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Power-Law Dynamics in Cortical Excitability as Probed by Early Somatosensory Evoked Potentials

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Introduction

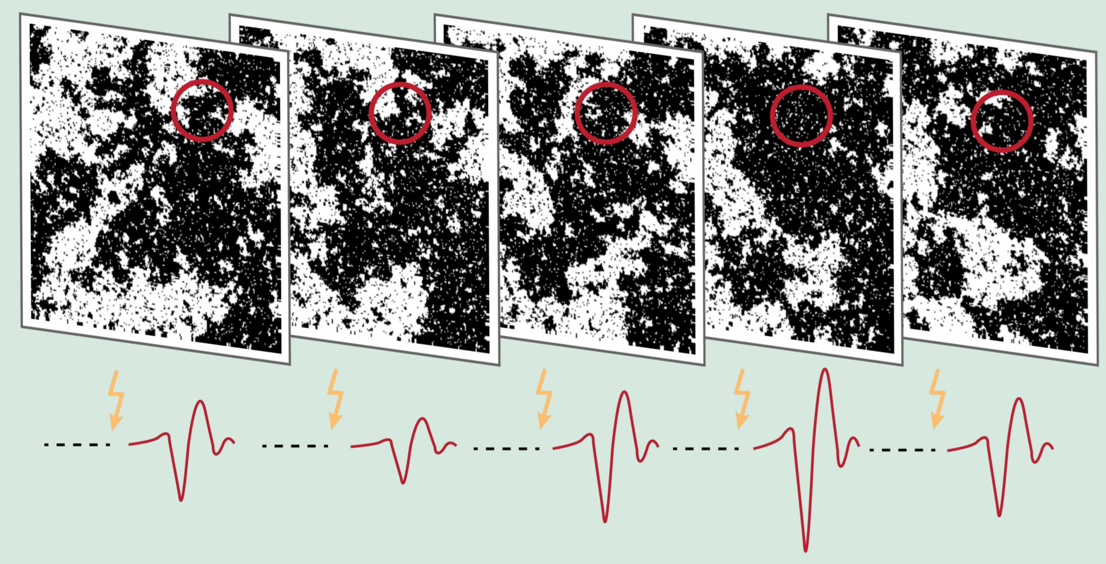
- Brain processes in response to identical sensory stimuli vary from moment to moment → fluctuations in cortical excitability (e.g. VanRullen, 2016; Iemi et al., 2017)
- Neuronal systems operate at a critical state
  - Optimal trade-off between robustness to perturbations and flexibility to adapt to changes (Munoz, 2018; Shew & Plenz, 2013)
  - Characteristic signature of a system being at a critical state: **spatio-temporal dependencies measured as "power-law dynamics"**
- "Probe" of cortical excitability: N20 component of the somatosensory evoked potential (SEP)
  - First afferent volley from thalamus to cortex (Allison et al., 1991)
  - Reflects excitatory post-synaptic potentials (EPSP) (Wikström et al., 1996; Bruyns-Haylett et al., 2017)
- **Hypothesis: Cortical excitability demonstrates long-range temporal dependencies (power-law dynamics).**

Methods

- 31 healthy subjects (male; 21-45 years)
- Electrical stimulation of the median nerve at the left wrist (1000 stimuli; ISI: 713±50 ms; intensity: 1.2 x motor threshold)
- EEG recording (60 channels) + compound nerve action potential (CNAP) of median nerve (on inner side of upper arm)
- Detrended Fluctuation Analysis (DFA) for evaluation of power-law dynamics:

$$\langle F(\tau) \rangle \propto \tau^{\alpha}$$

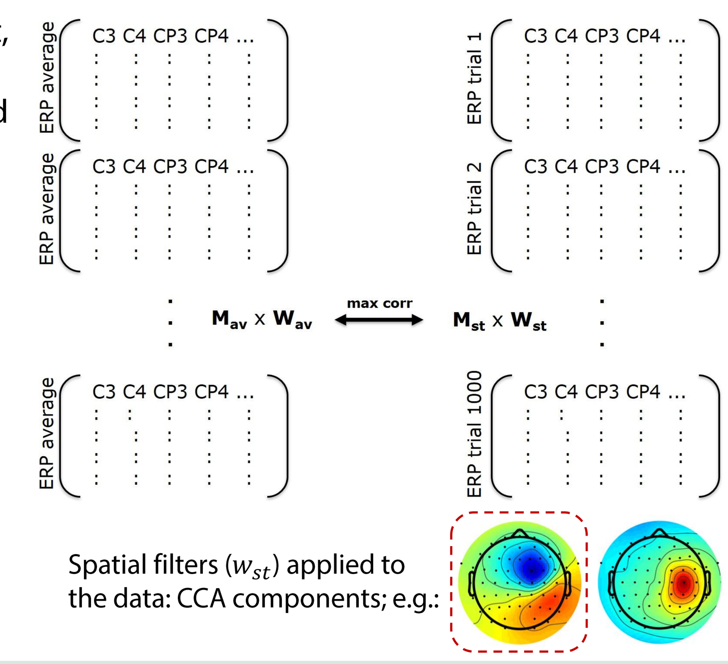
The DFA exponent α indicates the degree of temporal dependencies within a time series (fluctuation F is measured in window sizes τ from 7 to 70 trials, i.e. ~5 to ~50 sec).



EEG analysis

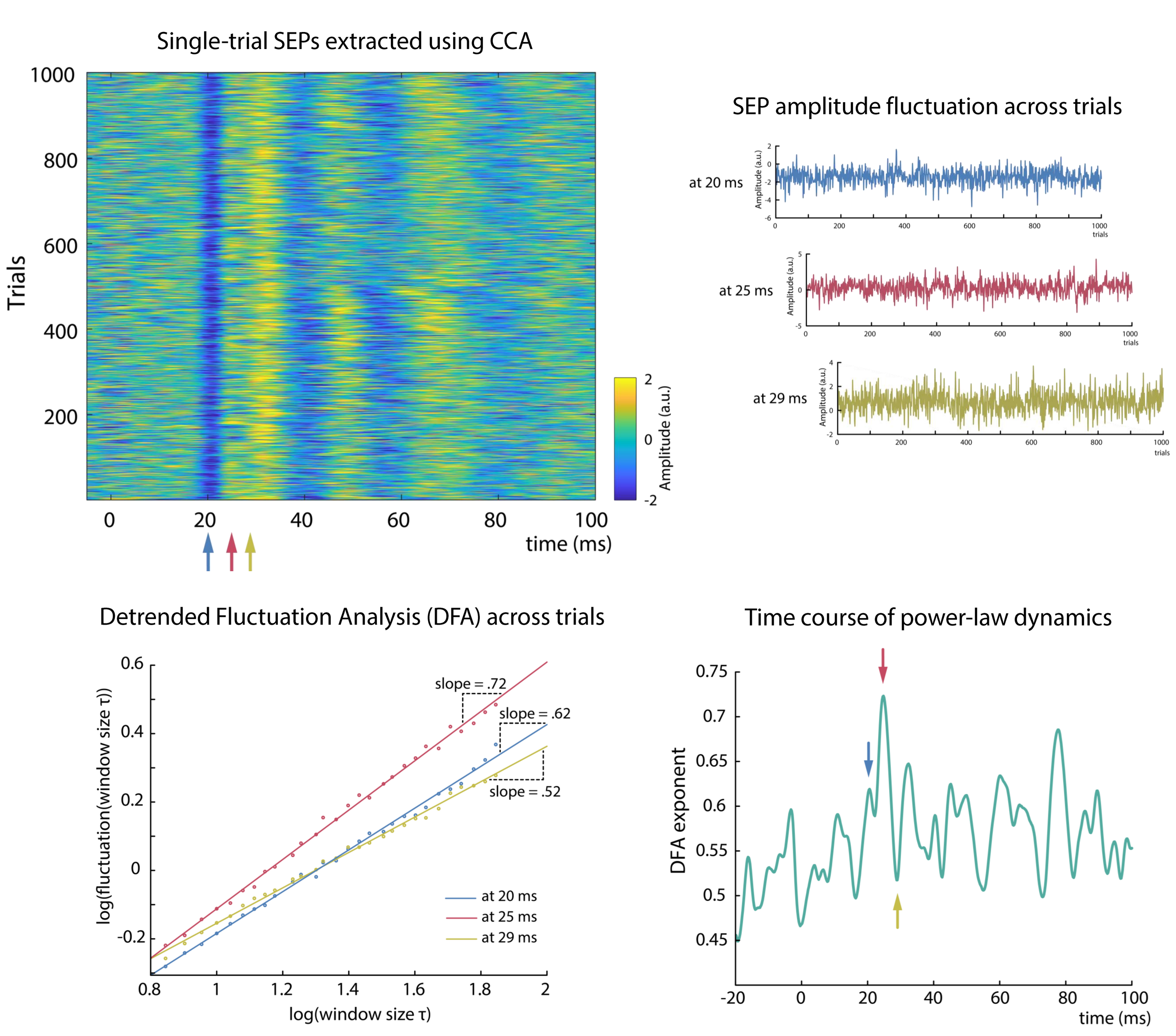
- Interpolation of stimulus artifact, average reference, artifact removal by visual inspection and ICA, band-pass filter 30-200 Hz
- Single-trial SEPs were extracted using Canonical Correlation Analysis (CCA) and components with a tangential spatial pattern were identified
- Source reconstruction was performed with eLoreta (Pascual-Marqui, 2007) based on individual head models

Canonical Correlation Analysis (CCA) for single trial extraction



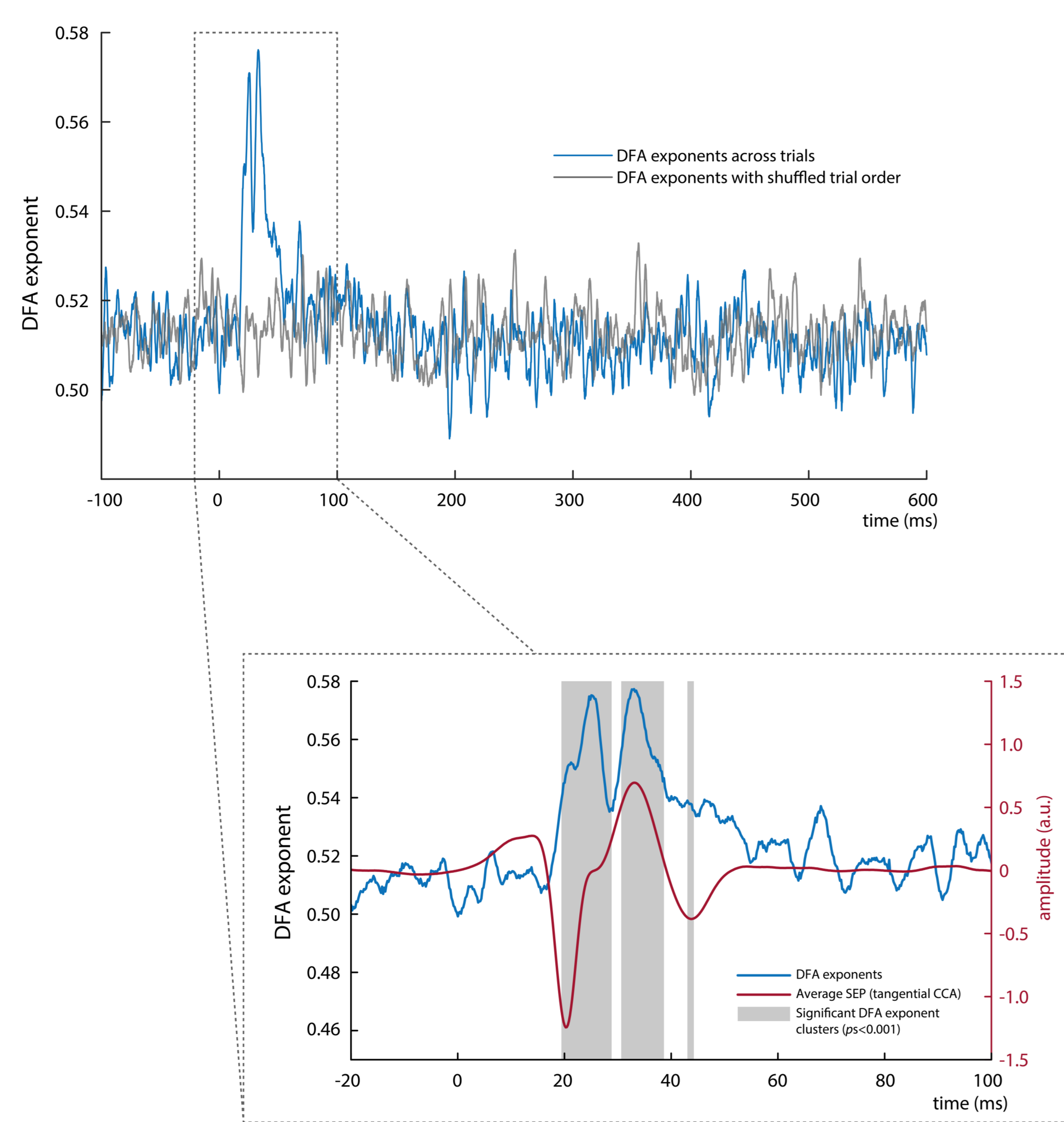
Results

1 Derivation of power-law dynamics from single-trial SEPs of an exemplary subject (tangential CCA component)



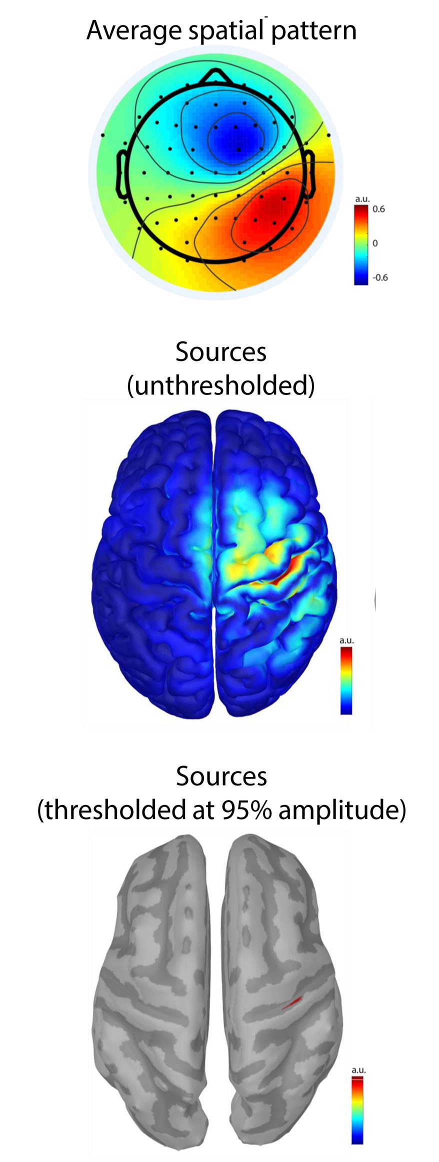
DFA exponent time courses were calculated individually for every subject before being averaged across subjects

Grand average of power-law dynamics (tangential CCA components)



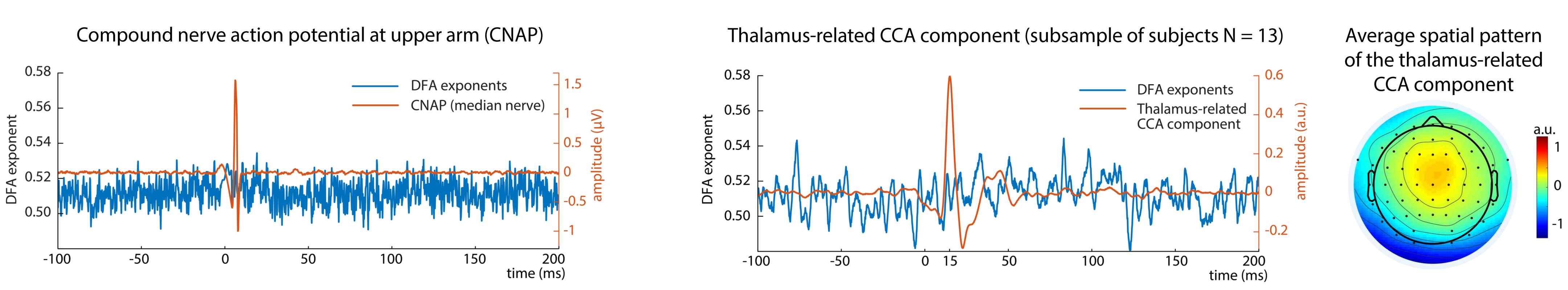
Power-law dynamics are present in the early SEP, starting around the peak of the N20 component

2 Source reconstruction (tangential CCA components)



Strongest generators of the SEP (tangential CCA component) in Brodmann area 3b, hand region

3 Control measures



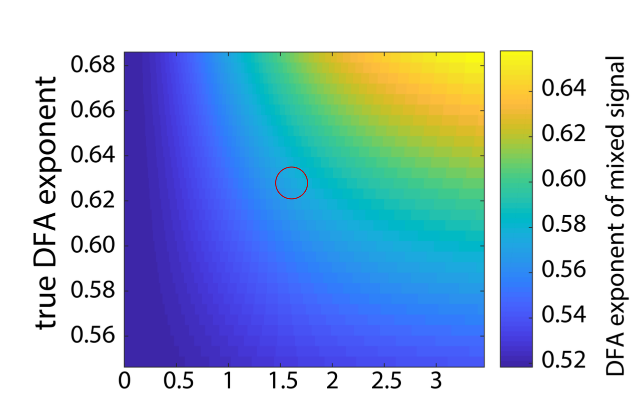
No power-law dynamics in peripheral nerve activity

No power-law dynamics in thalamic activity (P15 component of the SEP)

4 Influence of signal-to-noise ratio (SNR)

- r (SNR ~ power-law dynamics) = .55; $p < .05$; average SNR = 1.64
- Simulations: Time series expressing power-law dynamics were mixed with white noise (DFA exponent of 0.5) and varying SNR

→ Given an SNR of 1.64, a true exponent of **~0.63** can be expected when observing an empirical exponent of ~0.575



Conclusions

- **Long-range temporal dependencies in fluctuations of cortical excitability**
  - Power-law dynamics are present in early somatosensory evoked potentials starting with the N20 peak which reflects EPSPs
  - Power-law dynamics likely of cortical origin
    - Starting with first cortical excitation (N20)
    - White noise in subcortical and peripheral signals
  - Presumably, underestimation of true exponents due to SNR
- **Results are consistent with the hypothesis that instantaneous neuronal excitability is poised at a critical state → *criticality hypothesis***

Open questions & project prospects

- Do power-law dynamics of cortical excitability reflect local or global fluctuations?
- Relation to ongoing activity (e.g. alpha oscillations)?
- Functional implications: Do fluctuations in initial cortical excitability influence stimulus perception (e.g. in somatosensory discrimination tasks)?
- What network parameters underlie long-range temporal dependencies in the primary somatosensory cortex and are they generalizable to other modalities?

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