Localizing Event-Related Potentials using New Approaches to Multi-source Minimum Variance Beamforming

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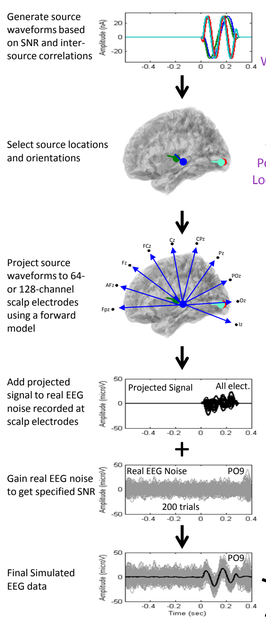
Introduction

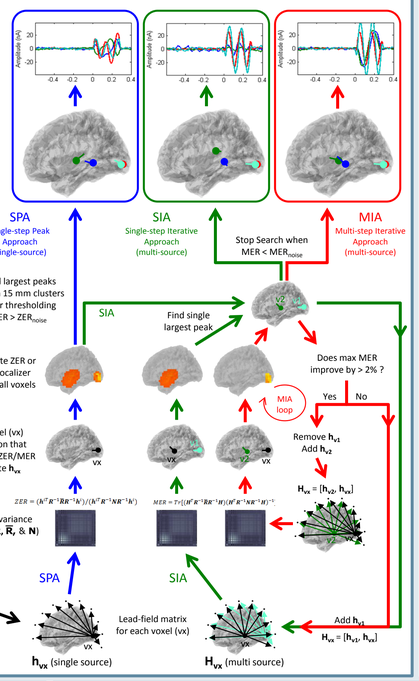
- Adaptive and non-adaptive beamformers have become prominent neuroimaging tools for localizing neural sources of EEG and MEG data
- Validation of these methods using simulated data is required to improve our confidence when interpreting results obtained from real recordings
- Improvements in beamformer methods continue to advance our ability to localize the spatiotemporal dynamics of brain function
- Single-source beamformers (e.g., SPA) can miss or inaccurately localize highly-correlated (r>.8) sources (e.g., Moiseev et al., 2011; Van Veen et al., 1997)
- Multi-source beamformers (e.g., SIA & MIA) can improve localization performance and accuracy (e.g., Diwakar et al., 2011; Moiseev et al., 2011)
- More accurate source localization leads to more accurate source waveform reconstruction; thus, better interpretations of spatiotemporal dynamics
- Source mixing (a.k.a. leakage) can generate false connectivity patterns
- Multi-source null-constraints can significantly reduce or eliminate source mixing

Methods

Source Simulation

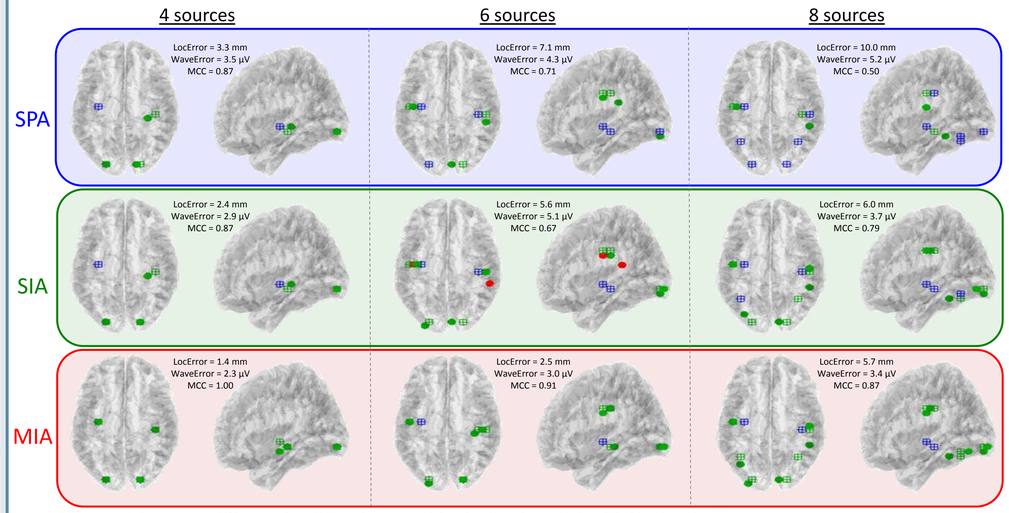


Source Reconstruction



Localization Results

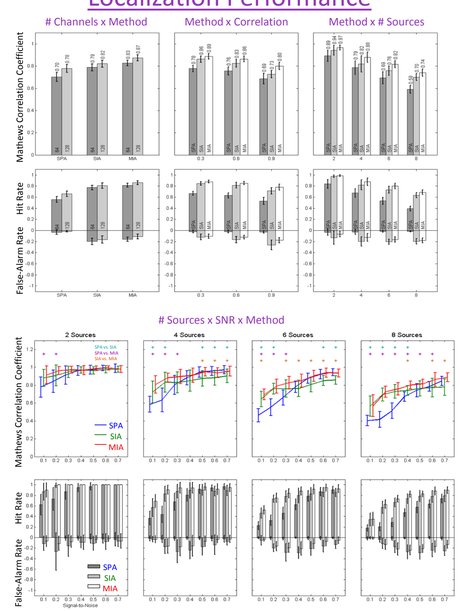
Multi-source beamformers (MIA & SIA) outperformed Single-source beamformer (SPA)



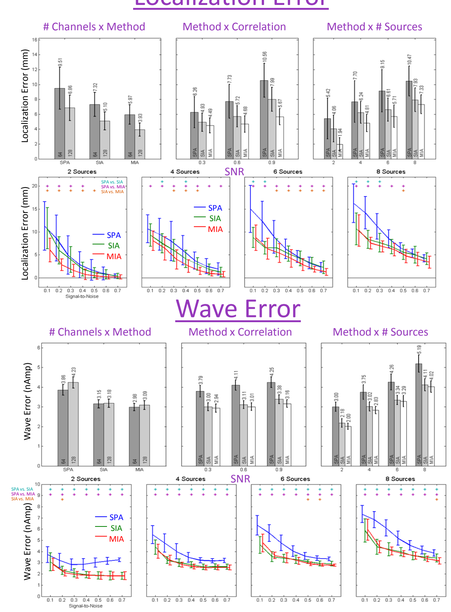
Examples of localization performances (MCC values) for Search Method by Source number (4, 6, and 8) for Monte-Carlo run #1 with an SNR = 0.2 and intra-pair correlation = 0.6. True source locations are colored as green baskets if they had a corresponding Hit for an observed source within 15 mm. Localization Error (LocError), waveform error (WaveError), and localization performance (Mathews Correlation Coefficient; MCC) for each condition are listed in parentheses above the images. MCC equal to 1 represents perfect localization performance, 0 represents chance performance, and -1 represents complete failure.

Miss True Location · Hit True Location · False Alarm Beamformer Location · Hit Beamformer Location

Localization Performance



Localization Error



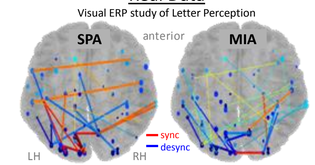
Wave Error

Functional Connectivity Challenge

WATCH OUT for Leaks!

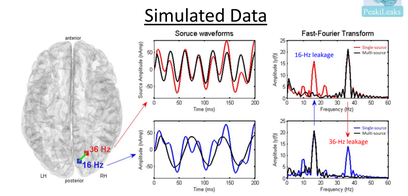
Real Data

Visual ERP study of Letter Perception



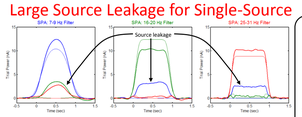
PLV for alpha band (9-10 Hz) at 380 ms post-stimulus onset

Simulated Data

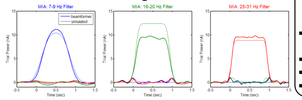


Type I Errors: Single-Source Beamformer & Phase-Locking Value (PLV)

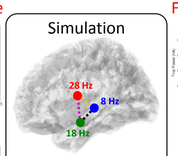
Large Source Leakage for Single-Source



No Source Leakage for Multi-Source

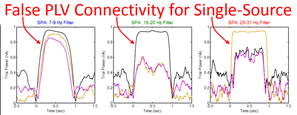


Simulation

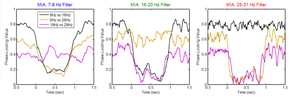


- Simulated sinusoidal waves: from 0 to 1 sec at 8, 18, & 28 Hz
- 15 mm separated sources
- No phase relationship
- PLV should =0→ No connectivity

False PLV Connectivity for Single-Source

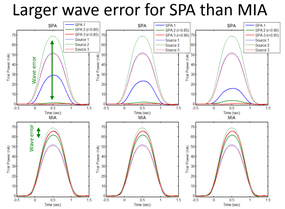


No PLV Connectivity for Multi-Source

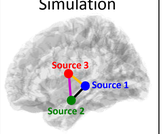


Type II Errors: Single-Source Beamformer & Phase-Lag Index (PLI)

Larger wave error for SPA than MIA

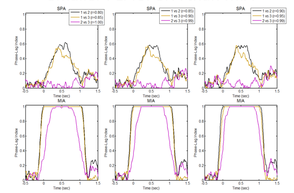


Simulation



- Simulated three 8-Hz sources
- Source correlations = 0.8 to 1.0
- Full phase-locking trial-to-trial
- PLI should = 1.0 from 0 to 1 sec

Smaller PLI for SPA than MIA



Conclusion

1) Use Multi-Source Beamformer (MIA) for ERP analyses in order to improve
   - localization performance
   - localization precision
   - source waveform reconstruction
   - finding "true" connectivity among sources
2) Source leakage can lead to finding false connections (Type I error)
3) Compensating for source leakage using PLI can lead to reduction in "true" connectivity (Type II error) when sources are highly correlated (e.g., bilateral auditory activation r>0.9)

Acknowledgements

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