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Using MEG to study large-scale functional networks underlying language processing

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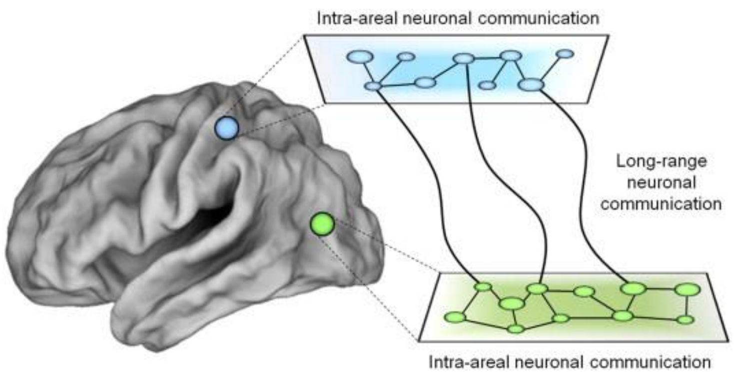
How does functional connectivity within the language network change during preparation for speech in a picture naming paradigm?

Do the various spectral components contribute differently to the network dynamics?

Task-related connectivity in MEG and fMRI – can we identify a shared cortical network?

Large-scale networks in the brain are thought to underlie cognition and behavior.

To support behavior, large-scale networks should be transiently formed and **reformed in a task-relevant manner** (e.g. by attention: Fries, 2005; Bastos et al., 2015).



Modified from Varela, 2001

Coherence among oscillating neuronal groups produces temporal windows of efficient communication (Fries, 2005).

Allows **flexibility in routing information**: an area can show distinct connectivity during different tasks despite the constancy of its anatomical wiring.

Coherence used as an index of functional connectivity.

Large-scale connectivity modulations in the language network: some challenges

We would like to:

- identify the entire network involved in the task (all-to-all connectivity)
- capture dynamic changes in connectivity (temporal resolution of MEG)

Things to consider:

- Field spread
- Power differences between conditions
- Speech causes muscle artefacts
- What's the statistical threshold: control condition
- Multiple comparisons

Liljeström et al., *Hum Brain Mapp* 2015

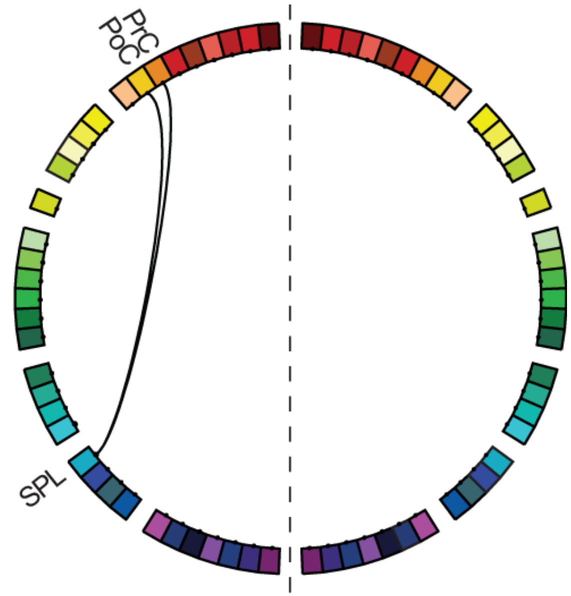
Functional networks were identified with whole-cortex mapping of coherence

Time-resolved networks: We used an event-related spatial filter (erDICS, Laaksonen et al. *NeuroImage* 2008).

All-to-all connectivity: Estimates computed for each cortical grid point (7-mm spacing) with all other grid points.

To address field spread:
Power-matched frequency bands: in the theta, alpha, beta and gamma range.
Long-range connectivity (minimum distance 4 cm).

Visualization: MEG connectogram



Liljeström et al., *Hum Brain Mapp* 2015; *Neuroimage* 2015

Picture naming involves all main stages of speech production

Conceptualization — Determining what to say.

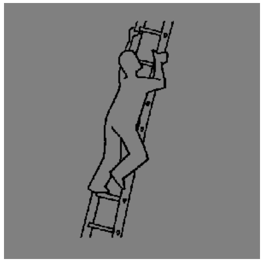
Formulation — Creating the linguistic form for that concept.

Execution — Motor coordination for articulation

- Object recognition
- Selecting a lexical item
- Phonological encoding
- Phonetic encoding
- Articulation

Levelt et al., 1999, 2001; Harley, 2001

Large-scale network modulations underlying preparation for motor speech



Overt vs. silent naming

Time-resolved networks:
Functional connectivity was calculated for two time windows preceding naming (0-300 ms and 300-600ms after picture onset).

Task-relevant interactions:
Modulations in connectivity determined by contrasting coherence results for overt and silent naming ($p<0.05$, FWE corrected)

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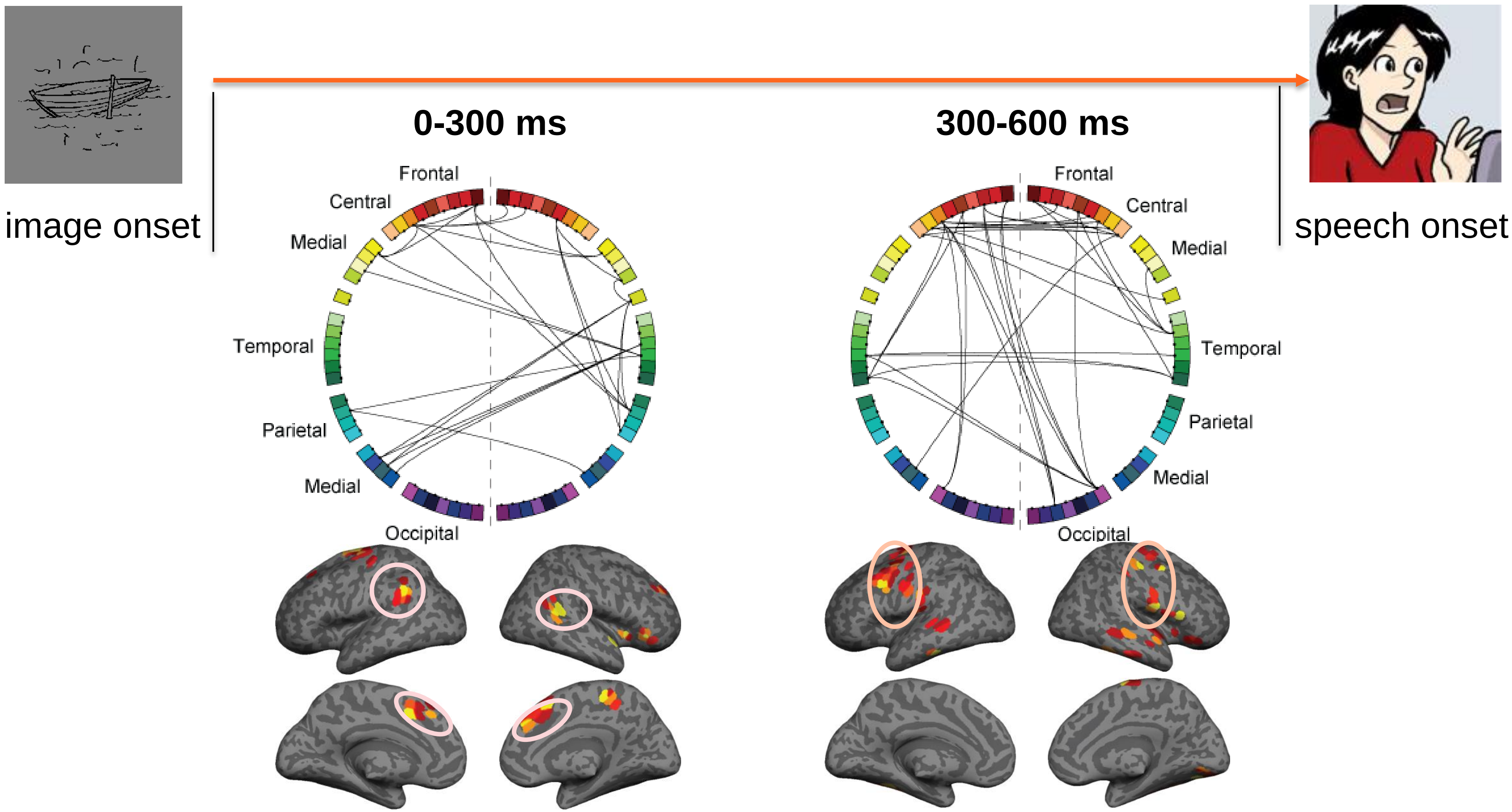
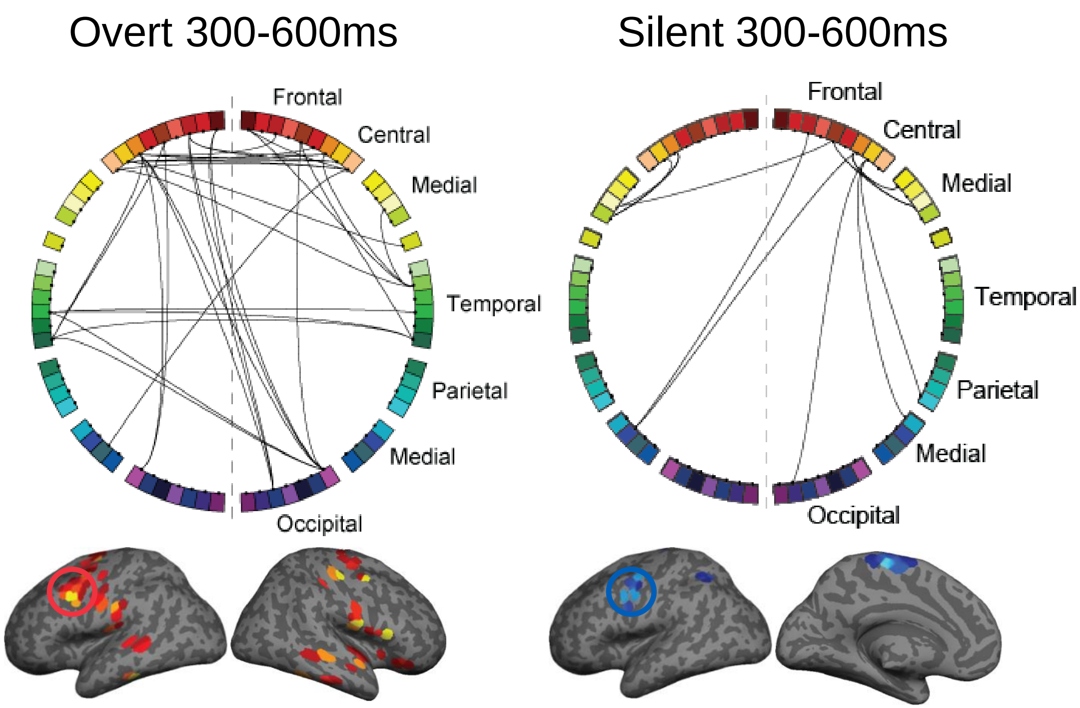
Liljeström et al., *Hum Brain Mapp* 2015

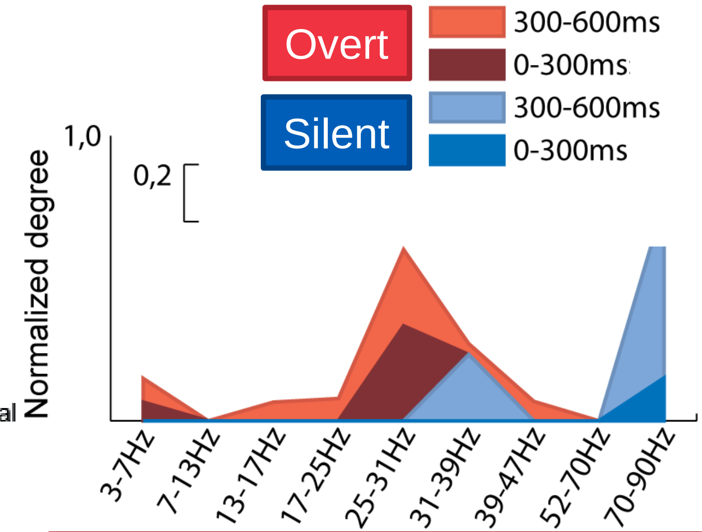
Enhanced connectivity strength during preparation for overt speech



Liljeström et al., *Hum Brain Mapp* 2015

Functional differentiation between beta and gamma long-range connectivity





Overt speech:
coherence in the beta band

Silent speech:
coherence in the gamma band

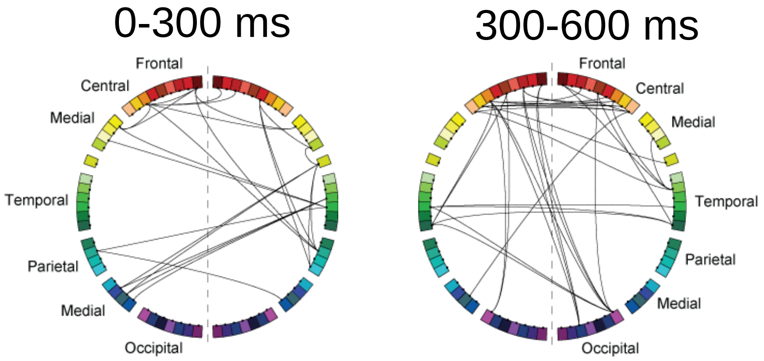
Ventral motor cortex involvement in both frequency bands.

Liljeström et al., *Hum Brain Mapp* 2015

Reconfiguration of the language network during motor preparation for speech

We demonstrated **a transient reorganization** of the large-scale functional networks that support language and speech.

Such changes can take place at time scales of **a few hundred milliseconds.**

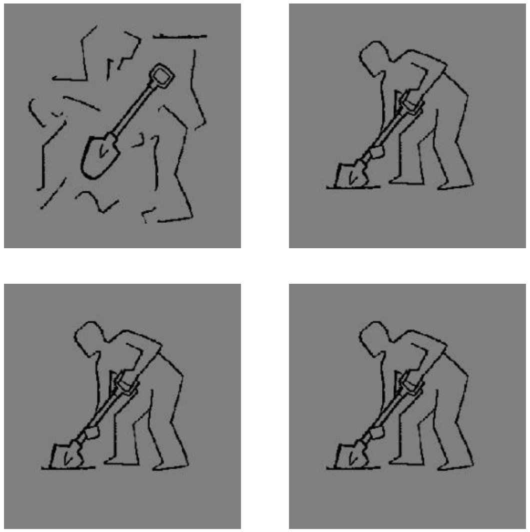


Frequency-specific interactions can carry information on functionally distinct network modules.

The dynamic nature of global functional networks can be **taken into account** when assessing task-relevant brain networks.

Liljeström et al., *Hum Brain Mapp* 2015

Task-related connectivity in MEG and fMRI – can we identify a similar cortical network?



Different visual stimuli
(action vs. object image),
same task (name the noun).

Different naming task
(verb vs. noun),
same stimuli.

Functional connectivity estimated using coherence for both
MEG (50-800ms) and fMRI.

Task-relevant interactions:
Modulations in connectivity determined by contrasting coherence results from the different categories.

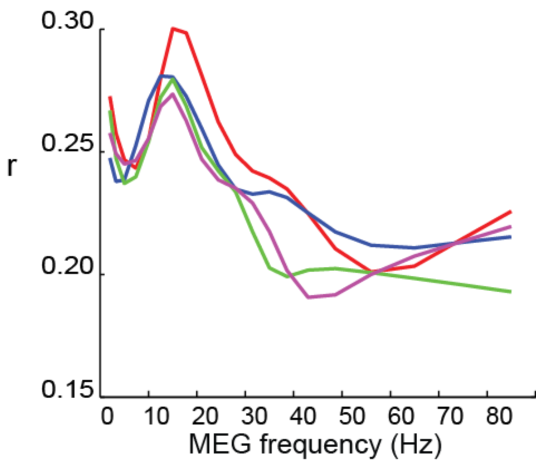
Liljeström, Stevenson et al., *NeuroImage* 2015

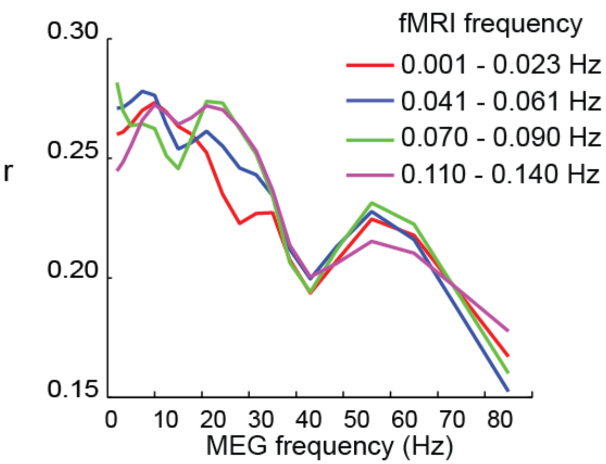
Greatest similarity between MEG- and fMRI-derived networks at frequencies below 30 Hz

- Consistent with resting-state studies: Brookes et al., 2011a,b; de Pasquale et al., 2012;Hipp et al., 2012; Hipp and Siegel, 2015.
- Our results further suggest that gamma frequency band interactions contribute to the haemodynamic networks.

Different naming task (verb vs. noun)

Different image (action vs object)





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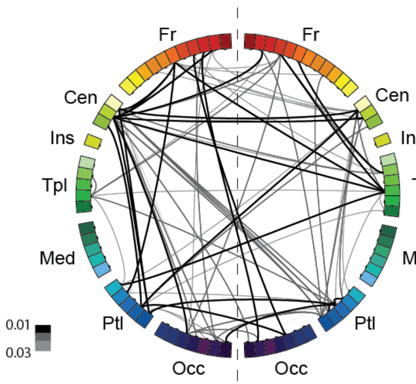
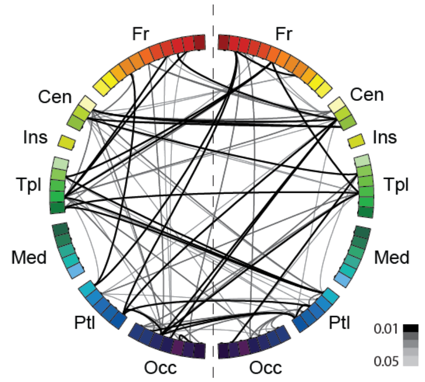
Liljeström, Stevenson et al., *NeuroImage* 2015

Comparison of networks

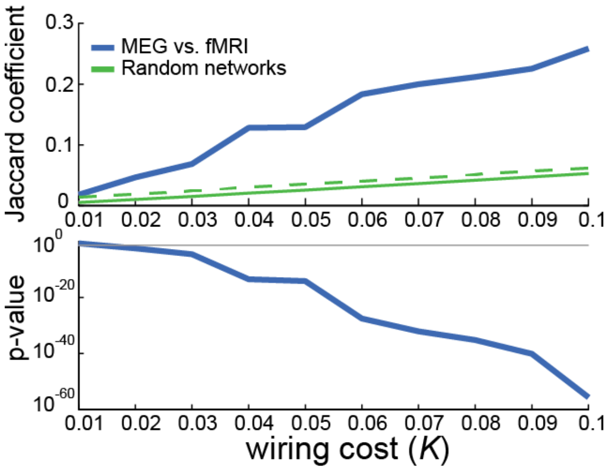


fMRI average network



MEG average network

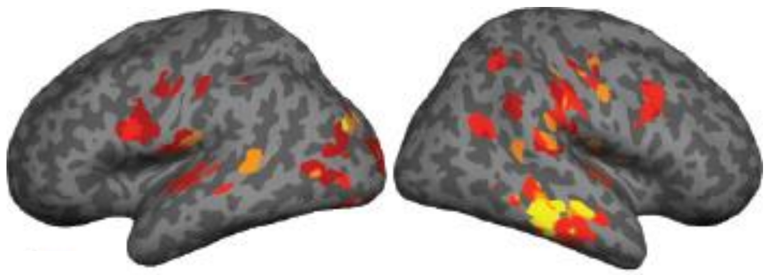
Different visual stimuli



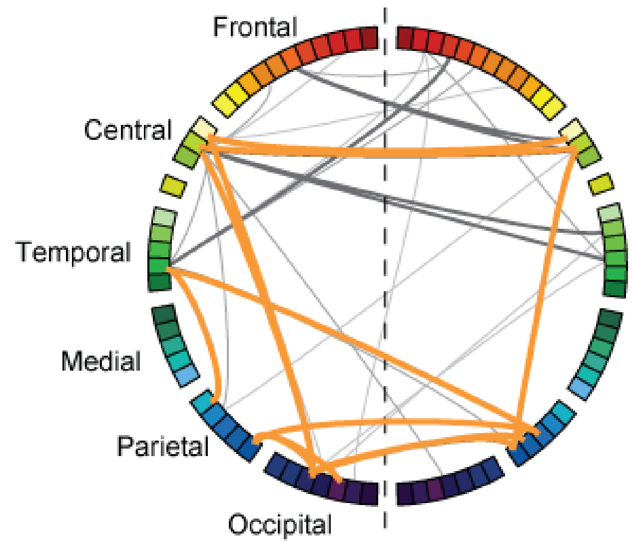
Wiring cost *K* = number of edges/all possible edges
Jaccard coefficient = overlapping edges/union of edges

Liljeström, Stevenson et al., *NeuroImage* 2015

Stimulus-related modulations: overlap between MEG and fMRI



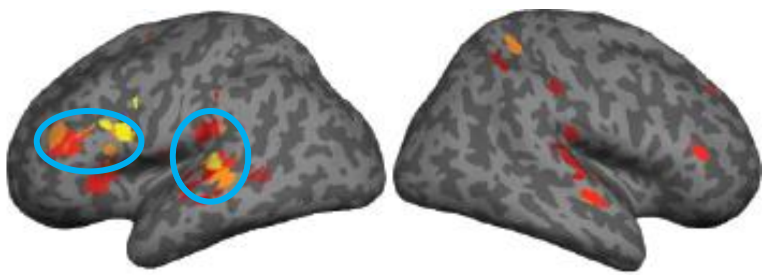
Different image (action vs object)

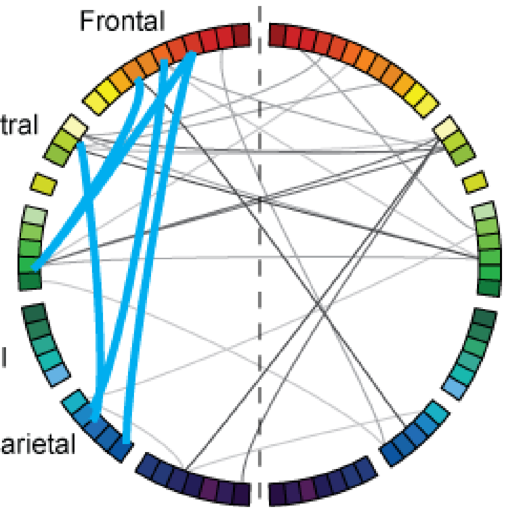


Common network hubs were seen in cortical regions previously associated with visual processing, object recognition, and action image processing.

Liljeström, Stevenson et al., *NeuroImage* 2015

Task-related modulations: overlap between MEG and fMRI





Different naming task (verb vs. noun)

The directly shared cortico-cortical connections between the left temporal and left inferior frontal cortex agree with the known structural connections between these regions

Liljeström, Stevenson et al., *NeuroImage* 2015

The relationship between MEG and fMRI networks: A summary

Overlapping task networks in MEG and fMRI.

Greatest similarity between MEG- and fMRI- derived networks observed at frequencies below 30 Hz.

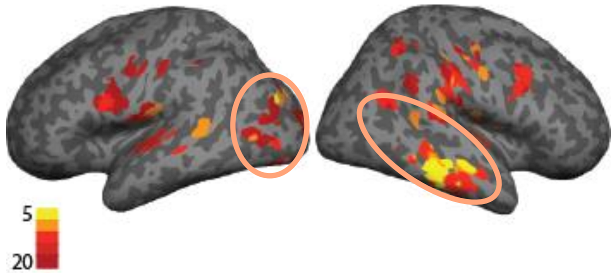
The spatial distribution of task-relevant network hubs identified using different task-manipulations differed widely, revealing a **reorganization of functional connectivity during task performance**.

Reorganization of large-scale functional connectivity during picture naming

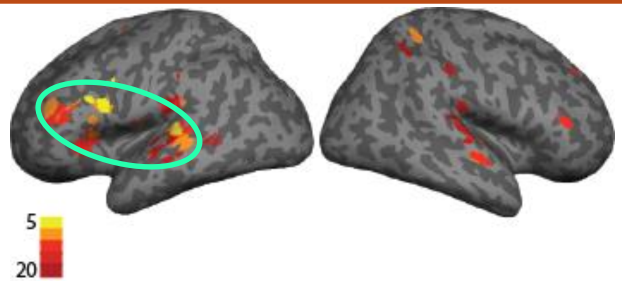
Conceptualization

Formulation

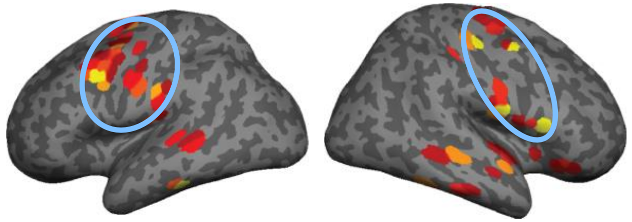
Execution



Different image (action vs object)



Different naming task (verb vs. noun)



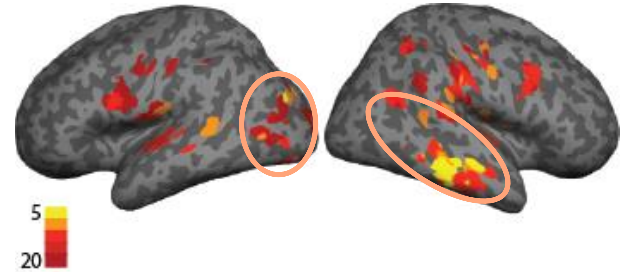
Overt vs silent naming

Liljeström et al., *Hum Brain Mapp* 2015
Liljeström, Stevenson et al., *NeuroImage* 2015

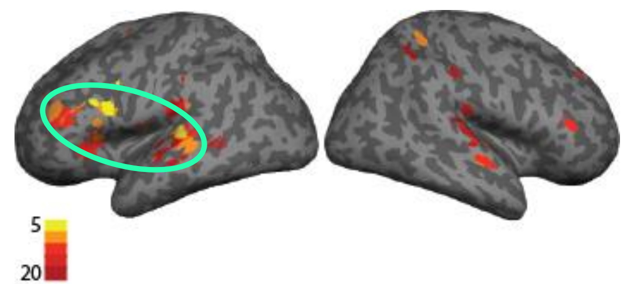
Future directions

Mapping the language network:
By introducing a battery of (properly power-matched) control conditions we may be able to identify several subnetworks inolved in visual object recognition, lexical-semantic processing, and motor speech output.

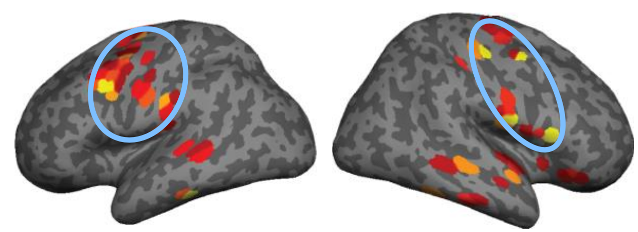
Network reorganization:
How do networks change as a function of e.g. disease, learning or aging?



Different image (action vs object)



Different naming task (verb vs. noun)



Overt vs silent naming

Liljeström et al., *Hum Brain Mapp* 2015
Liljeström, Stevenson et al., *NeuroImage* 2015

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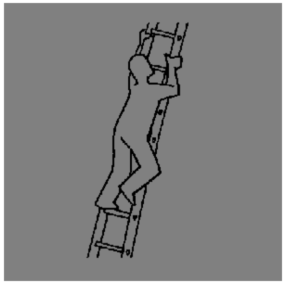
Thank you!

Co-authors:
Jan Kujala
Claire Stevenson
Riitta Salmelin

fMRI connectivity estimated using coherence



We used power-matched frequency bands to avoid spurious coherence modulations. Data from five additional subjects were used to determine frequency bands of interest in fMRI.

Average nodal timecourses were extracted, segmented by task, mean centered, windowed (tapered cosine) and concatenated into blocks of individual task conditions (Sun, et al., 2004).

In a global search, coherence estimates were computed for each cortical node with all other nodes in frequency bands of interest.

Task-relevant interactions:
Modulations in connectivity determined by contrasting coherence results from the different categories.

Liljeström, Stevenson et al., *NeuroImage* 2015