An Automated Sleep Spindles Detection Tool and its Use on Spindles Analysis and Parameterization

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Introduction

Sleep spindles are bursts of neural oscillatory activity that are generated by the thalamic pacemaker during stage 2 NREM sleep in a frequency range of 11-16 Hz. Typically, the duration of a spindle is between 0.5–2 seconds. Sleep spindles are characterized by a progressively increasing, then a gradually decreasing, amplitude.

The interest in sleep spindles is growing in clinical research, since they have been associated with

- Neurological Disorders (e.g. Schizophrenia)
- Quality of sleep
- Learning

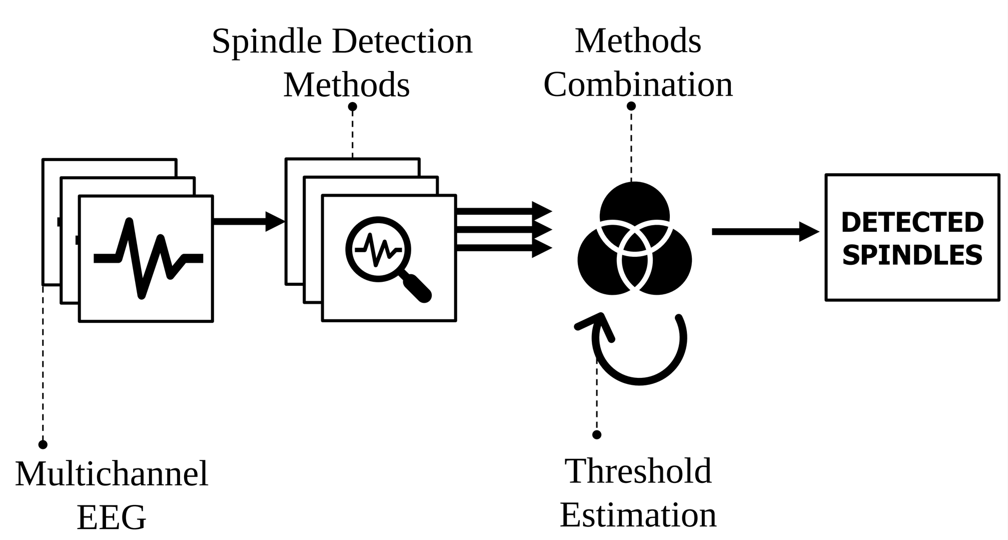
The manual detection of these spindles is **slow** and **subjective**

Automated detection is based on **objective** criteria and produces results in a **deterministic way.**

Objectives

The general idea of this work is to detect spindles with high reliability, in order to design a reliable system. The following steps were implemented:

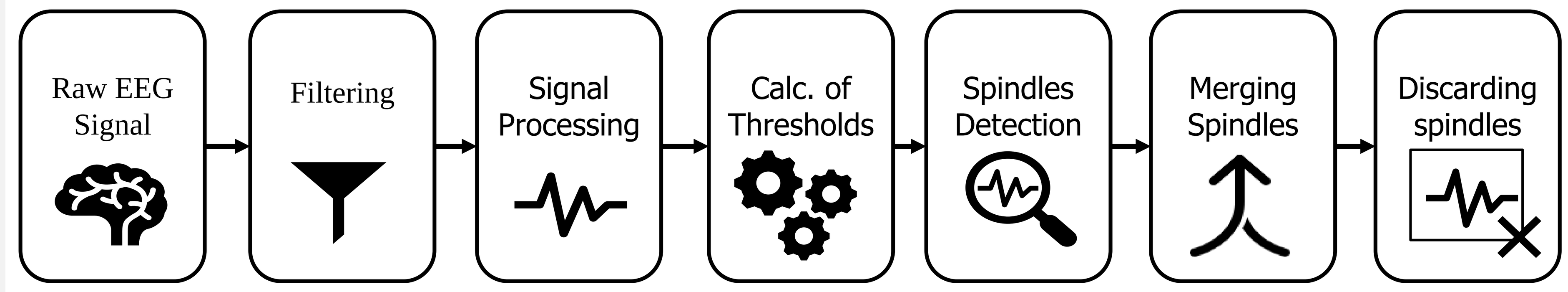
- Utilization of three publicly available detection methods.
- Threshold play crucial role to methods' performance and calculating the threshold using mean and standard deviation may be sub-optimal.
- Estimation of optimum thresholds through an iterative process.
- Combine methods to enhance detection reliability.



Proposed approach tested with artificial and real EEG signals. Artificial signal generated using a database of spindles with different characteristics, specified by experts using real EEG signals.

Automated Detection Methods

Automated detection methods used can be summarized by a standard pipeline, with the following stages



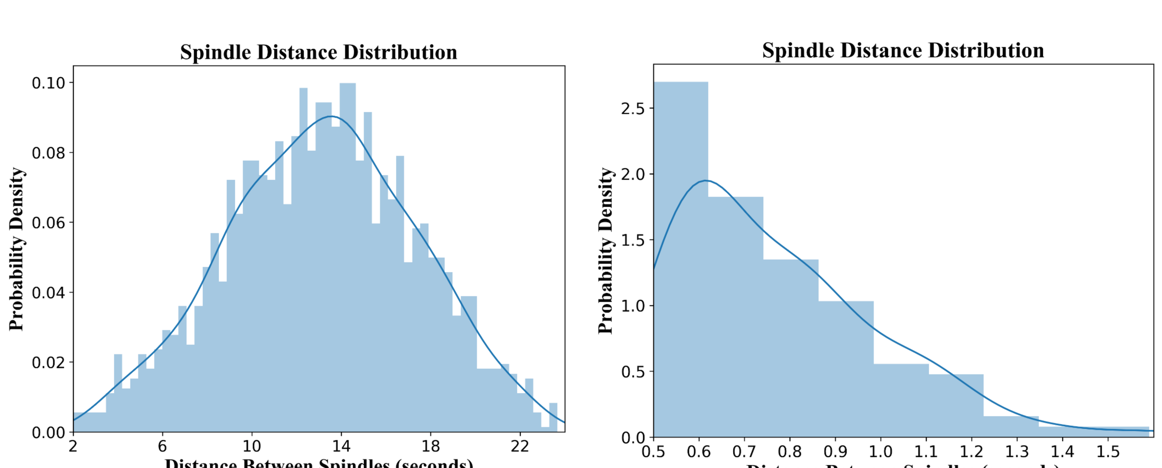
We utilize three detection methods that use different metrics, in order to analyze the EEG signal from different perspectives. The methods selected have the following characteristics:

PIPELINE STAGES	DETECTION METHODS		
AUTHOR	FERRARELLI	MÖLLE	UCSD
FILTERING	• Zero-phase Chebyshev FIR filter • Band: 11-15 Hz • Roll-off: 0.9 Hz	• Zero-phase Chebyshev FIR filter • Band: 11-16 Hz • Roll-off: 0.9Hz	• Wavelet Transformation with real wavelets • Band: 11-16 Hz • Wavelet Duration: 1 sec
SIGNAL PROCESSING	• Rectification • Signal Envelope	• RMS	• Rectification • Convolution with Tukey window
DETECTION THRESHOLD	$k_d \times mean(signal)$	$mean(signal) + k_d \times std(signal)$	$median(signal) + k_d \times std(signal)$
SPINDLE LIMITS THRESHOLD	$k_{sel} = \frac{k_d}{4}$	Same as Detection Threshold	Same as Detection Threshold
SPINDLE DETECTION	Above Selection Threshold	Above Detection Threshold	Above Detection Threshold
SPINDLE MERGING	Merge when overlapping	Merge when overlapping	Merge when overlapping
SPINDLE DISCARDING	0.5 – 2 seconds	0.5 – 2 seconds	0.5 – 2 seconds

Artificial EEG Signal

EEG Signal Properties:

- Duration : 1 – 16 hours
- Spindle Density : 1 – 10 spindles/minute
- Sampling Frequency : 500 Hz
- Spindle duration : 0.5 – 1.6 seconds
- Spindles Dataset : 104 spindles from Cz channel
- Noise Frequency Band : 0 – 20 Hz
- Distance Between Spindles : Truncated Gaussian Distribution ~X(μ, σ, lower)
- Noise in Sigma Band : 20% of spindle sigma power



Real EEG Signal

In addition to the artificial signal to our database, there is an EEG signal from Cz channel of one subject:

- Duration : 30 minutes
- Sleep Stage : NREM

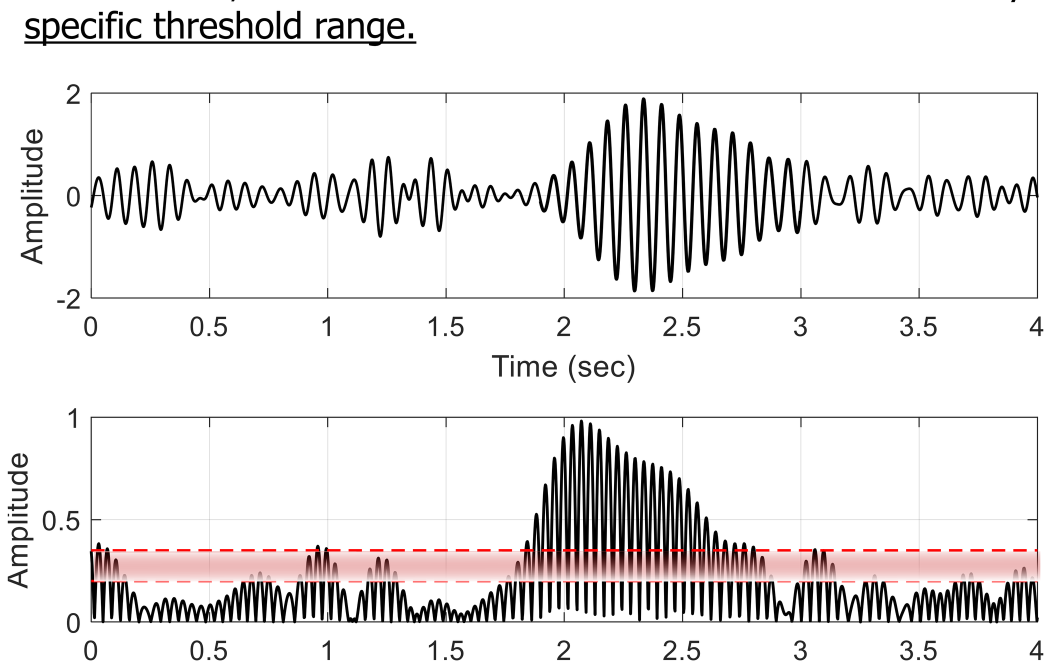
Methods' Evaluation

Methods were tested on signals which varied in time and spindle density. The spindles density is in the range of 1-10 spindles per minute. Since the signal is artificial, the spindles' location is apriory known for evaluation purposes, but not for detection.

Each method's performance was evaluated by modifying the detection threshold t in the range (0,1), where 1 is the maximum of the used metric. For each threshold, we present

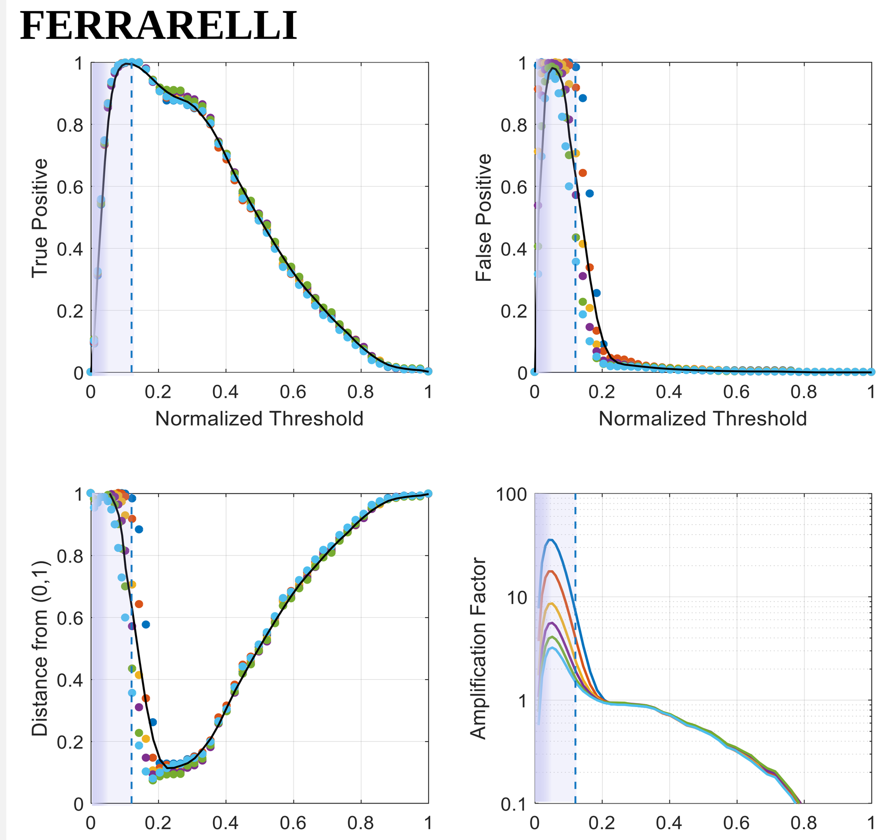
- The Confusion Matrix (TP, FP, FN, FP)
- The Receive Operator Curve (ROC)

In this work, it is concluded that a method is reliable only in a <u>specific threshold range.</u>



Performance Results

FERRARELLI



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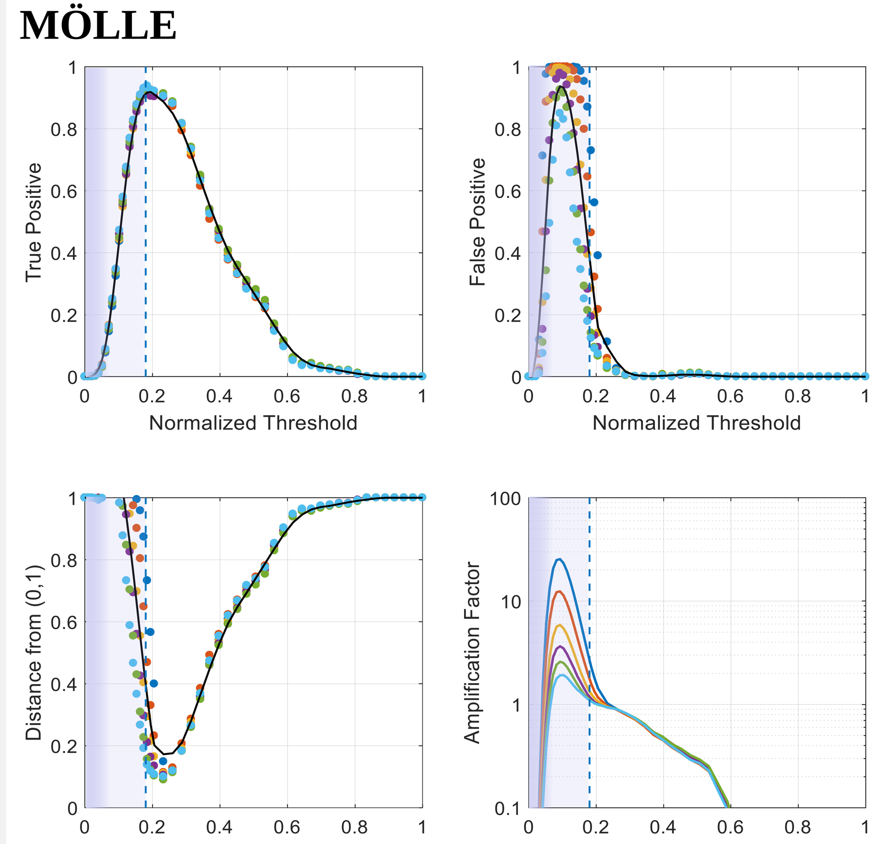

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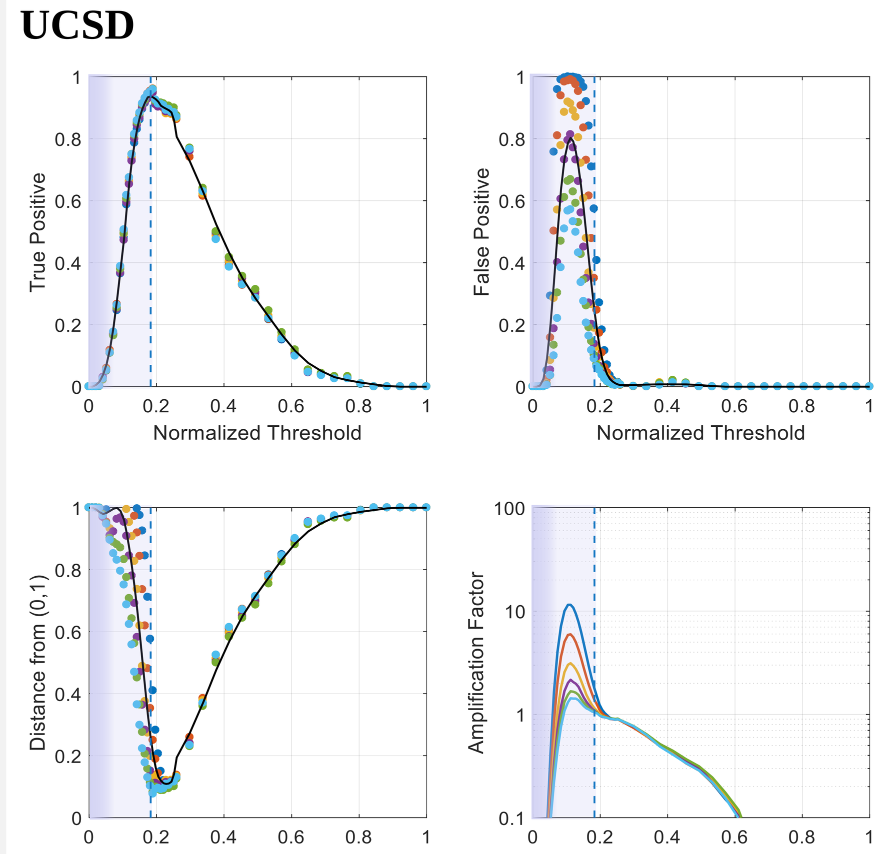


ROC

The performance of a method can be summarized by the Receiving Operating Curve were:

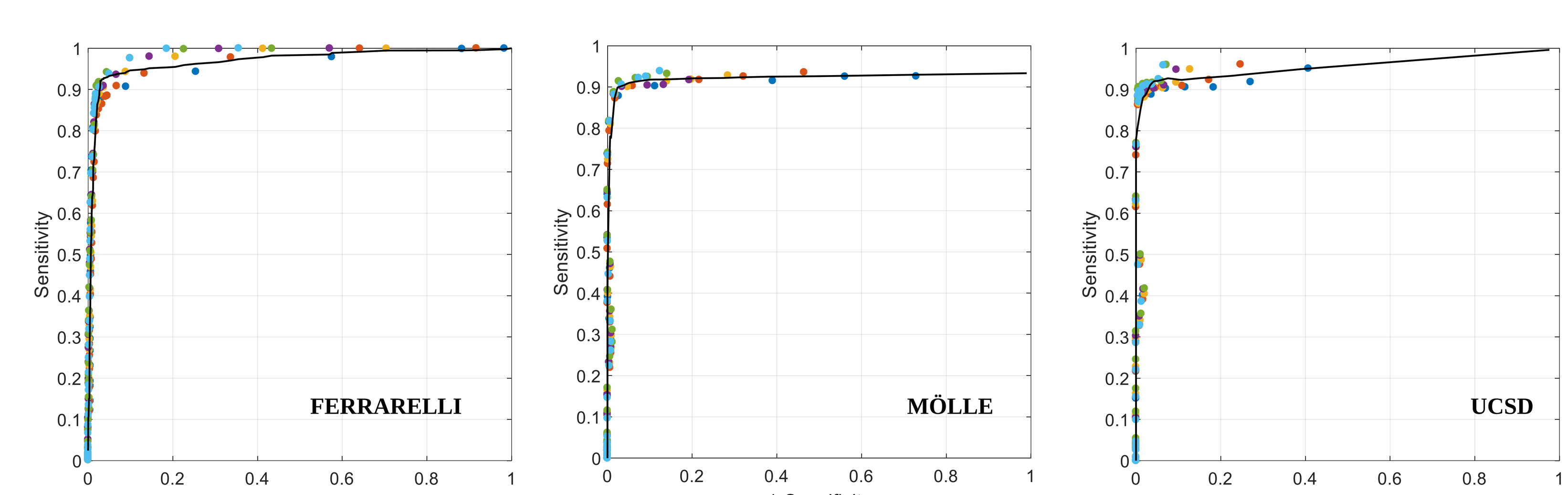
- X-axis represents the False Positive Rate (FPR):

$$FPR = 1 - specificity = \frac{TN}{TN + FP}$$

- Y-axis represents the True Positive Rate (TPR):

$$TPR = specificity = \frac{TP}{TP + FN}$$

- Method's best performance is achieved at the nearest point of the ROC at $p(0,1)$



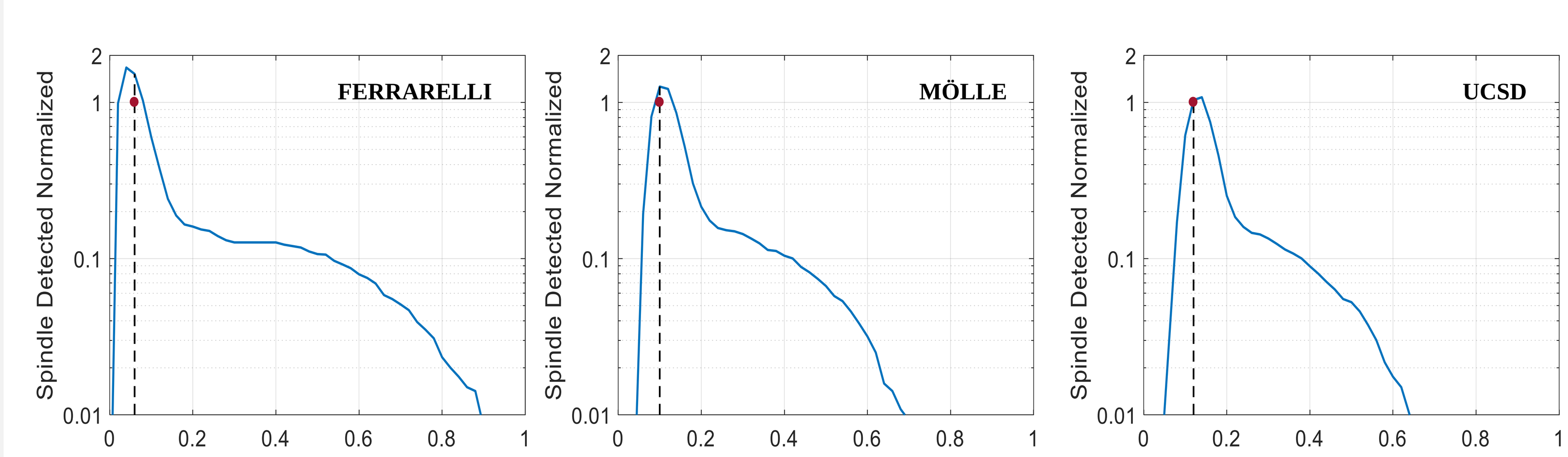
Methods' Combination

To improve the reliability of the spindle detection we consider the case that a spindle is found if it is detected by all three methods. For this experiment the real EEG signal was used:

- The methods were applied to the EEG for various detection thresholds.
- Each method was applied individually to derive the number of spindles, depending on the detection threshold value.
- The thresholds for which the most common spindles were detected, were defined as the optimum thresholds.

The maximum spindles detected from the combination of the three methods is smaller than the maximum spindles detected by each detection method.

<u>The use of methods with similar detection reliability is mandatory for getting the best result.</u>



References

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