Enhanced Sleep Spindle Detector Based on the Fujimori Method

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agenda

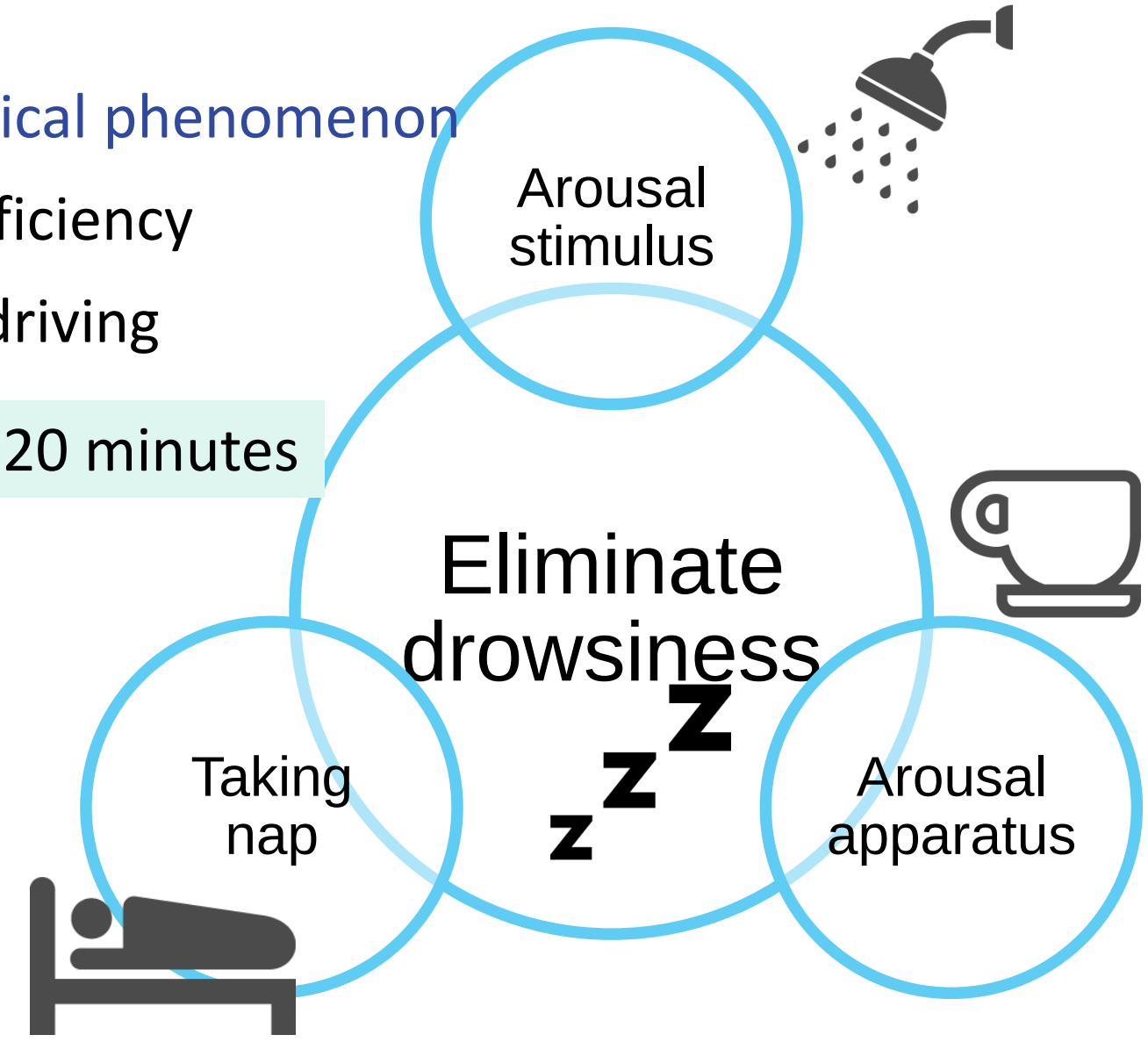
1. Introduction
2. Proposed Method
3. Experiment
4. Conclusion

INTRODUCTION | Afternoon Sleepiness

Routine physiological phenomenon

- Reduces work efficiency
- Leads to asleep driving

Take a nap within 20 minutes



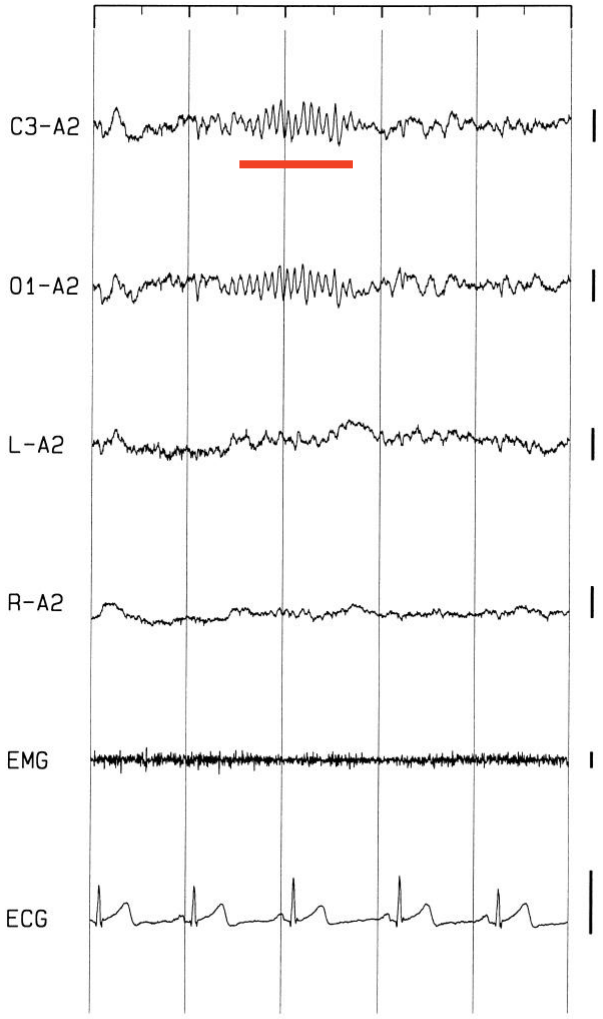
INTRODUCTION | Sleep Stage

	Sleep Stage	State of body	Features of EEG
Wake	Wake	Wake	
REM	REM		Eye movement
NREM	Stage 1	Holding Posture	Non-REM
	Stage 2	Holding the Neck	Sleep Spindles
	Stage 3	● Deeper Sleep ● Sleep Inertia	Theta waves, delta waves
	Stage 4		

Wake up before fall in stage 3

Taking a nap of 20 minutes or less

INTRODUCTION | def. of Sleep Spindles



stage 2 sleep spindle

Sleep spindles are defined as trains of 12 – 16 Hz waves of 10 μV or greater amplitude, composed of at least six consecutive waves, or train duration longer than 0.5 s.

Sleep Computing Committee, Japanese Society of Sleep Research, “LEARNING MANUAL OF PSG CHART polysomnogram, sleep stage scoring, interpretation”

INTRODUCTION | Conventional Method

Fourier Transform

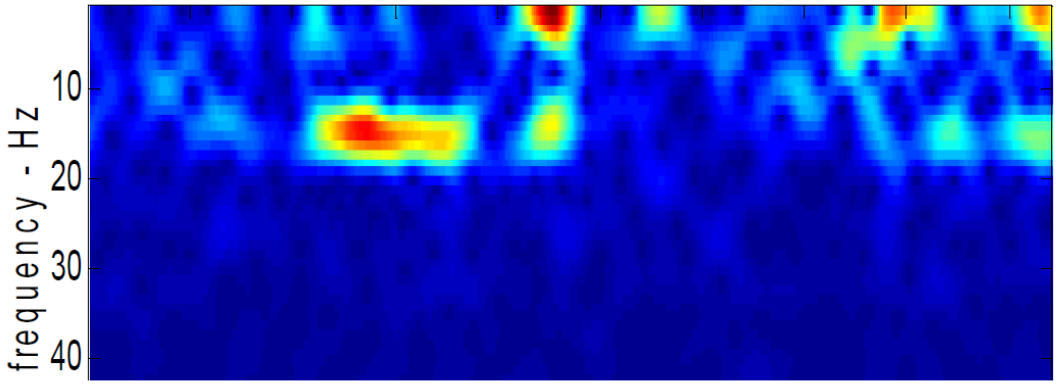
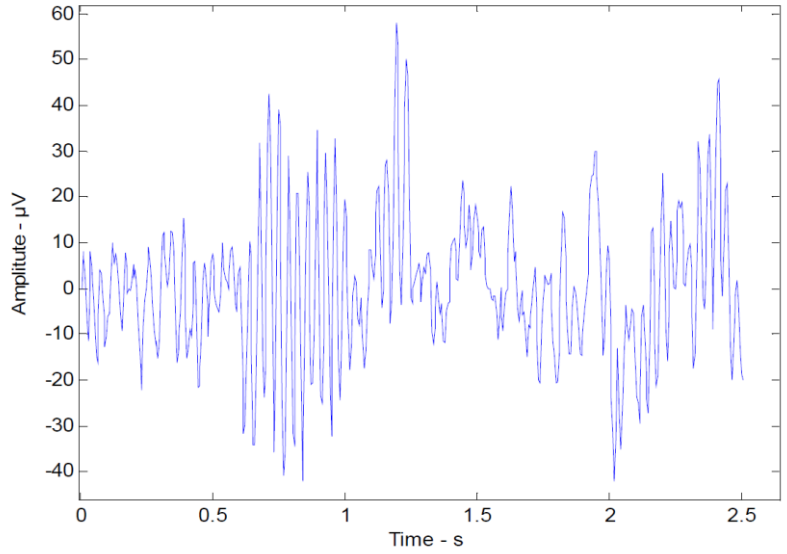


Fig. 2 Example of SS detection using STFT



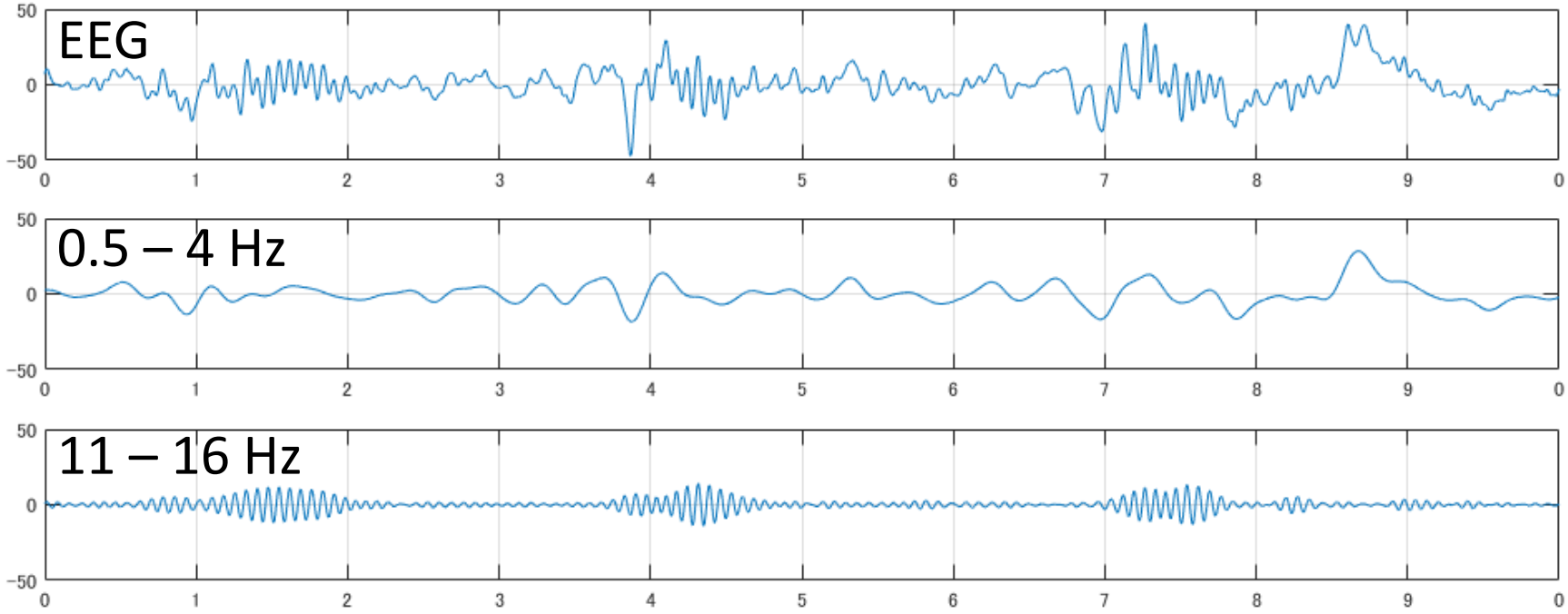
- Clinical analysis doesn't capture EEG like sine waves
- Front and rear relationship collapses

Ahmed, B.; Redissi, A. & Tafreshi, R.
"An automatic sleep spindle detector based on wavelets and the Teager energy operator"

INTRODUCTION | Conventional Method

Fourier Transform

represents the signal as a sum of the sines and cosines.



Usually, EEG is not observed as sine waves.

We think the FT is not appropriate for EEG analysis

INTRODUCTION | EEG Scoring

Visual Scoring

Observe
chronological changes

Time consuming at confirming every component

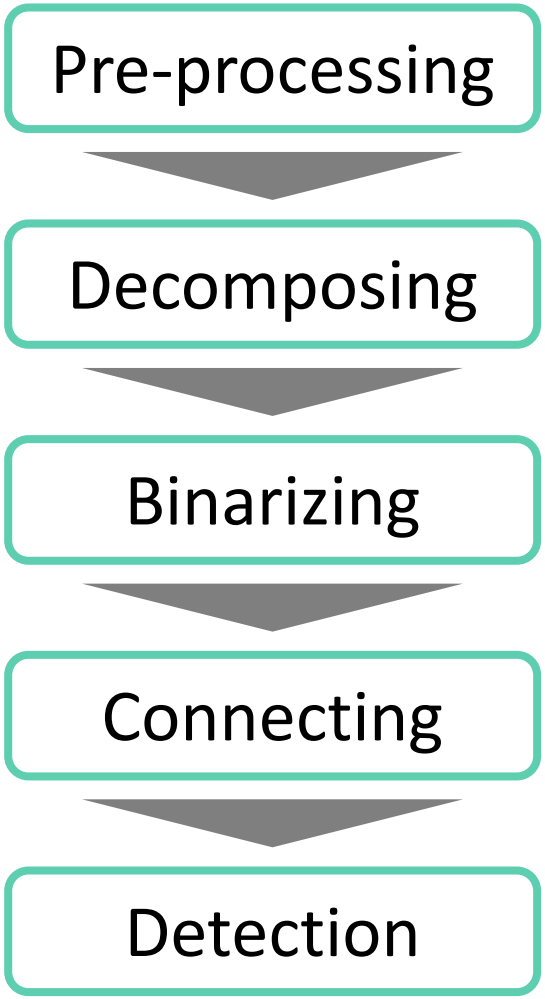
Automatic Analysis

Analyze EEG
in short time

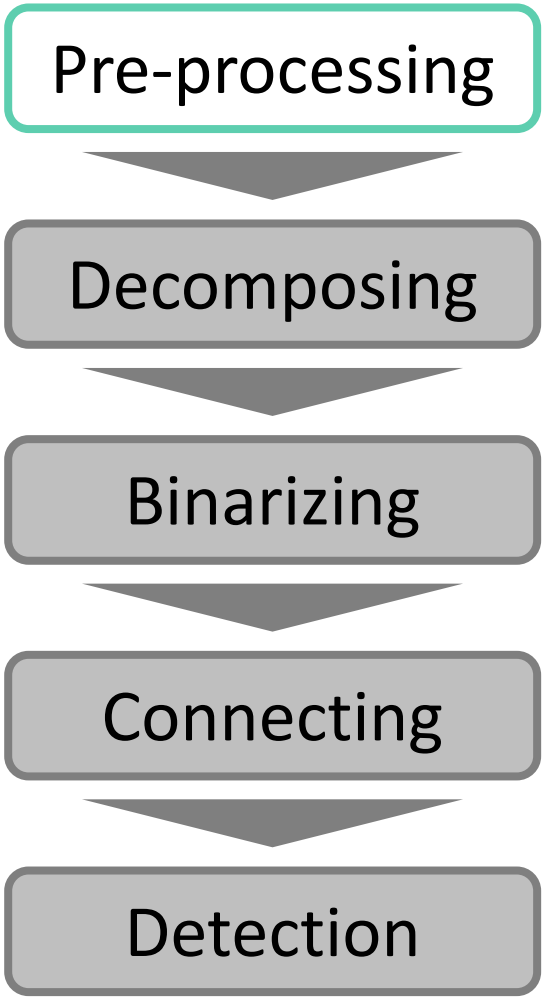
NOT clinically

An automatic sleep spindle detection method
(simulates the way of visual scoring)

PROPOSED METHOD



PROPOSED METHOD



PROPOSED METHOD | Pre-processing

Biological phenomena

EMG, Eye movement

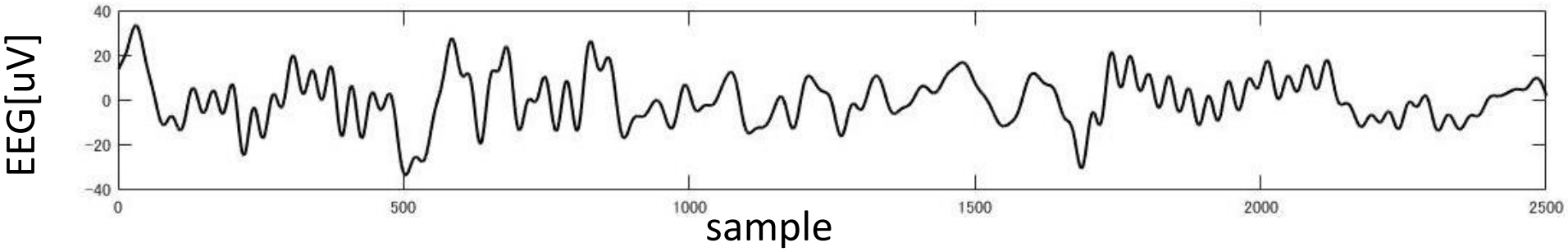
Environment

Electrostatic induction

electroencephalograph

Polarization voltage of electrode

Removal of unnecessary EEG and noise
Low-pass FIR digital filter (500 orders)



PROPOSED METHOD

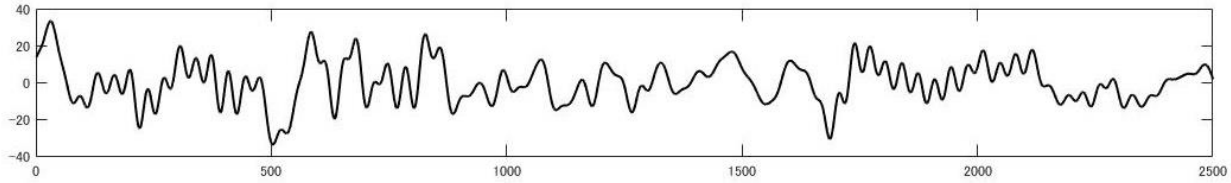
Pre-processing

Decomposing

Binarizing

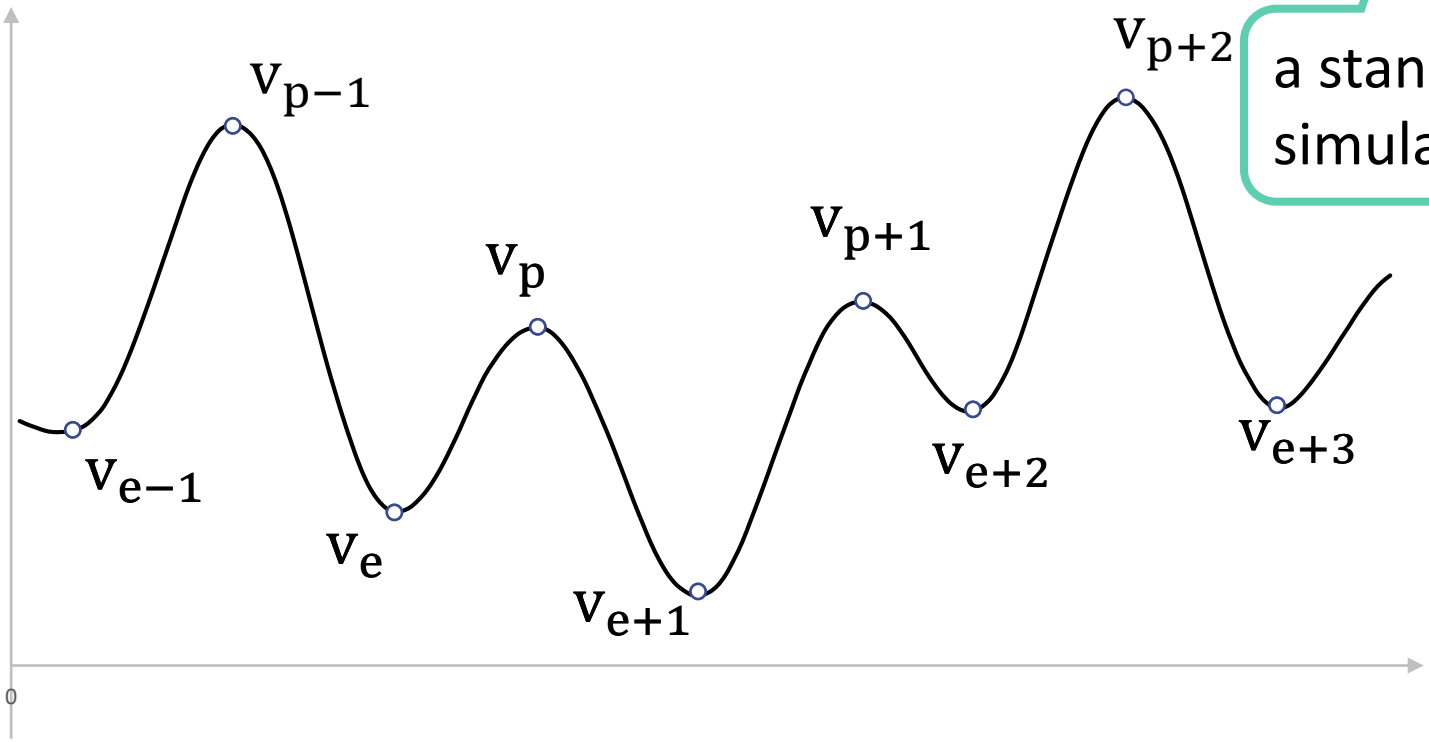
Connecting

Detection



PROPOSED METHOD | Decompose

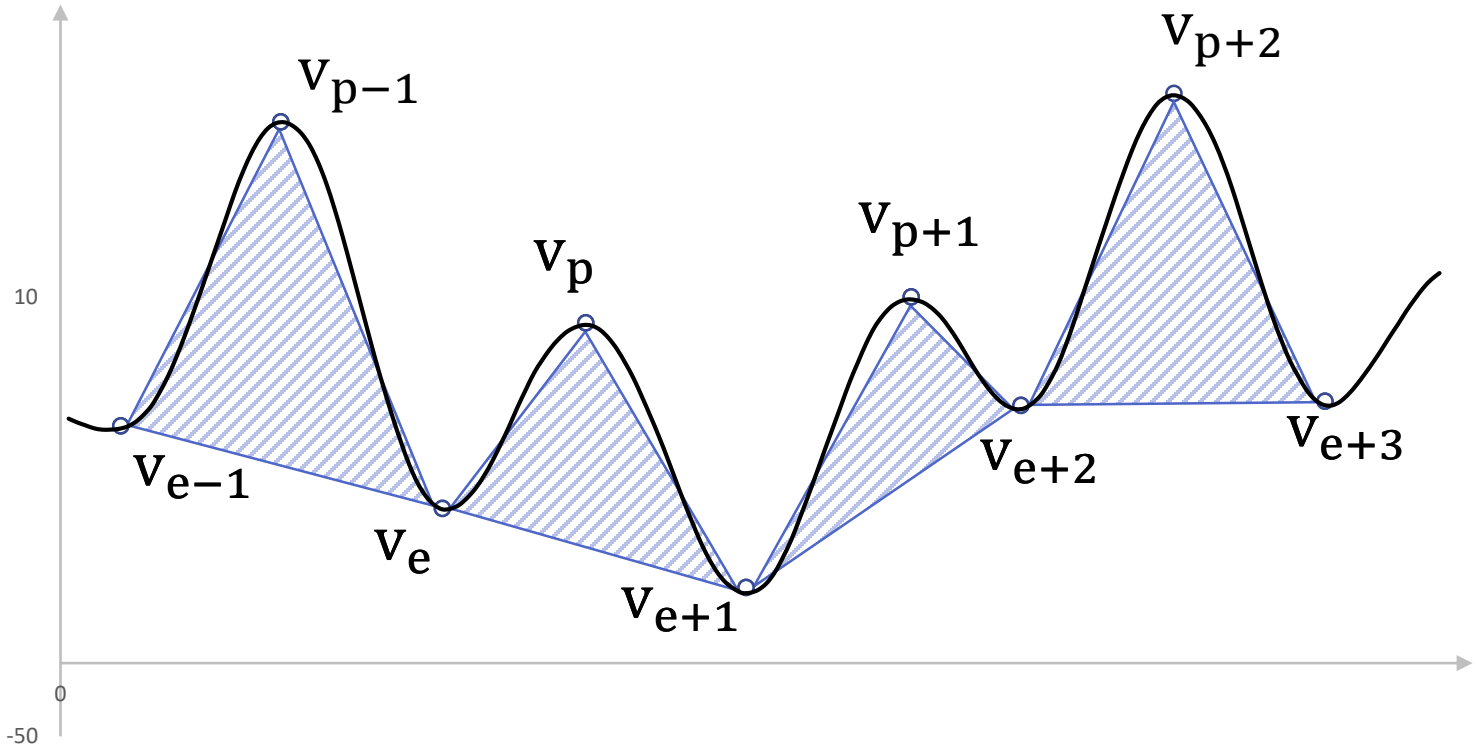
Decompose EEG components with **the Fujimori's method**



a standard technique to simulate Visual scoring

PROPOSED METHOD | Decompose

Decompose EEG components with the Fujimori's method



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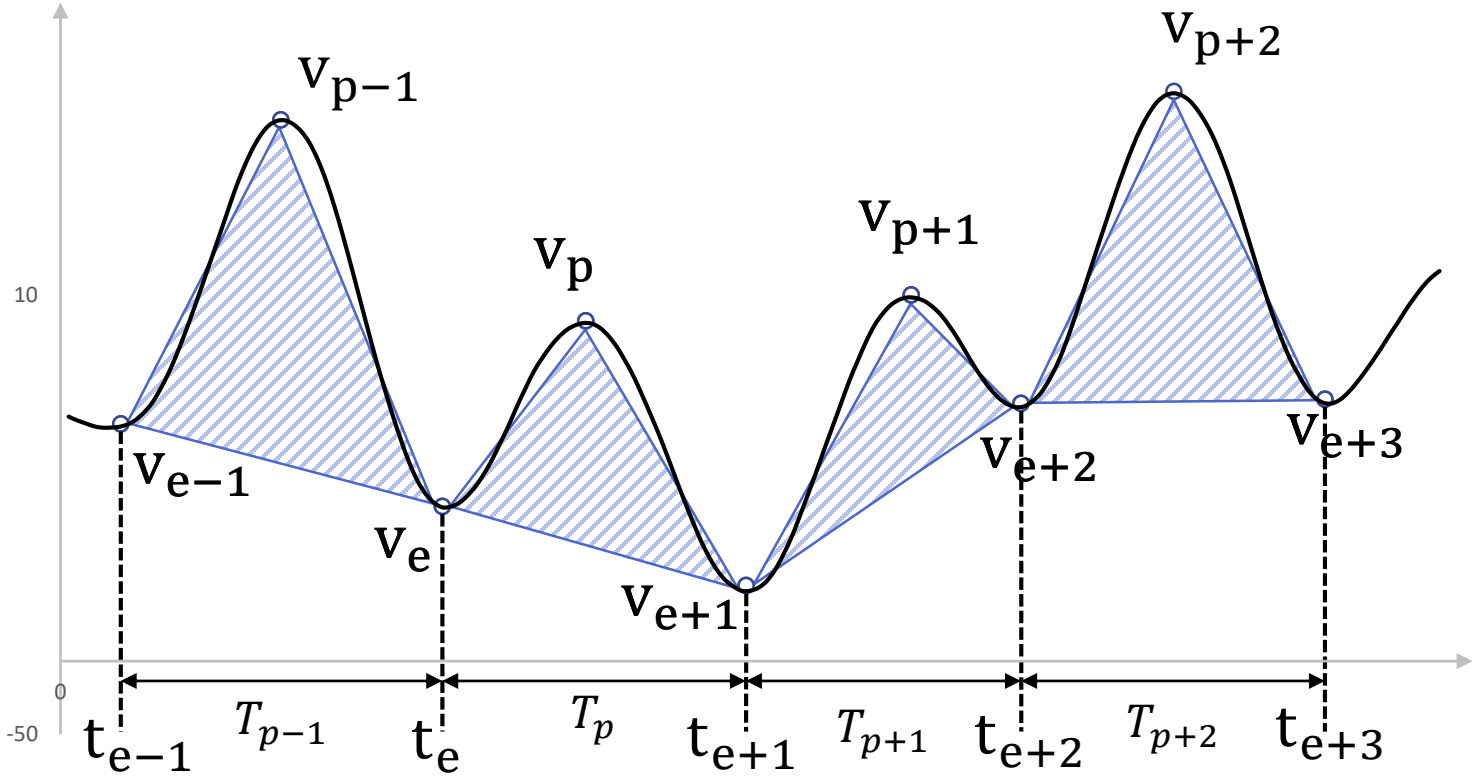

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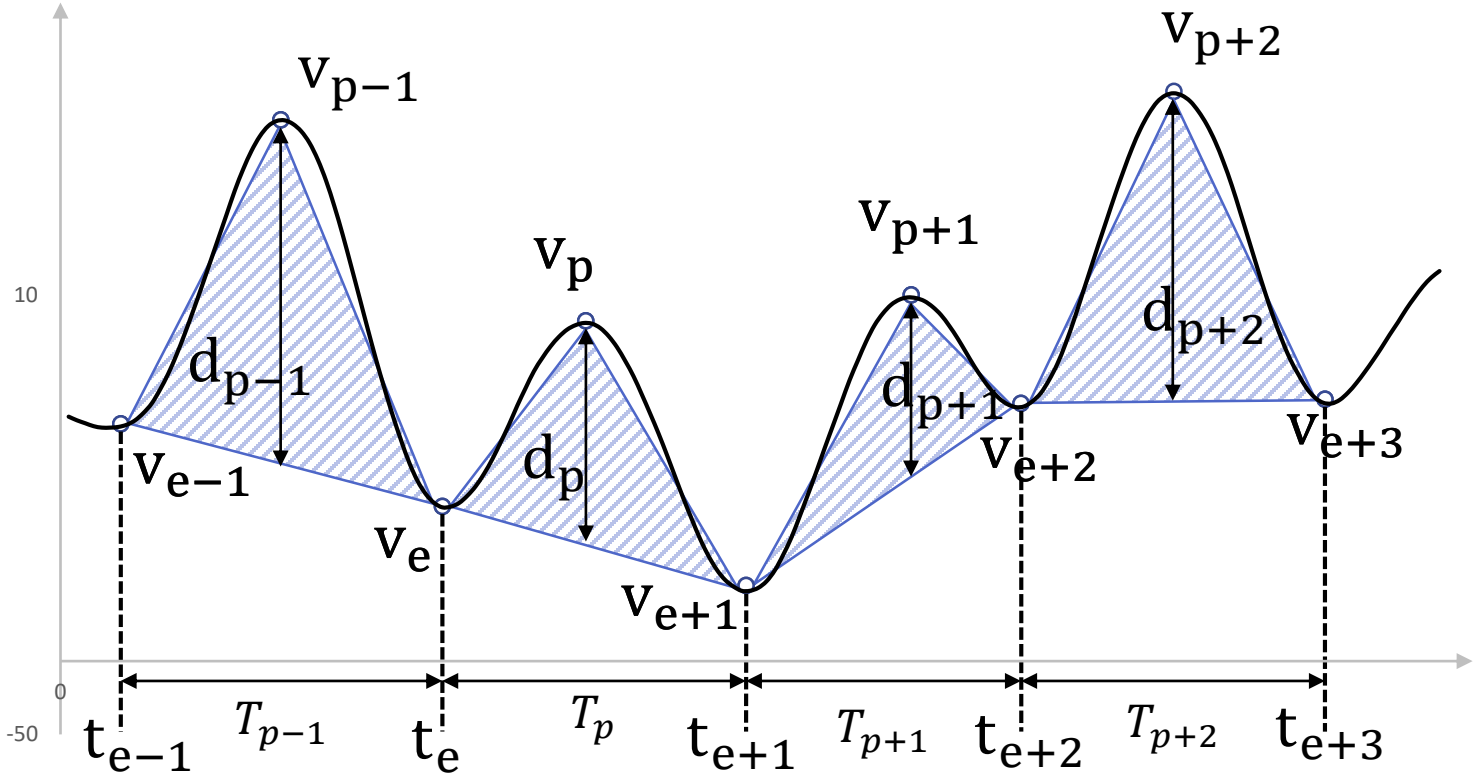

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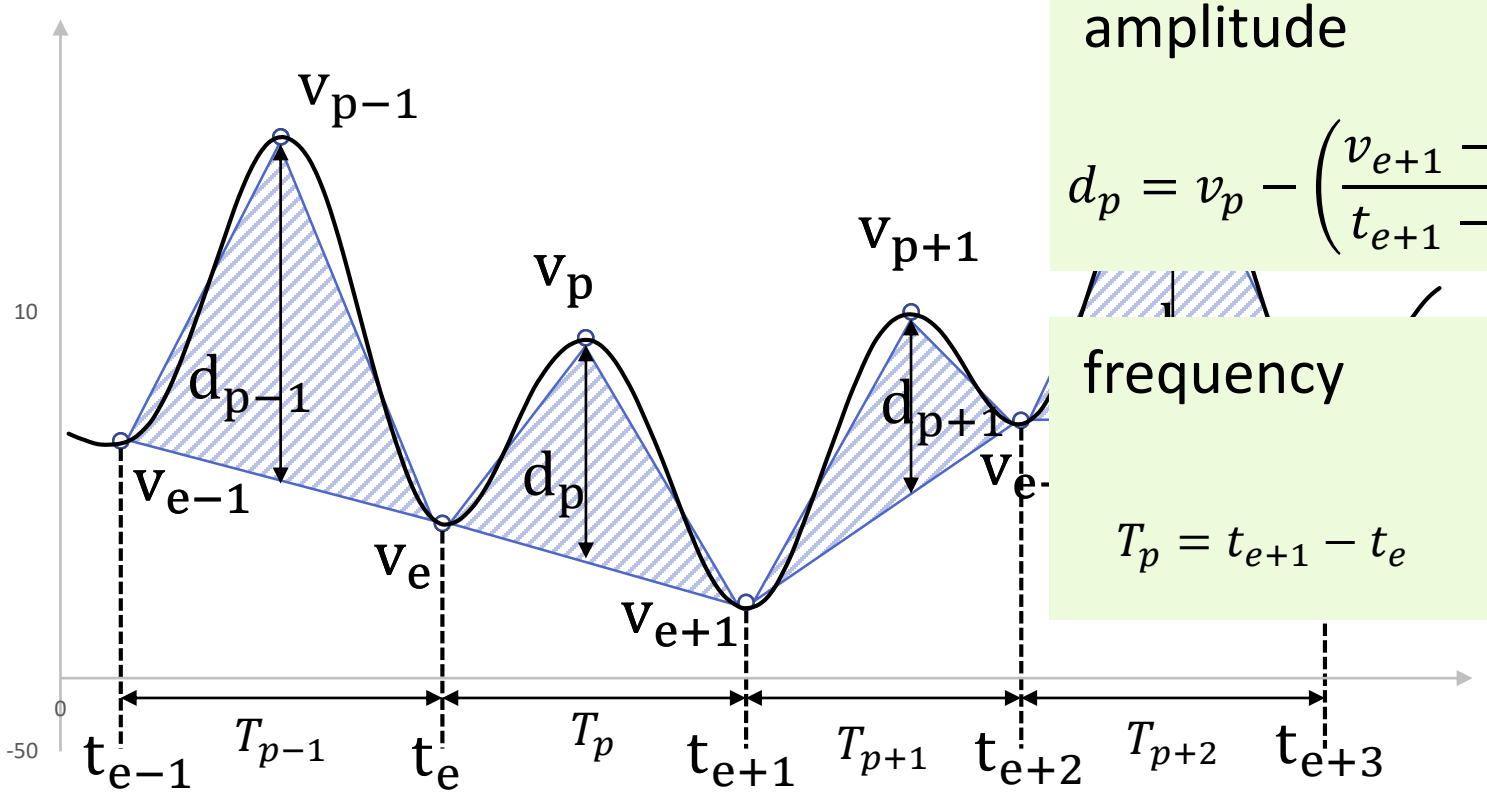


amplitude

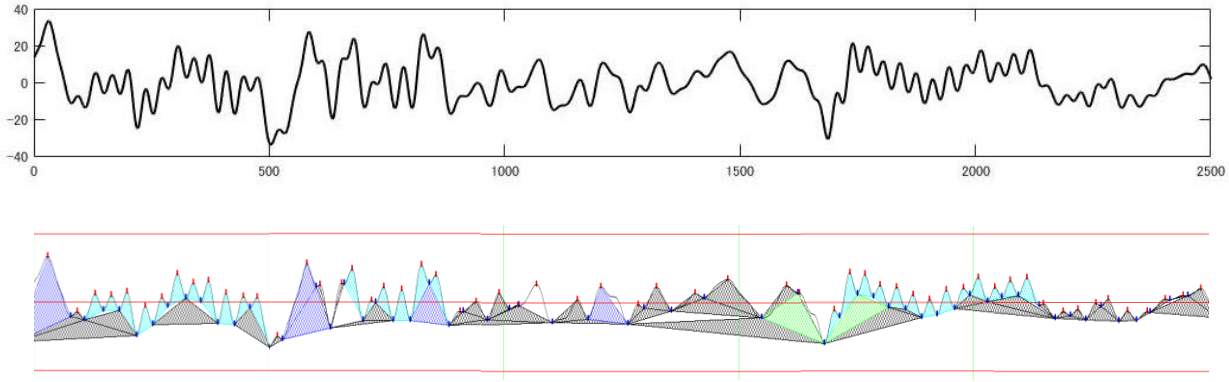
$$d_p = v_p - \left(\frac{v_{e+1} - v_e}{t_{e+1} - t_e} \times (t_p - t_e) + v_e \right)$$

frequency

$$T_p = t_{e+1} - t_e \qquad f_{T_p} = \frac{1}{T_p} = \frac{1}{t_{e+1} - t_e}$$

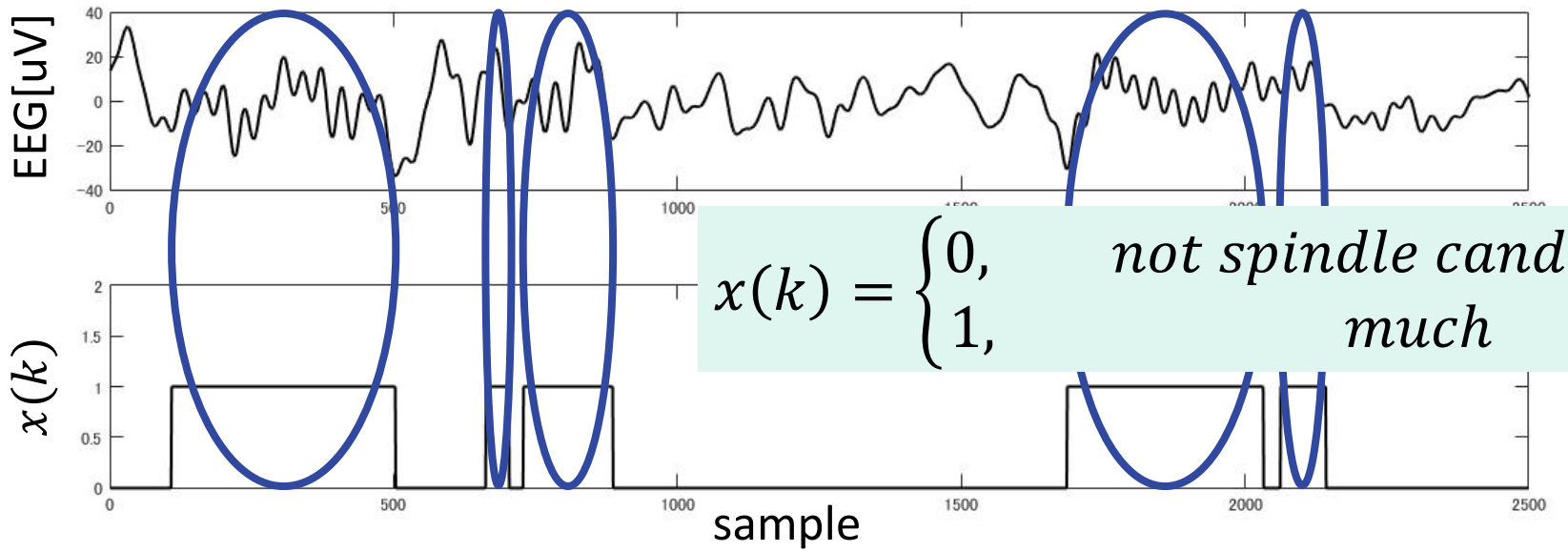
PROPOSED METHOD

- Pre-processing
- Decomposing
- Binarizing
- Connecting
- Detection



PROPOSED METHOD | Binarizing

Extraction of Spindle Candidates



$$x(k) = \begin{cases} 0, & not\ spindle\ candidates \\ 1, & much \end{cases}$$

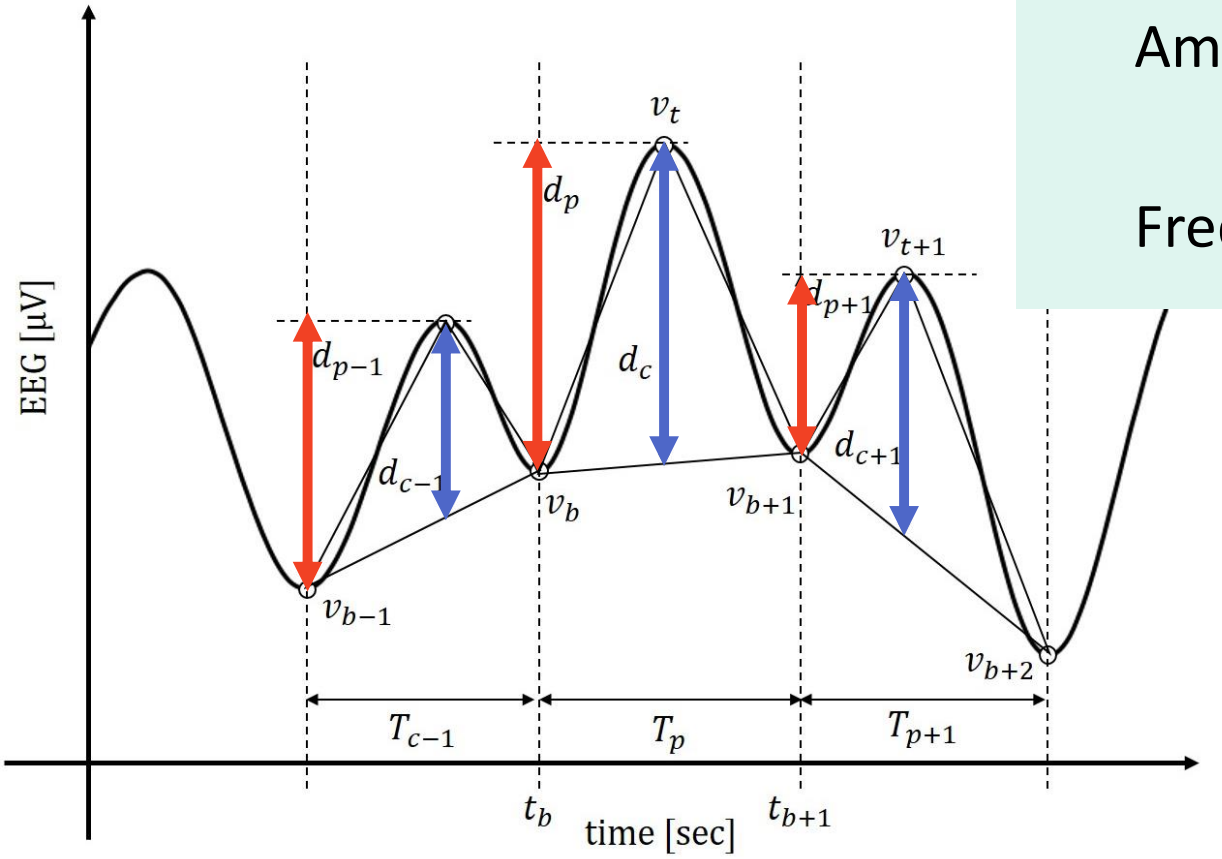
Judgment condition

Amplitude: rise over 10 uV

Frequency: between 11 Hz and 16 Hz

PROPOSED METHOD | Binarizing

Extraction of Spindle Candidates



Judgment condition

Amplitude: ①$d_c \geq 10\ \mu V$ (conv.)

②$d_p \geq 8\ \mu V$ (prop.)

Frequency: $11 \leq \frac{1}{T_p} \leq 16$

PROPOSED METHOD

- Pre-processing
- Decomposing
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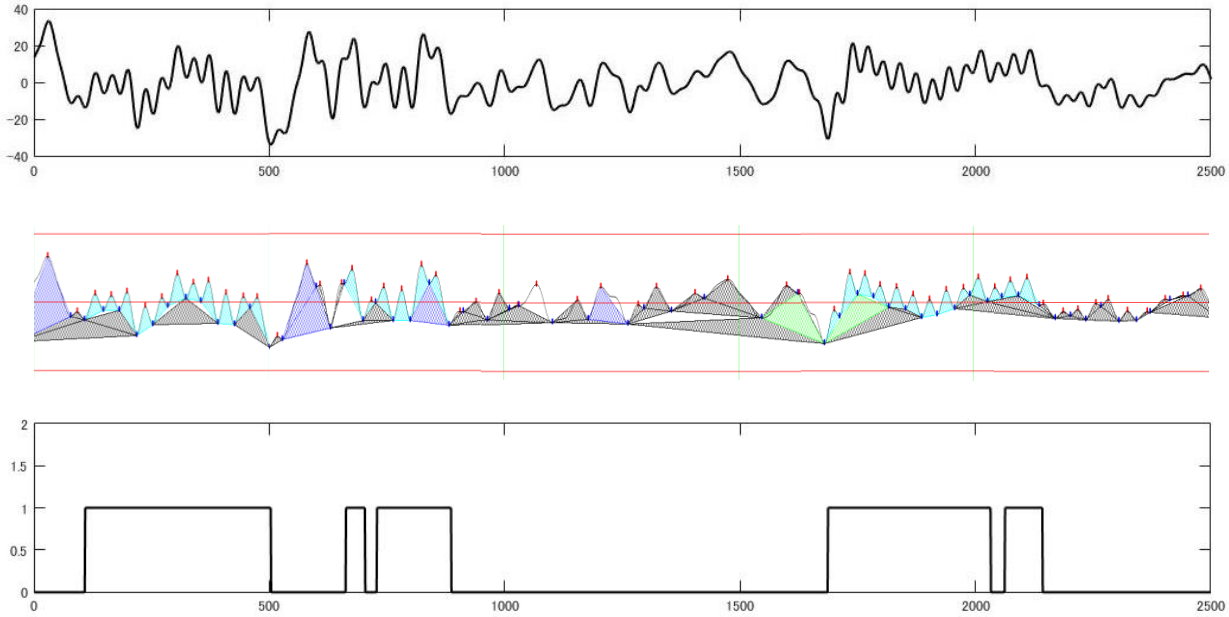
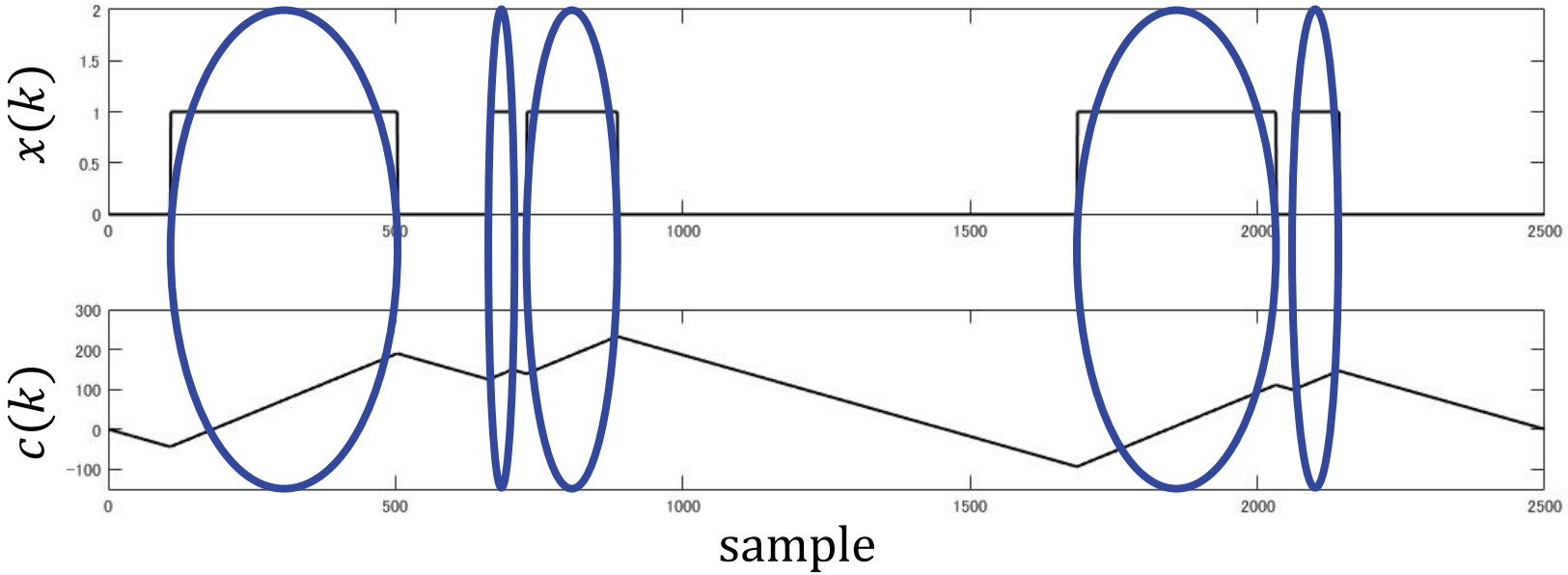


PROPOSED METHOD | CUSUM chart

Cumulative **Sum** chart

- Indicates the cumulative sum of deviations from the target values for each sample value

$$c(k) = \begin{cases} 0, & k = 0 \\ c(k-1) + (x(k) - \bar{x}), & k = 1, 2, \cdots, n \end{cases}$$

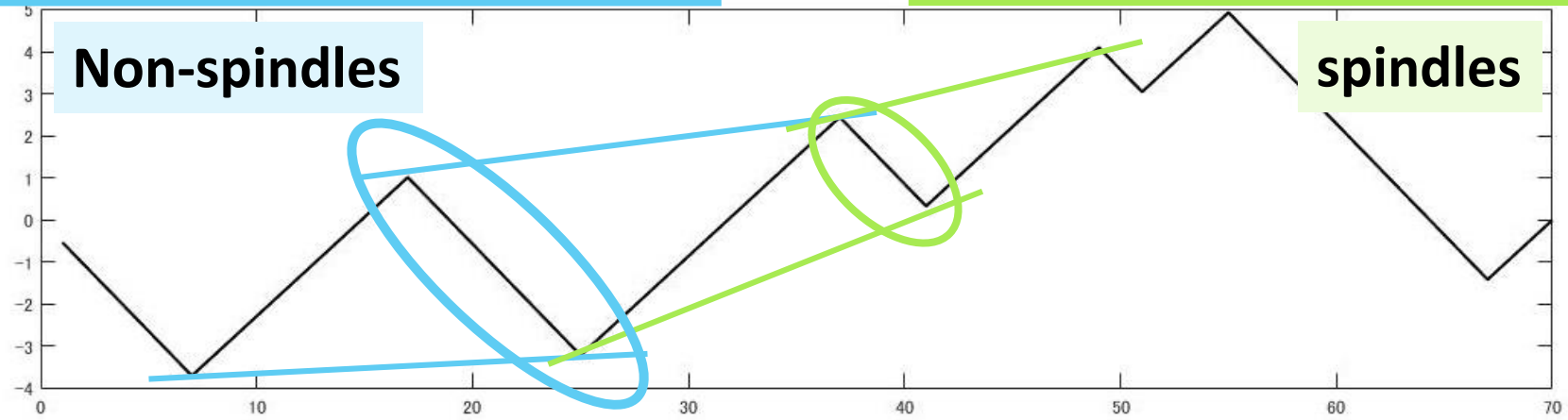


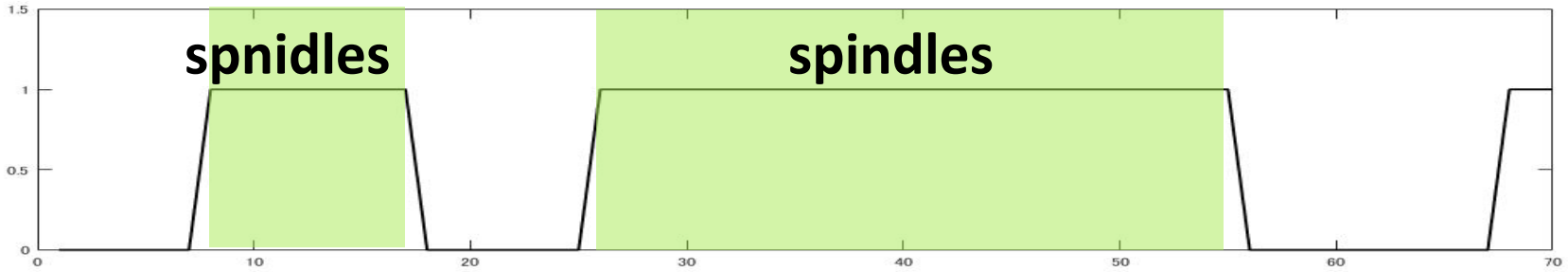
PROPOSED METHOD | CUSUM chart

$c_{v_i} < c_{v_{i+1}}$ & $c_{m_i} < c_{m_{i+1}}$ & Decrease less than 0.2s

- ✓ In increasing
- ✓ **Declining** for **more than 0.2s**

- ✓ In increasing
- ✓ Decrease less than 0.2s





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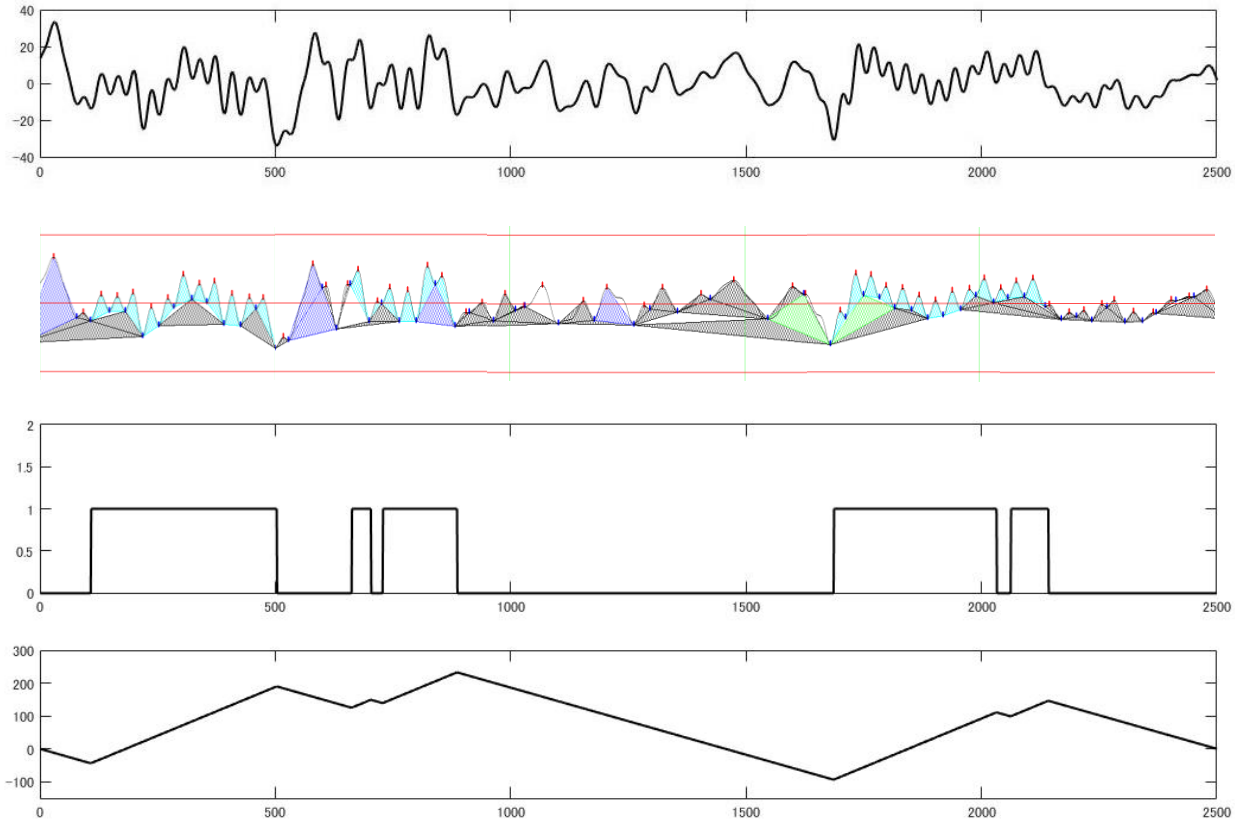


PROPOSED METHOD | Detection

International standards of sleep spindles

Sleep spindle consists of waves from 12 Hz to 14 Hz
that occur for at least 0.5 seconds.

Automatic detection

It is often set to 11 – 16 Hz

Proposed method

At least 0.5 seconds or 6 waves

EXPERIMENT

Subject Information

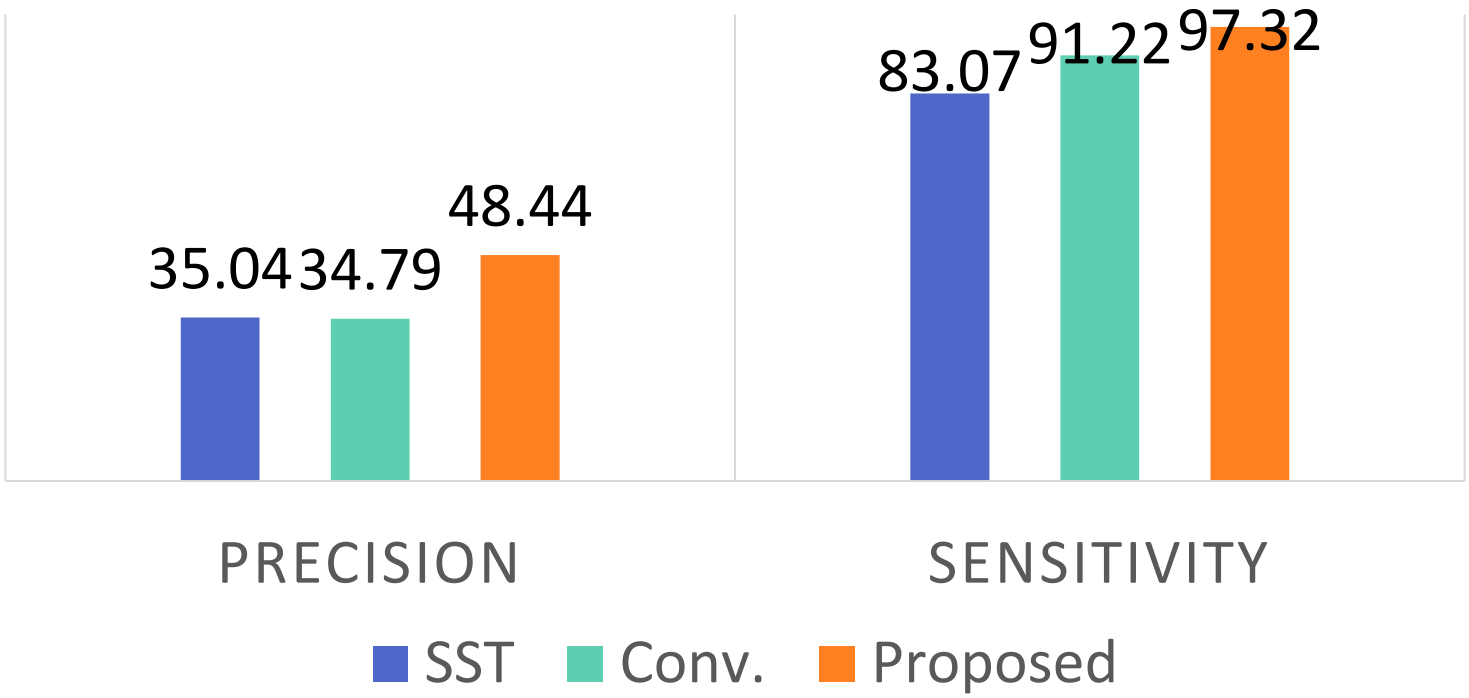
Target	2 male, 9 female
Age	21 – 24
Sampling frequency	500 Hz
Electrodes	C3-A2 (10-20)
Sleeping time	regular
One hour sleep EEG from 14:00	

Evaluation

Concordance rate of expert's judgment
(the number of spindles)

EXPERIMENT | Result

	SST	Conv.	Proposed
Precision	35.04	34.79	48.44
Sensitivity	83.07	91.22	97.32



FUTURE WORKS

- Detect non-spindles from candidates.
  - Different approach to CUSUM
- Analyze a lot of data
  - Ask other experts to judgement
- Apply to sleep quality analysis
  - Theta wave, delta wave, etc…

CONCLUSION

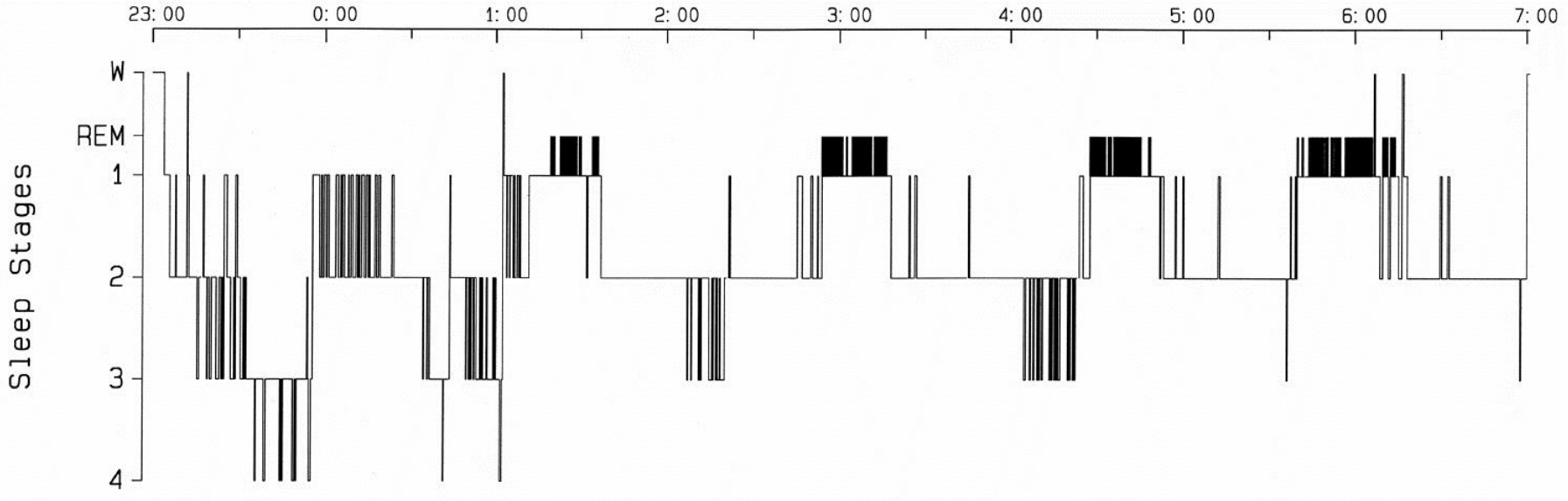
Automatic Analysis Method of Sleep in Sleep Stage 2

- The proposed method simulates the way of visual scoring in time domain.
- It achieved 90 % detection rate.
- In future, we have to detect non-spindles from spindle candidates.

Thank You for Kind Listening!!!

APPENDIX

INTRODUCTION | Sleep Stage



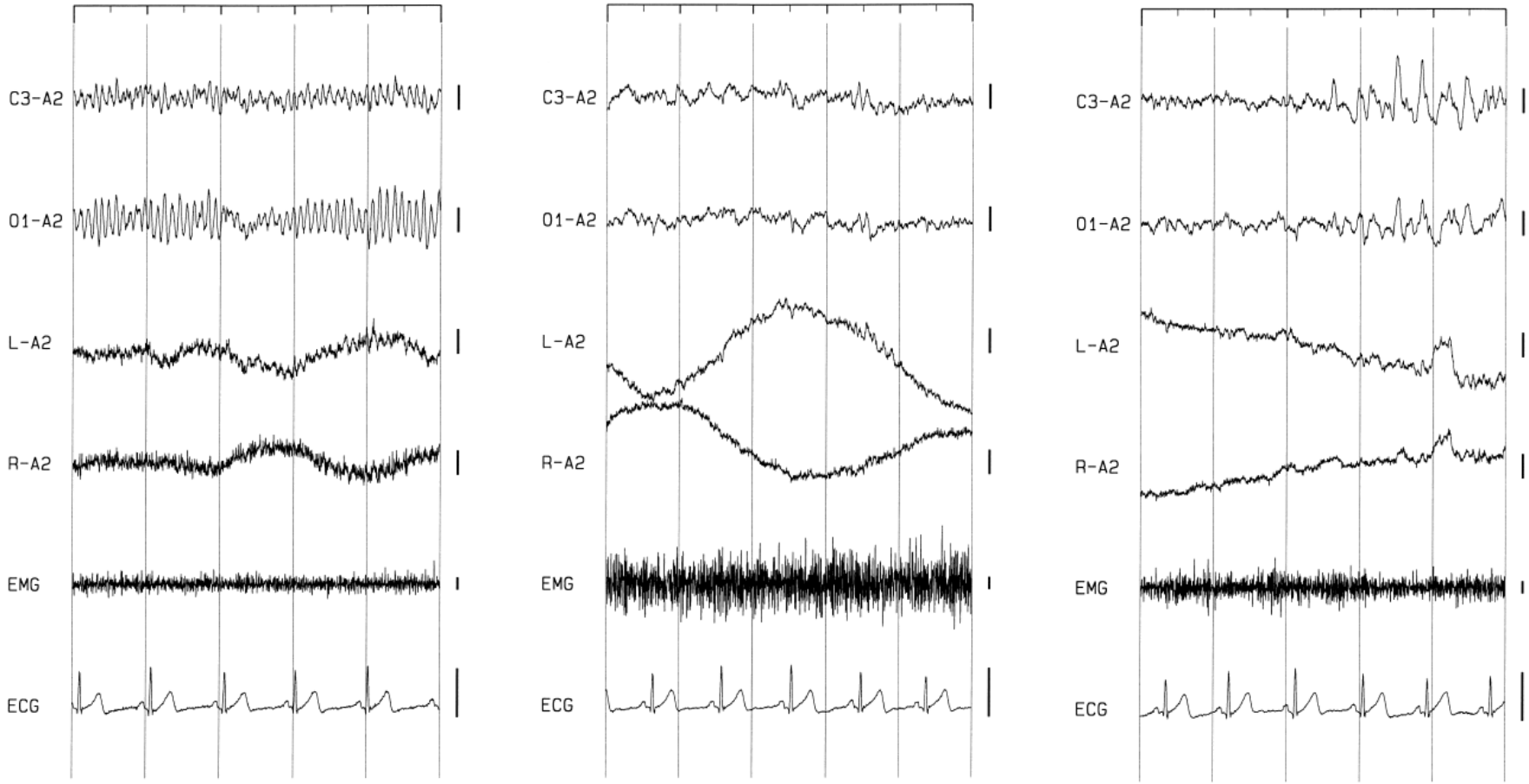
INTRODUCTION | Sleep Spindle

Sleep spindles are defined as trains of 12 – 16 Hz waves of 10 μV or greater amplitude, composed of at least six consecutive waves, or train duration longer than 0.5 s.

The appearance of the waveform train is not specified in the definition (i.e. a ‘spindle’ shape is not a requirement for identification as a sleep spindle). Although the mean frequency of a single train of waves can be used as a single descriptor for identified sleep spindles, its use must be clearly reported. Similarly, if a different amplitude threshold is used to identify sleep spindle activity, the threshold value must be clearly reported.

Sleep Computing Committee, Japanese Society of Sleep Research,
“LEARNING MANUAL OF PSG CHART polysomnogram, sleep stage scoring, interpretation”

INTRODUCTION | Sleep Spindle



stage W α waves

stage 1 low voltage, mixed frequency EEG (higher than 2 Hz, lower than 8 Hz)

stage 1 vertex sharp waves

Characteristic polysomnographic patterns for scoring sleep stages

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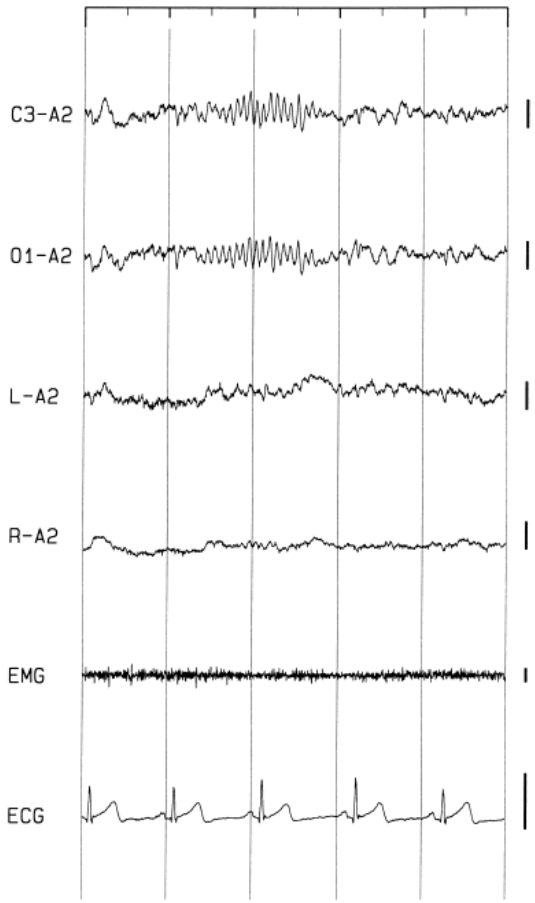
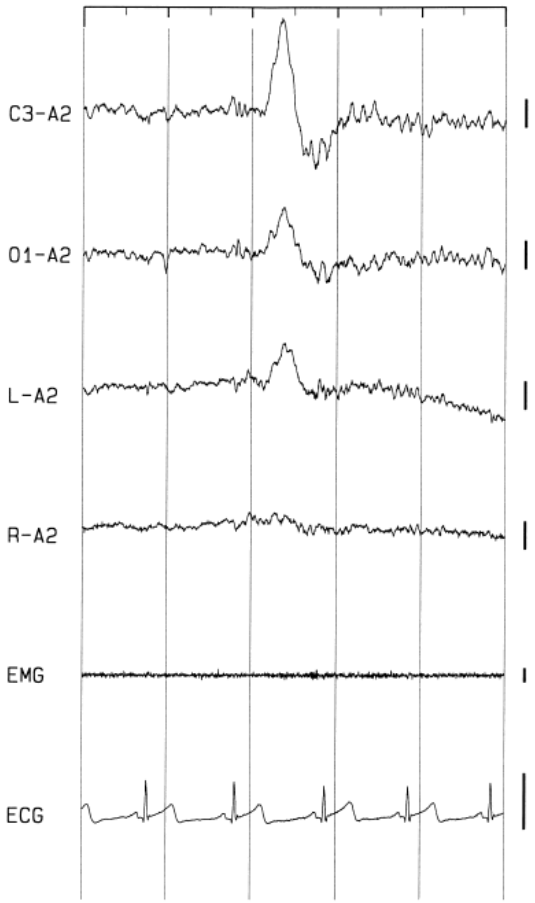
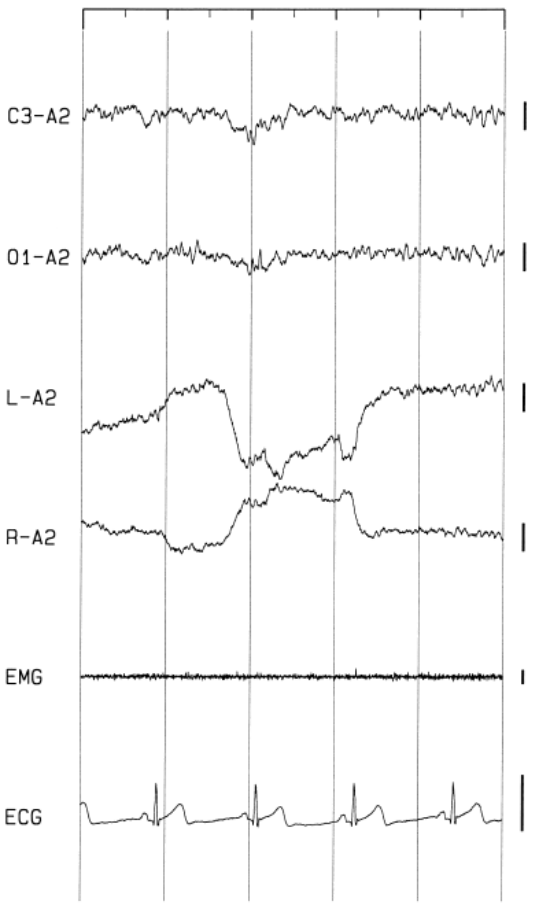
INTRODUCTION | Sleep Spindle



stage 2 sleep spindle



stage 2 K-complex



stage REM Rapid Eye Movements (REMs)

Characteristic polysomnographic patterns for scoring sleep stages

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INTRODUCTION | Conventional Method

Fourier Transform

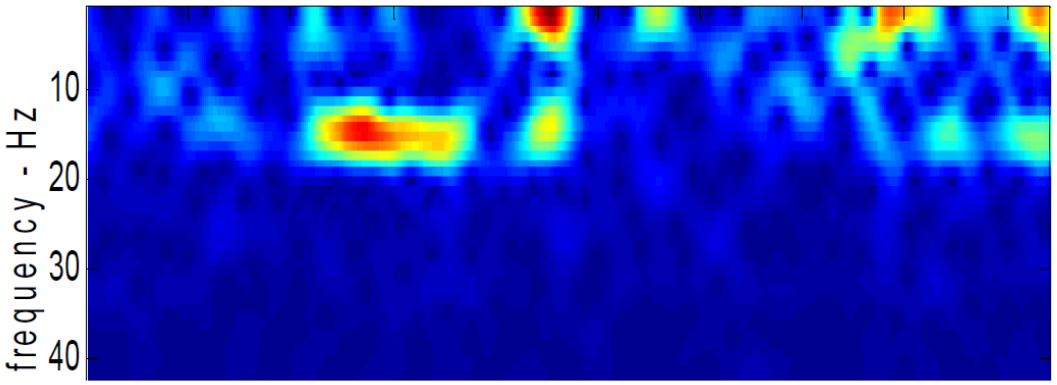
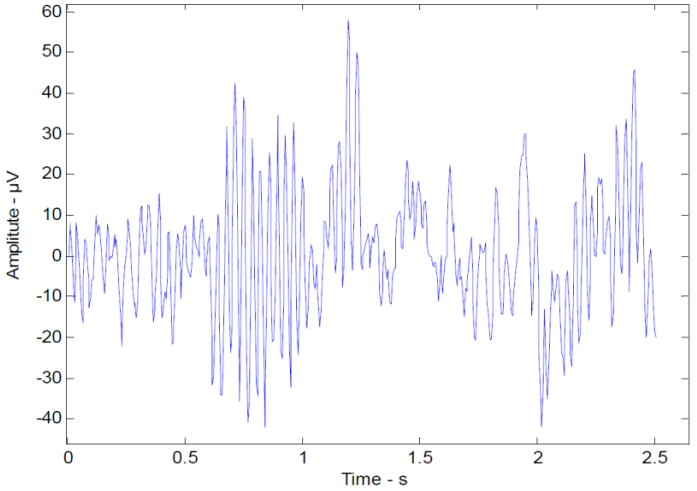


Fig. 2 Example of SS detection using STFT



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- Clinical analysis doesn't capture EEG like sine waves
- Front and rear relationship collapses

Simulate the way of doctors to detect spindles

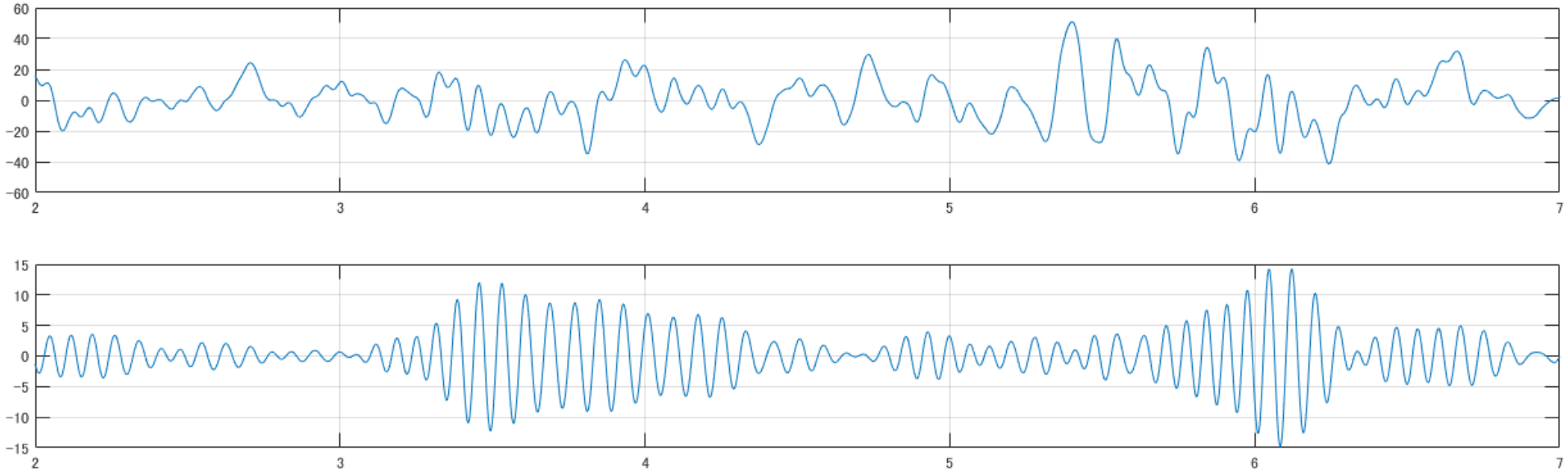
We propose an automatic EEG analysis method

Fujimori's method & cumulative sum chart

INTRODUCTION | Conventional Method

Fourier Transform

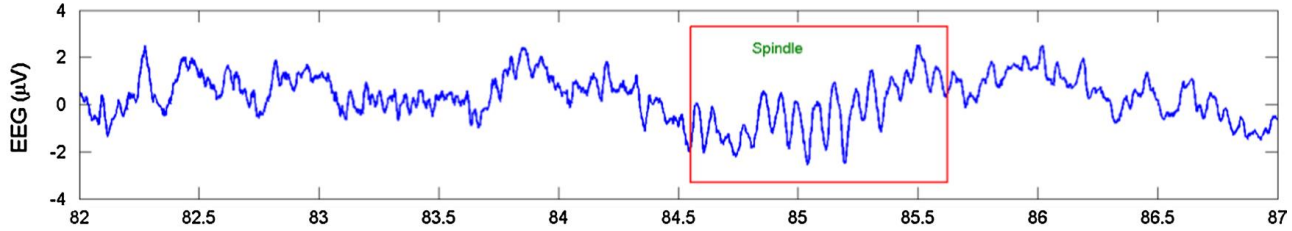
represents the signal as a sum of the sines and cosines.



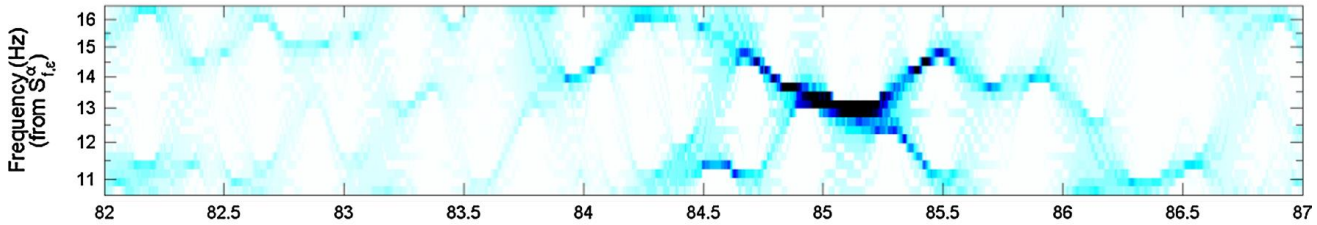
Usually, EEG is not observed as sine waves.

We think the FT is not appropriate for EEG analysis

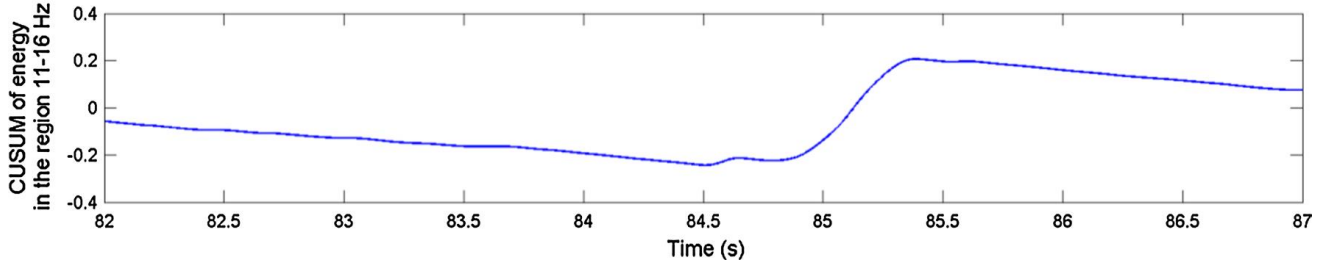
INTRODUCTION | Conventional Method



Synchrosqueezing transform



CUSUM chart with magnitudes of the EEG from SST



Kabir, M. M.; Tafreshi, R.; Boivin, D. B. & Haddad, N.
Enhanced automated sleep spindle detection algorithm based on synchrosqueezing
Medical & biological engineering & computing, Springer, **2015**, *53*, 635-644

EXPERIMENT | Result

SST	Positive	Negative
+	157	32
-	291	0

conv.	Positive	Negative
+	135	13
-	253	0

Prop.	Positive	Negative
+	218	5
-	232	0