Jürgen Kurths

On the difference of cardiorespiratory synchronization and coordination

CHARITÉ

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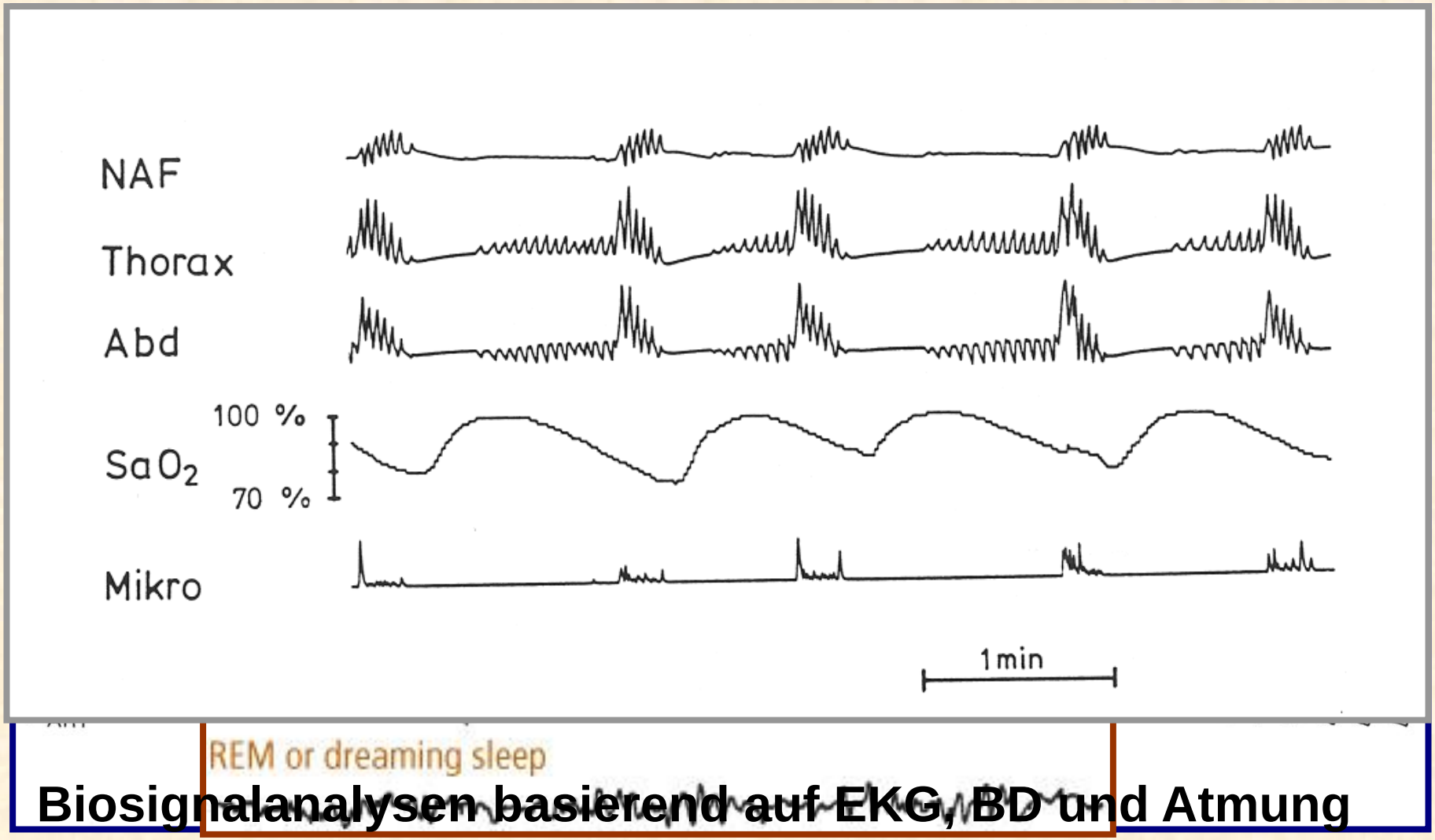
Kardiorespiratorische Polysomnographie



Biosignalanalysen basierend auf EKG, BD und Atmung

Jürgen Kurths

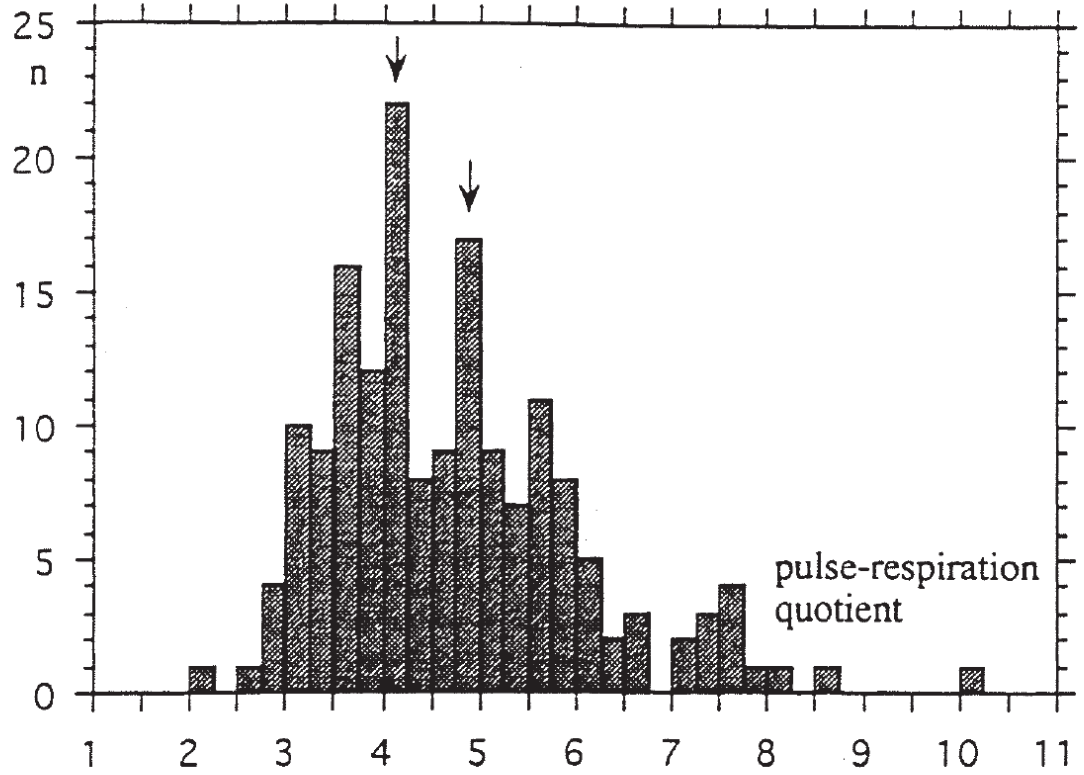
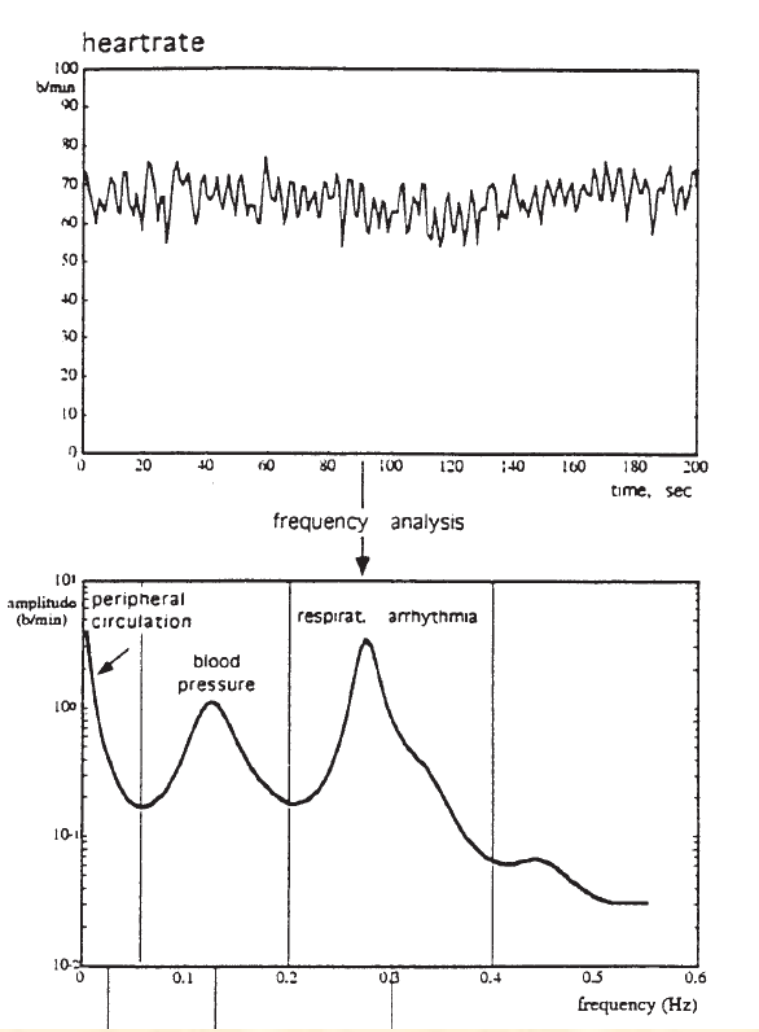


Fig. 5. Histogram of pulse-respiration quotients in 160 resting persons. The modulus of the histogram can be found at a PRQ of 4:1. Note that the histogram shows accumulations around whole- number ratios (4:1, 5:1) (arrows).

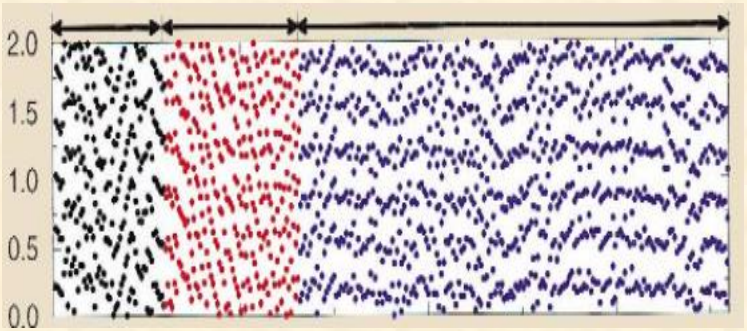
Moser et al.1995

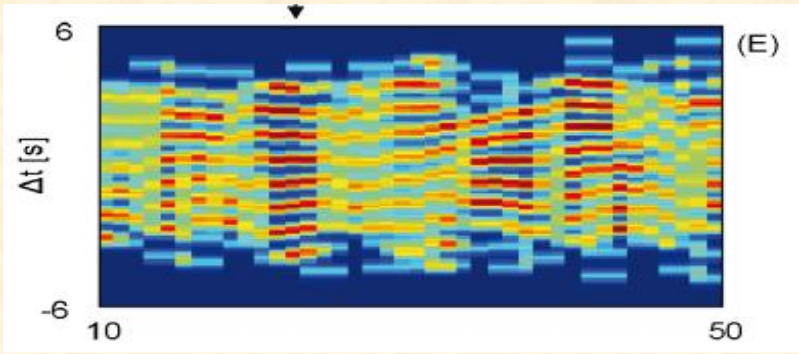
Jürgen Kurths



Moser et al.1995

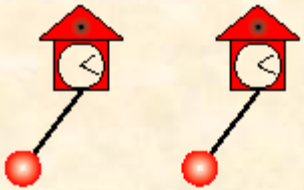
Kardiorespiratorische Synchronisation vs. Kardiorespiratorische Koordination

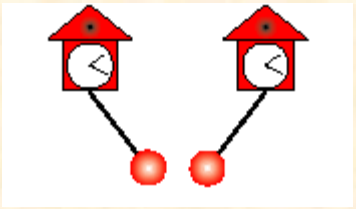




Synchrogramm vs. Koordigramm

Synchronisation (Christiaan Huygens)





Pendeluhren am selben Balken (Fachwerkhaus)

... It is quite worth noting that when we suspended two clocks so constructed from two hooks imbedded in the same wooden beam, the motions of each pendulum in opposite swings were so much in agreement that they never receded the least bit from each other and the sound of each was always heard simultaneously. Further, if this agreement was disturbed by some interference, it reestablished itself in a short time. For a long time I was amazed at this unexpected result, but after a careful examination finally found that the cause of this is due to the motion of the beam, even though this is hardly perceptible.(Huygens, 1673)

Historie: Kardiorespiratorische Synchronisation

Coleman, W. M. (1920). On the correlation of the rate of heart beat, breathing, bodily movement and sensory stimuli. *The Journal of Physiology, 54*(4), 213.

Bucher, K. (1944). Über den Entstehungsmechanismus der pulssynchronen Atmung. *Helvetica Physiologica et Pharmacologica Acta, 2*, 519-605.

Engel, P., Hildebrandt, G., Scholz H.-G. (1968). Die Messung der Phasenkoppelung zwischen Herzschlag und Atmung beim Menschen mit einem neuen Koinzidenzmeßgerät, *Pflügers Archiv 298*: 258.

Historie: Kardiorespiratorische Koordination

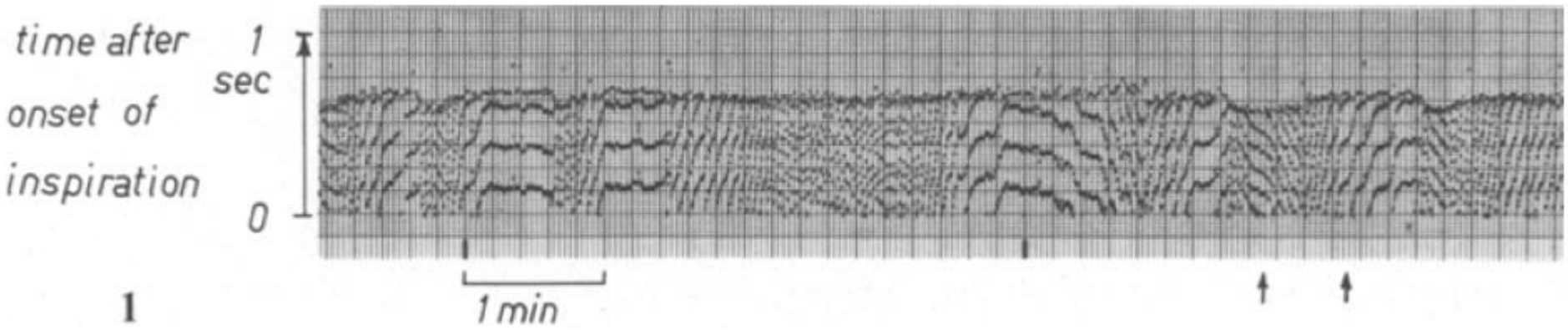
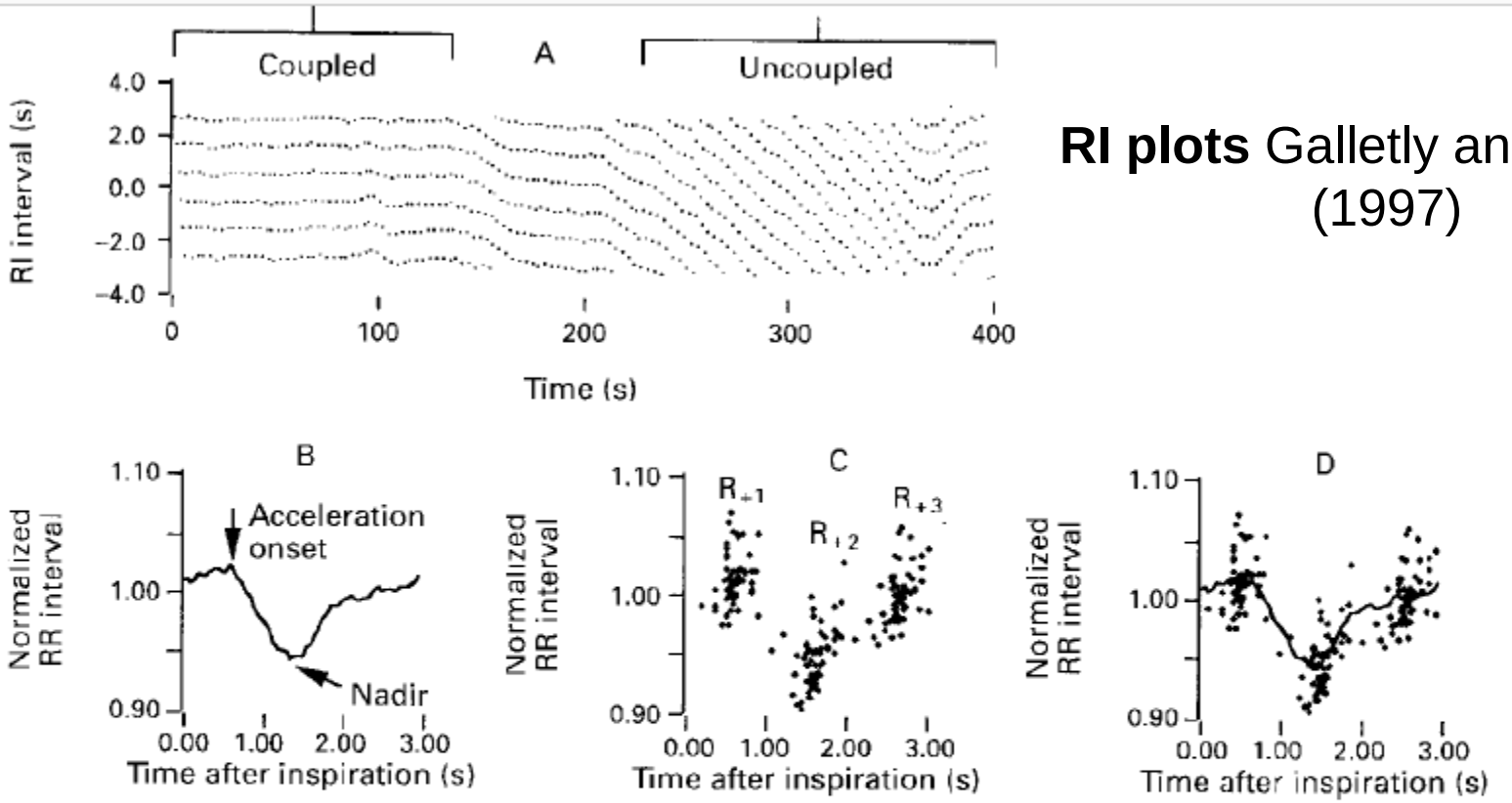


Fig. 1
Experimental record showing the characteristic synchronization pattern between heart rate and ventilation rate provided by the computer analysis in a rabbit. During synchronization a 3:1 rhythm is encountered. First arrow: splitting and apparent doubling of the rhythm. The second arrow shows a period in which transient entrainment and escape phenomena are especially pronounced

IR plots Kenner et al. (1976)

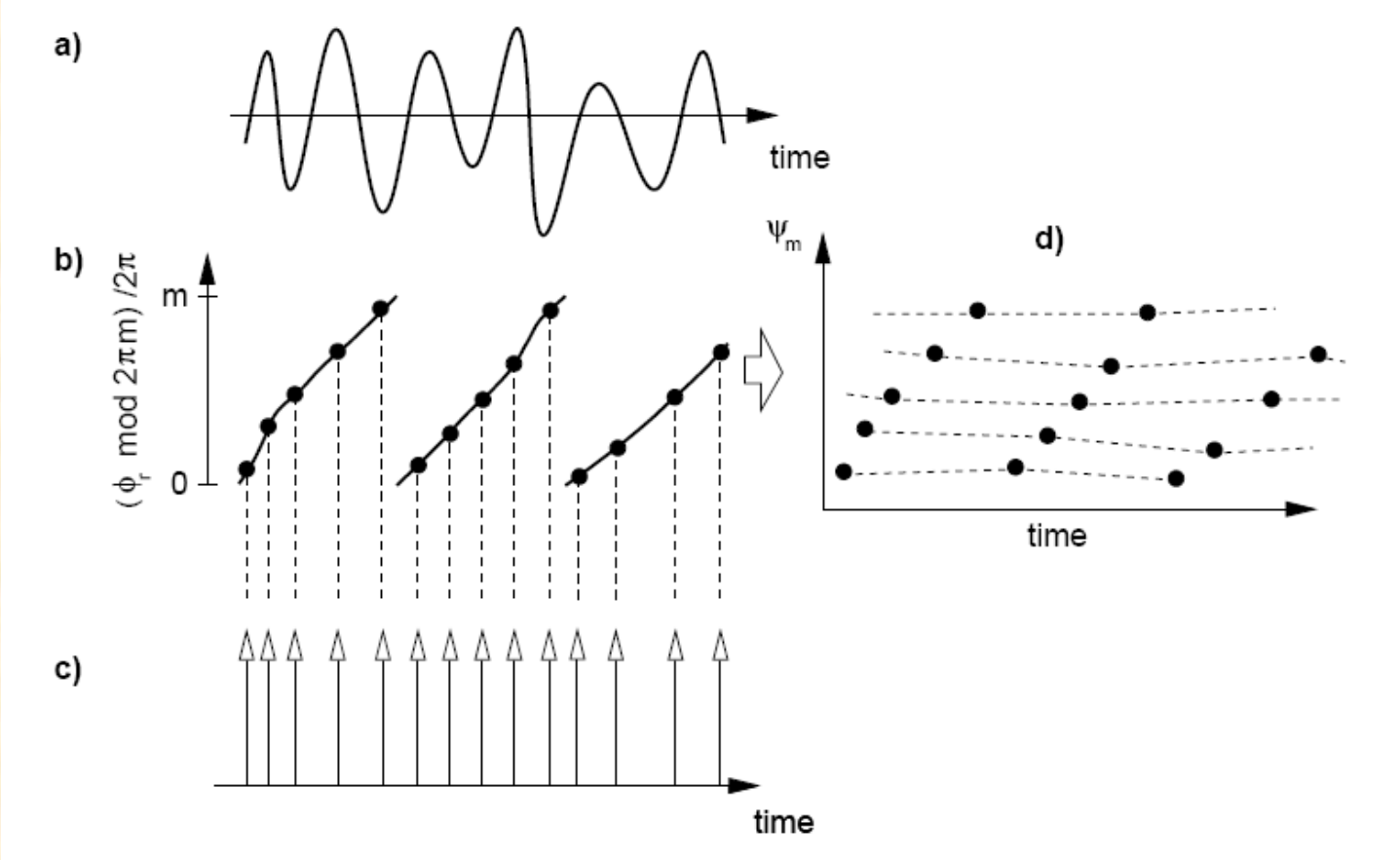
Historie: Kardiorespiratorische Koordination



RI plots Galletly and Larsen (1997)

Figure 2 A: Representative example of an RI interval time series showing a segment (0–140 s) of strong cardioventilatory phase coupling during which time heart beats occurred in constant relationship to inspiratory onset, and a weakly coupled segment in which heart beats occurred at all phases of the ventilatory cycle (220–400 s). B: Mean value of the normalized, preceding RR interval (RR interval/mean RR) for time periods after inspiratory onset (RSA curve) was determined from the weakly coupled segment. Acceleration onset and nadir were measured. C: Normalized RR values for intervals derived from the strongly coupled segment show grouping of RR intervals as a result of the timing relationship between R waves and inspiratory onset. D: Superimposition of plots B and C demonstrates that the heart beat grouping R_{+1} has fallen at the acceleration onset of the RSA curve and has therefore been preceded by the longest possible RR interval, and that the R_{+2} grouping has fallen at the RSA nadir and has therefore been preceded by the shortest RR interval for that RSA curve.

Synchrogramm, Schäfer et al. Nature 1998

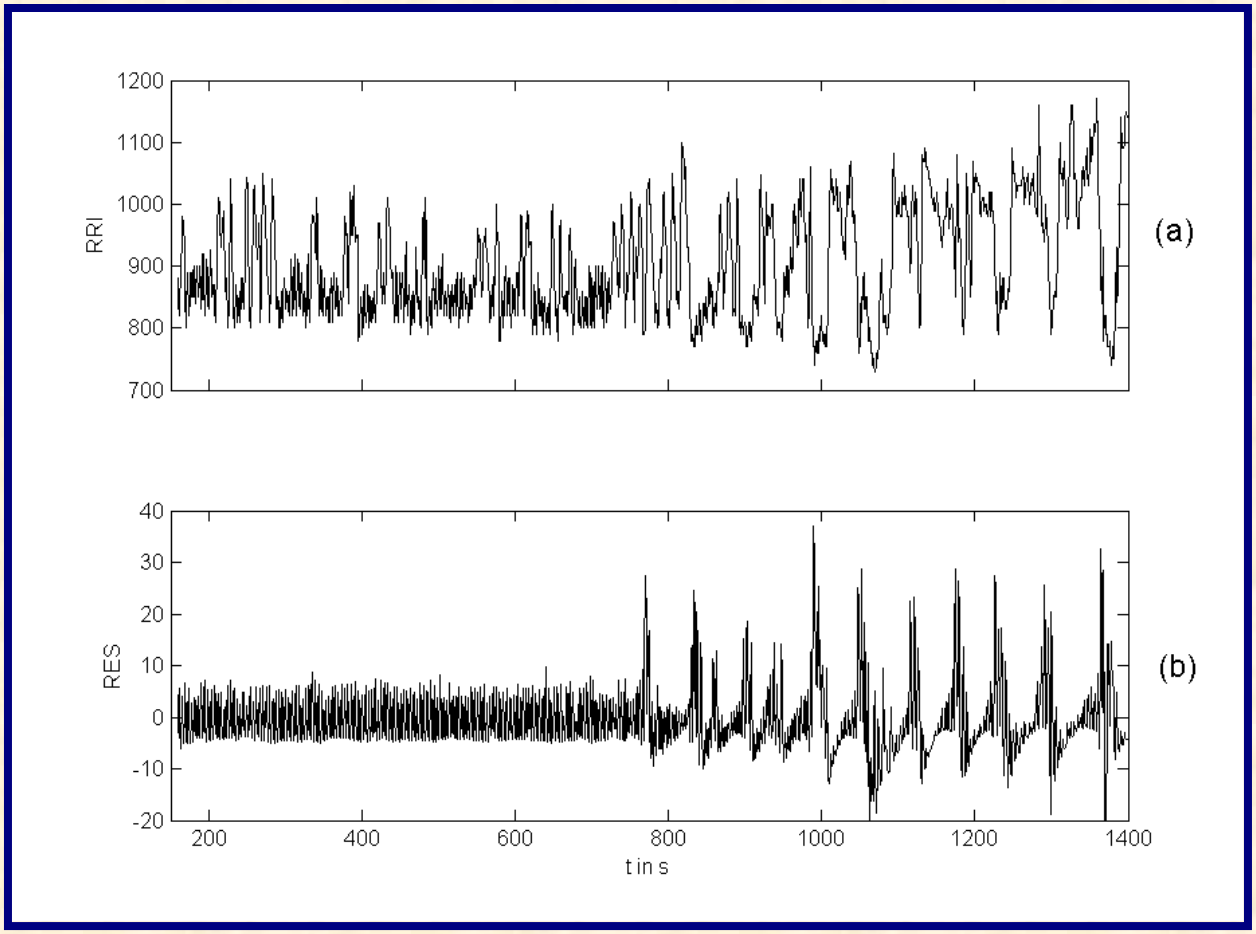


Calculation of phase for each heart beat during respiration.

Plotting synchronization diagrams.

Kardiorespiratorische Synchronisation

NREM **REM**



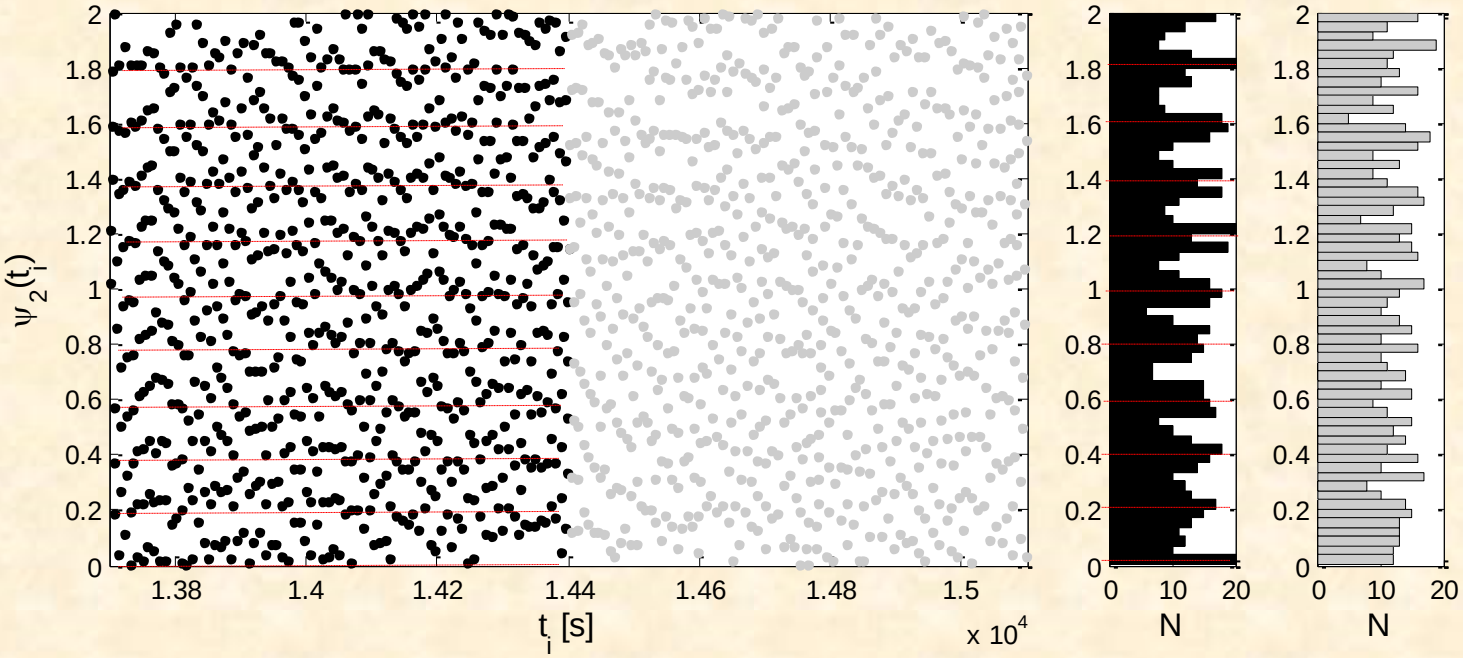
Beat-to-beat intervals

Respiration

Penzel T, Wessel N, et al., Cardiovascular and respiratory dynamics during normal and pathological sleep. Chaos **2007, 17: 015116.**

Kardiorespiratorische Synchronisation

NREM **REM**

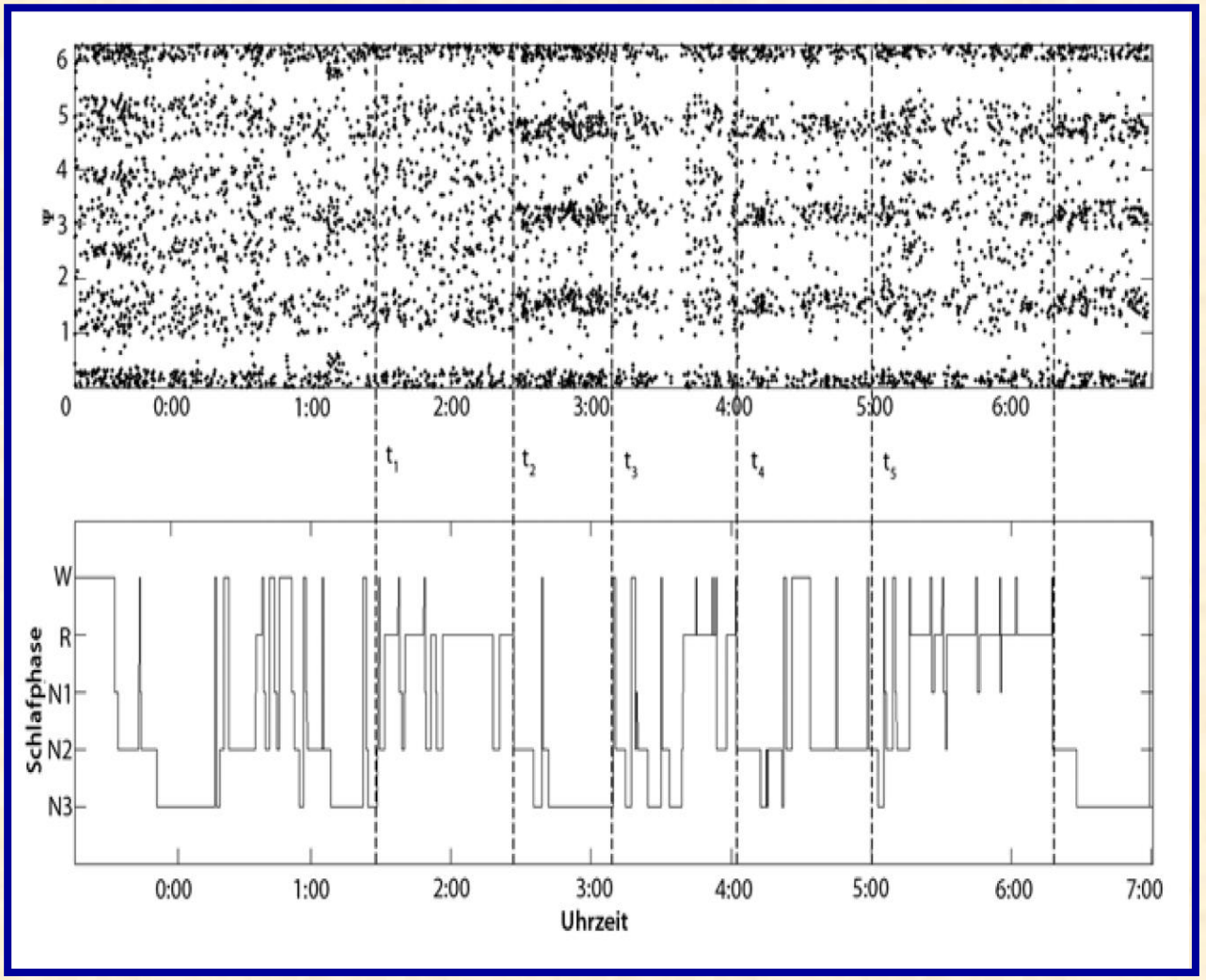


Synchrogram, Schäfer Nature 1998

→ Statistical **phase synchronization** analyses

→ Difference in **distributions**

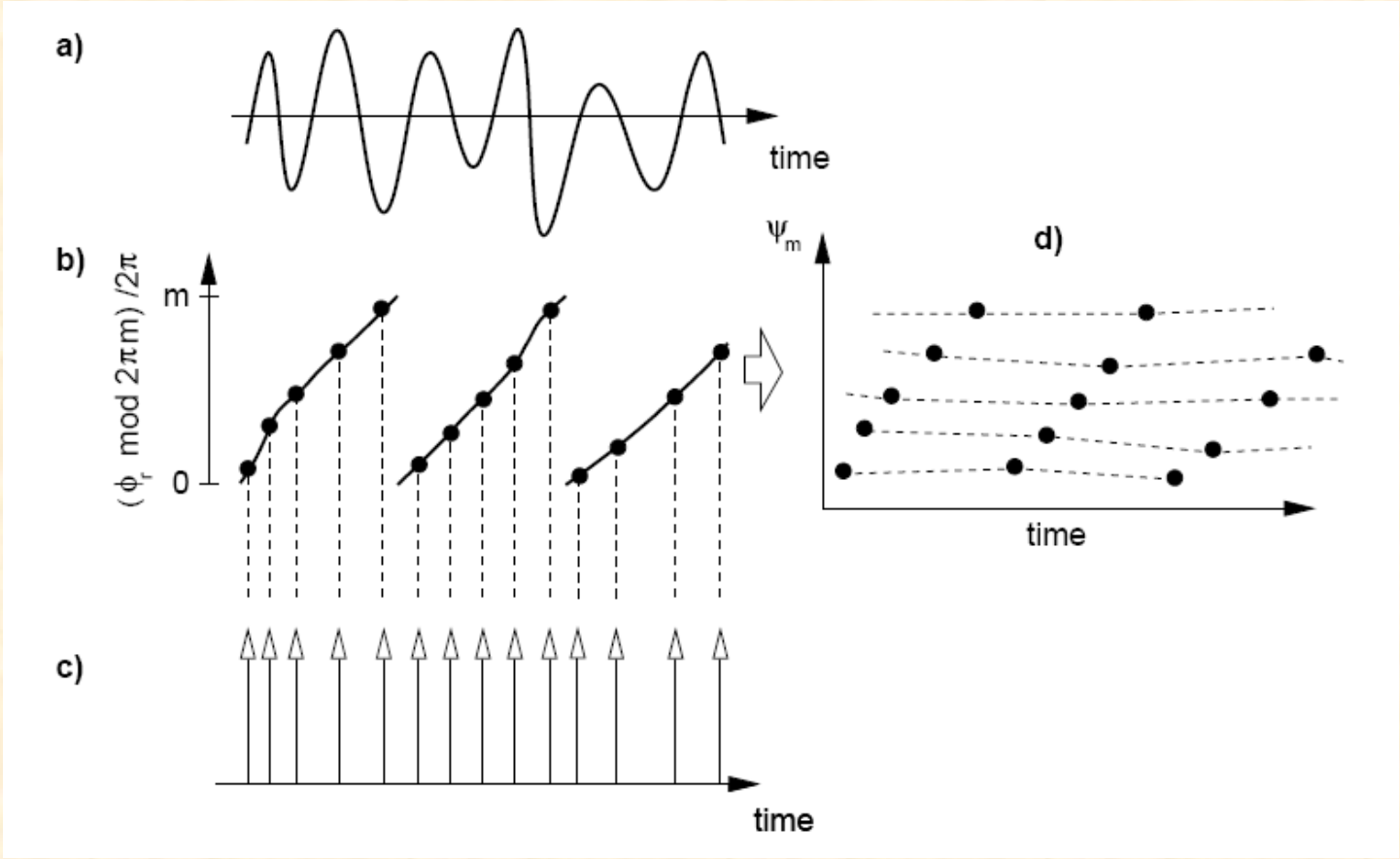
Kardiorespiratorische Synchronisation während einer Nacht

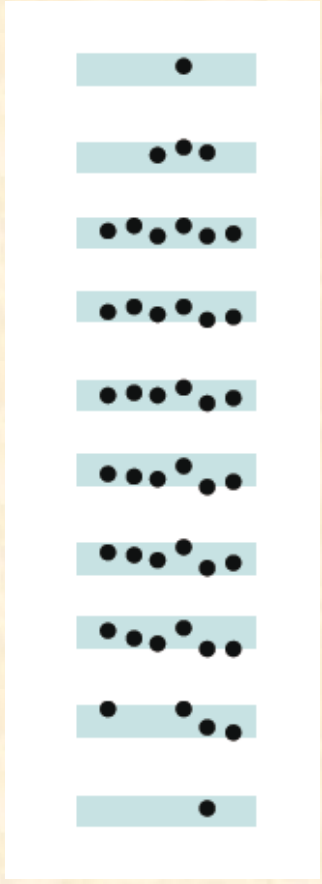


Müller et al. Somnologie 2012

Limitationen des Synchrogramms

Definition of a phase! **We lose the time dependence!**



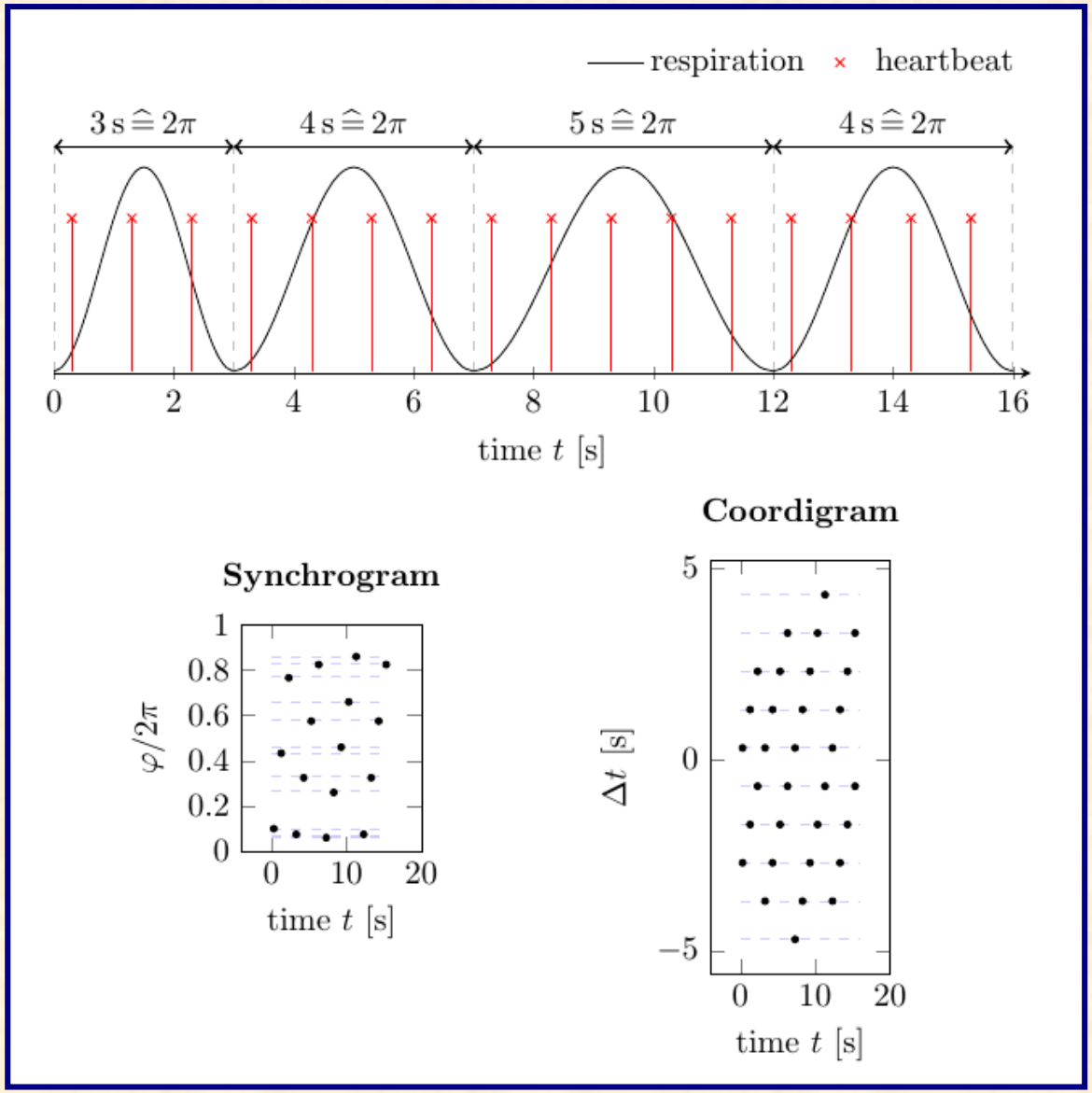


Calculation of phase for each heart beat during respiration.

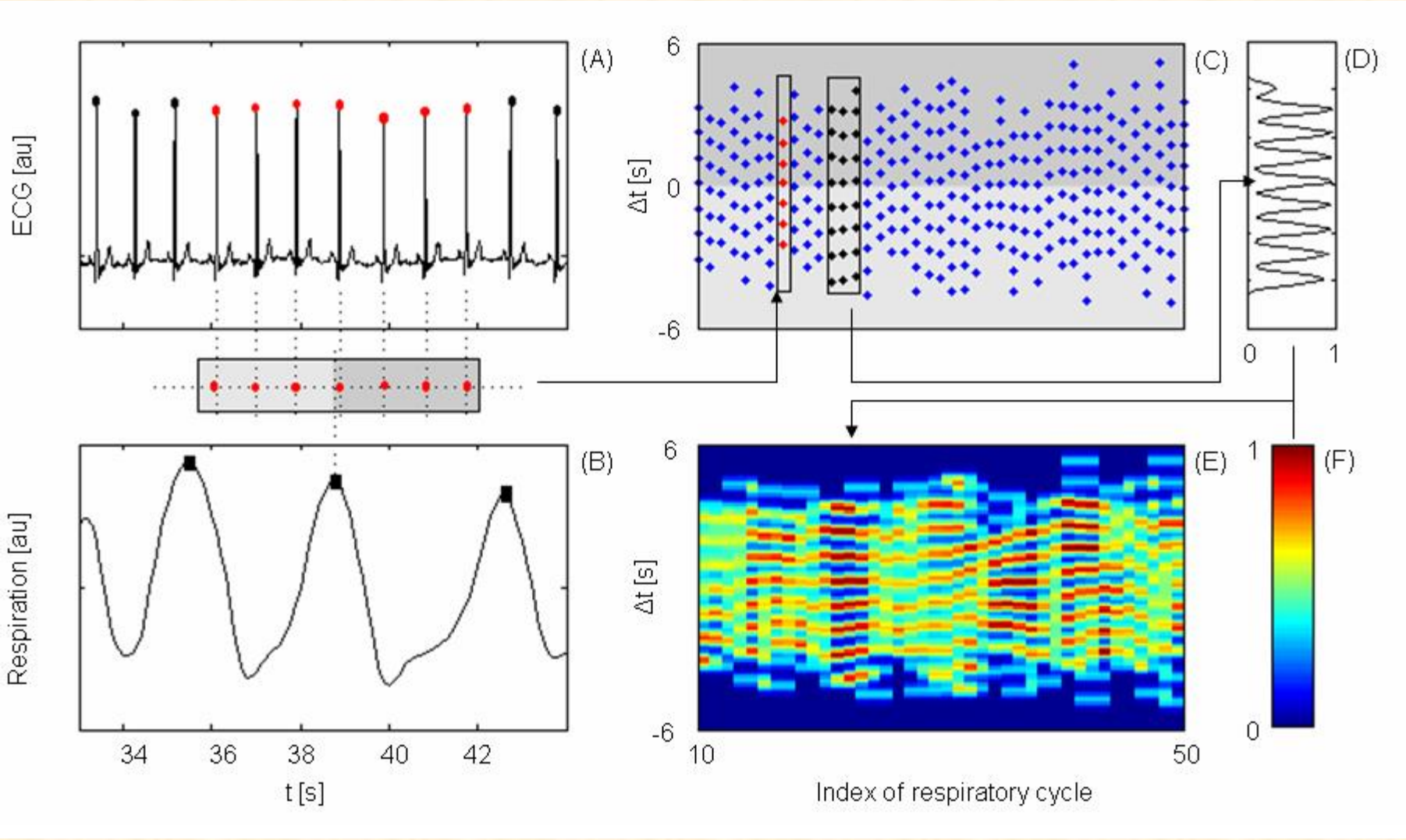
Plotting synchronization diagrams.

Coordigram

Limitationen des Synchrogramms

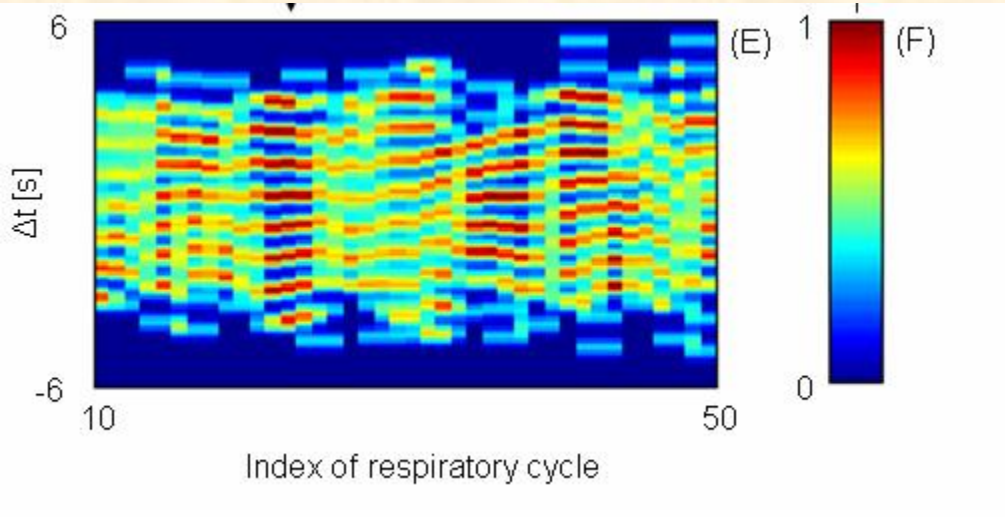


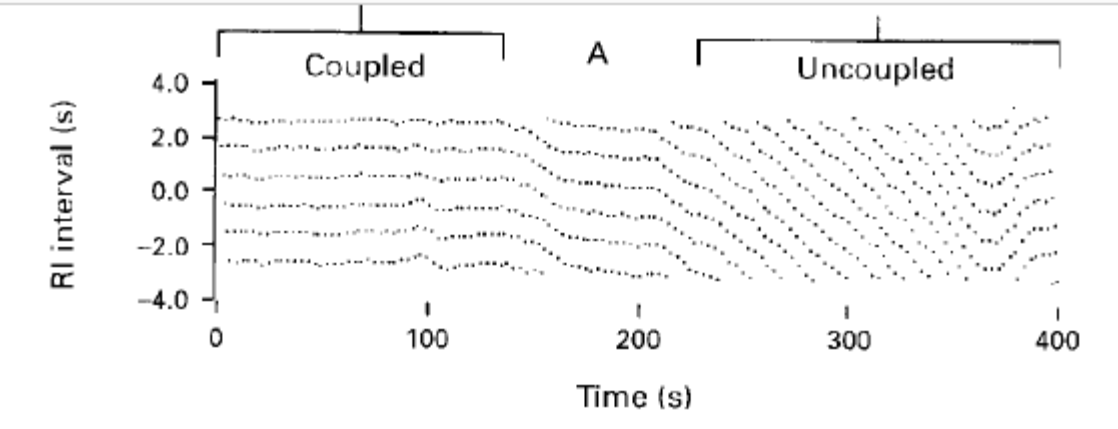
Visualisierung: Kardiorespiratorische Koordination



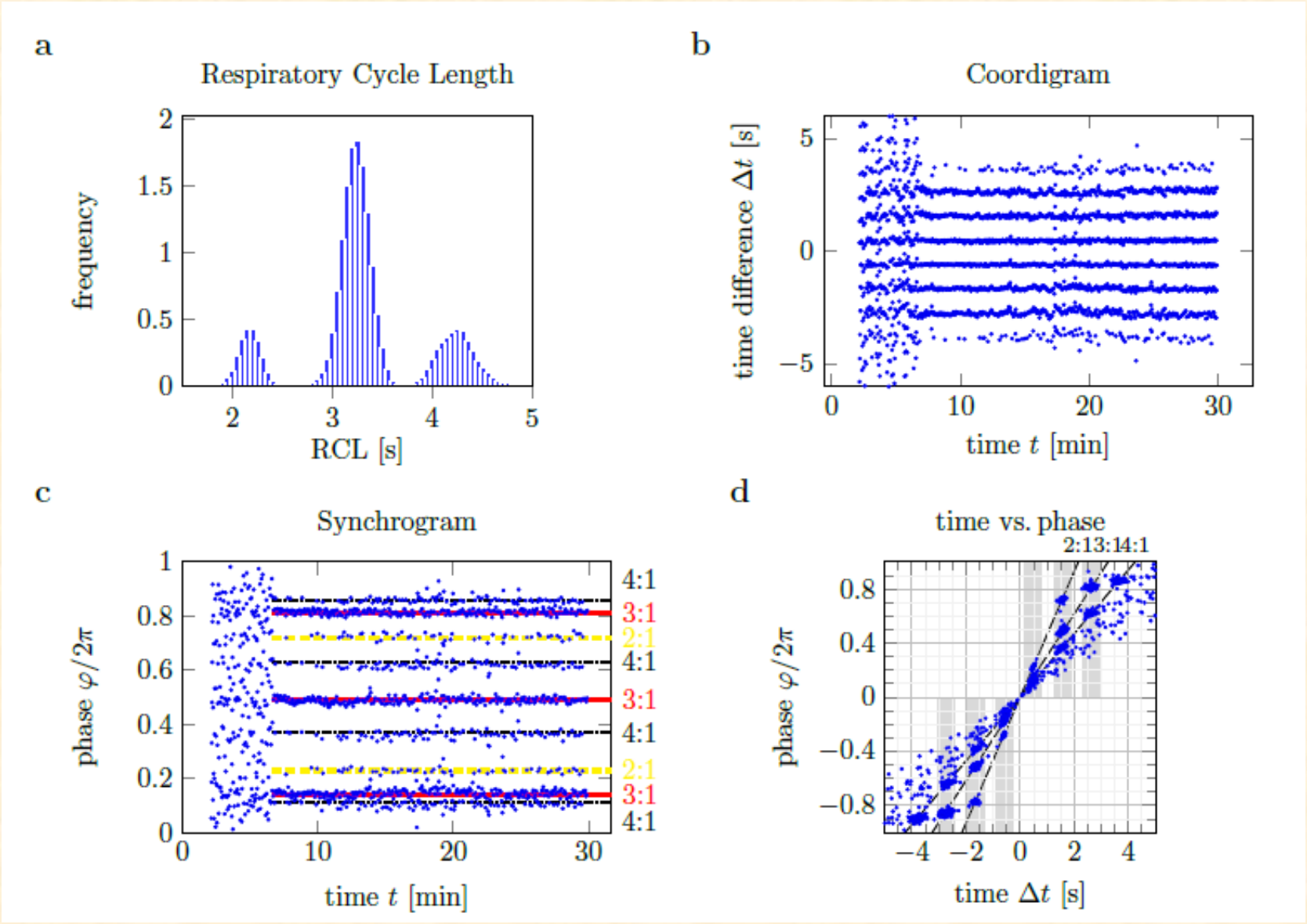
Riedl et al. 2014

Coordigram: A generalization of the RI plot





Beispiel: KRK und falsche KRS



Kardiorespiratorische Koordination stabil auch bei Störungen

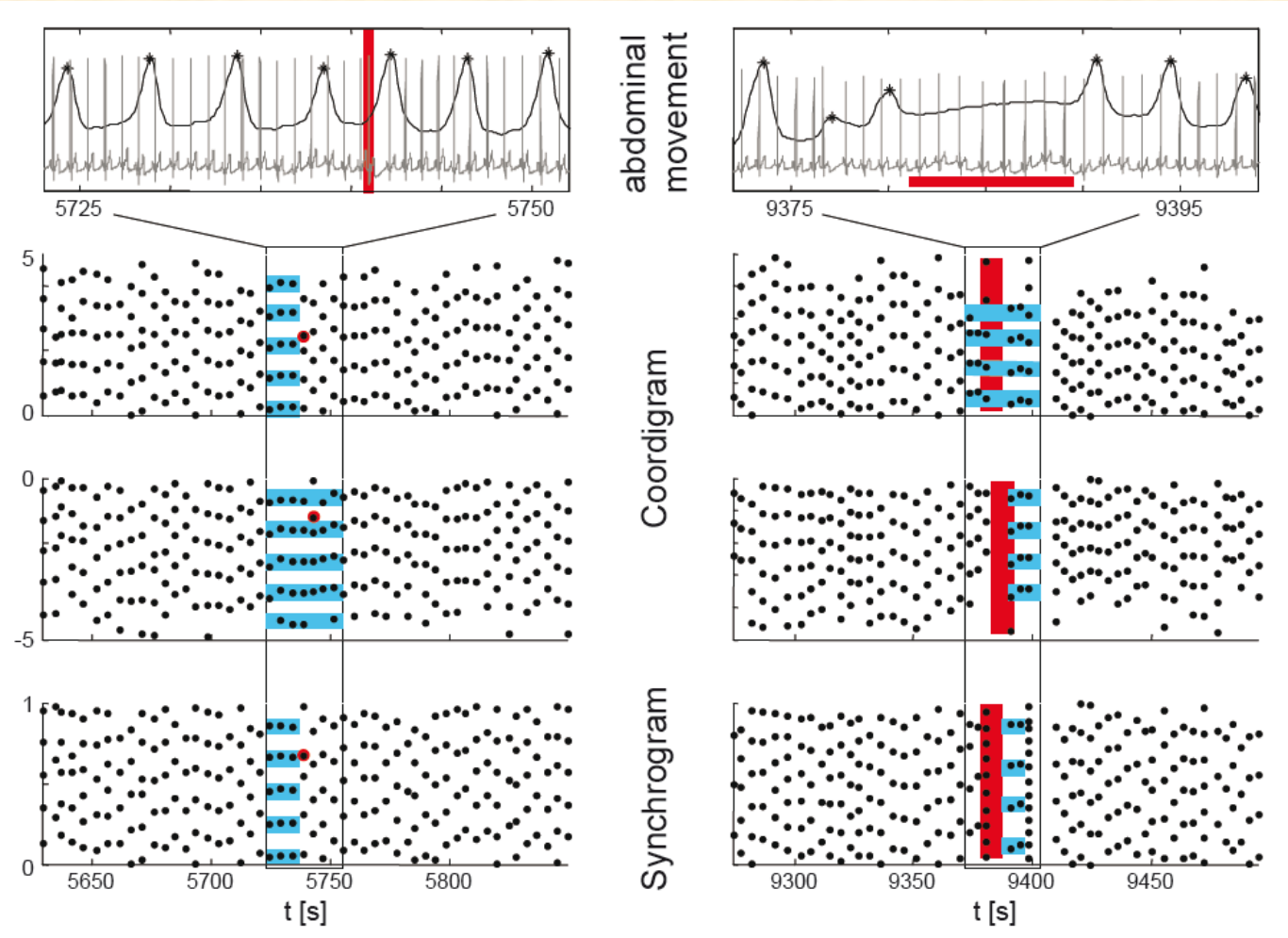
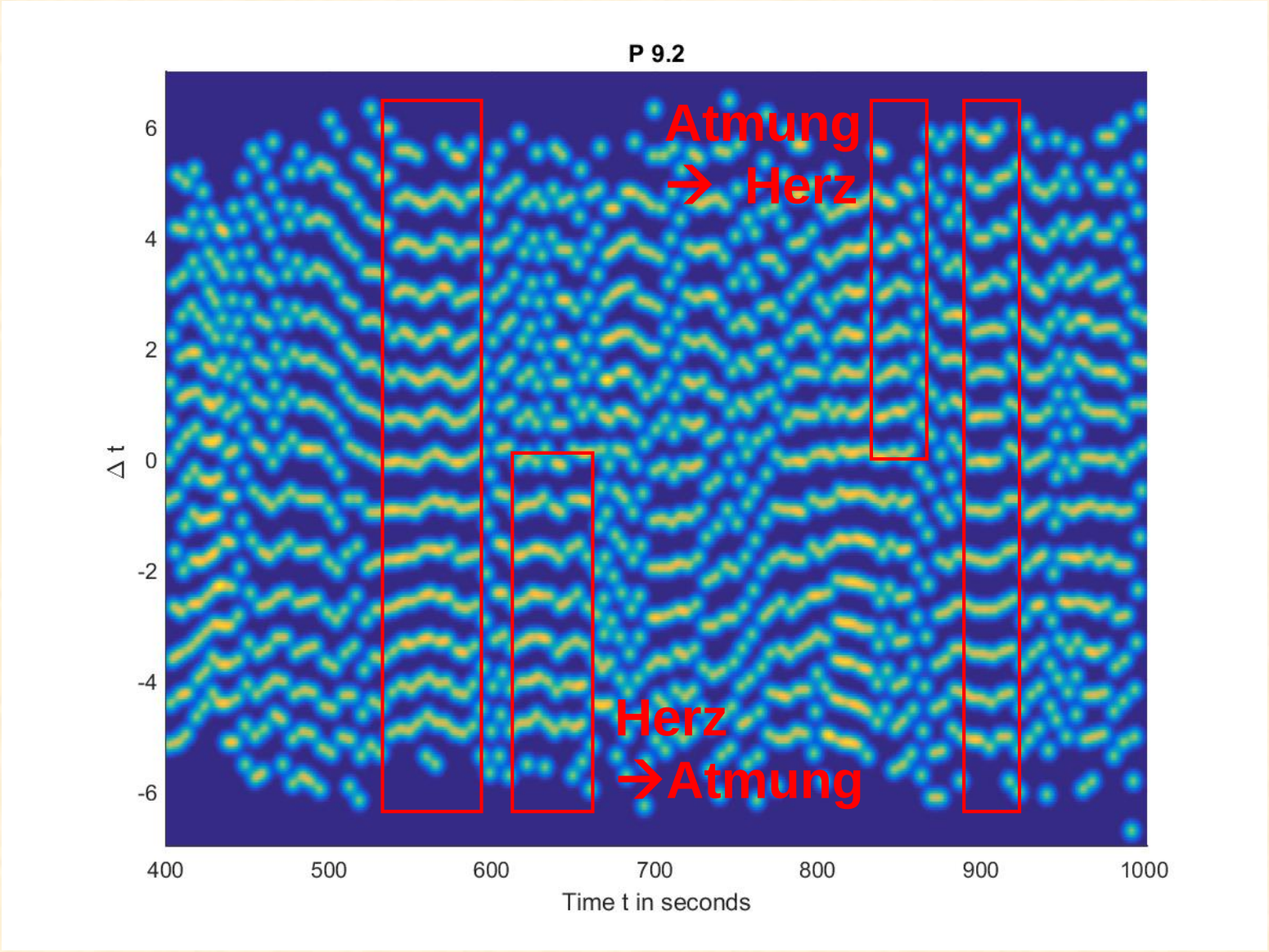


Figure : Red - ectopic heart beat (left column) and central apnea (right column); Blue - coordination before and after the disturbances

Kopplungsrichtung: Kardiorespiratorische Koordination



Kardiorespiratorische Koordination

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PLOS | ONE

Cardio-Respiratory Coordination Increases during Sleep Apnea

Maik Riedl[1], Andreas Müller[1], Jan F. Kraemer[1], Thomas Penzel[2], Juergen Kurths[1,3], Niels Wessel[1]*

1 Cardiovascular Physics, Department of Physics, Humboldt-Universität zu Berlin, Berlin, Germany, 2 Department for Cardiology, Sleep Medicine Centre, Charité Universitätsmedizin Berlin, Berlin, Germany, 3 Research Domain on Transdisciplinary Concepts and Methods, Potsdam Institute for Climate Impact Research, Potsdam, Germany

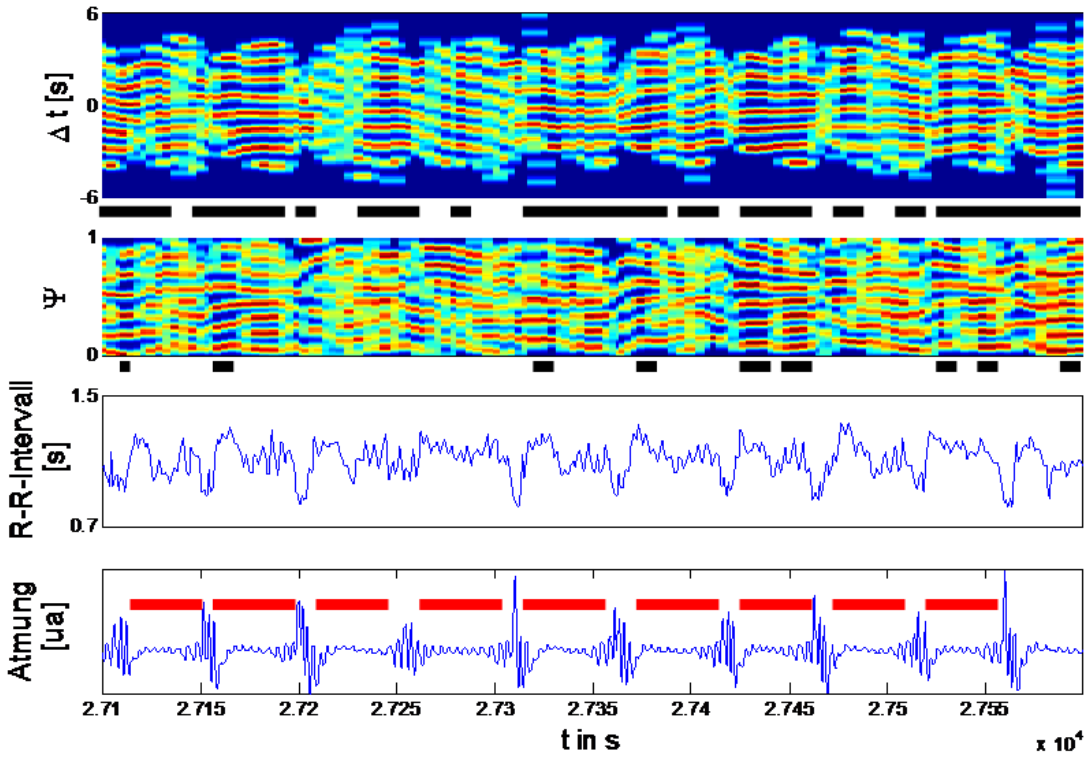
- Nocturnal measurements of 27 males suffering from obstructive sleep apneas (in total 10814 obstructive apneas and hypopneas)
- The tests show a higher number of occurrences of detected CRC when compared to normal breaths:

  (i) during AHE ($p<10^{-51}$), and,

  (ii) after AHE ($p<10^{-15}$).

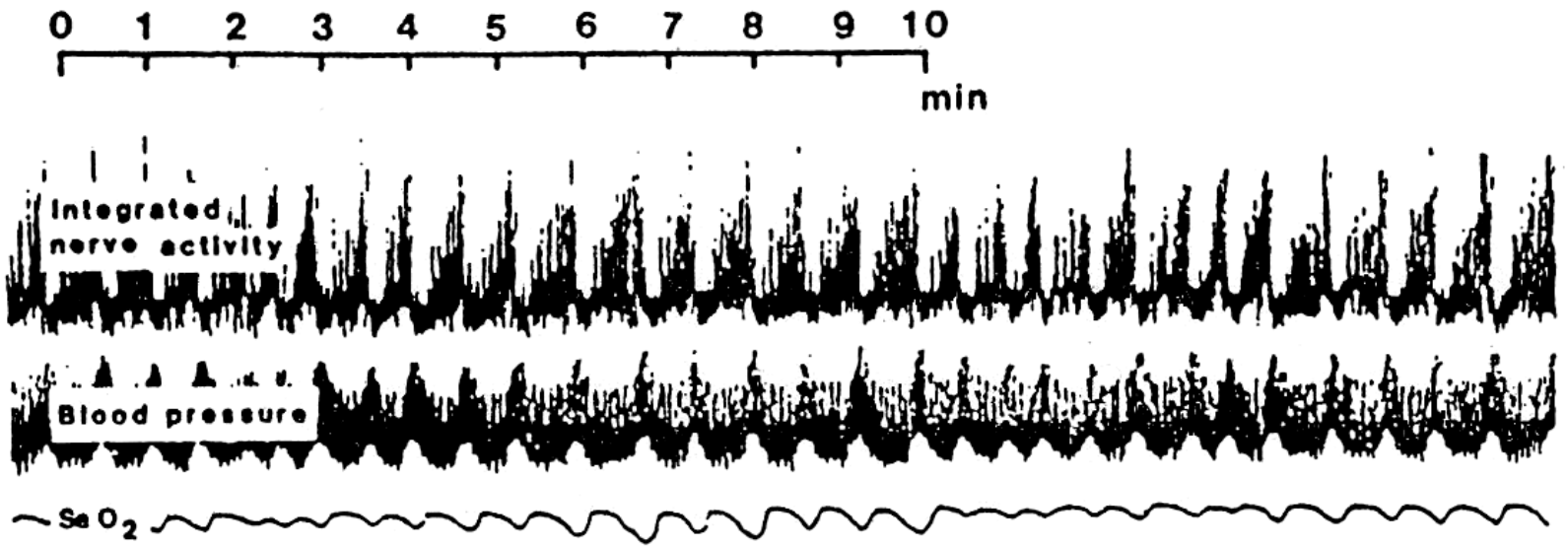
Beispiel: KRK und KRS während Apnoen

Koordination vs. Synchronisation



- **Koordigramm**, schwarze Balken: Koordination
- **Synchrogramm**, schwarze Balken: Phasensynchronisation
- rote Balken: Apnoen

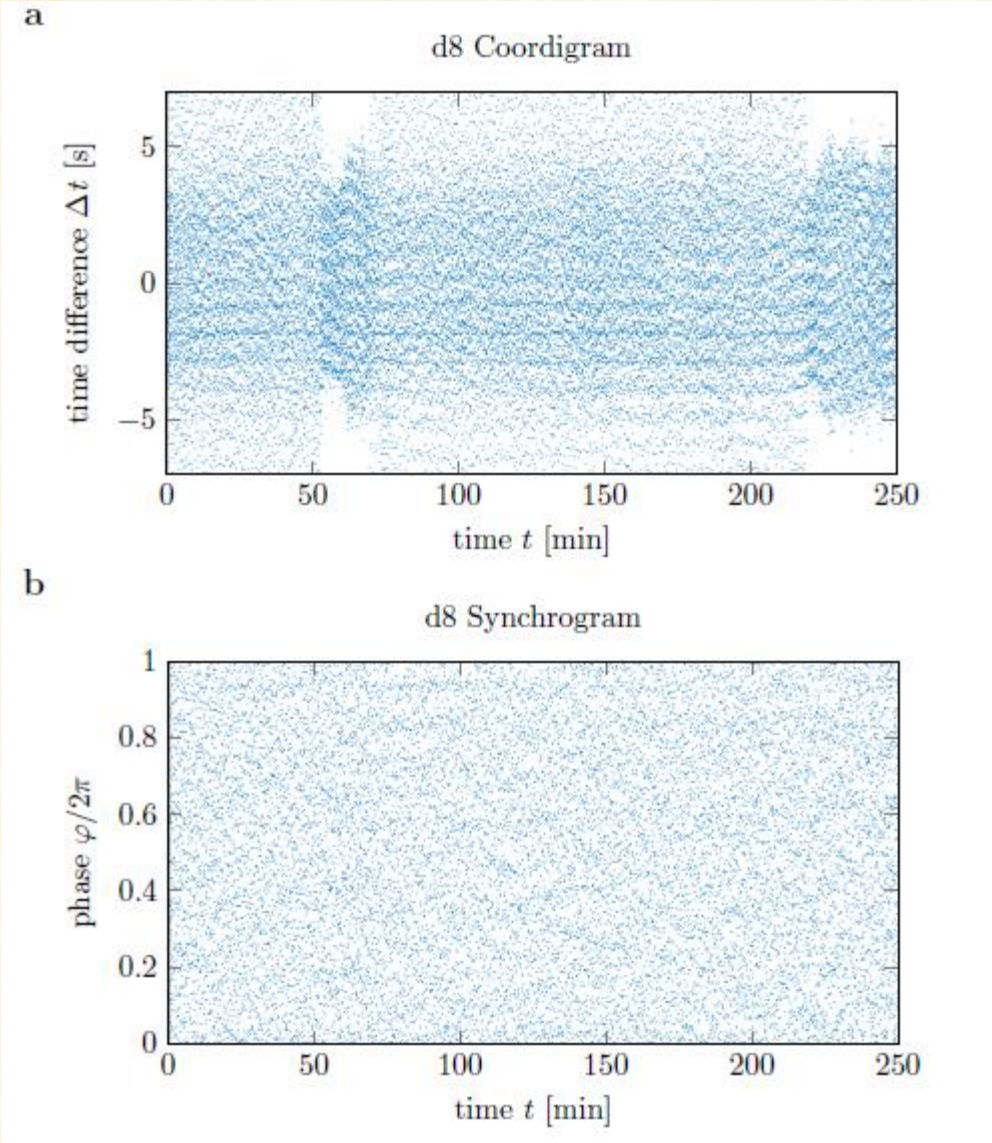
Sympathetic activity during sleep apnoea



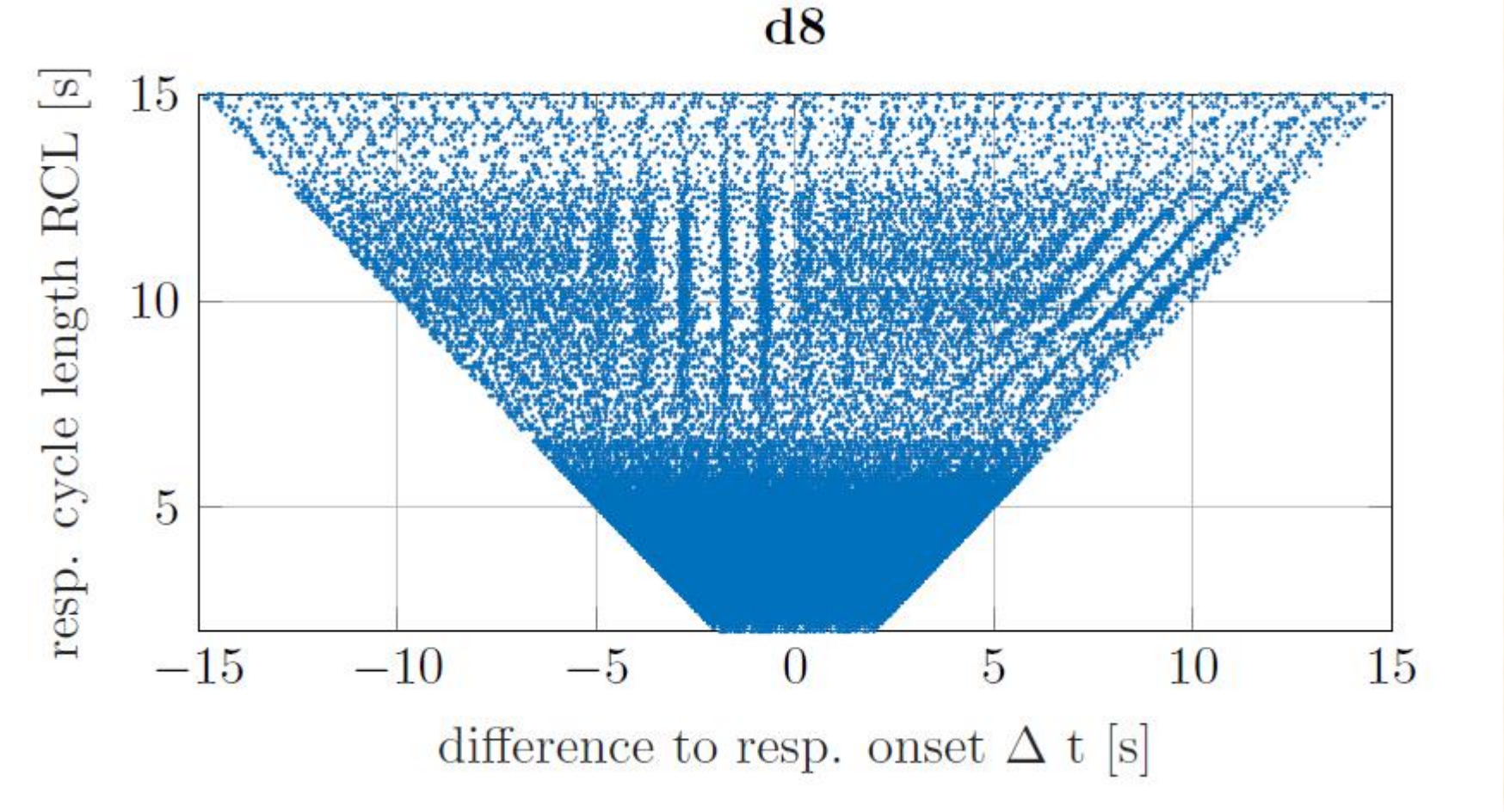
A representative recording of apneic events during sleep in an OSAS patient. Note repetitive increases in integrated nerve activity and shifts in blood pressure in association with apnea (indicated by decrease in oxygen saturation). The time scale is indicated at the top

Somers et al.
NEJM 1993

Beispiel: d8 aus Riedl et al. 2014



Beispiel: d8 aus Riedl et al. 2014



Sympatho-respiratory Coupling (Dick et al.)

Prog Brain Res. 2014 ; 209: 191–205.

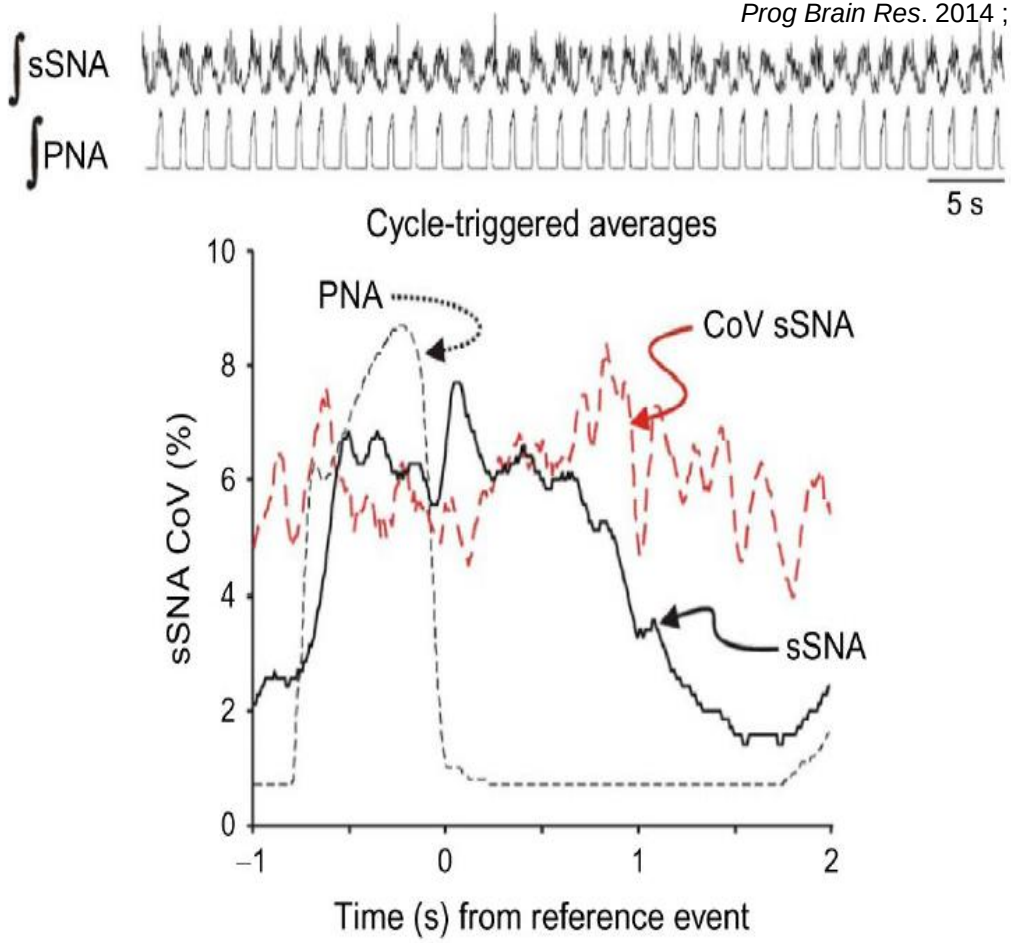
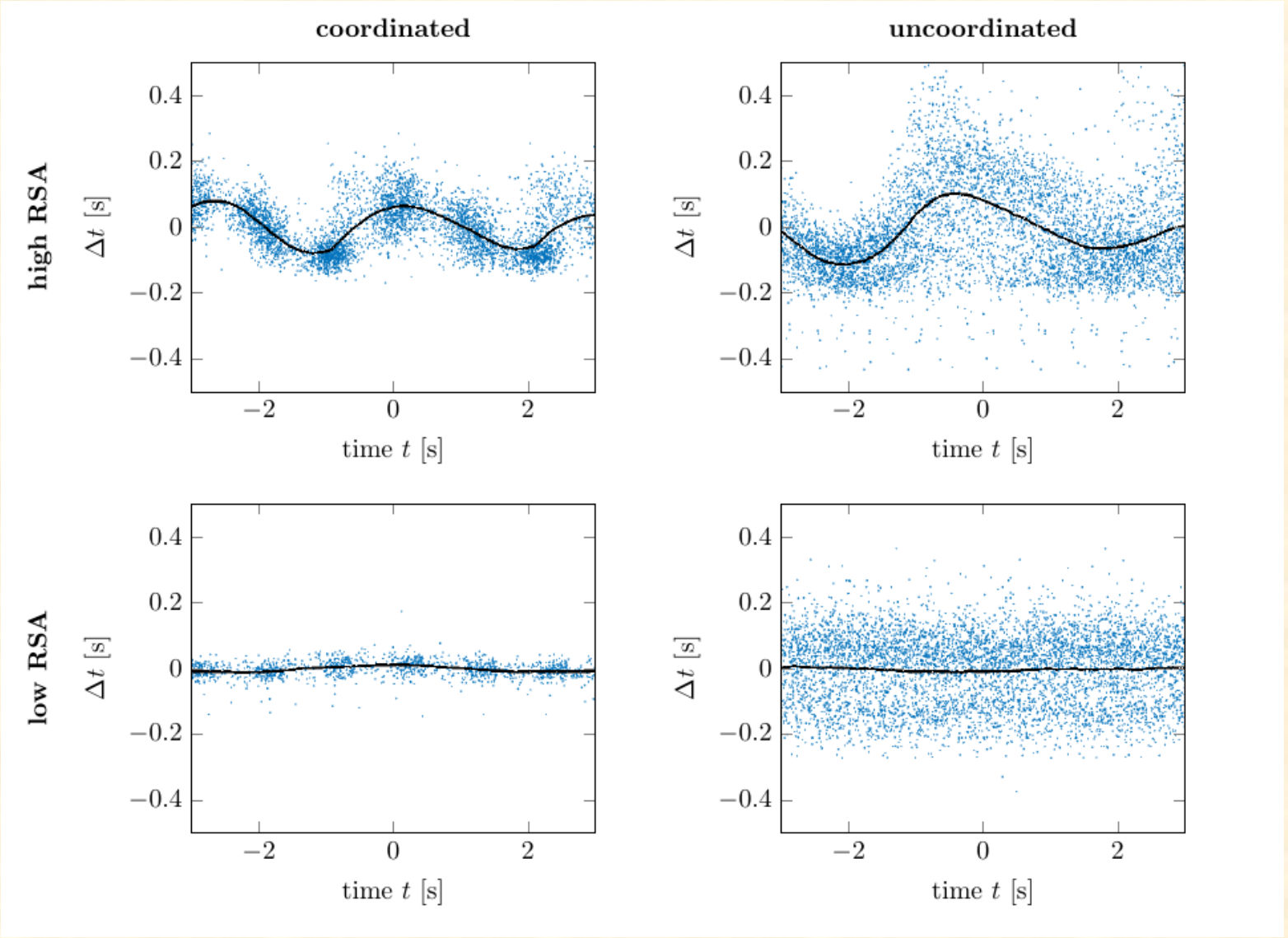


FIGURE 2.

Sympatho-respiratory coupling is high following chronic intermittent hypoxia. The bursts of

Prog Brain Res. 2014 ; 209: 191–205.

Koordination vs. RSA



Maik Riedl, Jan F. Krämer, Harald Krause,

CHARITÉ **Thomas Penzel, Niels Wessel**

Salvador Dali **Sleep** 1937