Multimodal Imaging Perspectives on Language in the Brain

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Structure of the talk

- What do we want to know?
- Strengths and limitations of imaging techniques
- The importance of temporal information
  - localising cognition in time
  - revealing spatio-temporal patterns
  - uncovering functional dynamics
- Integration of results from multimodal neuroimaging

What do we want to know?

What do we want to know about a cognitive process c_i?

- *Where* in the brain does c_i occur?
  - In which (set of) brain area(s) a_i?
- *When*, relative to other processes, does c_i occur?
  - At which point in time (in which time range) t_i?
- *How* is c_i realised in neural tissue?
  - As which (type of) neuronal circuit n_i?
- *Why* is c_i realised as n_i in a_i at t_i?
  - What are the underlying neuroscientific laws?

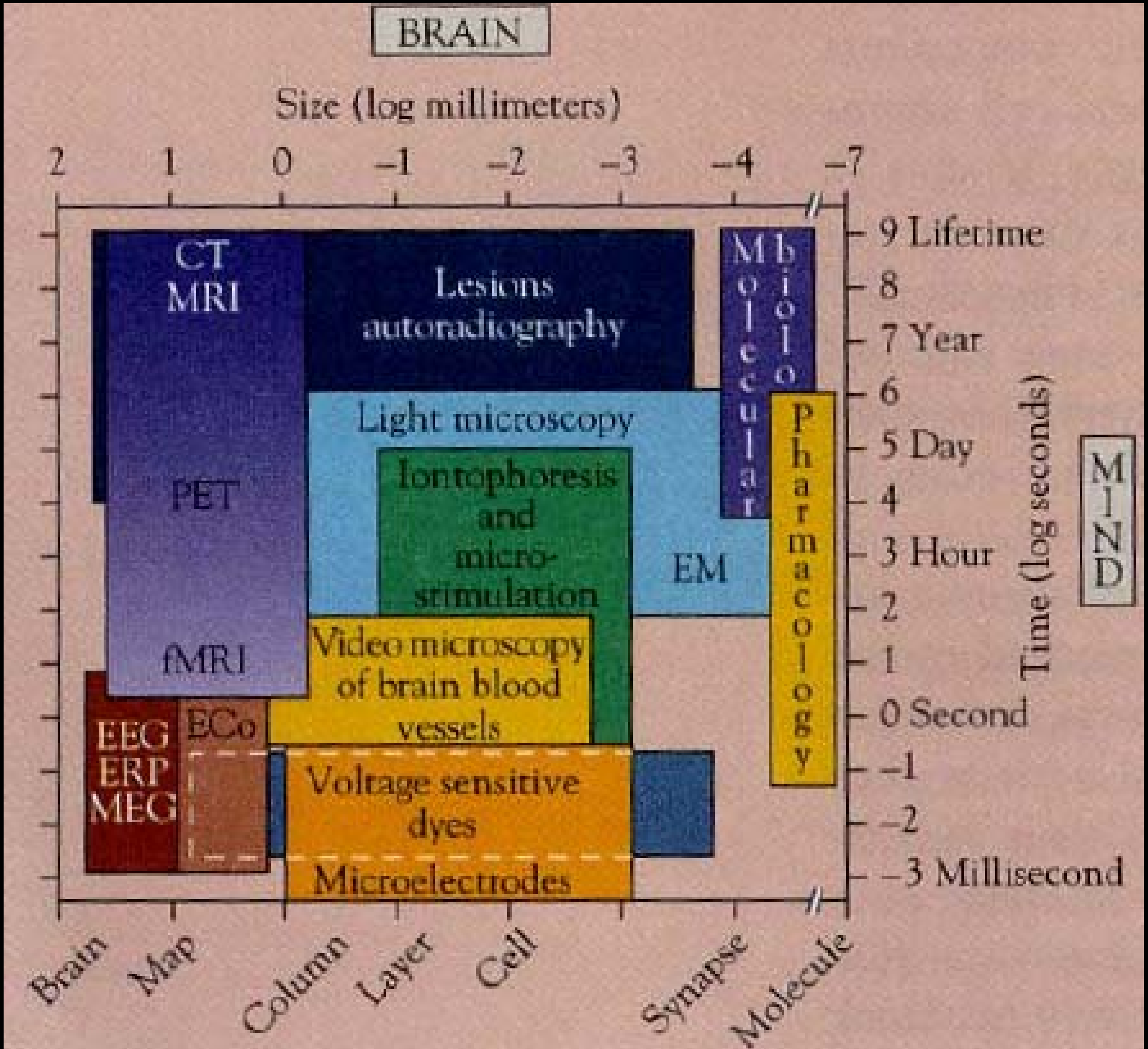
What can neuroimaging tell us about a cognitive process C_i?

- *Where* in the brain does c_i occur?
  - In which (set of) brain area(s) a_i?
- *When*, relative to other processes, does c_i occur?
  - At which point in time (in which time range) t_i?

What can neuroimaging tell us about a cognitive process C_i?

- *Where*?
  - Activation of which (set of) brain area(s) a_i does co-occur with c_i?
- *When*?
  - Activation at which time point (in which time range) t_i does co-occur with c_i?

Neuroimaging methods

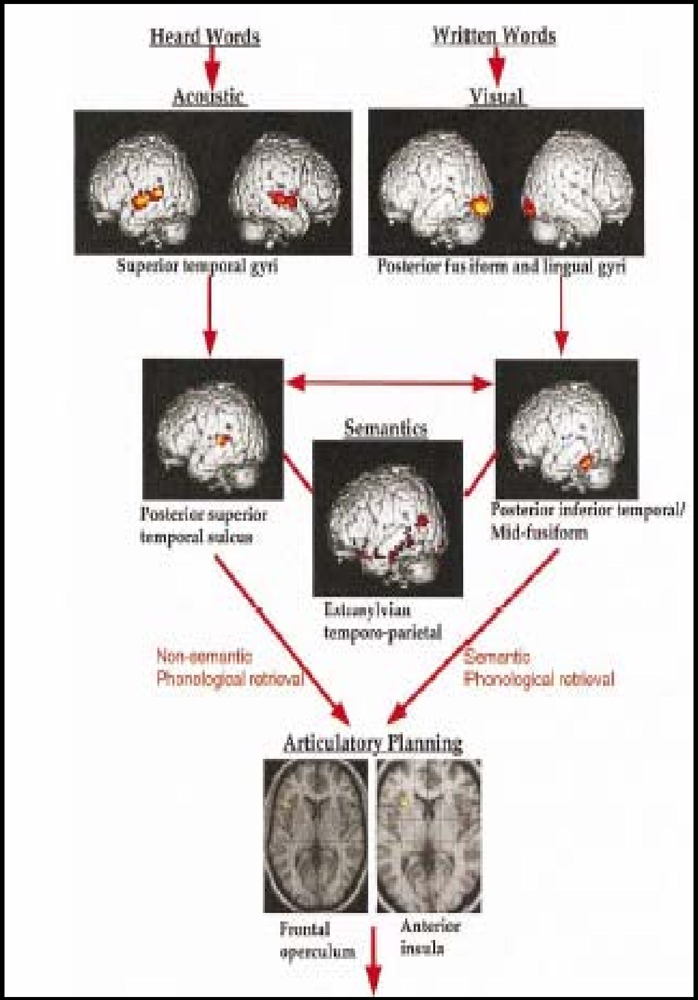


Posner & Raichle 1999

Neuroimaging methods

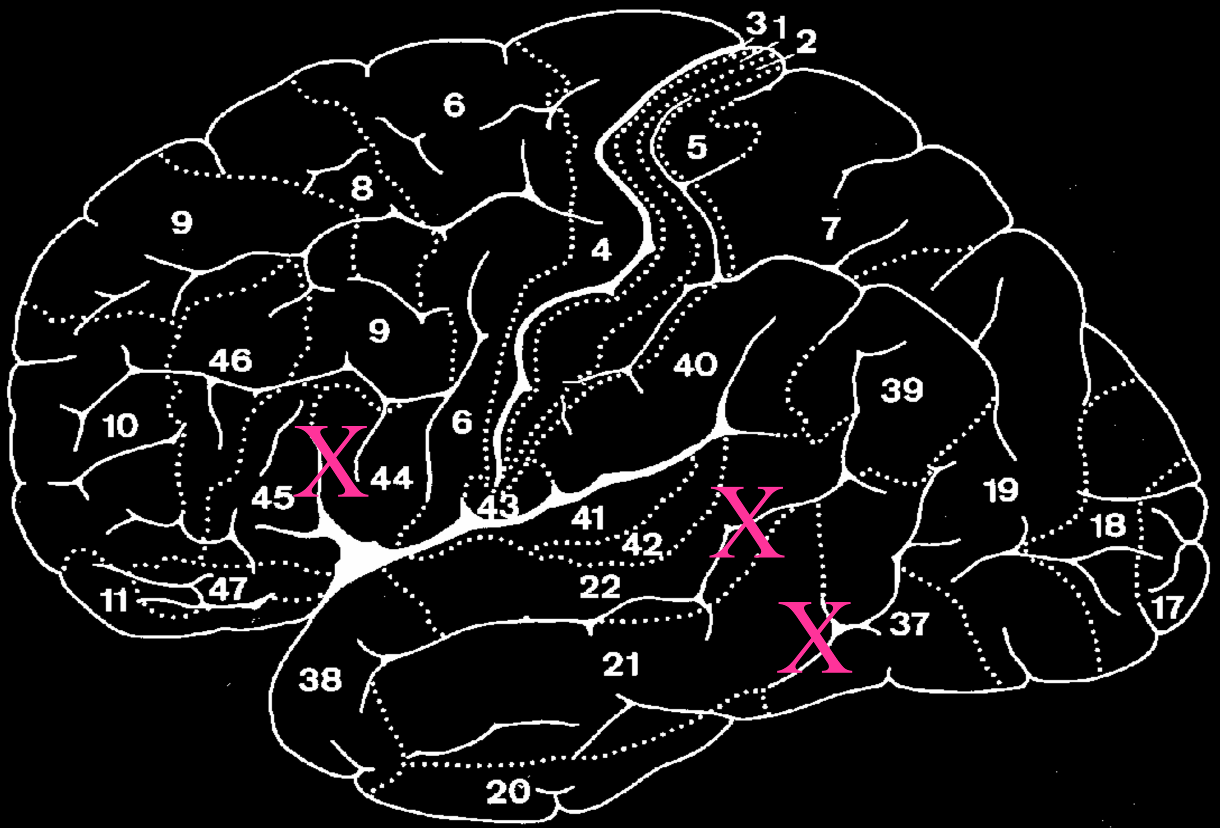
Type	**hemodynamic**	**neurophysiological**
Name	fMRI, PET	MEG, EEG
reflects	metabolites in the blood	activity of nerve cells
precision		
in space	*millimetres*	centimetres
in time	seconds	*milliseconds*

Language processing loci inferred from metabolic imaging results

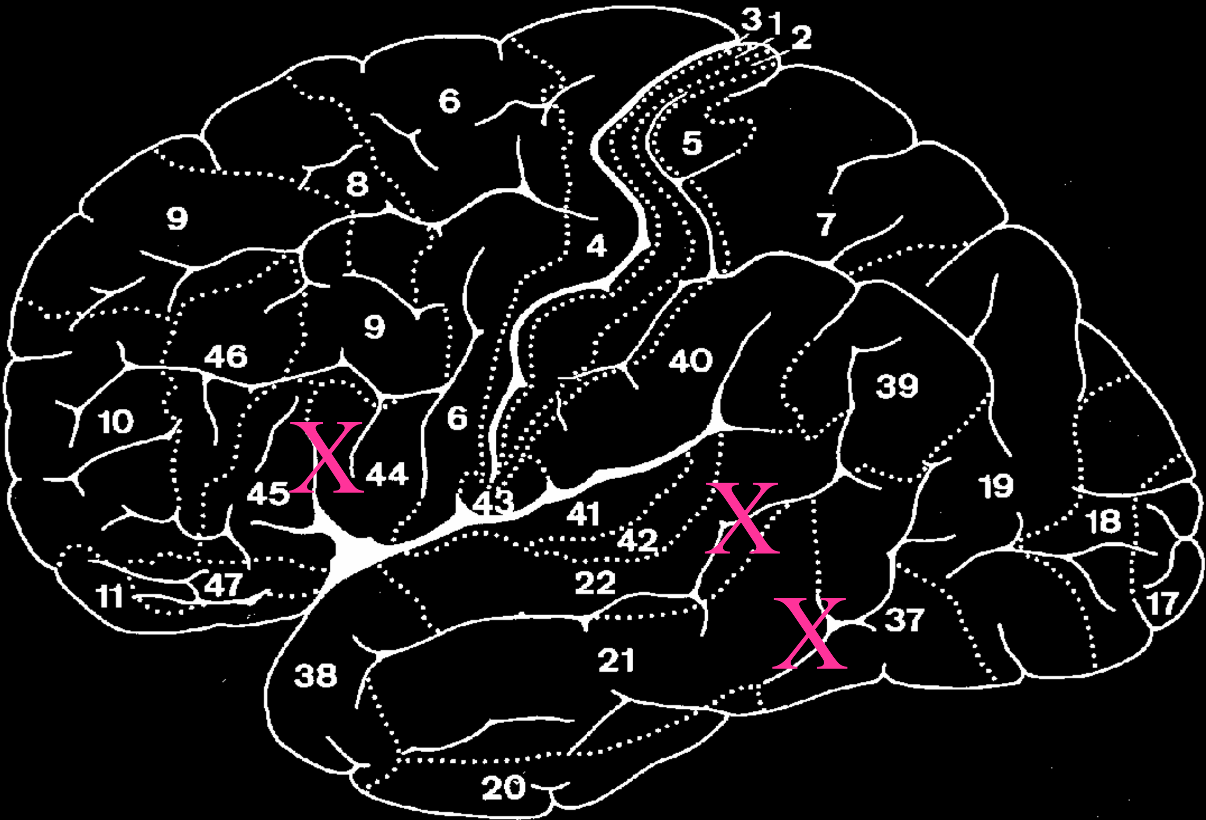


Price, *J Anat 2000*

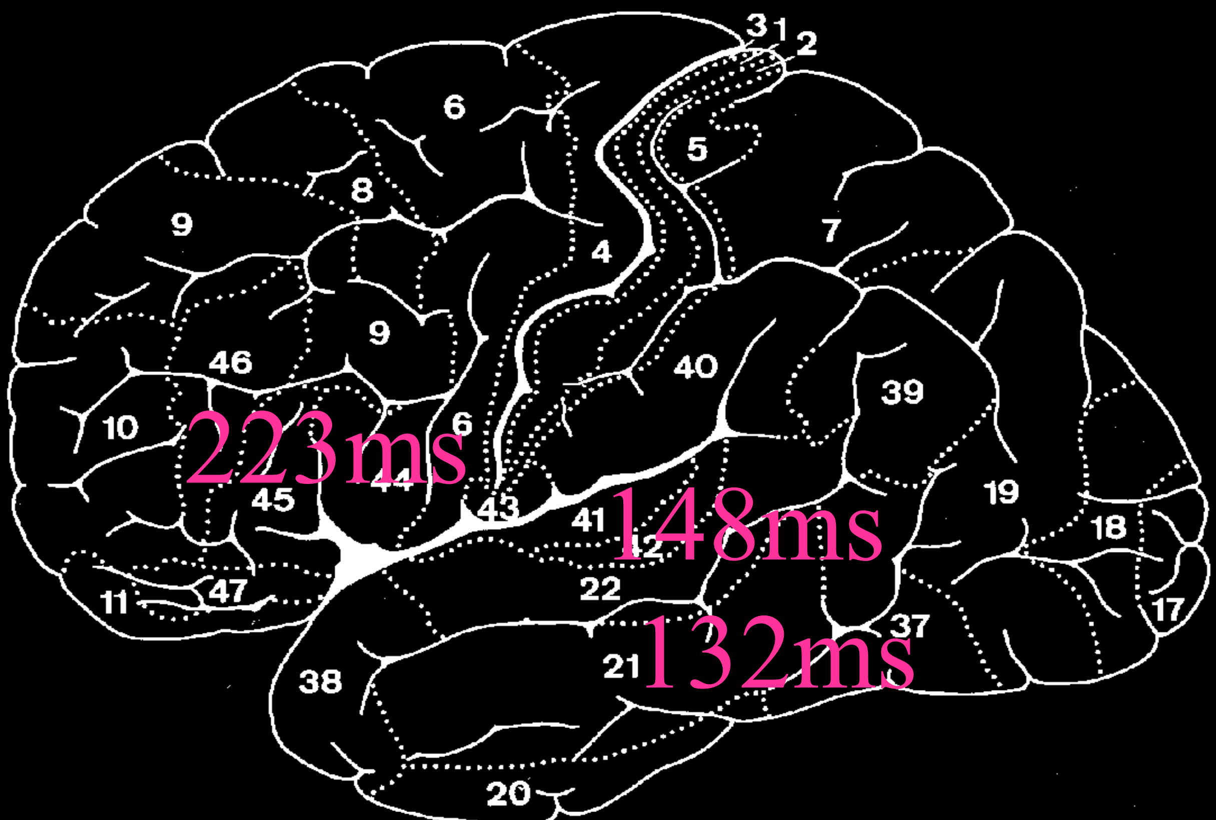
fMRI provides a static picture of cortical activation



This activation likely has a *time course*



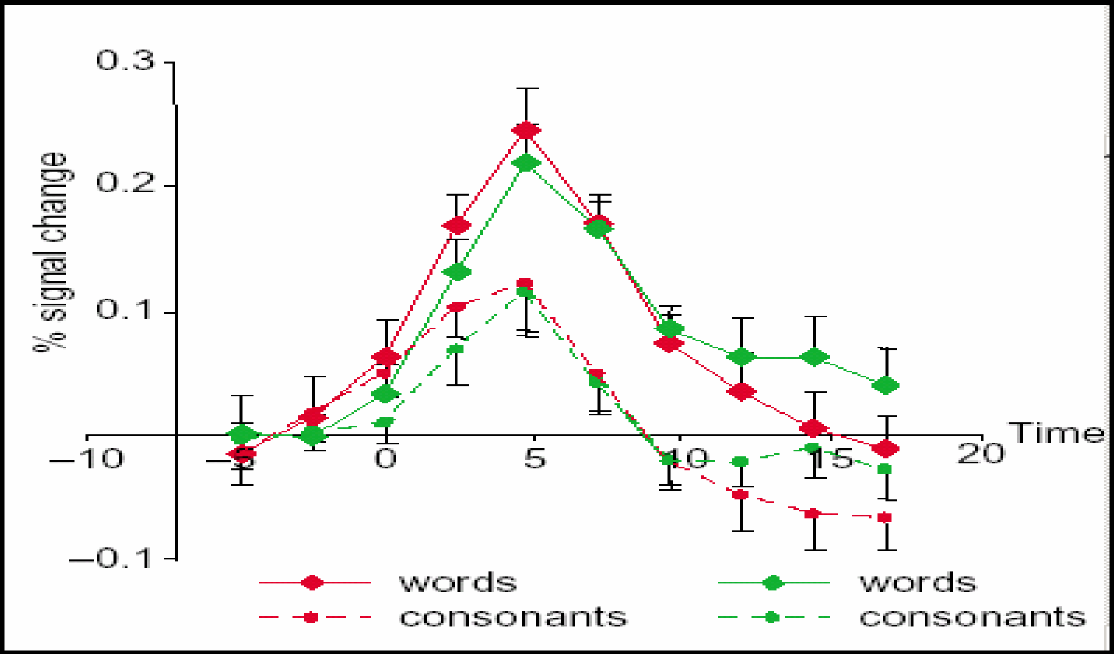
Spatio-temporal dynamics
(hypothetical)



The importance of *temporal information*

- Neurophysiological brain processes are extremely fast.
  - Activity can spread throughout the brain within milliseconds
- Cognitive processes can be near-simultaneous.
  - Lexical, semantic and syntactic processes occur within a fraction of a second (Marslen-Wilson & Tyler, 1980)

fMRI does not follow fast-changing neurophysiological activity and cognitive processes



The Haemodynamic Response Function (HRF) acts as a low pass filter of the neurophysiological brain response

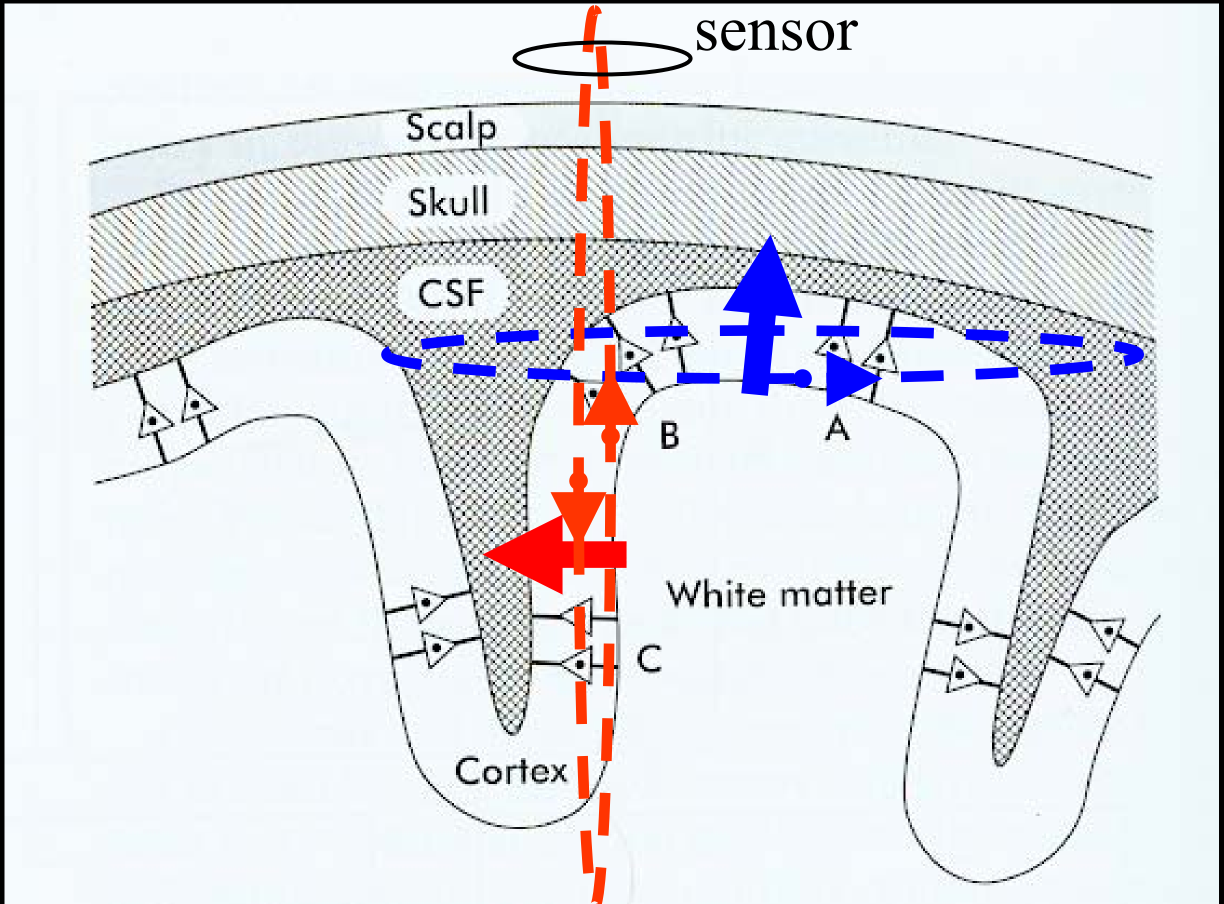
MEG and EEG can reveal the fast spreading of neural activity

They directly measure neurophysiological changes caused by post-synaptic potentials in large neuronal populations

- Electroencephalography (EEG): potential changes
- Magnetoencephalography (MEG): magnetic field changes

Example: Biophysics of the MEG

- Activity in sulci close to the scalp surface is picked up
- Activity on gyri and in deep structures can be invisible



MEG and EEG: brain imaging in time and space

- neuromagnetic changes in the brain can be tracked with millisecond precision
- to estimate the locus of cortical activation, the MEG must be recorded through numerous sensors

State-of-the-art MEG devices include up to ~300 gradio/magnetometers

306-channel MEG system
Vectorview, Elekta-Neuromag,
Helsinki, Finland

MEG/EEG: How can we localise in space?

The localisation challenge: von Helmholtz' Inverse Problem

- A surface topography can always be explained by more then one (set of) underlying source(s)

von Helmholtz H. Über einige Gesetze der Vertheilung elektrischer Ströme in körperlichen Leitern, mit Anwendung auf die thierisch-elektrischen Versuche. *Annals of Physics and Chemistry* 1853; 89: 211-233, 353-377.

Are there strategies to overcome the *Helmholtz Inverse Problem*?

MEG/EEG Source Estimates

1. Equivalent Current Dipole (ECD)
   applicable only for one main source
2. Multiple dipole solutions
   arbitrary decision on number/loci of sources
3. Minimum Norm (MN) Estimate (eg, L1/L2 norm)
   explains a topography by the source constellation with the least amount of source activity; blurring
4. Anatomically constrained MN estimate
   source space restricted to grey matter

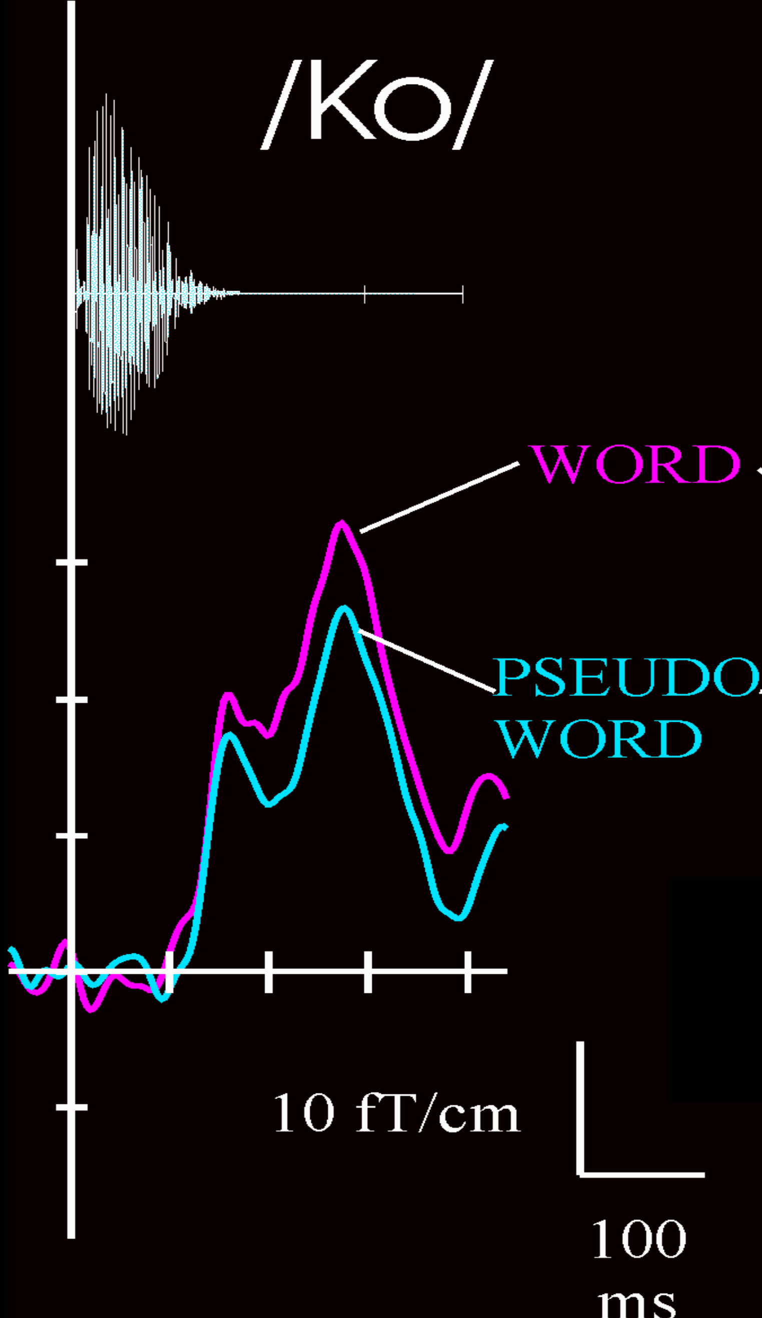
MEG/EEG: Why do we need it?

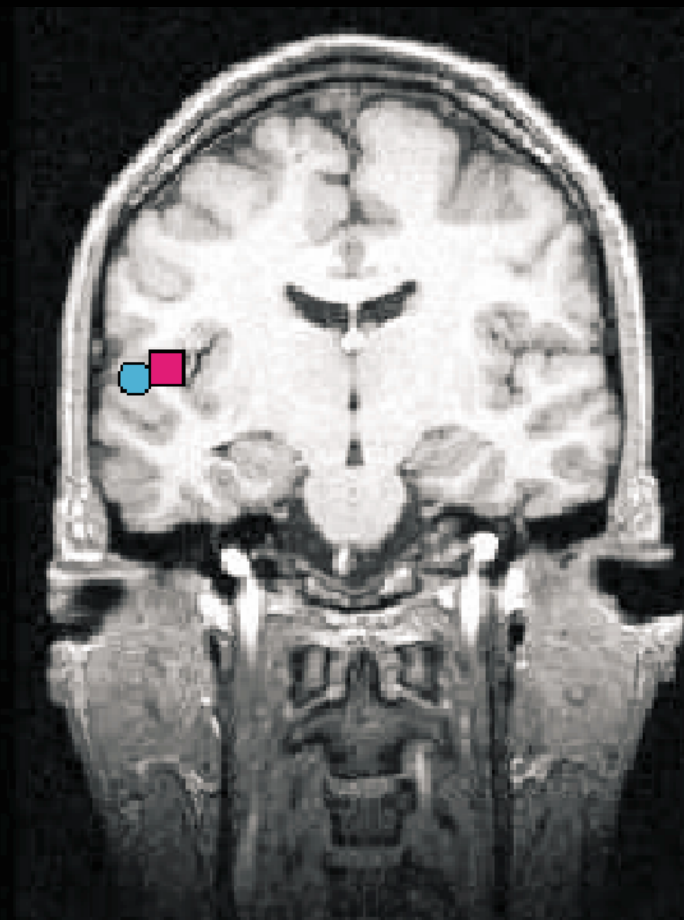
- To learn *when exactly* an event in the brain occurs (*localisation in time*; example: word recognition)
- To learn in *which sequence* cortical areas become active (*spatio-temporal dynamics*; example: Δt (ST-IF))
- To learn *how* the cortex becomes active (*functional dynamics*; example: synchroneous oscillatory dynamics in the gamma band)

Example 1: Localisation in time

- When exactly does a cognitive brain process occur?
- The case of word recognition as reflected by the Mismatch Negativity (MMN)

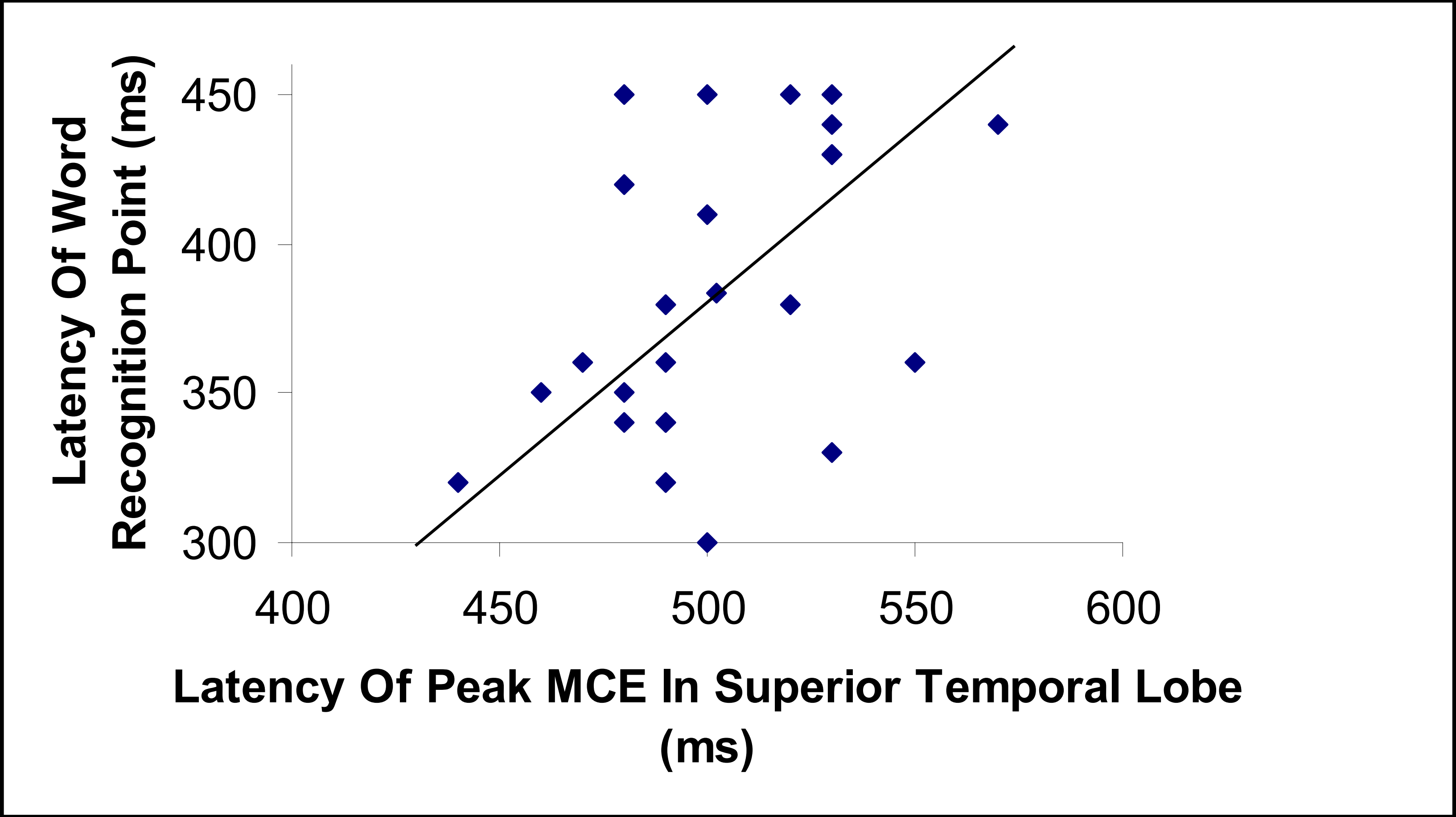
MMN enhanced in word context (MEG)





Pulvermüller, Kujala, Shtyrov, Simola, Tiitinen, Martinkauppi, Alku, Alho, Ilmoniemi, Näätänen, *Neuroimage* 2001

Word recognition point ~ peak latency of sup. temporal source

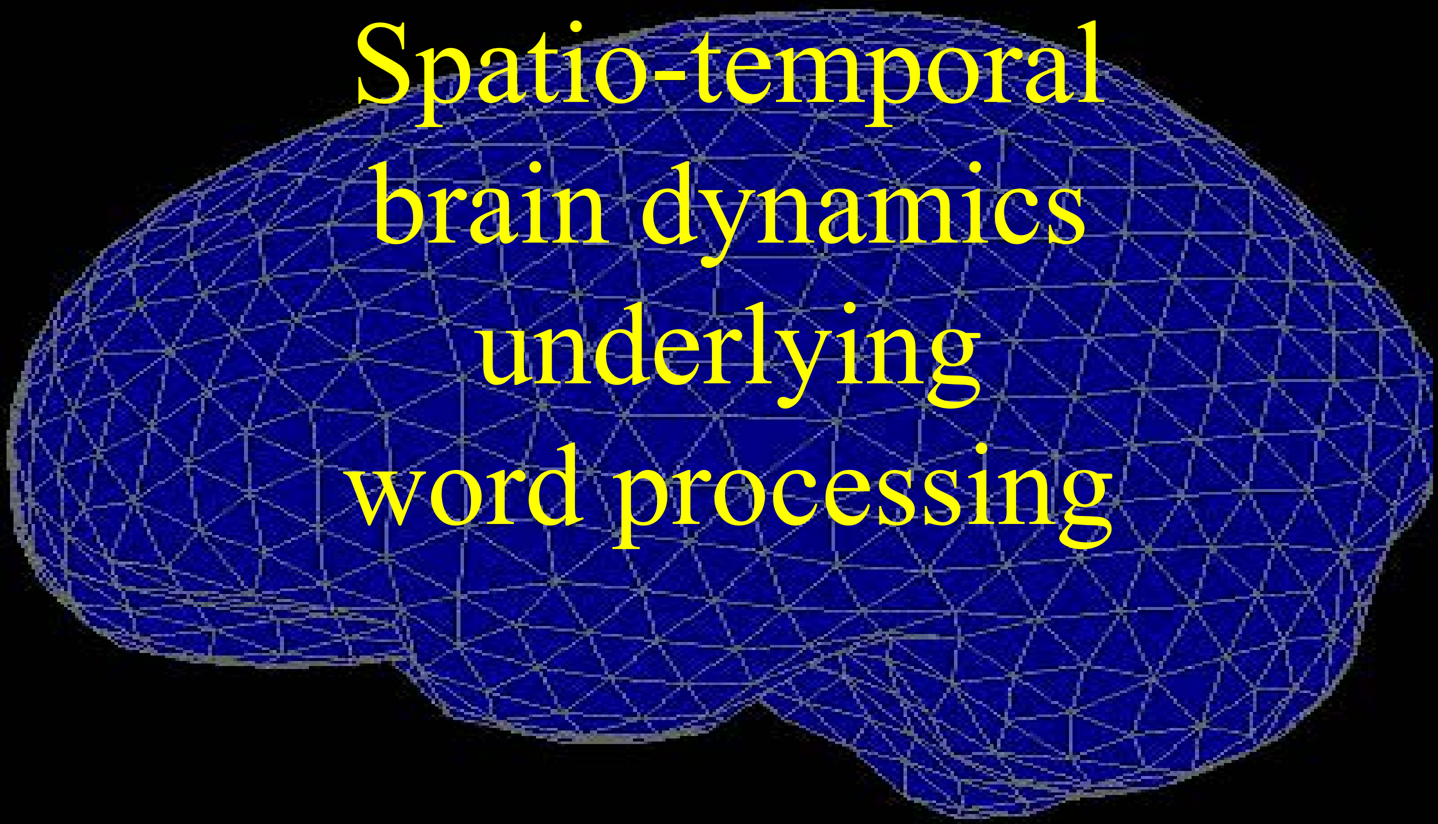


Pulvermüller, Shtyrov, Ilmoniemi & Marslen-Wilson, *in preparation*

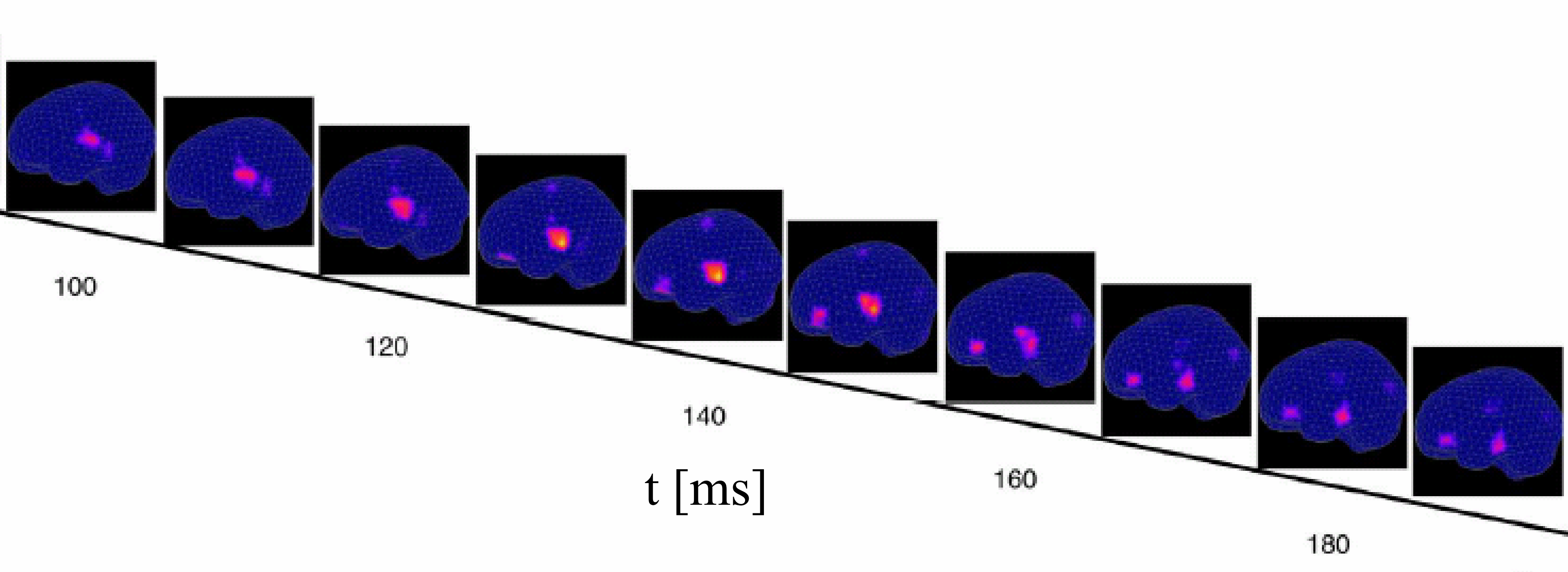
Example 2: Spatio-temporal dynamics

- In which order do cortical areas become active when a given cognitive process occurs?

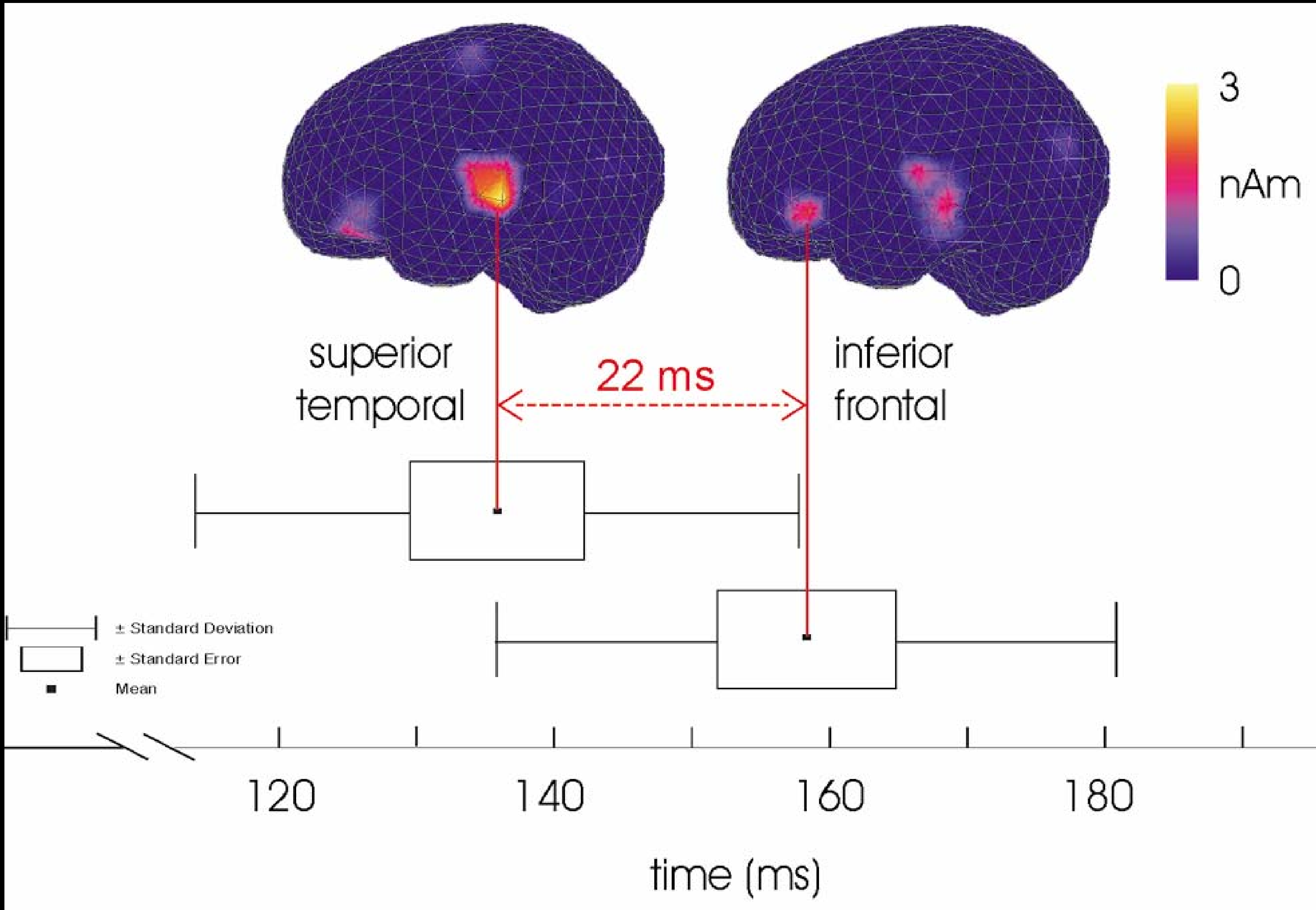
Spatio-temporal brain dynamics underlying word processing



Minimum Norm Estimates of cortical sources activated by words

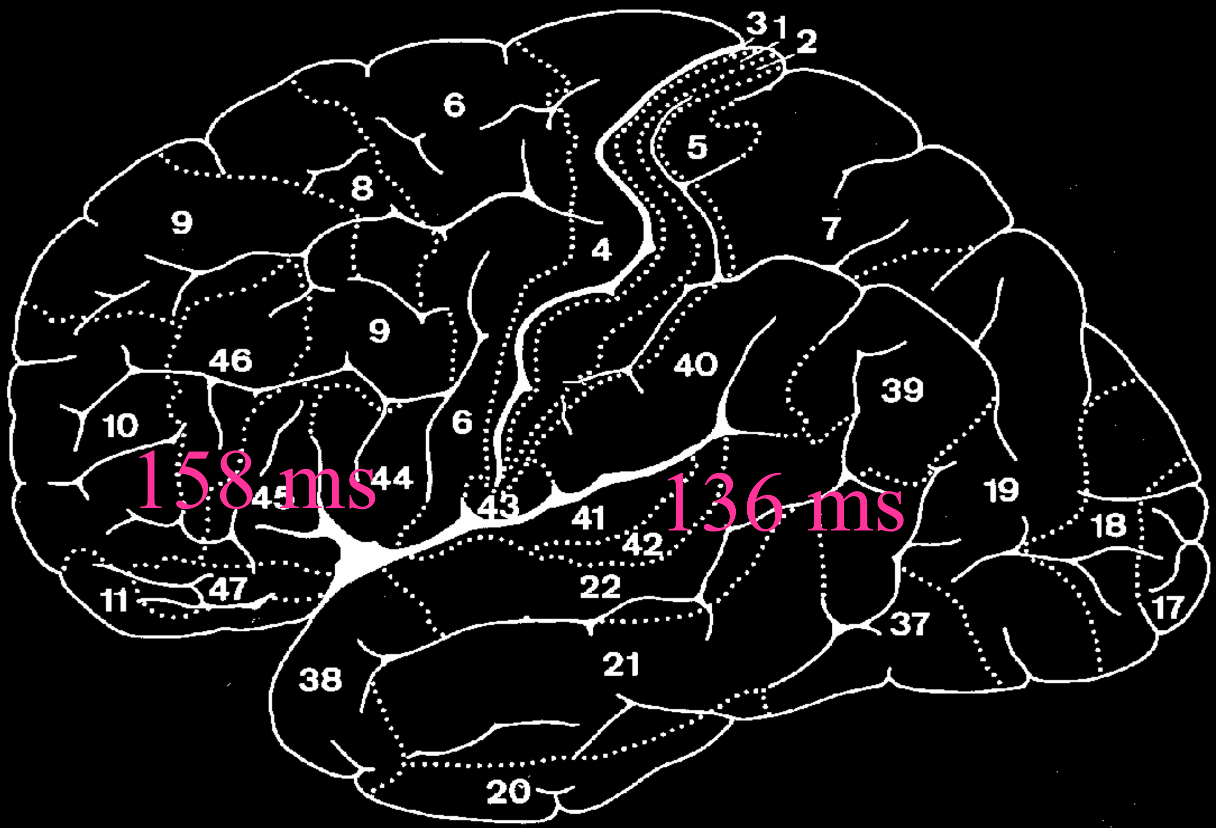


Pulvermüller, Shtyrov & Ilmoniemi, *Neuroimage 2003*



Pulvermüller, Shtyrov & Ilmoniemi, *Neuroimage 2003*

When hearing words, area *A* becomes active at time *t*

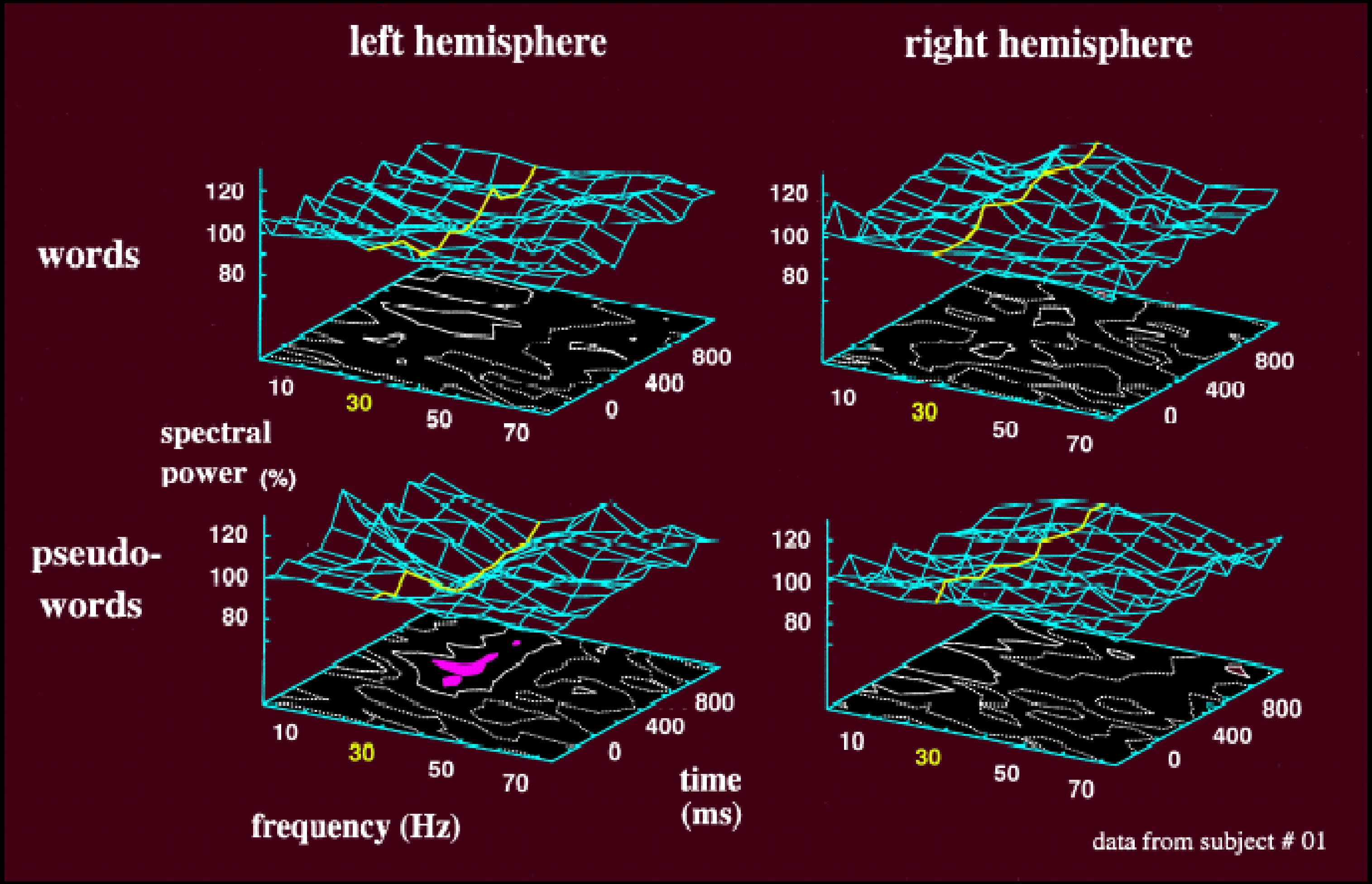


Pulvermüller, Shtyrov & Ilmoniemi, *Neuroimage 2003*

Example 3: Fast functional dynamics

- In which way do cortical networks become active when a given cognitive process occurs?
- The case of synchronous neural oscillations in the gamma band (> 20 Hz) as a basis of word processing

Gamma band activity elicited by words and pseudowords



Pulvermüller et al., *Psycoloquy* 1994; *Neuroreport* 1995;
Electroencephalogr. Clin. Neurophysiol. 1996; *Prog. Neurobiol.* 1997

MEG/EEG: strengths and limitations

- track neurophysiological activity
- imaging in both time (millisecond precision) and space (centimetre accuracy)
- limited spatial conclusions

Integration of fMRI and MEG/EEG results

Strategy 1:

Using fMRI hotspots to restrict source solutions

e.g., Ahlfors et al., *J Neurophysiol* 1999

Strategy 2:

Building a neural network model and fit it to both fMRI and MEG/EEG results

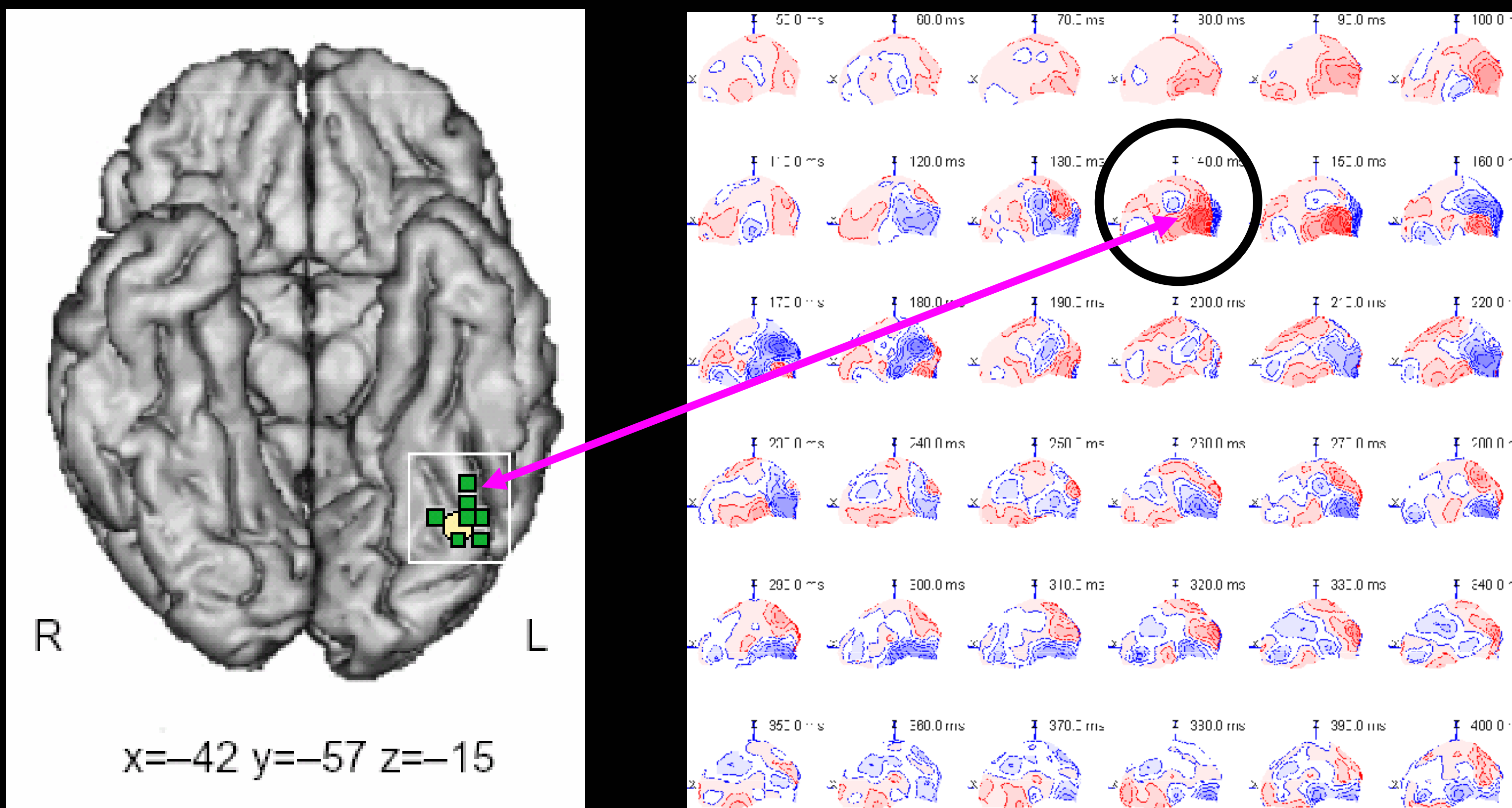
Arbib et al., *Hum Brain Mapp* 1995
Horwitz et al., *Hum Brain Mapp* 1999, 2002, *Neural Networks* 2000

Integration of fMRI and MEG/EEG results

Strategy 3:

Correlating MEG/EEG sources with fMRI localisation

Spatio-temporal dynamics: word reading



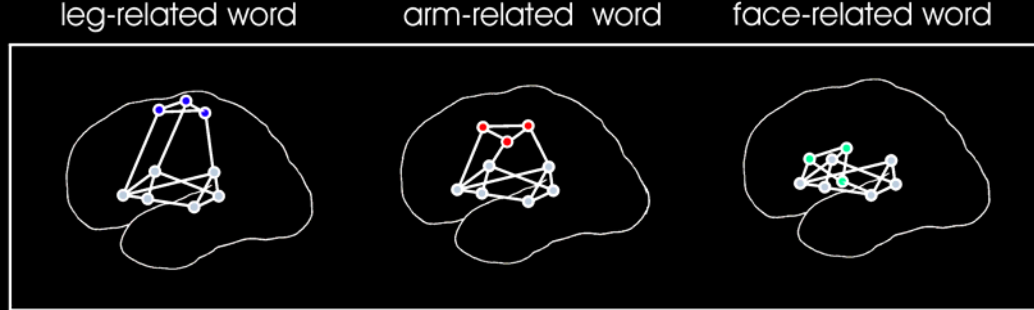
McCandliss, Cohen & Dehaene, *Trends Cognit Sci* 2003; Hauk, Pulvermüller et al., in prep.

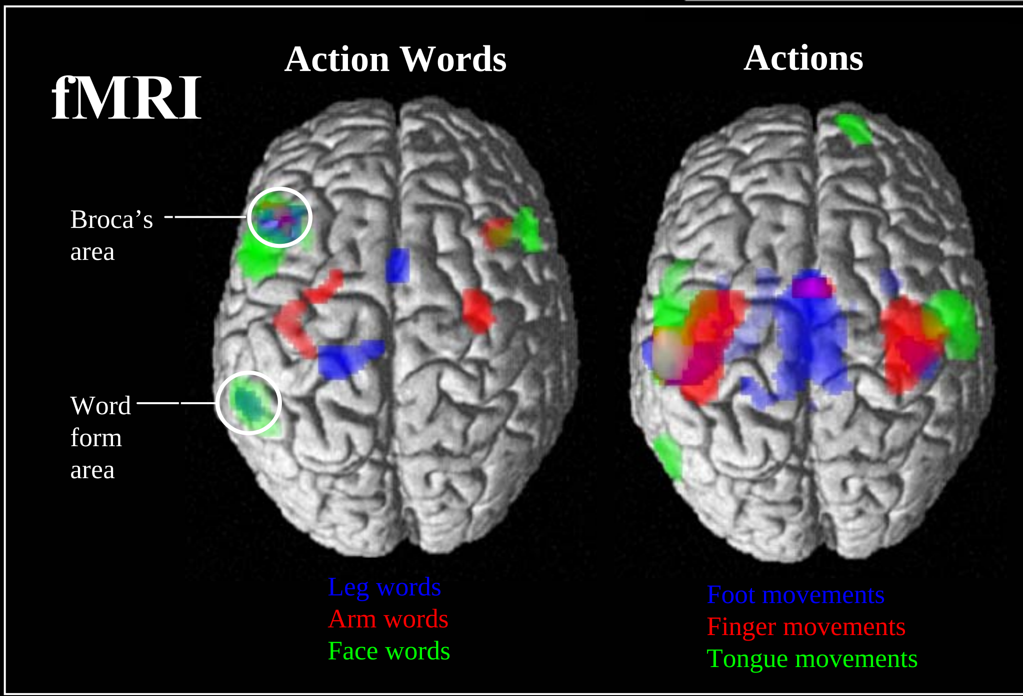
Integration of fMRI and MEG/EEG results

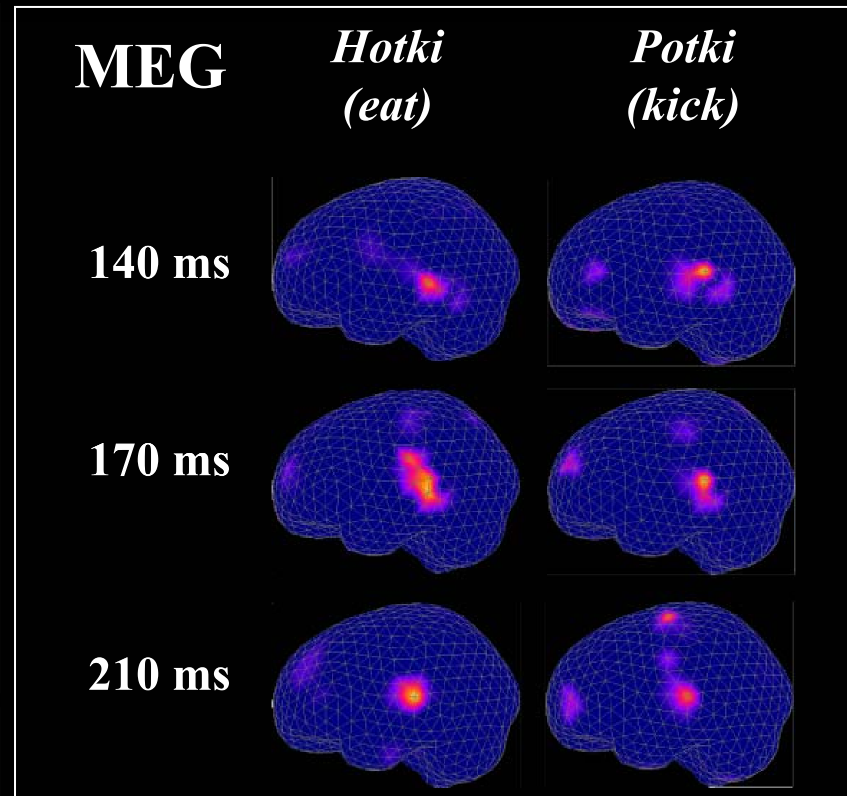
Strategy 4:

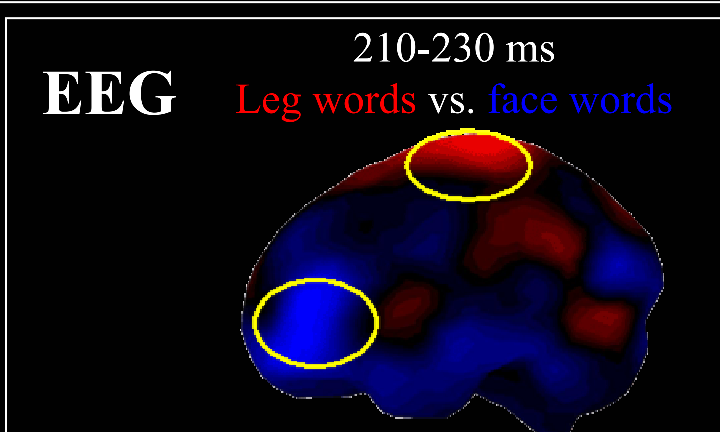
Comparing MEG/EEG source estimates with fMRI localisation

Action word processing









Hauk & Pulvermüller, *Hum Brain Mapp* 2004
Hauk, Johnsrude & Pulvermüller, *Neuron* 2004
Shtyrov, Hauk & Pulvermüller, *Eur J Neurosci*
Pulvermüller, Shtyrov & Ilmoniemi, submitted

Conclusion

MEG/EEG and fMRI investigations are important for studying the spatio-temporal brain dynamics related to language processes

Why do we need MEG/EEG in the investigation of cognitive processes?

- *to precisely localise cognitive processes in time*
- *to determine spatio-temporal dynamics of brain activity*
- *to study functional dynamics*

Thanks to:

Dr. Yury Shtyrov

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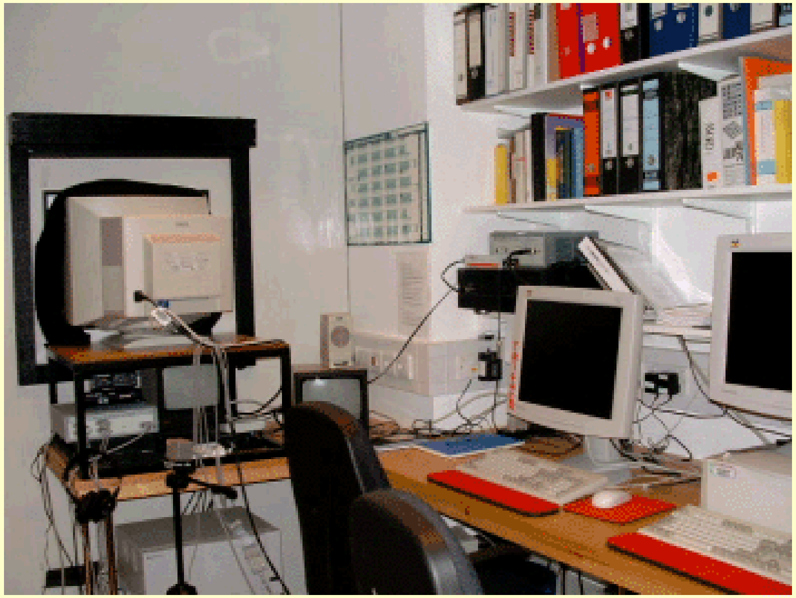

Thanks to:

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