HRV 2006

HRV in Sleep Apnea Detection and Sleep Stability Assessment

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Outline

- Overview of ECG-based sleep apnea detection
- Hilbert transform detection of sleep apnea
  - Sleep apnea heart rate oscillations
  - Hilbert transform detection algorithm
- Cardiopulmonary coupling (CPC)
  - ECG-derived respiration (EDR)
  - CPC detection algorithm
  - Sleep spectrograms
    - Normal sleep
    - Sleep state switching
    - Sleep apnea detection

- **Overview of ECG-based sleep apnea detection**

- Hilbert transform detection of sleep apnea
  - Sleep apnea heart rate oscillations
  - Hilbert transform detection algorithm

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Sleep Apnea

- Intermittent cessation of breathing during sleep
- Affects millions worldwide with increased morbidity and mortality
- Diagnosis by polysomnography expensive and encumbering and not readily repeated
- Need for simple, easily implemented screening and detection techniques

PhysioNet/Computers in Cardiology Challenge to Detect Sleep Apnea from a Single Lead ECG

PhysioNet · PhysioBank · PhysioToolkit

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the research resource for
complex physiologic signals

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Detecting and quantifying sleep apnea based on the ECG: A challenge from PhysioNet and Computers in Cardiology 2000

Update (22 September 2000): The deadline for entries has passed and no further entries will be accepted. The final scores have now been posted here, together with links to the abstracts submitted by entrants for presentation at Computers in Cardiology.

Update (14 March 2003): Several of the participants in this challenge, together with the organizers, have published a paper that compares the methods used in the challenge and investigates how several of the most successful strategies can be combined. This paper can now be read on-line:

> [PDF] Penzel T, McNames J, de Chazal P, Raymond B, Murray A, Moody G. Systematic comparison of different algorithms for apnoea detection based on electrocardiogram recordings. *Medical & Biological Engineering & Computing* **40**:402-407, 2002.

http://www.physionet.org/challenge/2000

ECG changes associated with sleep apnea

- Changes due to neuroautonomic and mechanical factors
  - Cyclic variations in heart rate
  - Cyclic variations in ECG amplitude or morphology

Automated Techniques to Detect Sleep Apnea from the ECG

- Time domain techniques
  - RR variability
  - Moving averages
  - Pattern detection
- Frequency domain techniques
  - Spectral analysis of heart rate variability
  - Hilbert transform
  - Wavelets
  - Time-frequency maps
- ECG morphology based techniques
  - ECG-derived respiration
  - ECG pulse energy
  - R-wave duration
  - QRS S-component amplitude

Penzel, et al. Med Biol Eng Comput 2002;40:402-407

- Overview of ECG-based sleep apnea detection
- **Hilbert transform detection of sleep apnea**
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  - **Hilbert transform detection algorithm**
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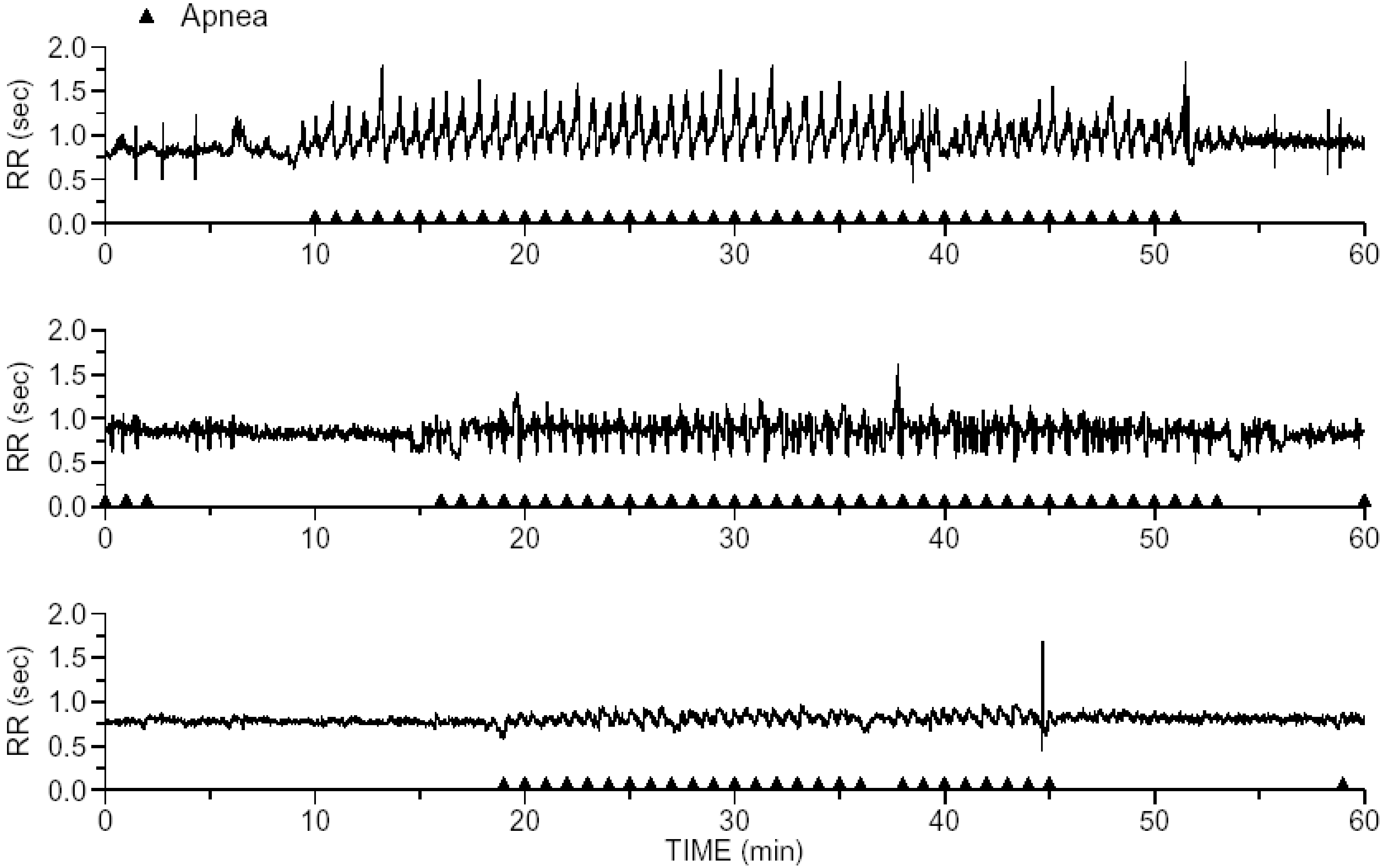
Sleep apnea typically associated with 0.01-0.04 Hz. oscillations in heart rate



Sleep Apnea Heart Rate Oscillations

- Transient and non-stationary with varying amplitudes and frequencies
- Difficult to detect and localize using standard Fourier spectral techniques
- Hilbert transform can be used to quantify instantaneous amplitudes and frequencies of heart rate oscillations
  - requires bandwidth limited signal

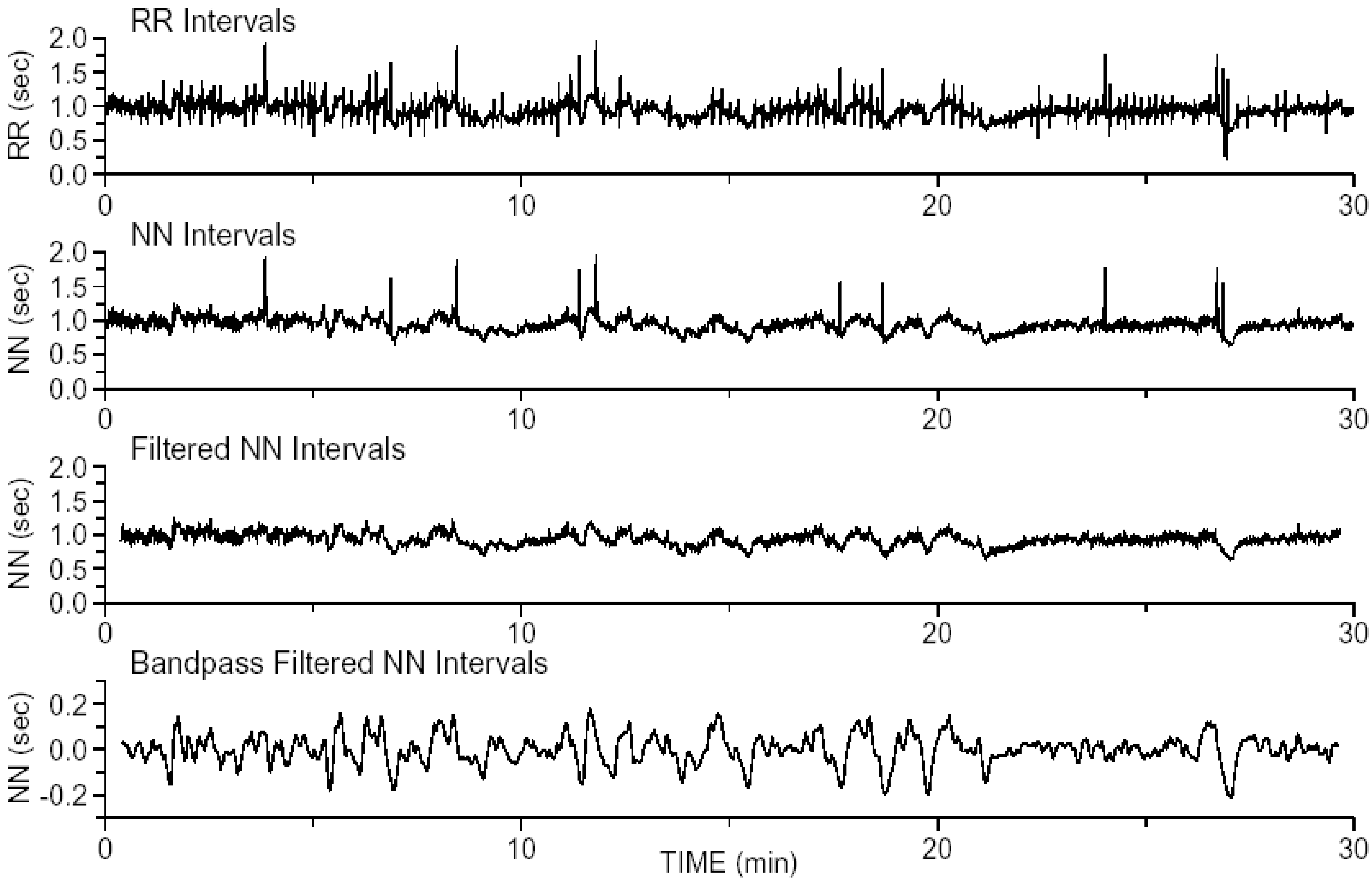
Hilbert Transform Sleep Apnea Detection Overview

- Extract NN interval series from RR intervals
- Filter and resample NN interval series
- Compute Hilbert Transformation
- Calculate local means, standard deviations and time within threshold limits for both Hilbert amplitudes and frequencies
- Detect periods when amplitude and frequency measures are within specified limits

RR Interval Preprocessing

- Extract normal sinus - normal sinus (NN) intervals
- Filter NN interval outliers
- Resample at 1 Hz
- Bandpass filter
  - Low pass filter (3db at 0.09 Hz)
  - High pass filter (3db at 0.01 Hz)

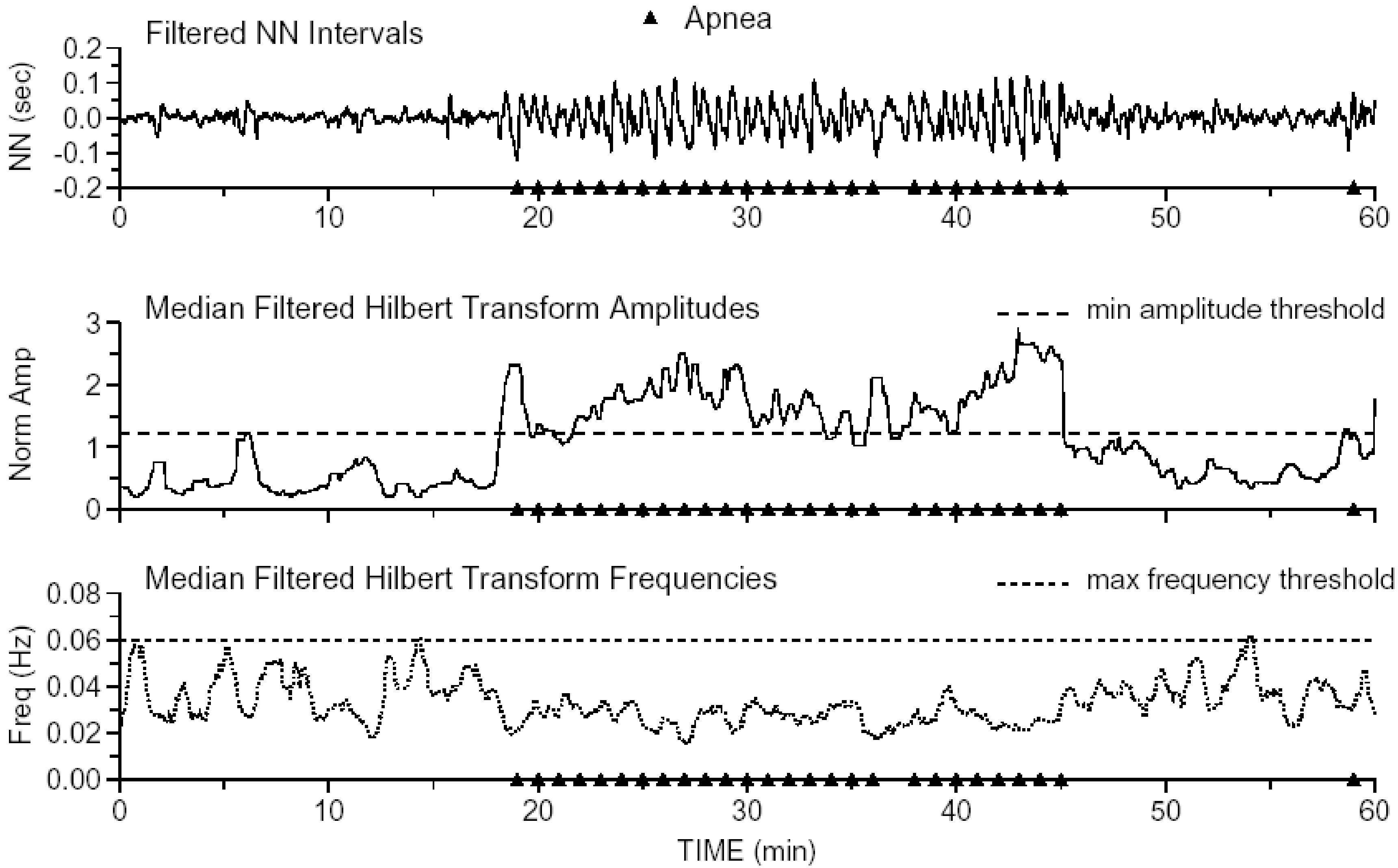
RR interval preprocessing



Hilbert Transformation

- Calculate instantaneous amplitudes and frequencies of filtered NN interval series
- Median filter amplitudes and frequencies
- Normalize Hilbert transform amplitudes
- Set minimum Hilbert amplitude threshold (dependent on dataset) and maximum Hilbert frequency threshold (0.06 Hz)

Hilbert Transform of filtered NN intervals



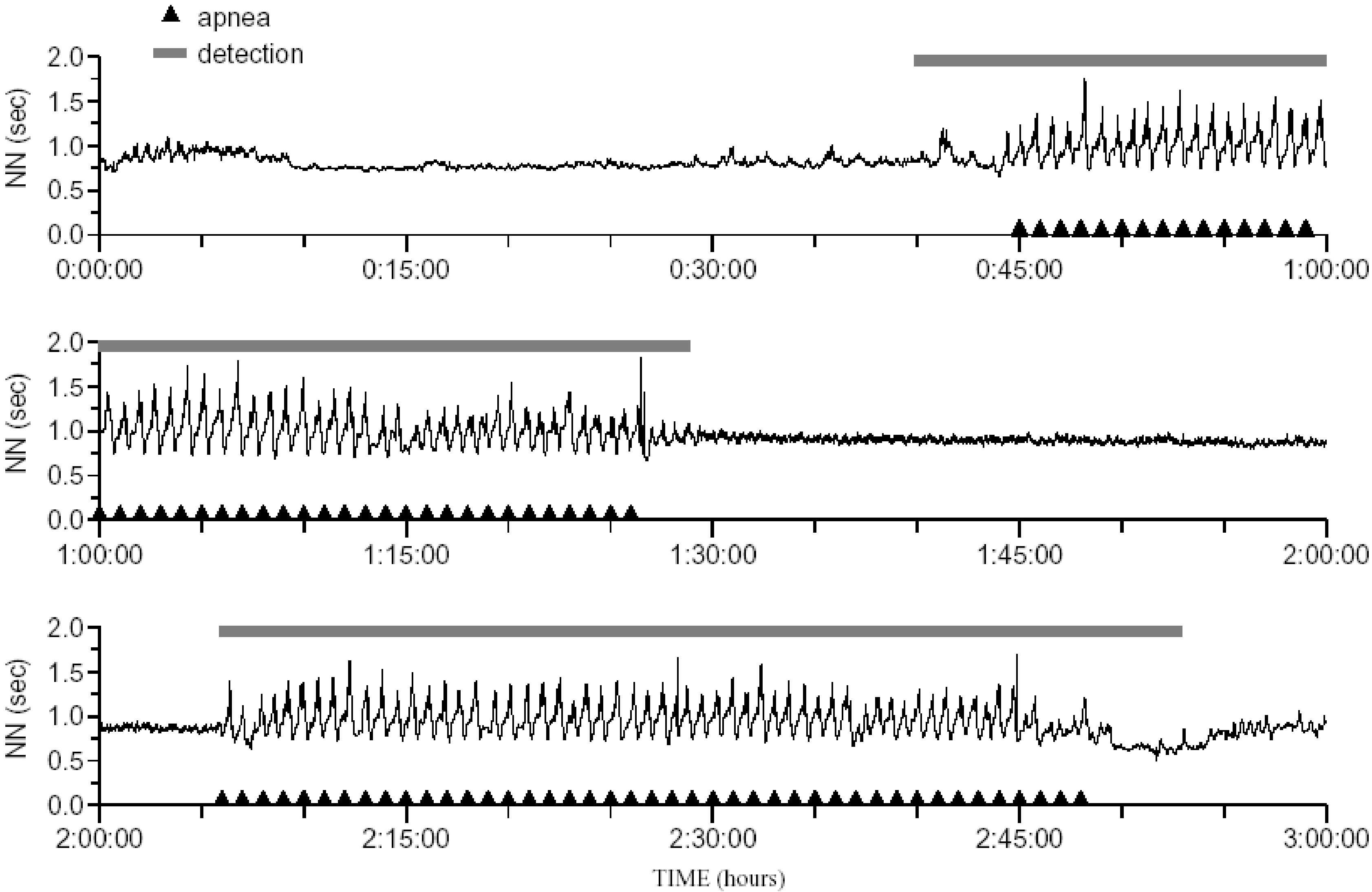
Sleep Apnea Detection Parameters

- Calculate local means, standard deviations and time within threshold limits for both Hilbert amplitudes and frequencies over 5-minute windows incremented each minute

- Select parameter limits that give the highest percentage of minute-by-minute true positive and true negative apnea detections

- Detect sequences where all six amplitude and frequency measures are within their specified limits for a minimum of 15 minutes

Detection of sleep apnea using the Hilbert transform



Hilbert Transform Sleep Apnea Detection Results

- PhysioNet Combined Training and Test Sets
  - Correctly classified 54 out of 60 apnea/control subjects (90.0%)
  - Correctly classified 28576 out of 34313 minutes with/without OSA (83.3%)

Hilbert Transform based Sleep Apnea Detection using a Single Lead Electrocardiogram (`apdet`)

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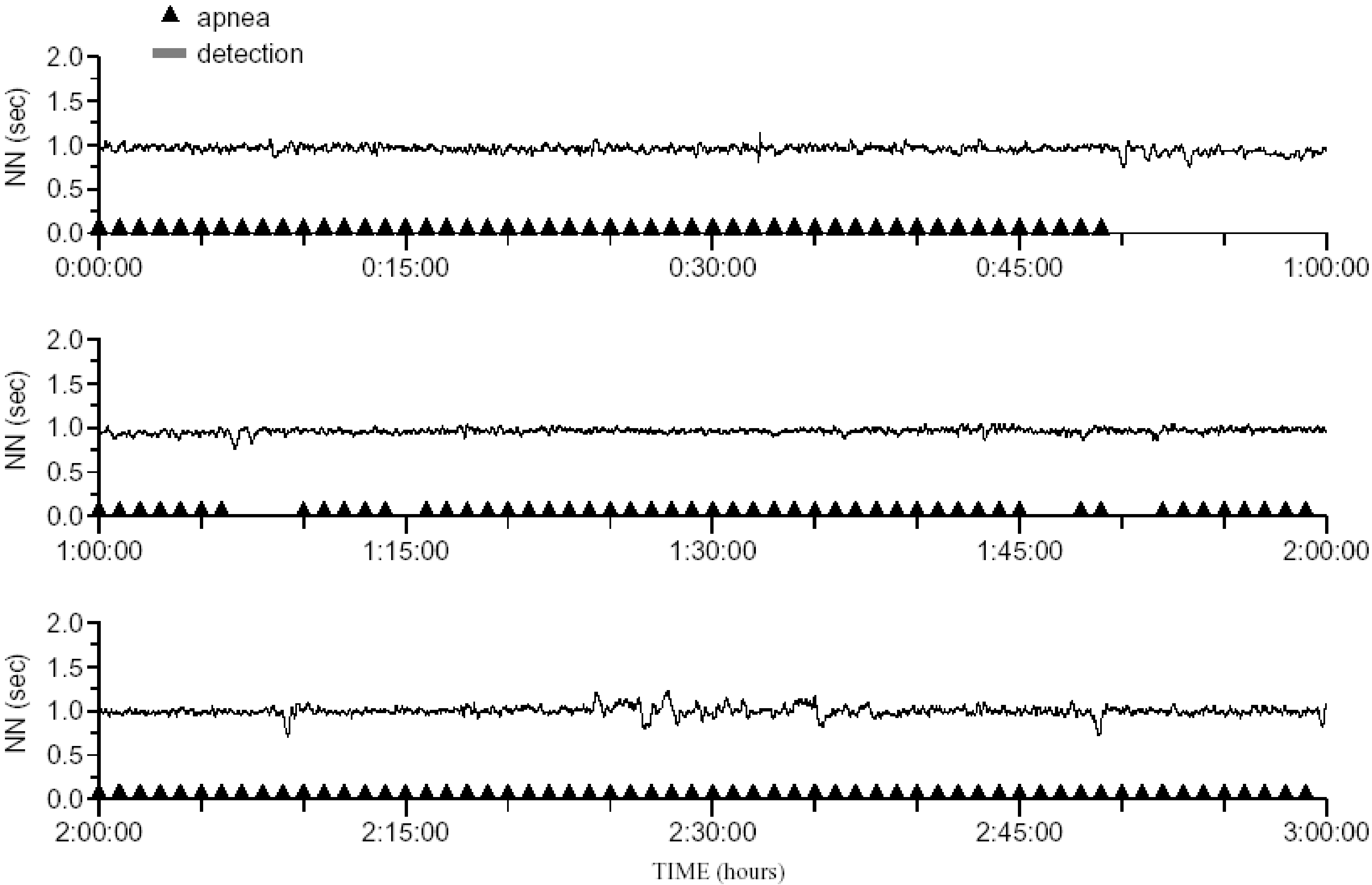
A detailed description of the `apdet` algorithm and its application can be found in: Detection of Obstructive Sleep Apnea from Cardiac Interbeat Interval Time Series. This article originally appeared in Computers in Cardiology 2000, vol. 27, pp. 753-756 (Piscataway, NJ: The Institute of Electrical and Electronics Engineers, Inc.). Please cite this publication when referencing this material.

The software described here was developed for the Computers in Cardiology Challenge 2000. Additional information regarding apnea detection from the ECG, as well as data to test the software, can be found at the challenge page.

http://www.physionet.org/physiotools/apdet

Source code freely available

Failure of the Hilbert transform apnea detector in the absence of respiratory modulation of heart rate



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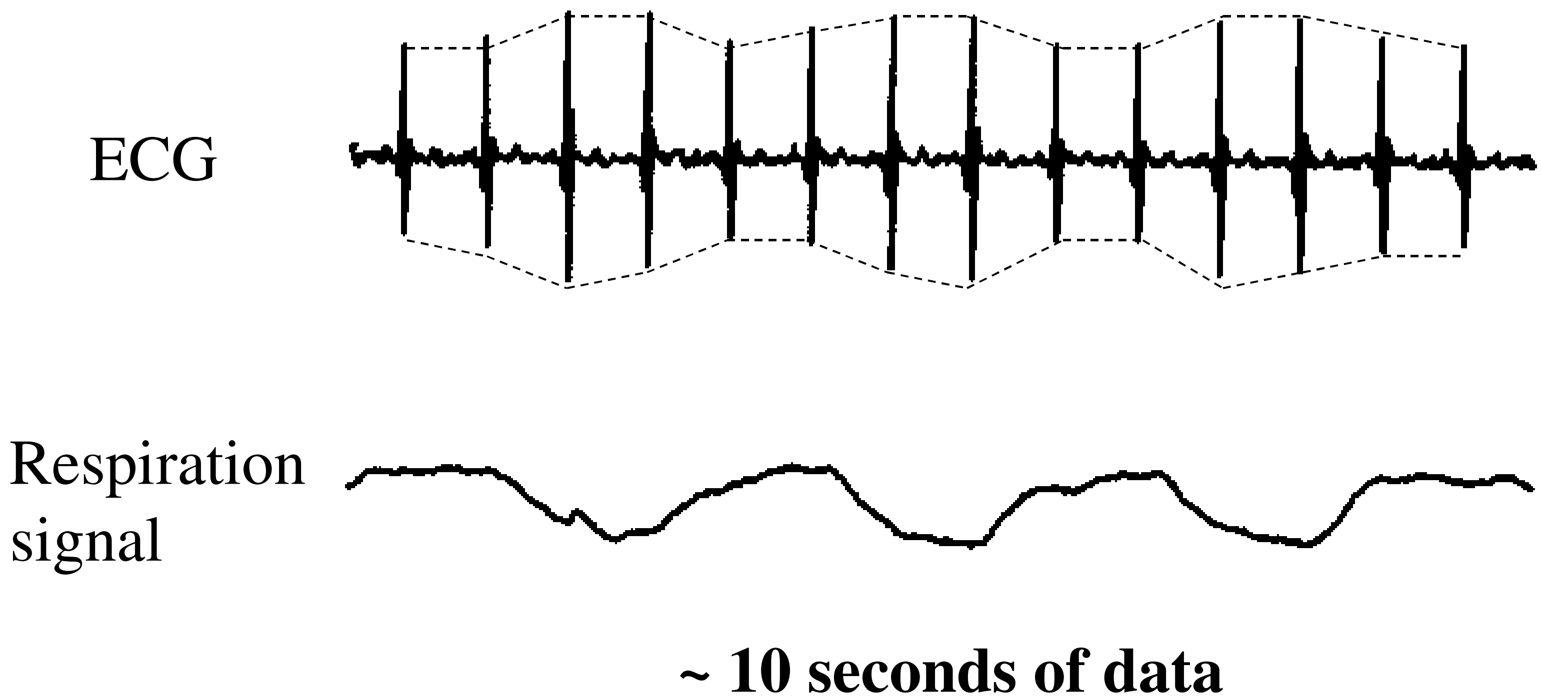
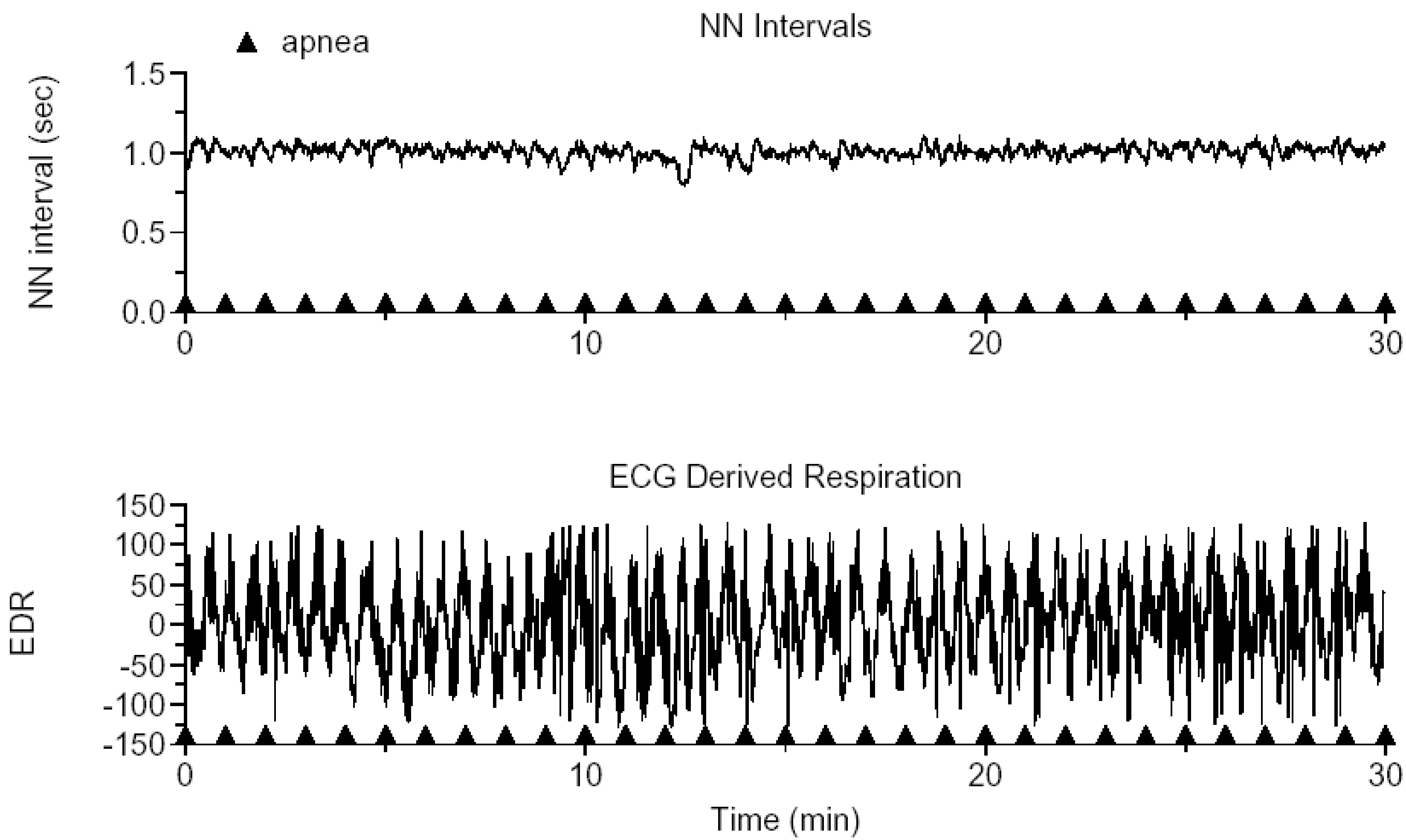
ECG-Derived Respiration (EDR): respiration modulates ECG amplitudes



Moody, et al. Comput Cardiol 1985:12;113-116

ECG-derived respiration in the absence of apparent respiratory modulation of heart rate



ECG-based Cardiopulmonary Coupling Detector

- Sleep disordered breathing (SDB) is associated with low-frequency oscillations in heart rate
- SDB also associated with low frequency variations in ECG waveform due to chest wall movement during respiration
- Using a continuous ECG, we combine both signals to measure the coupling between respiration and heart rate variations

Cardiopulmonary Coupling (CPC) Overview

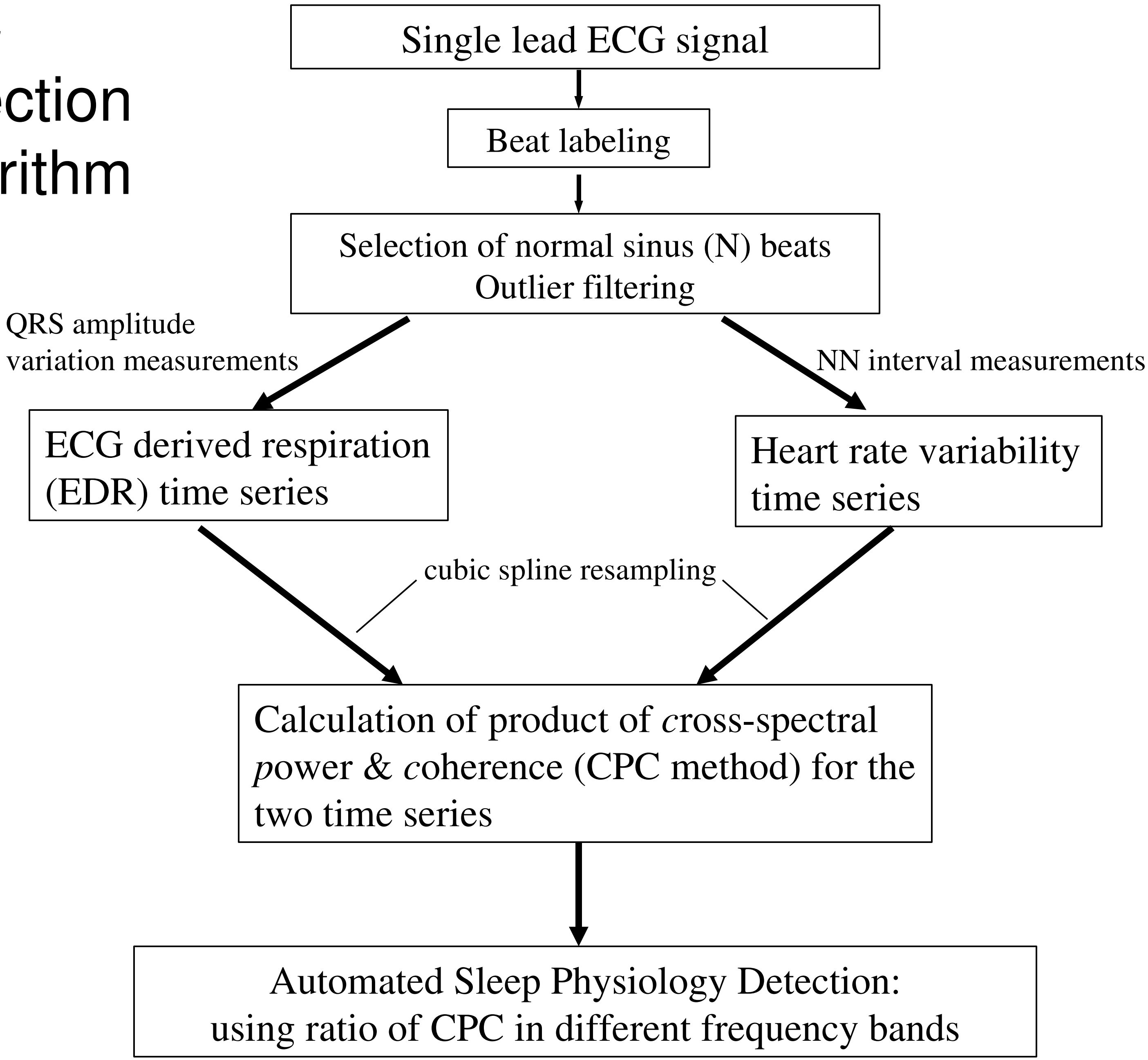
- Employs Fourier based techniques to analyze the R-R interval series and its associated EDR signal
  - Measures the common power of the two signals at different frequencies by calculating their cross-spectral power
  - Measures the synchronization of the signals at different frequencies by computing their coherence
  - Uses the product of coherence and cross-spectral power to quantify the degree of cardiopulmonary coupling at different frequencies

CPC Detection Algorithm

- Identify beats and classify as normal or ectopic
- Extract NN interval time series and its associated EDR time series
- Filter outliers due to false or missed detections
- Linearly resample at 2 Hz.
- Calculate the product of cross-power and coherence over a moving 1024 point window
- Plot coherent cross-power at various frequencies as a function of time (sleep spectrogram)

Thomas, et al. SLEEP 2005;28(9):1151-1161.

CPC Detection Algorithm



Patent pending

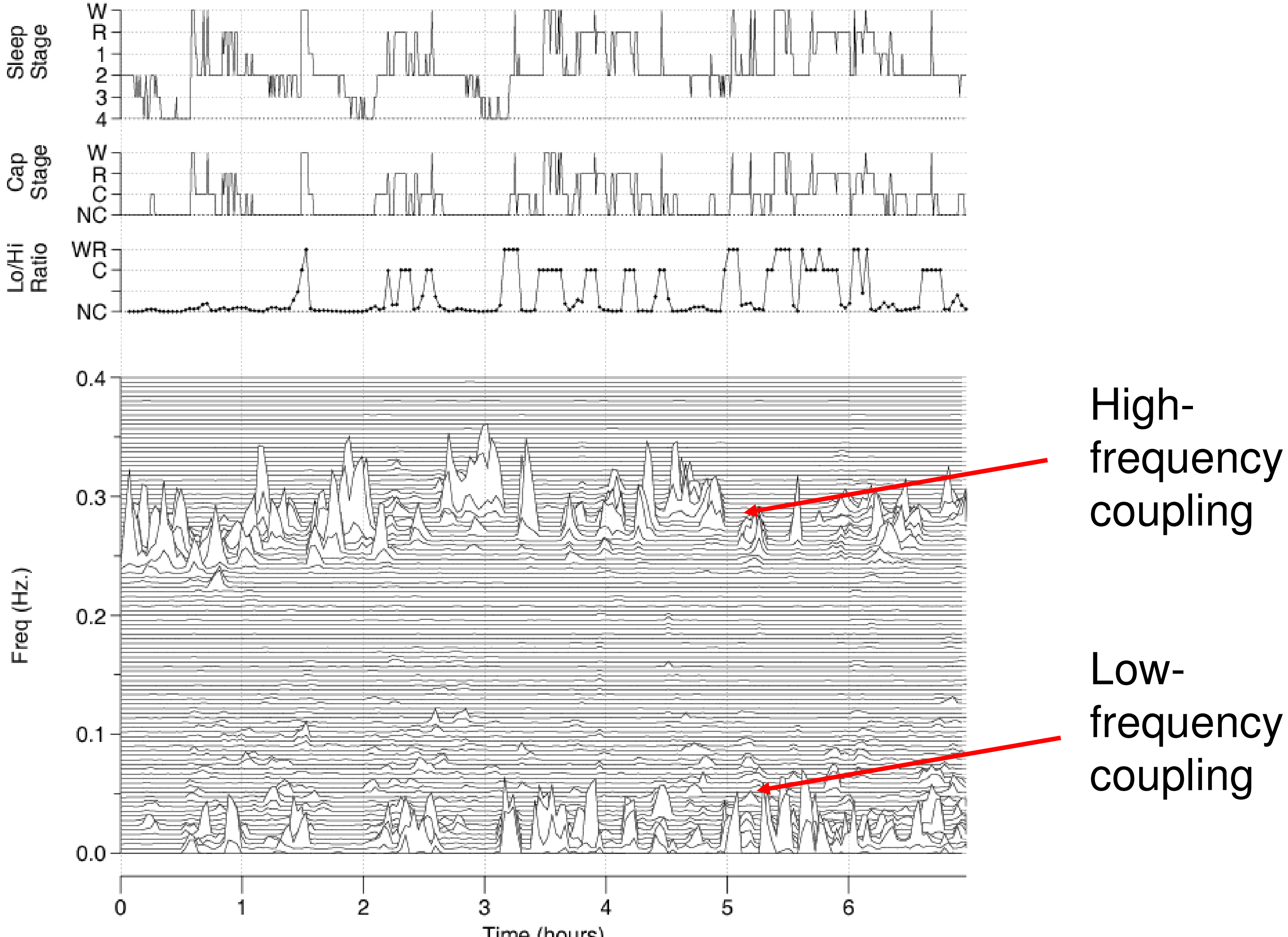
CPC Reveals Two Cardiopulmonary Coupling Regimes

- High frequency coupling (0.1-0.4 Hz. band) corresponds to respiratory sinus arrhythmia
- Low frequency coupling (0.01-0.1 Hz. band) associated with SDB
- Coupling states do not correspond with standard sleep staging but do follow scoring using the EEG-based “Cyclic Alternating Pattern” (CAP) paradigm
  - CAP: unstable, light sleep; low frequency coupling
  - Non-CAP: stable, deep sleep; high frequency coupling

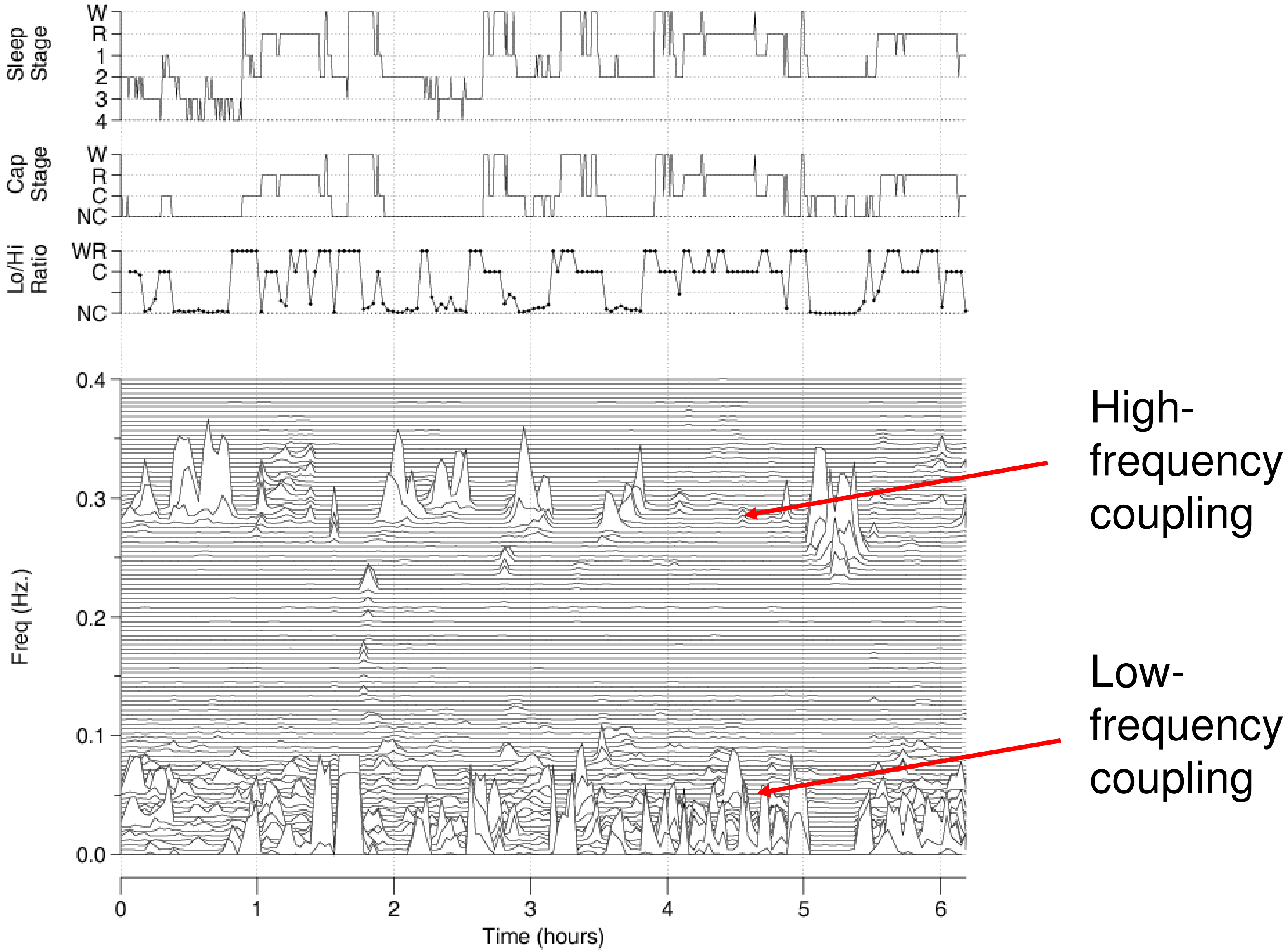
CPC Detection of CAP/Non-CAP Sleep States

- Using appropriate thresholds for high and low frequency coupling magnitudes and their ratios it is possible to detect CAP/Non-CAP sleep states
- Parameters selected that give the greatest sensitivity and specificity for the detection of CAP (C), Non-CAP (NC) and Wake/REM (WR) in scored sleep studies
- Parameters also selected that give the greatest sensitivity and specificity for apnea detection in PhysioNet sleep apnea database

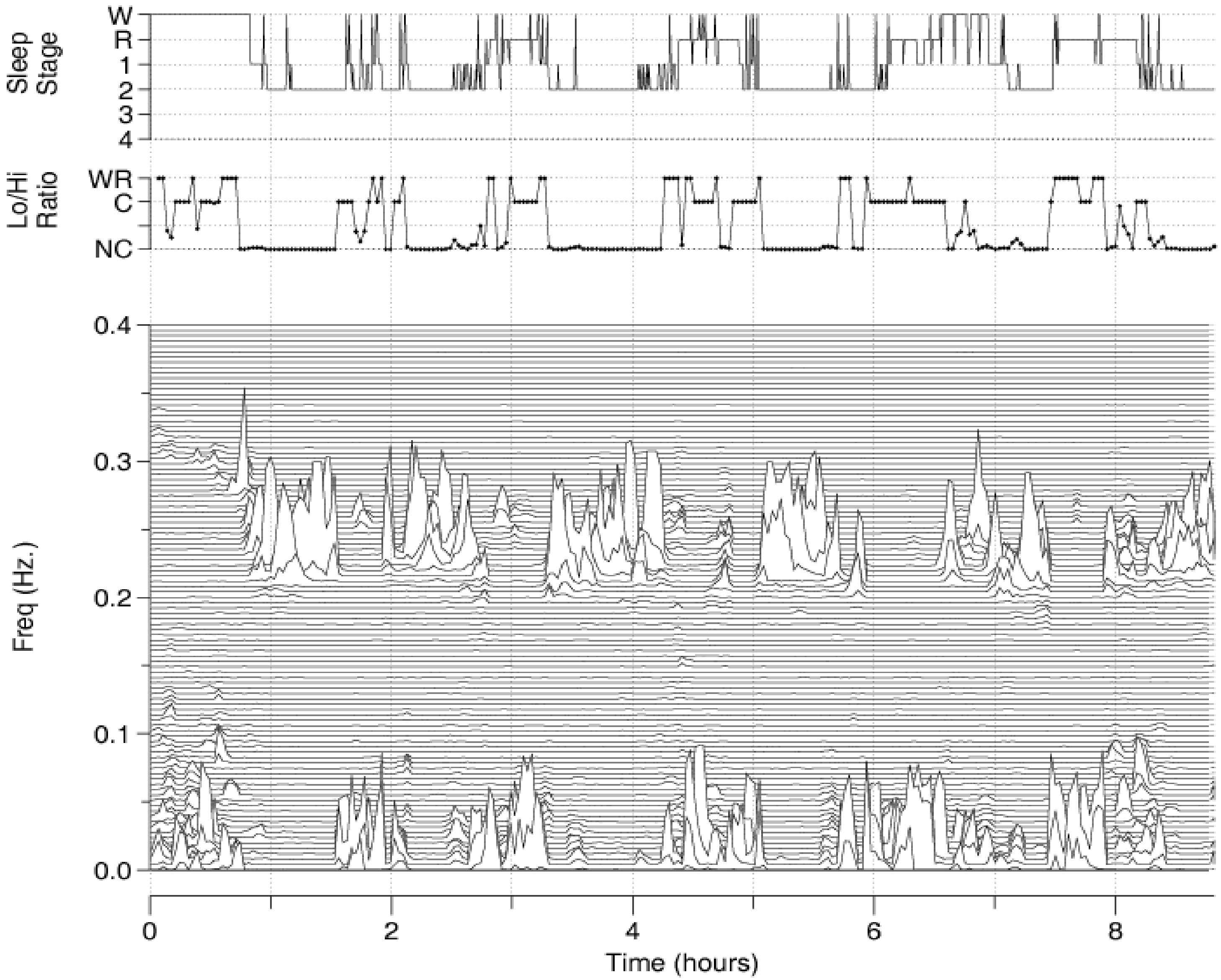
Sleep spectrogram in a healthy 22-yr old



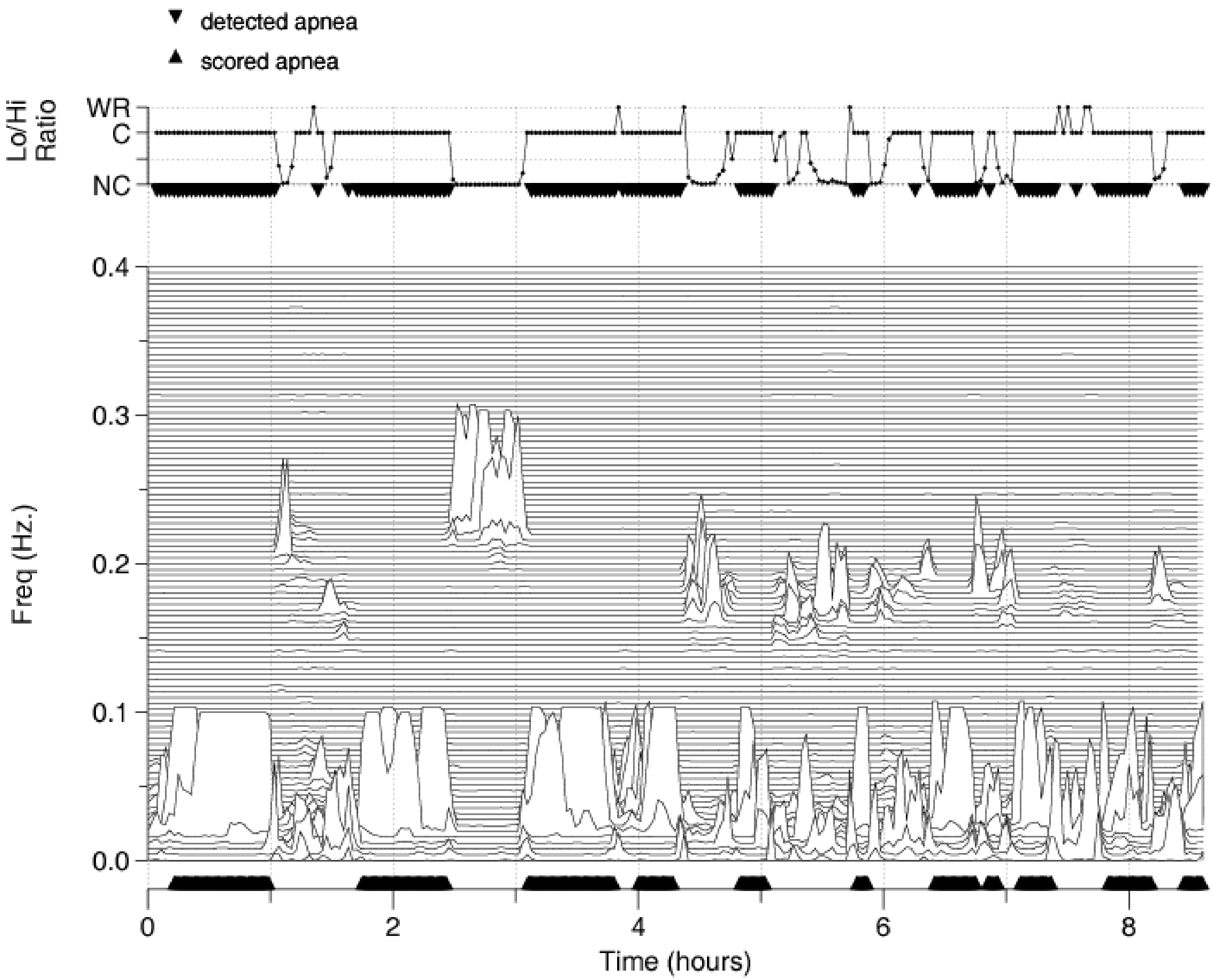
Sleep spectrogram in a healthy 56-yr old



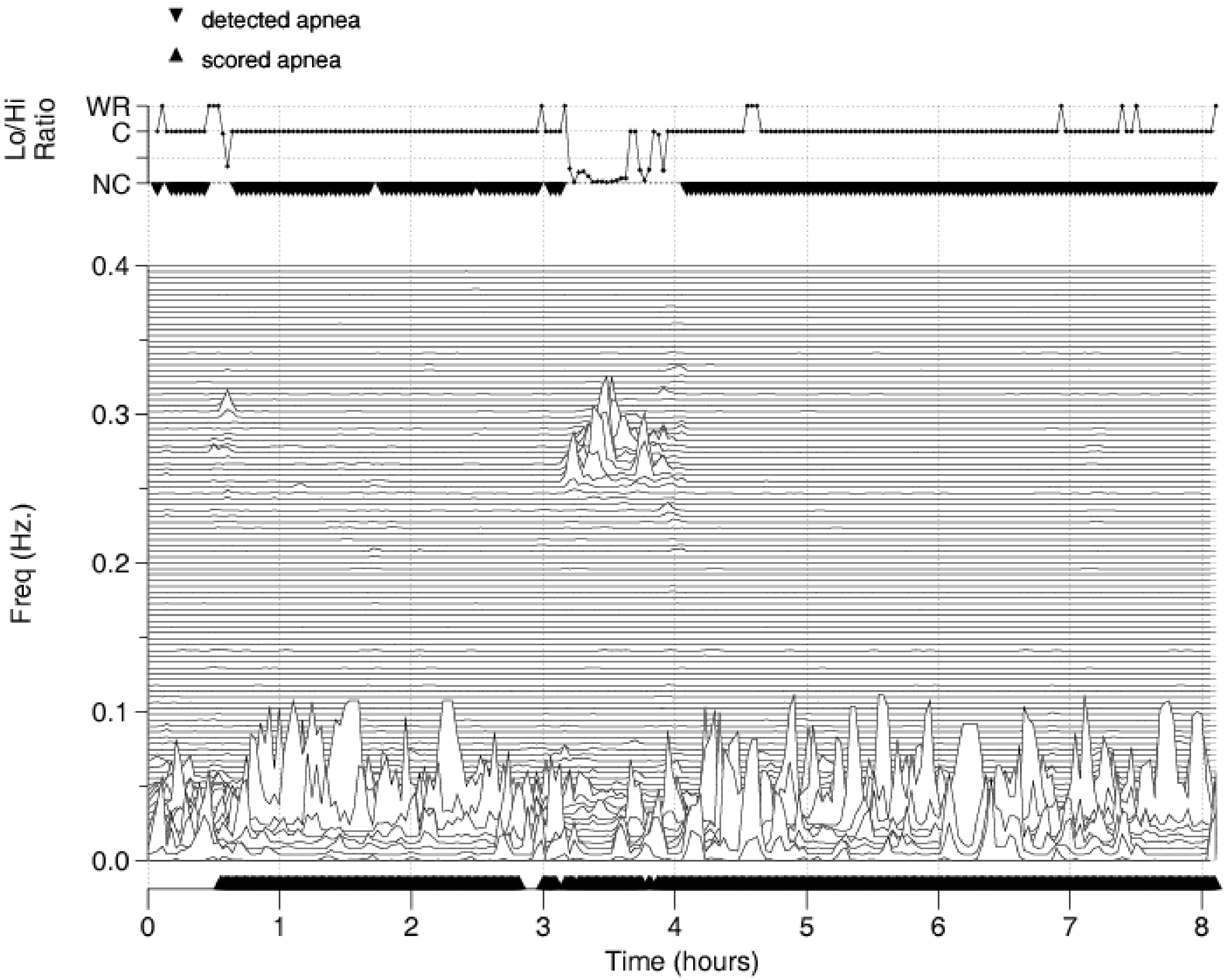
Sleep state switching in a healthy subject



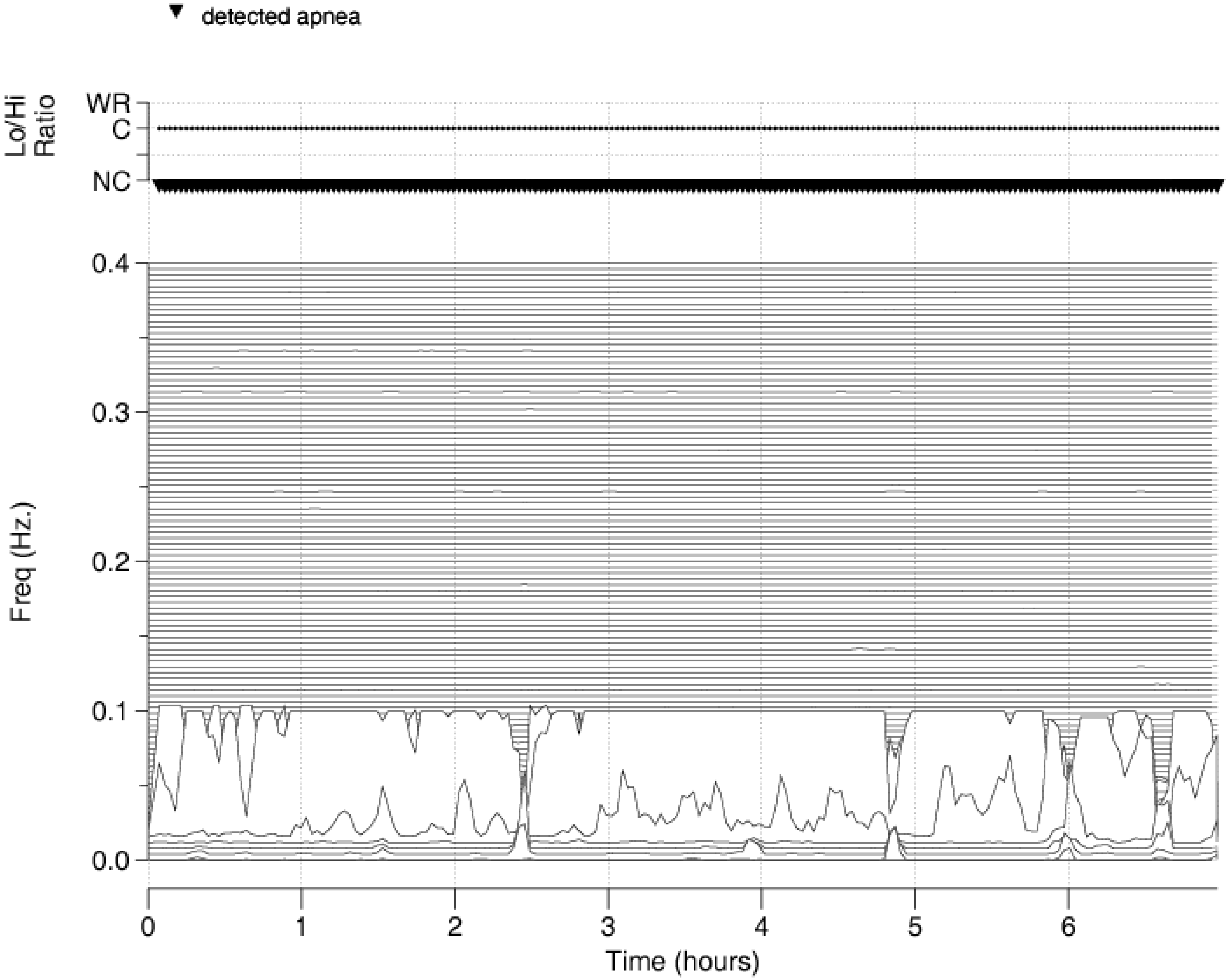
Sleep spectrogram and apnea detection



Sleep spectrogram and apnea detection in a severe apnea subject

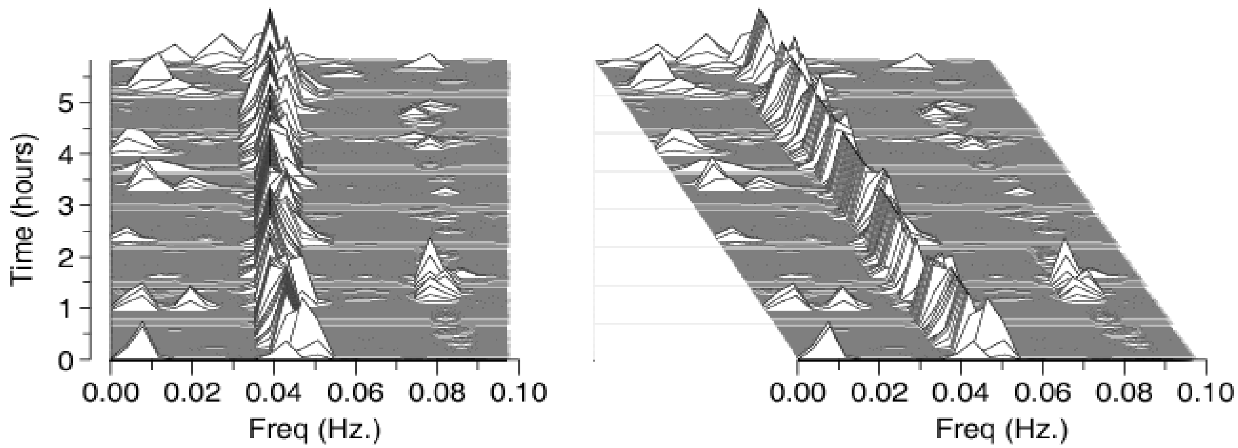


Sleep spectrogram and apnea detection in a severe apnea subject

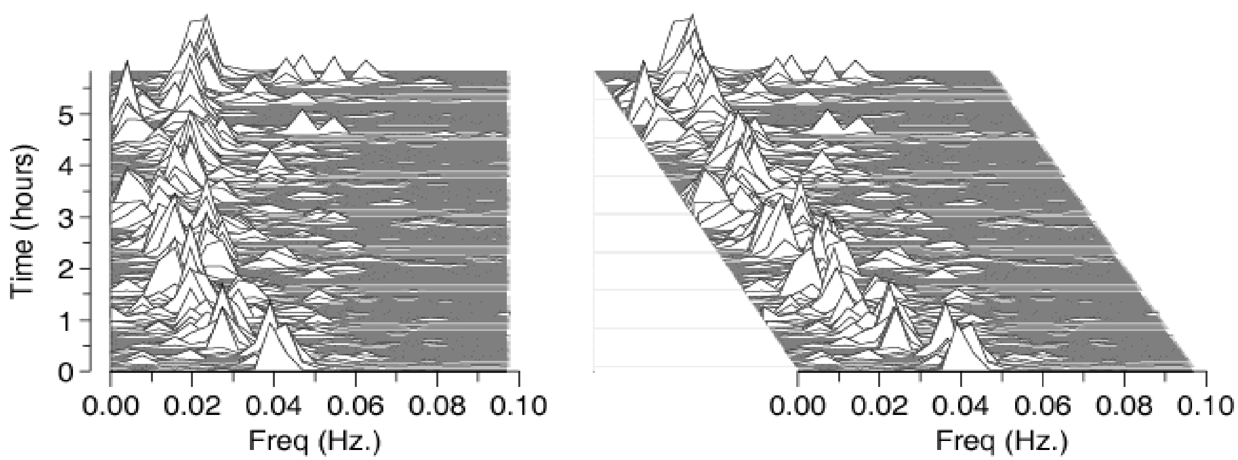


Narrow-band and broad-band low frequency coupling in sleep apnea syndromes

Narrow-band coupling (central apnea)



Broad-band coupling (obstructive apnea)



Conclusions

- Sleep disordered breathing syndromes can be detected in a fully automated fashion from a single lead ECG
- Stable (Non-CAP) and unstable (CAP) sleep states can be detected by measuring the coupling between respiration and heart rate
- In healthy individuals sleep state spontaneously switches between stable and unstable throughout the night
- Loss of high frequency coupling is indicative of unstable sleep/pathologic states

References

- Goldberger AL, Amaral LAN, Glass L, et al. PhysioBank, PhysioToolkit, and PhysioNet: components of a new Research Resource for Complex Physiologic Signals. Circulation 2000;101:e215-220
- Mietus JM, Peng CK, Ivanov PC, et al. Detection of obstructive sleep apnea from cardiac interbeat interval time series. Comput Cardiol 2000;27:753-756
- Moody GB, Mark R, Zoccola A, et al. Derivation of respiratory signals from multi-lead ECGs. Comput Cardiol 1985;12:113-116
- Penzel T, McNames J, de Chazal P, et al. Systematic comparison of different algorithms for apnoea detection based on electrocardiogram recordings. Med Biol Eng Comput 2002;40:402-407
- Terazano MG, Parrino L, Fioriti G, et al. Atlas, rules, and recording techniques for the scoring of cyclic alternating pattern (CAP) in human sleep. Sleep Med 2001;2:537-553
- Thomas RJ, Mietus JE, Peng CK, Goldberger AL. An electrocardiogram-based technique to assess cardiopulmonary coupling during sleep. SLEEP 2005;28(9):1151-1161