Seizure detection scorer with dual band peaks method documentation

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The dual band peaks method detects SWDs in LFP data by considering the consistency of the timing between peaks in low and high frequency bands.

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3.1   Overview

The consistency of the time between signal peaks in lower and higher frequencies is considered. For SWDs, the lower frequencies correspond to the underlying seizure modulation, while the higher frequencies correspond to the sharper periodic peaks. When a seizure is occurring, the time differences in peaks of both bands become consistent. This is quantified with a rolling variance of the time differences, where and SWD-like behaviour in either band manifests as a sharp drop in variance.
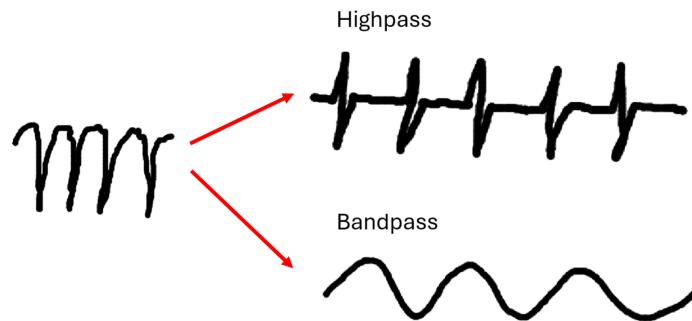

Figure 1
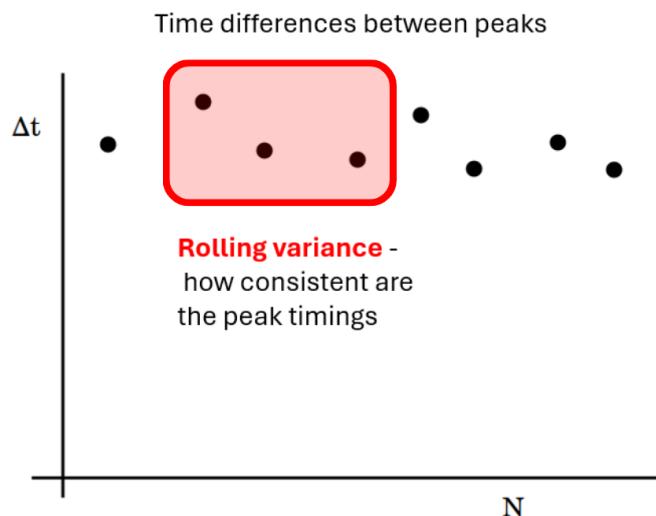
Figure 2

Samples where the variance is lower than a threshold are detected and, with specified padding, are converted into a binary mask of true and false states, indicating low variance
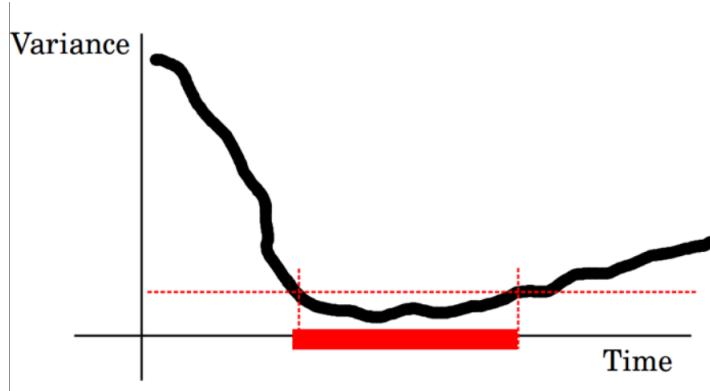
Figure 3

regions. A bitwise logical AND operation is used to combine the two to get potential seizures.

Finally, to reduce false positives, a the rolling mean power of the unfiltered signal is used in conjunction with a threshold to detect regions of high signal power. A further bitwise logical AND operation combines the variance states with the power states. This stage is optional, but highly effective.

Before any seizures are shown or verified, basic merging and filter may be done. If the data has many bad periods or disconnections, this is advisable.

Detection is done per frame of a specified length (referred to as detection frame).
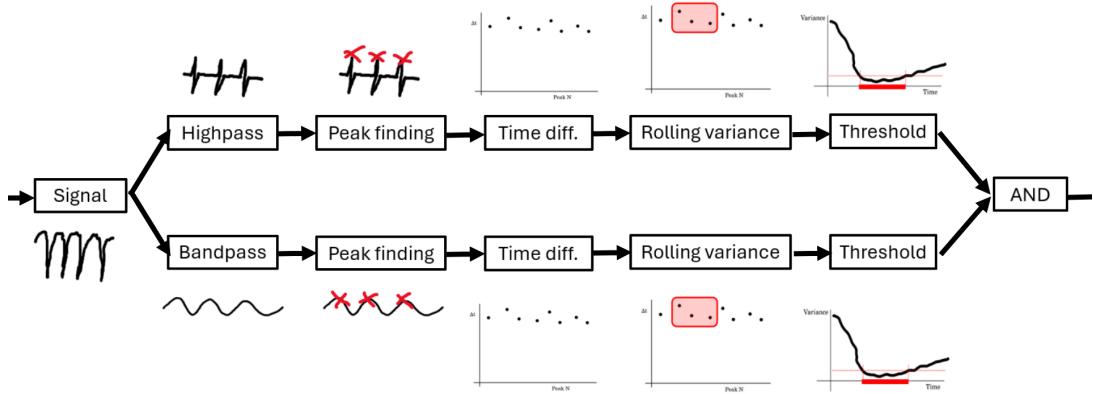
Figure 4

3.2   Main parameters

For the timing variance to be effective, a minimum peak height must be set. However, since the amplitude and sensitivity of the signal varies widely across recordings, this cannot be set to a fixed value. Instead, all peaks are first detected without restriction. Then, from the distribution of peak heights, a minimum peak height is taken from a set quantile. This is repeated for both bands. The two minimum heights are then used

to find peaks again, in conjunction with the additional restriction of a minimum peak distance.

From this, the rolling time difference and its variance is computed. The rolling time variance has a fixed threshold for both bands.

The most relevant parameters to tune can be changed and saved within the interface. If enabled, by pressing C while in a detection frame, the constants window will open up from where bars can be used to adjust the constants. These are:

Parameter	Description	Unit
Quantile bandpass	Bandpass peak quantile	Hz
Quantile highpass	Highpass peak quantile	Hz
Threshold bandpass	Rolling variance threshold for bandpass	s^2
Threshold highpass	Rolling variance threshold for highpass	s^2
Window size	Rolling window size, in terms of variance of peak time differences	even natural numbers
Spread	Amount of padding in states of either band around a variance threshold crossing point	s

Table 1: Main parameters

For tuning the parameters, see 5.2

3.3 Input stage processing

If bad periods are passed, those segments of the signal can optionally be excluded prior to any further signal processing.

The mean of the signal is taken and subtracted from the the raw signal, after which nans are replaced with zeros and a low pass filter with a $1Hz$ cutoff is applied. The mean is subtracted from the signal in order to minimise the "sharpness" of the transition after nans are replaced with zeros, which would create artefacts which could affect later detection near edges of missing data.

3.4 Output stage processing

Before any results are shown in seizure detection frames, optional merging and filtering may be done.

Following detection, bad periods, if passed, are excluded, such that no seizure can be detected in a bad period. This is distinct from removal of bad periods before detection, as there may be edge effects near missing data.

At the very end before returning the data, very short gaps are merged (10 samples), these usually corresponding to window transitions. Excel sheet saving saves the version prior to merging and after merging. In most cases these will be identical.

4 Utilities

The following features are implemented to allow for the algorithm to be effectively used. These can be enabled or disabled in the `params` file.

4.1 Manual verification

For each frame of detection, detected seizures may be manually verified whereby they can be accepted, rejected or their boundaries modified.

In the verification window, the following controls are used:

Control	Operation
Accept as is	Y
Modify start	Left cursor click
Modify end	Right cursor click
Reject	X
Reset and accept original	R

Table 2: Controls and their operations in the verification window

Note: in case the user accidentally swaps the start and end, a prompt will appear with the suggested correction.

Additionally, if verification is enabled, in the detection frame view, K may be pressed to reject all detected seizures and L may be pressed to accept all detected seizures. This skips the seizure by seizure verification stage and continues to the next detection frame.

It is important to note the verification will only show positives. If manual verification is being done, it is advisable to adjust the constants to catch nearly every seizure, even if there are more false positives. Those may be easily manually rejected.

After verification, overlapping periods are merged, as the user may adjust two periods such that they overlap. An appropriate message is displayed to indicate this was done.

4.2 Constant tuning window and constant saving

Pressing C while in a detection frame will open a window for constant tuning, where quantiles, thresholds and spread may be tuned. Pressing Y will accept the changes and pressing X will reject them.

This window is enabled by default but may be disabled if undesired. Additionally, after the constants are changed, the detection process will reset to the beginning of the file. If this is unwanted, it may be disabled, but this would mean a portion of the file is detected with different constants.

The Following table contains different constant saving modes which may be specified

In order to use per animal, per session and per session per animal, an appropriate file structure is necessary, where the base directory contains animals, each animal contains sessions.

Name	String to specify	Description
None	"none"	Constants loaded from defaults
Global	"global"	A single set of constants is used globally for all files
Per Animal	"per_animal"	Separate constants are saved for each animal, applicable to all sessions.
Per Session	"per_session"	Constants are saved per session and shared across different animals.
Per Session per Animal	"per_session_per_animal"	Constants are saved separately for each session and for each animal.

Table 3: Constants Saving Mode Descriptions

4.3   Spreadsheet output

If a location is specified, two spreadsheets will be outputted, one before and one after merging detection frames. Each contains all seizures and all nonseizures.

4.4   Specific start and end indecies

Specific start and end indecies for detection may be passed. Not however that the peaks for threshold setting will still be detected across the entire passed data.

4.5   Backup file

A backup file is automatically saved after each detection frame. If the same file is loaded and a backup file exists, the user will be prompted to load from it.

Note that if a start and end index are passed, they must match the originally used one when the backup was made in order for the backup to be recognised. This is intentional and prevents unexpected behaviour.

4.6   Bad interval exclusion

If bad periods are passed and bad interval exclusion from input signal is enabled, this will replace the bad intervals with nans.

4.7   Merging and filtering

Merging of close and filtering of short seizures can be enabled. This will merge and filter before anything is shown to the user in the detection frame, and hence will not be shown for verification either. While this may remove false positives and close gaps, it is important to note that no data is saved anywhere before this step, so it should be used cautiously.

4.8 Remarks

Generally, the bandpass quantiles should be adjusted in bigger steps than the highpass quantiles.

If just increasing or decreasing quantiles does not work, it may help to increase the quantile(s) and increase the threshold(s), or decrease the quantile(s) and decrease the threshold(s). This will give a different behaviour as you are making one thing more sensitive and the other less.

False positives are preferred over false negatives as there is a manual verification step for every detected seizure. So, false positives can easily be discarded, while false negatives will not be explicitly shown.

5 Pipeline and suggested usage

5.1 Overview

The terminal output guides the user through use, options and controls.

5.2 Tuning constants

5.2.1 Quantiles

All peaks in a band are taken and the value of a set quantile becomes the threshold. Anything above this threshold is then considered a peak in later processing with timings and variances.

If the detection is too sensitive, inspect the variances in the bandpass and the highpass - where is the variance generally low, independently of whether there is a seizure or not? If you zoom into the data, does it look like too many peaks which shouldn't be considered peaks are marked as such (red cross)? Increase the variance for said band(s). This will make the computed peak threshold higher and thus make the detection less sensitive. Do the opposite if not sensitive enough.

If it seems like the variance has sufficient range (very low when there is a seizure, higher up or out of range generally where there is none), then the quantiles are set right.

5.2.2 Variance thresholds

The variance thresholds set how low the rolling variance of the time differences in the peaks has to be for this to be considered a seizure.

If the rolling variance looks good (the variances get distinctively low during a seizure, but higher elsewhere), the threshold may be adjusted. If the variance decreases near a seizure, but does not go below the threshold, then the threshold needs to be increased.

5.2.3 Window size

If short seizures are not being caught, the window size should be lowered. This will cause issues elsewhere, probably increasing the amount of false positives. Using rolling power

likely helps with this. Furthermore, the quantile(s) could be increased and/or variance threshold(s) decreased.

Window size can be increased if you wish to prevent short false positives.

Window size should be an even number.

5.2.4 Power parameters

Power is found using rolling power of a set window size. A threshold is found my taking all amplitudes of the signal, finding the average of the 0.01 and 0.99 quantile and multiplying that by a constant factor. The primary variables to tune are the rolling window size and this threshold power factor. There is also a set duration of time padding around each detection, which may also be tuned.

5.3 Others

If dealing with a specific recording method, very low/high sampling rate or phenotype, the following parameters might be changed

The band frequency should correspond to the low frequency component of seizures, while the high frequency component should correspond to the spikes. If e.g. the spikes are not being detected, perhaps the frequency cutoff of the highpass is too low.

The minimum duration between peaks is specified. If dealing with very noisy data, this minimum limit might be forcing a low variance, leading to false positives. To detect more peaks not constrained by this distance, this value can be lowered, but note that this will result in more peaks overall so the quantiles will have to be adjusted. Another possible need to adjust this is if using very high/low sampling rates.

6 Effectivness

For noise to go though, it must be periodic and present in both bands, which is not something most of noise is like.

7 Full list of parameters

Variables:

Name	Variable Name	Default Value	Comment
Duration per frame	periods_len_minutes_seizure	20 min	Duration of each analysis frame
Bandpass lower frequency	f_band_low	2 Hz	Lower frequency limit for bandpass filter
Bandpass upper frequency	f_band_high	9 Hz	Upper frequency limit for bandpass filter
Highpass cutoff frequency	f_hf_cut	35 Hz	Cutoff frequency for highpass filter
Merge gap	merge_gap	0.4 s	Time gap for merging detections.
Short cutoff	short_cutoff	0.4 s	Minimum seizure length (filtering)
Rolling Power Window size	window_power	2.0 s	Window length used for power calculation
Threshold power multiplier	threshold_power_factor	0.75	Multiplier for threshold computed from mean of power minimum and maximum
Power padding duration	pad_power_duration	0.45 s	Duration to pad around power threshold events
Default quantile for bandpass	quantile_band_default	0.6	Default quantile used for bandpass min. peak height
Default quantile for high frequency	quantile_hf_default	0.98772	Default quantile for high-frequency min. peak height
Default bandpass threshold	threshold_band_default	0.004	Default threshold level for bandpass peak time variance
Default High Frequency Threshold	threshold_hf_default	0.001	Default threshold level for high-frequency peak time variance
Default window size	window_size_default	4 s	Number of peaks to consider when computing rolling variance of peak timings
Default spread factor	spread_default	1.0 s	How much to pad around variance threshold crossings in both bands before converting to binary mask
Minimum peak distance	peak_dist	0.035 s	Minimum distance between detected peaks
Verification padding time	verification_padding_time	6 s	Time duration shown around each frame during verification

Table 4: Constants

Name	Variable Name	Default Value	Comment
Verify seizures	verify_seizures	False	Enable verification stage for each detected seizure
Disable user input	no_user_input	False	Disables user input
Live constant adjustment	live_constant_adjust	True	Allows adjustment of detection constants inside detection window
Restart after adjustment	restart_after_adjust	True	Restarts analysis from start of file after live adjustment of detection constants
Merge and filter	merge_and_filter	False	Merging of close and filtering of short seizures before showing on window - no data is saved prior to this
Power Threshold Use	use_power_threshold	True	Option to use power threshold as extra detection layer
Exclude bad periods from signal	exclude_bad_from_input_sig	False	Excludes signals marked as bad from input signal
Remove bad periods from detections	remove_bad_from_detected	True	Removes detections flagged as bad from results
Remove signal drift	remove_drift	True	Removes low frequency component and DC drift in signal data

Table 5: Modes