Reliability of EEG functional connectivity based modular network organization

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Questions are welcome!

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How reliable are functional connectivity measures in EEG resting state?

Estimating source space connectivity from EEG data is challenging due to low SNR, spatial leakage and the abundance of metrics and parametrizations. In the absence of ground truth we should expect a proper metric to show within-subject and group-level consistency. Here we test the reliability of four different metrics on a large (*N* = 200) EEG resting state dataset (cf. Colclough et al., 2016). We further evaluate the overall modularity of the network and its consistency.

EEG recording and preprocessing (EEGLAB v2020)**:**
- *N* = 200; age 18 – 26y, *M* = 21.3 (*SD* = 1.8)
- Resting state with eyes open and visual fixation, one session
- Recording with 64-channels in 10-20 system, 1 kHz sampling, online lowpass with 100 Hz cutoff
- Re-referenced to average
- Band pass filter for 0.5 - 80 Hz, notch filter around 50 Hz
- Interpolation of max two bad channels
- ICA-based artifact removal
- Selected 75 non-overlapping, 4 secs long epochs from all subjects

Source localization (Brainstorm 2020August)**:**
- BEM head model with sLORETA, 15000 vertices
- Standard MNI template, no anatomical scans for participants
- Averaged source waveforms for 62 cortical areas based on the Desikan-Killany-Tourville atlas ("Mindboggle")

Frequency bands:
- EEGLAB FIR filters for frequency bands delta (0.5-4 Hz), theta (4-8 Hz), alpha (8-13 Hz), beta (13-30 Hz), gamma (30-80 Hz).

We only report here results for the **alpha** band.

Connectivity measures:

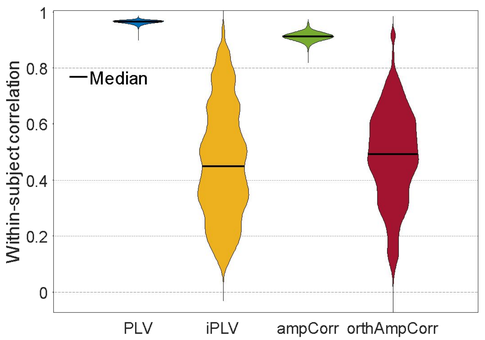
We selected one-one widely used phase- and amplitude envelope-based measure, both uncorrected and corrected for spatial leakage (zero-phase connections).

Phase-based
- Uncorrected: **Phase Locking Value (PLV);** Mormann et al., 2000
- Corrected: **Imaginary part of Phase Locking Value (iPLV)**; Palva and Palva, 2012

Amplitude envelope-based:
- Uncorrected: **Amplitude envelope correlation (ampCorr)**
- Corrected: **Correlation on pairwise-orthogonalized source data (orthAmpCorr)**; same method as in Coquelet et al., 2020

Within-subject reliability

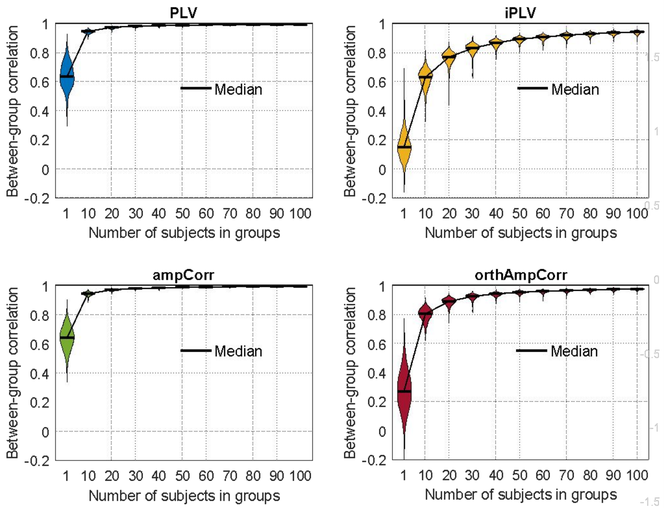
For each subject:
- we randomly divided their epochs into two halves
- averaged the corresponding connectivity matrices
- correlated the two averaged matrices
- repeated the above 1000 times and took the median correlation coefficient



Between-subject reliability

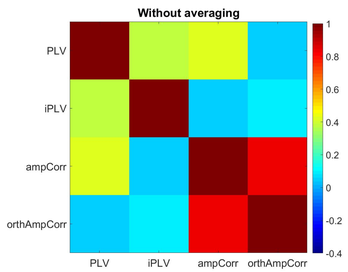
- Averaged the connectivity matrices across all epochs for each subject
- Randomly selected groups of subjects for a given group size
- Averaged subject-level connectivity matrices in groups
- Correlated subgroup-level connectivity matrices
- Repeated the above 1000 times

- For group size = 1 we pairwise correlated all subjects' connectivity matrices

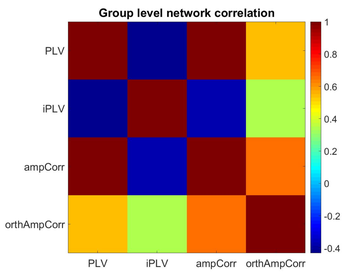


Relations between different measures

Correlations between measures for raw connectivity values (all edges from all subjects, all epochs)



Correlations between measures for group-level mean connectivity values (all edges of the connectivity matrix averaged across epochs and subjects)

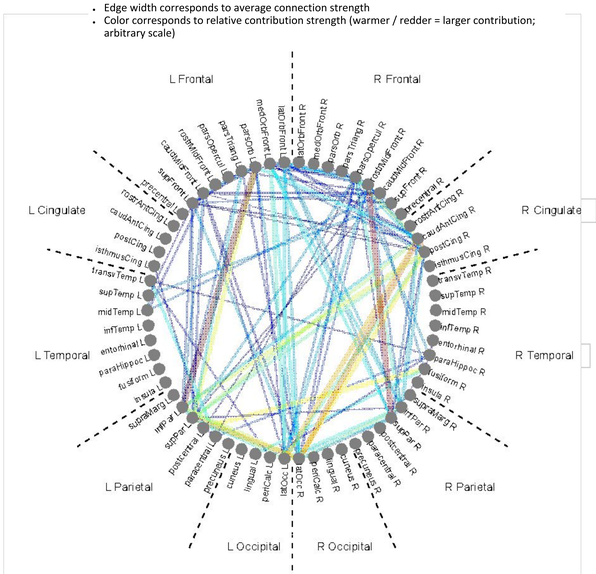


Edge contributions to between-subject reliability

The circle plot depicts the top ~5% of connections contributing the most to between-subject reliability for group sizes *N* = 100.

- Plot is for **orthAmpCorr**, as the most representative measure

- Edge width corresponds to average connection strength
- Color corresponds to relative contribution strength (warmer / redder = larger contribution; arbitrary scale)



Take aways

- There is a trade-off between spatial leakage correction and consistency: corrected measures (**iPLV** and **orthAmpCorr**) show considerable within-subject and between-subject variability relative to uncorrected measures (**PLV** and **ampCorr**). This difference – while smaller – remains there with increasing group sizes.
- There is a marked difference between different connectivity measures, even for the overall group average. In particular, **iPLV** depicts a different connectivity map.
- At least for **ampCorr** and **orthAmpCorr**, large-scale, overall functional connectivity is comparable to known EEG / MEG resting state descriptions.
- The edges showing the largest consistency correspond to (1) bilateral fronto-parietal, (2) right cingular-occipital, and (3) right cingular – left parietal, long-range connections.
- Between-subject reliability in terms of modules remains relatively low. Values around 0.4-0.5 correspond to different module memberships of ~20 nodes.
- Not shown, but modularity partition similarity across different metrics reflects the differences in group average connectivity maps.

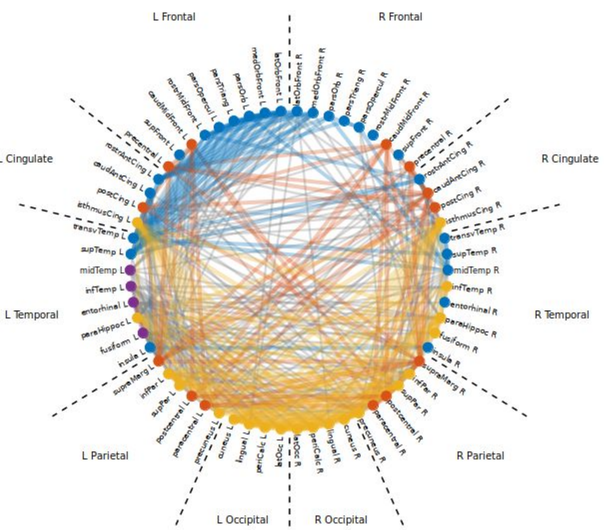
Between-subject reliability in modularity

Modularity detection with a default quality function and a Louvain-like algorithm (Mucha et al., 2010; Bassett et al., 2013; Bazzi et al., 2016).

Group-average partition shown for **orthAmpCorr**, as representative for other measures as well.

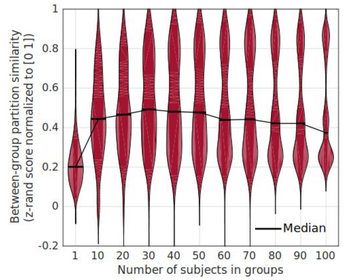
- Modularity detection first on subject-level connectivity matrices (averaged over epochs), 100 repetitions, iterative consensus partition (Bassett et al., 2013)
- Group-level partition is the consensus partition over subject-level partitions
- Estimated null models for the quality function from surrogate (phase-scrambled) data
- At spatial resolution parameter (gamma) = 1

- Colors = Modules (*n* = 4) Edge width = relative connection strength



Between-subject reliability of modularity as a function of group size

- Modularity calculated on subgroup average matrices
- Similarity measured with z-rand scores



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A PDF version of this poster and the reference list is available at https://github.com/dharmatarha/Sfn_poster_2021Jan
All code used for connectivity and modularity measures can be found at https://github.com/dharmatarha/eeg_network_pipeline/