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
# Neuroimaging methods

<table>
<thead>
<tr>
<th>Type</th>
<th>hemodynamic</th>
<th>neurophysiological</th>
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</thead>
<tbody>
<tr>
<td>Name</td>
<td>fMRI, PET</td>
<td>MEG, EEG</td>
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<tr>
<td>reflects</td>
<td>metabolites in the blood</td>
<td>activity of nerve cells</td>
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<tr>
<td>precision</td>
<td>millimetres</td>
<td>centimetres</td>
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<tr>
<td>in space</td>
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<td>in time</td>
<td>milliseconds</td>
<td>milliseconds</td>
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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 than one (set of) underlying source(s)

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: $\Delta t$ (ST-IF))
- To learn *how* the cortex becomes active (*functional dynamics*; example: synchronoeous 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
\sim 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
superior temporal \[\rightarrow 22 \text{ ms} \leftarrow\] inferior frontal

Pulvermüller, Shtyrov & Ilmoniemi, *Neuroimage* 2003
When hearing words, area $A$ becomes active at time $t$
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

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
Integration of fMRI and MEG/EEG results

Strategy 3:
Correlating MEG/EEG sources with fMRI localisation
Spatio-temporal dynamics: word reading

Integration of fMRI and MEG/EEG results

Strategy 4:
Comparing MEG/EEG source estimates with fMRI localisation
Action word processing

fMRI

Action Words
Leg words
Arm words
Face words

Actions
Foot movements
Finger movements
Tongue movements

MEG
Hotki (eat)
Potki (kick)

140 ms
170 ms
210 ms

EEG
210-230 ms
Leg words vs. face words

Hauk & Pulvermüller, *Hum Brain Mapp* 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
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