Hierarchical Bayesian Model for Simultaneous EEG SOurce and FOrward MOdel REconstruction (SOFOMORE)

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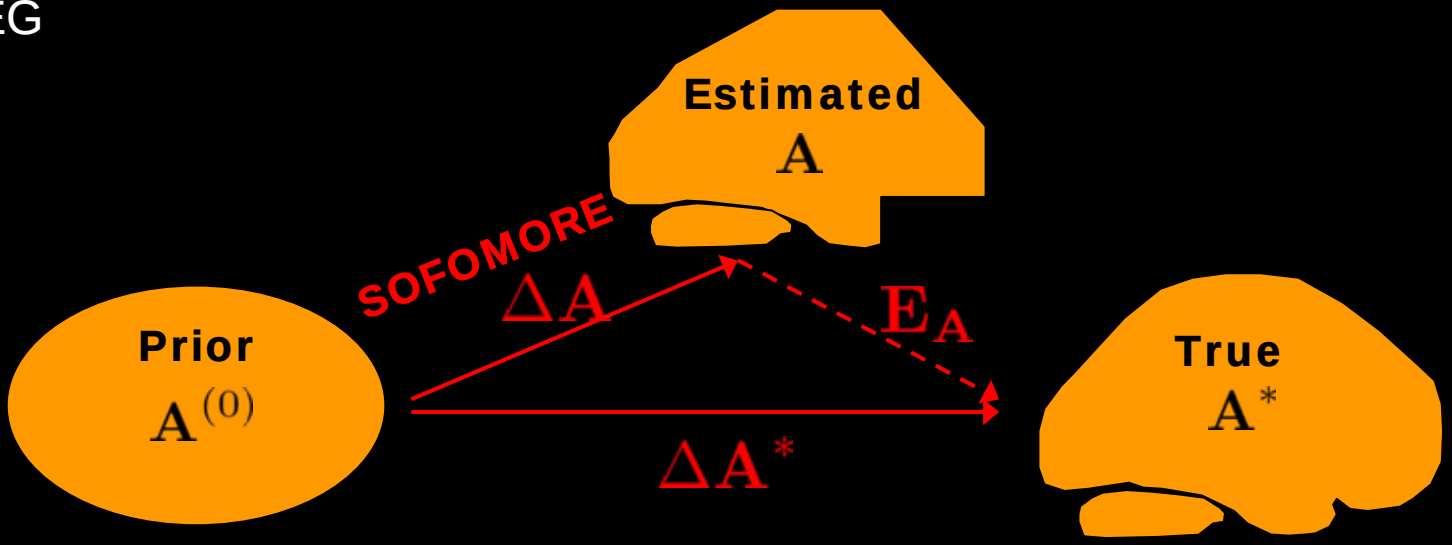
Overview

- Forward problem
- Principle of forward model reconstruction
- The SOFOMORE model
- Experiments
  - Simulations
  - Real EEG
- Conclusion



The Forward Problem

Algebraic Formulation (Baillet et al., 2001)

$$\mathbf{M} = \mathbf{A}\mathbf{S} + \mathcal{E} \tag{1}$$

with

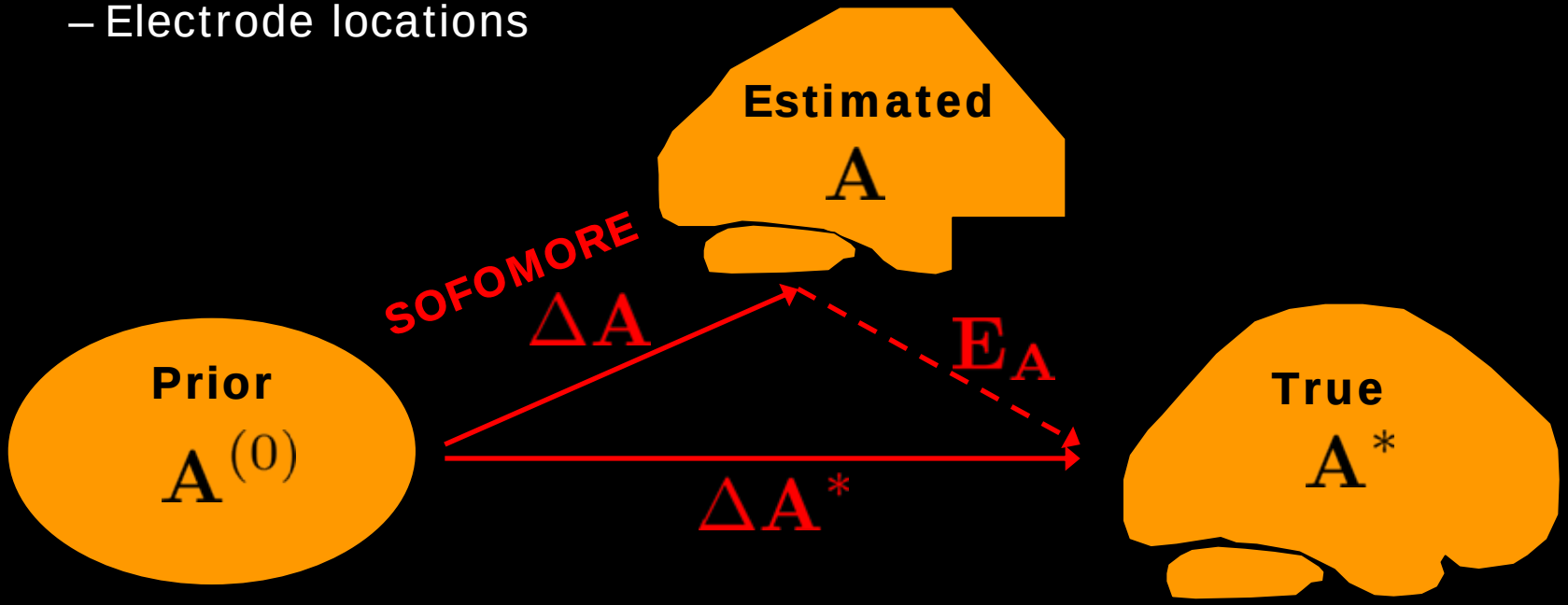
- $\mathbf{M} \in \Re^{N_c \times N_t}$ as the measured EEG signal, $(\mathbf{M} = \{\mathbf{m}_t\}_{t=1}^{N_t})$
- $\mathbf{S} \in \Re^{N_d \times N_t}$ as the current sources, $(\mathbf{S} = \{\mathbf{s}_t\}_{t=1}^{N_t})$
- $\mathbf{A} \in \Re^{N_c \times N_d}$ as the forward model/Lead field matrix, $(\mathbf{A} = \{\mathbf{a}_i\}_{i=1}^{N_d})$
- $\mathcal{E} \in \Re^{N_c \times N_t}$ as an additive noise term

Head models consisting of 3-spheres were generated by the SPM5 software, http://www.fil.ion.ucl.ac.uk/spm/ (which actually uses BrainStorm)

Different complexity of head models: spheres, BEM, FEM, see e.g. (Mosher et al., 1999; Wolters et al., 2004; Ramon et al., 2006)

Principle of reconstructing the Forward Model

- Uncertainties involved in the formulation of the forward model
  - Tissue segmentation
  - Tissue conductivities
  - Electrode locations

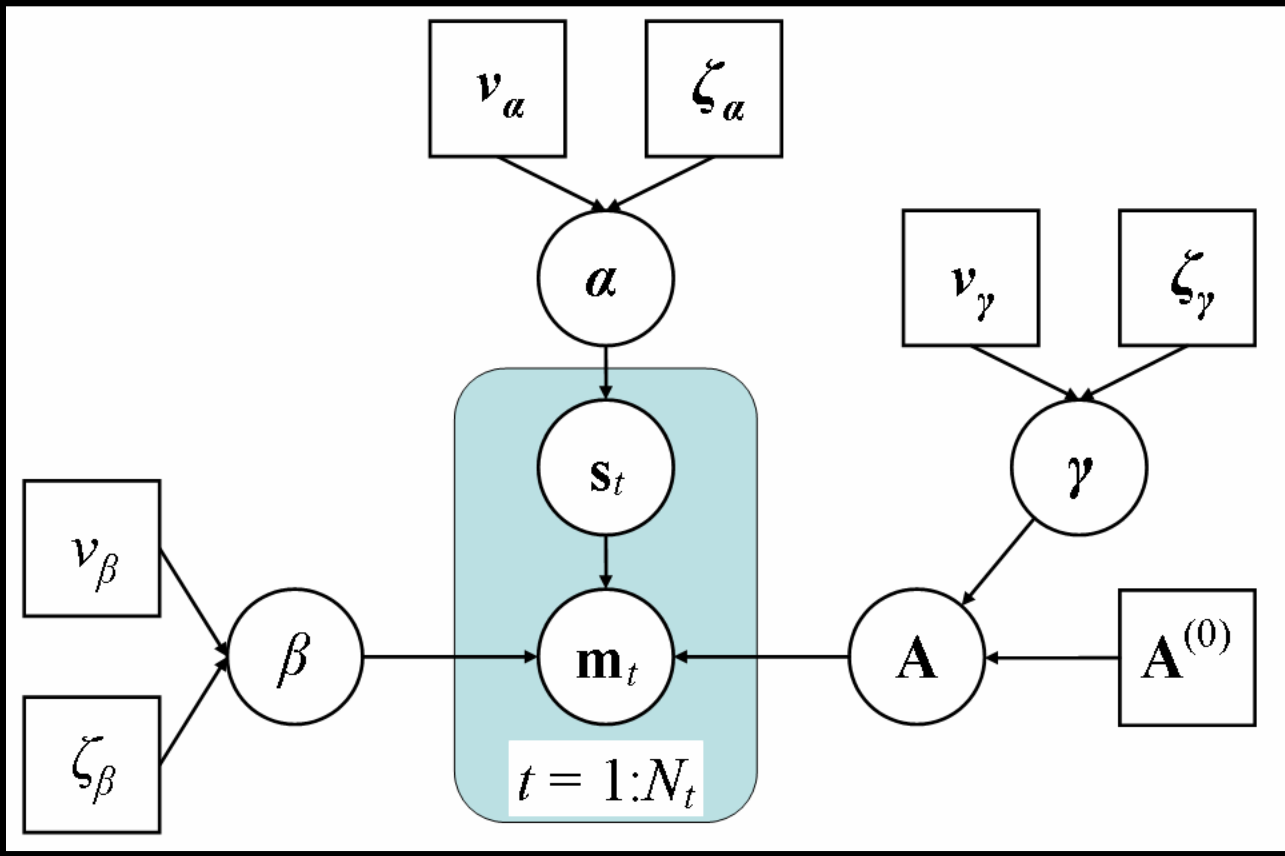


- Previous work:
  - (Lew et al.,2007; Plis et al., 2007)

The SOFOMORE Model

Prior distributions

- $\mathcal{N}\left(\mathbf{m}_t \,|\mathbf{A}\mathbf{s}_t, \beta^{-1}\mathbf{I}\right)$
- $\mathcal{N}\left(\mathbf{s}_t \,|\mathbf{0}, \mathrm{diag}\left(\boldsymbol{\alpha}^{-1}\right)\right)$
- $\mathcal{N}\left(\mathbf{a}_i \,\middle|\, \mathbf{a}_i^{(0)}, \gamma_i^{-1}\mathbf{I}\right)$
- $\mathcal{G}\left(\beta \,|\nu_\beta, \zeta_\beta\right)$
- $\mathcal{G}\left(\alpha_i \,|\nu_{\alpha_i}, \zeta_{\alpha_i}\right)$
- $\mathcal{G}\left(\gamma_i \,|\nu_{\gamma_i}, \zeta_{\gamma_i}\right)$

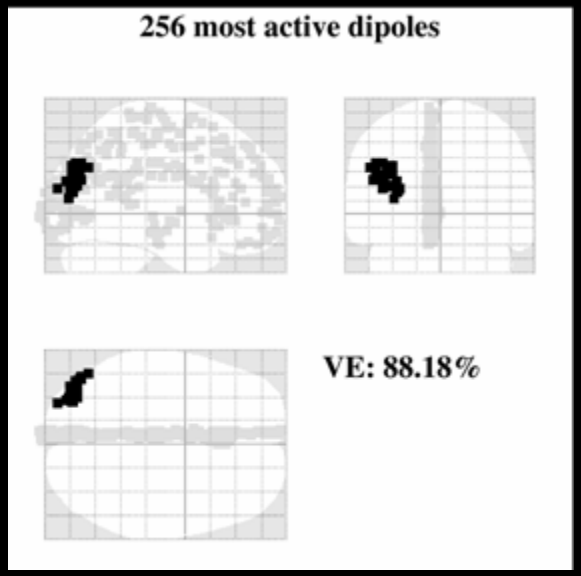


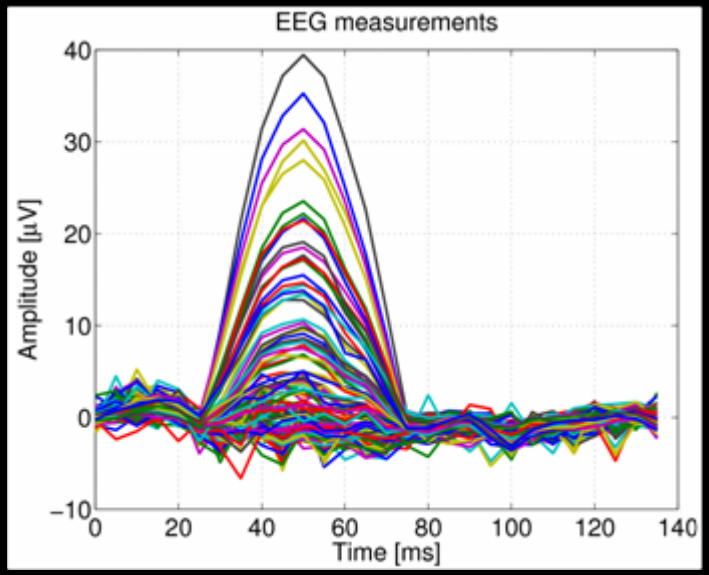
Maximize posterior distribution of the sources $\boldsymbol{\theta} = \{\mathbf{S}, \mathbf{A}, \boldsymbol{\alpha}, \beta, \boldsymbol{\gamma}\}$: $p\left(\mathbf{S}\,|\mathbf{M}\right) = \dfrac{p\left(\mathbf{M},\mathbf{S}\right)}{p\left(\mathbf{M}\right)} = \dfrac{\int p\left(\mathbf{M},\boldsymbol{\theta}\right)\mathrm{d}\boldsymbol{\theta}_{\backslash \mathbf{S}}}{p\left(\mathbf{M}\right)}$ =>VB (Bishop, 2006)

Experiment: Simulation Setup

- True A:
  - Conductivities (brain:skull:scalp): 0.33:0.0041:0.33 S/m, corresponding to conductivity ratio 1:1/80:1, (Oostendorp et al., 2000)
  - Resolution: 7204 vertices

$$\mathrm{SNR} = P_{\mathrm{cEEG}}/P_{\mathrm{noise}} = 10$$





Results: Simulations

Error measure

- Variance Explained (VE)

$$\mathrm{VE} = \sum_{j=1}^{N_c} \mathrm{var}\left(\mathbf{M}_{j\cdot} - \mathbf{a}_j^T \mathbf{S}\right) / \sum_{j=1}^{N_c} \mathrm{var}\left(\mathbf{M}_{j\cdot}\right)$$

- Mean Square Error (MSE)

$$\mathrm{MSE} = \sum_{t=1}^{N_t} \left\|\hat{\mathbf{s}}_t - \mathbf{s}_t\right\|^2 / \sum_{t=1}^{N_t} \left\|\mathbf{s}_t\right\|^2$$

- Degree of Focalization (DF)

$$\mathrm{DF} = \sum_{i \in \Theta} \left\|\hat{\mathbf{S}}_{i\cdot} - \mathbf{S}_{i\cdot}\right\|^2 / \sum_{i \in \Theta} \left\|\mathbf{S}_{i\cdot}\right\|^2$$

- Area under ROC-curve (AUC)

Minimum Norm (MN) Method
(Hämäläinen and Ilmoniemi, 1994)

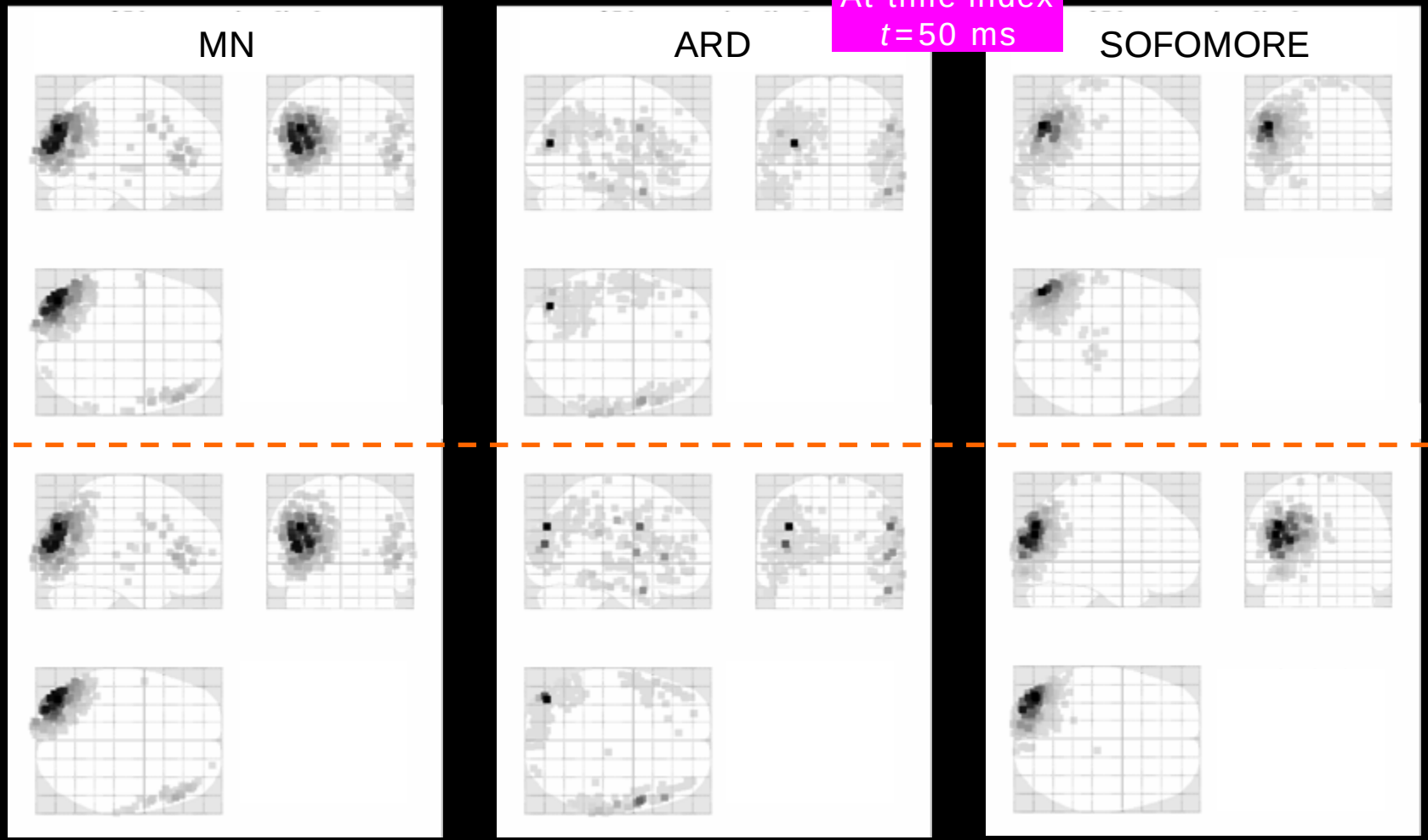
	MN		
	1:1/15:1	1:1/80:1	1:1/250:1
VE	99.0%	98.8%	98.8%
MSE	0.85	1.08	5.05
DF	0.76	0.42	0.30
AUC	0.93	0.97	0.98

	ARD		
	1:1/15:1	1:1/80:1	1:1/250:1
VE	99.5%	99.1%	98.7%
MSE	3.92	20.21	119.86
DF	2.11	8.03	78.44
AUC	0.89	0.93	0.87

	SOFOMORE		
	1:1/15:1	1:1/80:1	1:1/250:1
VE	95.5%	91.6%	81.5%
MSE	0.91	0.76	0.74
DF	0.88	0.69	0.56
AUC	0.92	0.99	0.99

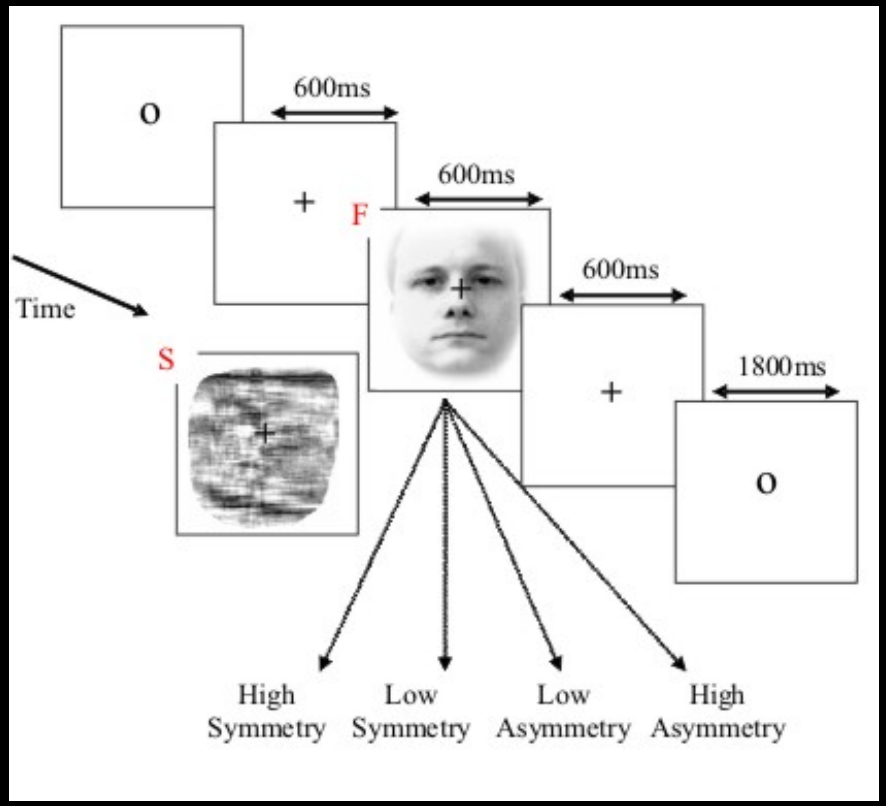
Results: Simulations (cont)

- Conductivity ratios (brain:skull:scalp): 1:1/15:1 (Homma et al., 1995), 1:1/80:1 (Oostendorp et al., 2000)



Experiments: Real EEG Setup

- Data set: Multimodal face-evoked responses (Henson et al., 2003; *http://www.fil.ion.ucl.ac.uk/spm/*)



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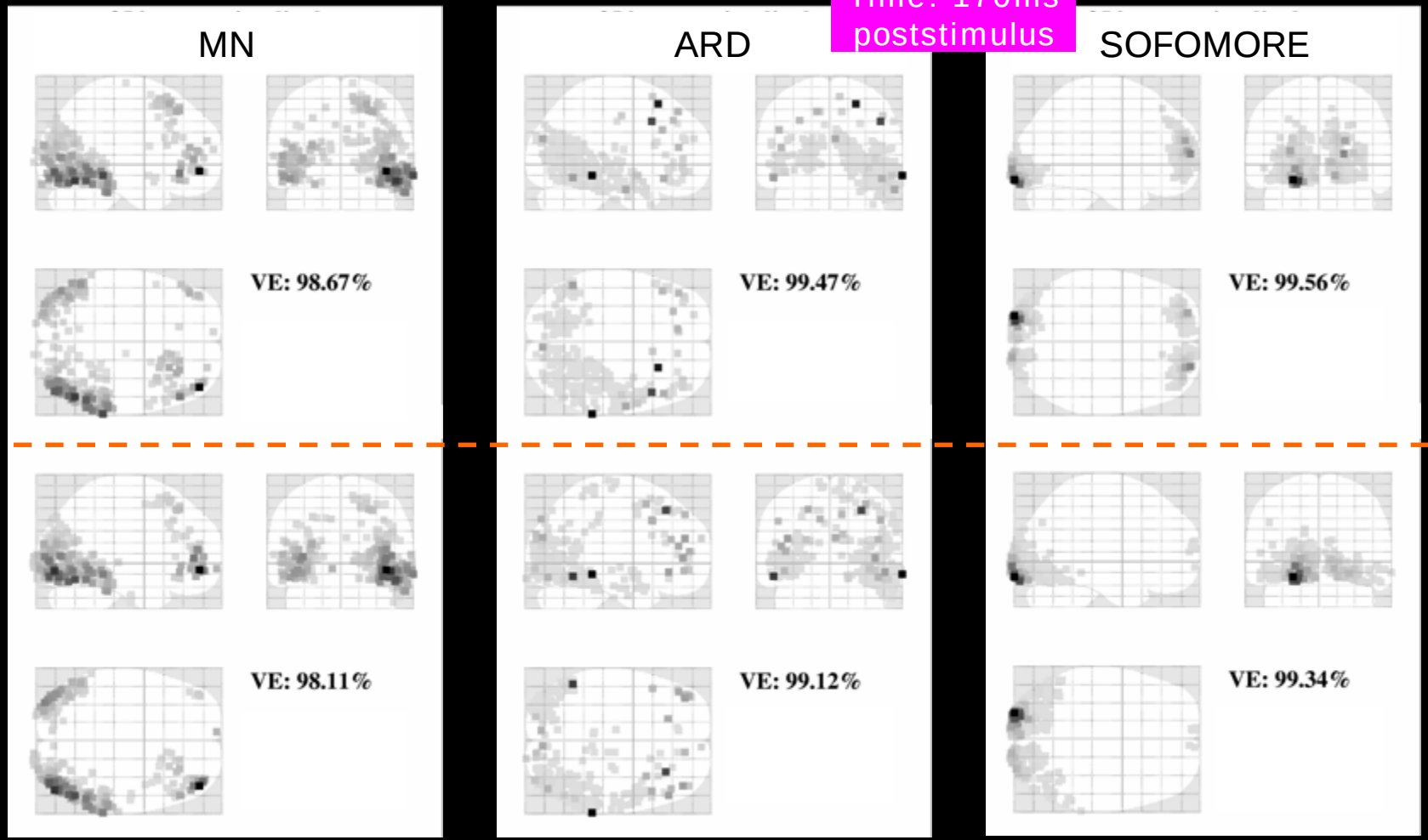

Conclusion

- Uncertain forward models degrade the source estimates
- Simultaneous source and forward model reconstruction reduces the influence of uncertain forward models on the source estimates
- On-going work:
  - Realistic head model
  - Temporal basis functions
  - Reducing computational complexity

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Thank you for your attention!