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Similarity and modular organization of resting-state EEG networks

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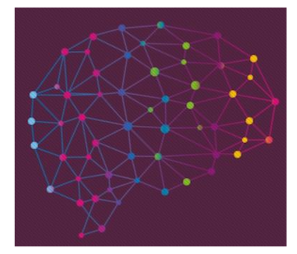

How similar are resting-state EEG networks on the group level using different functional connectivity measures?

Estimating source space connectivity from EEG data is challenging due to low SNR, spatial leakage and the abundance of metrics and parametrizations. Here we test (1) The group-level reliability of four different functional connectivity methods on a large (N = 200) EEG resting-state dataset (cf. Colclough et al., 2016);
(2) The relationships between different connectivity methods by comparing group-level connectivity matrices with different similarity measures;
(3) The group-level reliability of module detection.

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

Thresholding of connectivity matrices:

- Generated surrogate data sets by phase-scrambling the source-localized, filtered data, 1000 times
- Estimated connectivity on each surrogate data set, with all methods
- Fitted surrogate connectivity values with truncated normal distributions, derived parametric estimates of surrogate connectivity matrices
- Thresholded average subject-level connectivity matrices (averaged across epochs) against surrogate estimates using FDR (q = .05)

Graph distance measures:

We selected two conventional distance measures, two spectral distance measures, and one distance measure based on the fast belief propagation method:

- **Correlation**
- **Euclidean distance**
- **Adjacency spectral distance**
- **Laplacian spectral distance**
- **DeltaCon**; Koutra et al., 2016

All code used for connectivity and modularity measures can be found at:
https://github.com/dharmatarha/eeg_network_pipeline

Poster and references are at:
https://github.com/dharmatarha/NagyPeter_ESCAN_2021_poster

Questions are welcome!

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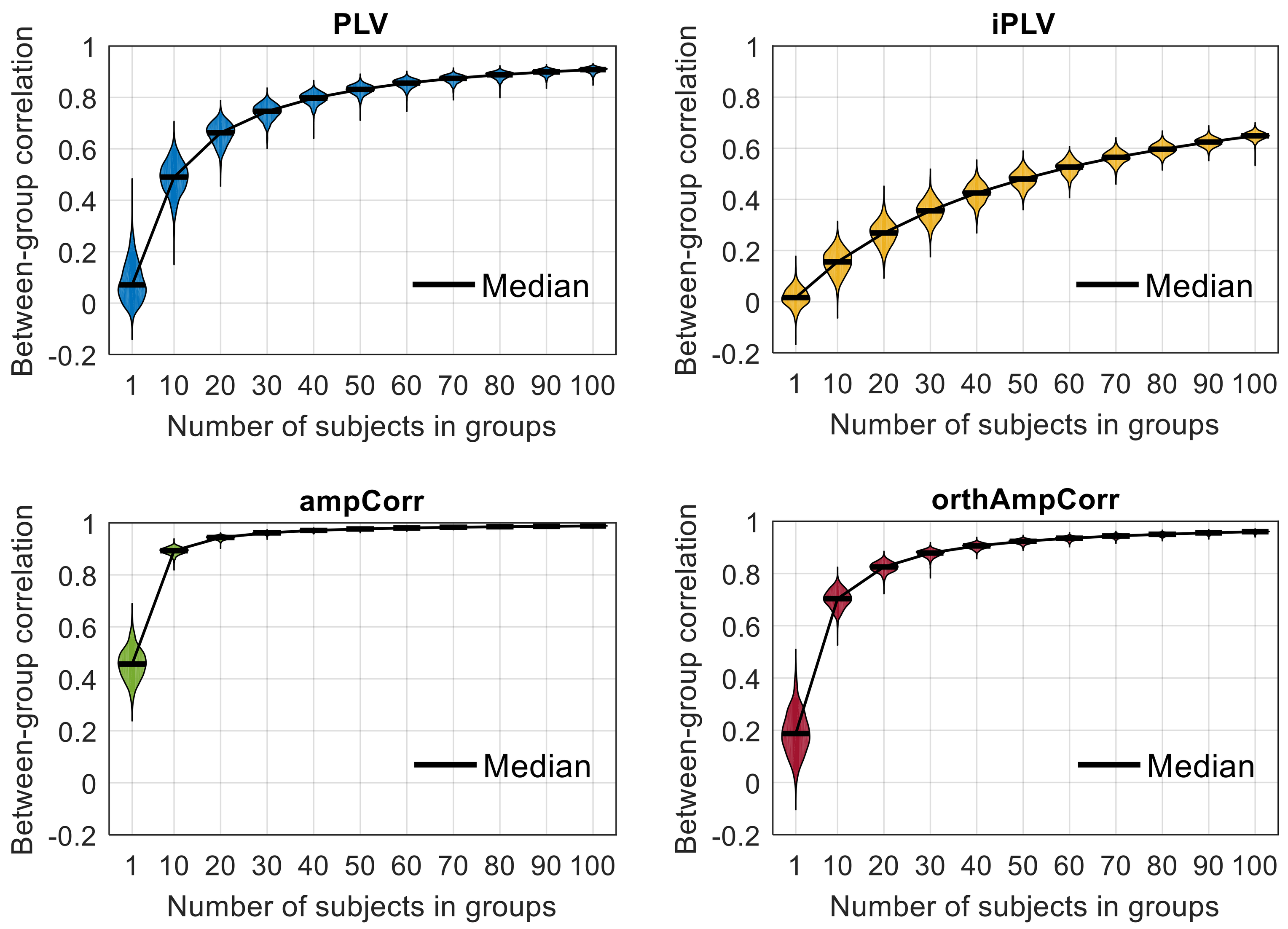
Between-subject reliability

- Started with subject-level average connectivity matrices (averaged across epochs and thresholded statistically)
- Randomly selected groups of subjects for a given group size, 1000 times
- Averaged subject-level connectivity matrices in groups
- Correlated subgroup-level connectivity matrices

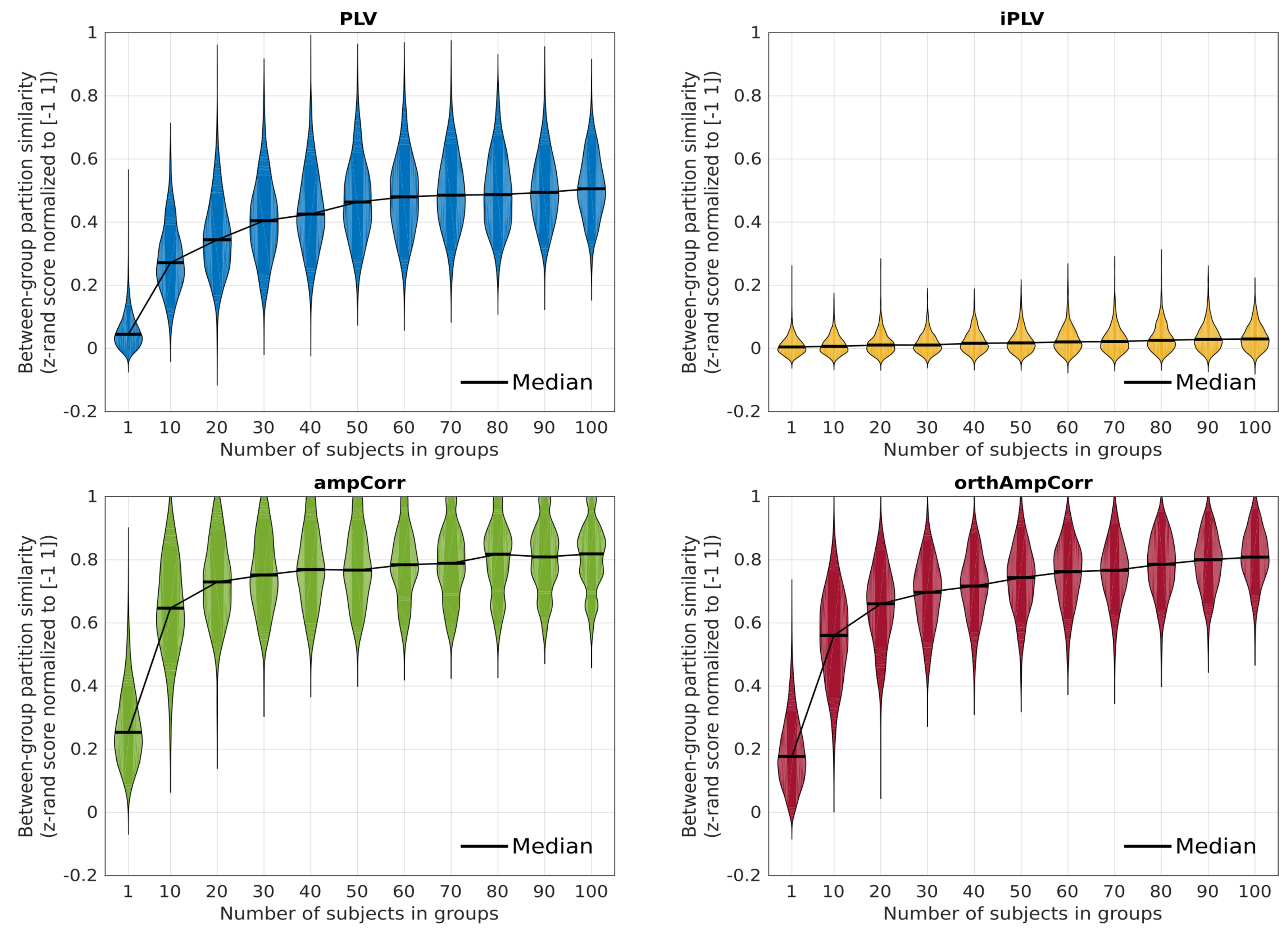
- For group size = 1 we pairwise correlated all subjects' connectivity matrices



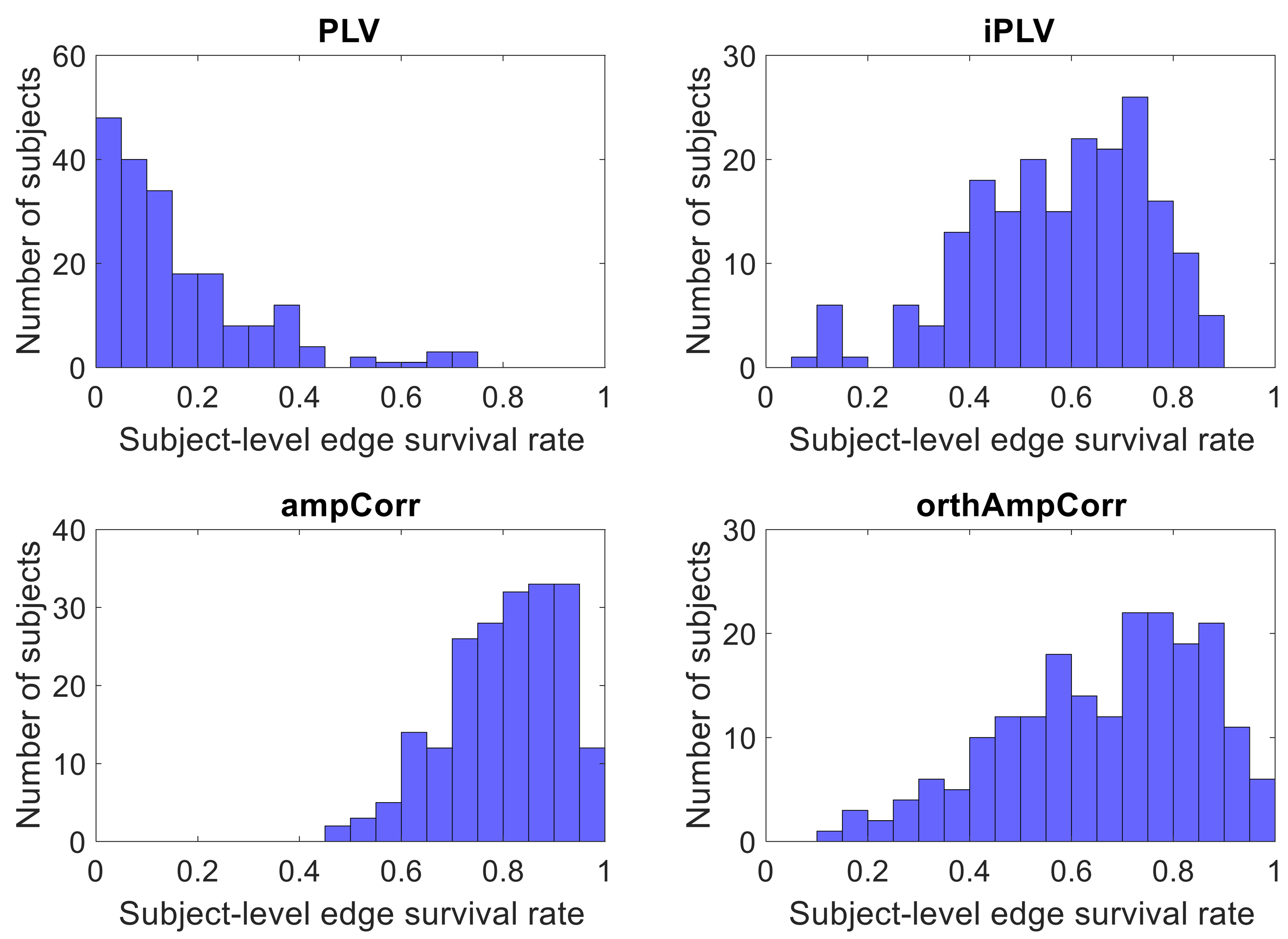
Module-detection reliability

- Started with subject-level average connectivity matrices (averaged across epochs and thresholded statistically)
- Randomly selected groups of subjects for a given group size, 1000 times
- Averaged subject-level connectivity matrices in groups
- Detected modules with Louvain-method (modularity maximization with Newman-Girvan null; 100 iterations for each; selection with consensus; resolution parameter γ = 1; see Bassett et al., 2013)
- Compared resulting partitions with z-rand score (Traud et al., 2011), normalized to range [-1 1]

- For group size = 1 we pairwise compared subjects' consensus partitions

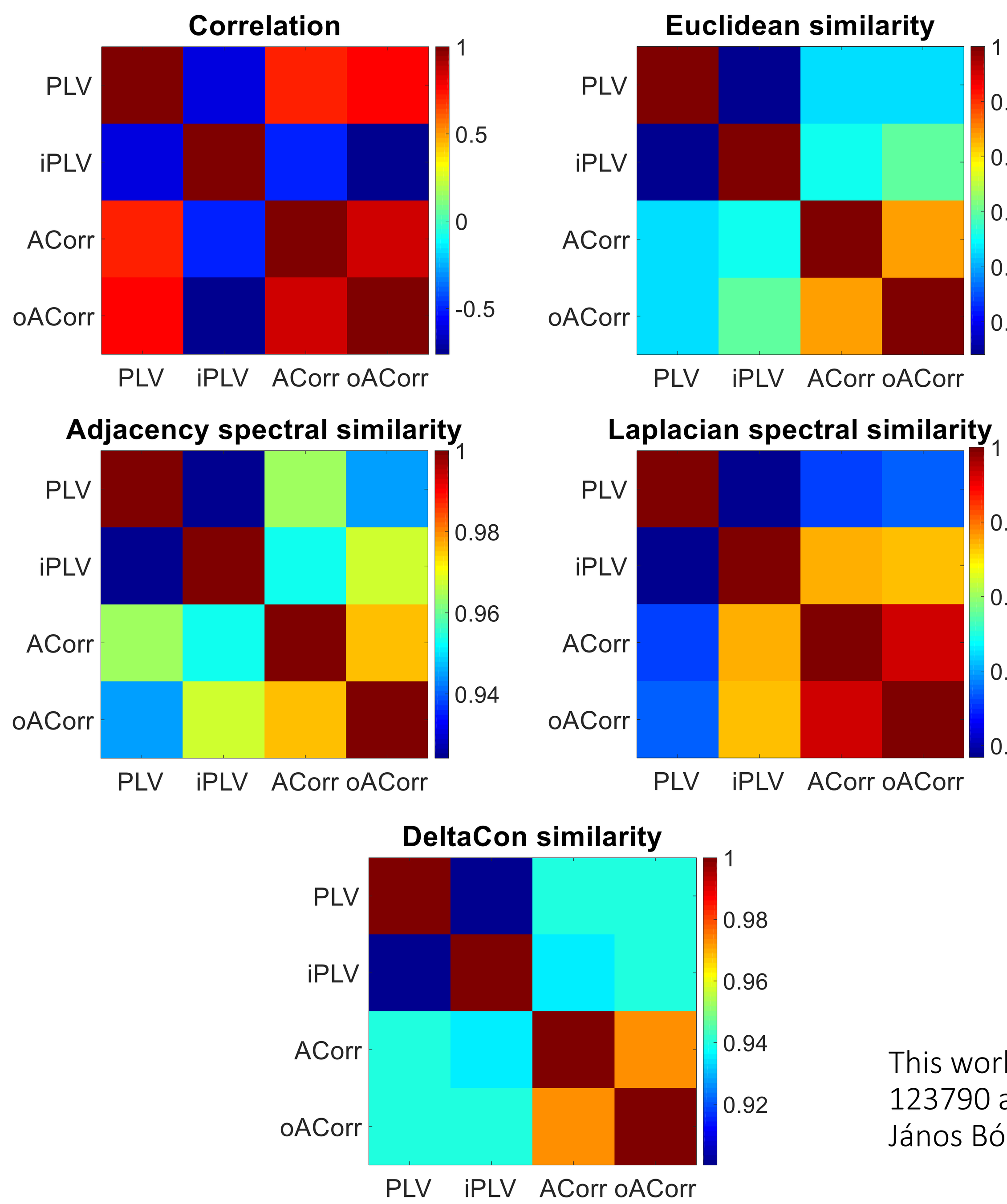


Edge survival rate after thresholding



Relations between different measures

- Averaged thresholded subject-level connectivity matrices (group-level connectivity values)
- Compared group-level connectivity matrices with different graph similarity (inverse of graph distance) measures



Take aways

- Amplitude envelope-based connectivity measures show higher between-subject reliability of connectivity matrices compared to phase-based connectivity measures.
- There is a trade-off between spatial leakage correction and consistency: corrected measures (**iPLV** and **orthAmpCorr**) show considerable between-subject variability relative to their uncorrected counterparts (**PLV** and **ampCorr**).
- **PLV** shows high susceptibility to the thresholding of connectivity matrices, compared to other measures.
- Group-level similarity of connectivity matrices is the highest between **ampCorr** and **orthAmpCorr** with all examined graph similarity measures. Group-level similarity between **PLV** and **iPLV** is very low everywhere. Similarity maps show high correspondence for Euclidean and DeltaCon similarity, but not for the other graph similarity measures.
- Module-detection reliability shows a similar picture to between-subject reliability of connectivity matrices, with higher reliability for amplitude envelope-based connectivity measures than for phase-based connectivity measures and higher reliability for uncorrected measures than for their counterparts corrected for spatial leakage.

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