Model-based analysis of whole-brain dynamics from fMRI: Applications to human cognition and neuropathologies

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Outline

Background

- Model-based analysis of fMRI: effective connectivity (EC)
 - marker of brain dynamics
 - combining anatomical and functional MRI data
 - interpretable markers
 - disentangling sources of variability
- Next steps
 - multimodal classification pipeline
 - representational learning

Activation maps versus connectivity approach



Criaud et al (2017) Behav Brain Res

Ongoing activity Functional connectivity (FC) brain region brain region

MarsAtlas, Auzias, Brovelli, et al.

Statistical analysis versus predictive statistics

Proxy for neuronal activity



Statistical analysis versus predictive statistics

Proxy for neuronal activity



Statistical analysis versus predictive statistics



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Prediction pipeline for cognition and neuropathology



Gilson, ..., Deco (2016) PLoS Comput Biol; Gilson et al. (2020) Net Neurosci

Anatomo-functional modeling



Gilson, ..., Deco (2016) PLoS Comput Biol; Gilson et al. (2020) Net Neurosci

Anatomo-functional modeling













Effective Connectivity (EC)



- Captures brain dynamical state (condition-specific)
- Modulation of directional anatomical connections
- Reflects synaptic strength + local excitability + neuromodulation + ...



Comparison with Dynamic Causal Model (DCM)



Comparison with The Virtual Brain (TVB)



Comparison with The Virtual Brain (TVB)



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Application to stroke patients



- fMRI scan + cognitive tests: memory, motor task, ...
- individual fit: 132 patients, 25 controls
- 300 ROIs, ~4000 EC/FC links as features
- 80%-20% train-test (stratified split)
- classifier: logistic regression

Classification patients versus healthy controls



chance level (shuffling surrogates)

Classification patients versus healthy controls



Informative EC links as cortico-cortical alterations



- EC: modulations in anatomical connections
- FC: change in correlated activity
- Many inter-hemispheric links/connections !

Prognosis of behavioral deficits



Prognosis of behavioral deficits



Interpretation in terms of cortico-cortical reconfiguration

Informative EC links



Interpretation in terms of cortico-cortical reconfiguration



Interpretation in terms of cortico-cortical reconfiguration



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Sources of variability: across sessions, conditions (tasks), subjects, ...

Similarity across resting-state sessions





Capture desired heterogeneity while discarding "noise"

- Signature for conditions
- Generalize across subjects
- Ignore session-to-session variability



Capture desired heterogeneity while discarding "noise"

- Signature for conditions
- Generalize across subjects
- Ignore session-to-session variability



"Orthogonality" of signatures



Pallarés, ..., Gilson (2018) Neuroimage

Strong bias by individuality



ARCHI social, Thirion et al (NeuroVault)

Strong bias by individuality



ARCHI social, Thirion et al (NeuroVault)

Take-home messages from past work

- Anatomo-functional model: balance between predictability and interpretability
 - EC provides robust subject- and task-specific signature
 - informative EC connections correspond to (putative) anatomical connections
- Difficult to generalize across subjects in complex task/condition environment
- Spatio-temporal structure of fMRI signals matters
- Does EC reflect propagation of neuronal activity? Proxy for information processing?

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Ongoing projects: BraINT + NEMO; sodium MRI





Function



- A Lefrère
- G Auzias
- R Belzeaux
- C Deruelle
- M Szinte
- J-L Anton
- J Sein
- **B** Nazarian
- G Masson

Ongoing projects: BraINT + NEMO; sodium MRI

100

120 140

160



A Lefrère

G Auzias

R Belzeaux

C Deruelle

M Szinte

J-L Anton

J Sein

B Nazarian

G Masson



EC

Function

Sodium maps



W Zaaraoui A-M Grapperon

Ongoing projects: BraINT + NEMO; sodium MRI



Classification pipeline



UMR 7020 📕





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- Small data: NEMO (patients)
- BraINT (ctrl)
- "Big" data: Human Connectome Project (ctrl)





- Small data: NEMO (patients)
- BraINT (ctrl)
- "Big" data: Human Connectome Project (ctrl)

Thank you!



