Directional brain-to-brain oscillation coupling reflects music ensemble leadership

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INTRODUCTION

- People process complex dynamic information in real time when coordinating with others in joint action, conversation, and music.
- Traditional research approaches (e.g., artificial stimuli, isolated environment) cannot fully reveal the neural mechanisms of interpersonal coordination in real-world situations.
- Most hyperscanning studies measure similarity of neural activities between individuals, but:
  - Similarity measures do not establish directional coordination (e.g., leader to follower)
  - They are confounded with the shared sensory environment among co-actors.

GOALS

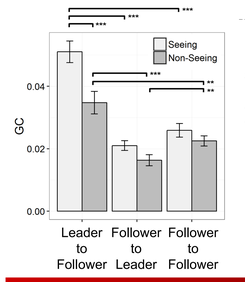
- **Can directional interpersonal coordination be measured by EEG?**
- **If yes, what brain regions & frequency bands are involved in interpersonal coordination?**

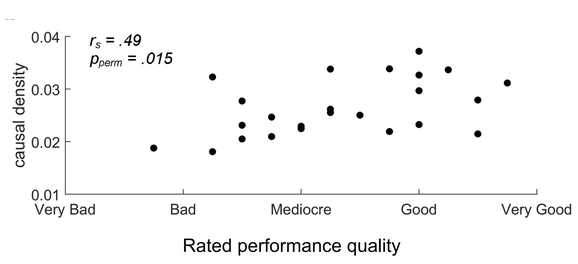
EXPERIMENTAL DESIGN

- 4 performers in a professional string quartet
- One player confidentially assigned to be the leader and the rest to be the followers
- Performers instructed to perform at their best within the role assigned to them
- Conditions where performers could either see each other or not (facing away)
- Performed one of 12 3-min pieces on each trial
- EEG (64 channel, 512 Hz)

PREVIOUS FINDINGS FROM ANALYZING BODY SWAY
(Chang et al., 2017, PNAS)

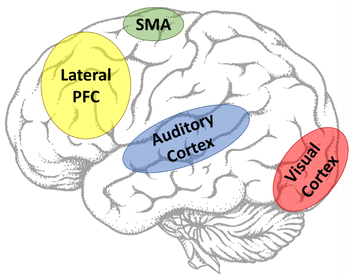
a) Granger causality (GC) of body sway reflects leader-to-follower relationship.
b) Seeing each other is not necessary for (a), but it magnifies (a).
c) Total GC in the ensemble reflects perceived performance quality.

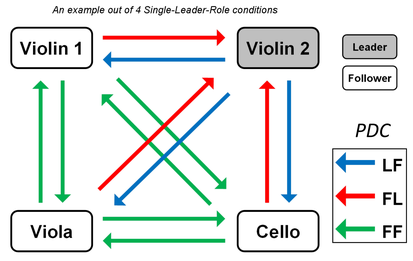




EEG SIGNAL PROCESSING

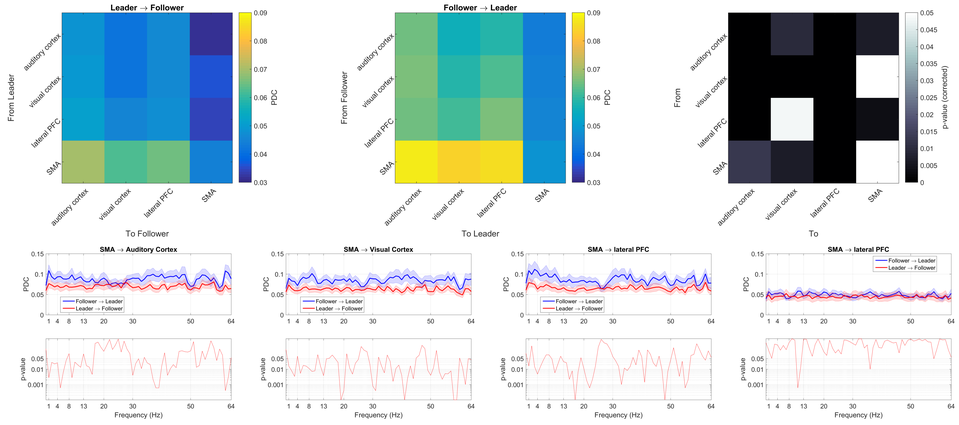
- 1 Hz high-pass filter, remove 60 Hz line noise (PREPpipeline of EEGLAB)
- Remove non-stationary artifacts using Artifact Subspace Reconstruction
- Downsample to 128 Hz
- Use beamforming to extract the source waveforms from bilateral ROIs
  - Auditory cortex: Heschl gyrus + superior temporal lobe
  - Visual cortex: occipital lobe
  - Lateral PFC (prefrontal cortex): DLPFC + VLPFC
  - SMA (supplementary motor area)
- Z-normalization for each time series
- Partial directed coherence (PDC)
  - PDC reflects the magnitude of directional information flow.
  - PDC among ROIs between individuals
  - Model order: 61 (477 ms), estimated by Bayesian information criterion
  - Collapse bilateral corresponding ROIs to lower the number of multiple comparisons





RESULTS

The Follower-to-Leader couplings were stronger than Leader-to-Follower



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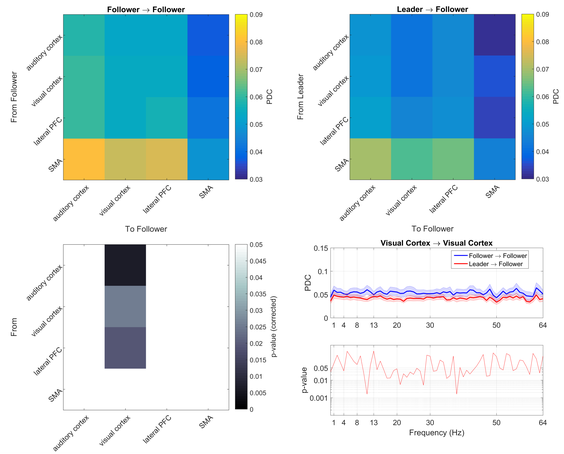

DISCUSSION

- Overall, the brain-to-brain coupling was weaker from leader-to-follower than the follower-to-leader and follower-to-follower directions.
  - The couplings of follower's SMA to leader's brain appears to be the strongest.
  - This counterintuitive result may suggest that
    - The followers were predicting the performance of the others.
    - The leader was monitoring the followers' performance.
- Frequency-domain partial directed coherence
  - Beta (13-30 Hz) and gamma (30-50 Hz) bands are involved in most brain-to-brain couplings from SMA.
- Next step: associations between brain-to-brain coupling & ratings of performance quality.
  - Find out what directed couplings are most relevant to interpersonal coordination in music ensemble performance.

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