Cycle by Cycle Analysis

Workshop

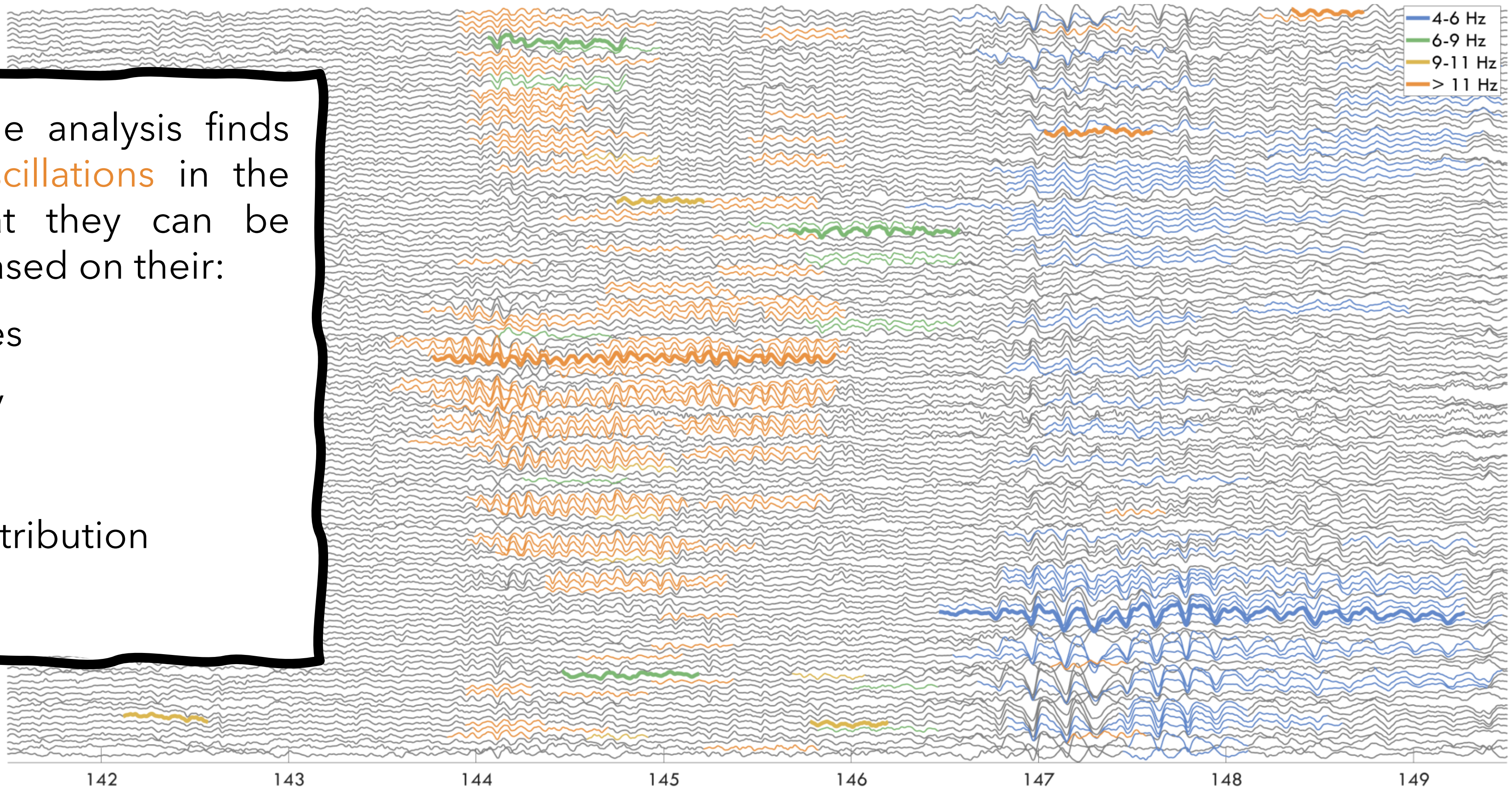
10.08.23

By Sophia Snipes

Schedule

2:00-3:00	Presentation on how cycle-by-cycle analysis works
3:00-3:30	Coffee break
3:30-5:30	Practical part
5:30-??	Apero!

Cycle-by-cycle analysis is for detecting oscillation bursts

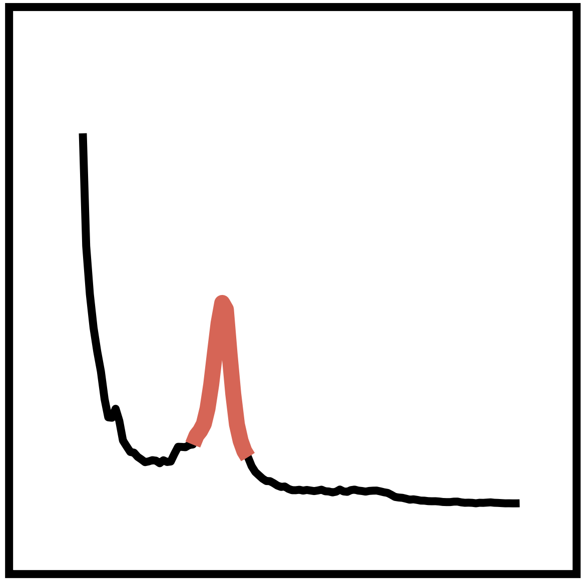


Cycle-by-cycle analysis finds bursts of oscillations in the EEG so that they can be quantified based on their:

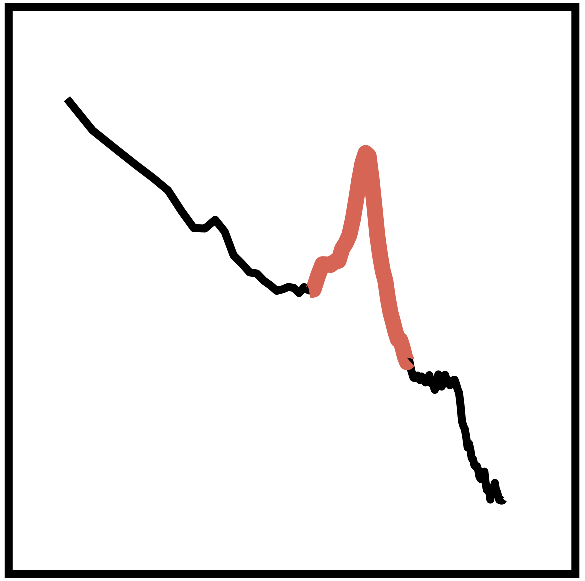
- Amplitudes
- Frequency
- Durations
- Spatial distribution
- Shape

The alternatives for quantifying oscillations

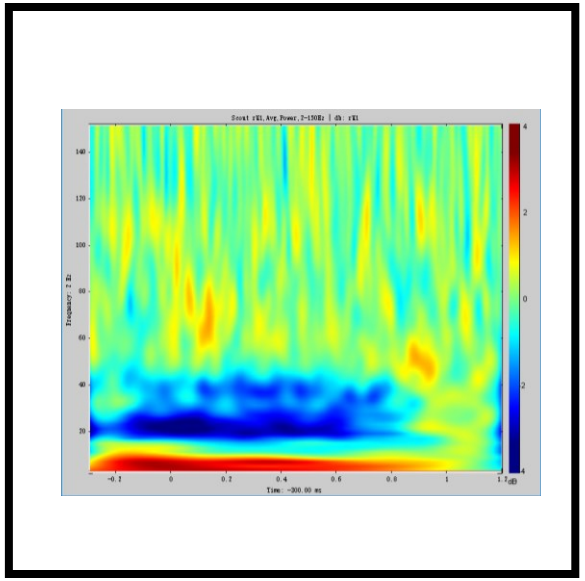
Spectral power



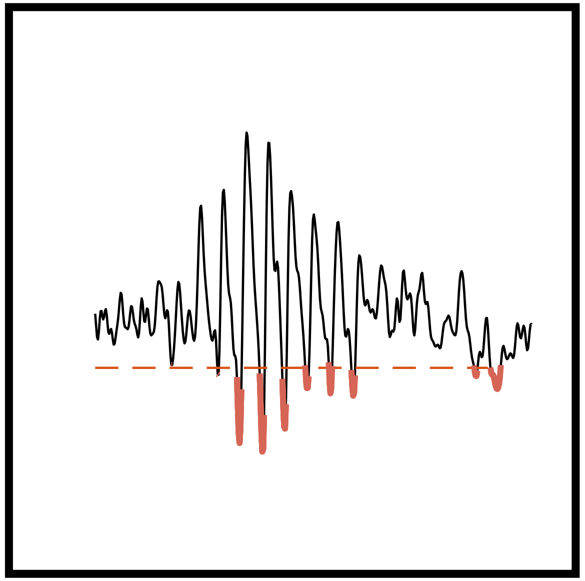
FOOOF



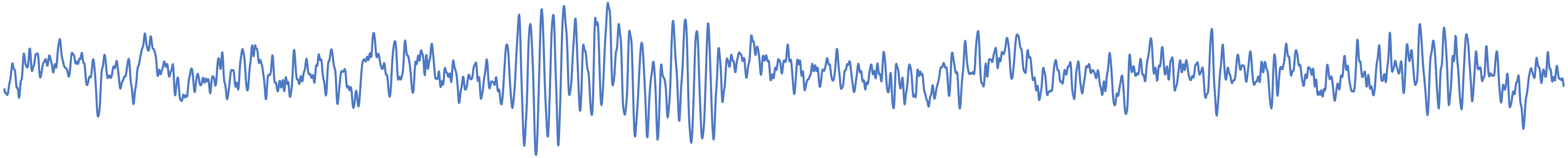
Time-frequency analysis

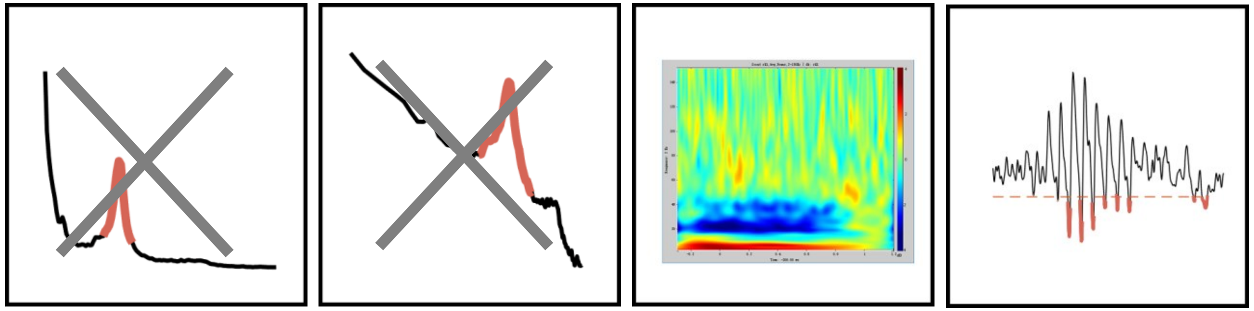


Thresholds



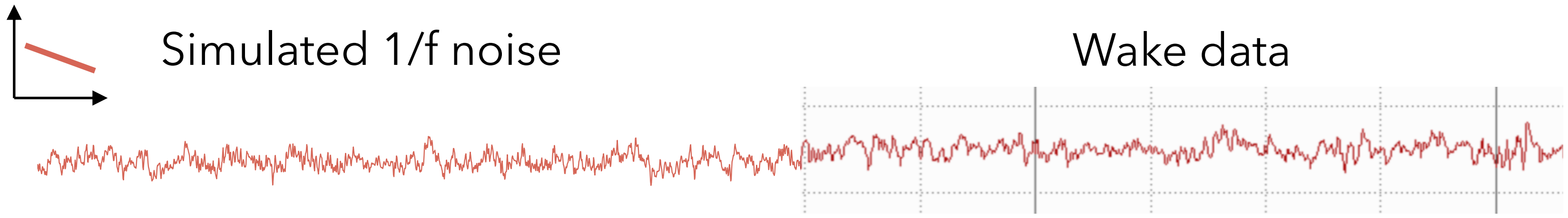
Problem 1: the EEG is non-stationary



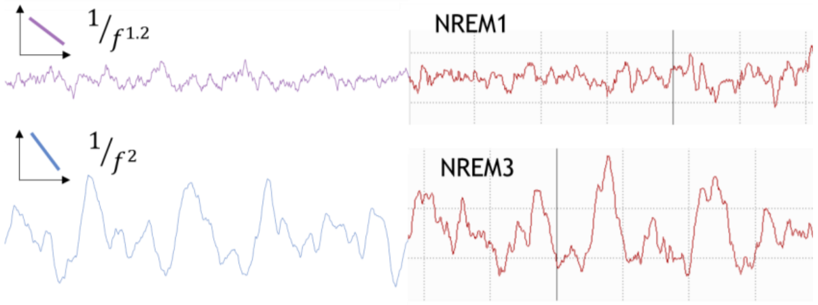


EEG oscillation bursts come and go, so simple power is not sufficient to quantify changes

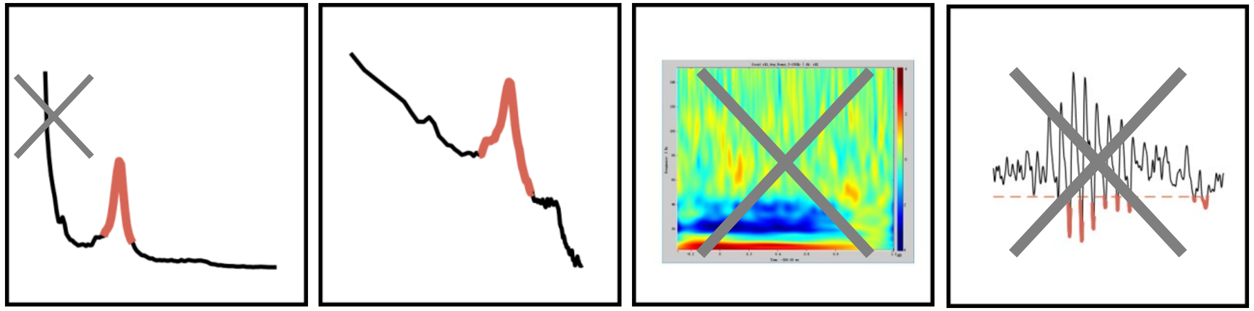
Problem 2: EEG is made of both oscillations and “colored background noise”



More than white noise, colored noise makes it all too easy to find false positive oscillations in the signal.

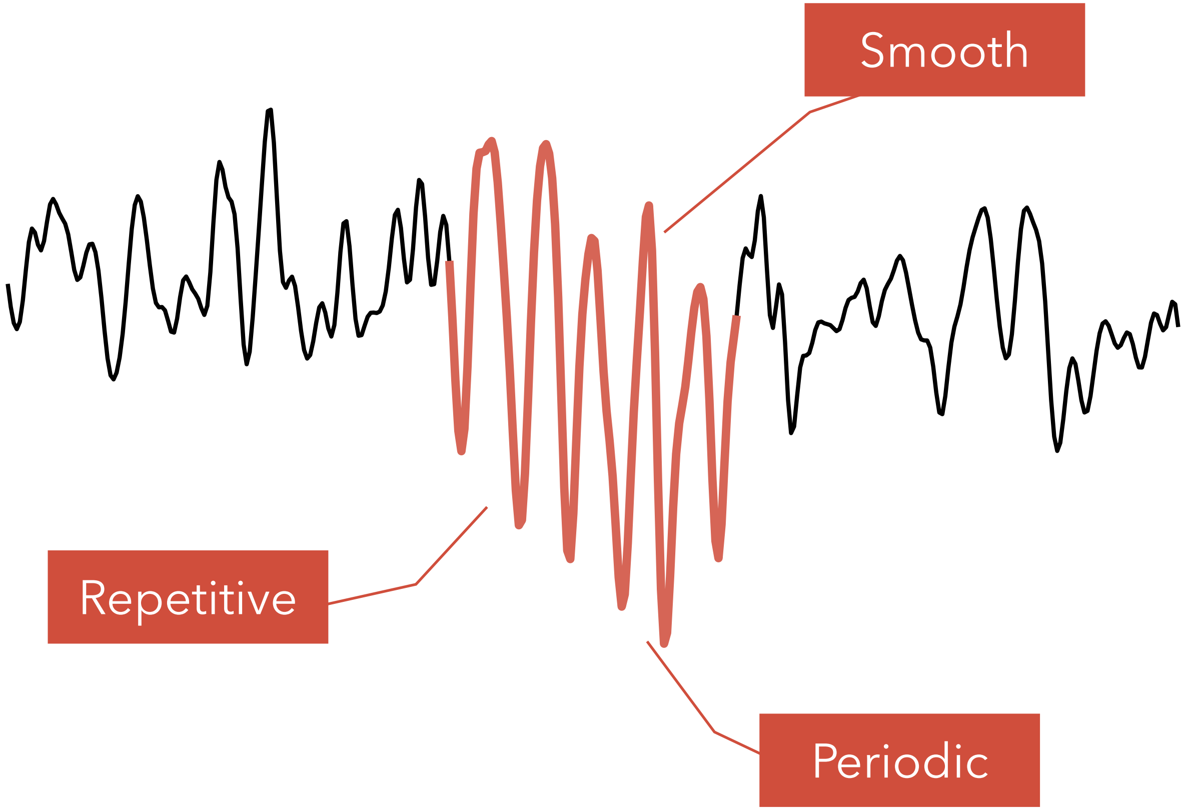


Background also changes with brain state, independently from oscillations.



Donoghue et al., 2020

Solution: cycle-by-cycle analysis finds bursts based on the shape of the signal



Other advantages:

- High temporal resolution
- High frequency resolution
- Robust to non-sinusoidal oscillations

Cole & Voytek, 2019

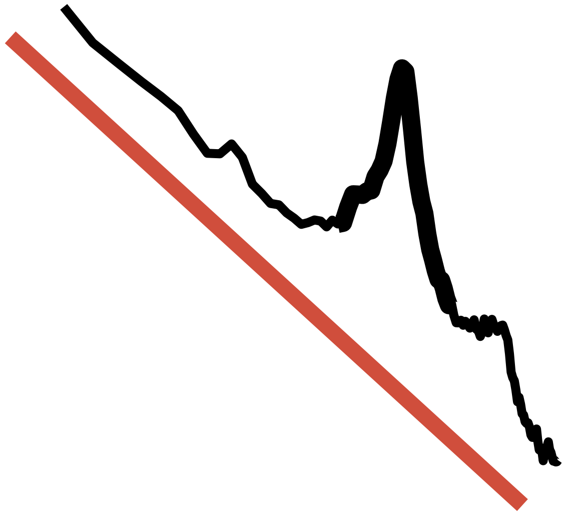
What can you do with cycle-by-cycle analysis?

- Cross-frequency coupling
- Connectivity analysis
- Burst categorization by waveform
- Dissociate changes in amplitude from quantities of oscillations
- Travelling waves
- Infra-slow oscillations

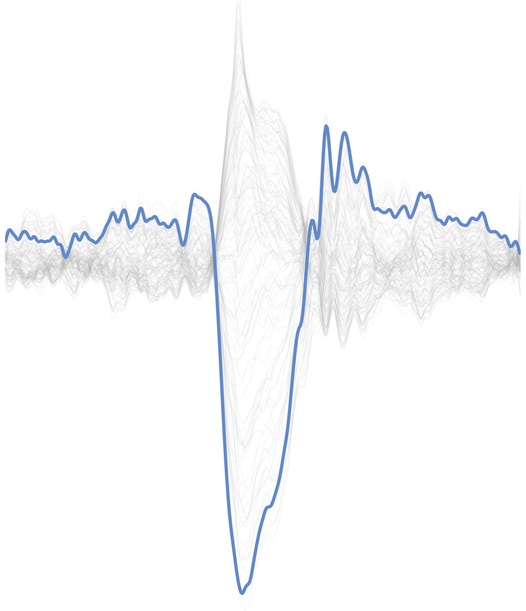
If it involves oscillations, then this is the analysis for you!

When NOT to use cycle-by-cycle analysis?

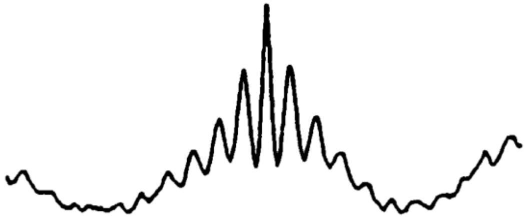
When interested in the background activity



When interested in isolated waves



Certain cross-frequency coupling



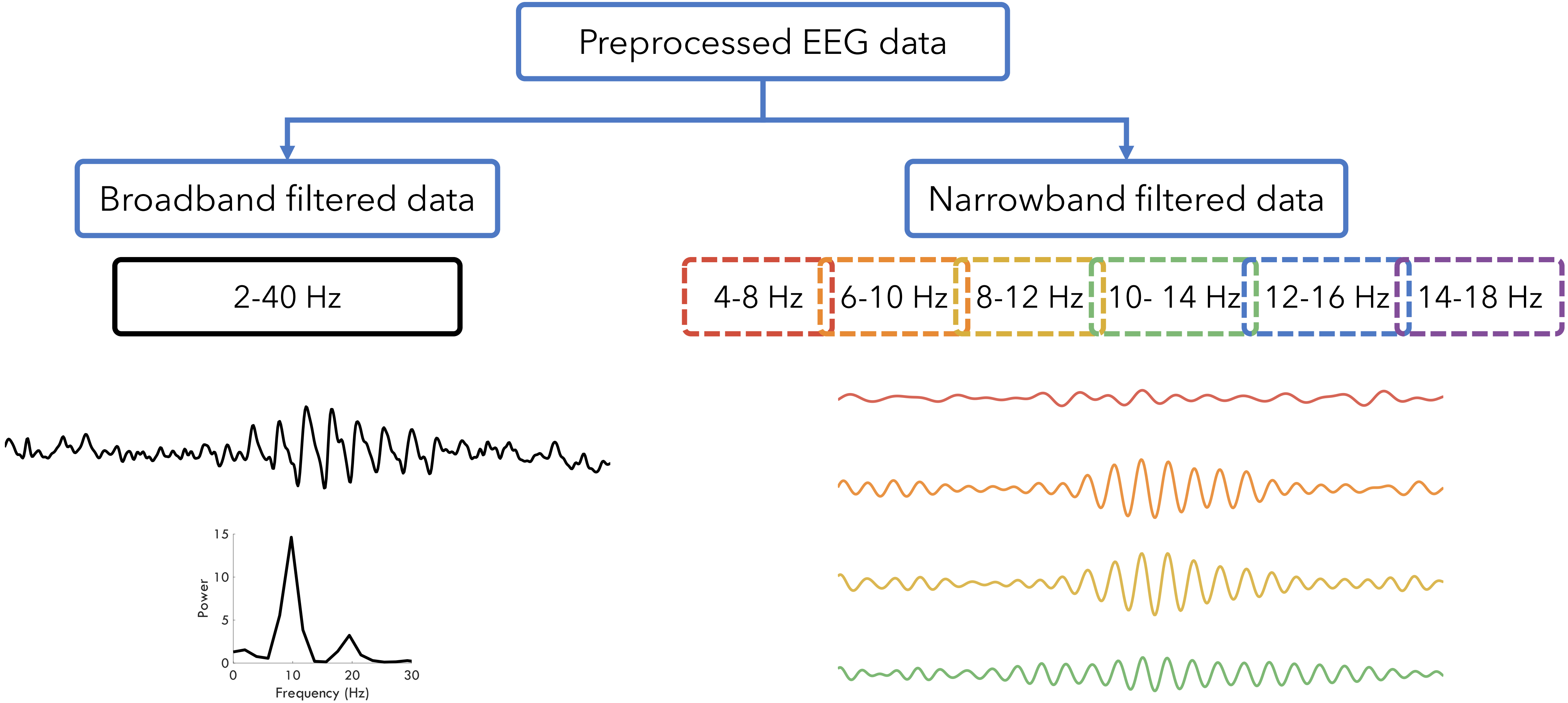
How it works

Step 1: Filter EEG data

Step 2: Detect all the cycles

Step 3: Group periodic cycles

Step 1: Filtering EEG data



Preprocessed EEG data

Broadband filtered data

2-40 Hz

Narrowband filtered data

4-8 Hz

6-10 Hz

8-12 Hz

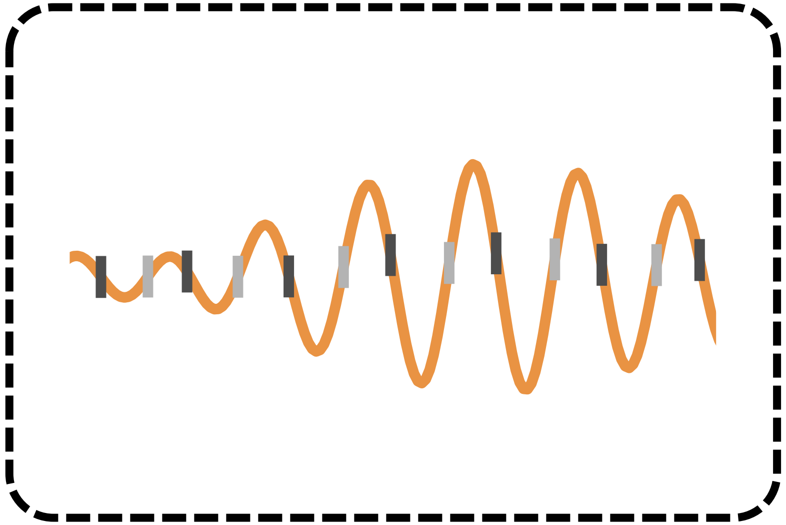
10- 14 Hz

12-16 Hz

14-18 Hz

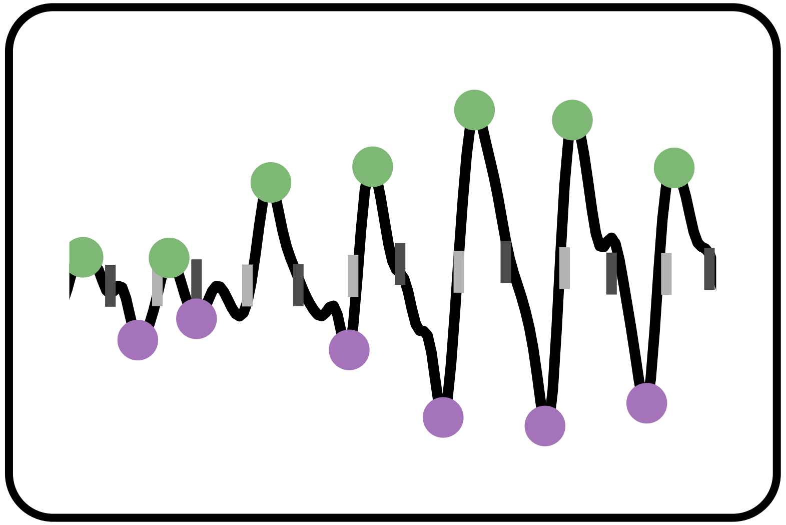
Step 2: detect all the cycles

I: Detect zero-crossings



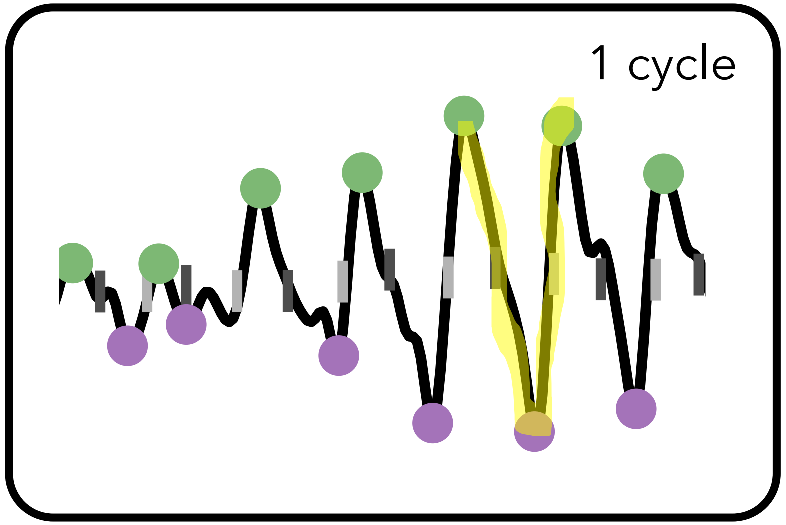
In **narrowband** data, identify all the positive and negative zero-crossings. N.B. this is the only step on the narrowband data.

II: Detect peaks



In the **broadband** data, detect positive and negative peaks between zero-crossings (max absolute value).

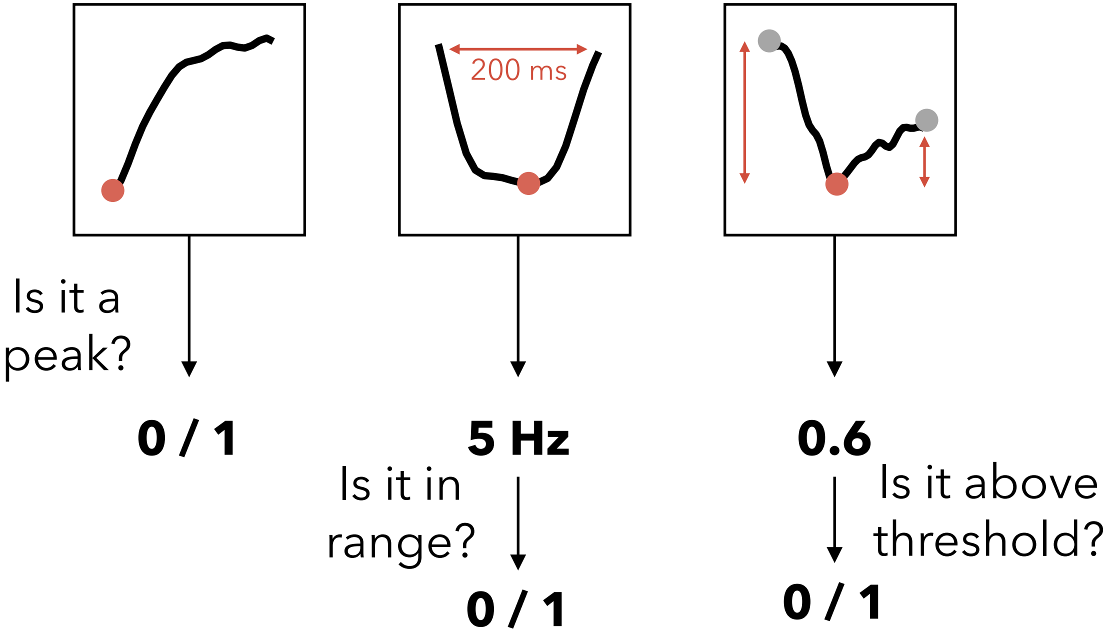
III: Divide into cycles



Each cycle is referenced to the negative peak, and starts and ends with the two neighboring positive peaks.

Step 3: group periodic cycles into bursts

I:
Assign properties to each cycle



Is it a peak?

0 / 1

5 Hz

Is it in range?

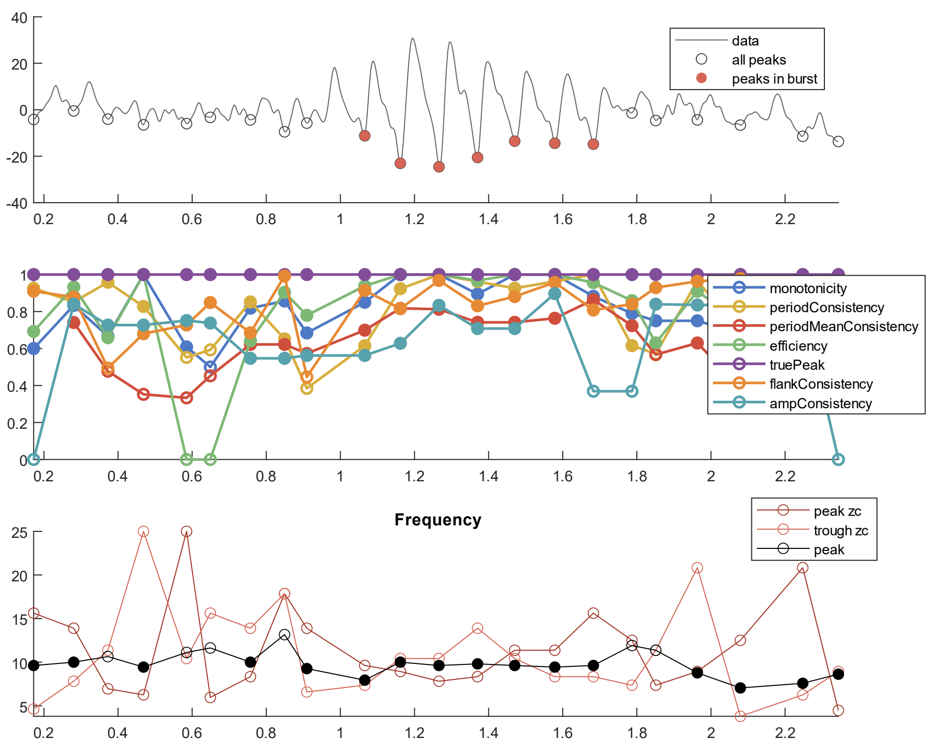
0 / 1

0.6

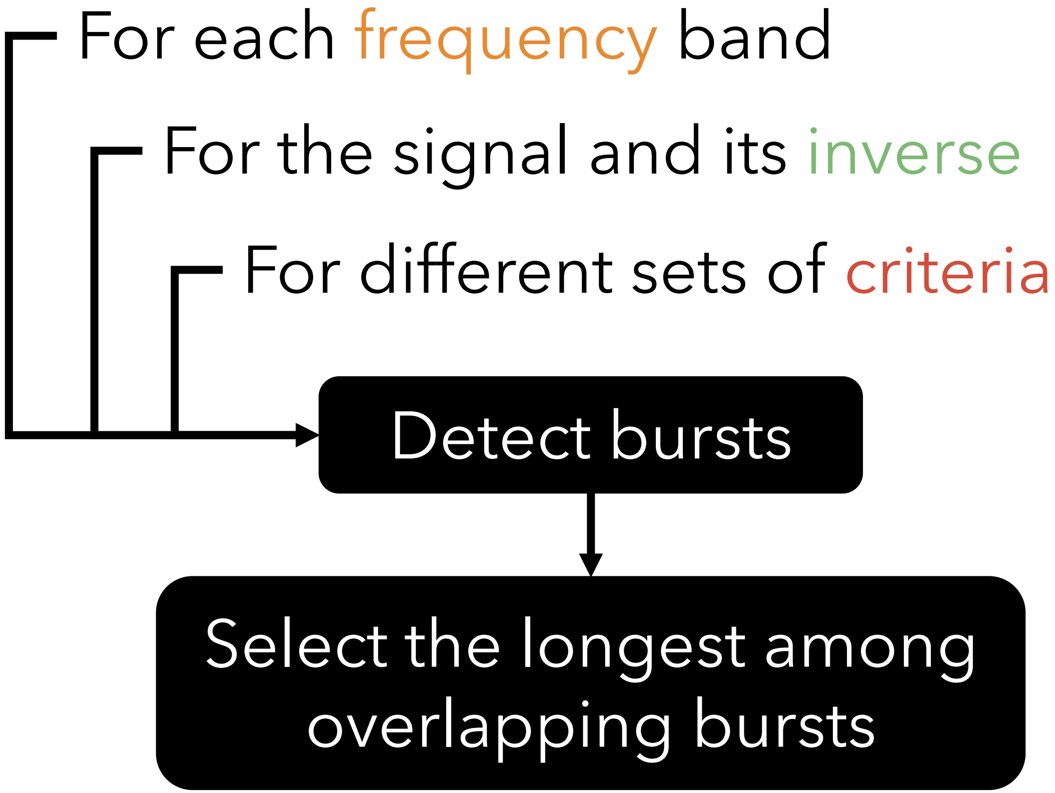
Is it above threshold?

0 / 1

II:
Bursts are when at least N cycles in a row meet all the criteria



For best results, apply multiple passes of burst detection



For each frequency band

For the signal and its inverse

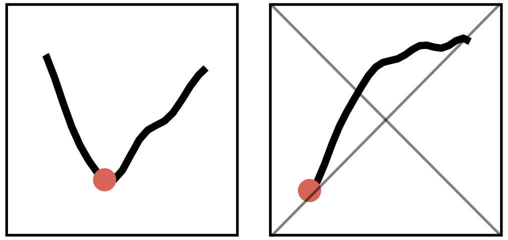
For different sets of criteria

Detect bursts

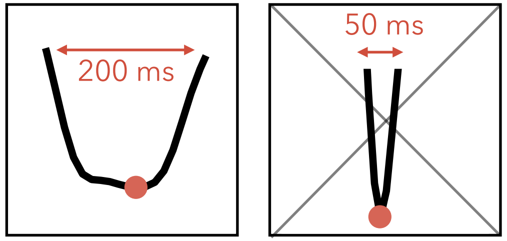
Select the longest among overlapping bursts

Criteria

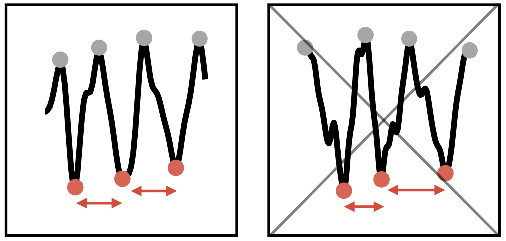
Local minimum



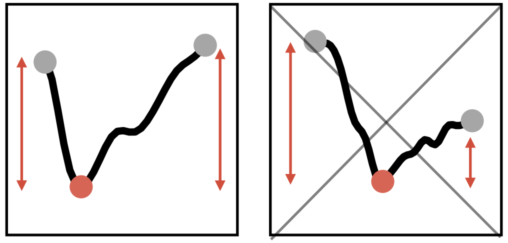
Correct period (per band)



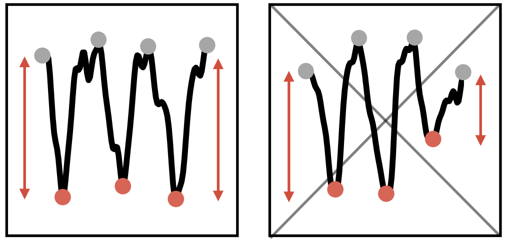
Consistent period



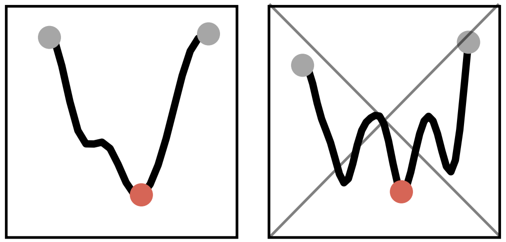
Consistent flank amplitudes



Consistent peak amplitudes

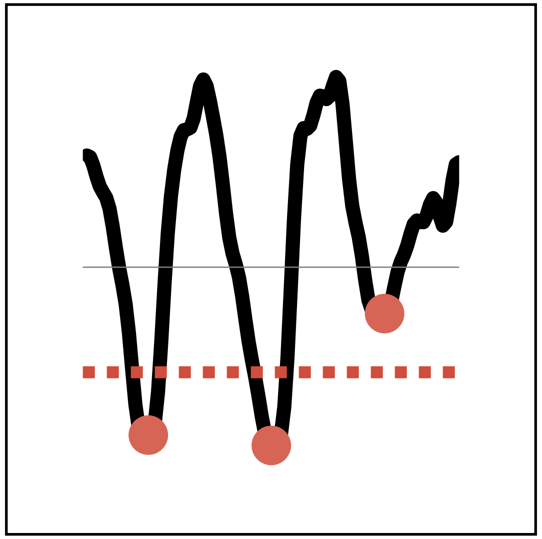


Monotonicity

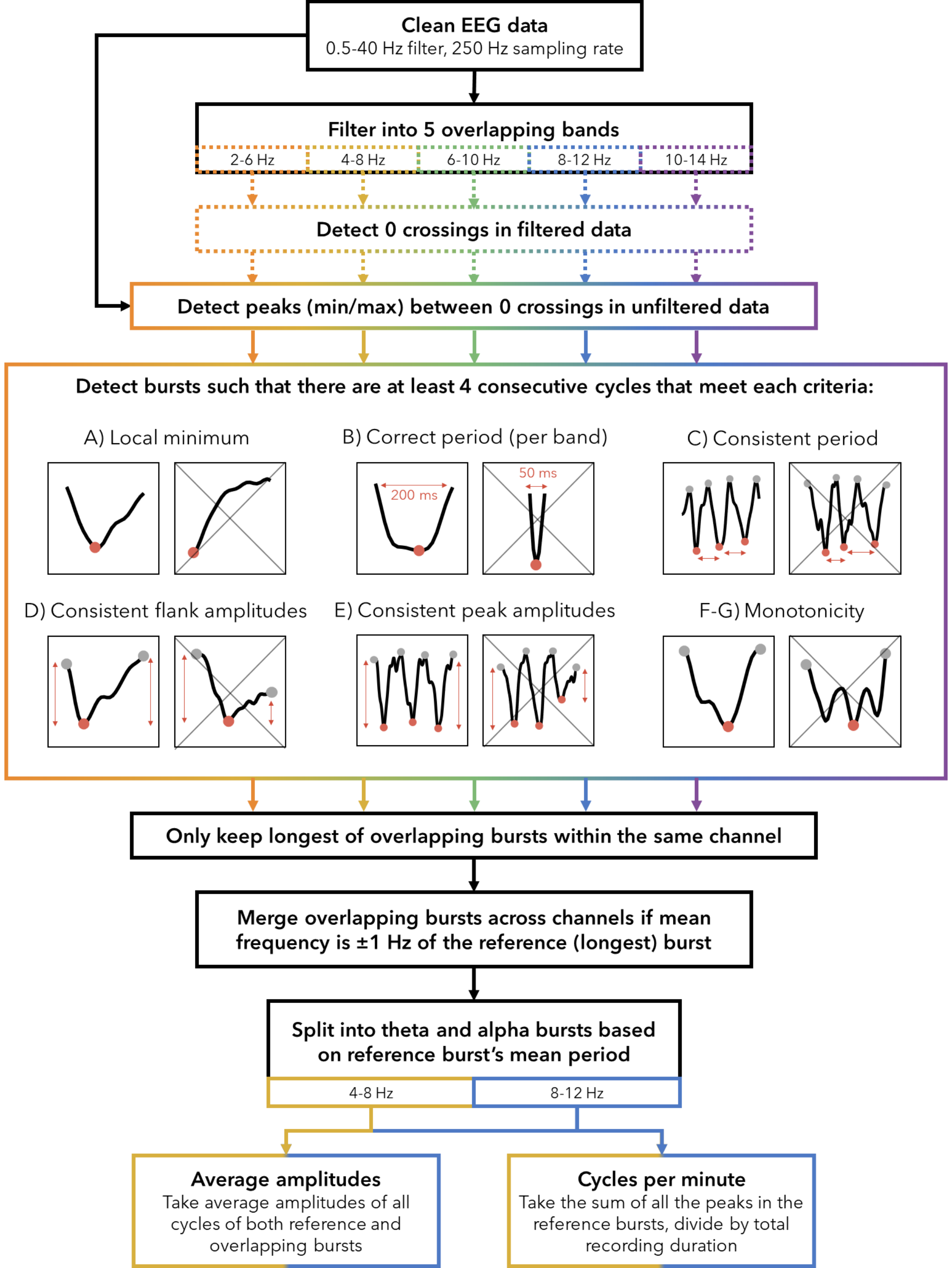


NOT Criteria

Minimum amplitude



The nitty-gritty details



Clean EEG data
0.5-40 Hz filter, 250 Hz sampling rate

Filter into 5 overlapping bands

Detect 0 crossings in filtered data

Detect peaks (min/max) between 0 crossings in unfiltered data

Detect bursts such that there are at least 4 consecutive cycles that meet each criteria:

A) Local minimum

B) Correct period (per band)

C) Consistent period

D) Consistent flank amplitudes

E) Consistent peak amplitudes

F-G) Monotonicity

Only keep longest of overlapping bursts within the same channel

Merge overlapping bursts across channels if mean frequency is ±1 Hz of the reference (longest) burst

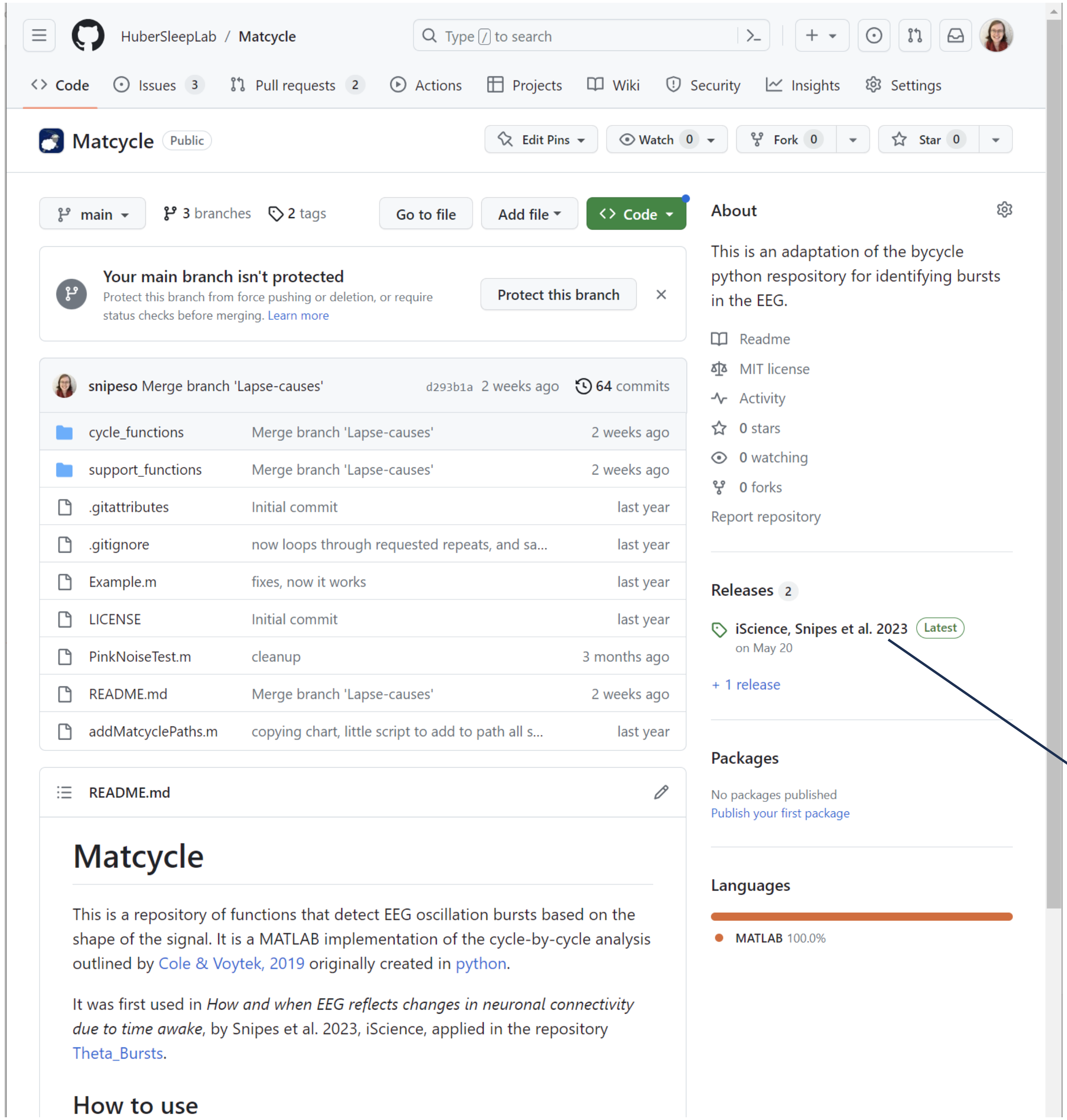
Split into theta and alpha bursts based on reference burst's mean period

Average amplitudes
Take average amplitudes of all cycles of both reference and overlapping bursts

Cycles per minute
Take the sum of all the peaks in the reference bursts, divide by total recording duration

Snipes et al. 2023

The repository



Your main branch isn't protected

Protect this branch from force pushing or deletion, or require status checks before merging. Learn more

Protect this branch

snipeso Merge branch 'Lapse-causes' d293b1a 2 weeks ago 64 commits

cycle_functions	Merge branch 'Lapse-causes'	2 weeks ago
support_functions	Merge branch 'Lapse-causes'	2 weeks ago
.gitattributes	Initial commit	last year
.gitignore	now loops through requested repeats, and sa...	last year
Example.m	fixes, now it works	last year
LICENSE	Initial commit	last year
PinkNoiseTest.m	cleanup	3 months ago
README.md	Merge branch 'Lapse-causes'	2 weeks ago
addMatcyclePaths.m	copying chart, little script to add to path all s...	last year

README.md

Matcycle

This is a repository of functions that detect EEG oscillation bursts based on the shape of the signal. It is a MATLAB implementation of the cycle-by-cycle analysis outlined by Cole & Voytek, 2019 originally created in python.

It was first used in *How and when EEG reflects changes in neuronal connectivity due to time awake*, by Snipes et al. 2023, iScience, applied in the repository Theta_Bursts.

How to use

About

This is an adaptation of the bycycle python respository for identifying bursts in the EEG.

- Readme
- MIT license
- Activity
- 0 stars
- 0 watching
- 0 forks

Report repository

Releases 2

iScience, Snipes et al. 2023 Latest
on May 20

+ 1 release

Packages

No packages published
Publish your first package

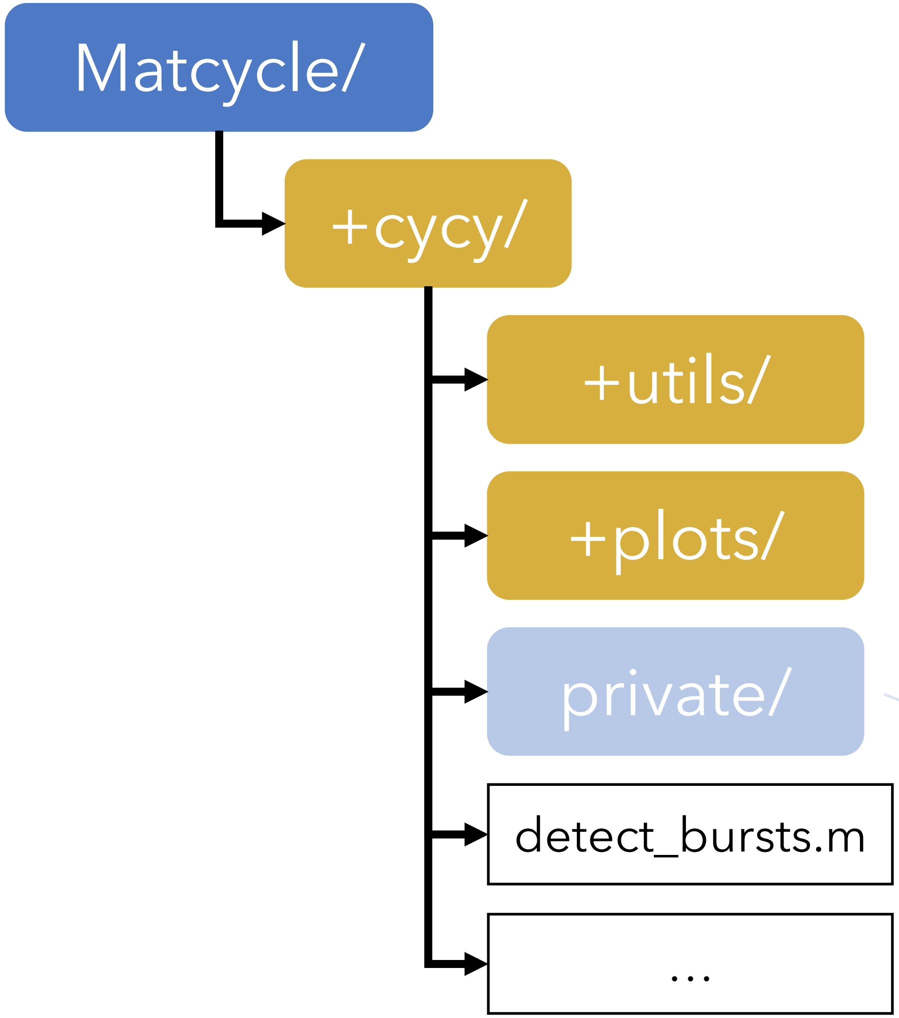
Languages

MATLAB 100.0%

https://github.com/HuberSleepLab/Matcycle

When publishing, create a "release", so you immortalize the version actually used to obtain results

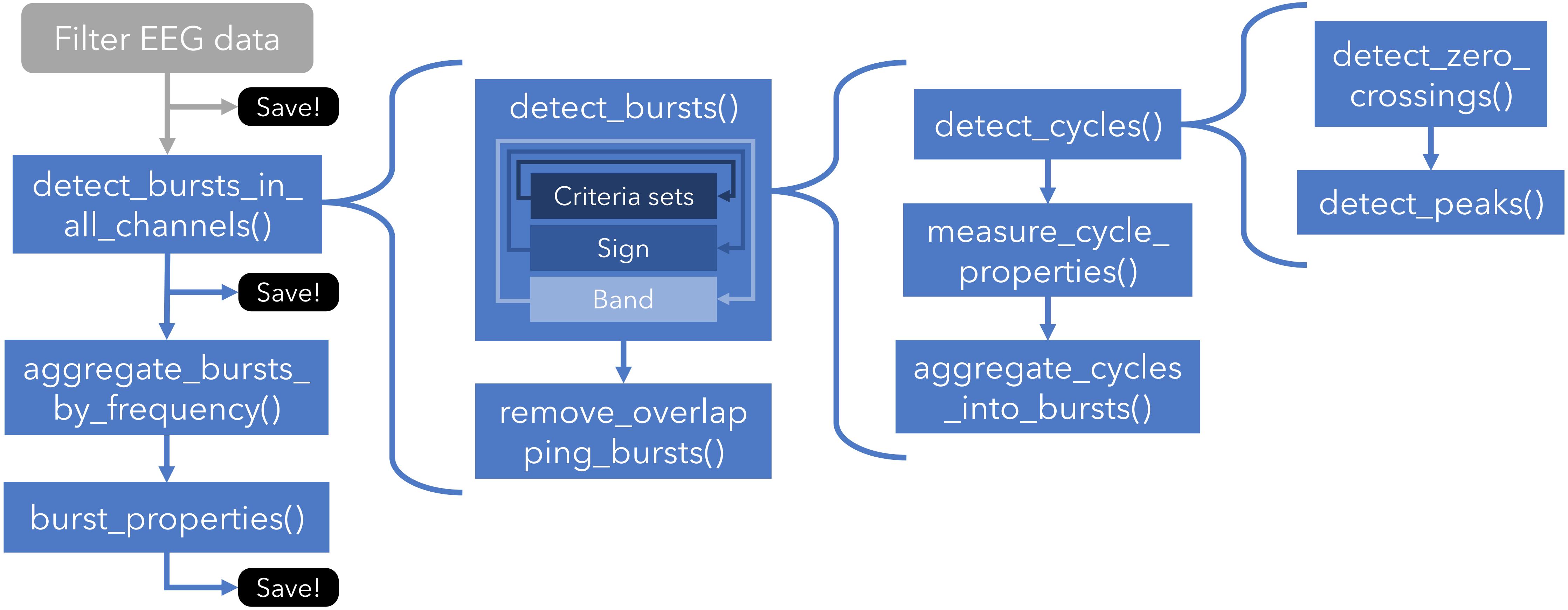
+Packages in MATLAB



1) Add the Matcycle folder to path
2) Call the main functions like so:
   “`cycy.detect_bursts()`”
3) Call support functions like so:
   “`cycy.utils.highpass_filter()`”

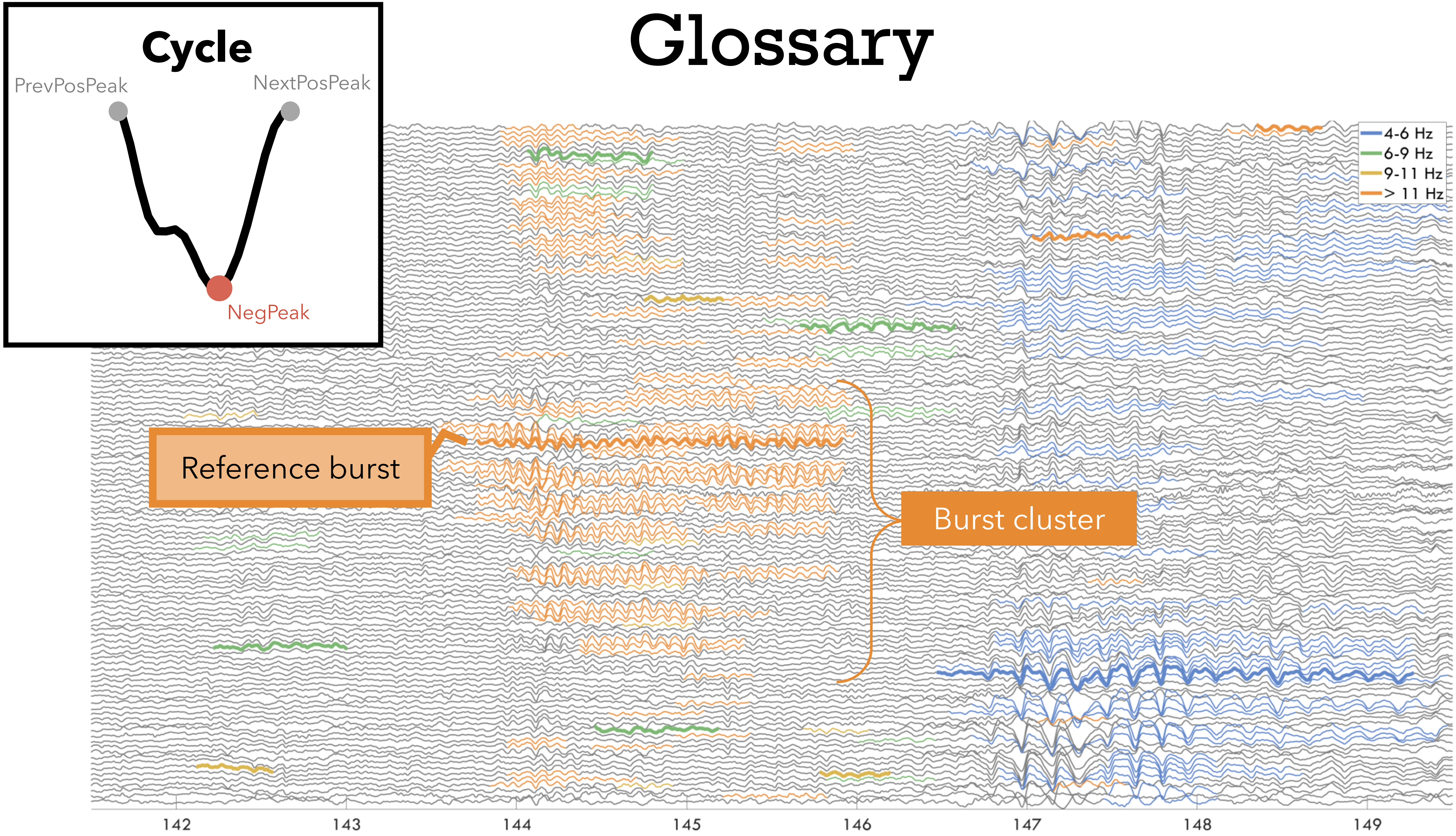
In MATLAB, if you have a folder called “private”, the functions can be called by scripts within the folder above, but not by scripts outside

The code



Filter EEG data
Save!
detect_bursts_in_all_channels()
Save!
aggregate_bursts_by_frequency()
burst_properties()
Save!
detect_bursts()
Criteria sets
Sign
Band
remove_overlapping_bursts()
detect_cycles()
measure_cycle_properties()
aggregate_cycles_into_bursts()
detect_zero_crossings()
detect_peaks()

Glossary



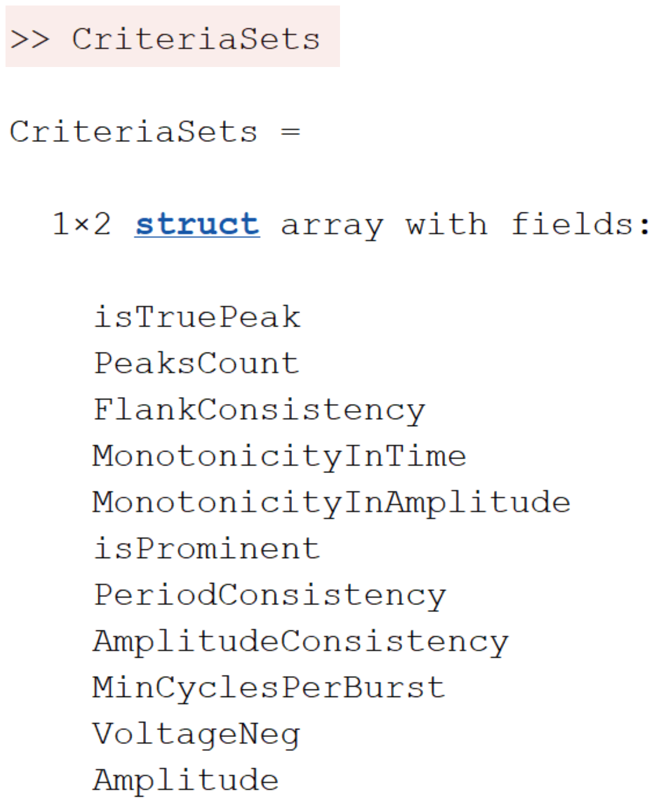
Cycle

Reference burst

Burst cluster

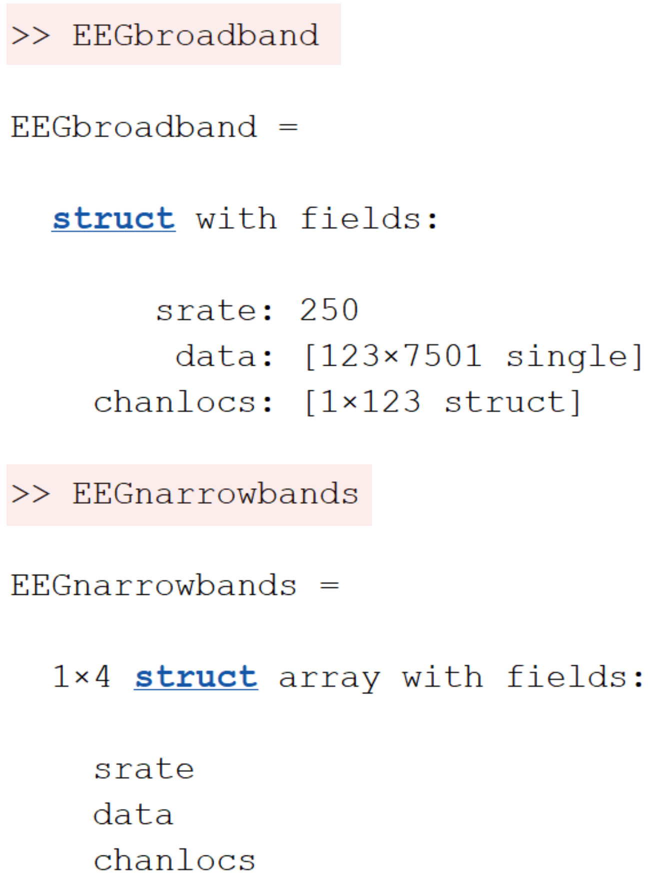
The Inputs

Criteria sets



```
>> CriteriaSets

CriteriaSets =

  1×2 struct array with fields:

    isTruePeak
    PeaksCount
    FlankConsistency
    MonotonicityInTime
    MonotonicityInAmplitude
    isProminent
    PeriodConsistency
    AmplitudeConsistency
    MinCyclesPerBurst
    VoltageNeg
    Amplitude
```

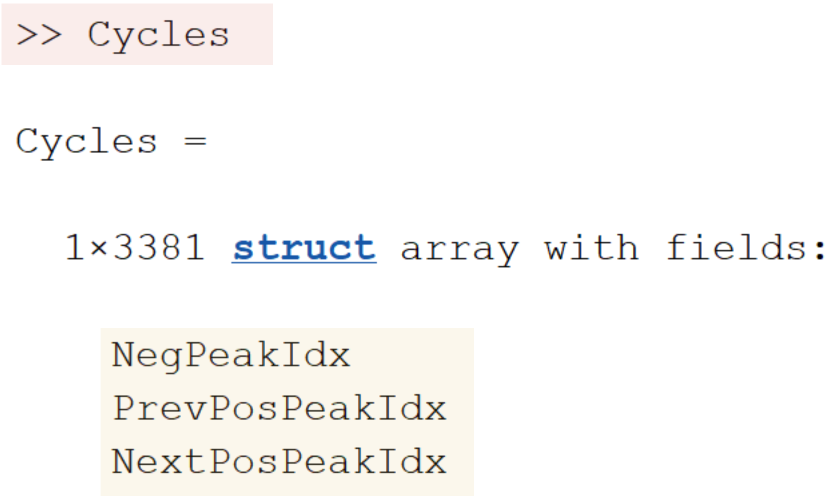
EEG data



```
>> EEGbroadband

EEGbroadband =

  struct with fields:

       srate: 250
        data: [123×7501 single]
    chanlocs: [1×123 struct]

>> EEGnarrowbands

EEGnarrowbands =

  1×4 struct array with fields:

    srate
    data
    chanlocs
```

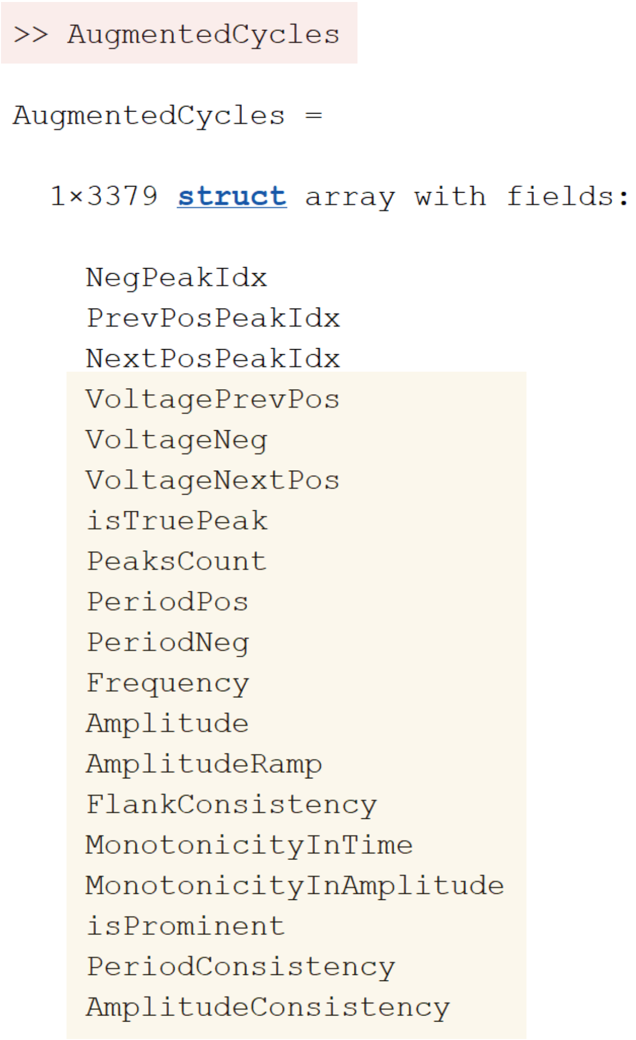
The Output: Cycles

Cycle Detection



```
>> Cycles

Cycles =

  1×3381 struct array with fields:

    NegPeakIdx
    PrevPosPeakIdx
    NextPosPeakIdx
```

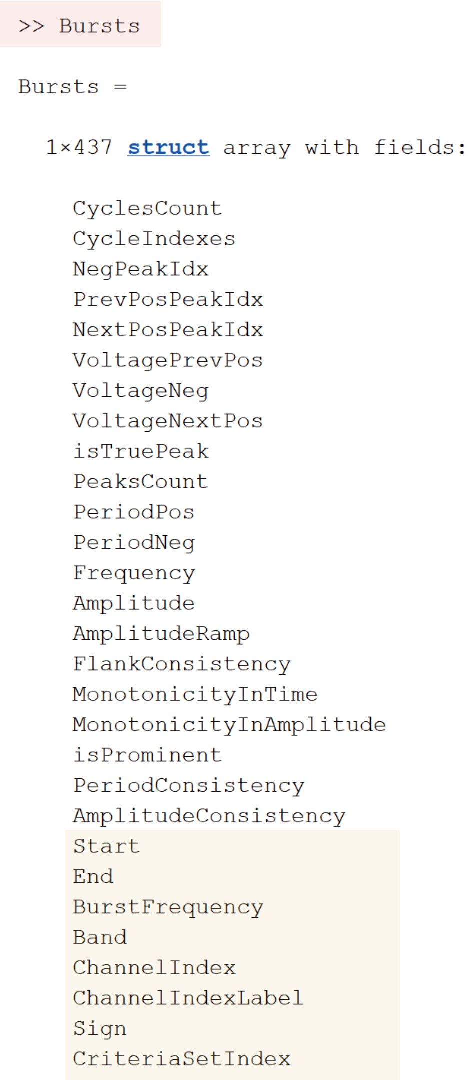
Cycle Properties



```
>> AugmentedCycles

AugmentedCycles =

  1×3379 struct array with fields:

    NegPeakIdx
    PrevPosPeakIdx
    NextPosPeakIdx
    VoltagePrevPos
    VoltageNeg
    VoltageNextPos
    isTruePeak
    PeaksCount
    PeriodPos
    PeriodNeg
    Frequency
    Amplitude
    AmplitudeRamp
    FlankConsistency
    MonotonicityInTime
    MonotonicityInAmplitude
    isProminent
    PeriodConsistency
    AmplitudeConsistency
```

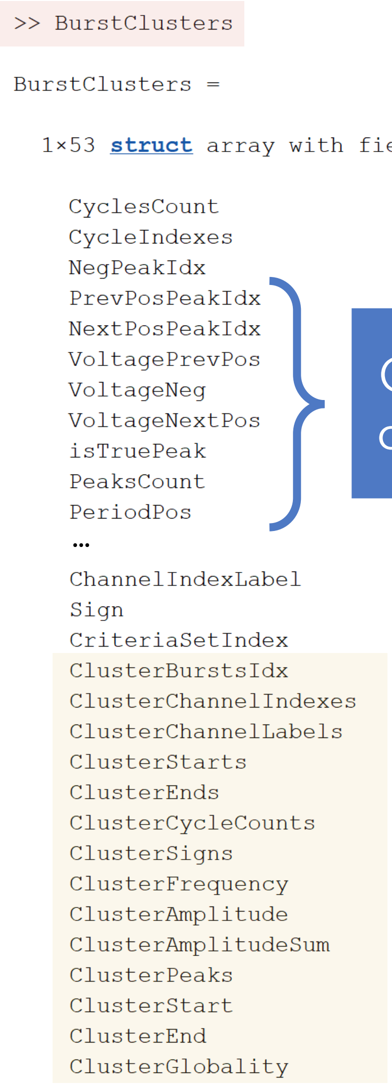
The Output: Bursts

Bursts



```
>> Bursts

Bursts = 

  1×437 struct array with fields:

    CyclesCount
    CycleIndexes
    NegPeakIdx
    PrevPosPeakIdx
    NextPosPeakIdx
    VoltagePrevPos
    VoltageNeg
    VoltageNextPos
    isTruePeak
    PeaksCount
    PeriodPos
    PeriodNeg
    Frequency
    Amplitude
    AmplitudeRamp
    FlankConsistency
    MonotonicityInTime
    MonotonicityInAmplitude
    isProminent
    PeriodConsistency
    AmplitudeConsistency
    Start
    End
    BurstFrequency
    Band
    ChannelIndex
    ChannelIndexLabel
    Sign
    CriteriaSetIndex
```

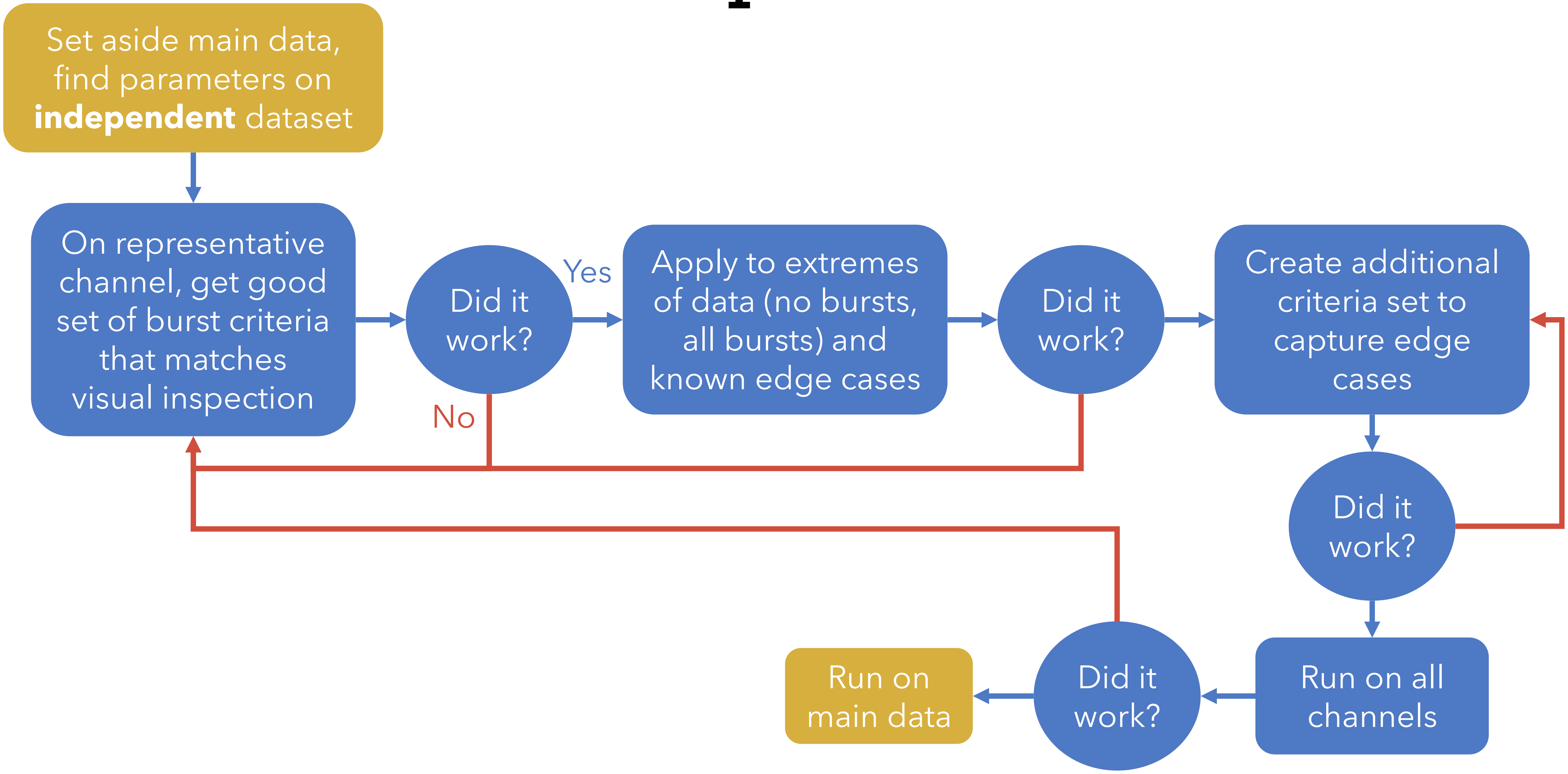
Burst Cluster



```
>> BurstClusters

BurstClusters = 

  1×53 struct array with fields:

    CyclesCount
    CycleIndexes
    NegPeakIdx
    PrevPosPeakIdx
    NextPosPeakIdx
    VoltagePrevPos
    VoltageNeg
    VoltageNextPos
    isTruePeak
    PeaksCount
    PeriodPos
    …
    ChannelIndexLabel
    Sign
    CriteriaSetIndex
    ClusterBurstsIdx
    ClusterChannelIndexes
    ClusterChannelLabels
    ClusterStarts
    ClusterEnds
    ClusterCycleCounts
    ClusterSigns
    ClusterFrequency
    ClusterAmplitude
    ClusterAmplitudeSum
    ClusterPeaks
    ClusterStart
    ClusterEnd
    ClusterGlobality
```

Cycle information of reference burst

The process



Set aside main data, find parameters on **independent** dataset

On representative channel, get good set of burst criteria that matches visual inspection

Did it work?

Yes

No

Apply to extremes of data (no bursts, all bursts) and known edge cases

Did it work?

Create additional criteria set to capture edge cases

Did it work?

Run on all channels

Did it work?

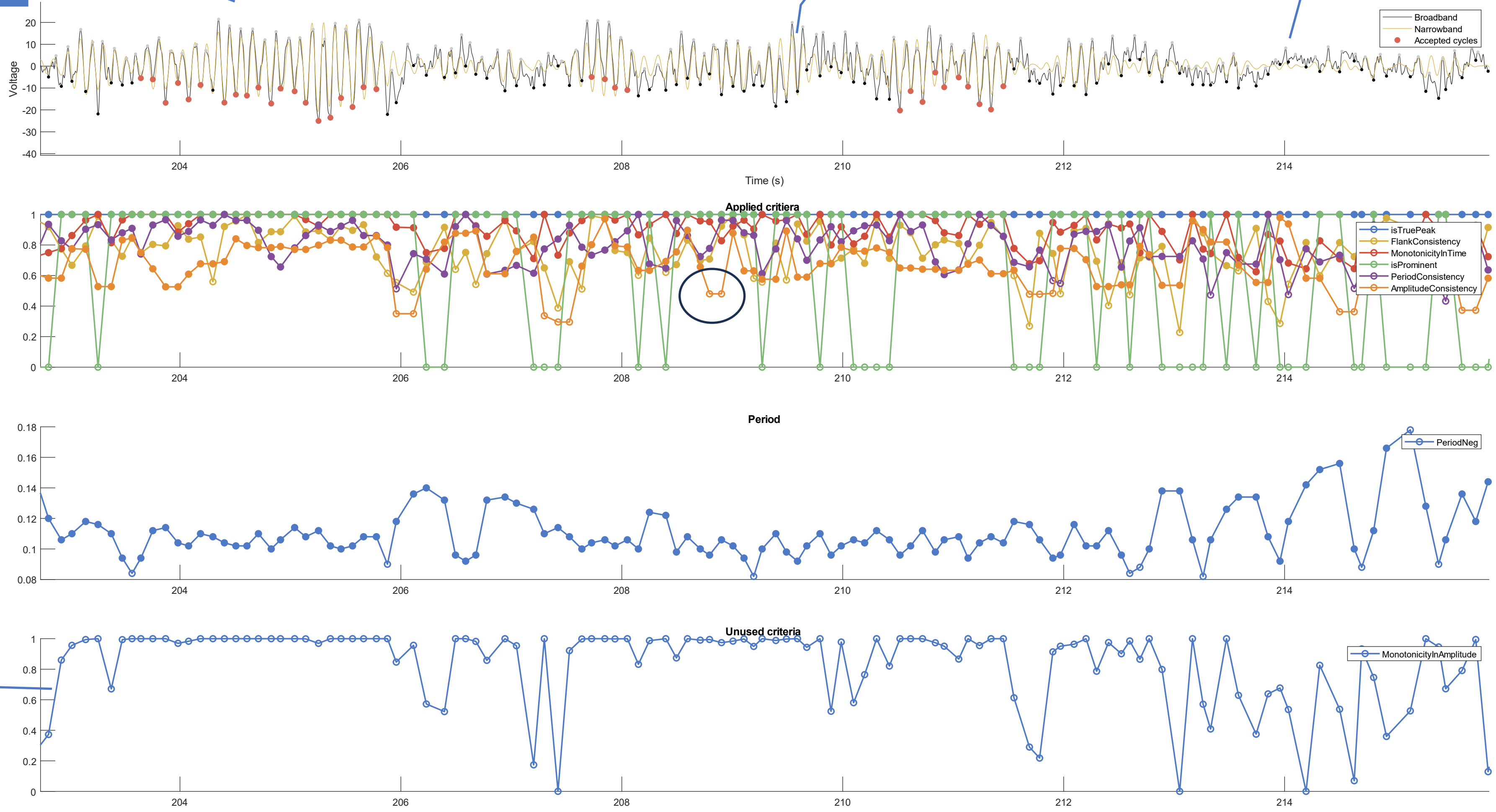
Run on main data

How to chose criteria and thresholds?

Does it correctly capture obvious bursts?

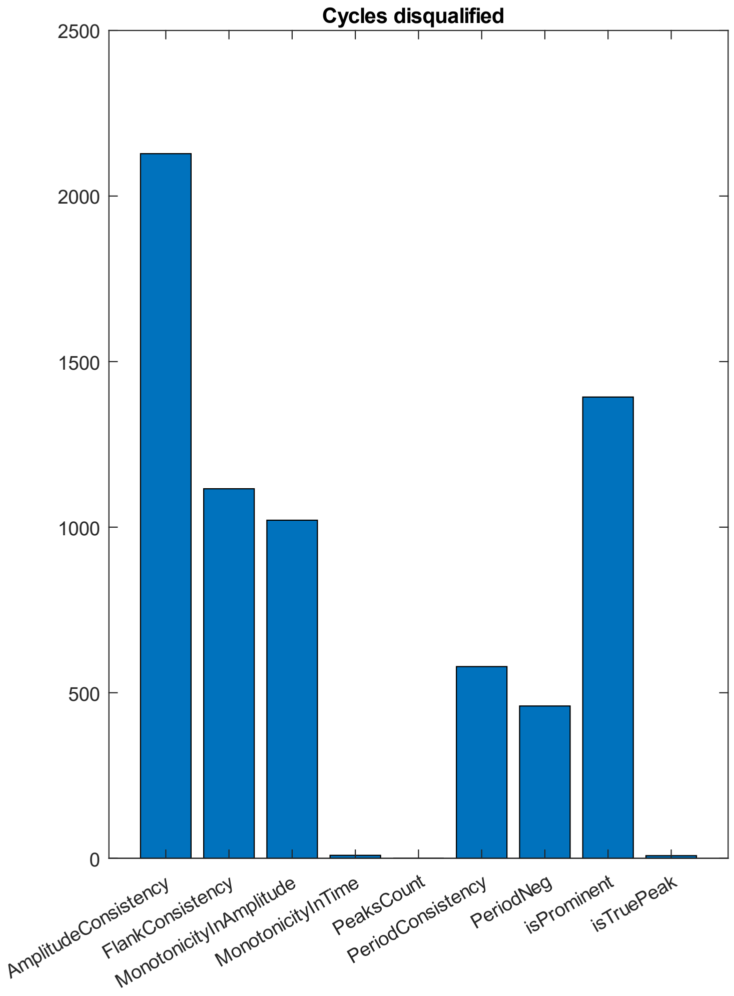
Why did it miss this burst?

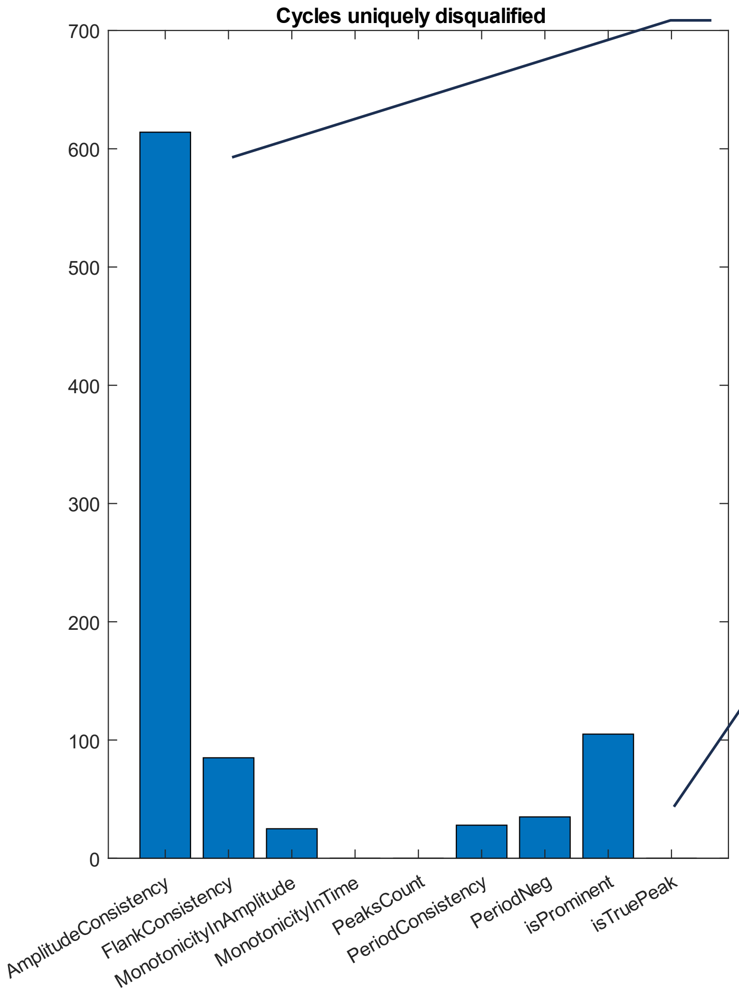
Does it correctly reject background activity?



Was a criteria I didn't use better?

Diagnostics: which criteria were more aggressive?

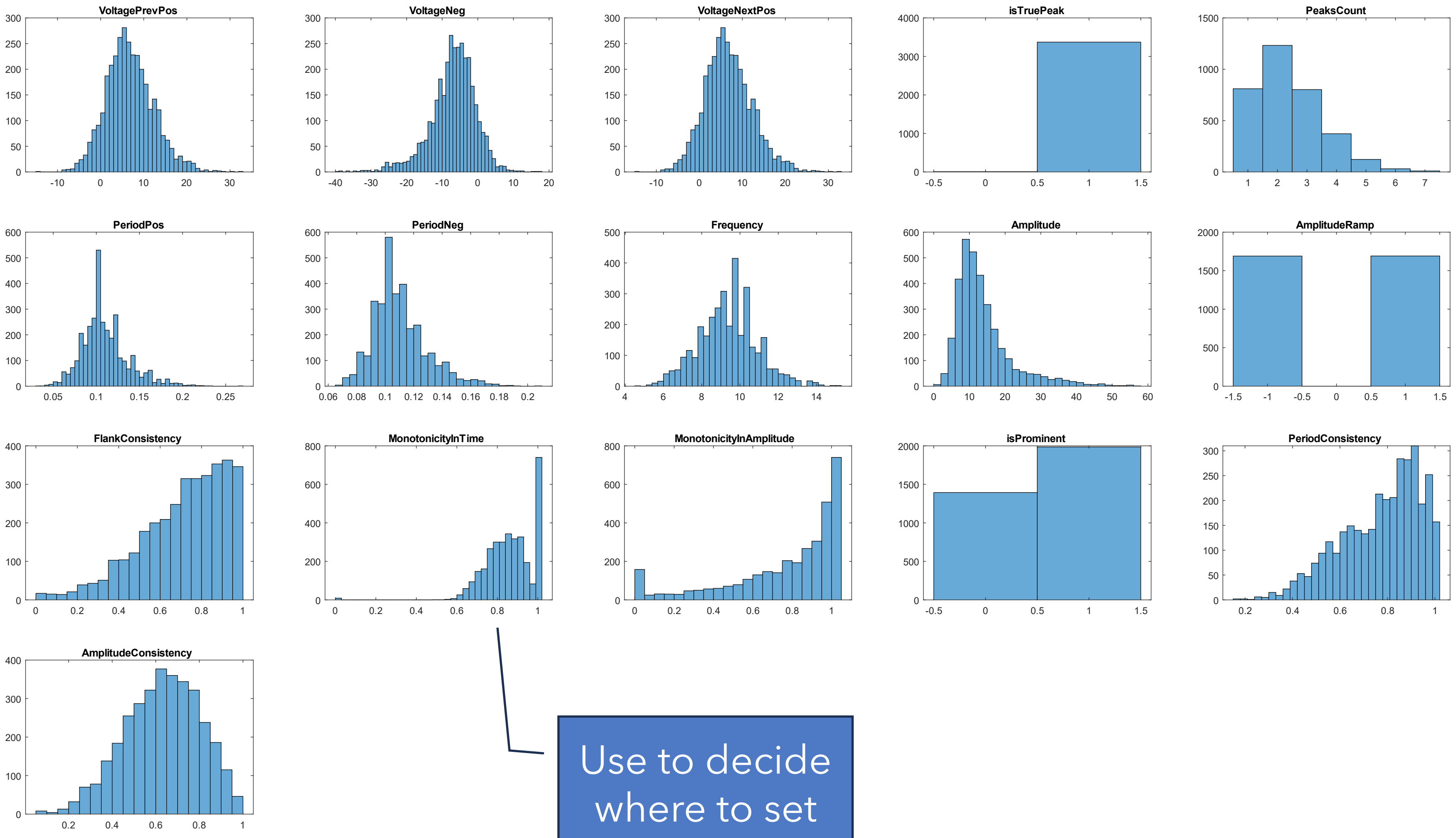




If one criteria is solely responsible for disqualifying a lot of cycles, threshold might be too strict

Could have omitted

Diagnostics: properties distributions



Use to decide where to set thresholds

Practical Part

Recommended Steps

1. Download the repository: https://github.com/HuberSleepLab/Matcycle

2. Run **SingleBandExample.m**. To understand how the analysis works, try adapting:
   - The EEG channel (if you have it, try with your own data!)
   - The narrow band frequency range
   - Criteria set thresholds

3. Run & adapt **MultiChannelExample.m** for your own data

4. Exercise for home: how long does it take to fall asleep?
   - Automatically quantify the interval between the last alpha burst and the first sleep spindle for your data

Bibliography

- Donoghue, T., Haller, M., Peterson, E. J., Varma, P., Sebastian, P., Gao, R., ... & Voytek, B. (2020). Parameterizing neural power spectra into periodic and aperiodic components. *Nature neuroscience*, *23*(12), 1655-1665.
- Cole, S., & Voytek, B. (2019). Cycle-by-cycle analysis of neural oscillations. *Journal of neurophysiology*, *122*(2), 849-861.
- Snipes, S., Meier, E., Meissner, S. N., Landolt, H. P., & Huber, R. (2023). How and when EEG reflects changes in neuronal connectivity due to time awake. *iScience*.