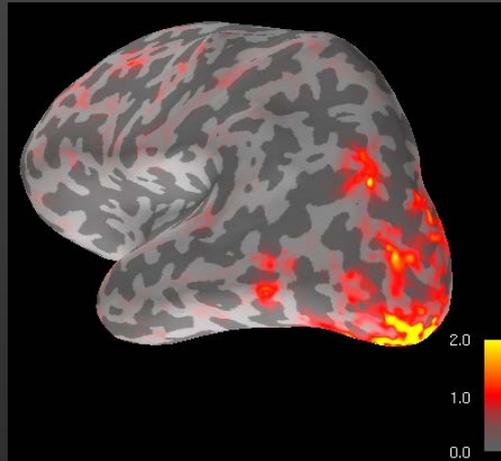
Magnetometers



Gradiometers



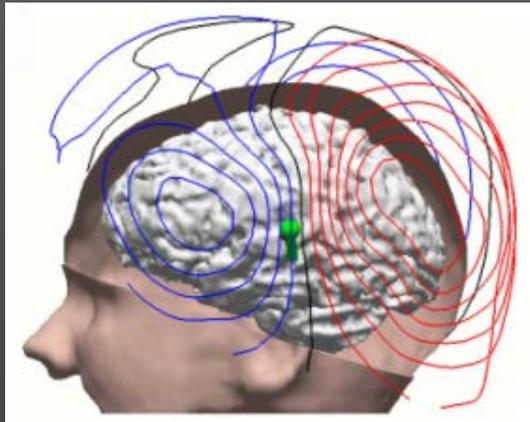
EEG



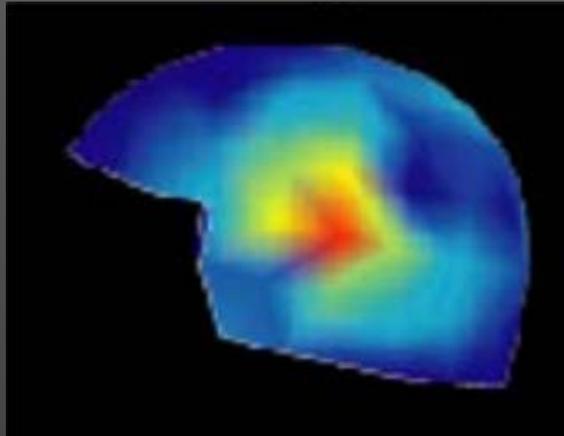
Minimum Norm Estimate

Example: Auditory Evoked Responses

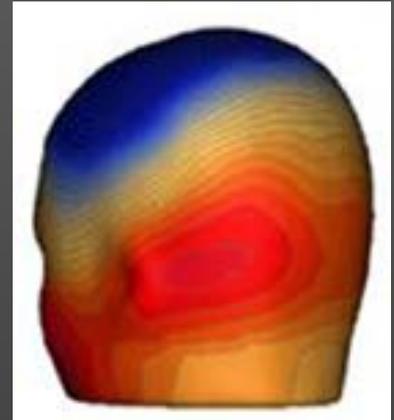
Auditory Evoked Fields ~100 ms



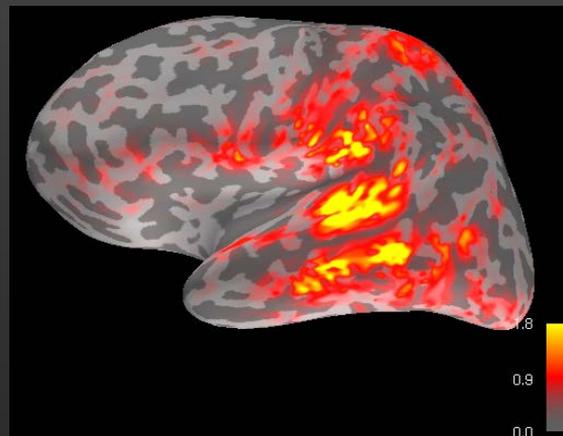
Magnetometers



Gradiometers



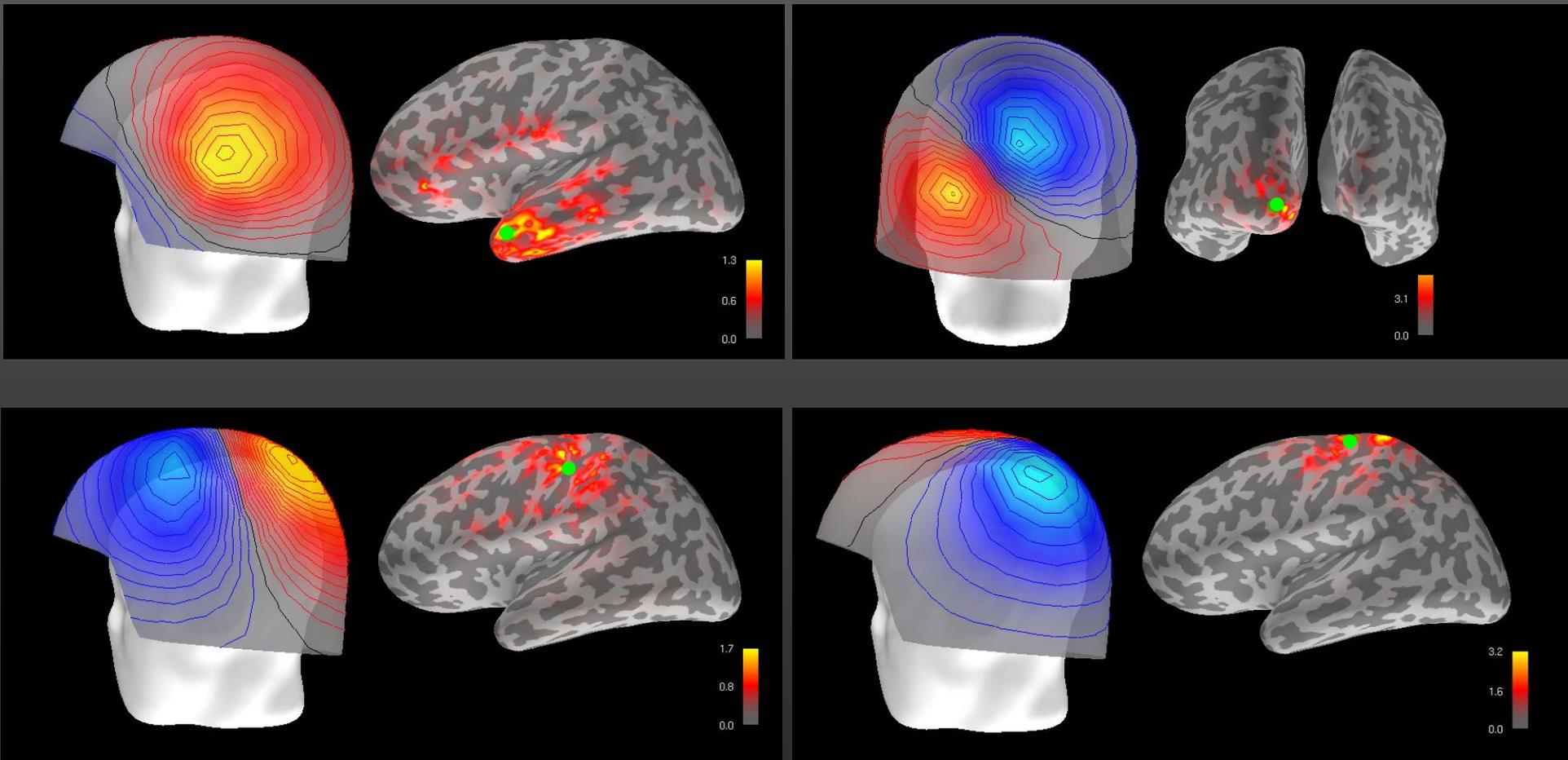
EEG



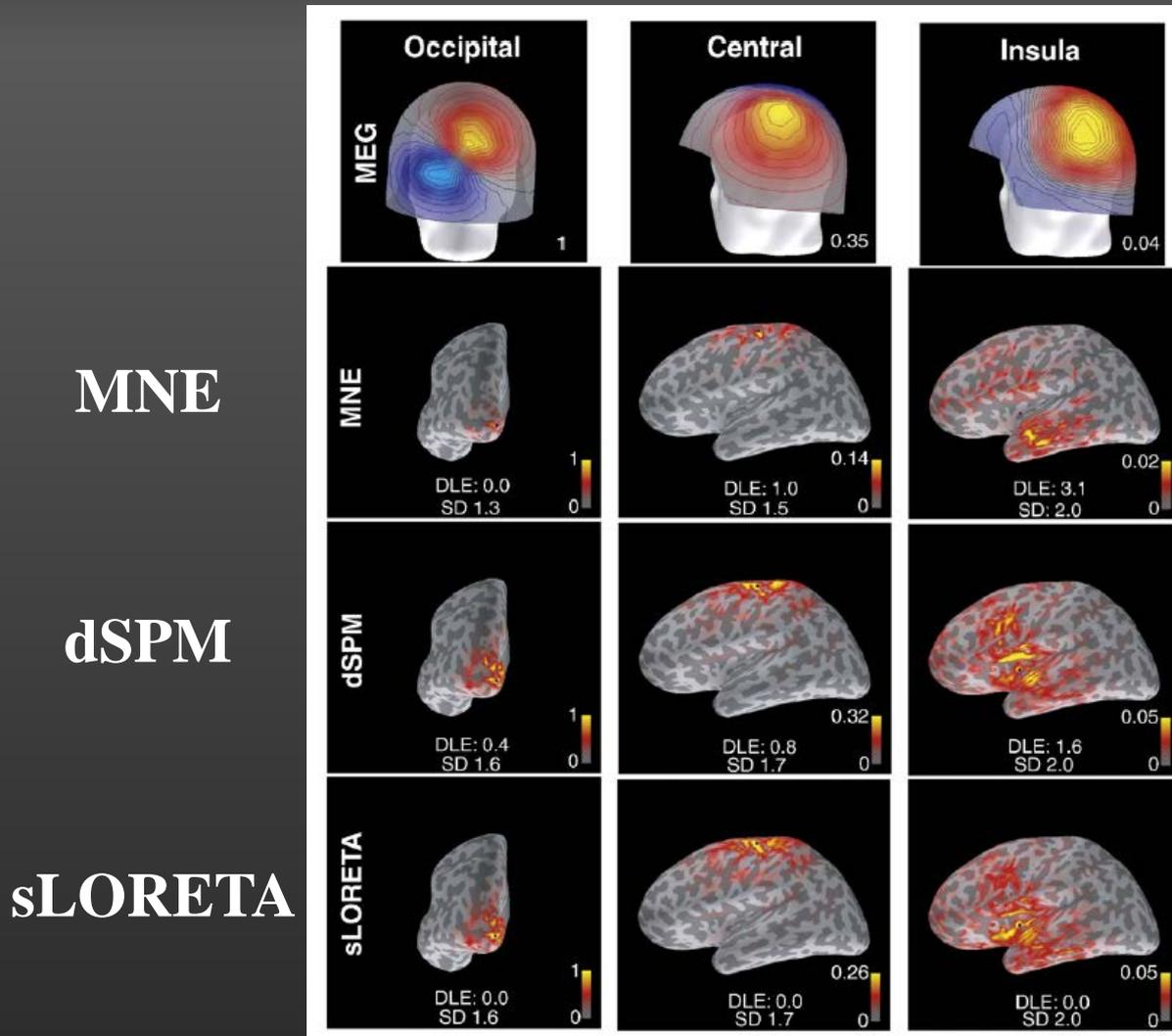
Minimum Norm Estimate

Spatial Resolution of Source Estimation

Simulated Data “Point-Spread Functions”

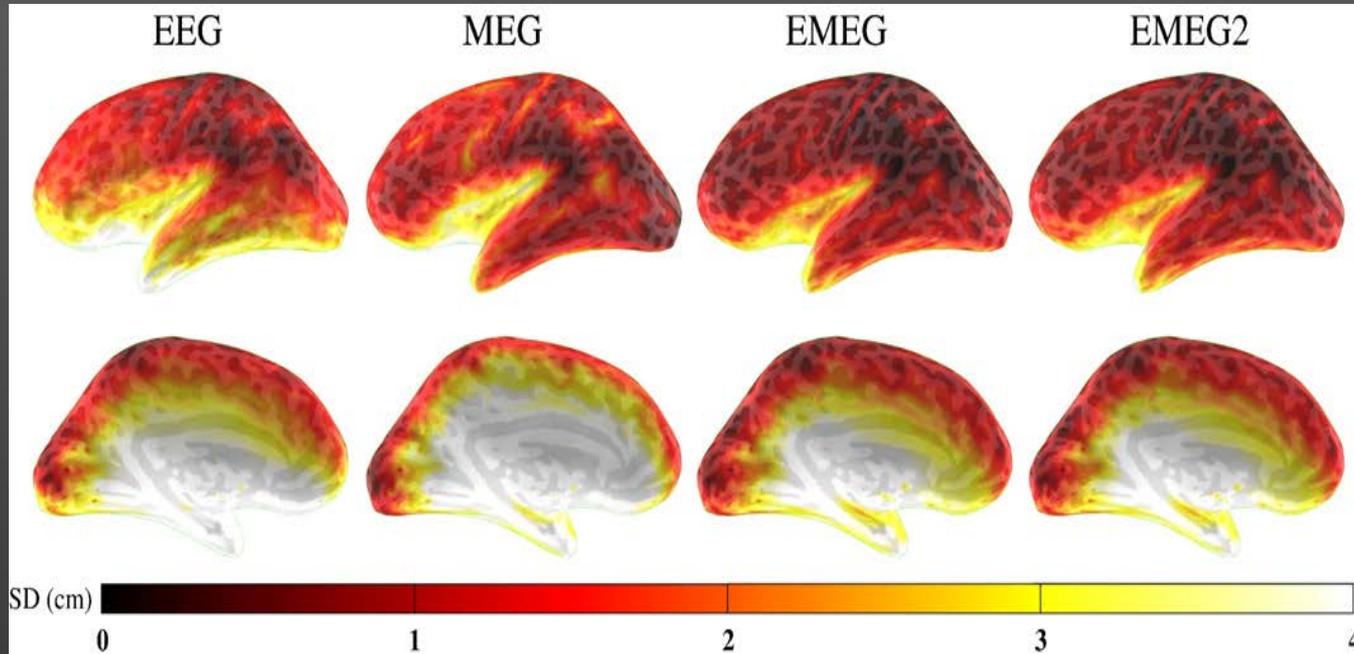


Methods Comparison for Source Estimation

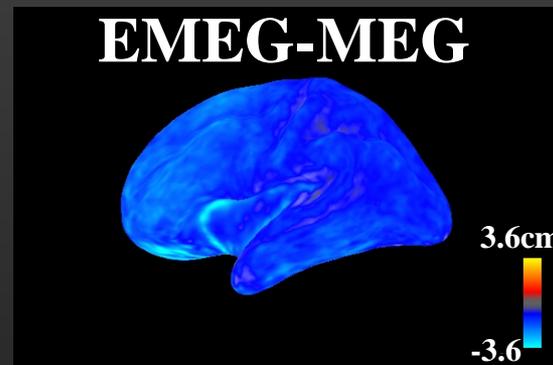


Combining EEG and MEG Improves Resolution

Spatial Extent

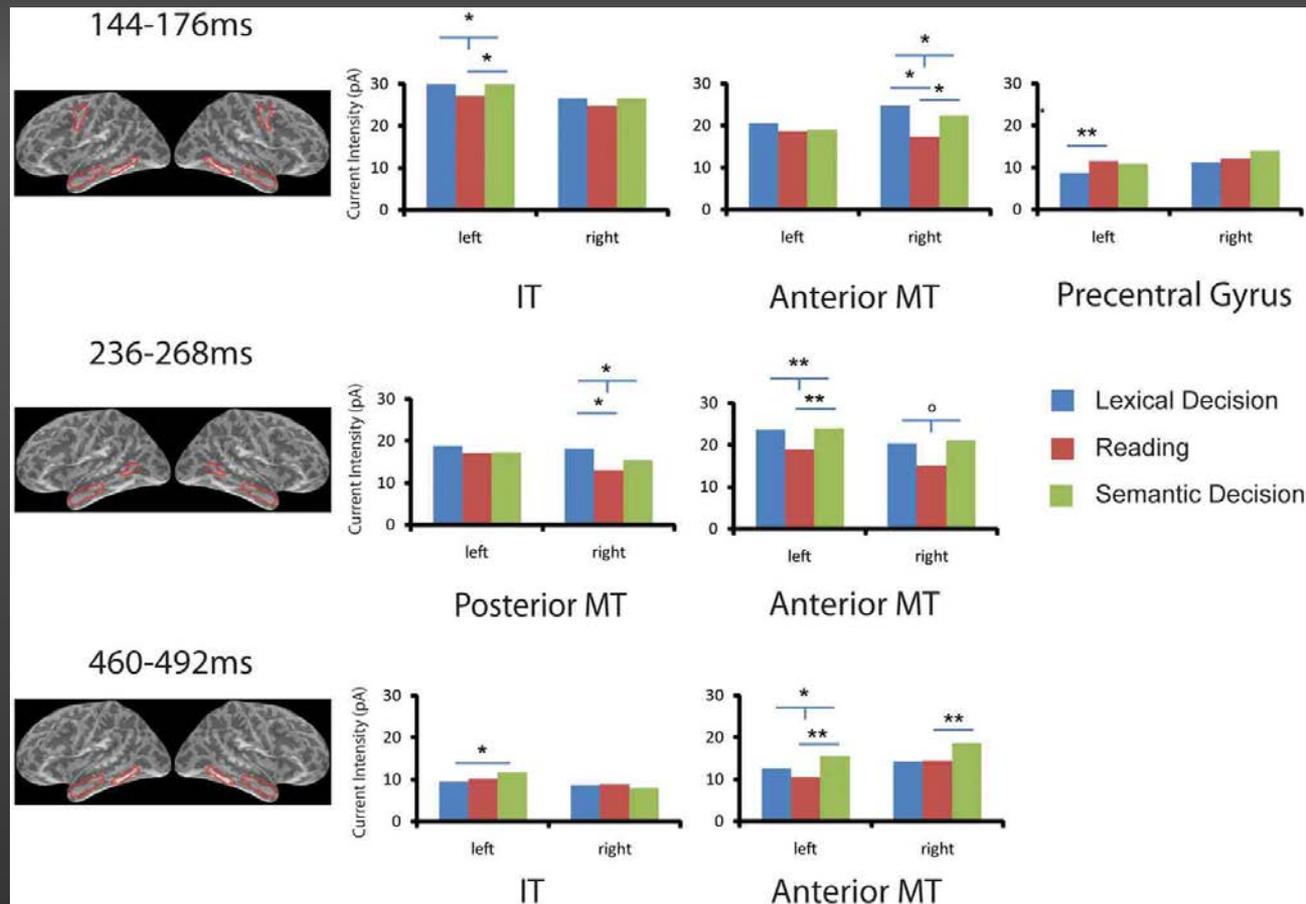


Molins et al., Neuroimage 2008



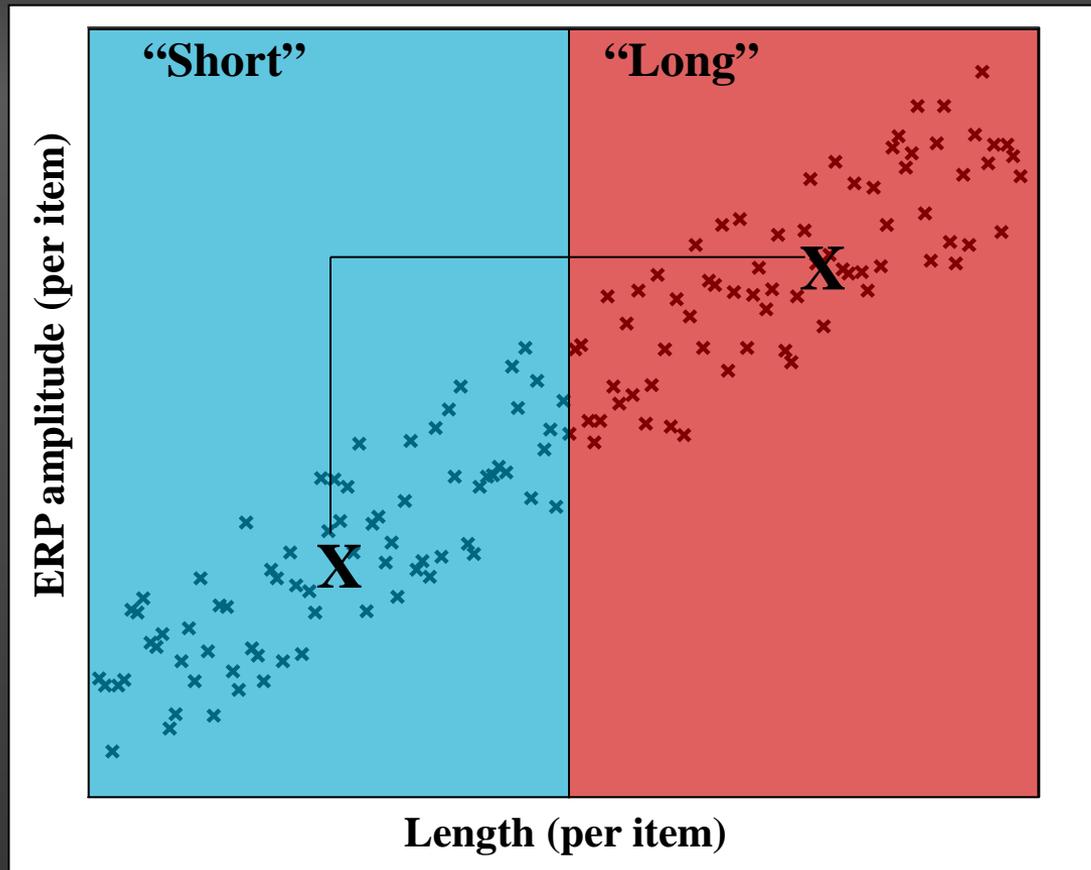
Stenroos&Hauk, in prep

ROI Source Space Analysis Using ANOVA

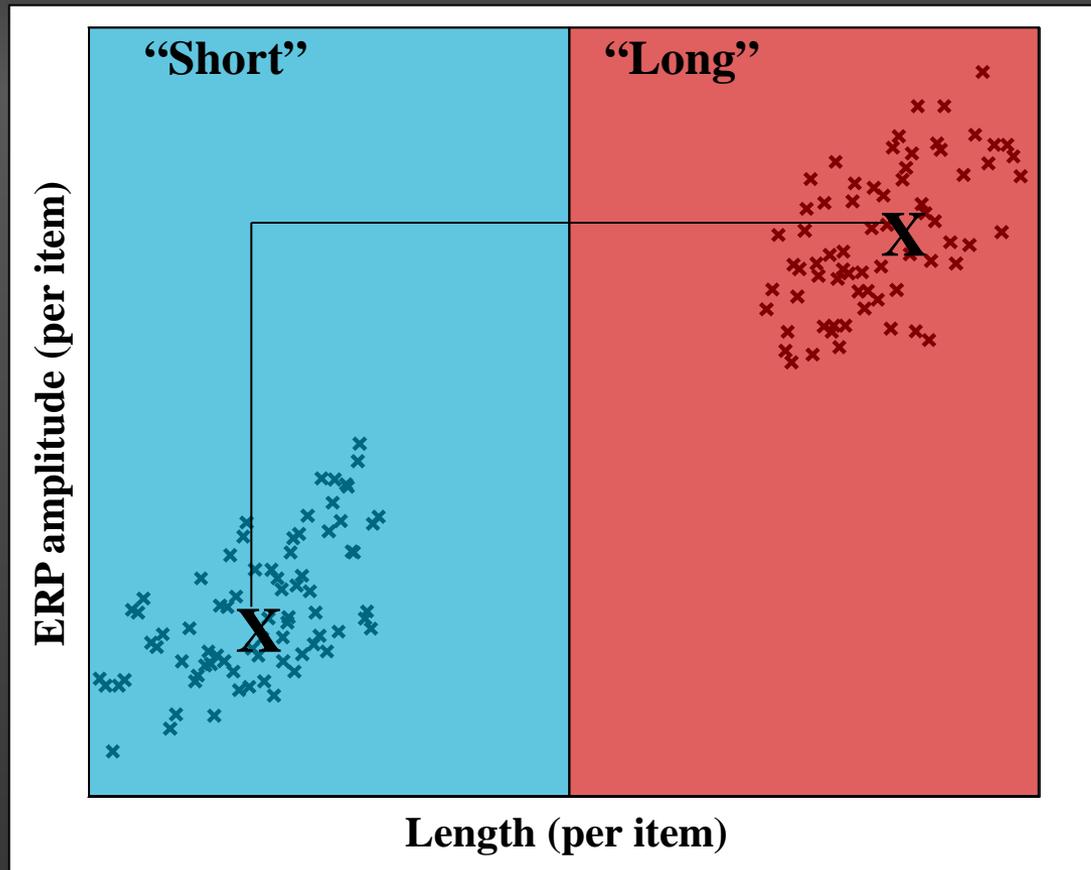


Early differential task modulation in different ROIs beginning ~150 ms,
Especially in left temporal areas
=> More evidence for early “filtering”

Factorial Analysis of ERP data



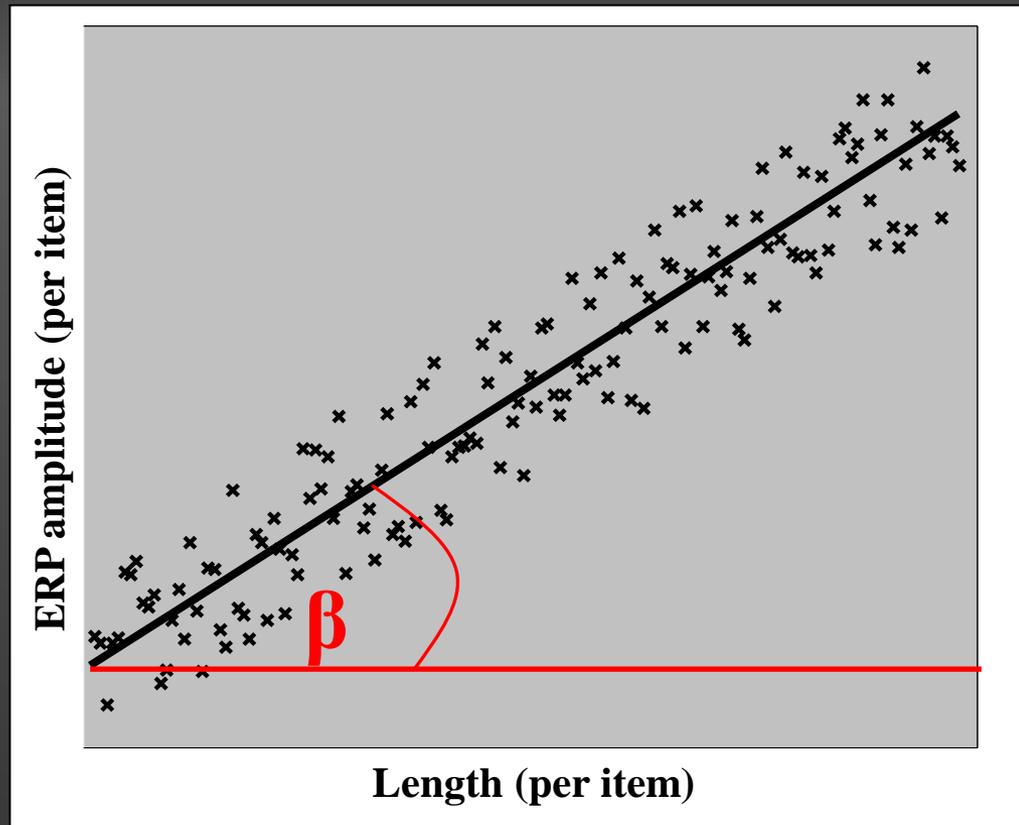
Factorial Analysis of ERP data



**Factorisation of psycholinguistic variables may lead to selection of
“awkward” items**

(e.g. Baayen et al., 1997; Ford et al., 2003)

Regression Analysis of ERP data



Regression analysis allows
“the language, instead of the experimenter, to define the stimulus set”

(Balota, 2004)

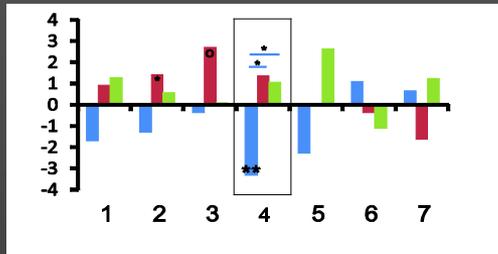
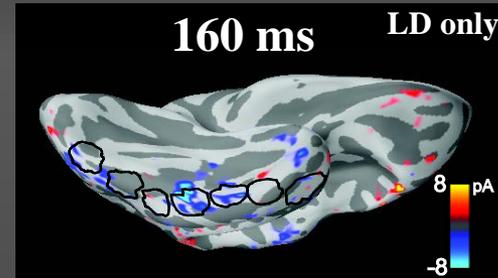
(see also Hauk et al., NI 2006, Biol Psychol 2009)

Task-Modulation of Word Frequency Effects

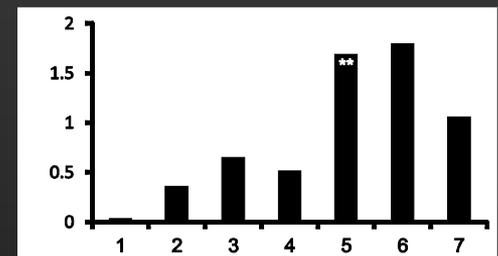
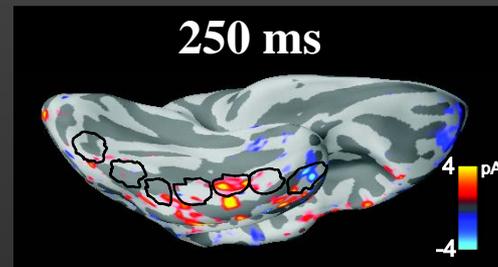
Early task modulation of word frequency effect

ROI analysis focussing on inferior temporal lobe

Later task-independent word frequency effect

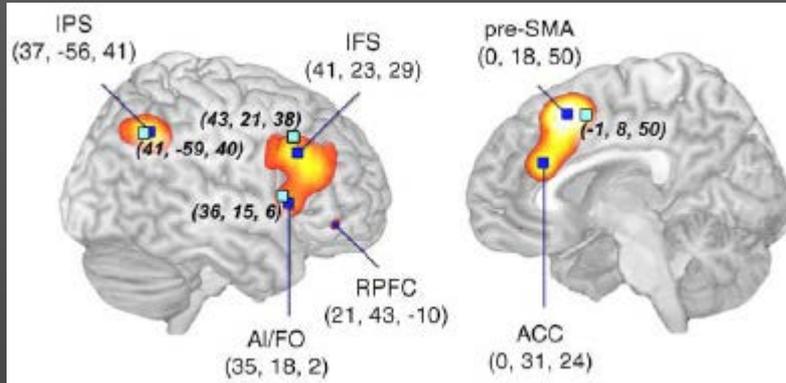


Semantic Decision
Lexical Decision
Silent Reading

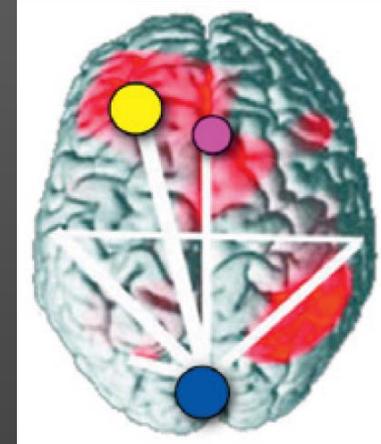


Activation in Brain Networks

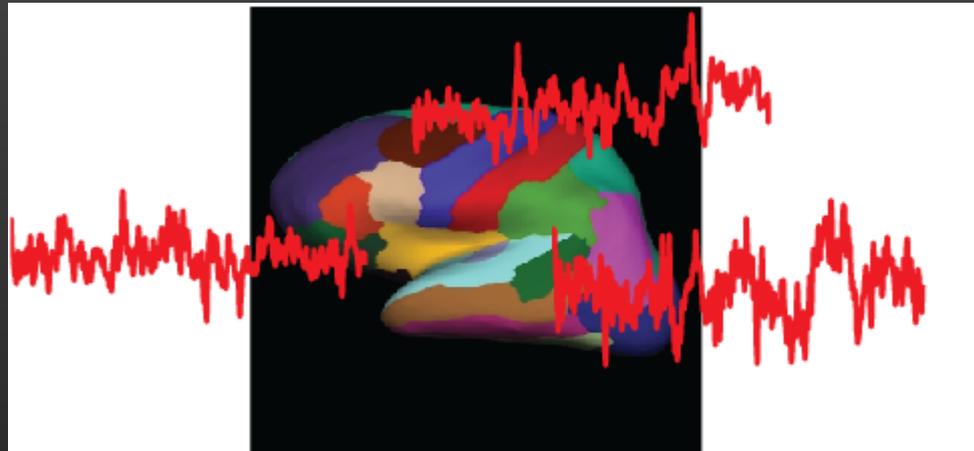
Fronto-Parietal Network



Duncan, 2010

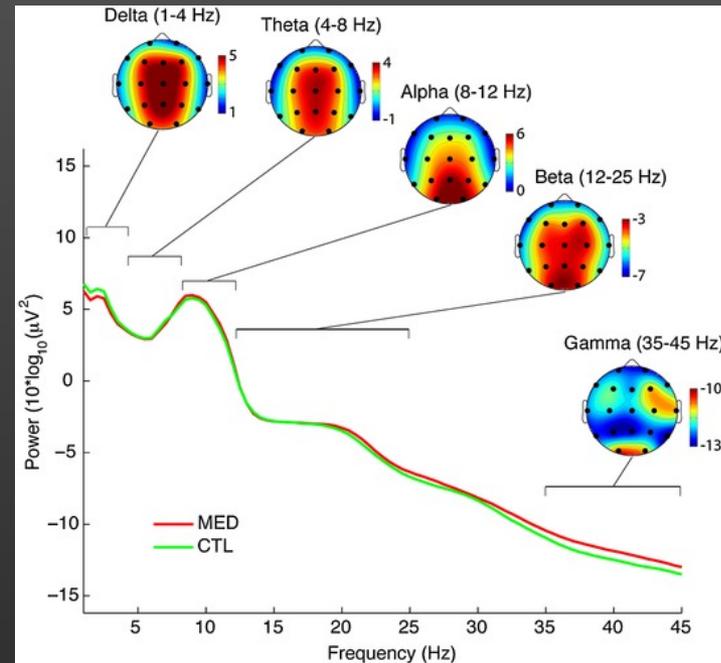
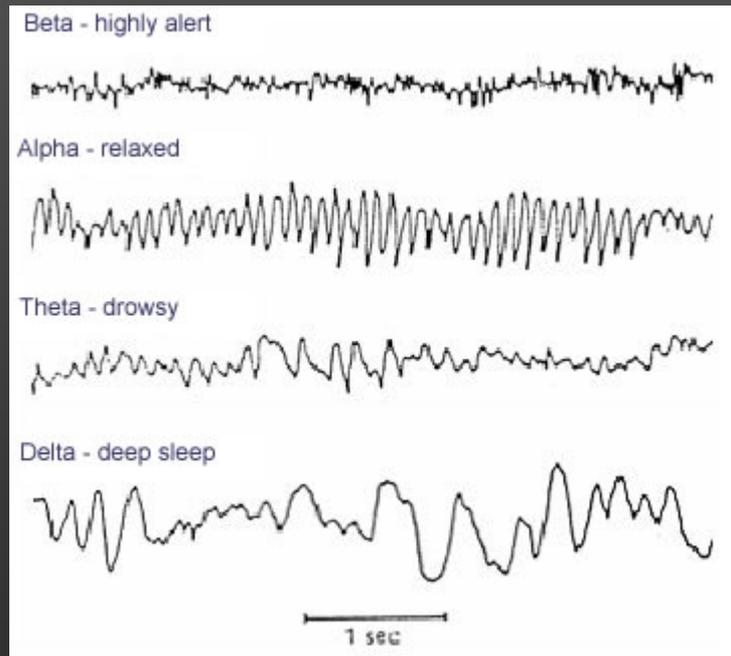


Palva & Palva, TICS 2012
Gross et al., PNAS 2004



"Brain Rhythms" and "Oscillations"

Time course and topography may differ
among different frequency bands
(and may depend on task, environment, subject group etc.)

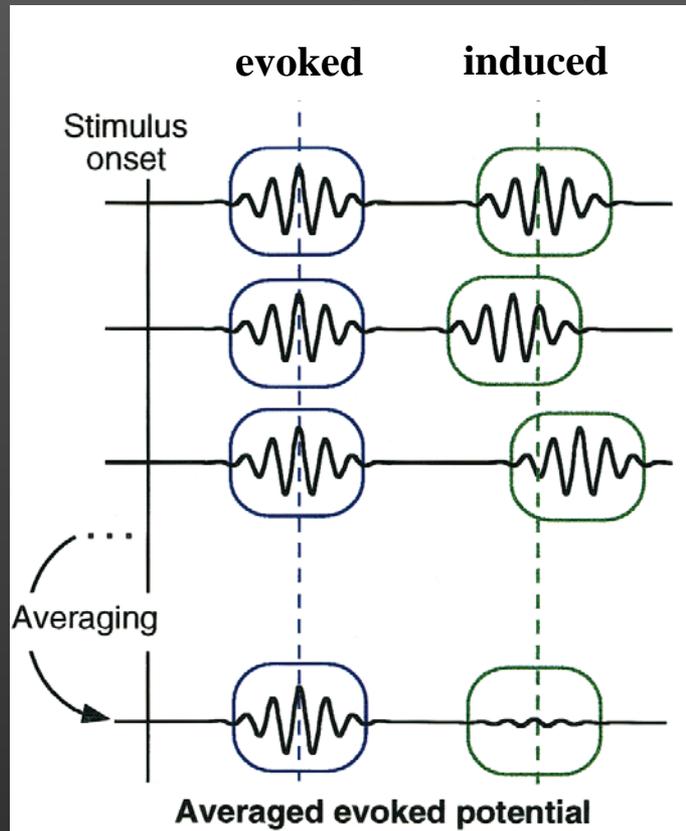


<http://link.springer.com/article/10.1007%2Fs10339-009-0352-1/>

"Induced" Brain Responses

"event-related oscillations"

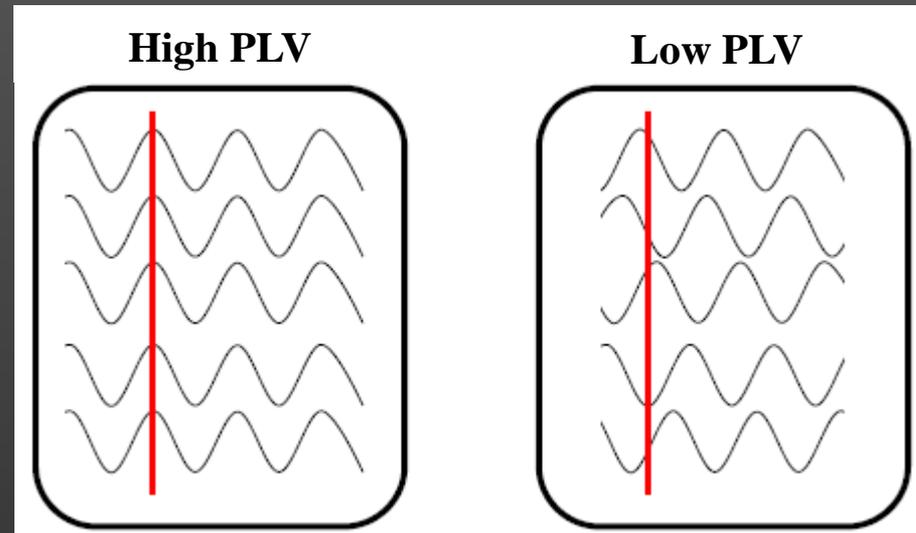
Oscillatory Activity



Tallon-Baudry & Bertrand, TICS 1999

Phase-Locking

Between regions, across trials

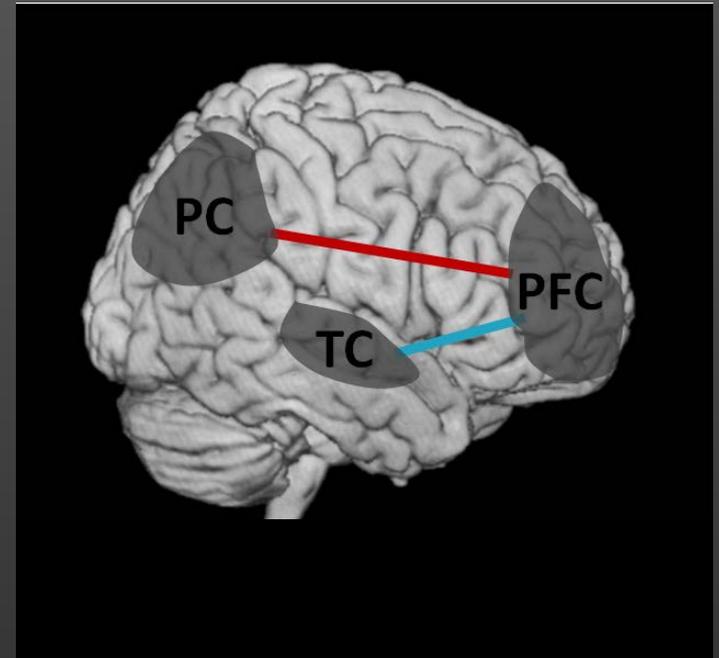
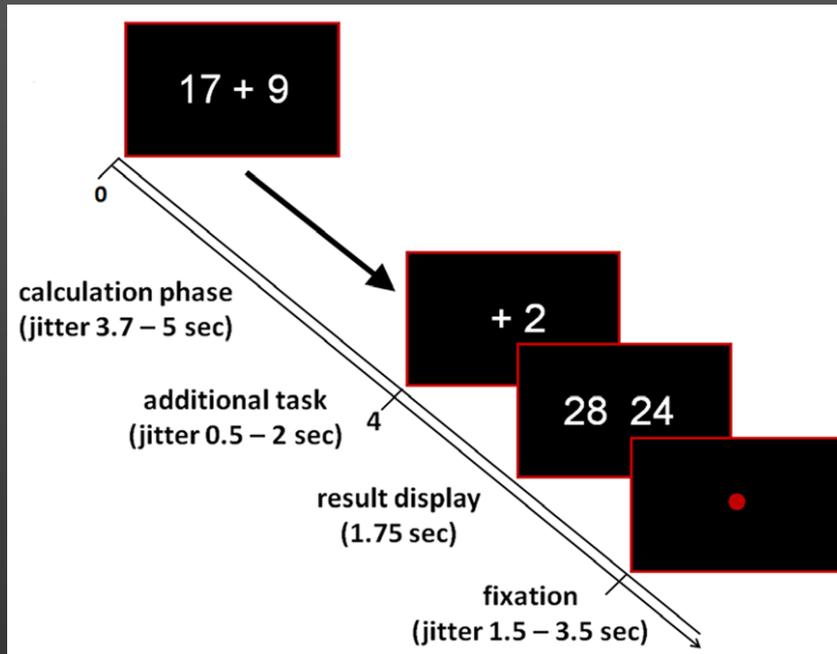


“Functional Connectivity”

vs

“Effective Connectivity”

Brain Networks Involved in Mental Arithmetic

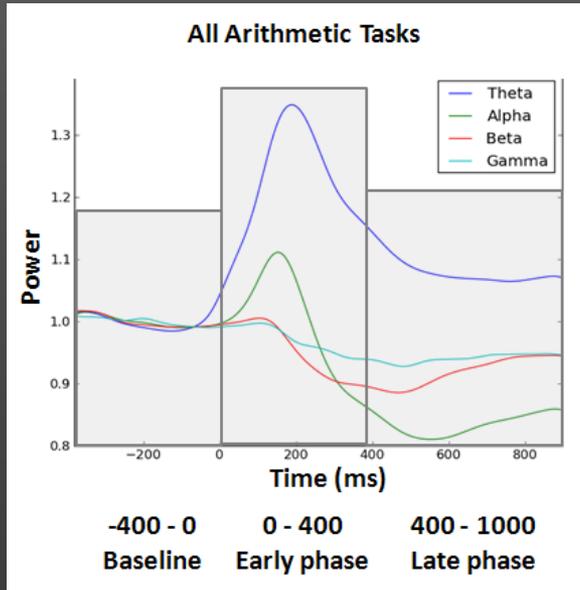


“Retrieval”: $2+3, 2*3$

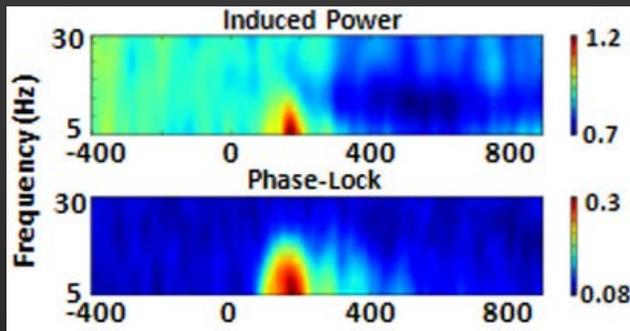
“Procedural”: $17+9, 9*12$

Mental Arithmetic: Time-Frequency Analysis

Time course of power
For different frequency bands



“Time-Frequency Plots”



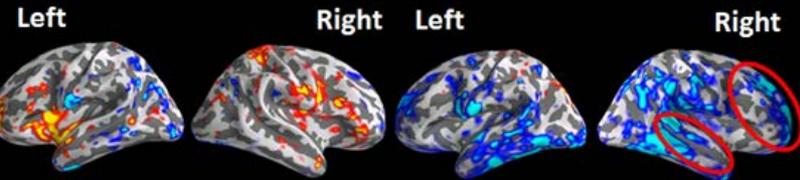
Source Estimates

Procedural - Retrieval Strategy

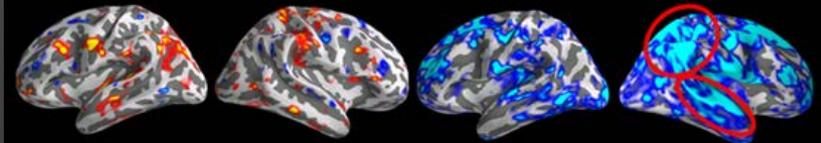
0 - 400 ms

400 - 1000 ms

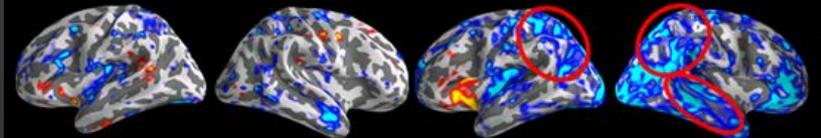
Theta



Alpha



Beta



-40 -20 0 20 40

t-value

Mental Arithmetic: Functional Connectivity Analysis

Seed-based phase-locking analysis

