DCM for fNIRS: Theory and Practice

Methods for Dummies 2021/22

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Thanks: Magda Dubois & Jolanda Malamud
Slides adapted in part from MfD 2004

Overview

1. Effective Connectivity
2. DCM overview
3. Bilinear model
4. Hemodynamic model
5. Model comparison
6. DCM for fNIRS
7. Motor Imagery example

Effective Connectivity

- Recalling PPI, EC models changes in coupling between regions
- In DCM inputs are deterministic as opposed to stochastic
- Plausible nonlinear, dynamic generative model of brain responses

DCM differs from previous approaches to modelling brain responses, using a dynamical, nonlinear approach and deterministic inputs

DCM overview

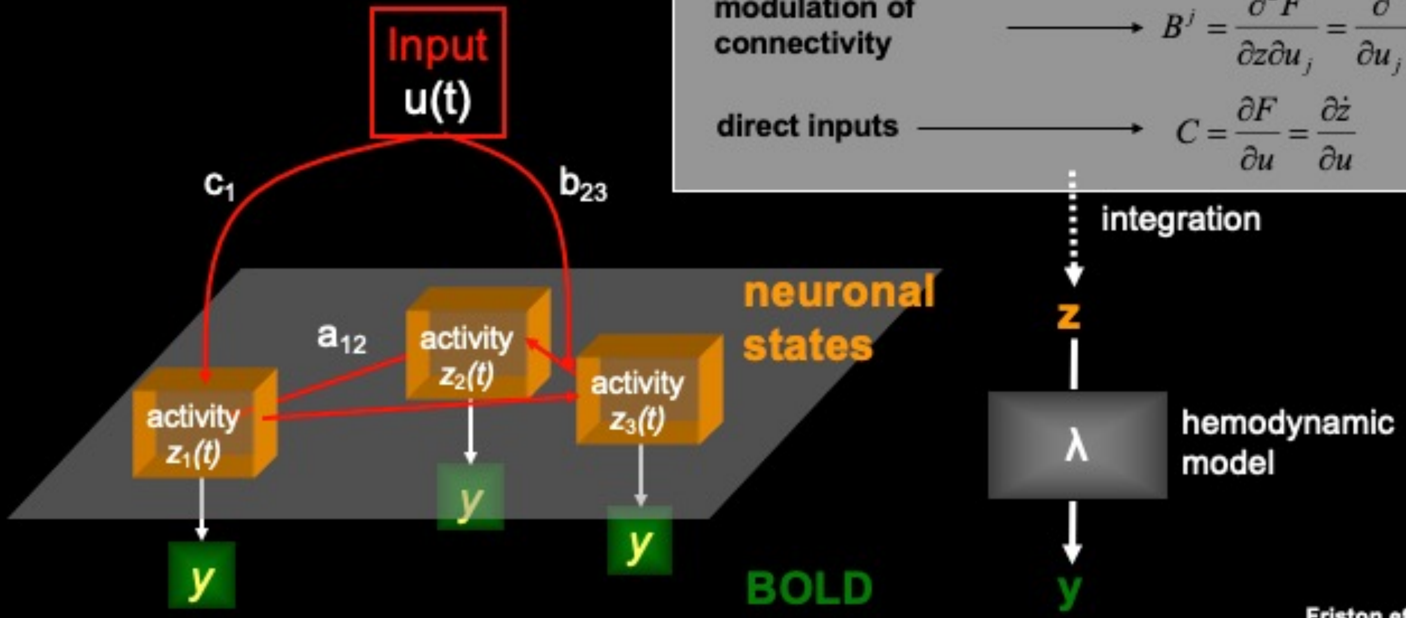
Neural state equation $\dot{z} = F(z, u, \theta^n)$

The bilinear model $\dot{z} = (A + \sum u_j B^j) z + Cu$

effective connectivity $\longrightarrow$ $A = \frac{\partial F}{\partial z} = \frac{\partial \dot{z}}{\partial z}$

modulation of connectivity $\longrightarrow$ $B^j = \frac{\partial^2 F}{\partial z \partial u_j} = \frac{\partial}{\partial u_j} \frac{\partial \dot{z}}{\partial z}$

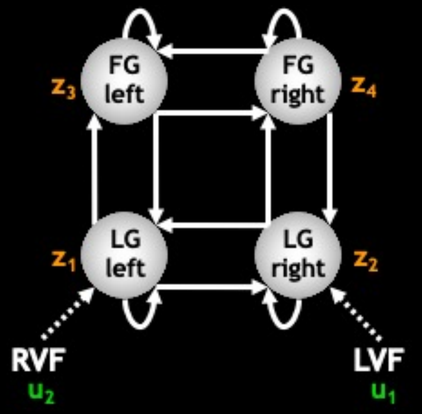
direct inputs $\longrightarrow$ $C = \frac{\partial F}{\partial u} = \frac{\partial \dot{z}}{\partial u}$



Friston et al. 2003, *NeuroImage*

Neuronal states are modelled separately for each region of interest, their connectivity matrix is acted upon directly and indirectly

Bilinear model



LG = lingual gyrus
FG = fusiform gyrus

Visual input in the
- left (LVF)
- right (RVF)

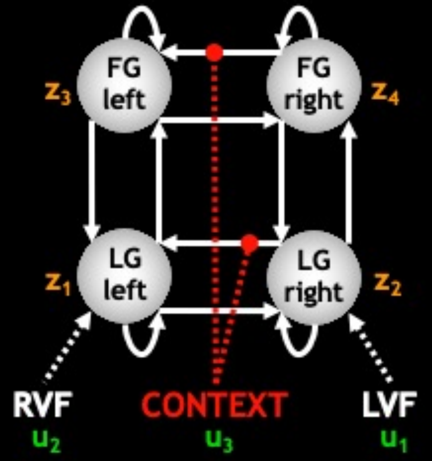
visual field.

$$\boxed{\dot{z} = Az + Cu}$$

$$\theta = \{A, C\}$$

state changes · effective connectivity · system state · input parameters · external inputs

$$\begin{bmatrix} \dot{z}_1 \\ \dot{z}_2 \\ \dot{z}_3 \\ \dot{z}_4 \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & 0 \\ a_{21} & a_{22} & 0 & a_{24} \\ a_{31} & 0 & a_{33} & a_{34} \\ 0 & a_{42} & a_{43} & a_{44} \end{bmatrix} \begin{bmatrix} z_1 \\ z_2 \\ z_3 \\ z_4 \end{bmatrix} + \begin{bmatrix} 0 & c_{12} \\ c_{21} & 0 \\ 0 & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \end{bmatrix}$$



$$\begin{bmatrix} \dot{z}_1 \\ \dot{z}_2 \\ \dot{z}_3 \\ \dot{z}_4 \end{bmatrix} = \left\{ \begin{bmatrix} a_{11} & a_{12} & a_{13} & 0 \\ a_{21} & a_{22} & 0 & a_{24} \\ a_{31} & 0 & a_{33} & a_{34} \\ 0 & a_{42} & a_{43} & a_{44} \end{bmatrix} + u_3 \begin{bmatrix} 0 & b_{12}^{3} & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & b_{34}^{3} \\ 0 & 0 & 0 & 0 \end{bmatrix} \right\} \begin{bmatrix} z_1 \\ z_2 \\ z_3 \\ z_4 \end{bmatrix} + \begin{bmatrix} 0 & c_{12} & 0 \\ c_{21} & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \\ u_3 \end{bmatrix}$$

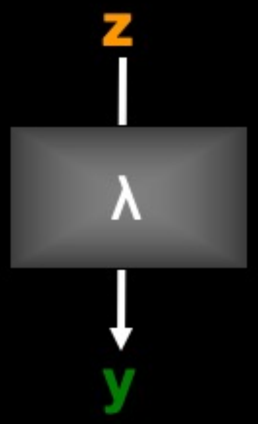
Inclusion of inputs effecting modulation between regions transforms a linear dynamical system into a bilinear model

Bilinear model

state changes | intrinsic connectivity | modulation of connectivity | system state | direct inputs | m external inputs

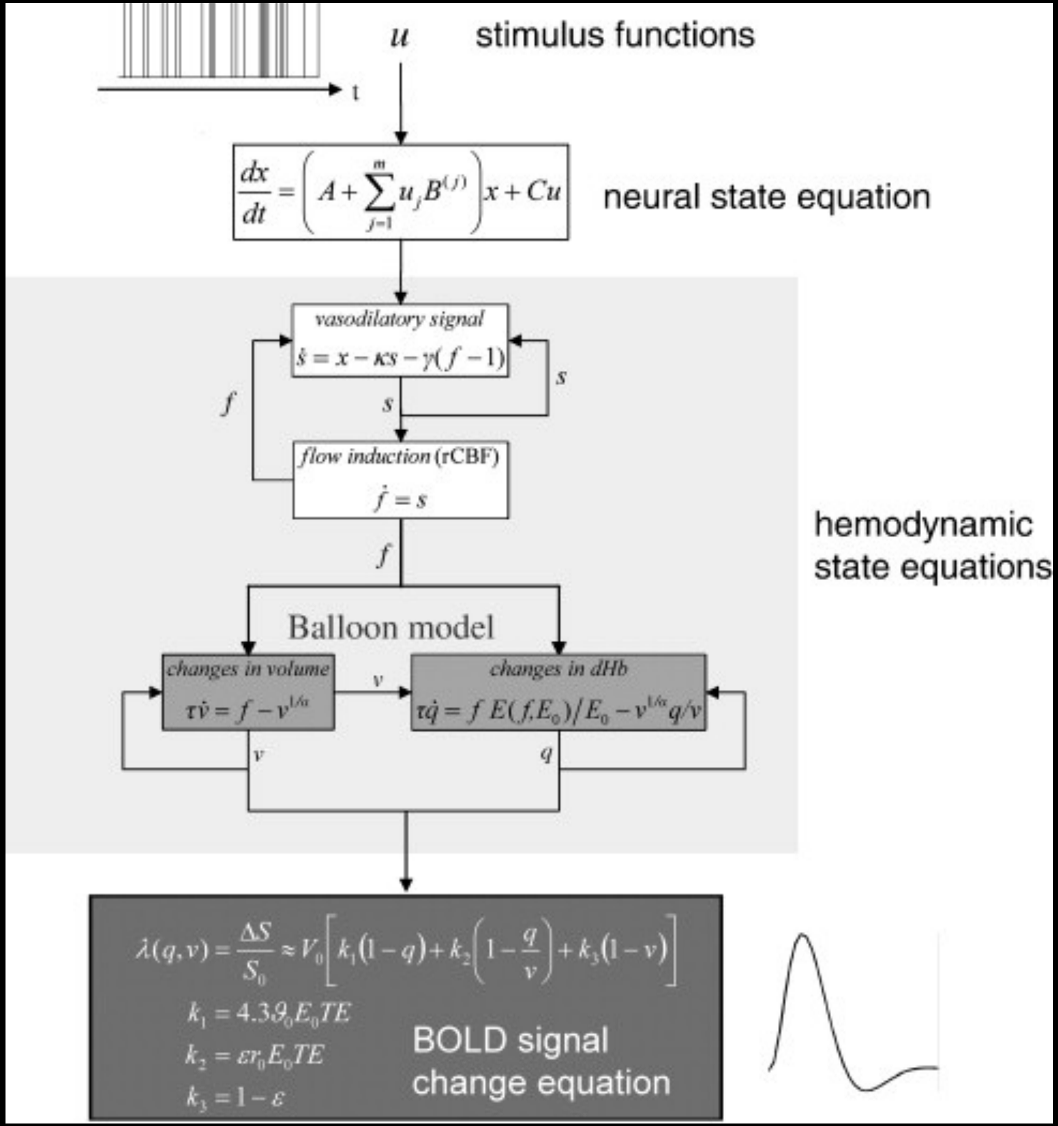
$$\begin{bmatrix}\dot z_1\\ \vdots\\ \dot z_n\end{bmatrix}=\left\{\begin{bmatrix}a_{11}&\cdots&a_{1n}\\ \vdots&\ddots&\vdots\\ a_{n1}&\cdots&a_{nn}\end{bmatrix}+\sum_{j=1}^{m}u_j\begin{bmatrix}b^j_{11}&\cdots&b^j_{1n}\\ \vdots&\ddots&\vdots\\ b^j_{n1}&\cdots&b^j_{nn}\end{bmatrix}\right\}\begin{bmatrix}z_1\\ \vdots\\ z_n\end{bmatrix}+\begin{bmatrix}c_{11}&\cdots&c_{1m}\\ \vdots&\ddots&\vdots\\ c_{n1}&\cdots&c_{nm}\end{bmatrix}\begin{bmatrix}u_1\\ \vdots\\ u_m\end{bmatrix}$$

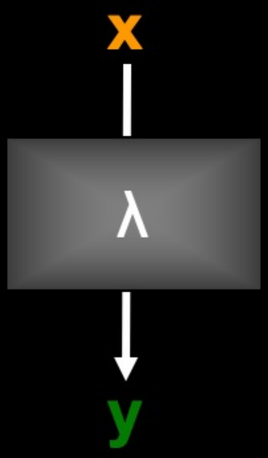
$$\dot z=(A+\sum_{j=1}^{m}u_jB^j)z+Cu$$



DCM estimates parameters at the neuronal level such that the modelled BOLD signals are maximally similar to the experimentally measured BOLD signals

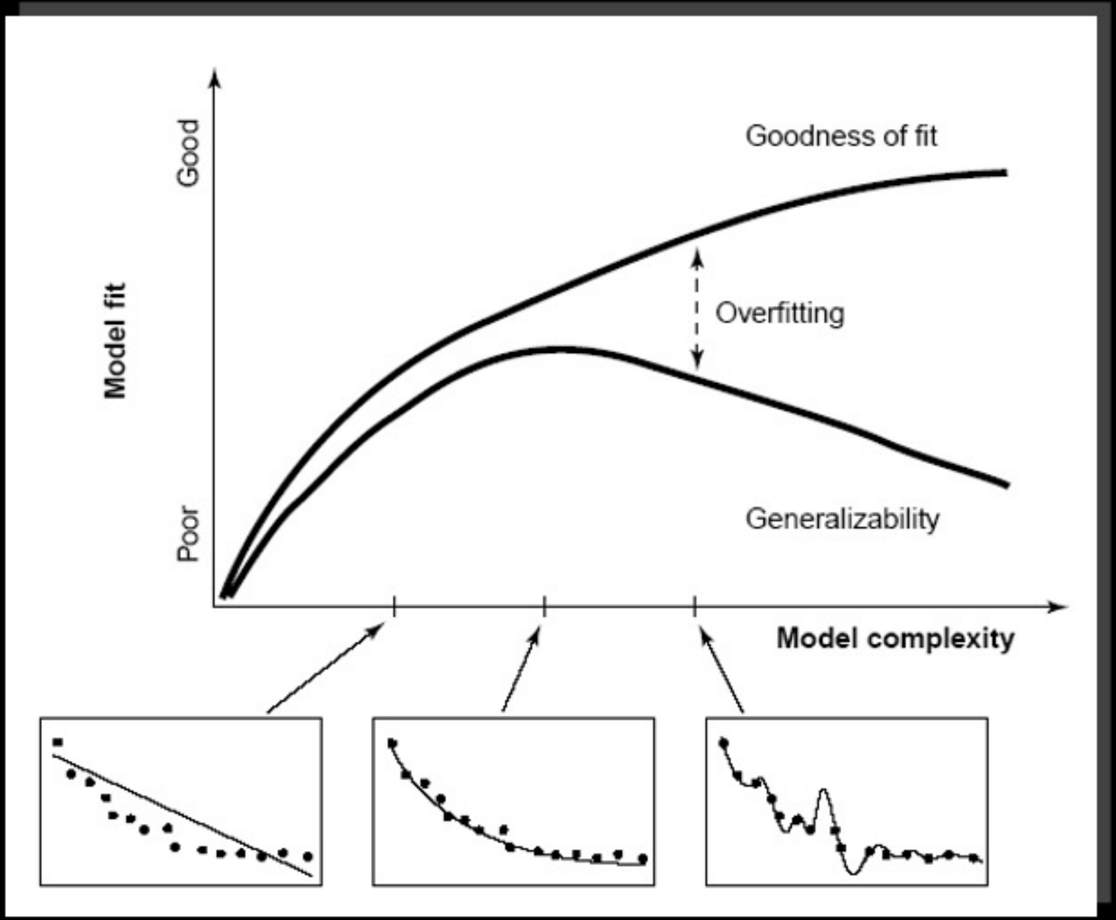
Hemodynamic model (BOLD)





Stephan et al. 2007, *Neuroimage*

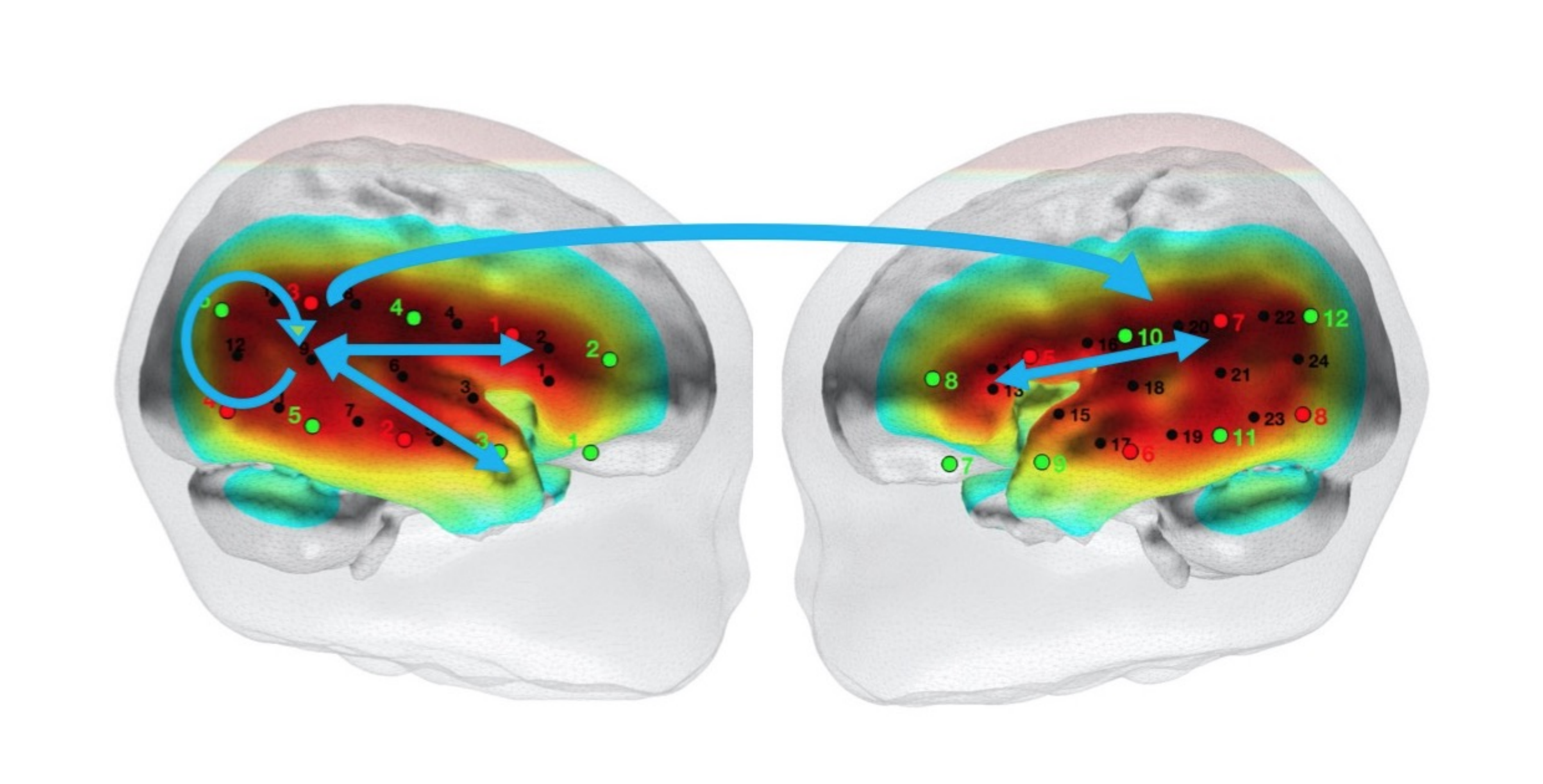
Model comparison



Pitt & Miyung (2002), TICS

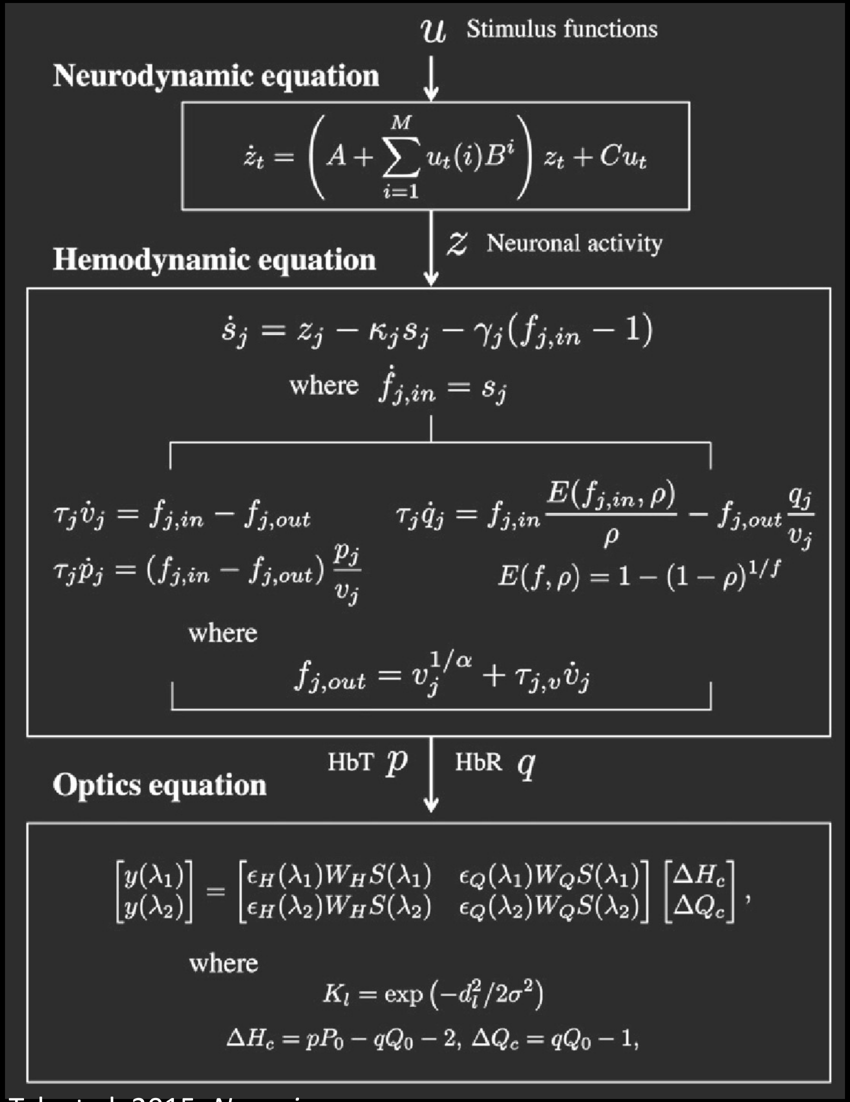
DCM for fNIRS

Neuroelectrics



BrainHack Donostia

DCM for fNIRS



Tak et al. 2015, *Neuroimage*

1. hemodynamics model:

the rate of HbT changes $\dot{p}_j$,

$$\tau_j \dot{p}_j = (f_{j,in} - f_{j,out}) \frac{p_j}{v_j},$$

2. optics model:

$$y_i(\lambda) = \frac{1}{\omega_{i,H}} \sum_{i=1}^{N} S_{i,j}(\lambda) \epsilon_H(\lambda) \Delta H_{j,c} + \frac{1}{\omega_{i,Q}} \sum_{i=1}^{N} S_{i,j}(\lambda) \epsilon_Q(\lambda) \Delta Q_{j,c}$$

3. optics model:

spatially extended hemodynamic sources

The neurodynamic and hemodynamic models used for DCM-fMRI analysis are extended for DCM-fNIRS

Motor Imagery example

Experimental Setup:

Session 1: squeeze and release a ball with right hand during task blocks
Session 2: kinaesthetic imagery of the same movement, without moving
In both: 5s blocks of tasks, 25s rest blocks

Previous findings:

- activation in SMA and premotor cortex during ME & MI
- reduced activation in M1 during motor imagery
- DCM for fMRI: SMA-M1 coupling may serve to attenuate M1 activation during MI

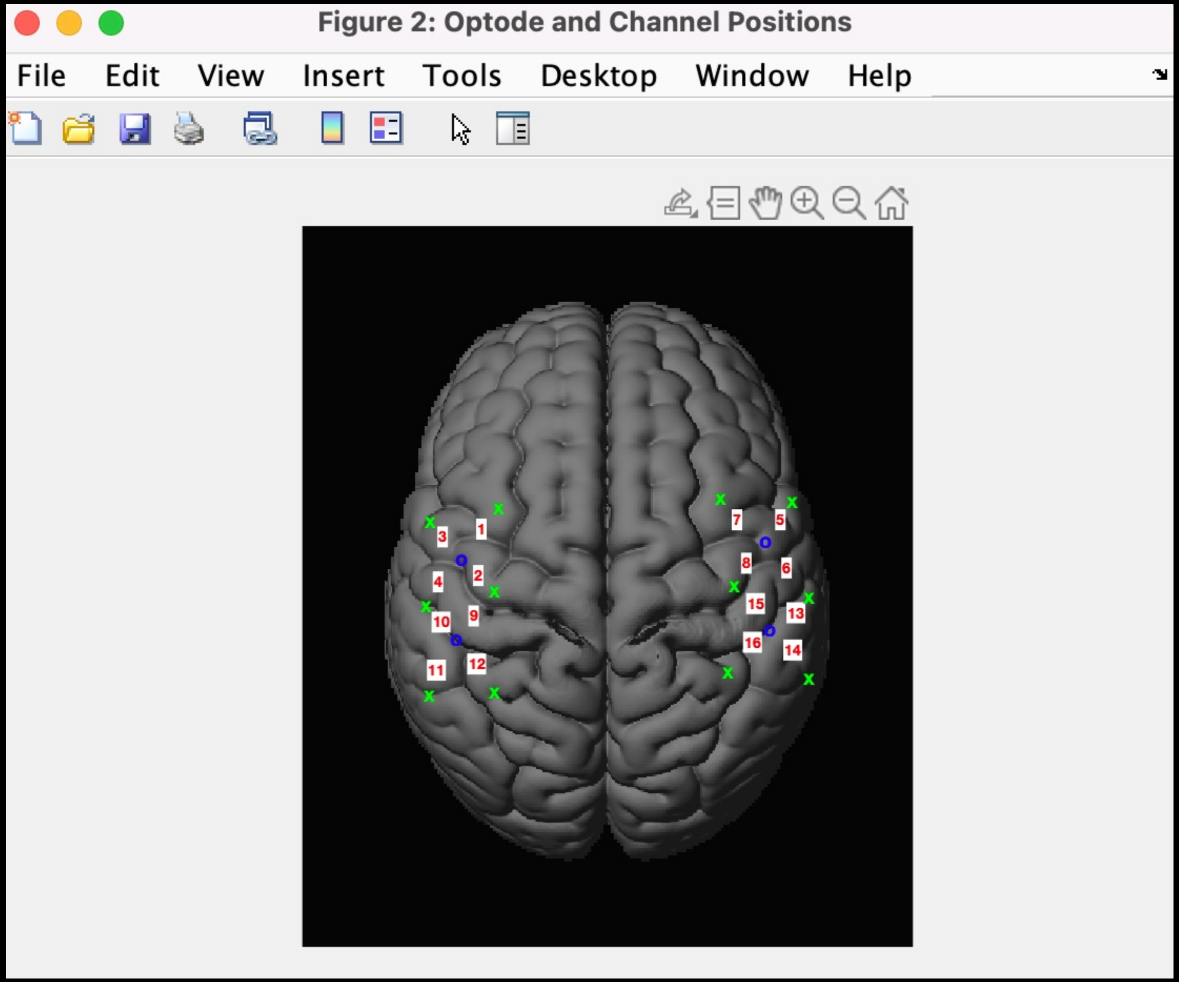
Objectives:

1. how the MI condition affects the directed connections between SMA & M1
2. how these interactions are associated with the activity in M1 and SMA during ME & MI

during motor imagery SMA and premotor cortex are active while M1 is not,
the example explores effects of SMA-M1 coupling

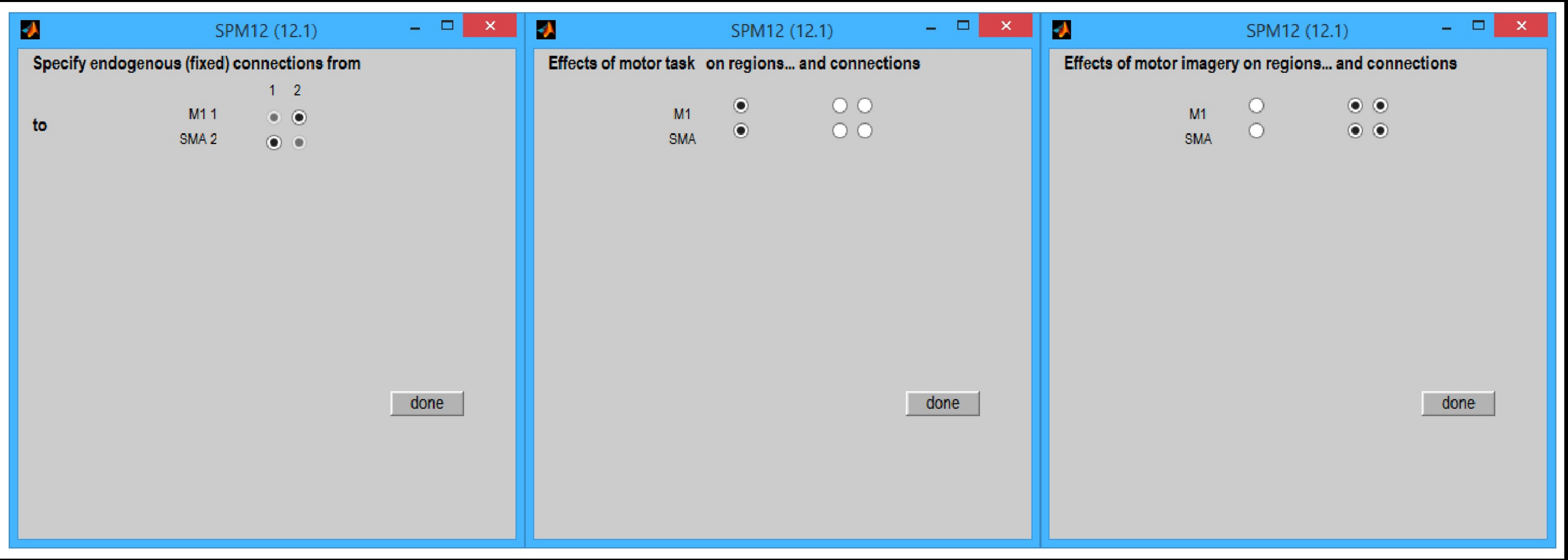
Motor Imagery example

Kempny et al. 2016, *Neuroimage*



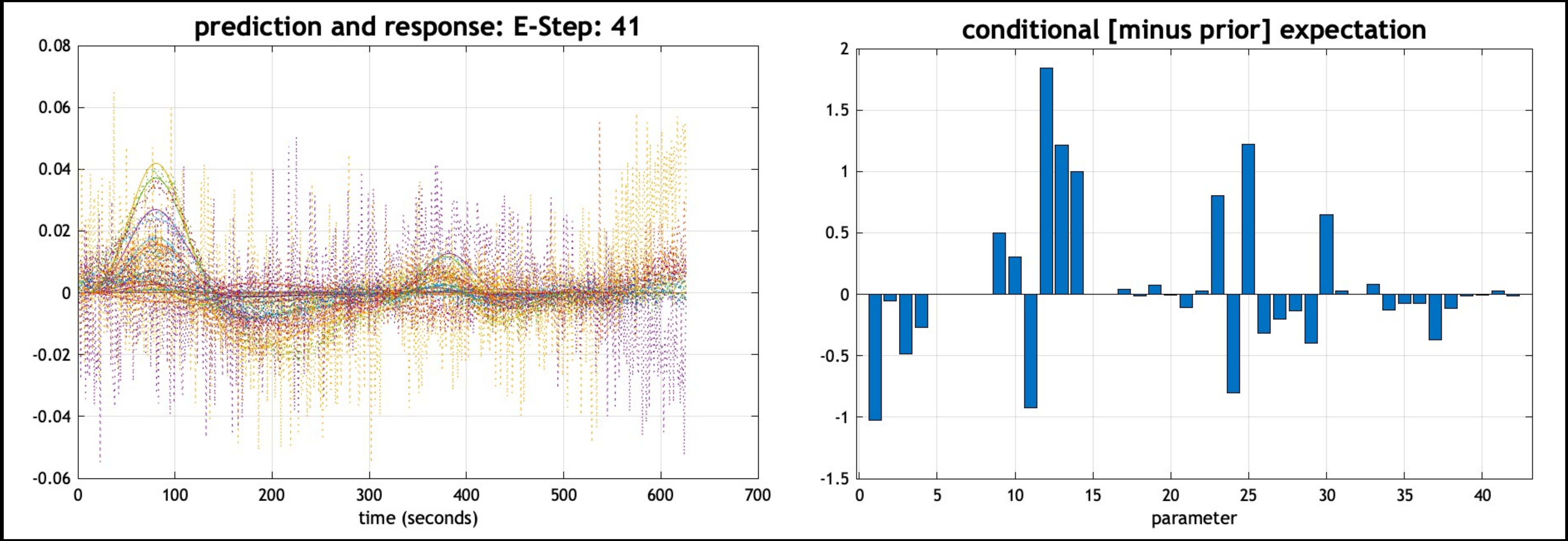
SPM12

Motor Imagery example



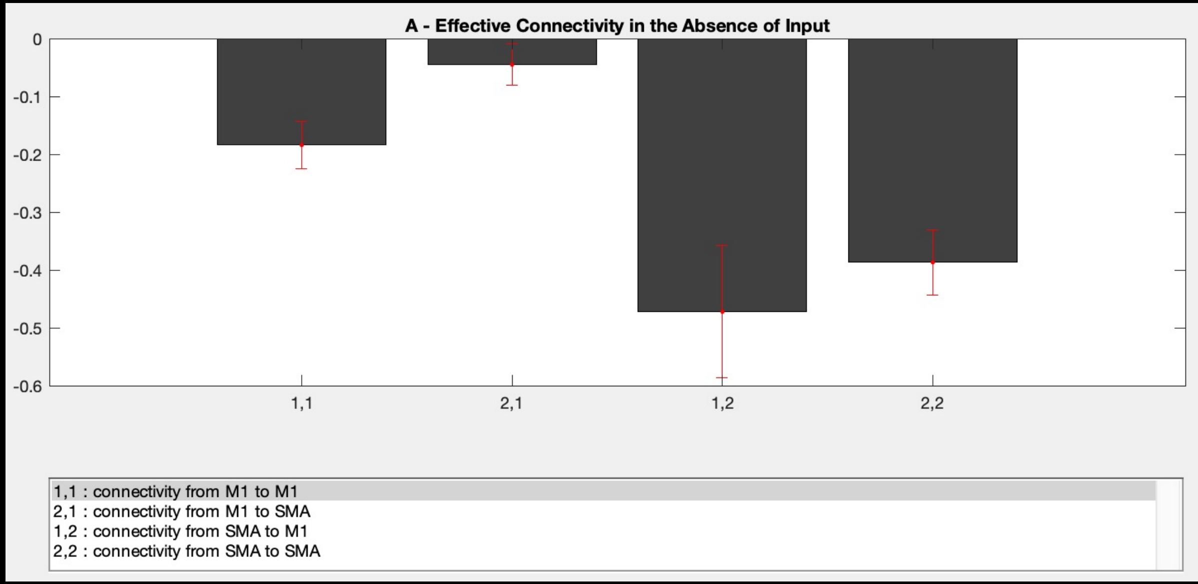
SPM12 Manual

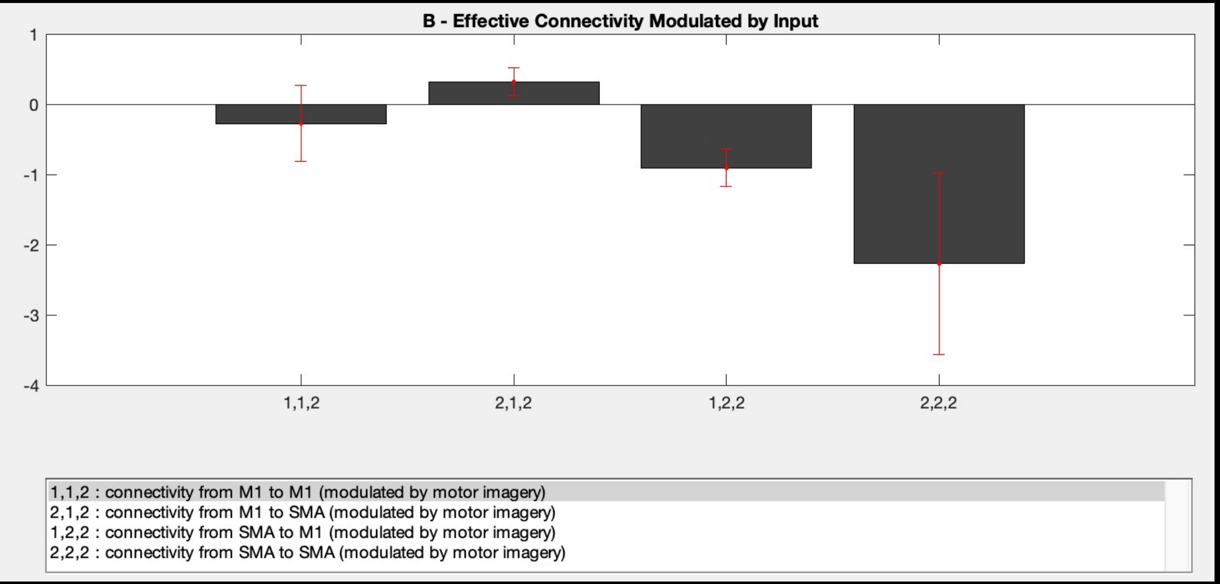
Motor Imagery example



SPM12

Motor Imagery example





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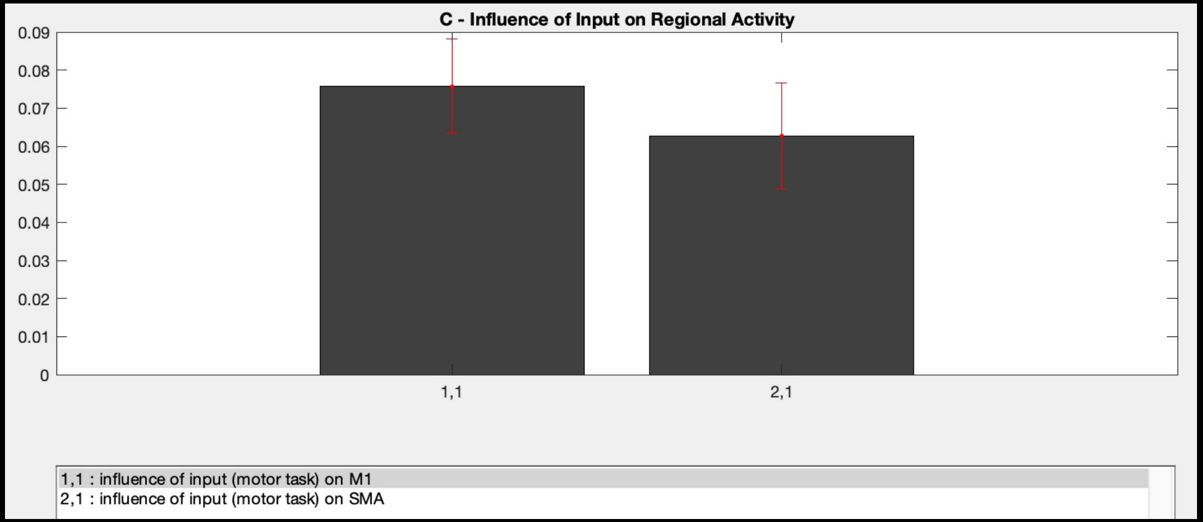
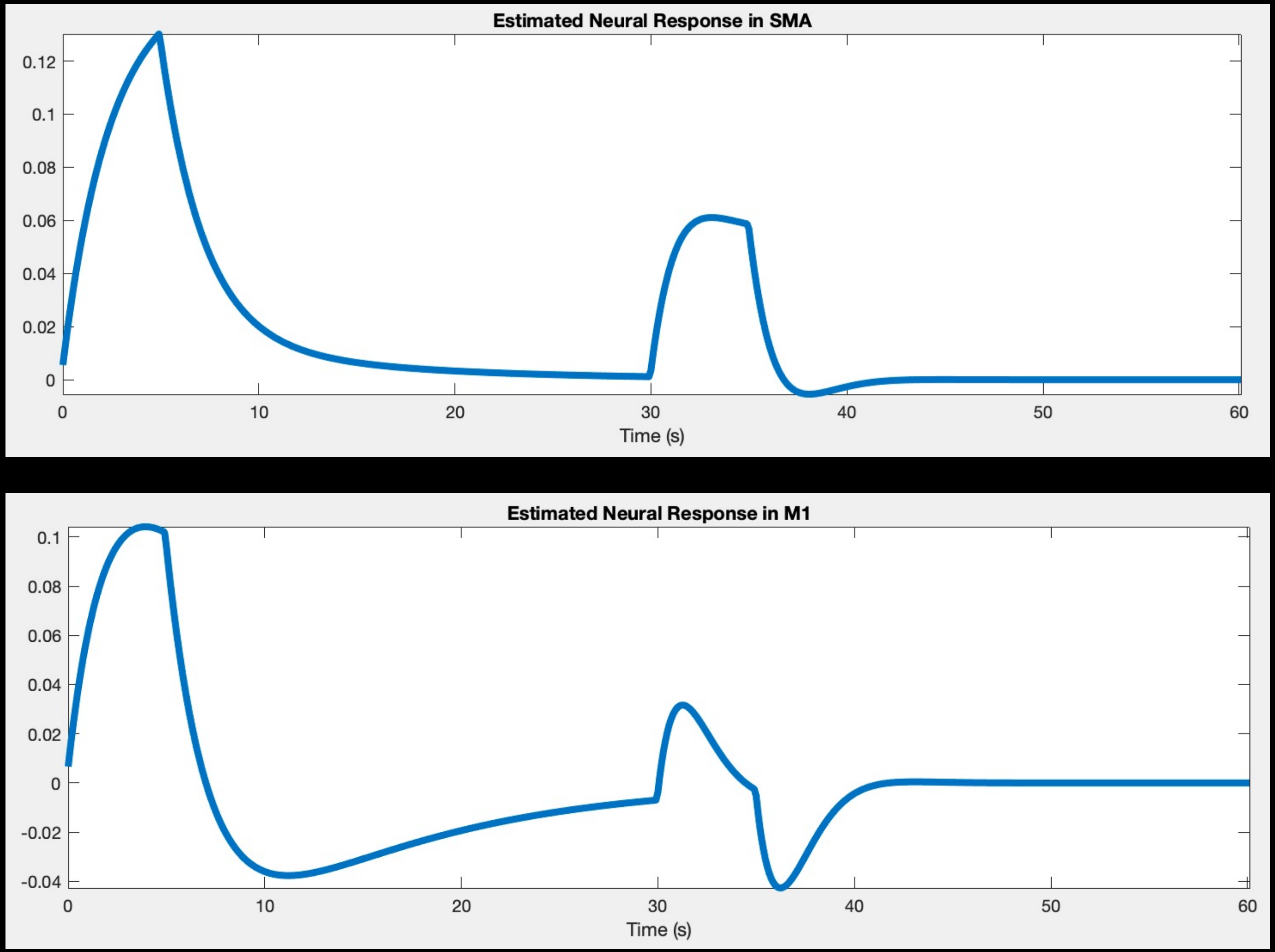


Motor Imagery example



SPM12

Questions

Thank you for your attention!

Questions?

References

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- Methods for Dummies previous cohorts, esp. den Ouden, H., & Hassabis, D. (2004). DCM for fMRI: Theory.
- Images also from: https://www.neuroelectrics.com, Lex Fridman podcast, & DALL·E 2 (Open AI).

Resources:

- **https://github.com/KevinAquino/DCM-course**
- **https://github.com/borjablanco/BHDonostia_2020_fNIRS**