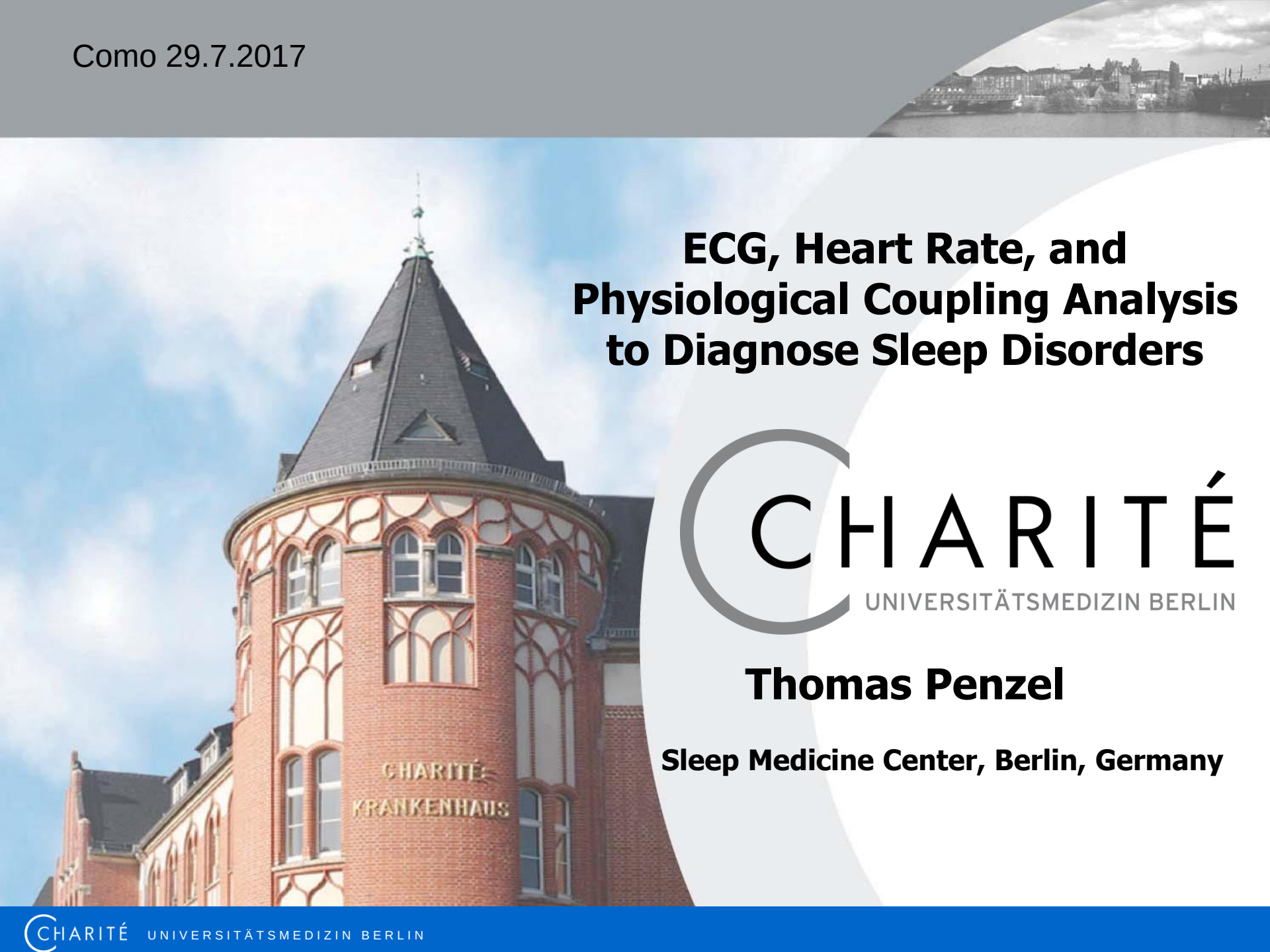
Como 29.7.2017



ECG, Heart Rate, and Physiological Coupling Analysis to Diagnose Sleep Disorders

CHARITÉ
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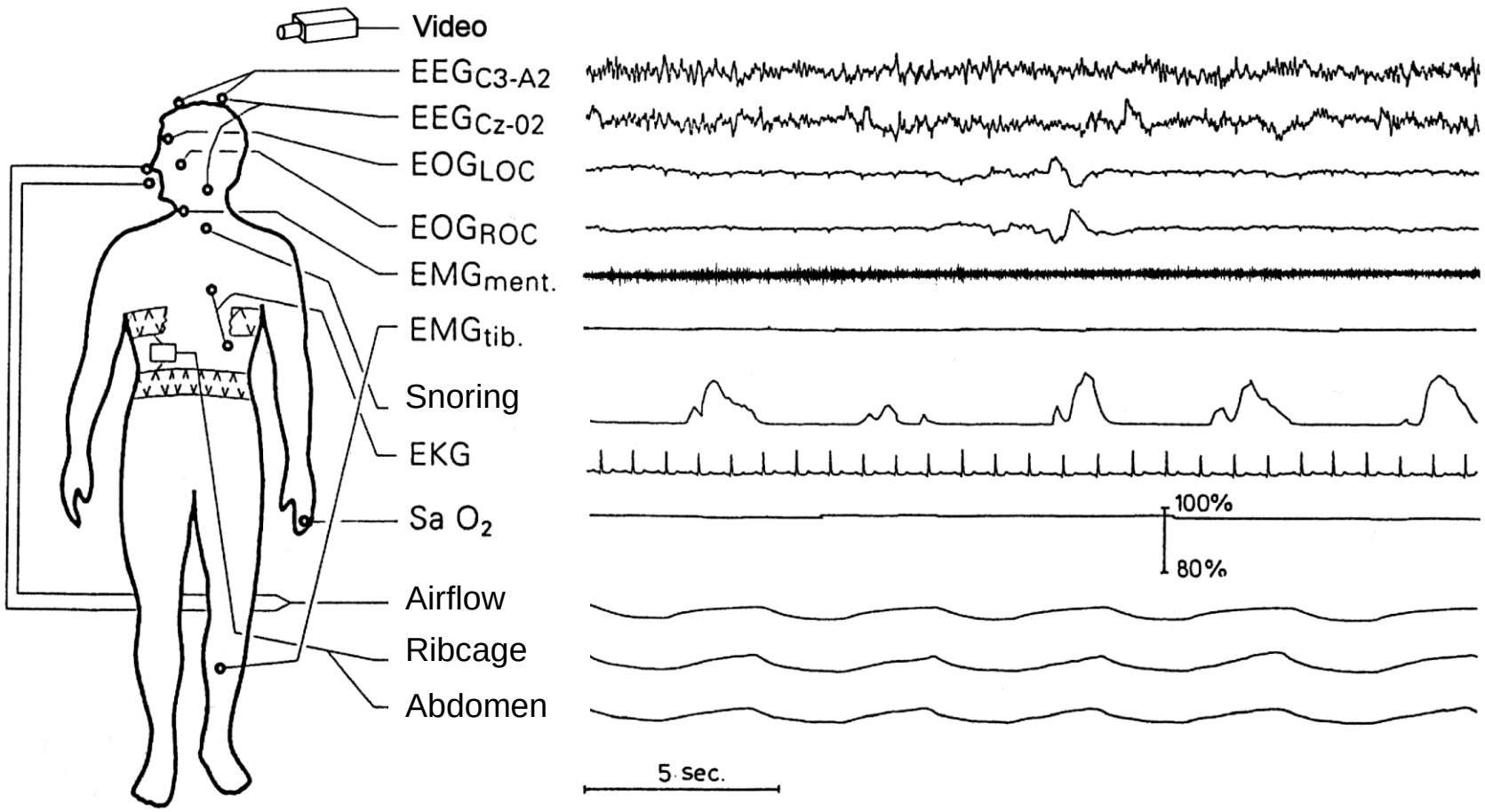
Sleep Medicine Center, Berlin, Germany

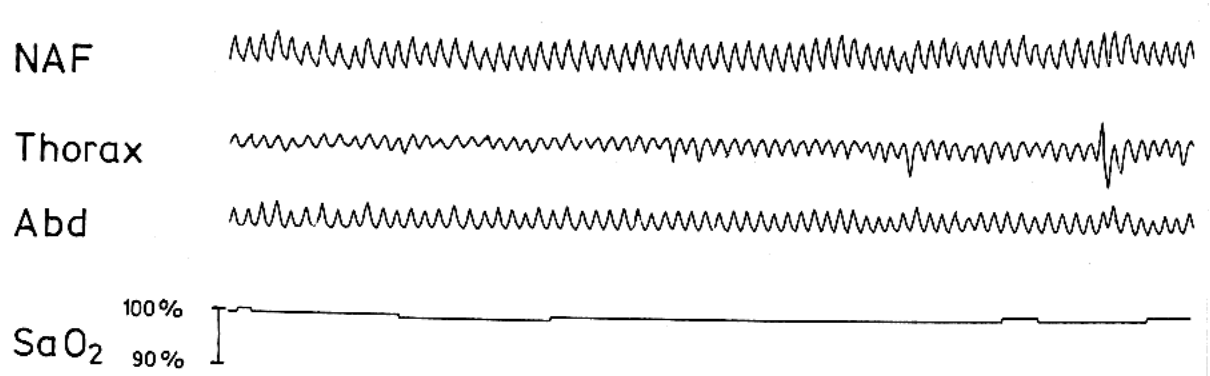
Cardiorespiratory Polysomnography



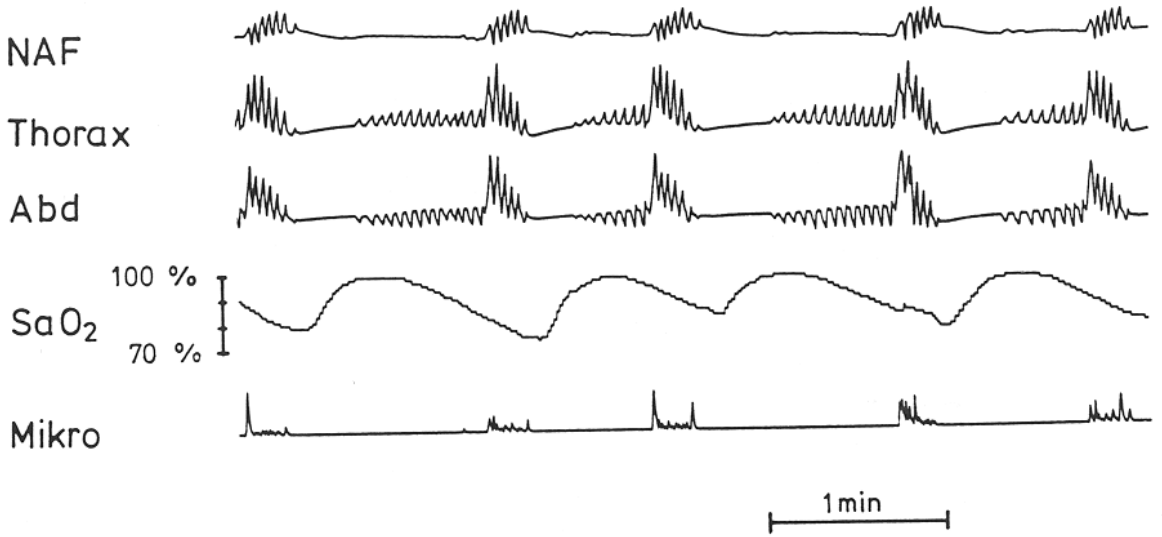
Sleep, respiration, cardiovascular signals, video monitoring

Respiration during sleep

Normal respiration during sleep is regular

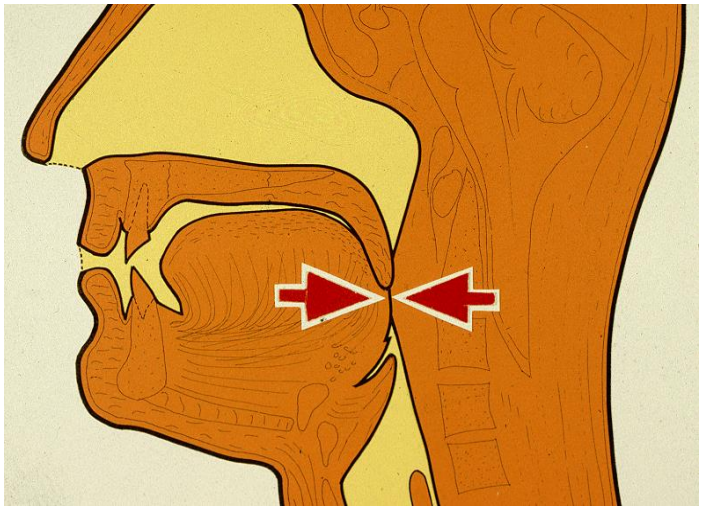


Disturbed respiration during sleep with apneas of > 10 sec duration

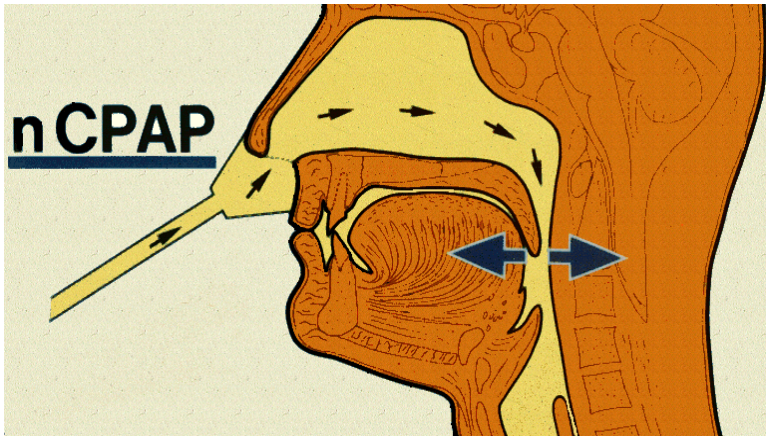


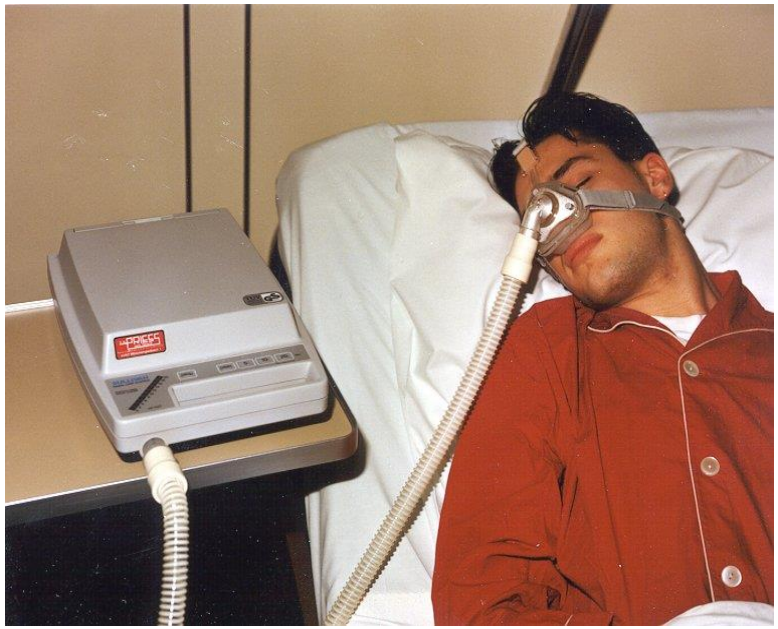
Mechanisms of obstructive sleep apnea

Collapse of the upper airways during sleep for 10 – 60 seconds up to 500 times per night. Relaxing of muscles.

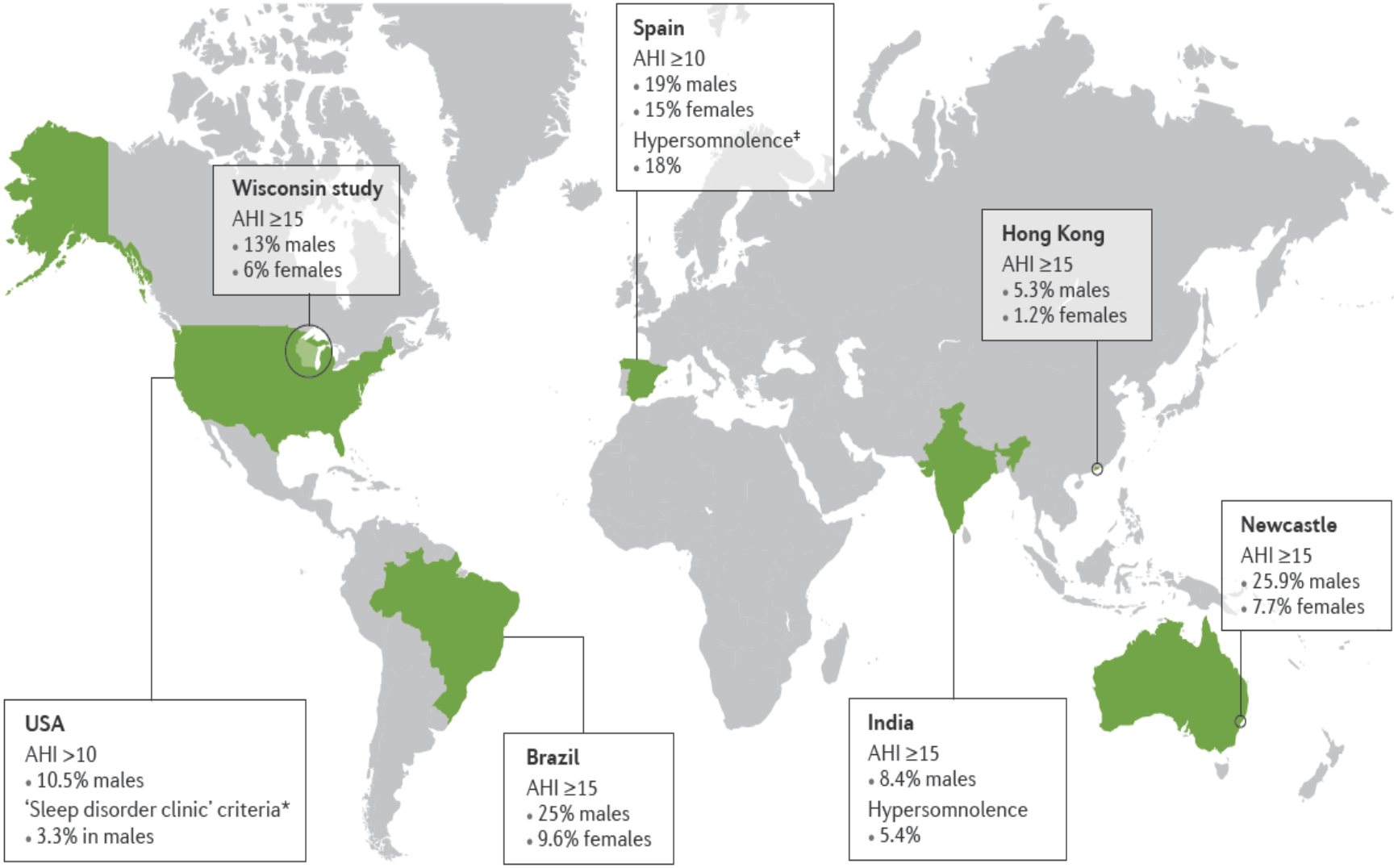


nCPAP = nasal continuous positive airway pressure through the nose with room air.
Pneumatic pressure opens the upper airways.





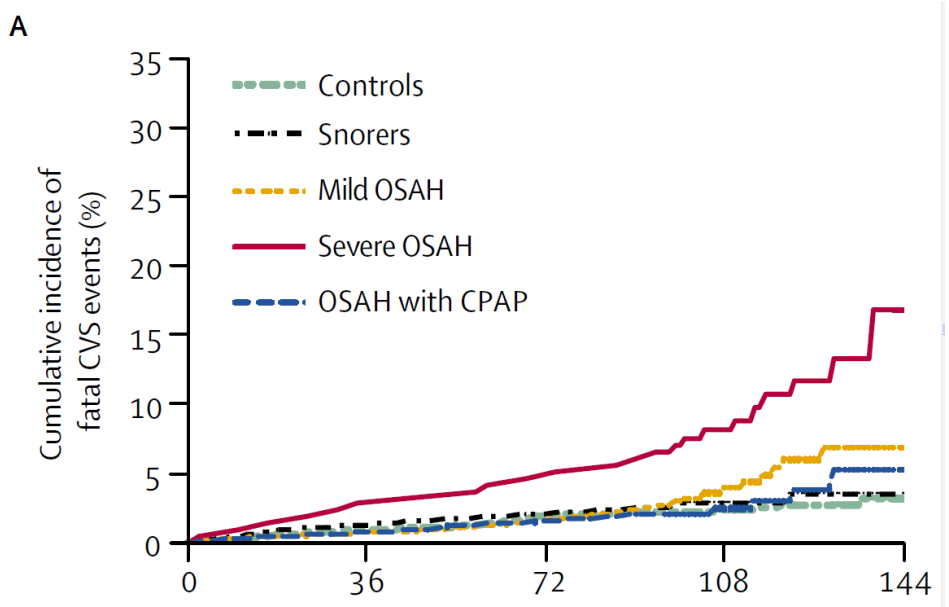
Prevalence for sleep disordered breathing

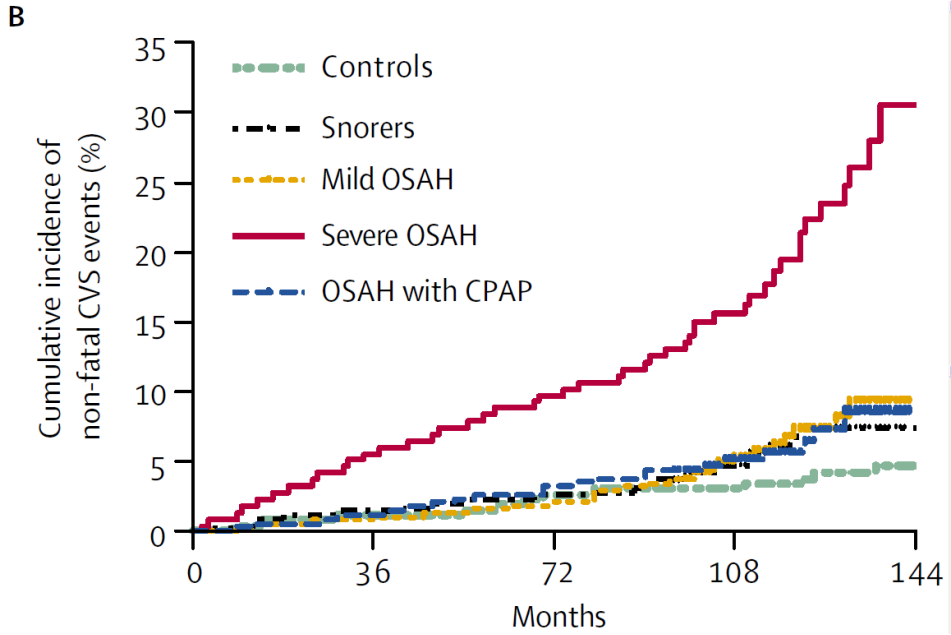


Levy et al. Nature Rev Disease Primers 2015;1

Increased mortality for obstructive sleep apnea

264 Control subjects
377 Snoring subjects
403 Obstructive sleep apnea OSA (mild and moderate)
235 OSA (severe)
372 treated OSA patients with CPAP





Marin et al. Lancet 2005

Home sleep apnea testing with Nox or Somnotouch

Signal parameters:
Airflow
Mikrophone

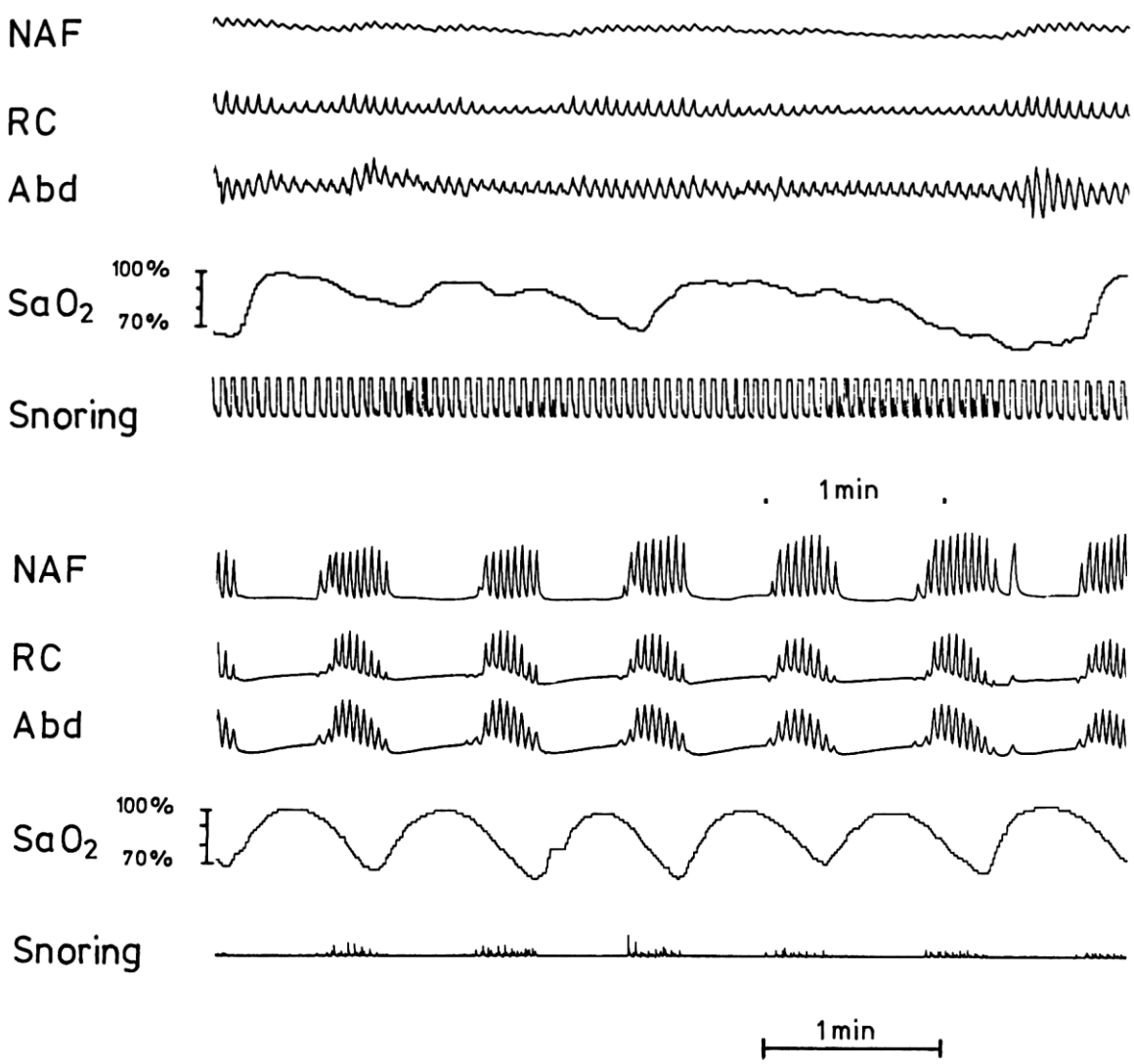
Oxygen saturation
Pulse rate
Body position

opt.: nCPAP pressure
opt.: respiratory effort
opt.: nasal pressure

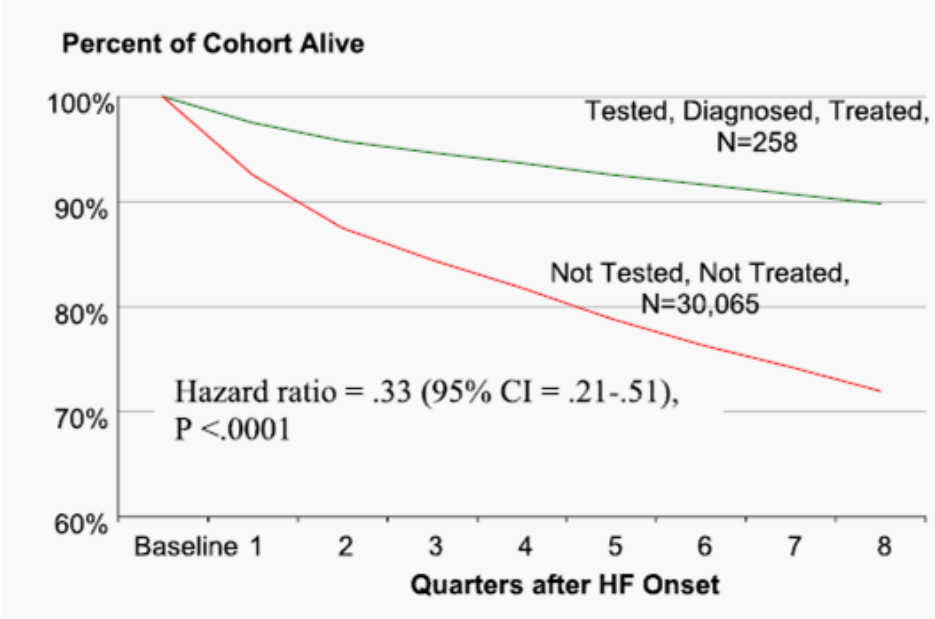
Hypoventilation and central sleep apnea

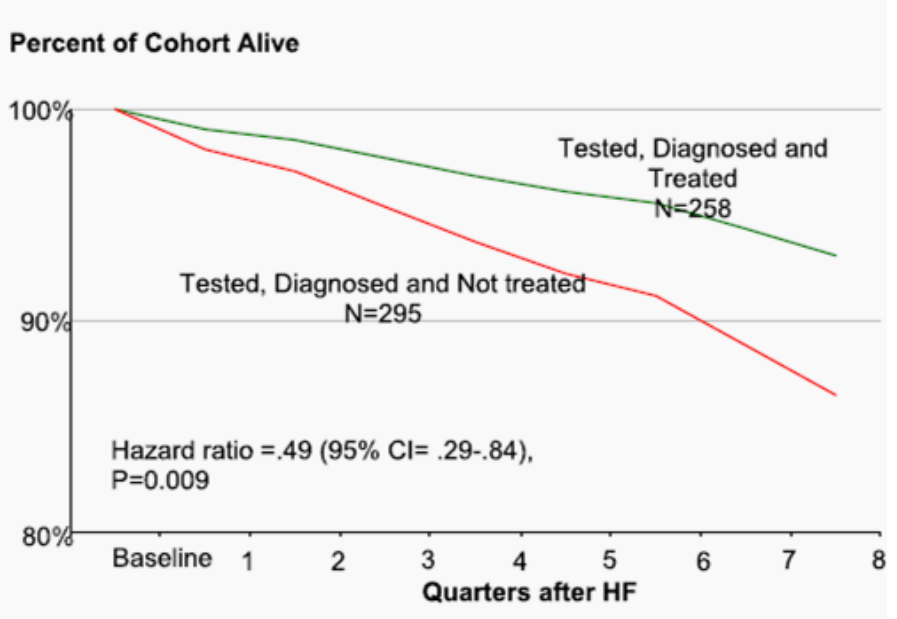
Hypoventilation with obstructive snoring

Central sleep apnea
Cheyne Stokes breathing



Mortality heart failure and Sleep apnea





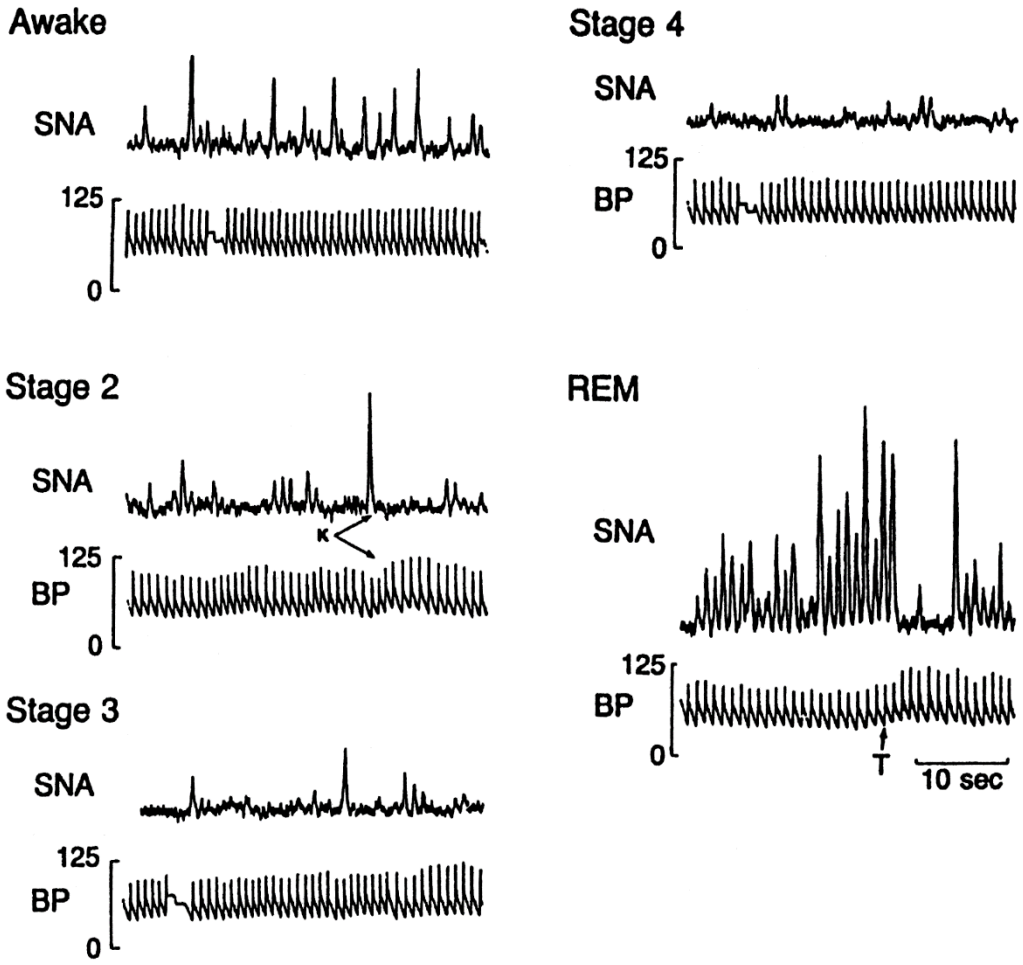
Javaheri et al. AJRCCM 183 (2011)

CVD Phenotypes

Comorbidities in sleep apnea:
Stroke, Myocardial infarction
Arrhythmias
Hypertension, Arteriosclerosis
Heart failure

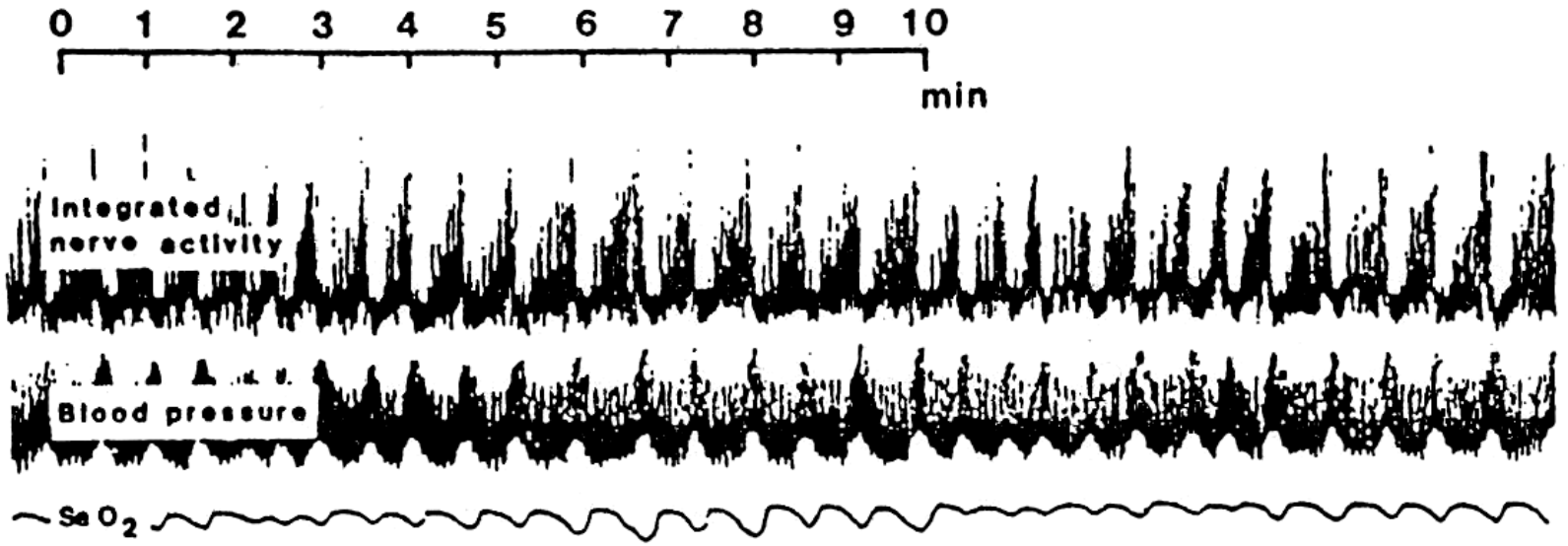
Assessment parameters:
ECG, Blood pressure
pulse wave properties (PTT, PWA)
endothelial function

Sympathetic activity during sleep



V.K. Somers et al. N. Engl J Med. (1993) 328

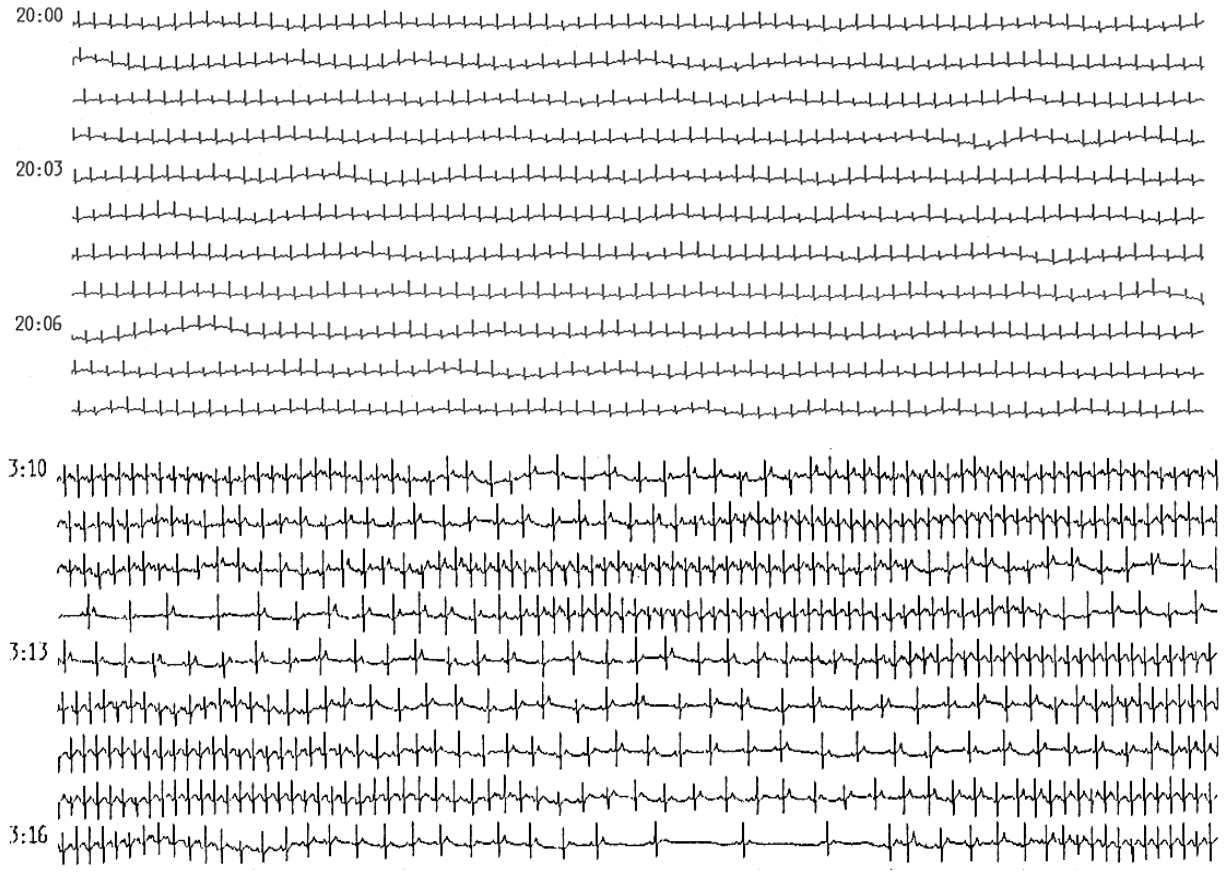
Sympathetic activity during sleep apnoea



A representative recording of apneic events during sleep in an OSAS patient. Note repetitive increases in integrated nerve activity and shifts in blood pressure in association with apnea (indicated by decrease in oxygen saturation). The time scale is indicated at the top

Hedner et al. 1983

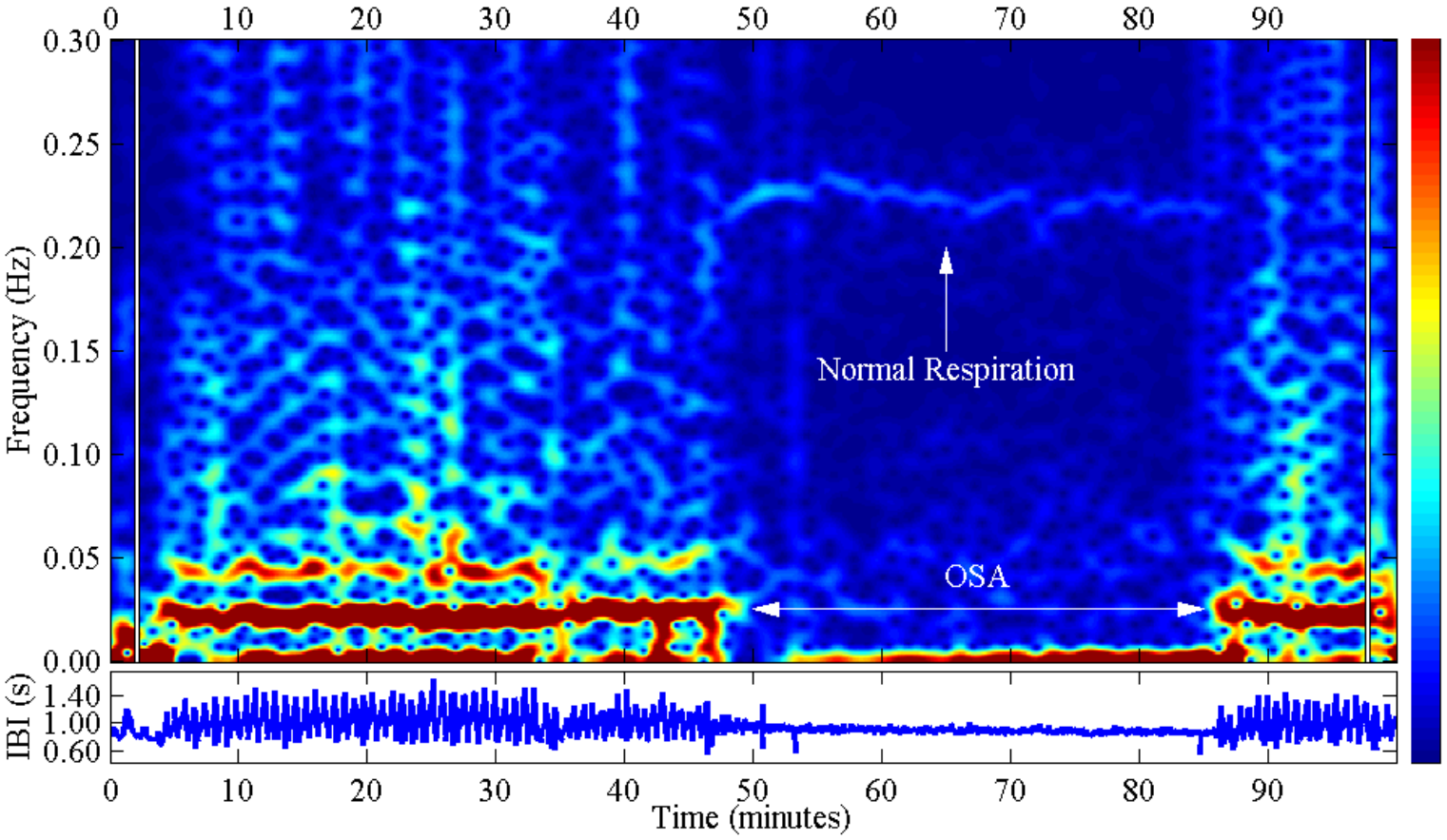
ECG of a control and a patient with sleep apnea



heart rate shows characteristic cyclical variations with sleep apnea

Penzel T et al. IEEE Trans. Biomed. Eng. 50: 1143-1151 (2003)
Stein PK et al. J. Cardiovasc. Electrophysiol. 14: 467-473 (2003)
DeChazal P et al. Physiol. Meas. 25: 967-983 (2004)

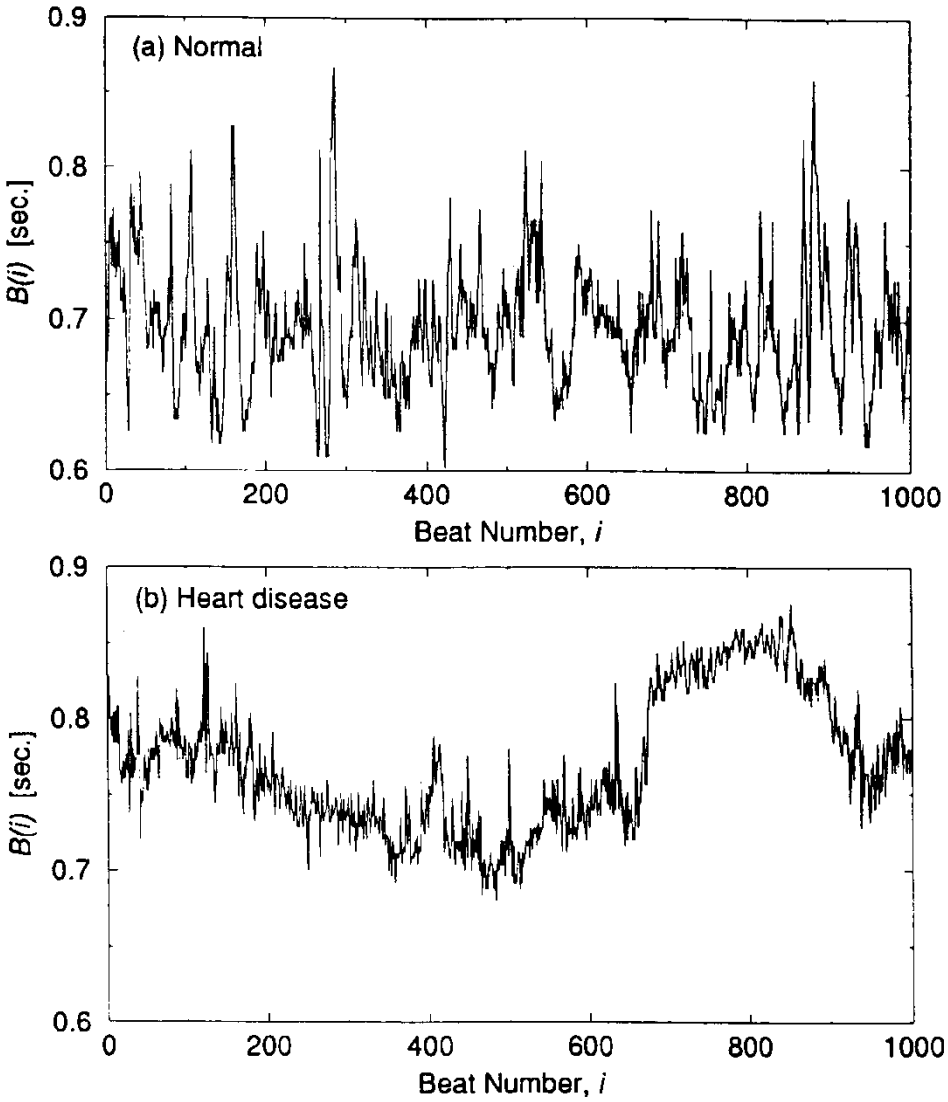
Identification of minutes with apnoea



IBI = Interbeat interval in seconds
OSA = Obstructive sleep apnea

Penzel et al. Med. Biol. Eng. 40:402-407 (2002)

Heart rate variability beyond spectral analysis



Heart rate variability changes in beat-to-beat sequences – random walk theory:

(a) healthy and (b) patients with heart failure

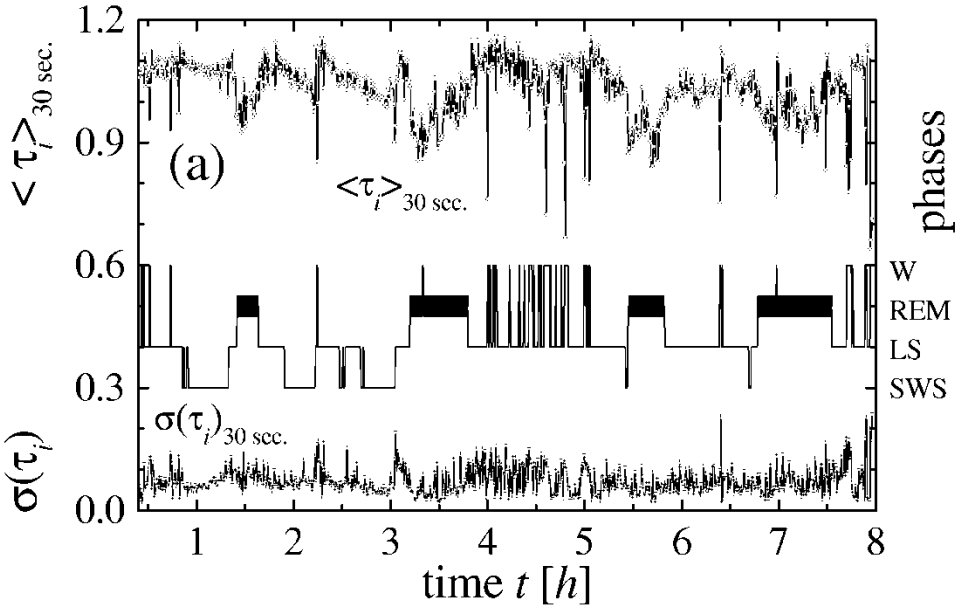
Applied to sleep stages and sleep apnea.

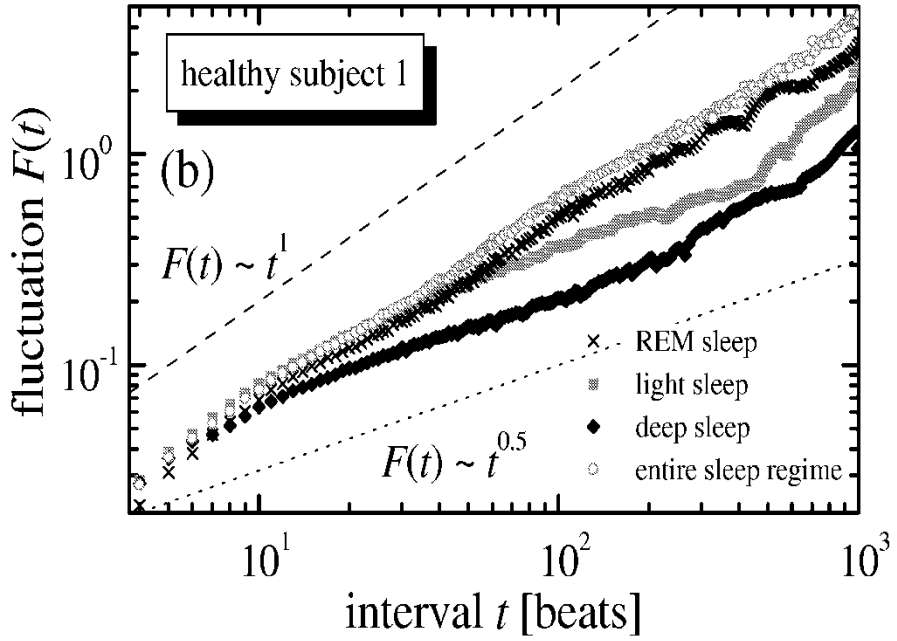
Peng CK, Goldberger A et al.
Chaos 1995; 5: 82-87
Bunde et al. Physical Review Letters 85; 2000

DFA of heart rate during sleep

Detrended fluctuation analysis (DFA) applied to heart rate during sleep

- separated for sleep stages
- for healthy subjects
- different scaling behavior in deep sleep and REM sleep



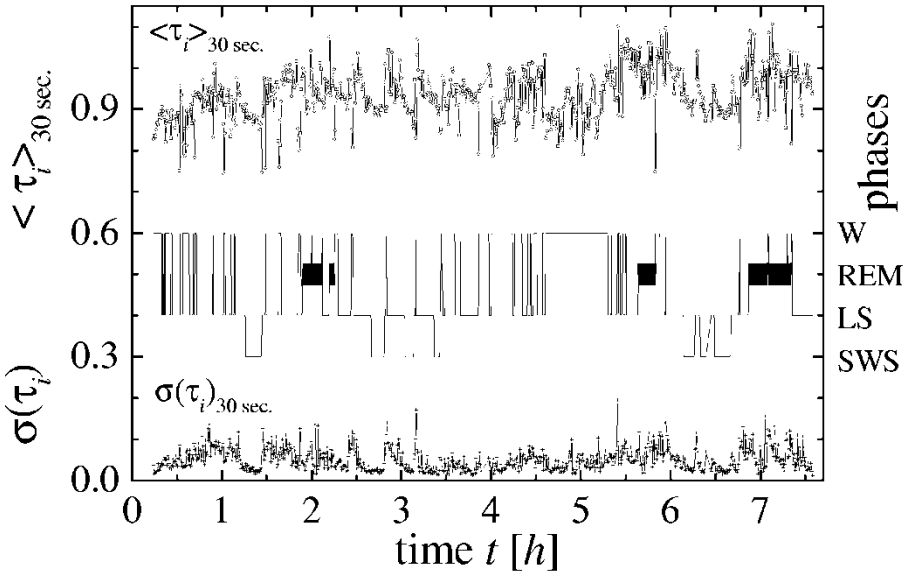


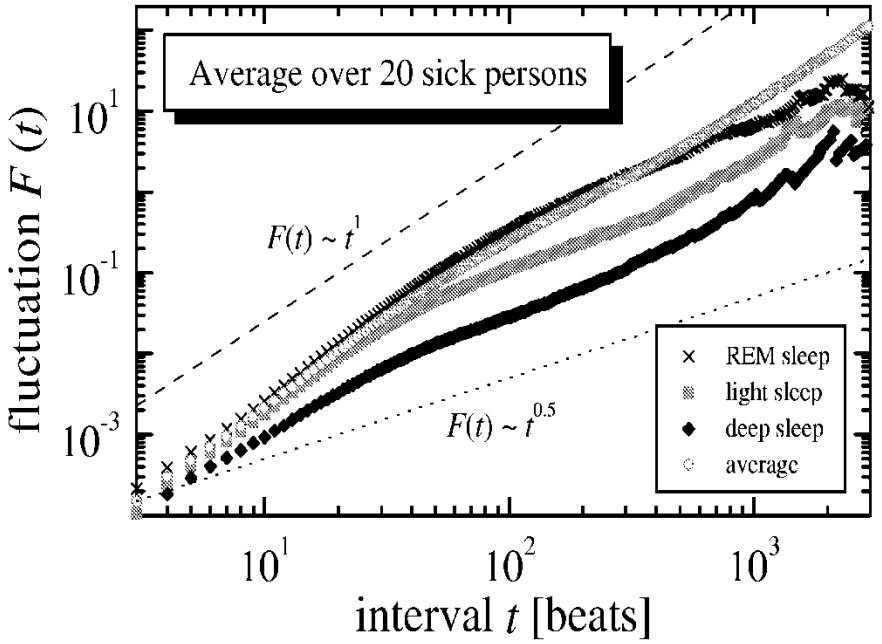
Bunde et al. Physical Review Letters 85; 2000

DFA in sleep apnea – heart rate and sleep

Detrended fluctuation analysis applied to heart rate during sleep

- again separated for sleep stages
- for patients with sleep apnea
- different scaling behavior in deep sleep and REM sleep

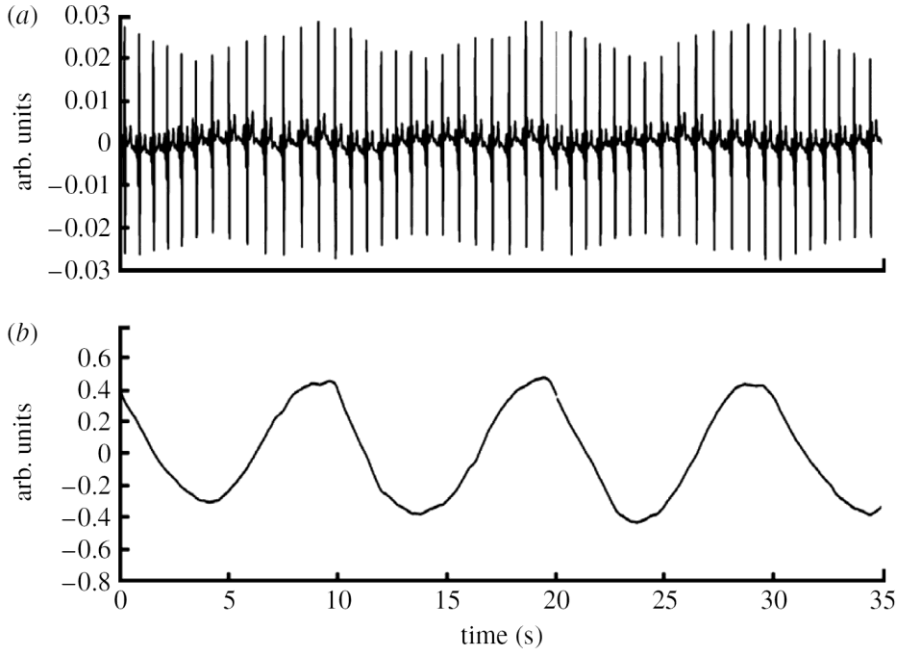




Bunde et al. Physical Review Letters 85; 2000

Long term ECG

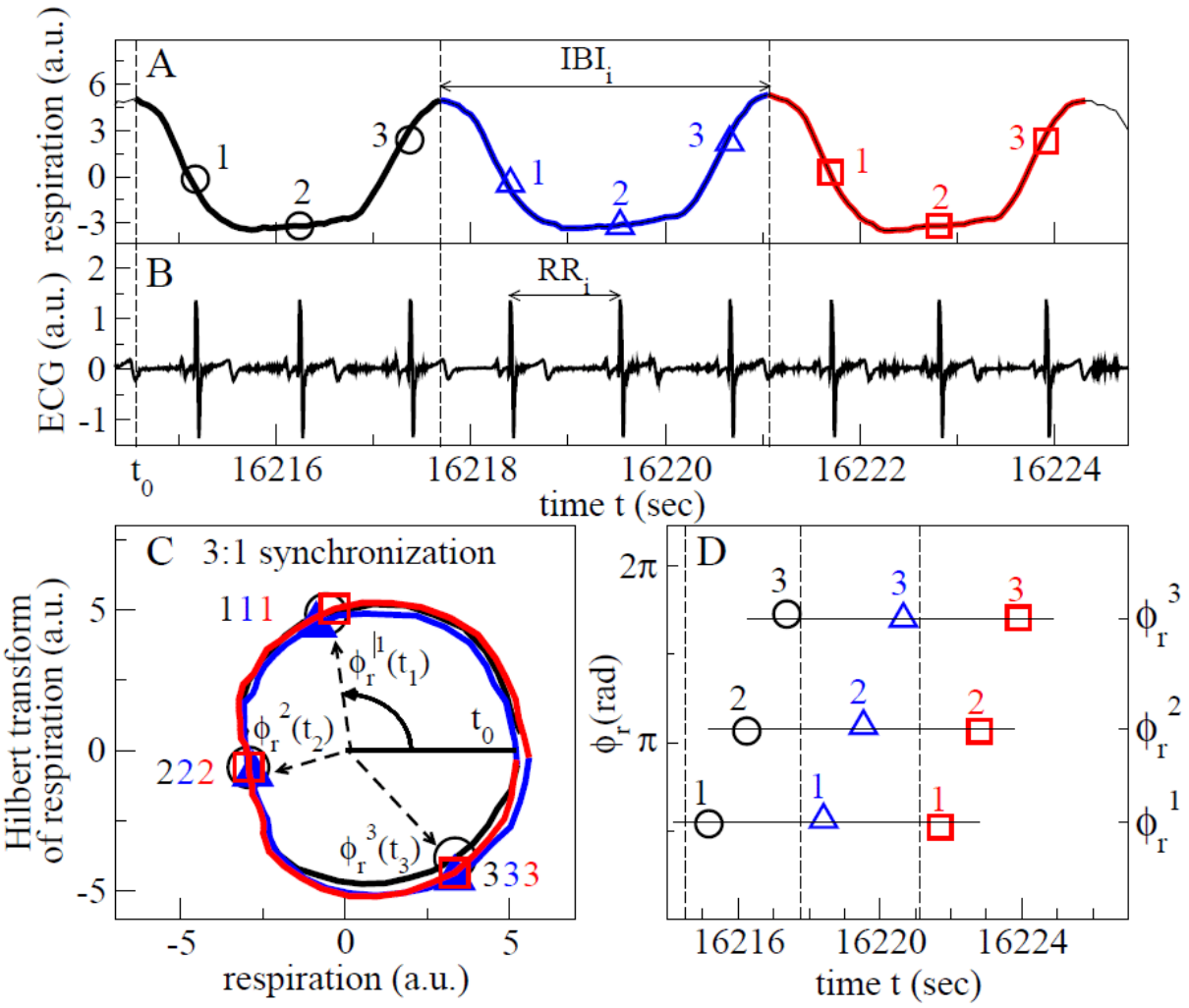
Holter ECG records not just heart rate but the full ECG with two or more leads



ECG derived respiration - EDR

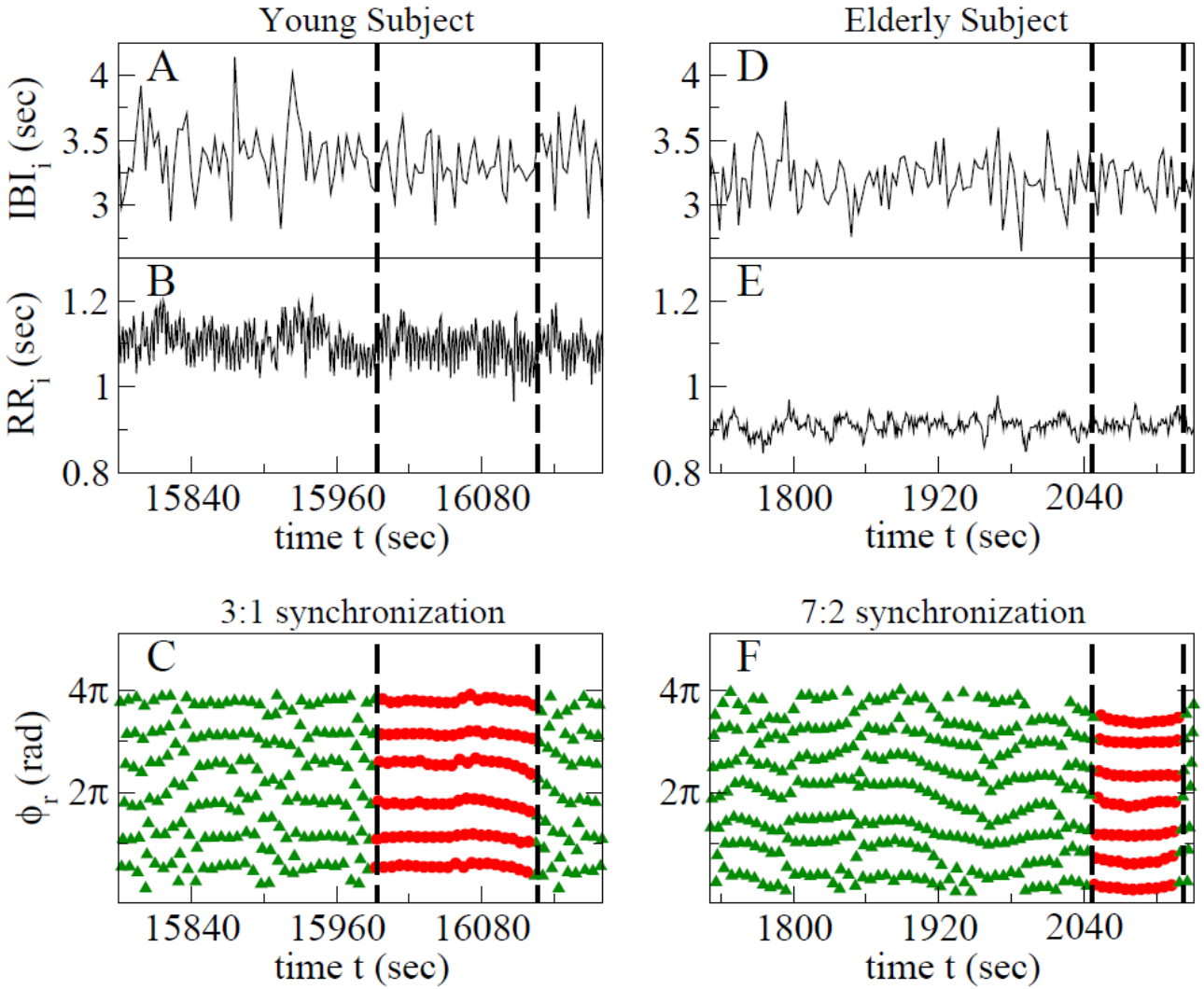
DeChazal P, Heneghan C, McNicholas W. Philos Transact A Math Phys Eng Sci 367: 369-389 (2009)

Coupling and synchronization



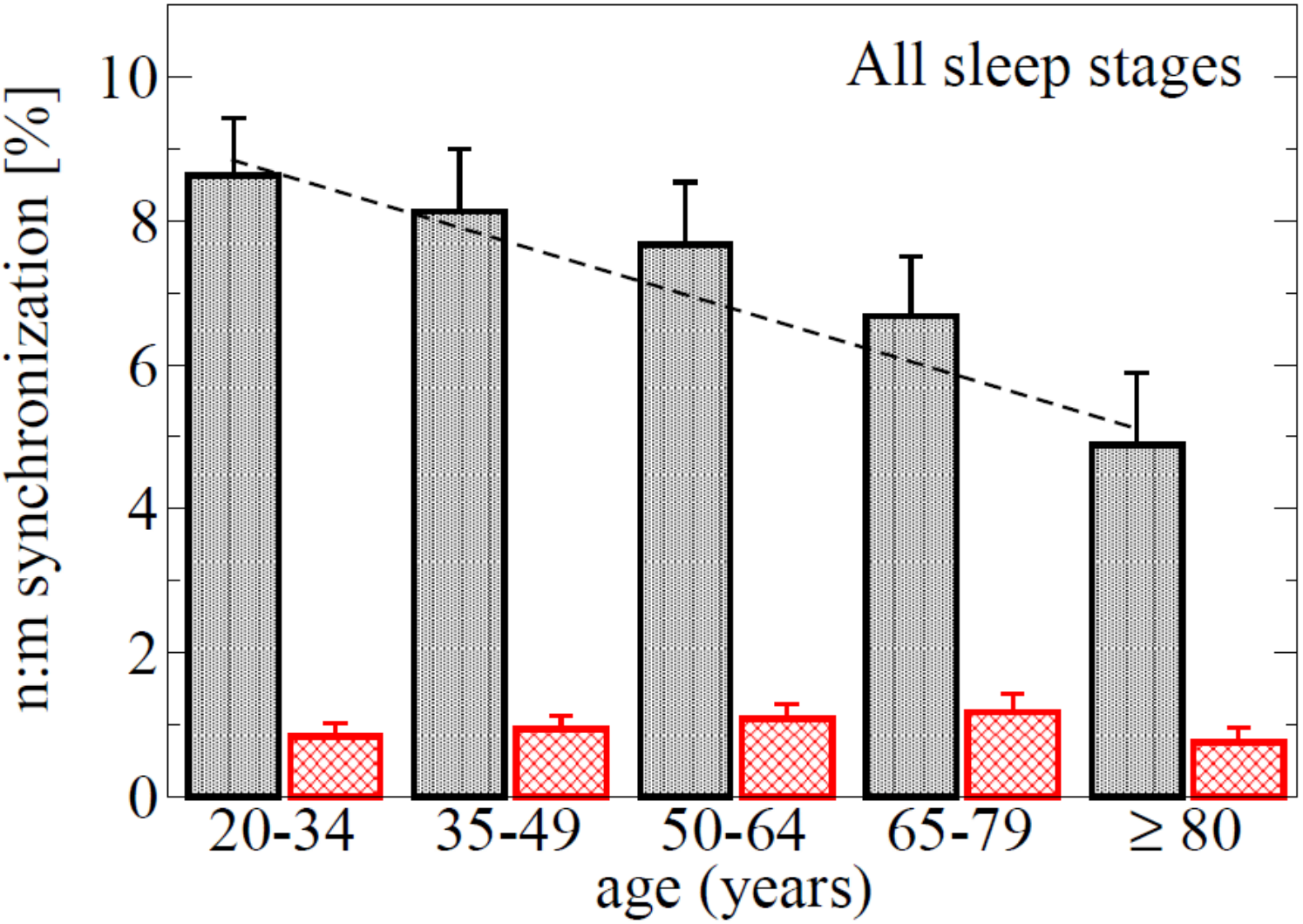
Bartsch R, et al. PNAS 109: 10181 (2012)

Phase synchronization



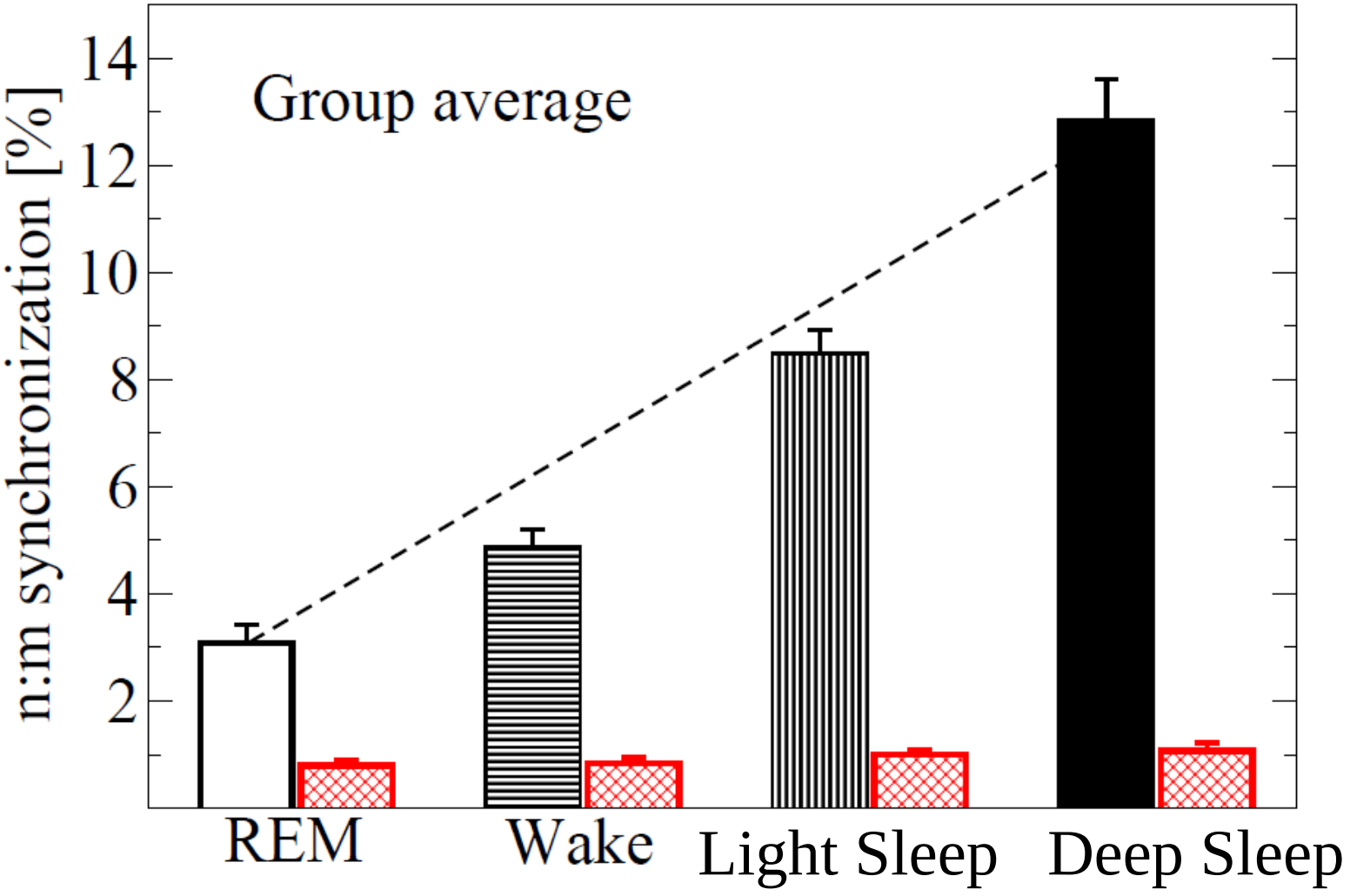
Bartsch R, et al. PNAS 109: 10181 (2012)

Phase synchronization and age



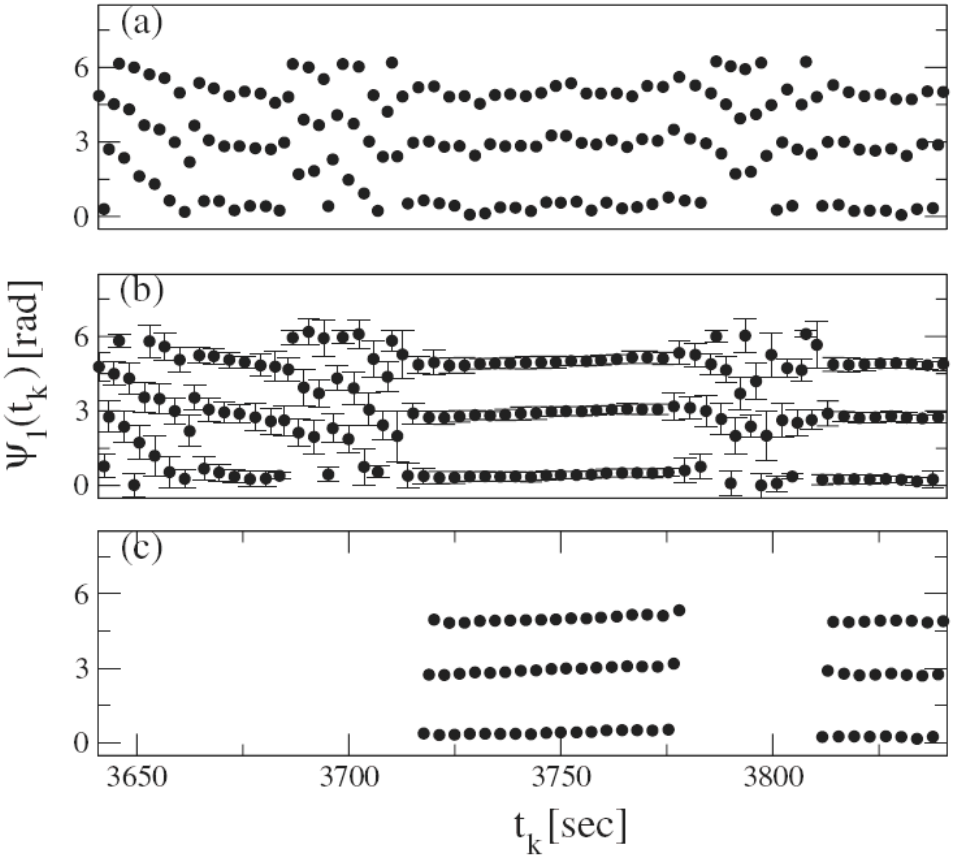
Bartsch R, et al. PNAS 109: 10181 (2012)

Phase synchronization and sleep stage



Bartsch R, et al. PNAS 109: 10181 (2012)

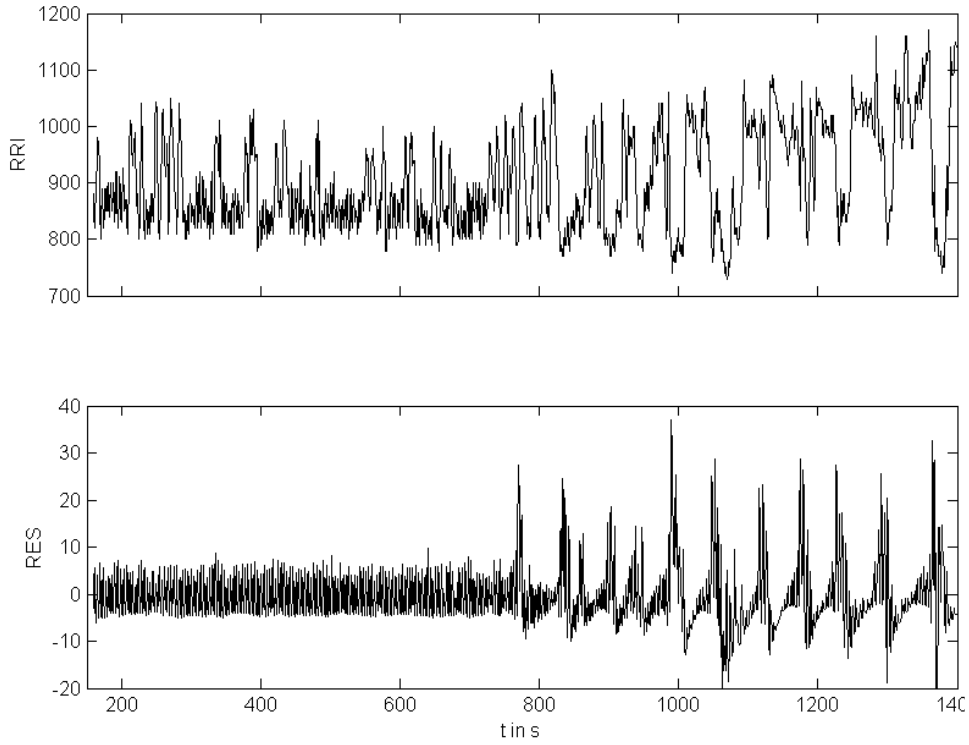
Synchronization analyzed during sleep stages

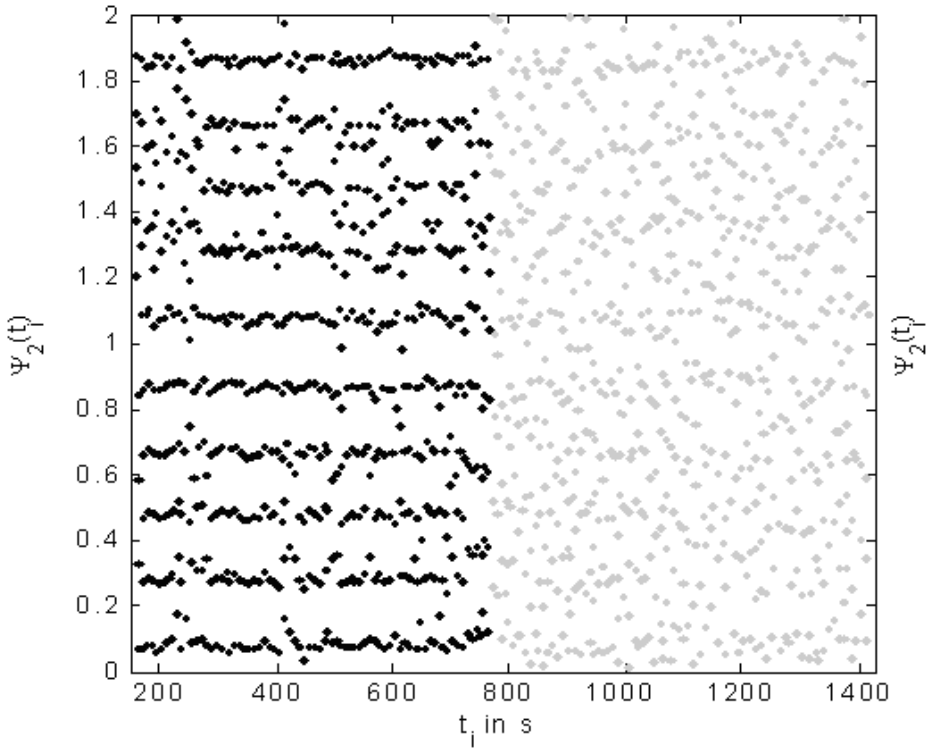


Synchronization diagram in 112 healthy sleep recordings. Automated calculation of phase using Hilbert transform and correction methods.

Bartsch et al. Phys. Rev. Letters 98: 054102 (2007)

Cardiorespiratory coupling is lost with apnea





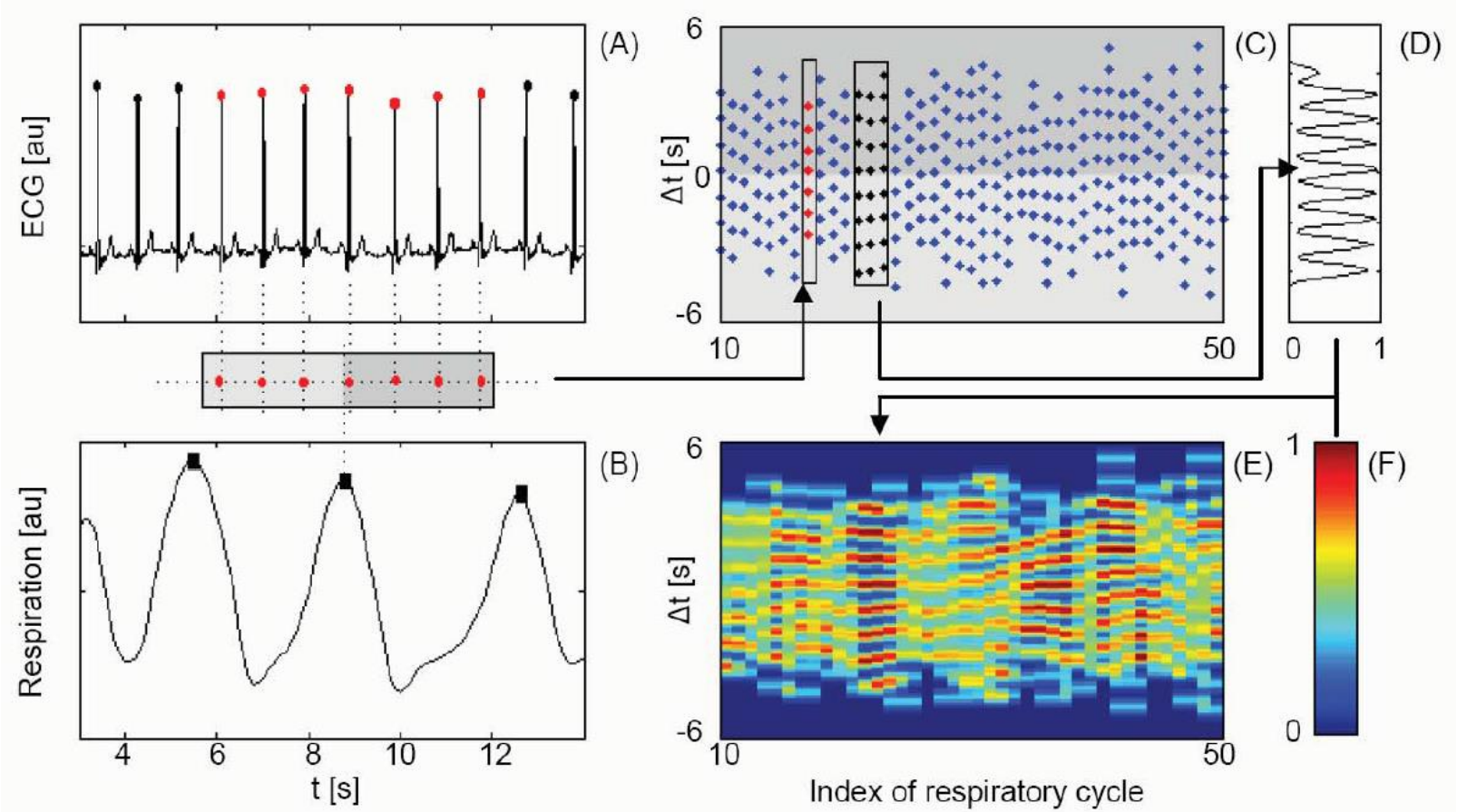
(a) R-R intervals, and (b) Respiration
during non-REM sleep, and a period with sleep apnea

Penzel et al. Chaos 17: 15116 (2007)

Cardiorespiratory coordination detection

Onset of cardiac cycle

Coordigram reflects temporal relation between respiration and cardiac cycle

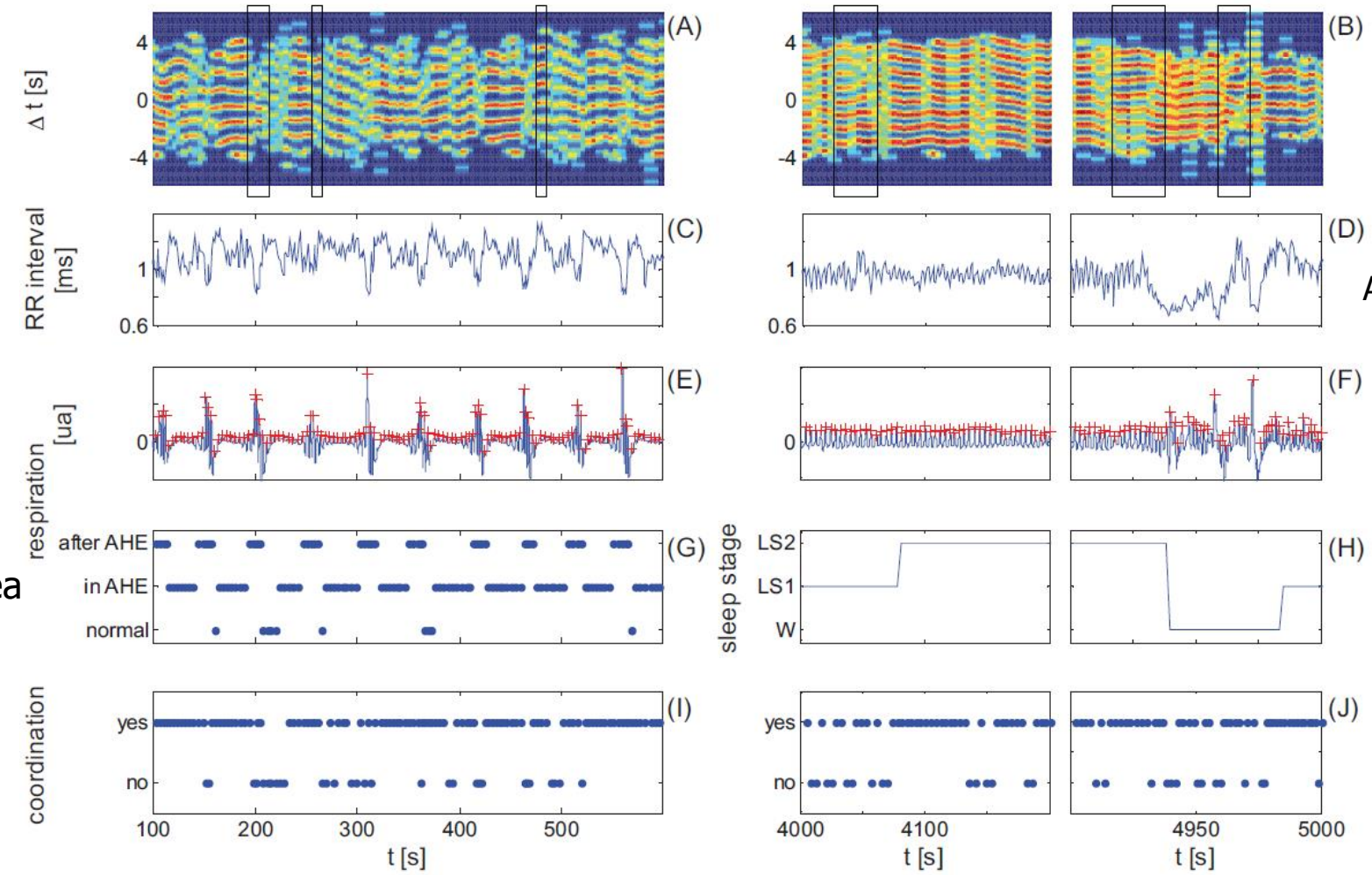


Onset of respiration

Cardiorespiratory coordination: positive range of t (red): heart triggers respiration; negative range of t: ventilation coordinates the heart

Riedl et al. Plos One (2014)

Cardiorespiratory coordination during apnea / arousal events

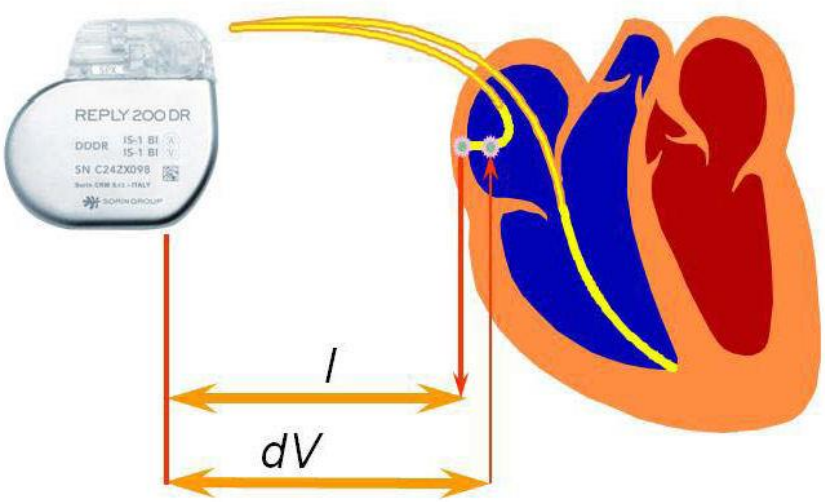


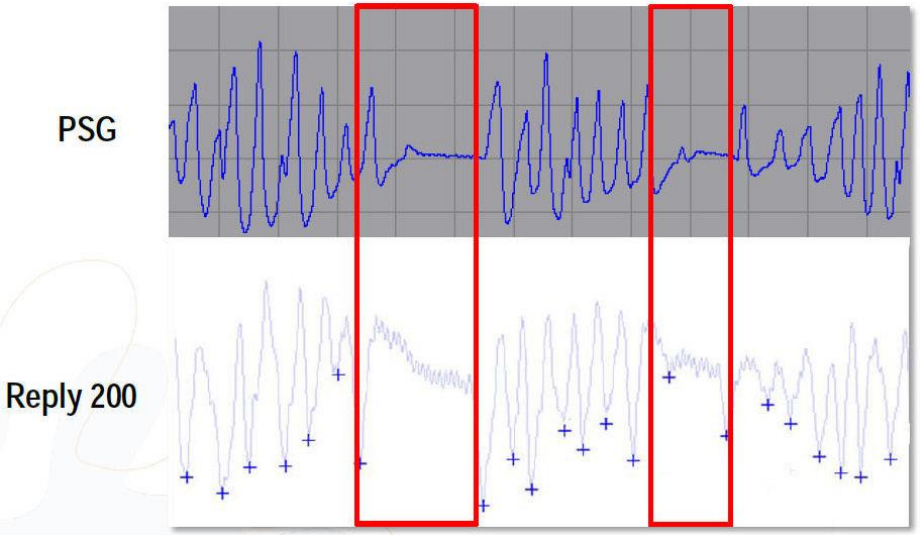
Frames in A and B mark asymmetric structures which indicate unidirectional influences.

Riedl et al. Plos One (2014)

ECG monitoring by cardiac pacemaker

Cardiac pacemakers do analyze respiration and do recognize apneas



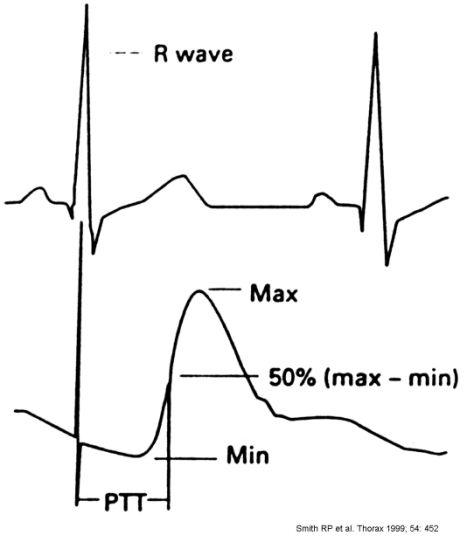


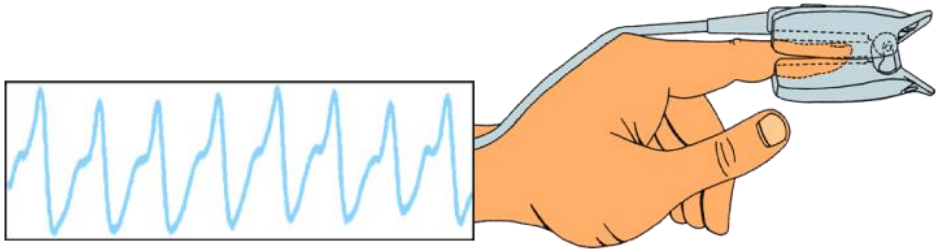
Transthoratic impedance Z_{th}: $Z_{th}\,(\Omega) = \frac{dV\,(V)}{I\,(A)}$

Defaye et al. Europace 15 S2: 249 (2013)
Pepin et al. Europace 15 S2: 196 (2013)

Pulse wave analysis

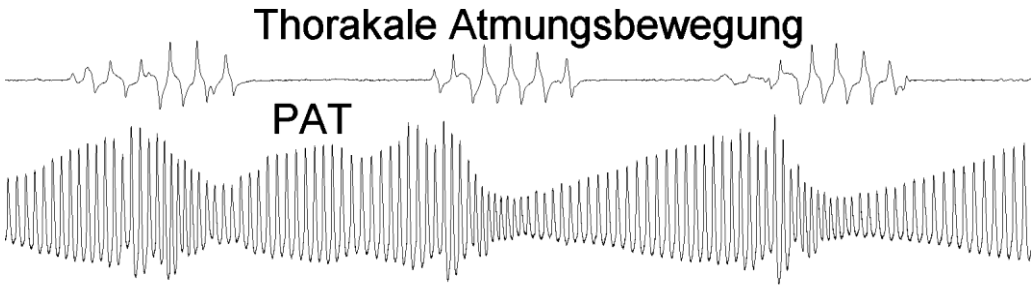
- Oxygen saturation
- Cardiac output
- Autonomous function
- Disease of peripheral vascular system
- Sleep related breathing disorders

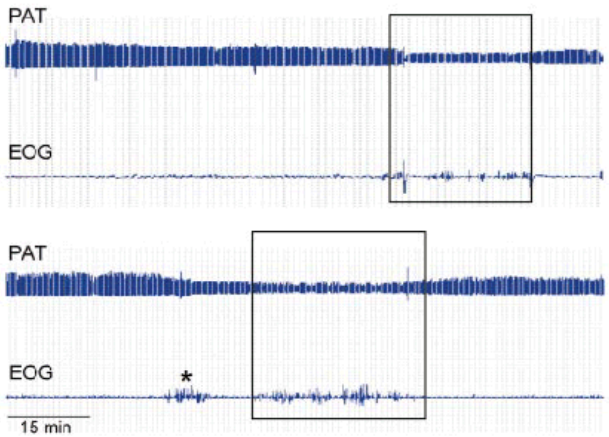




Derive pulse wave from finger – devices

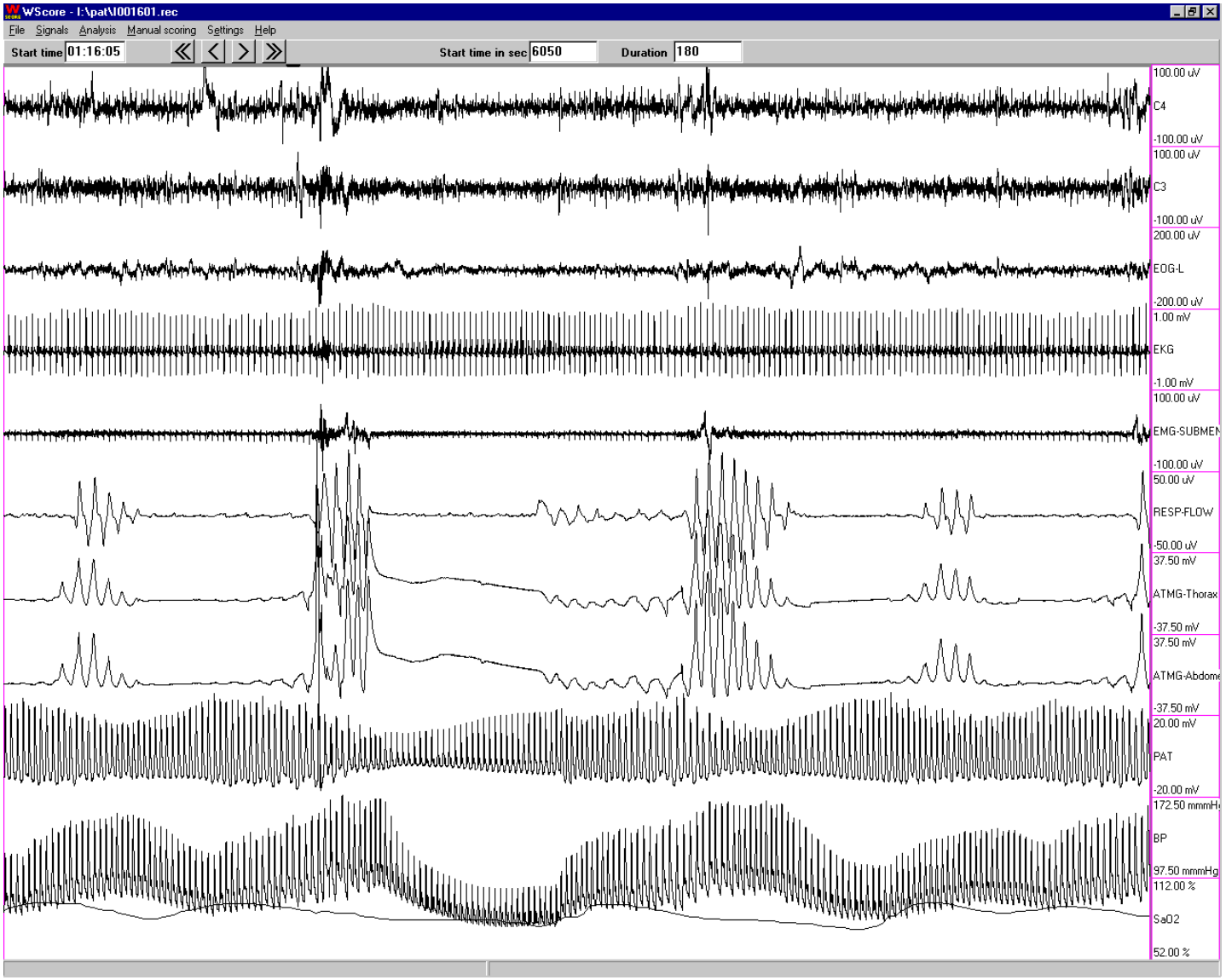
Parameter:
- Peripheral arterial tone
- Pulse oximetry
- Actigraphy





Schnall RP et al. Sleep 22:939-946 (1999)
Lavie P et al. Nature Medicine 6:606 (2000)
Penzel et al. Physiol. Meas. 25: 1025-1036 (2004)

Peripheral arterial tone (PAT) during obstructive apnea



Smartphone applications

Movement analysis
Microphone analysis
additional single-use sensors

Grifantini K. IEEE Pulse, Sept. 2014

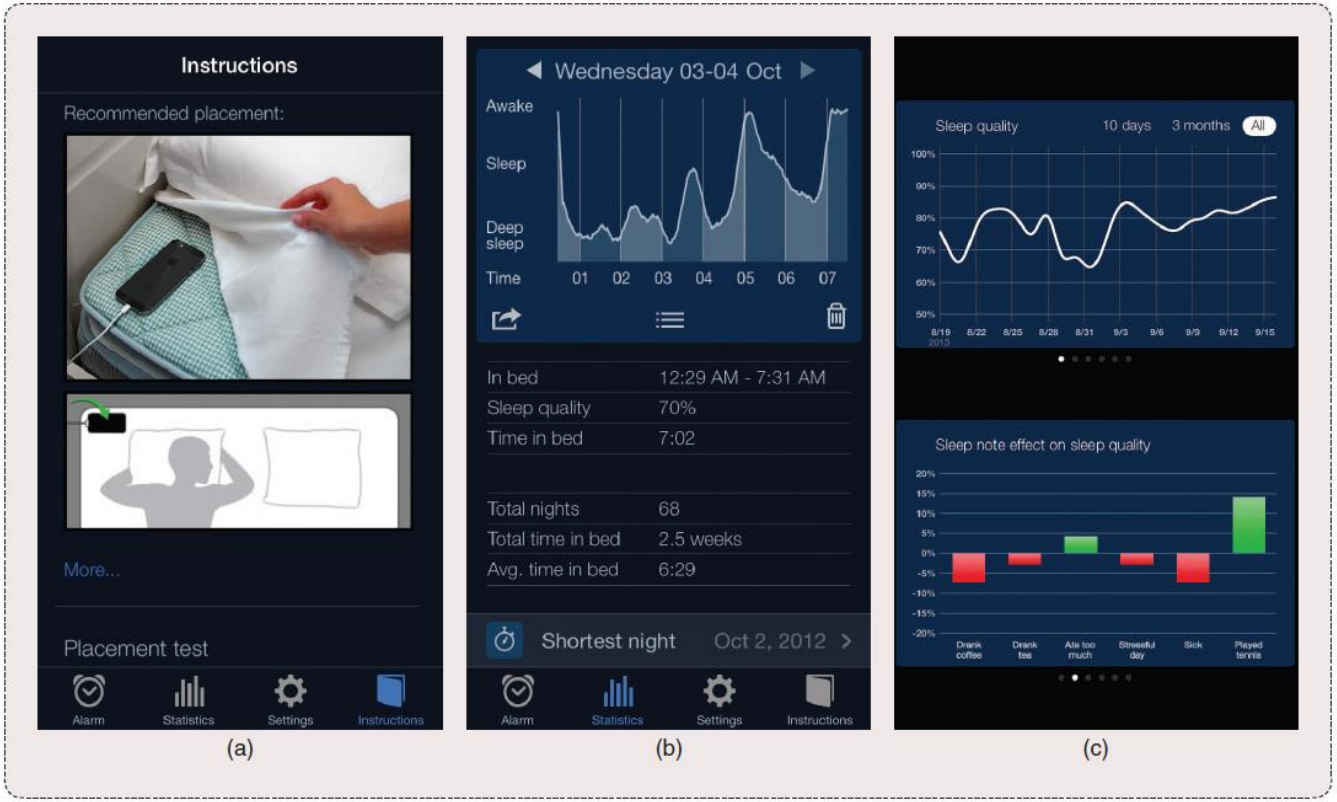
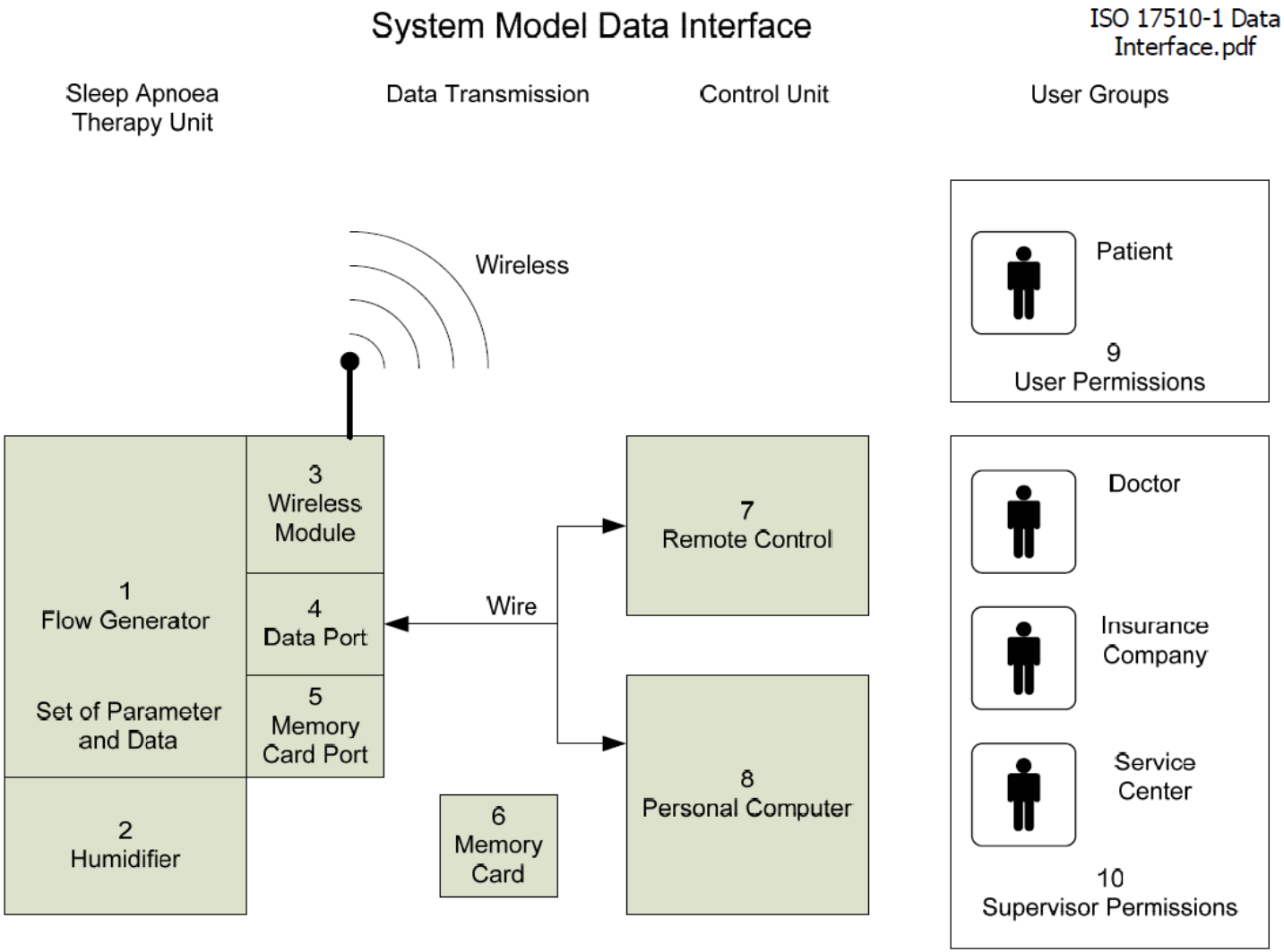


FIGURE 1 Sleep Cycle uses the accelerometer in smartphones to detect movement. The app uses these readings to attempt to graph a user's sleep patterns. The screenshots show (a) the recommended placement of the smartphone, (b) the user's sleep statistics, and (c) sleep quality graphs. (Image courtesy of Sleep Cycle.)

Compliance recording and treatment follow up



Conclusions

What we know:

- New methods help to understand physiology
- coupling of respiration and heart rate mirrors regulation
- cardiorespiratory coupling differs in sleep stages
- cardiorespiratory coupling is impaired in sleep apnea

What we don't know:

- cardiovascular risk assessment: (stroke, myocardial infarction, hypertension, arteriosclerosis, heart failure)
- genotype – phenotype