Cortical excitability shapes somatosensory perception with spatiotemporally structured dynamics

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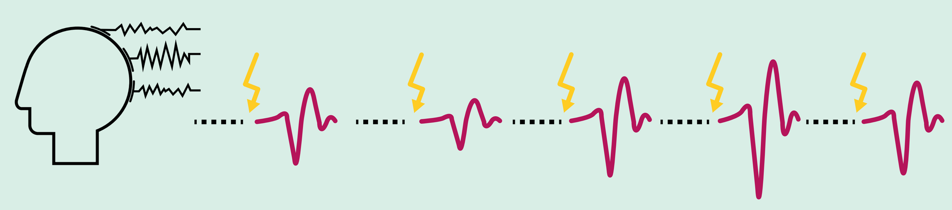
Introduction



In perception, no neural response is exactly the same, even to identical sensory stimuli – why?

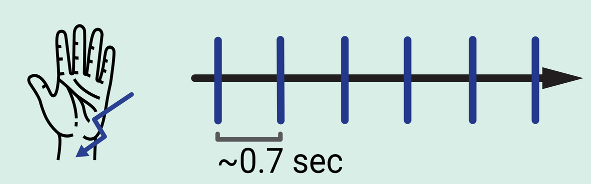
- Moment-to-moment variability of sensory processing is associated with instantaneous changes of cortical excitability. [1-4]
- Yet it is unclear how these dynamics are organized and on which level the modulation of perception takes place.

1. **What is the temporal structure of spontaneous fluctuations of cortical excitability?**
2. **How do excitability changes relate to the intensity perception of sensory stimuli?**
3. **Do these fluctuations reflect local or global dynamics?**

Methods

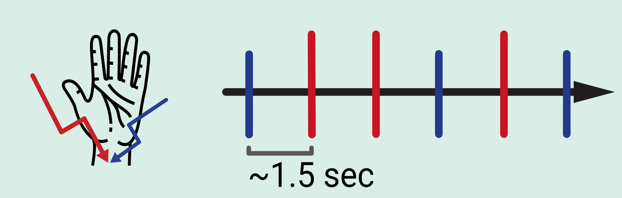
➢ Three somatosensory stimulation paradigms in humans

- Study 1 (N=31): "Resting-state" incl. median nerve stimulation



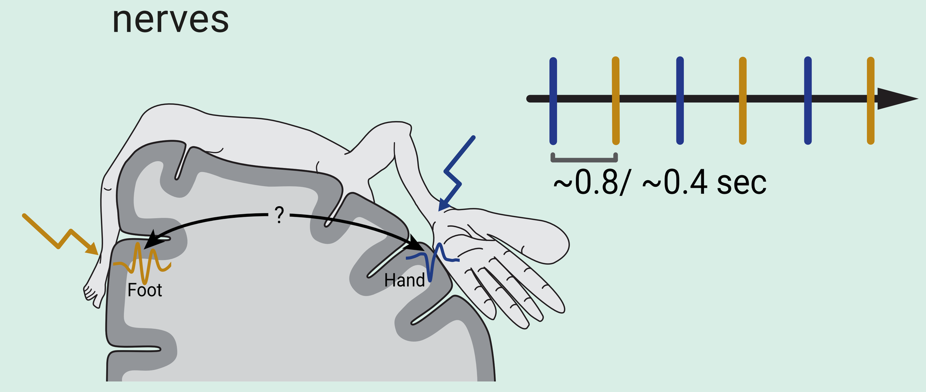
- 1000 stimuli of same intensity: 1.2 x motor threshold
- no task

- Study 2 (N=32): Somatosensory discrimination task



- 1000 stimuli of two intensities
- Task: indicate stimulus intensity by button press
- Δintensity: slightly above least noticeable difference

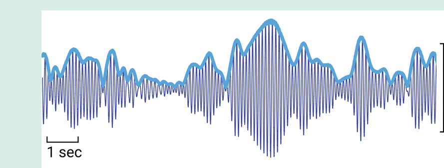
- Study 3 (N=38): Alternating stimulation of median and tibial nerves



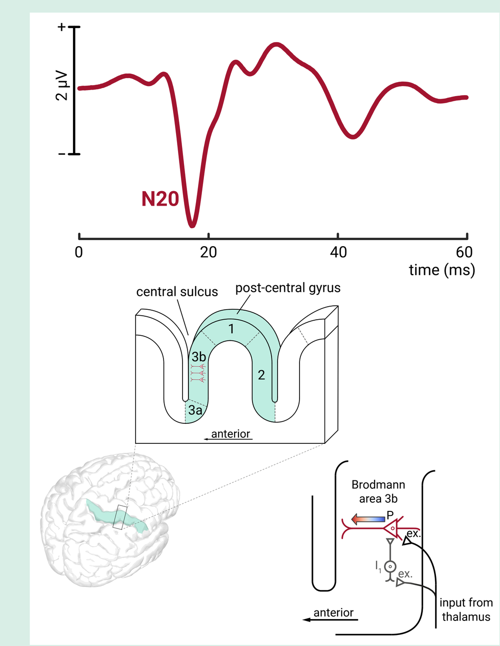
ISI varied between participants: $N_{long}=15$; $N_{short}=23$

➢ EEG measures of cortical excitability

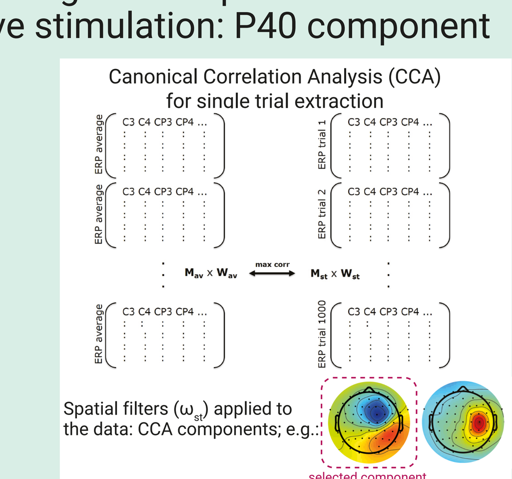
a) Pre-stimulus oscillatory activity in the alpha band (8-13 Hz) of the EEG [4-7]



b) N20 component of the somatosensory evoked potential (SEP)



- reflects initial excitatory post-synaptic potentials (EPSP) in Brodmann area 3b [8-10]
- direct measure of cortical excitability in response to median nerve stimulation
- Single-trial SEPs extracted using Canonical Correlation Analysis (CCA) [11]
- homologous component in tibial nerve stimulation: P40 component



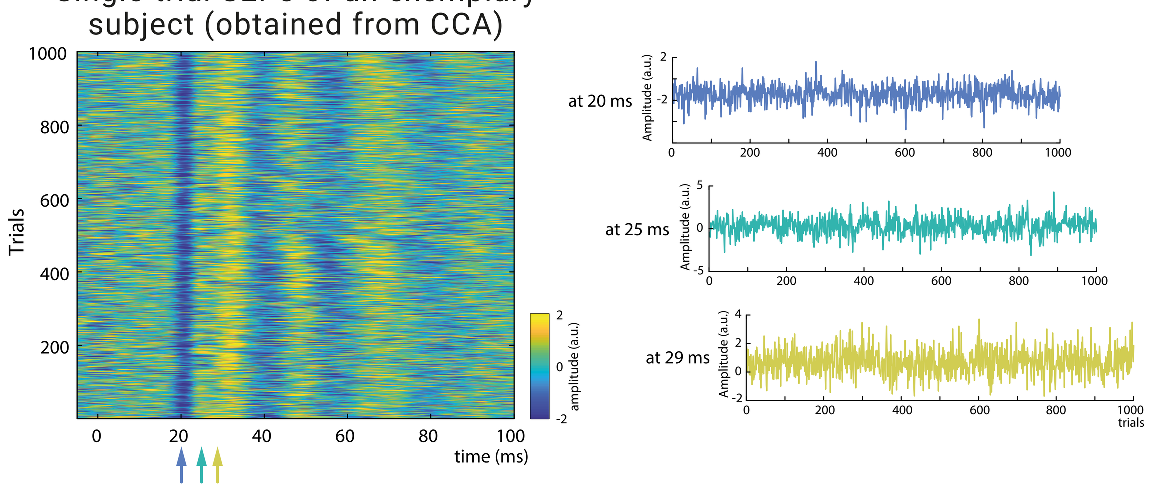
➢ Additional peripheral measures:

- CNAP (compound nerve action potential)
- CMAP (compound muscle action potential)

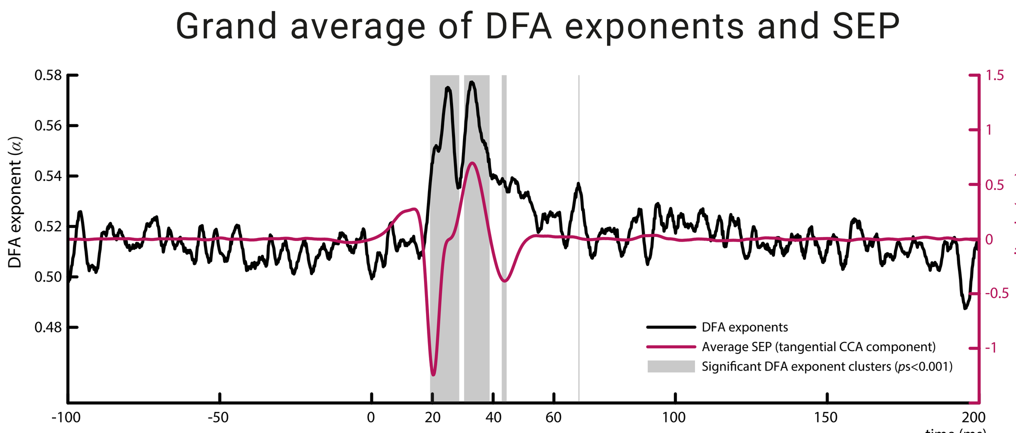
Results

Study 1 — Signatures of criticality in excitability fluctuations

Single-trial SEPs of an exemplary subject (obtained from CCA)



Grand average of DFA exponents and SEP



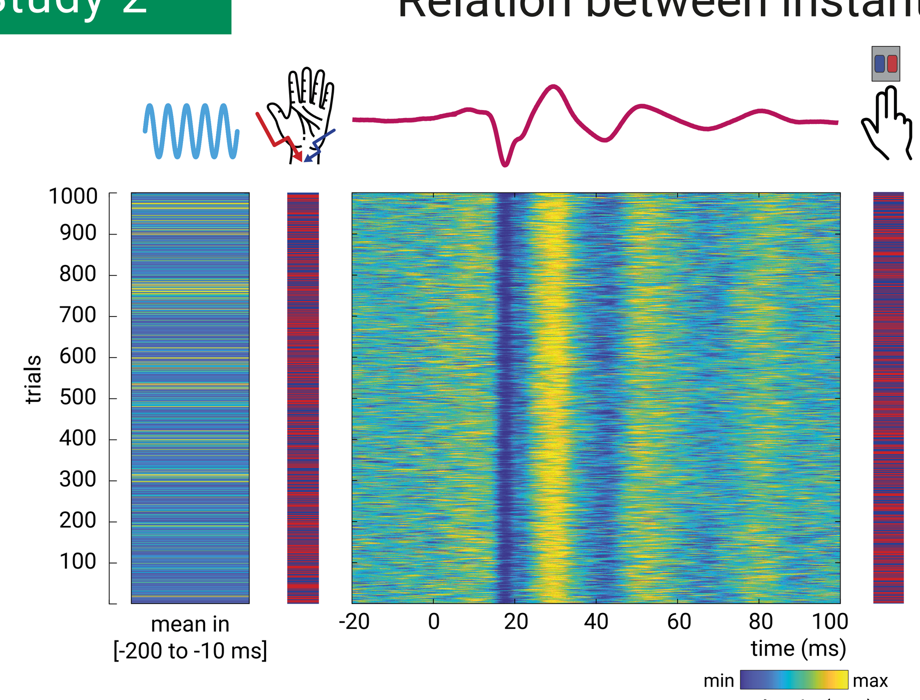
- Variability in cortical excitability is of a special type: power-law dynamics in early SEP amplitudes over trials ("scale-freeness"), quantified using Detrended Fluctuation Analysis (DFA[12]):

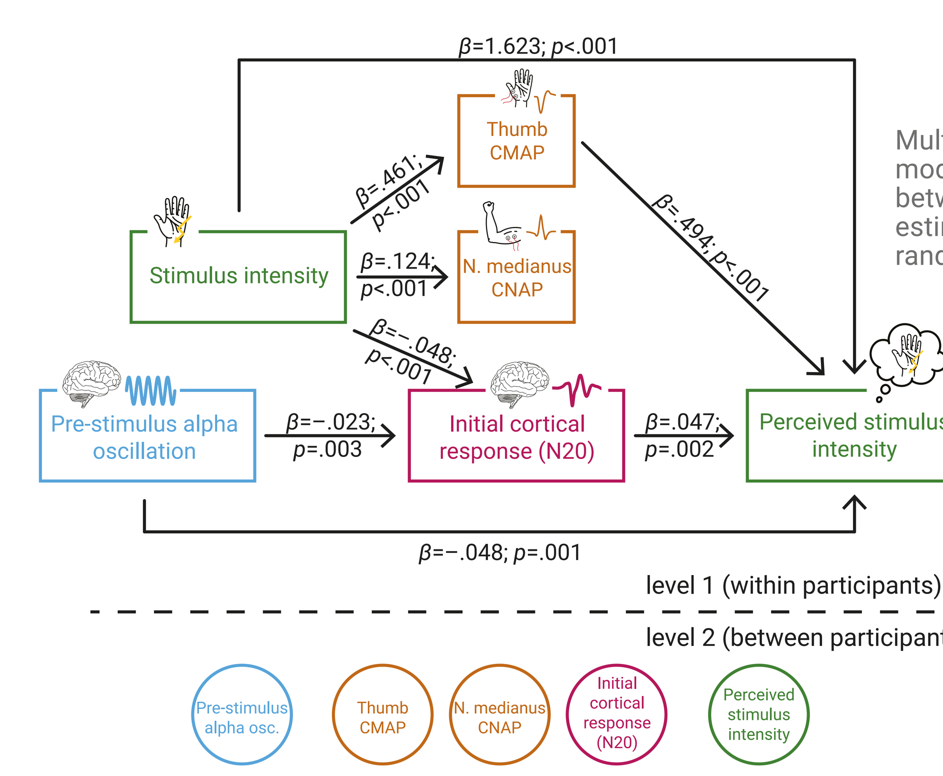
$$F(\tau) \sim \tau^{\alpha}$$

- Signature of (self-)organization of a system at a so-called critical state [13-15]

Stephani, Waterstraat, Haufe, Curio, Villringer & Nikulin, 2020, JNeurosci

Study 2 — Relation between instantaneous excitability and perceived stimulus intensity



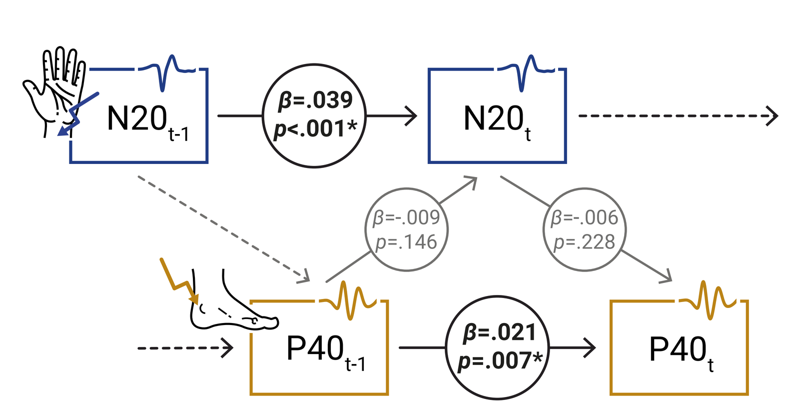


Multi-level structural equation model (SEM) with effect paths between manifest variables estimated on level 1 and random intercepts on level 2.

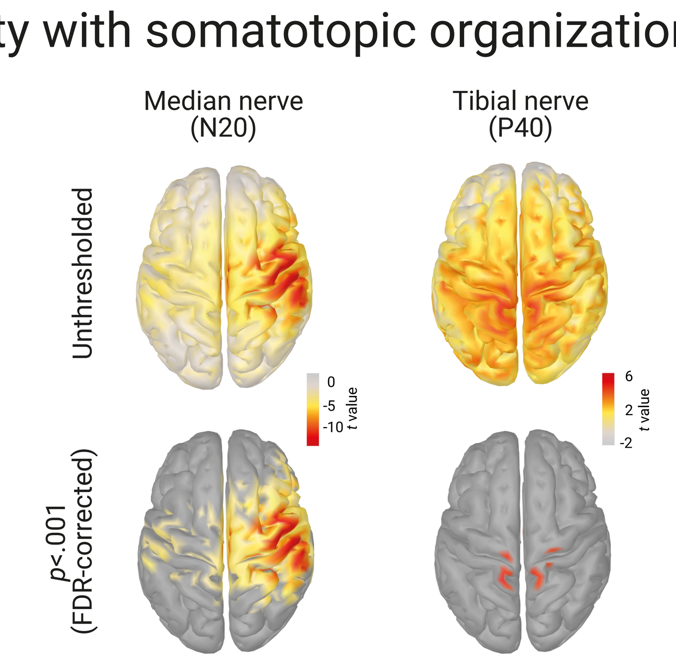
- Neural excitability shapes the perceived stimulus intensity already during the very first cortical response (~20 ms)
- Reflected both in fluctuations of pre-stimulus alpha oscillatory activity (8-13 Hz) and single-trial SEPs

Stephani, Hodapp, Jamshidi Idaji, Villringer & Nikulin, 2021, eLife

Study 3 — Local dynamics of cortical excitability with somatotopic organization



Cross-lagged structural equation model: Path coefficients reflect random slopes on group level, derived from a bayesian model estimation with corresponding *posterior predictive p-values* (performed in *Mplus*).



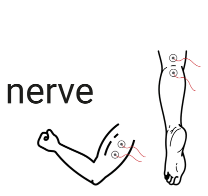
Linear mixed effects models in source space:

$N20 \sim 1 + prestimulus\ alpha_{vertex\ i} + (1|subject)$

$P40 \sim 1 + prestimulus\ alpha_{vertex\ i} + (1|subject)$

Analysis pooled across long and short ISIs (N=38).

- Temporal dependencies within but not between stimulation sites
- No influence on effects by ISI and by peripheral nerve activity (not shown here)



- Effects show a somatotopic organization (spatial specificity)

Stephani, Nierula, Villringer, Eippert & Nikulin, 2022, NeuroImage

Discussion

1. Cortical excitability fluctuates over time with a temporal structure that is characteristic for dynamics near a critical state.
   →Possible benefits: dynamic range, information processing and capacity are maximized [16,17]
2. Changes of cortical excitability influence how strong stimuli are perceived from earliest cortical processing onwards.
   →In line with previous findings on alpha oscillations [18, 19] and extending to supra-threshold stimuli
   →Opposing signatures of stimulus intensity and excitability in initial cortical responses (may reflect the EEG´s sensitivity to post-synaptic currents not potentials)
3. Spatially confined neural state-response dynamics: Excitability fluctuations are organized somatotopically.

Conclusion:

Spontaneous fluctuations of cortical excitability do not occur stochastically independently (=random noise) but reflect structured system dynamics (=functional signals) with behaviorally relevant consequences for perception.

Study 1 | Study 2 | Study 3

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