Simulating Cross-Frequency Coupling Between the Auditory Cortex and Subcortex

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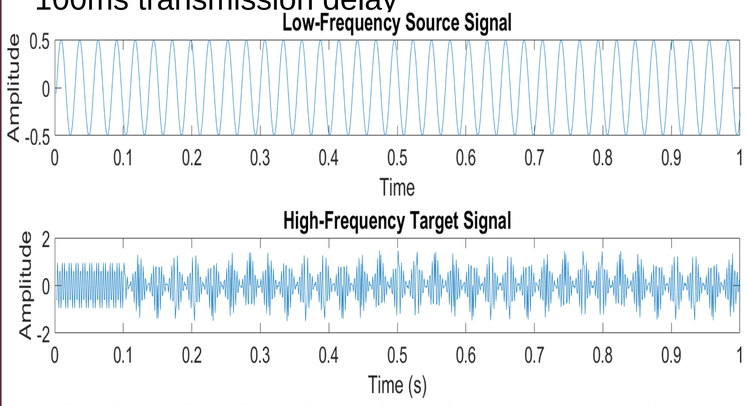
Introduction

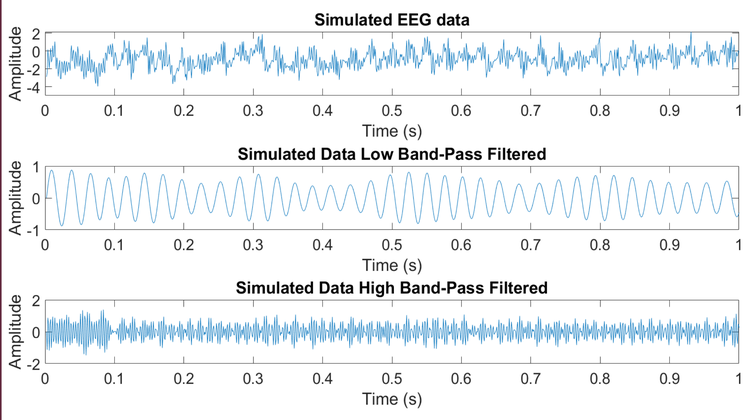
- Auditory pathway has more efferent projections than afferent projections indicating a high level of top-down auditory processing [1]
- **Can we estimate the top-down processing?**
- Can use EEG to index cortical and subcortical activity
  - 40 Hz response indexes auditory cortex, and is elicited by amplitude modulations of ~40 Hz[2]
  - Frequency Following Response (FFR) indexes subcortical activity, comprised of the same frequencies present in the pitch of the sound [3]
- Second, need a reliable estimate of directed connectivity for cross-frequency coupled signals
- **Goal: Test measures of directed connectivity for simulated cross-frequency coupling, specifically Phase- Amplitude coupling (PAC)**

Methods

- Simulated phase-amplitude coupling between a 37Hz sine wave and 300 Hz sine wave, with a 100ms transmission delay



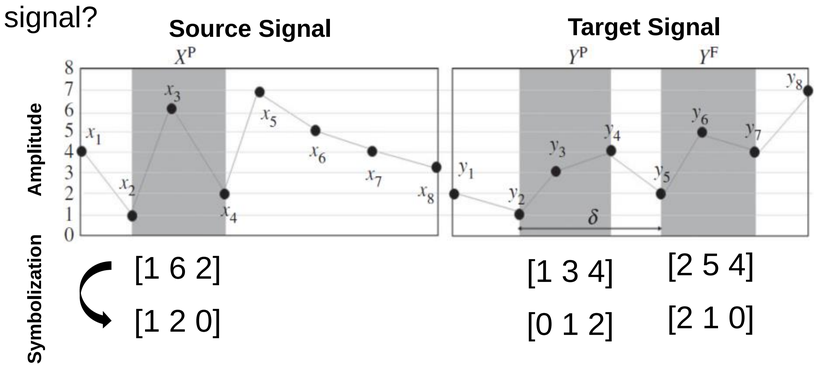
- Added previously collected resting state EEG data to make the noise realistic.
- Band-pass filtered the summed EEG data to separate out the low and high frequency activity



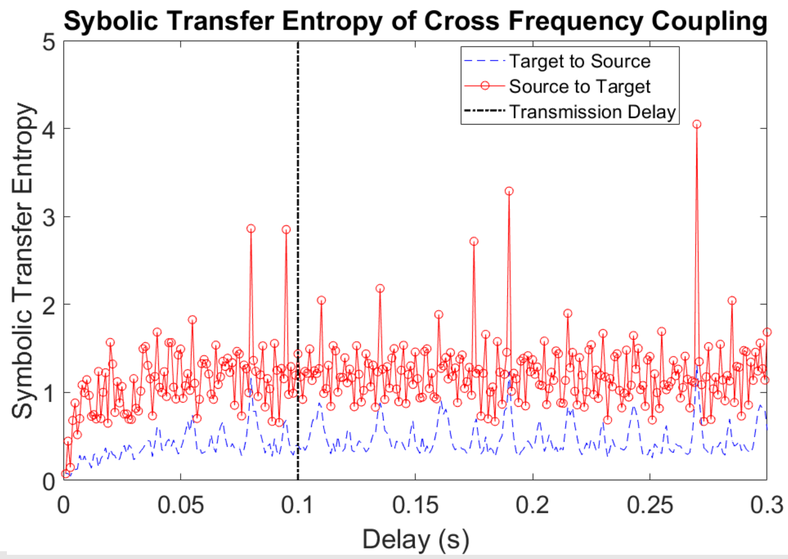
- Used 3 measures of directed connectivity
  - **Symbolic Transfer Entropy** (STE) [4]
  - **Granger Causality** (GC) [5]
  - **Phase Transfer Entropy** (PTE) [6]
- Can they a) differentiate between source and target and b) accurately detect the transmission delay

Methods & Results

- **Symbolic Transfer Entropy** is a non-linear measure of predictability based on conditional and transitional probability [4]
- Does knowing the past of a source signal increase the predictability of a target signal?



- Parameters
  - *Lag* = delay between the past and future, **We used delays 0 to 300**
  - *Embedding Dimension* = # of points to symbolize, **We chose 5**
  - *Time Scaling Factor* = samples between symbolized points, **We chose 1**



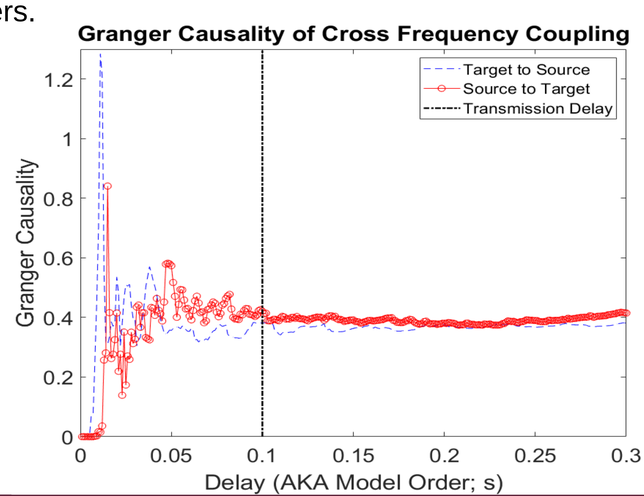
- **Granger Causality** is a linear measure of predictability based on auto-regressive modeling
- Does the past of a source signal predict the future of a target signal, over and above the target signal itself?

$$Y_t = \sum_{j=1}^{\infty} d_{1j} Y_{t-j} + \eta_{1t}, \quad \mathrm{var}(\eta_{1t}) = \Gamma_1$$

$$Y_t = \sum_{j=1}^{\infty} c_{2j} X_{t-j} + \sum_{j=1}^{\infty} d_{2j} Y_{t-j} + \eta_{2t}, \quad \mathrm{var}(\eta_{2t}) = \Gamma_2$$

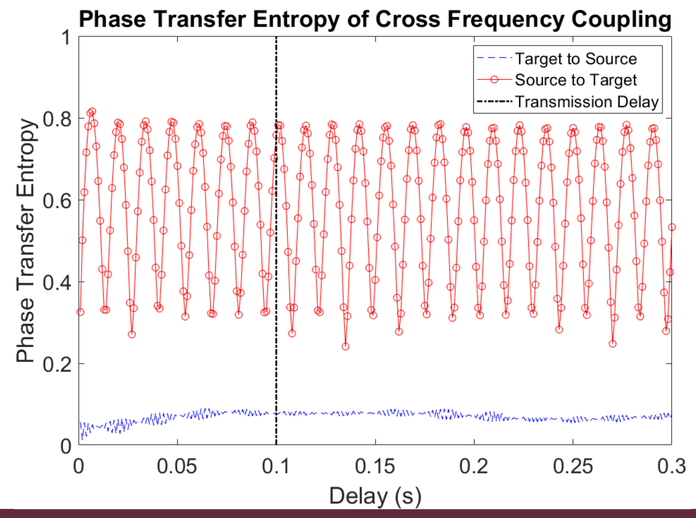
$$\textit{Granger causality} = F_{X \to Y} = \ln \frac{\Gamma_1}{\Gamma_2}$$

- Parameters:
  - Model order = length into the past being considered for the AR models
- Model order is similar to delay for STE, thus, calculated GC over multiple model orders.



More Methods & Results

- **Phase Transfer Entropy** is a non-linear measure of predictability, similar to STE. However, PTE is based on instantaneous phase and binning the phase space to calculate probability [6]
- We extracted instantaneous phase from the high and low band passed signals using the Hilbert transform.
- Parameters:
  - Bin width: Size of bins used in histograms to transitional and conditional probabilities[9]



Discussion

- No measure of directed connectivity accurately detected the transmission delay
  - Might be best to test with multiple delays and average across them
- Both STE and PTE detect the direction of connectivity
  - PTE is more stable, but STE has greater estimates
- Granger causality incorrectly estimates the source for short model orders (less than 50 ms)
  - Assumption of stationarity was violated for the data set
- More modern GC measure use non-linear methods, could preform better than linear GC
- Only test phase-amplitude coupling, simulate other types of coupling such as phase-phase coupling or amplitude-amplitude coupling

References

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Acknowledgments

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