Time-Resolved Parameterization of Aperiodic and Periodic Brain Activity

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Introduction

Brain activity is characterized by complex dynamics across multiple coexisting time scales, with fluctuations corresponding to physiology[1], behaviour[2], and disease[3]. Recent work has shown that brain activity can be decomposed into at least two broad types of dynamics: one that is **periodic** (rhythmic), and one that is **aperiodic** (arrhythmic)[4]. Many tools exist to study the distinct roles of periodic and aperiodic brain activity[4], but these methods cannot resolve their respective signal **dynamics in time**.

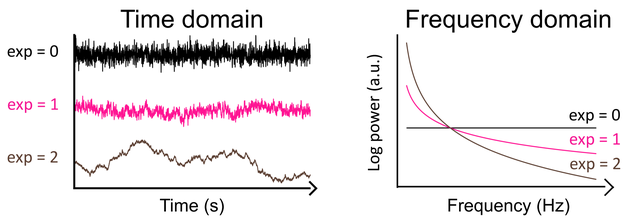
Here, we develop an open-source, **time-resolved** approach to **parameterize aperiodic and periodic fluctuations** in brain signals. We demonstrate the strengths of this method with extensive controlled simulations of naturalistic brain activity.

Methods

We parameterize spectral components of brain activity in frequency-space using *specparam*[4].

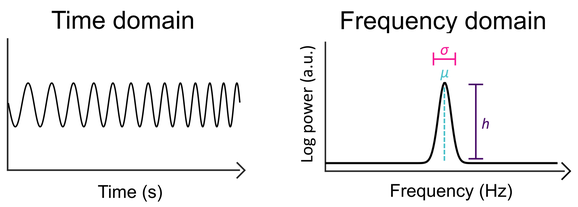
Aperiodic activity is parameterized as an inverse power-law function of the form:

$$A(f) = b - \log f^{a}$$, where a = exponent, b = offset

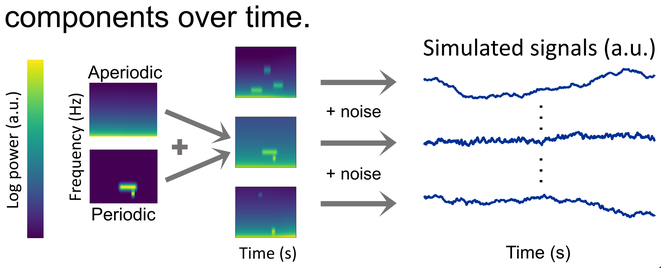


Periodic components are parameterized using multiple Gaussian functions of the form:

$$P(f) = \sum_{k=1}^{n} h_k * e^{-\frac{\left(\frac{f-\mu_k}{\sigma_k}\right)^2}{2}}$$, where n = # of peaks, h = amplitude, μ = centre freq., σ = st. dev.

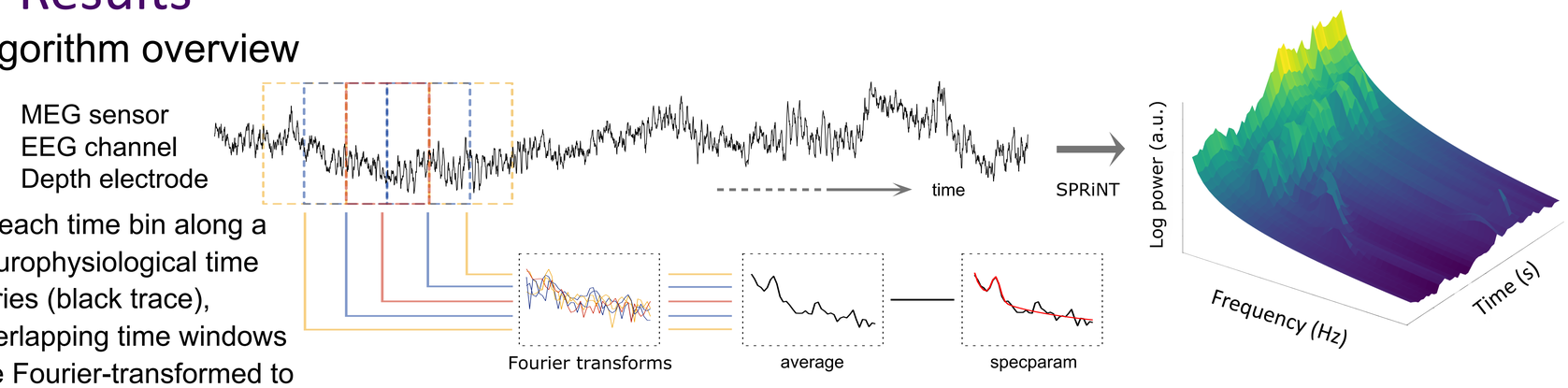


We simulated 10,000 unique, dynamic neural signals using scripts adapted from NeuroDSP[5], with variable aperiodic and periodic signal components over time.



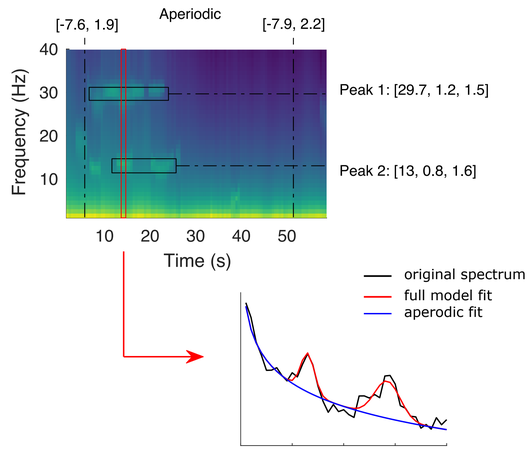
Results

Algorithm overview



At each time bin along a neurophysiological time series (black trace), overlapping time windows are Fourier-transformed to yield an estimate of spectral contents, which is subsequently parameterized using *specparam*[4]. This procedure is iterated over time by sliding the overlapping windows to generate a parameterized spectrogram of neural activity. We refer to this algorithm as *SPRiNT*, for Spectral Parameterization Resolved in Time.

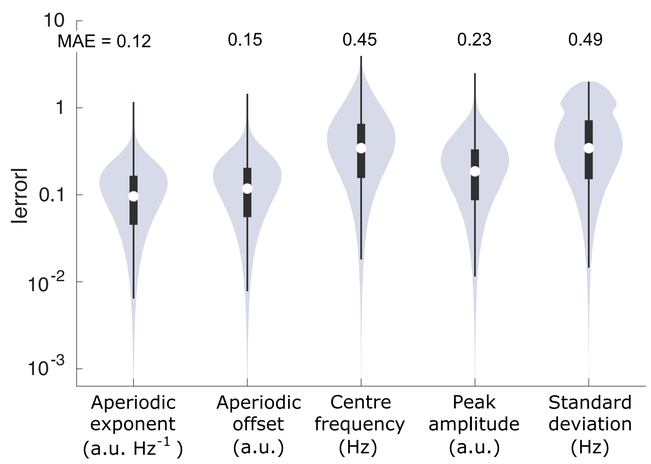
Performance assessment



Each unique time series simulation was composed of a dynamic aperiodic component and 1-4 oscillatory peaks.

Algorithm performance was measured at each time window using mean absolute error (MAE) of estimated parameters and specificity/sensitivity of oscillatory peak detection.

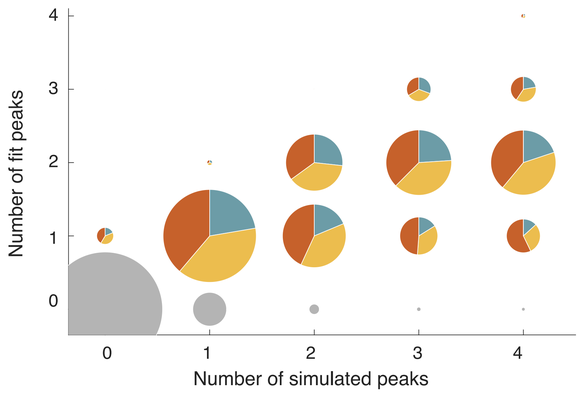
Algorithm performance

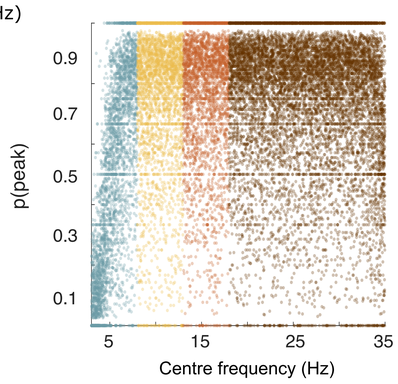


Dynamic aperiodic parameters were estimated accurately.

Peak bandwidth was systematically over-estimated, while centre frequency and amplitude were estimated accurately.

Overall, oscillatory peaks were detected with 69% sensitivity and 89% specificity.





SPRiNT had proportionally less sensitivity for peaks in the 3-8 Hz range (blue).

Discussion

We present SPRiNT as an open-source tool to parameterize the neural spectrogram.

SPRiNT accurately estimates spectral parameters in the presence of aperiodic and periodic dynamics. Peak bandwidth estimation can be improved by increasing resolution in frequency (at the cost of temporal resolution).

Sensitivity to oscillatory peaks was lower between 3-8 Hz, but remained consistently higher above 9 Hz.

SPRiNT facilitates exploring aperiodic dynamics in neurophysiological data.

Data availability

Simulation parameters and time series are available online[6]. The SPRiNT algorithm and scripts needed to produce all results shown are available on Github[7]. SPRiNT is distributed as an open-source plug-in for *Brainstorm*[8].

References

1. Gao et al. (2017), Inferring synaptic excitation/inhibition balance from field potentials.
2. Ouyang et al. (2020), Decomposing alpha and 1/f brain activities reveals their differential associations with cognitive processing speed.
3. van Heumen et al. (2021), Aperiodic Fluctuations of Neural Activity in the Ictal MEG of a Child With Drug-Resistant Fronto-Temporal Epilepsy.
4. Donoghue et al. (2020), Parameterizing neural power spectra into periodic and aperiodic components.
5. Cole et al. (2019), NeuroDSP: A package for neural digital signal processing.
6. Wilson and da Silva Castanheira (2022), Time resolved parameterization of aperiodic and periodic brain activity [data repository].
7. Wilson and da Silva Castanheira (2022), lucwilson/SPRiNT: SPRiNT v1.0.3 [Github repository].
8. Tadel et al. (2011), Brainstorm: A User-Friendly Application for MEG/EEG Analysis

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