Fictional or Functional Connectivity? Validating and improving functional connectivity analyses for EEG

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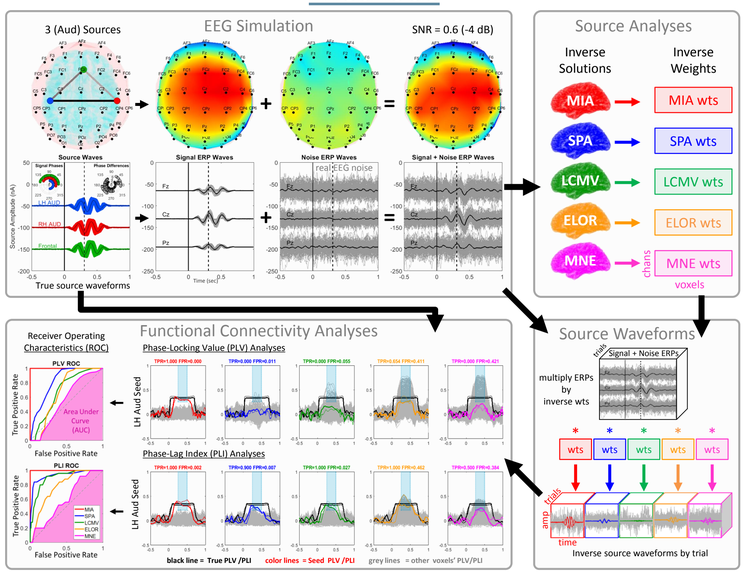
Introduction

- **Functional Connectivity (FC)** has become prominent in neuroimaging analyses of EEG and MEG data.
- **Major problem** with FC analyses is **source mixing** (a.k.a. **leakage**) due to electrical volume conduction and mathematical constraints in most single-source modeling procedures (e.g., SPA, LCMV, eLORETA, and MNE).
- Source mixing generates **false** (a.k.a **fictional**) **connectivity** patterns.
- Multi-source null-constraints in beamforming methods can significantly reduce or eliminate source mixing. (e.g., MIA=multiple-iterative step approach; Herdman et al., 2018)
- Multi-source beamformers can; therefore, provide better estimates of functional connectivity from EEG data.

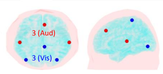
Objective

- To verify inverse-source solutions for FC analyses using simulated data (known truths) so that we feel more confident when interpreting FC results obtained from source modeling of real EEG & MEG data (unknown truths)

Methods



- Source Configurations = 3 (Aud), 3 (Vis), 6 (Aud + Vis)
- Signal-to-Noise Ratio (SNR) = 0.2 (-14 dB), 0.4 (-8 dB), 0.6 (-4 dB)
- PLV/PLI = 0.4 for all possible connections among simulated sources
- Inverse Source Analyses:
  - multi-source (MIA) & single-source (SPA) scalar beamformer (Moiseev et al., 2011; Moiseev & Herdman, 2013; Herdman et al., 2018)
  - single-source inverse solutions (LCMV, eLORETA, and MNE) (www.fieldtriptoolbox.org)
- Head Model & Leadfields = Boundary-Element Model; 590 voxels (15 mm^3) x 64 EEG Channels

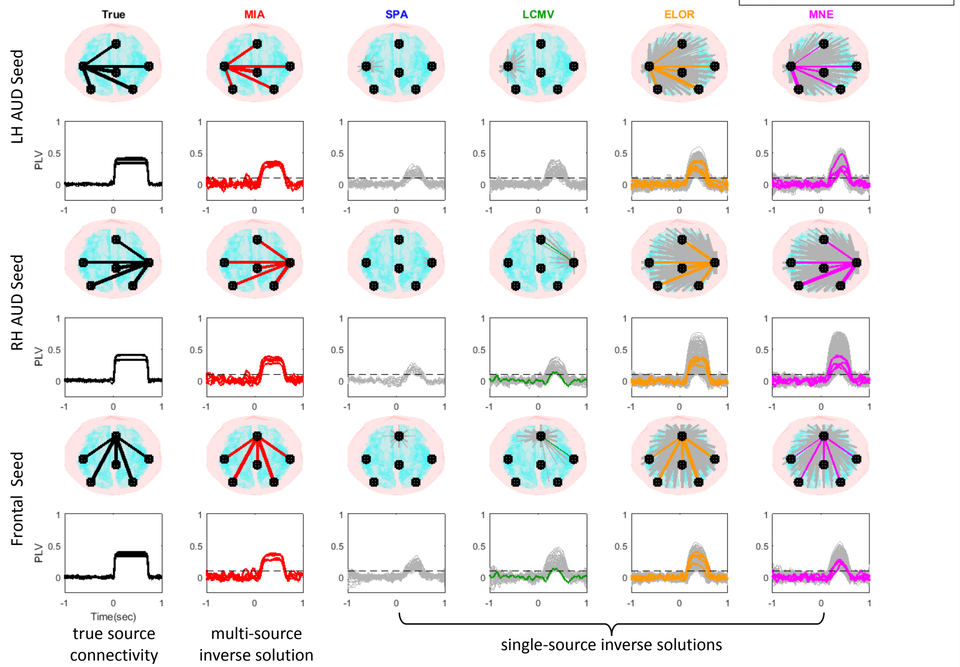


Functional Connectivity Results

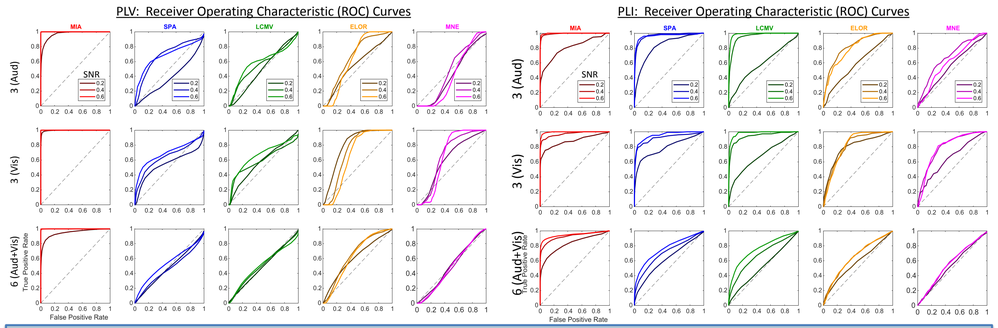
Multi-source beamformers (MIA) found **all TRUE** connections and no false connections
Single-source inverse methods (SPA, LCMV, ELOR, MNE) found **many FALSE** connections

Grand-Averaged PLI Maps for 6 sources (Aud+Vis) at SNR=0.6

color lines = True Positives
grey lines = False Positives

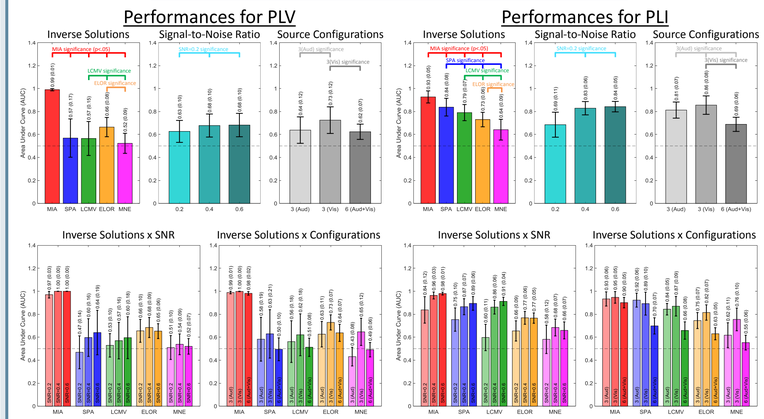


Multi-source beamformer (MIA) **outperformed** single-source methods (SPA, LCMV, ELOR, MNE)

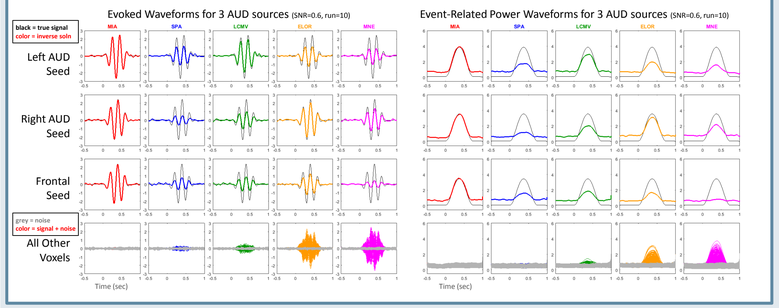


PLI improved performances but multi-source method still significantly better than single-source method
Six sources largely reduced performances for single-source methods, but not for multi-source beamformer (MIA)

Functional Connectivity Statistics



Better source waveform reconstructions for multi-source beamformer (MIA) than single-source methods (SPA, LCMV, ELOR, MNE)



Conclusions

1) **Use Multi-Source Beamformers** (e.g., MIA) for functional connectivity analyses of EEG in order **to improve**:
   - ✓ **Finding TRUE connections**
   - ✓ **Finding few, if any, false connections**
   - ✓ **source waveform reconstruction and localization**
2) Using Phase-Lag Index (PLI) can help but many false connections are still found for single-source inverse methods
3) Because **single-source inverse methods** (SPA, LCMV, eLORETA, and MNE) create large source leakages and find many false connections, these methods **should be used with caution when conducting functional connectivity analyses of EEG**.

Acknowledgements

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