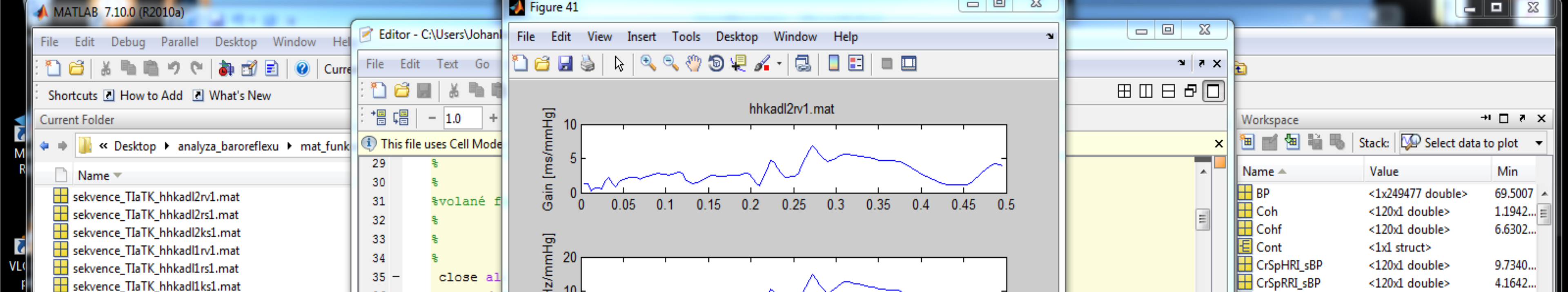
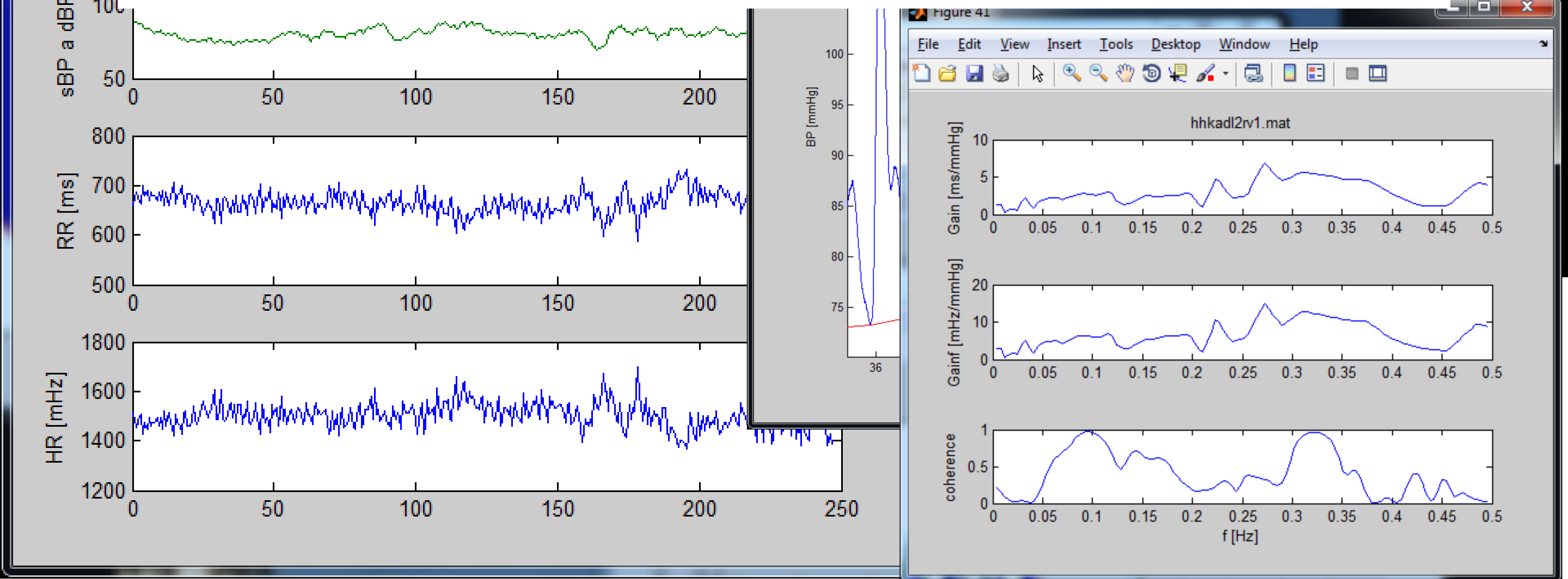


Variability of cardiovascular signals



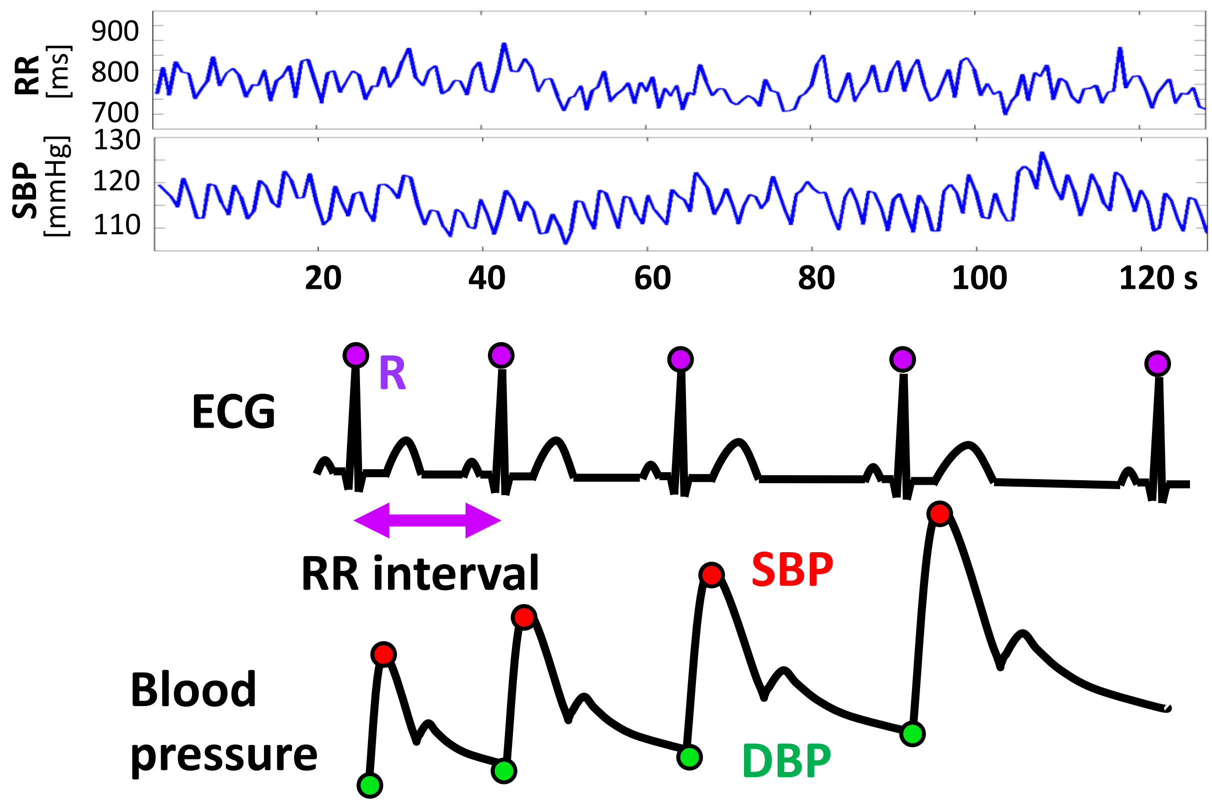
Cardiovascular signal variability

- **Cardiovascular signals (C-V signals)**
  - Easy to measure
    - EGG: RR intervals, heart rate - HR (1/RR)
    - Blood pressure: systolic (SBP), diastolic (DBP), mean (MAP), pulse pressure (PP)
  - Difficult to measure directly (bioimpedance method), can be evaluated indirectly from blood pressure wave (Windkessel model)
    - Stroke volume (SV), cardiac output (CO), total peripheral resistance (TPR)
  - Very difficult to measure directly (invasive measurement)
    - Blood flow and pressure in various places of vessels

Signal: time series

Beat to beat (for example 5 minutes)

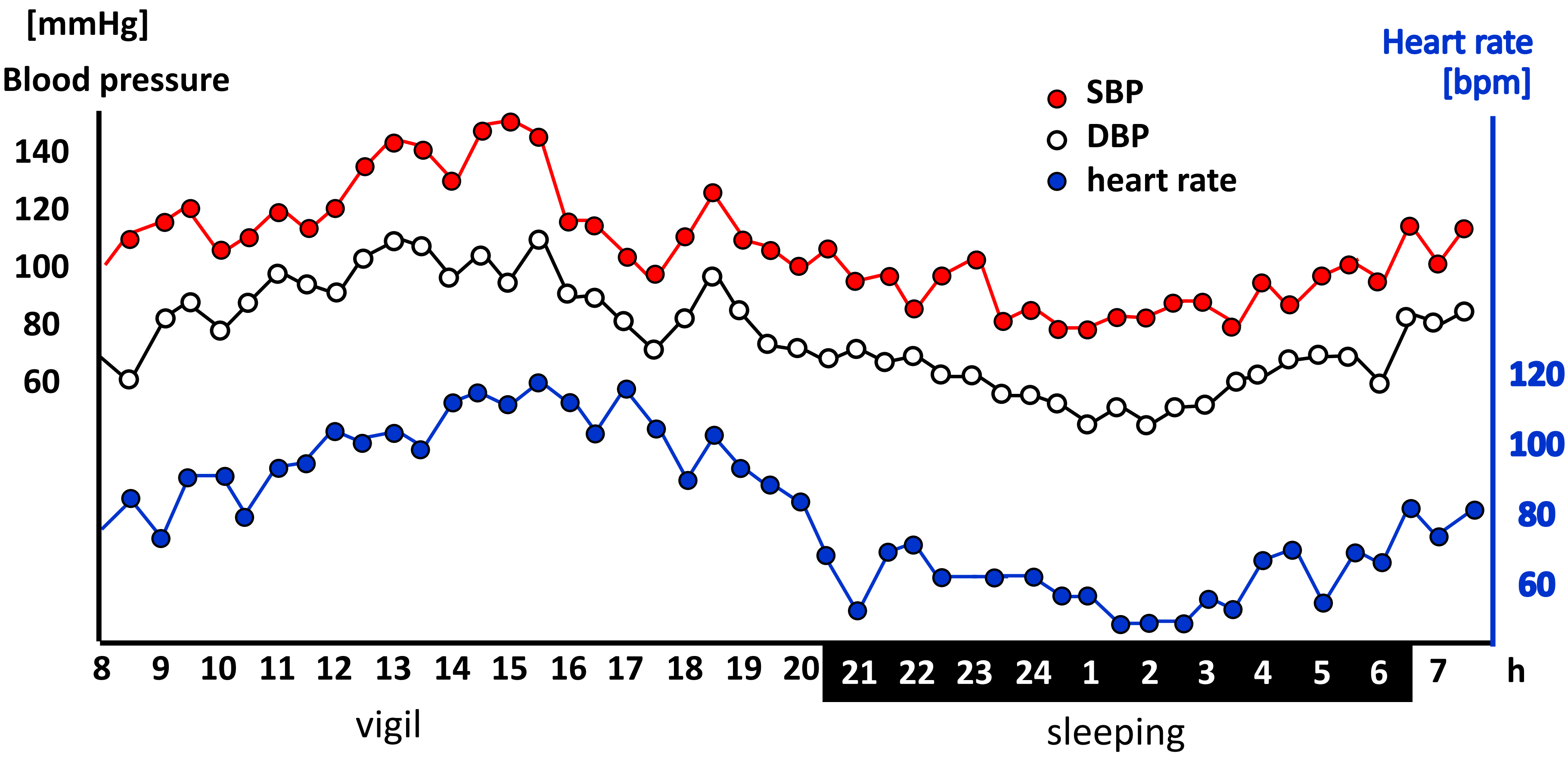
- RR interval: 805, 820, 815, 817, 822, 816,….. ms
- Hear rate: 70, 73, 68, 65, 67, 71,….. bpm
- Systolic blood pressure: 115, 117, 120, 116, 121, 119,….. mmHg



Signal: time series

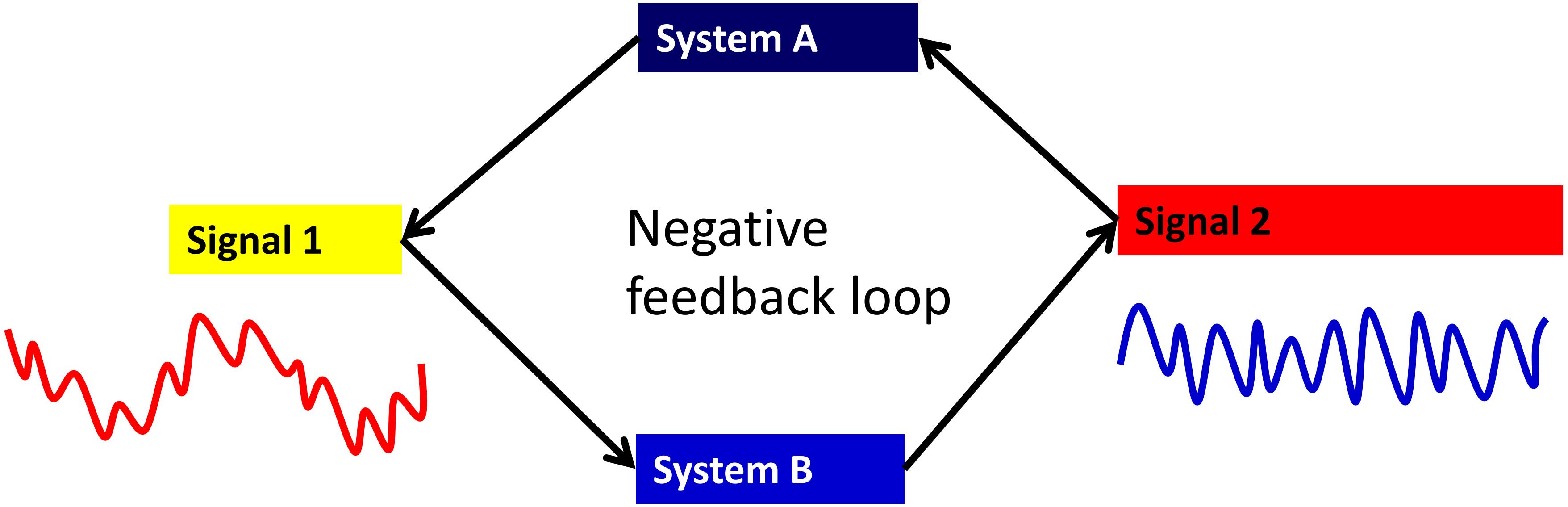
Every 15 minutes

- 24-hour blood pressure measurement, ECG Holter



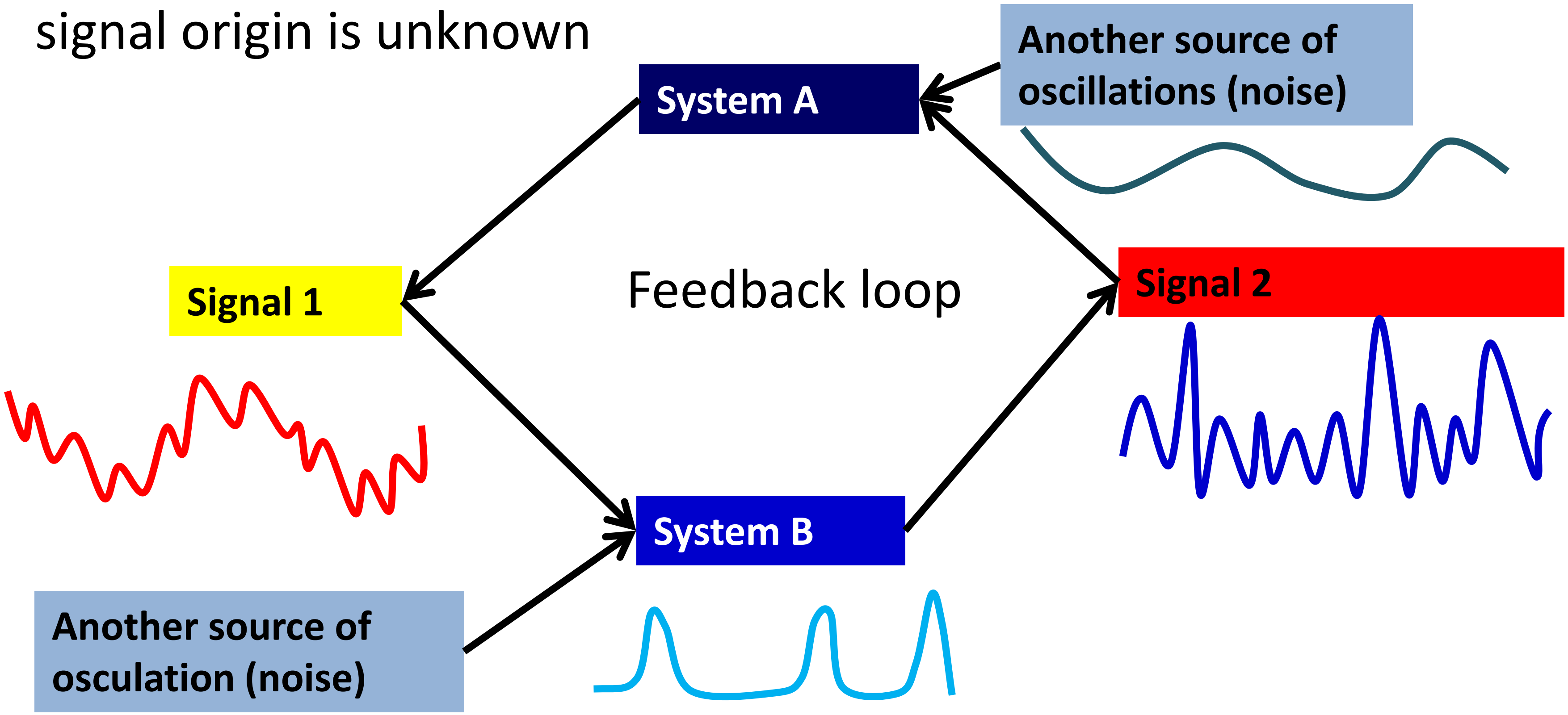
Variability of cardiovascular signals

- Cardiovascular system is regulated by negative feedback
- Negative feedback forms oscillations in the signals – the longer feedback loop, the slower oscillations
- Analysis of oscillations in the C-V signals contains information about regulatory mechanism

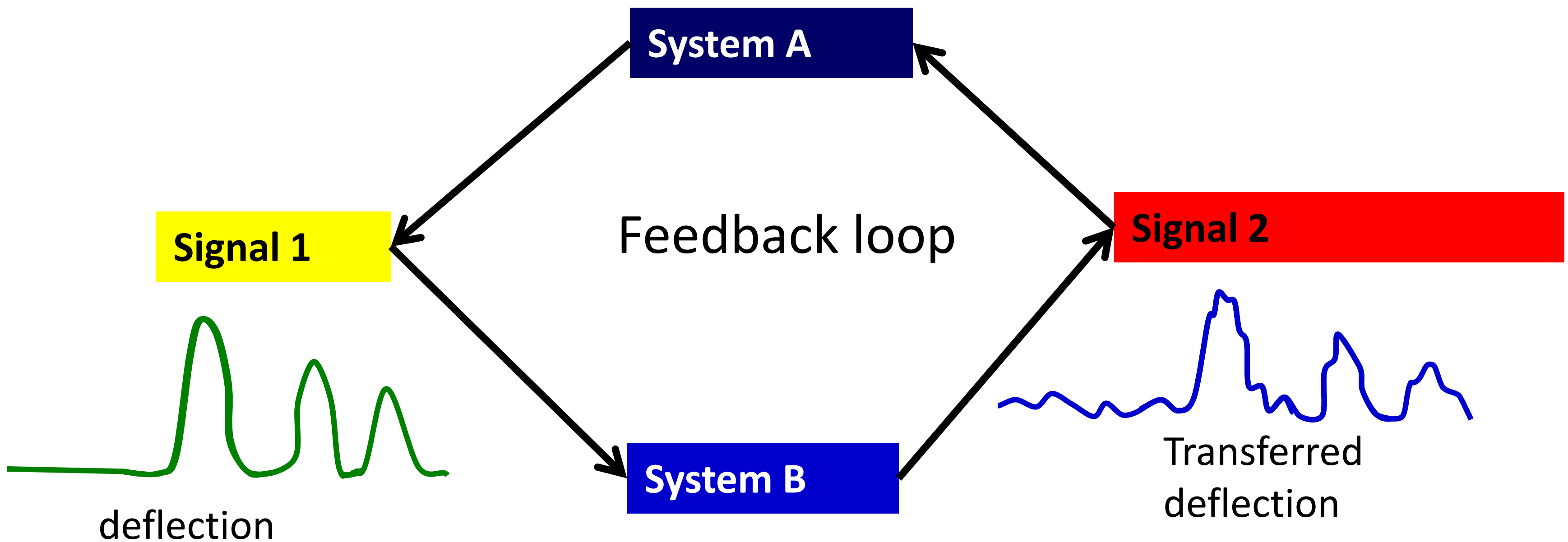


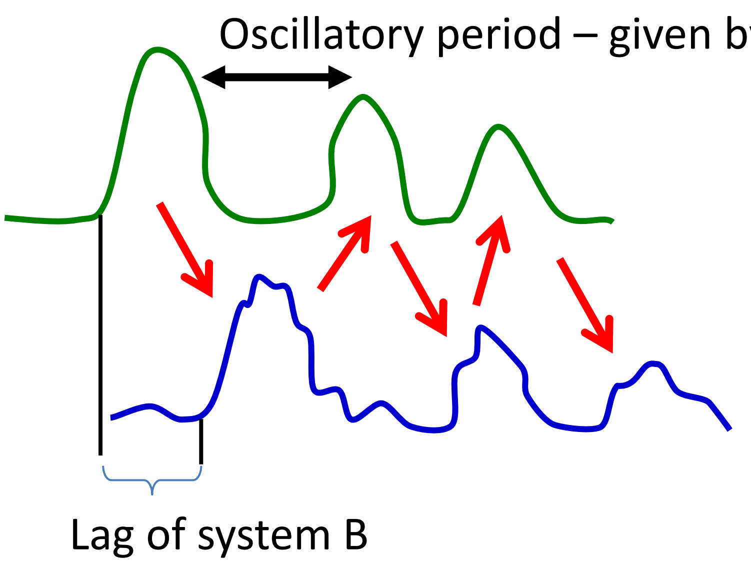
Brief introduction in theory of systems

- Biological systems are complex – more than one input, system setting and outputs can change
- System transforms input signal into output signal – analysis of input/output signals helps to understand the system
- noise: another input signal – we do not care about signal and/or signal origin is unknown



Source of oscillations

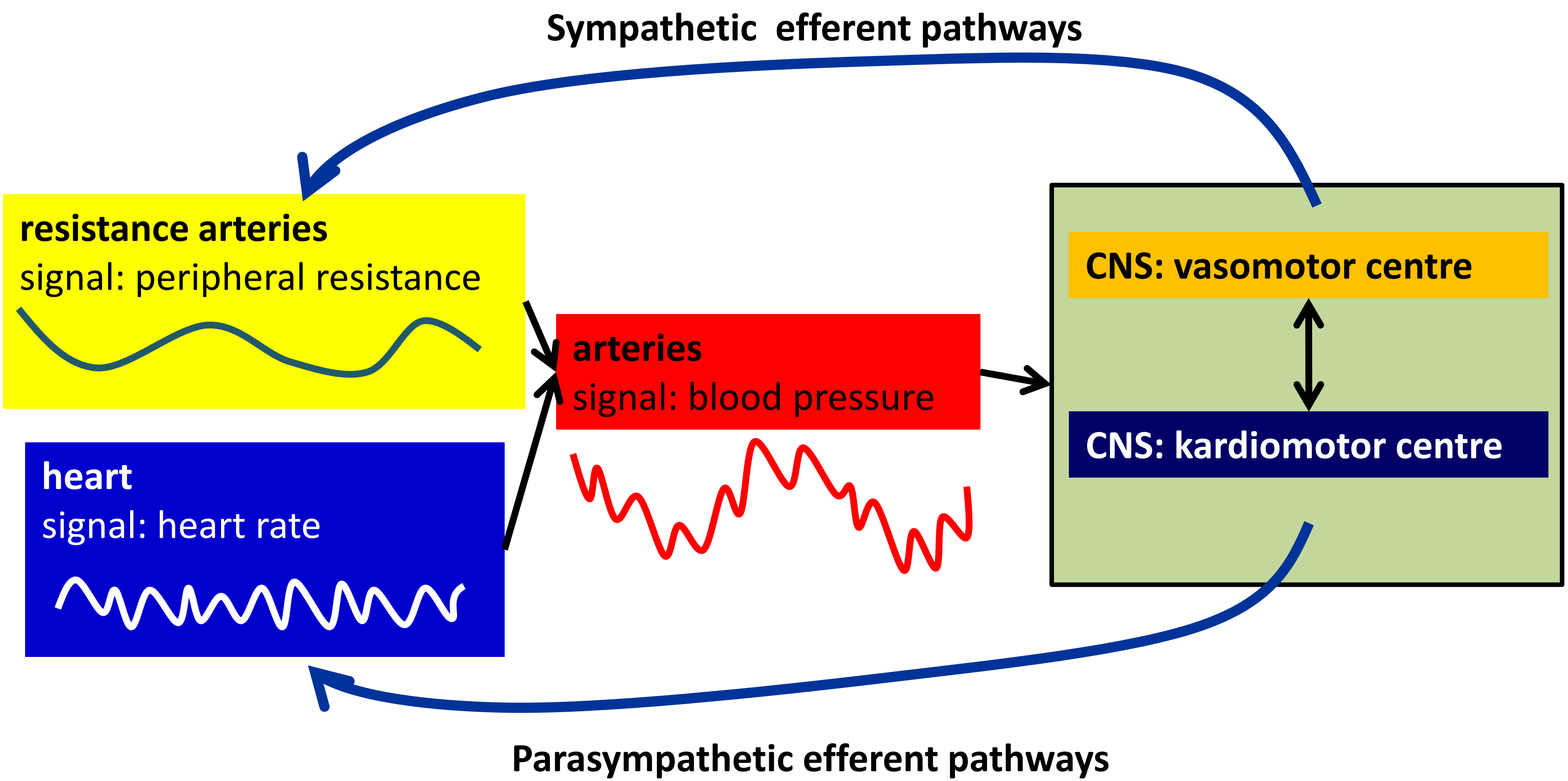




Frequency of oscillation = 1/period

→ **frequency (spectral) analysis** provides information about system

Feedback loop - baroreflex



Methods of the variability assessment

methods

Time-domain methods

Statistic methods

Geometric methods

Frequency-domain methods

Non-linear methods

(index of ireversibility, entropy based indices, symbolic analysis…)

Statistic methods

(Variations on Standard Deviation)

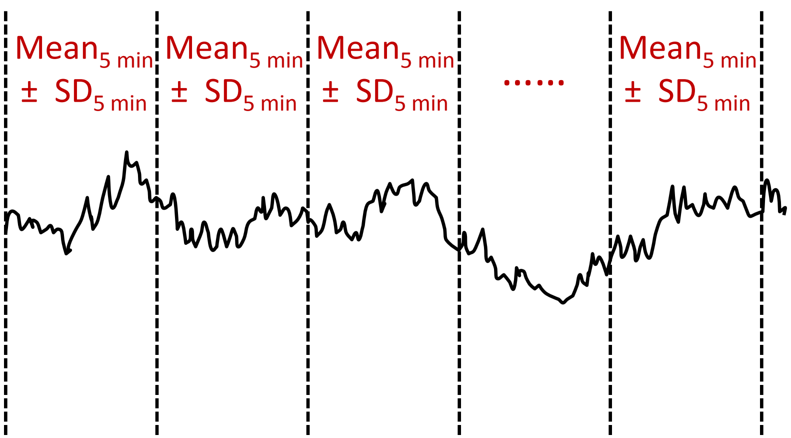
24-hour record of RR intervals

$Mean_{24\text{-}h} \pm SD_{24\text{-}h}$

$SD_{24\text{-}h}$ counted from all RR-intervals in 24 hours — **SDRR**

$SD_{24\text{-}h}$ counted from all normal RR-intervals in 24 hours — **SDNN**

24-hour record of RR intervals divided into 5-min segments ($Mean_{5\ min} \pm SD_{5\ min}$)



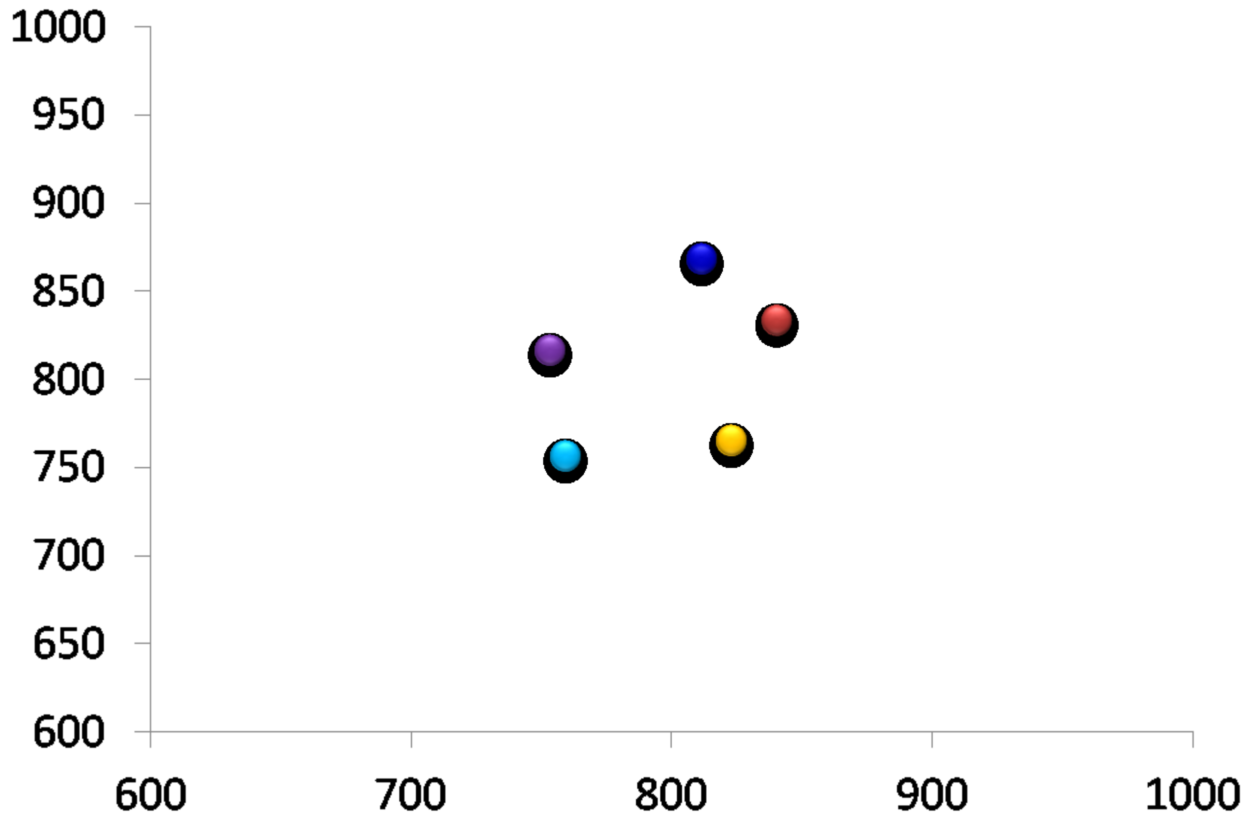
SD counted from all $Mean_{5\ min}$ — **SDANN**

SD counted from all $SD_{5\ min}$ — **SDANNIDX**

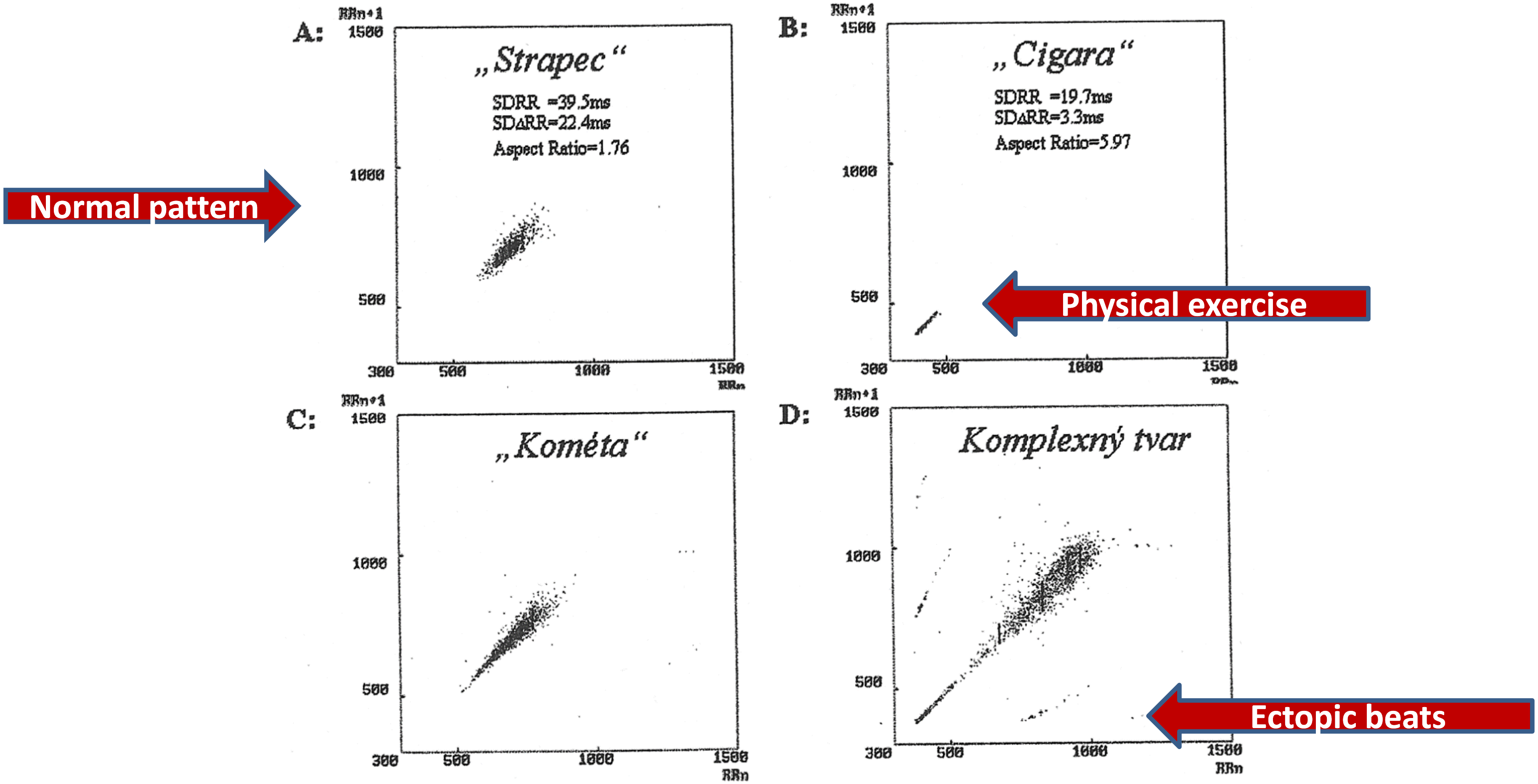
Geometric methods

RR (ms)

840 x
828 y x
760 y x
756 y x
808 y x
856 y
768
780
808
756
708
728
756
732
708



Geometric methods

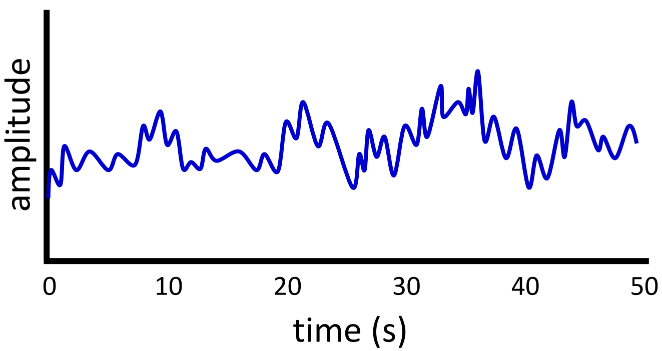


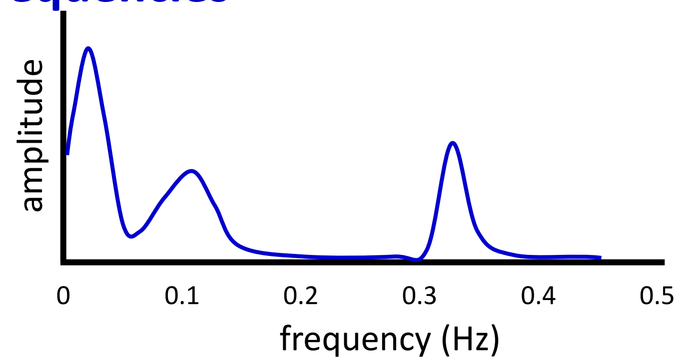
Frequency domain methods – spectral analysis

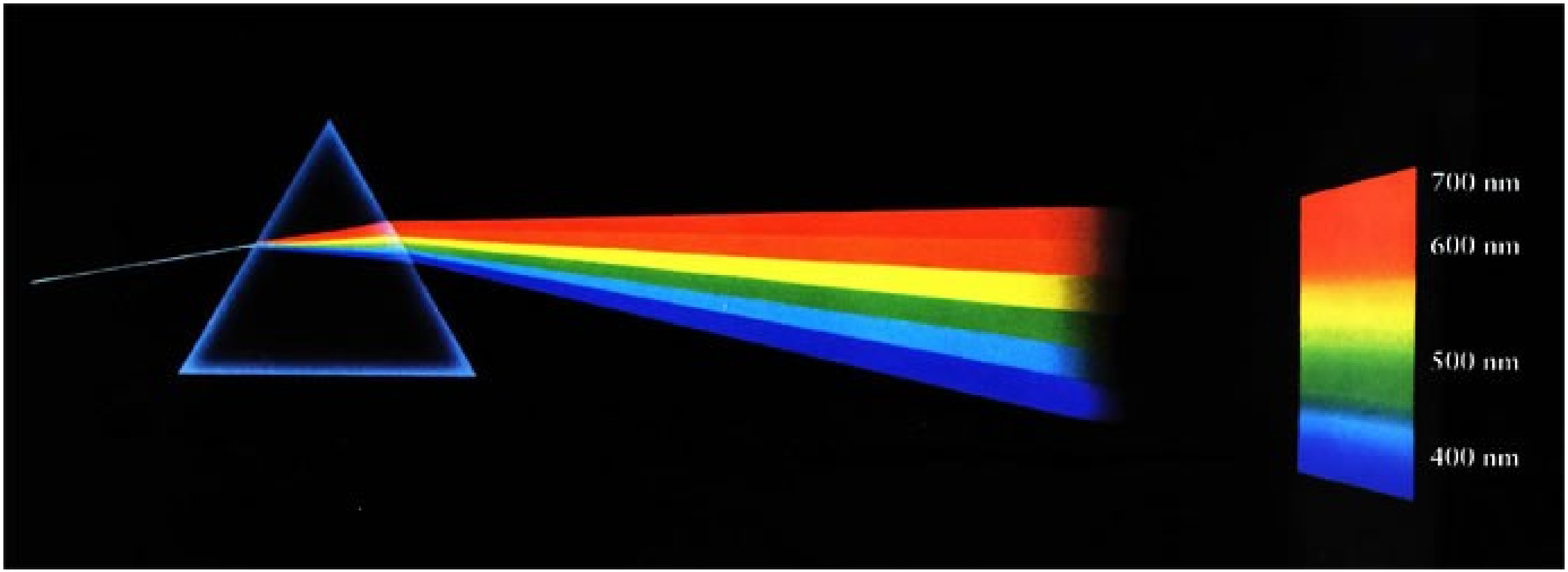
Time series
Signal in time domain

Spectrum
Signal in frequency domain

Signal is decomposed in individual frequencies





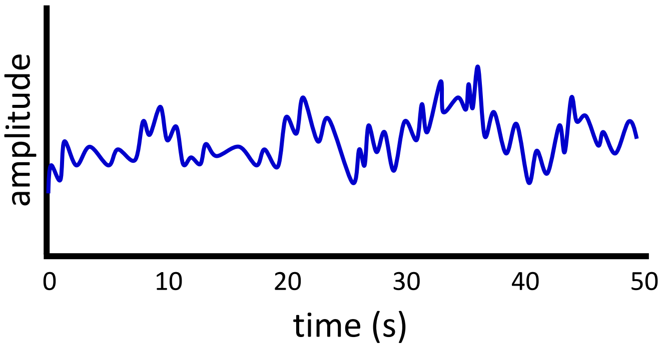


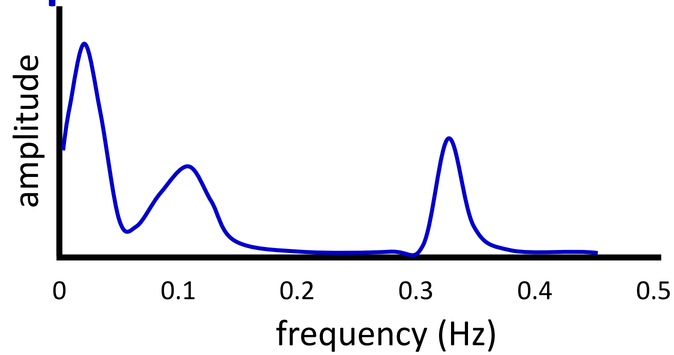
Frequency domain methods – spectral analysis

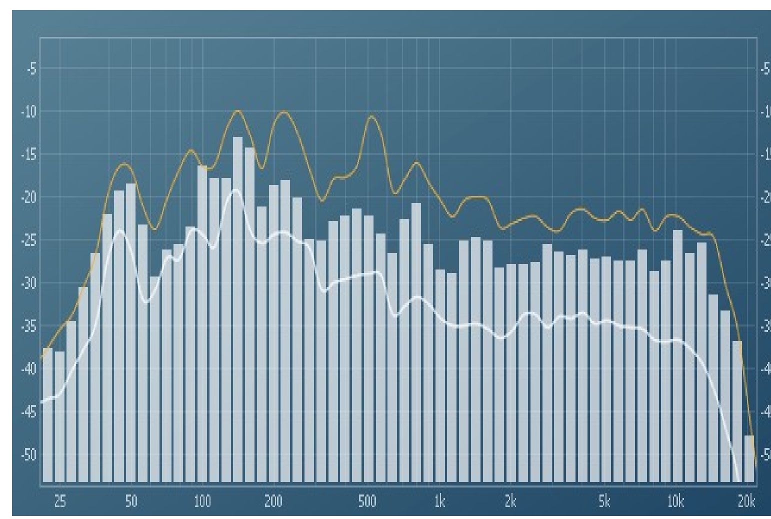
Time series
Signal in time domain

Spectrum
Signal in frequency domain

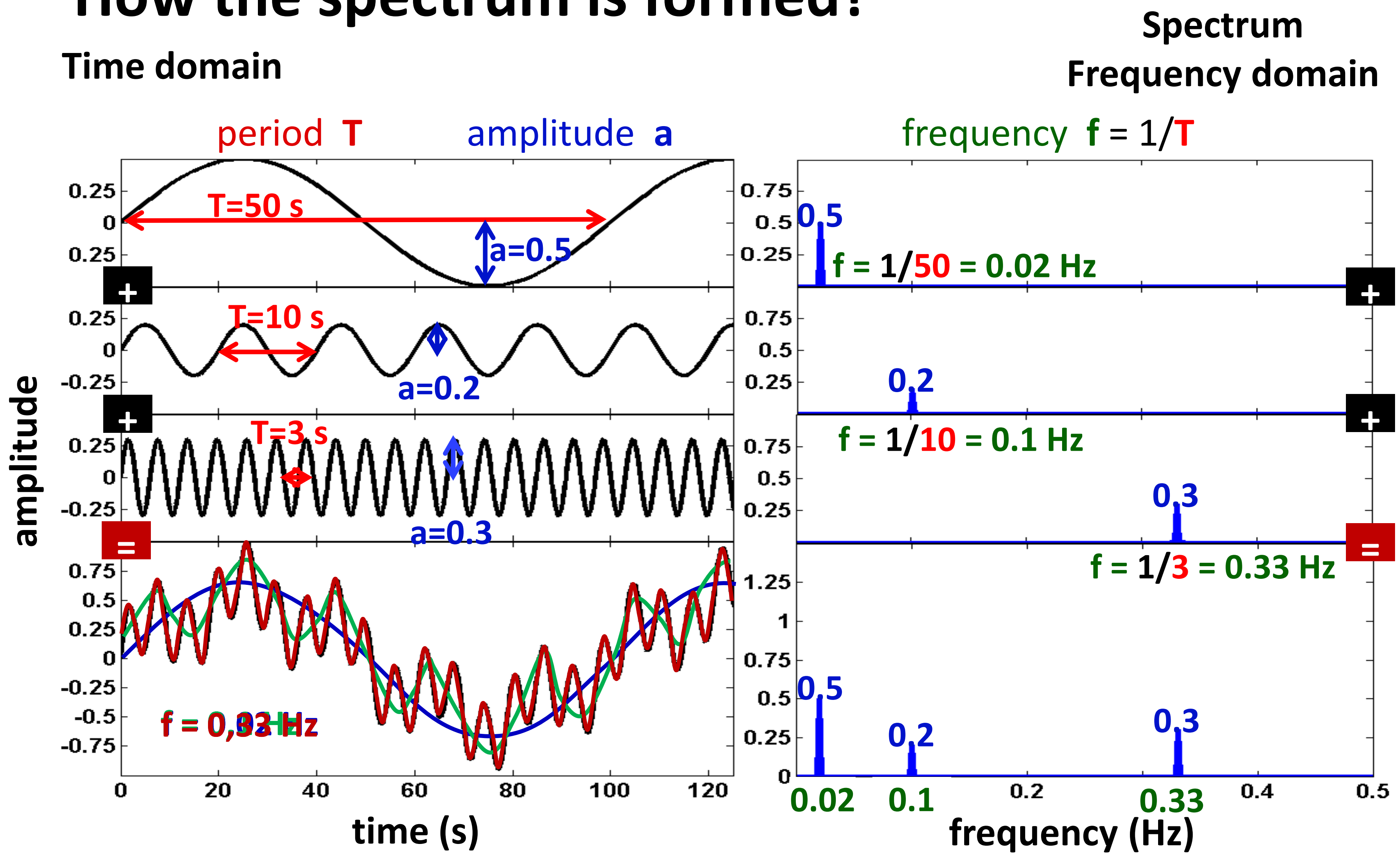
Signal is decomposed in individual frequencies





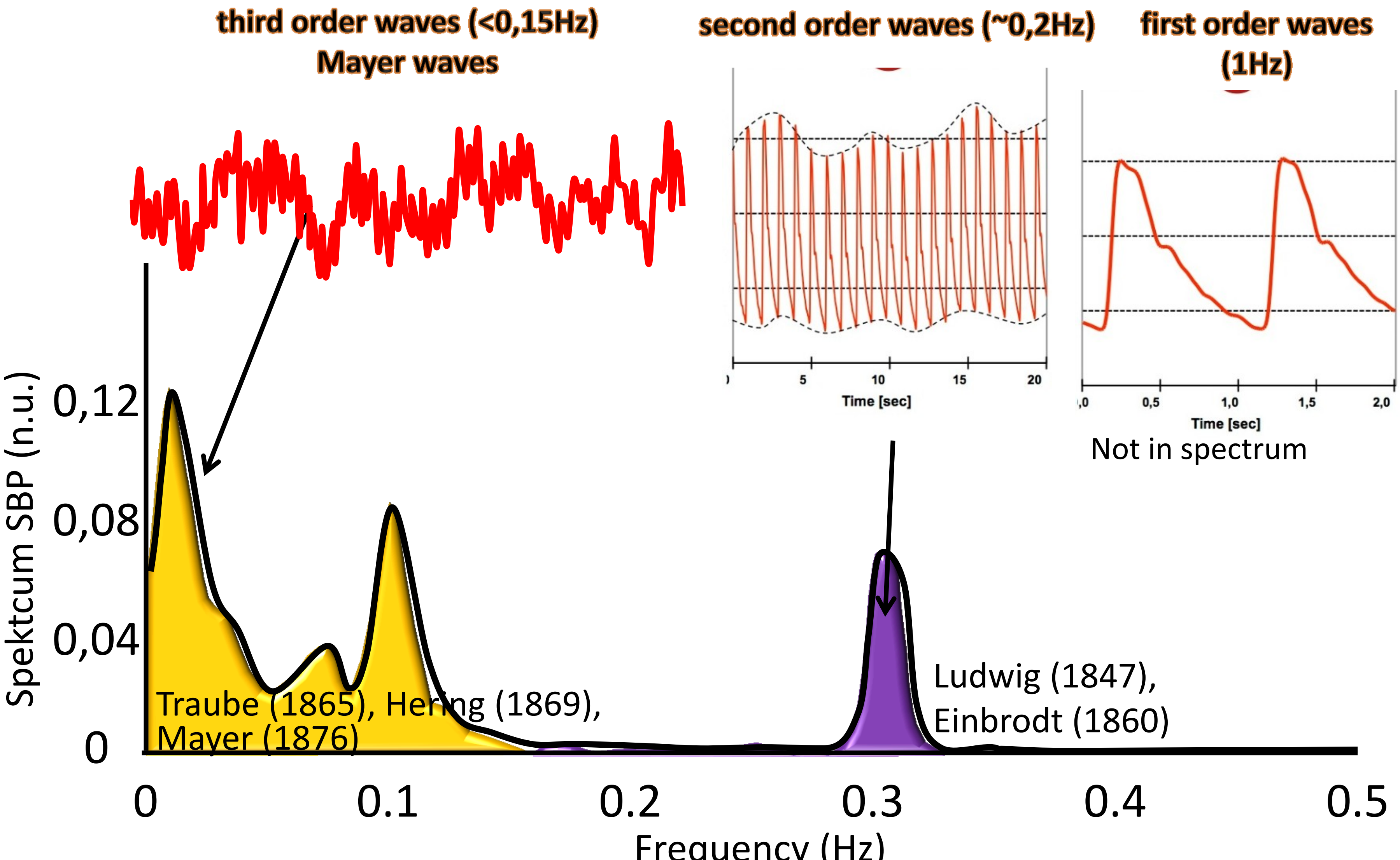


How the spectrum is formed?



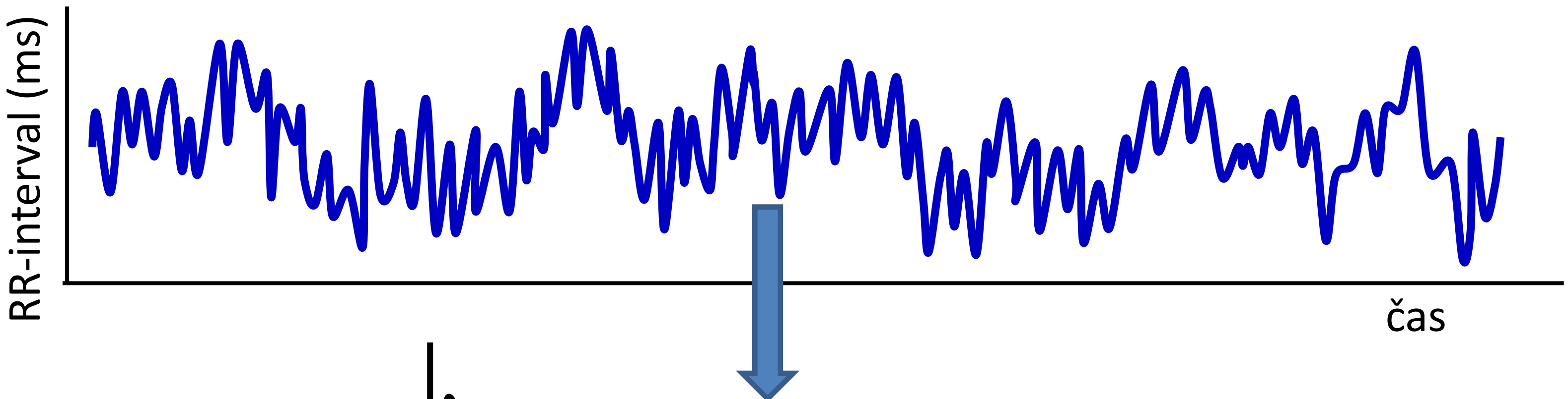
Blood pressure variability – spectrum of SBP

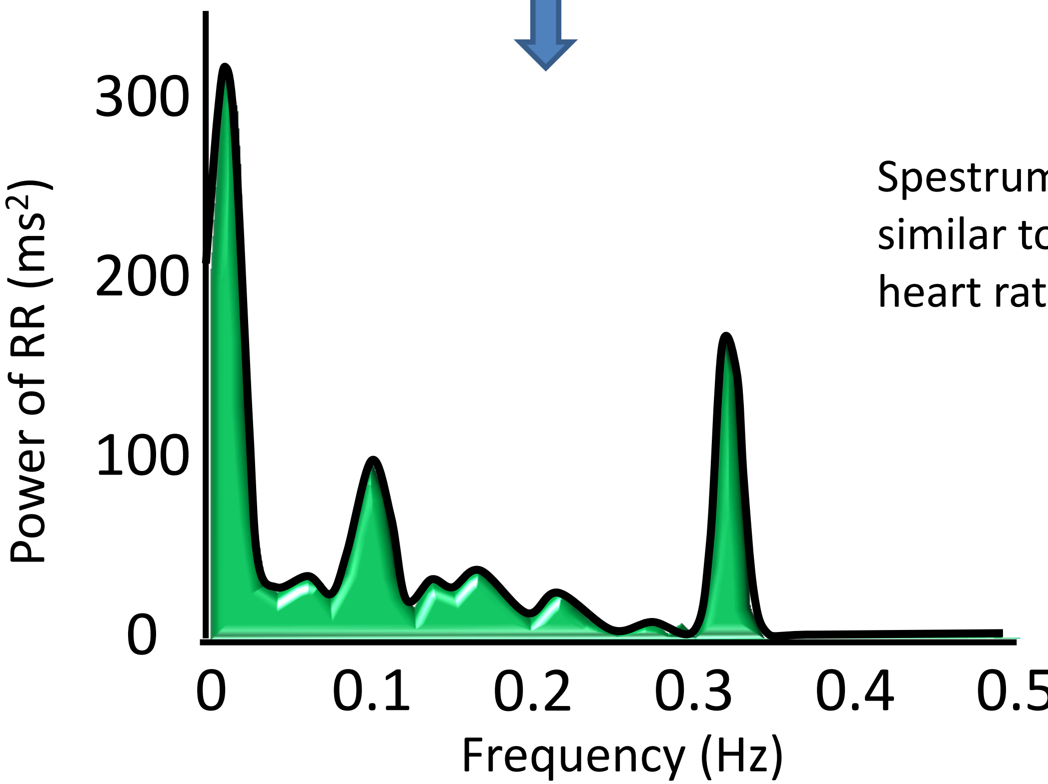
Signal: beat-to beat series of systolic blood pressure (5 minutes)



Heart rate variability (HRV)

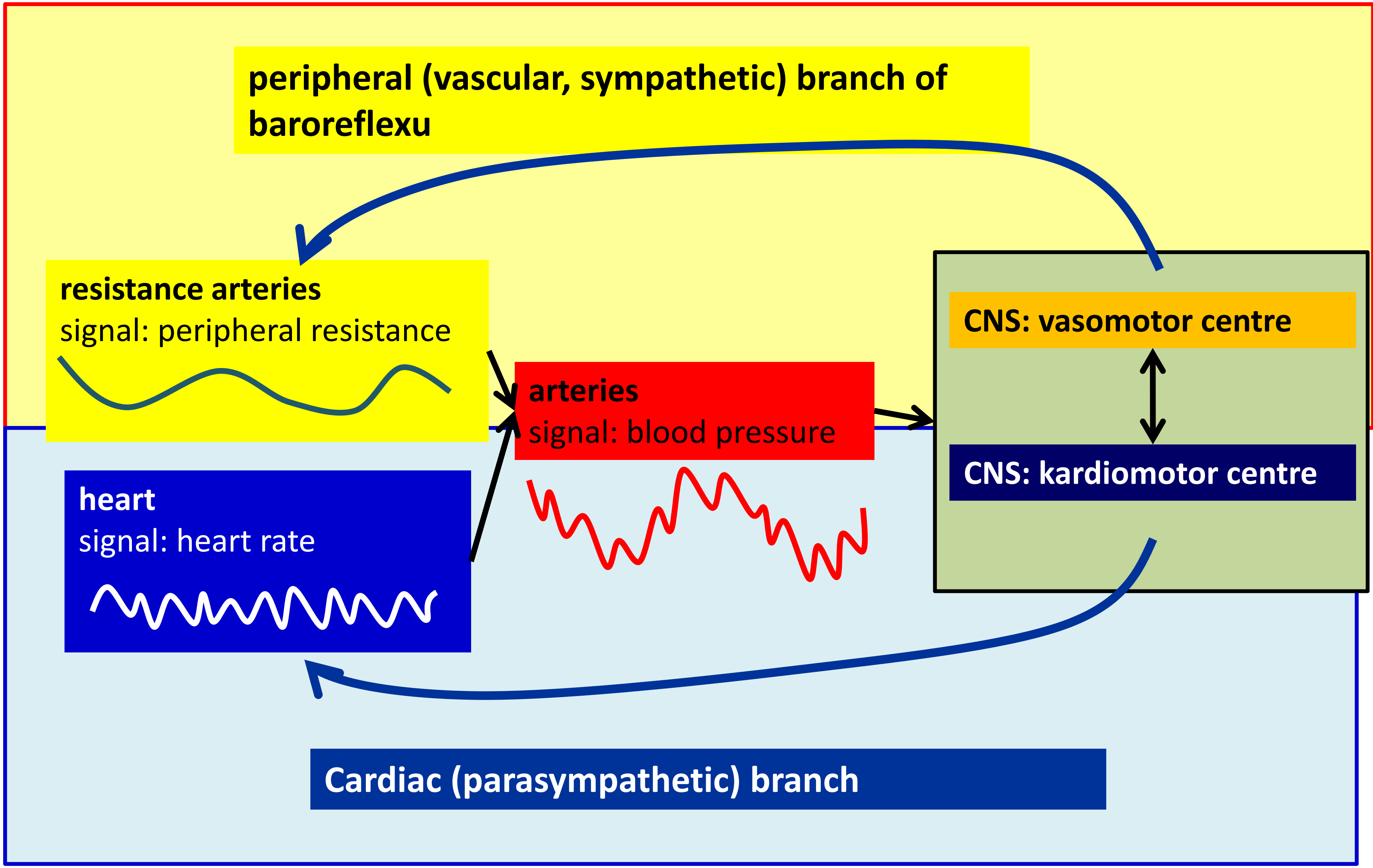
Signal: beat-to-beat RR-intervals (5 min)





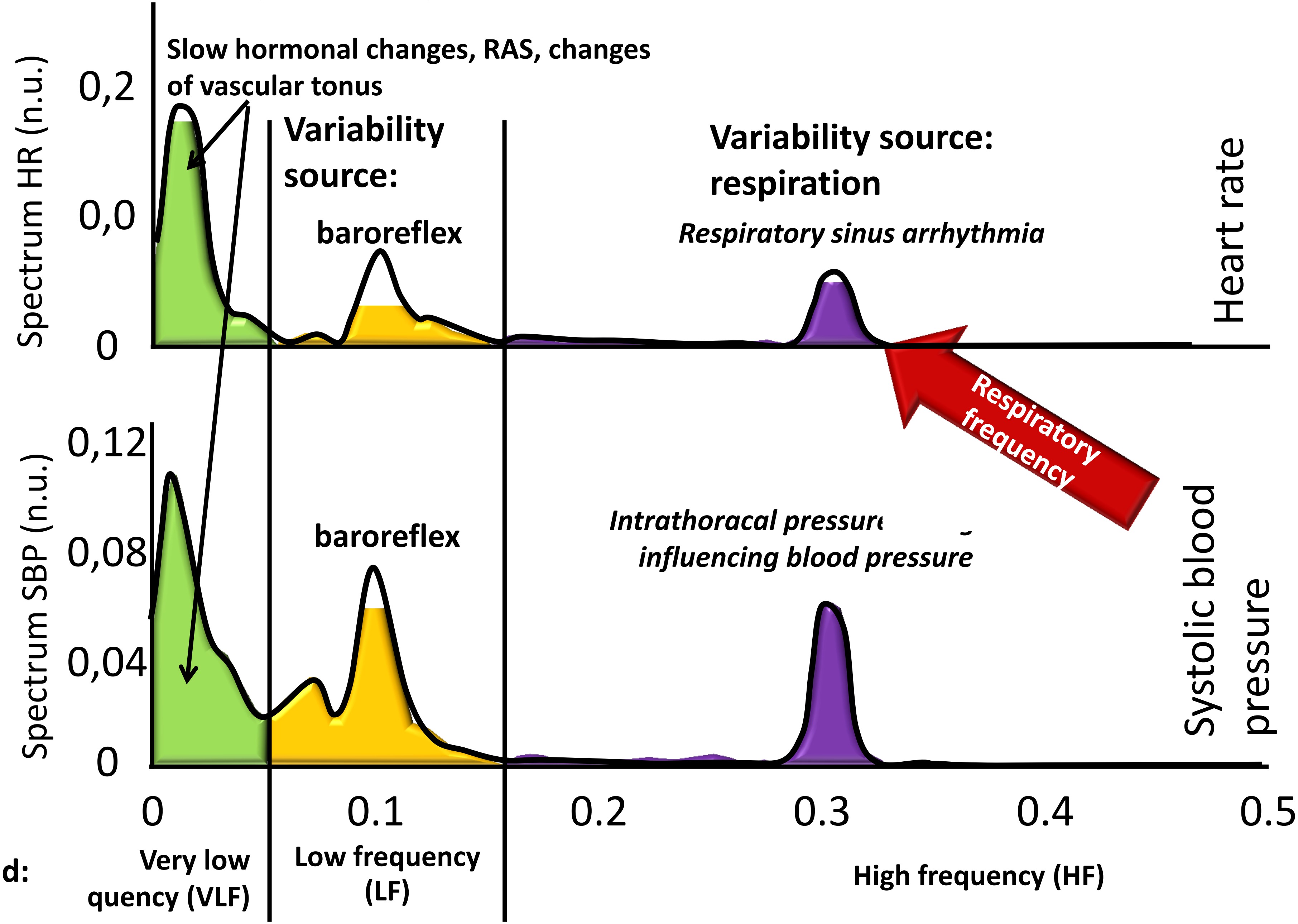
Spestrum of RR intervals is similar to the spectrum of heart rate

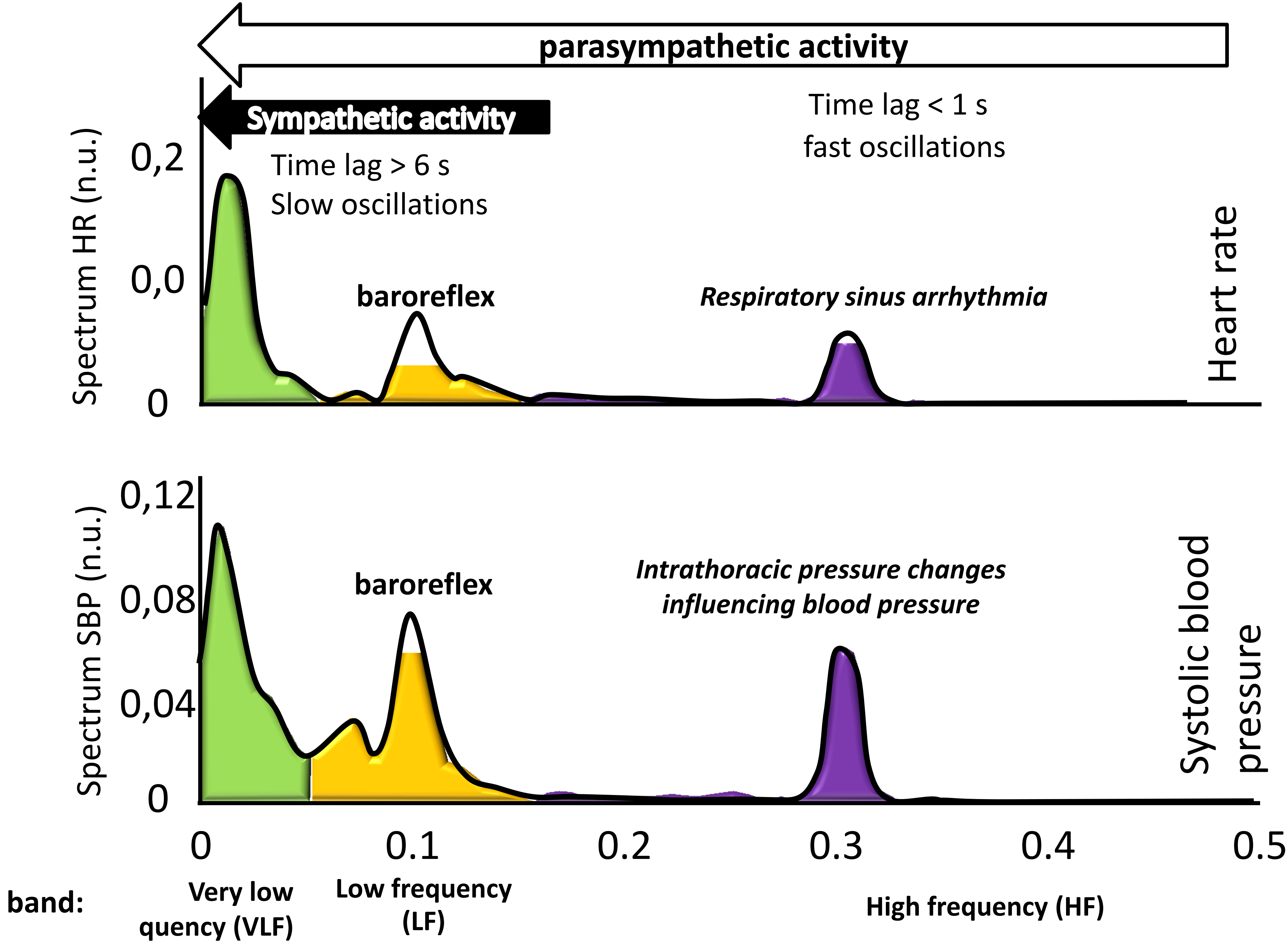
Baroreflex

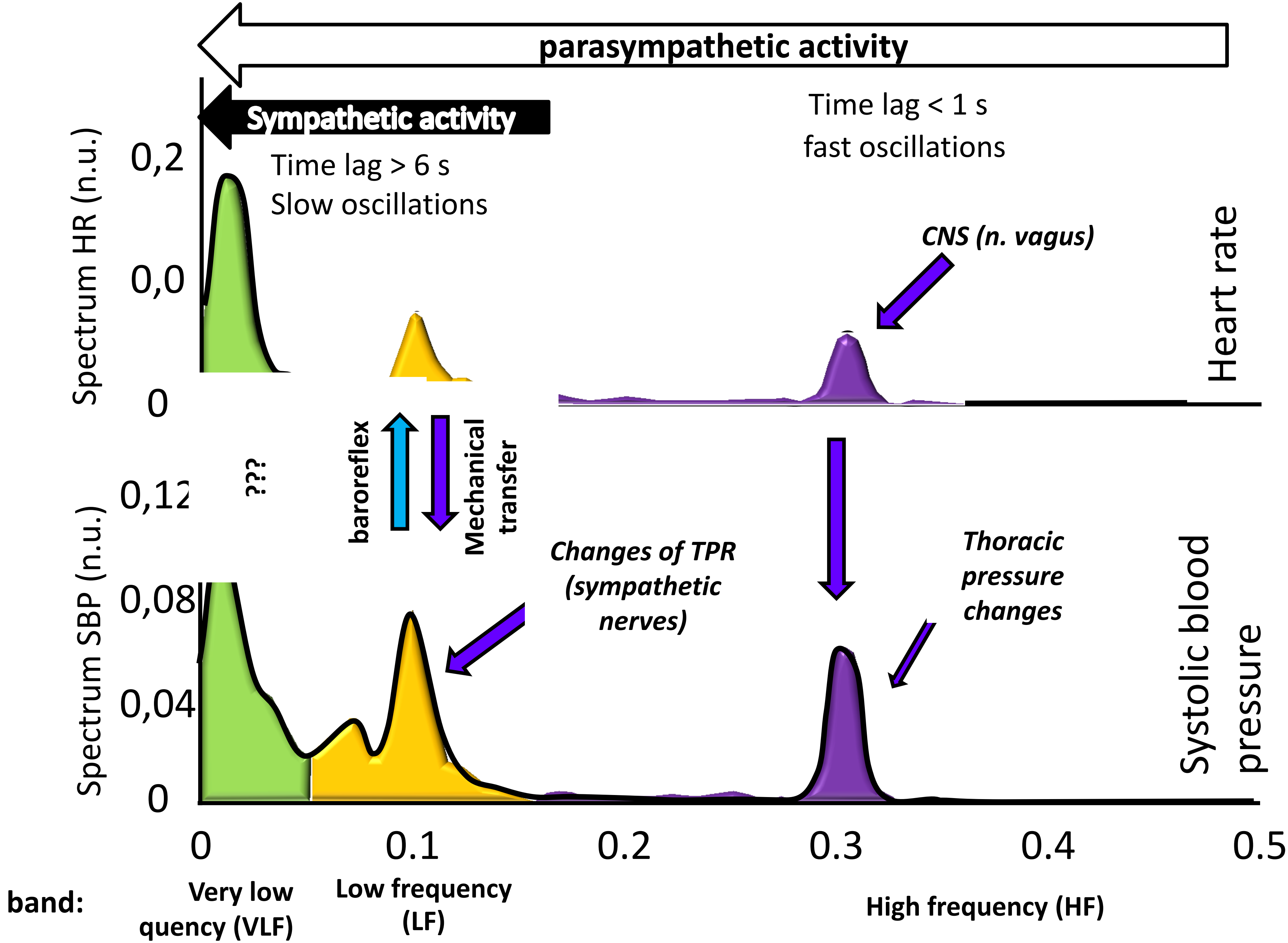


peripheral (vascular, sympathetic) branch of baroreflexu
resistance arteries
signal: peripheral resistance
arteries
signal: blood pressure
CNS: vasomotor centre
CNS: kardiomotor centre
heart
signal: heart rate
Cardiac (parasympathetic) branch

Physiological significance – frequency bands



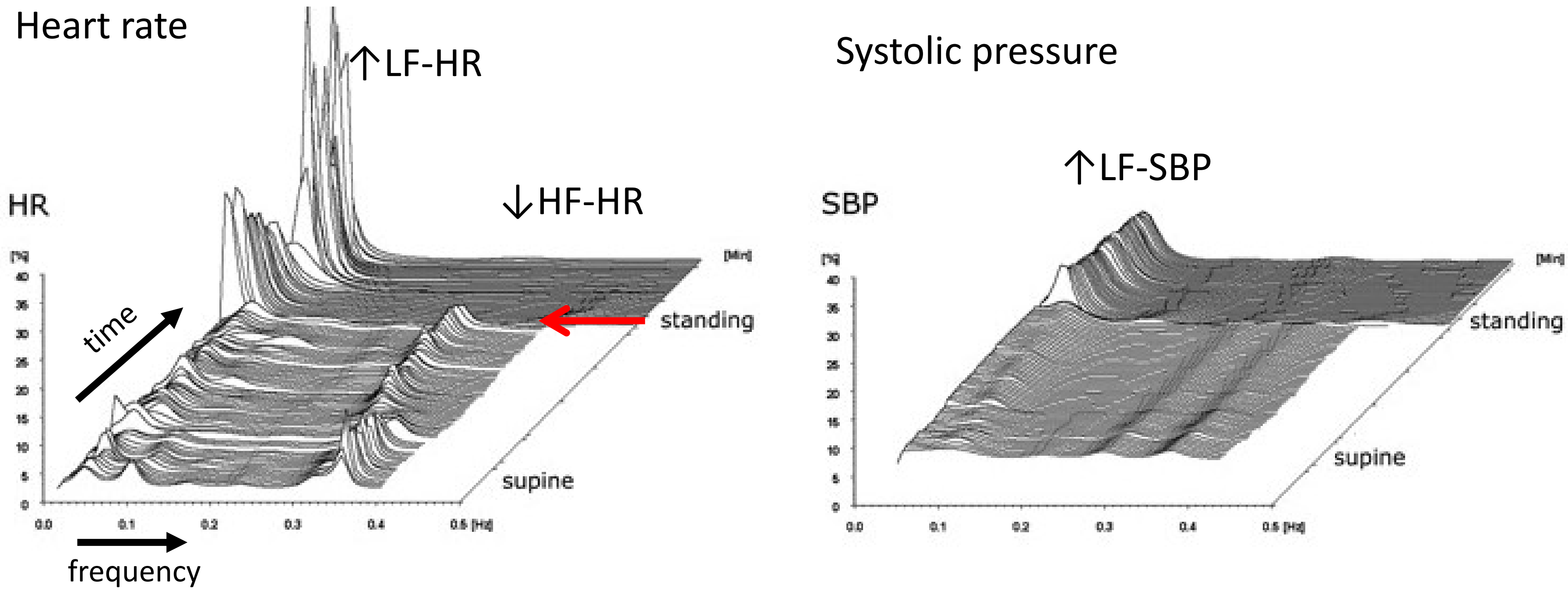

parasympathetic activity
Sympathetic activity
Time lag < 1 s
fast oscillations
Time lag > 6 s
Slow oscillations
Spectrum HR (n.u.)
0,2
0,0
0
baroreflex
Respiratory sinus arrhythmia
Heart rate
Spectrum SBP (n.u.)
0,12
0,08
0,04
0
baroreflex
Intrathoracic pressure changes
influencing blood pressure
Systolic blood pressure
0
0.1
0.2
0.3
0.4
0.5
band:
Very low quency (VLF)
Low frequency (LF)
High frequency (HF)



parasympathetic activity
Sympathetic activity
Time lag > 6 s
Slow oscillations
Time lag < 1 s
fast oscillations
CNS (n. vagus)
Heart rate
Spectrum HR (n.u.)
0,2
0,0
0
baroreflex
Mechanical transfer
???
0,12
0,08
0,04
0
Spectrum SBP (n.u.)
Changes of TPR (sympathetic nerves)
Thoracic pressure changes
Systolic blood pressure
0
0.1
0.2
0.3
0.4
0.5
band:
Very low quency (VLF)
Low frequency (LF)
High frequency (HF)

Variability changes: orthostatic challenge

Sympatho-vagal ratio LF-HR/HF-HR

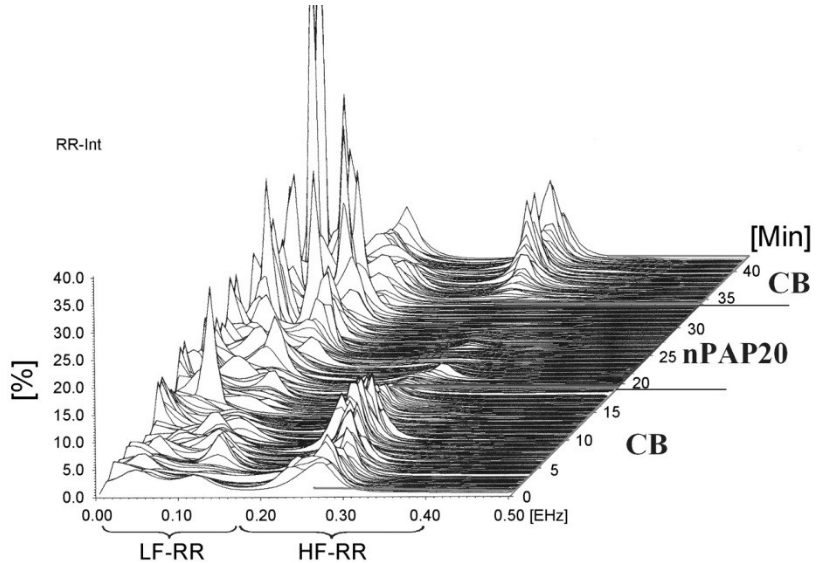


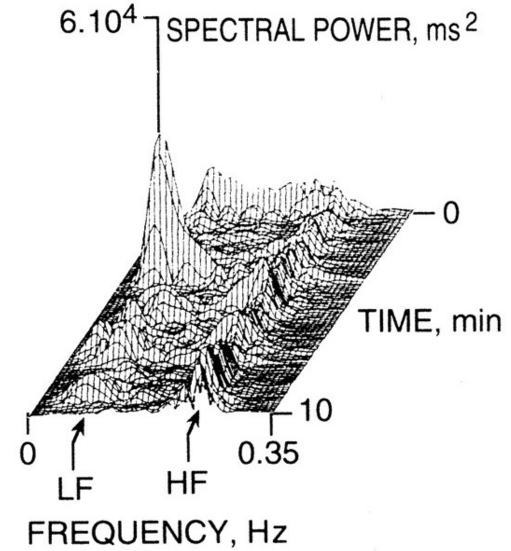
Orthostatic challenge:

- Increase of sympathetic activity → increase of low frequency HR and SBP variability (LF-HR, LF-SBP)
- Decrease of parasympathetic activity → decrease of variability in respiratory frequency (HF-HR)

➡ **analysis of autonomic nervous system function**

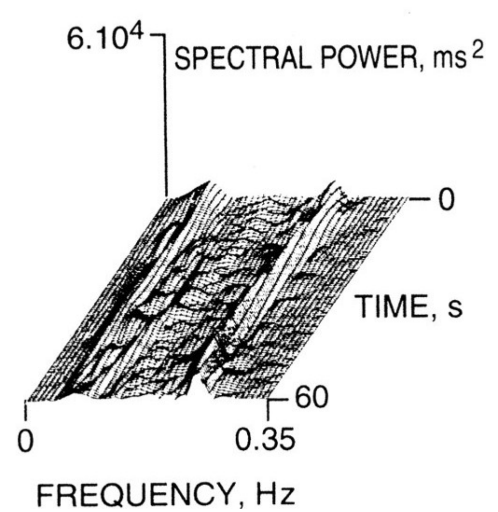
Heart rate variability (HRV) changes



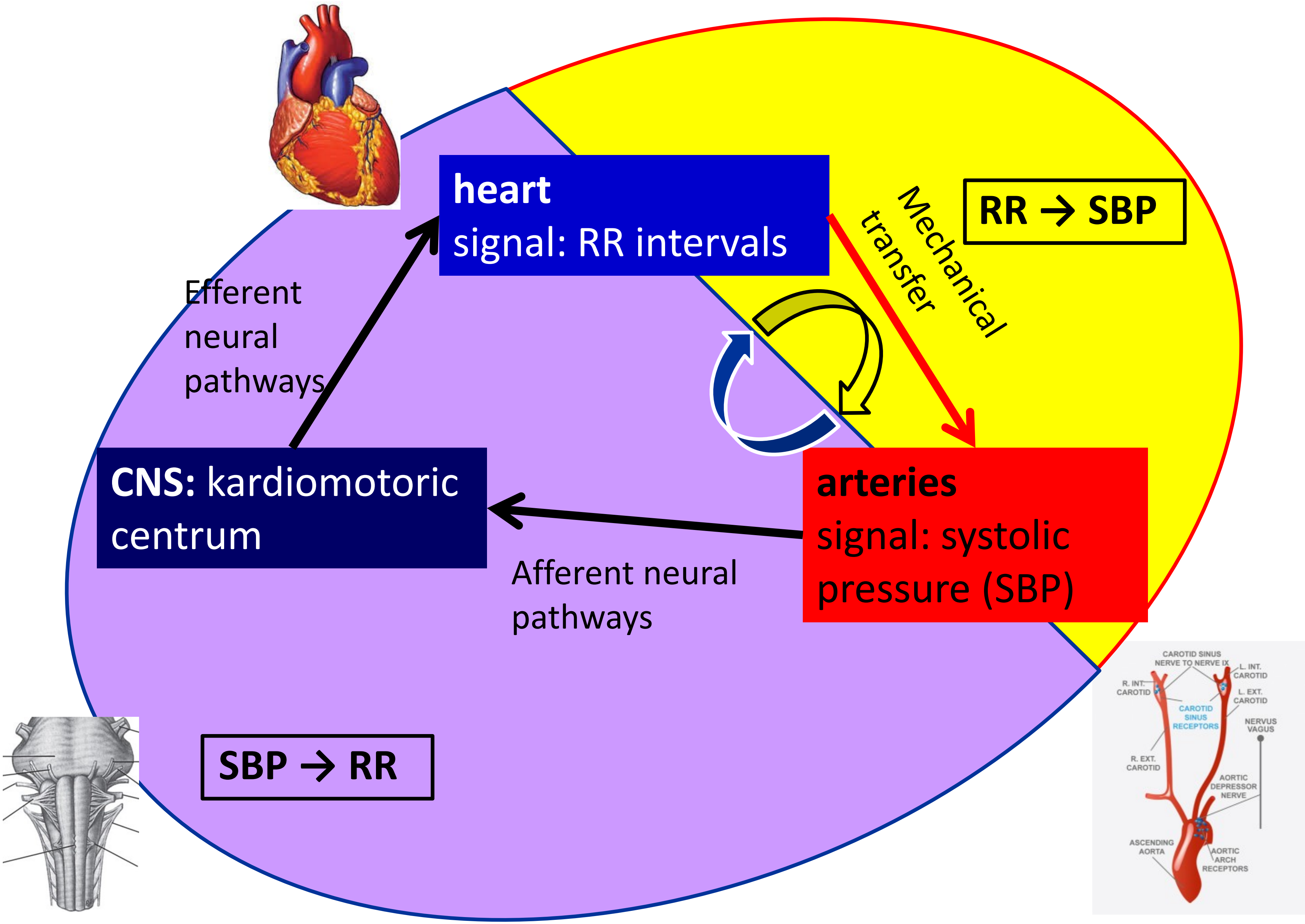


HRV in respiratory frequency decreases in stress situations (↑sympathetic activity)

- Physiologically – sport, mental stress
- Pathologically – diabetes, hear failure
- Transplanted heart
- **Predictor of the cardiovascular risk**

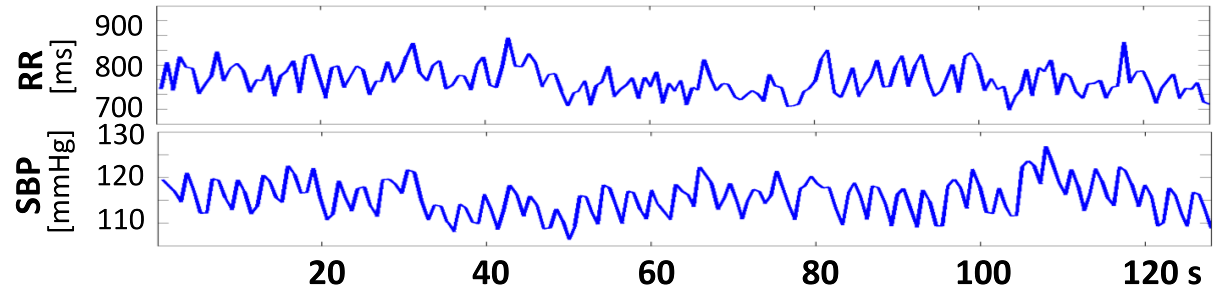


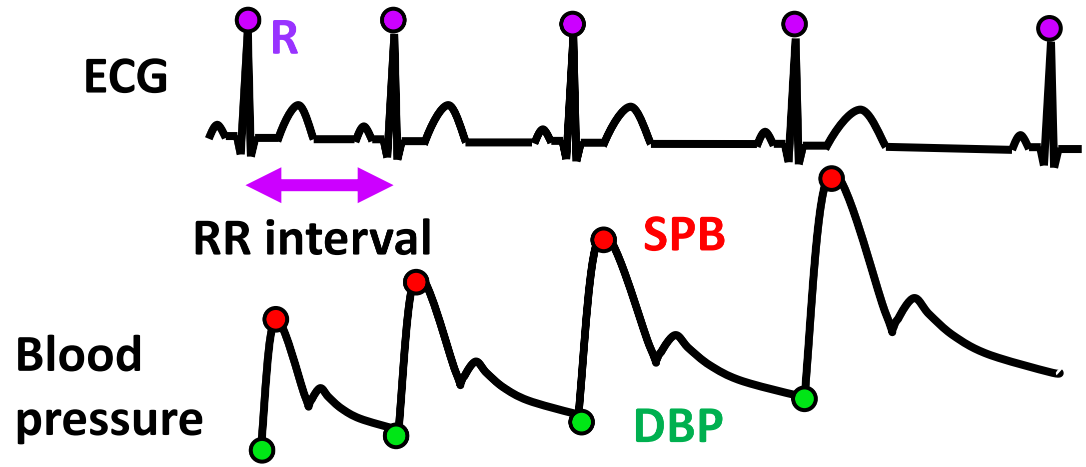
Evaluation of baroreflex function



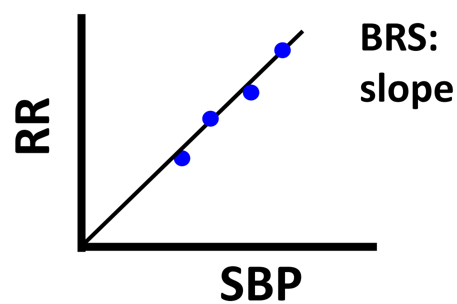
Baroreflex sensitivity (BRS)

Cardiac baroreflex can be evaluted by analysis of SBP- HR interaction





BRS: change of cardiac cycle caused by change of SBP by 1 mmHg [ms/mmHg]



Baroreflex sensitivity

Laboratory methods:

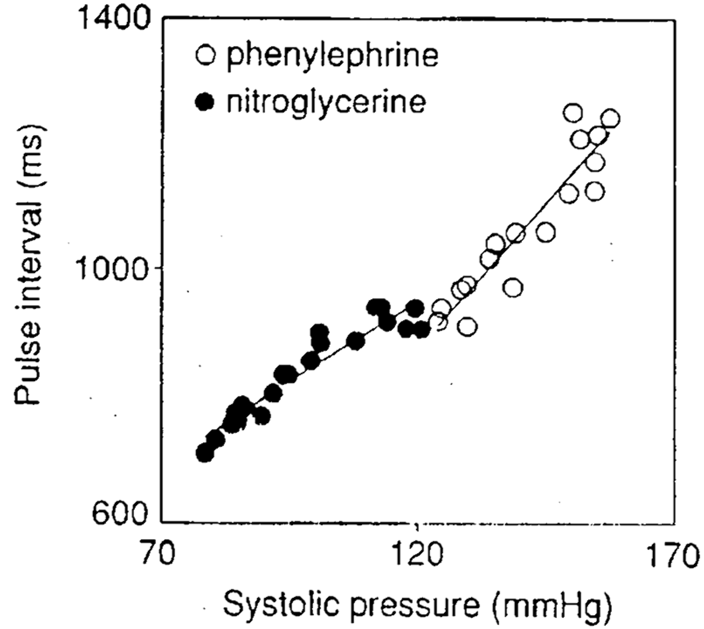
- Phenylephrin application (standard)
- neck suction
- Valsalva manoeuvre

Spontaneous methods:

in time domain: sequence analysis

in spectral domain: cross-spectral analysis, α-index

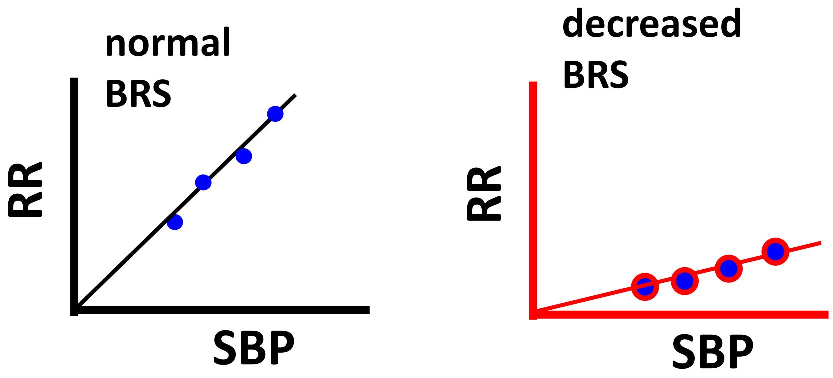
Bolus injections of vasoactive drugs



Baroreflex sensitivity – physiological significance

- Baroreflex function – regulation of blood pressure changes by changes of HR and TPR
- Cardiac branch of baroreflex is mediated by vagal nerves
  → BRS is increased in higher vagal activity and decreased in sympathetic activity
  → BRS is decreased in stress
  → BRS depends on RR interval length

- **Long-time decreased BRS reflects dysfunction in blood pressure regulation – cardiovascular risk**



Decreased BRS

- Physiologically
  - psychic stress – increased sympathetic activity
  - Physical exercise – increased sympathetic activity
  - In old age

- Pathologically
  - hypertension – decreased baroreceptor sensitivity (atherosclerosis, increased arterial stiffness)
  - diabetes – neuropathy of autonomic nervous system
  - Chronic depression (neurogenic)
  - Heart insufficiency/failure – heart do not response
  - Transplanted heart - denervation
  - Myocardial infarction – heart do not response



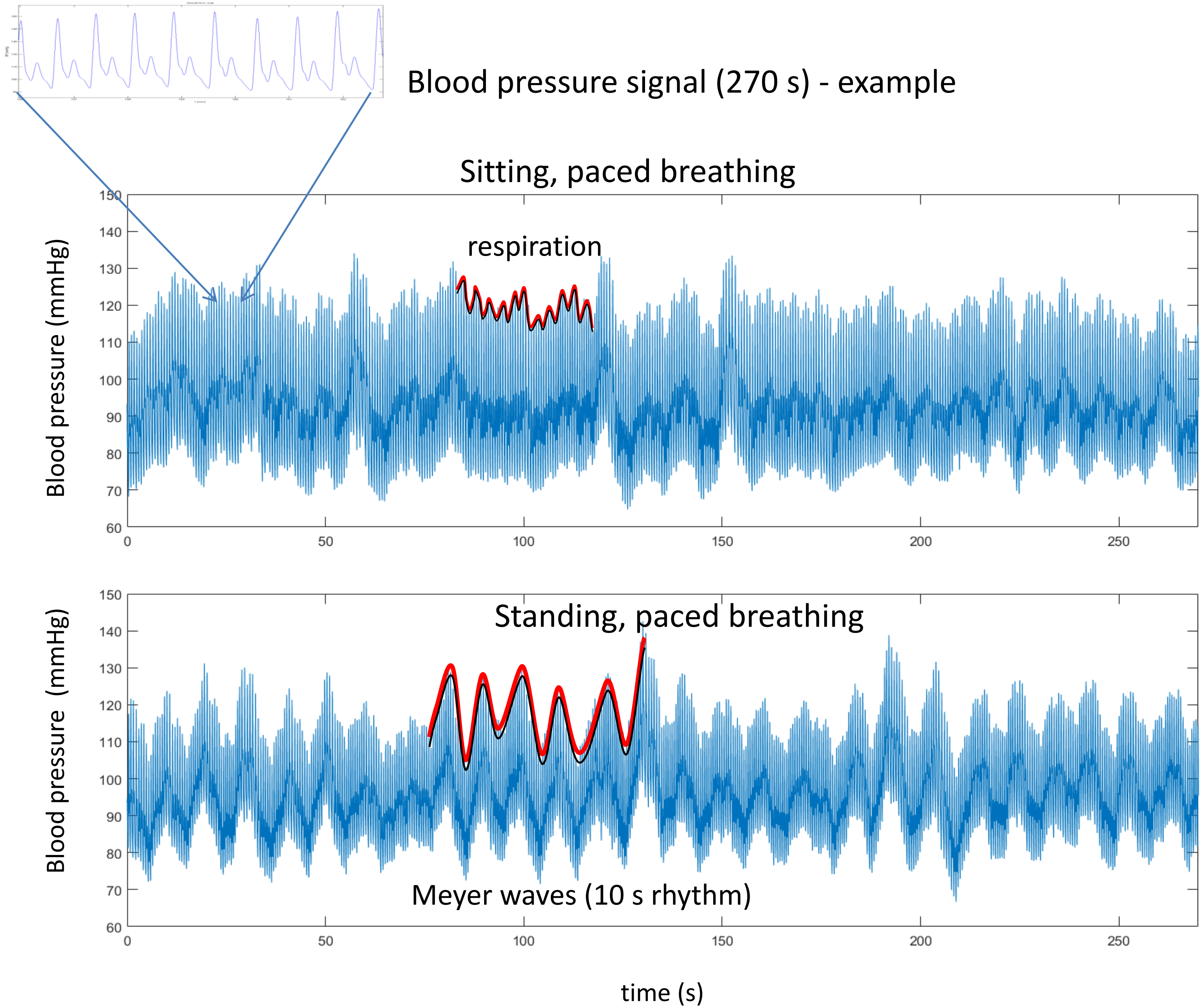




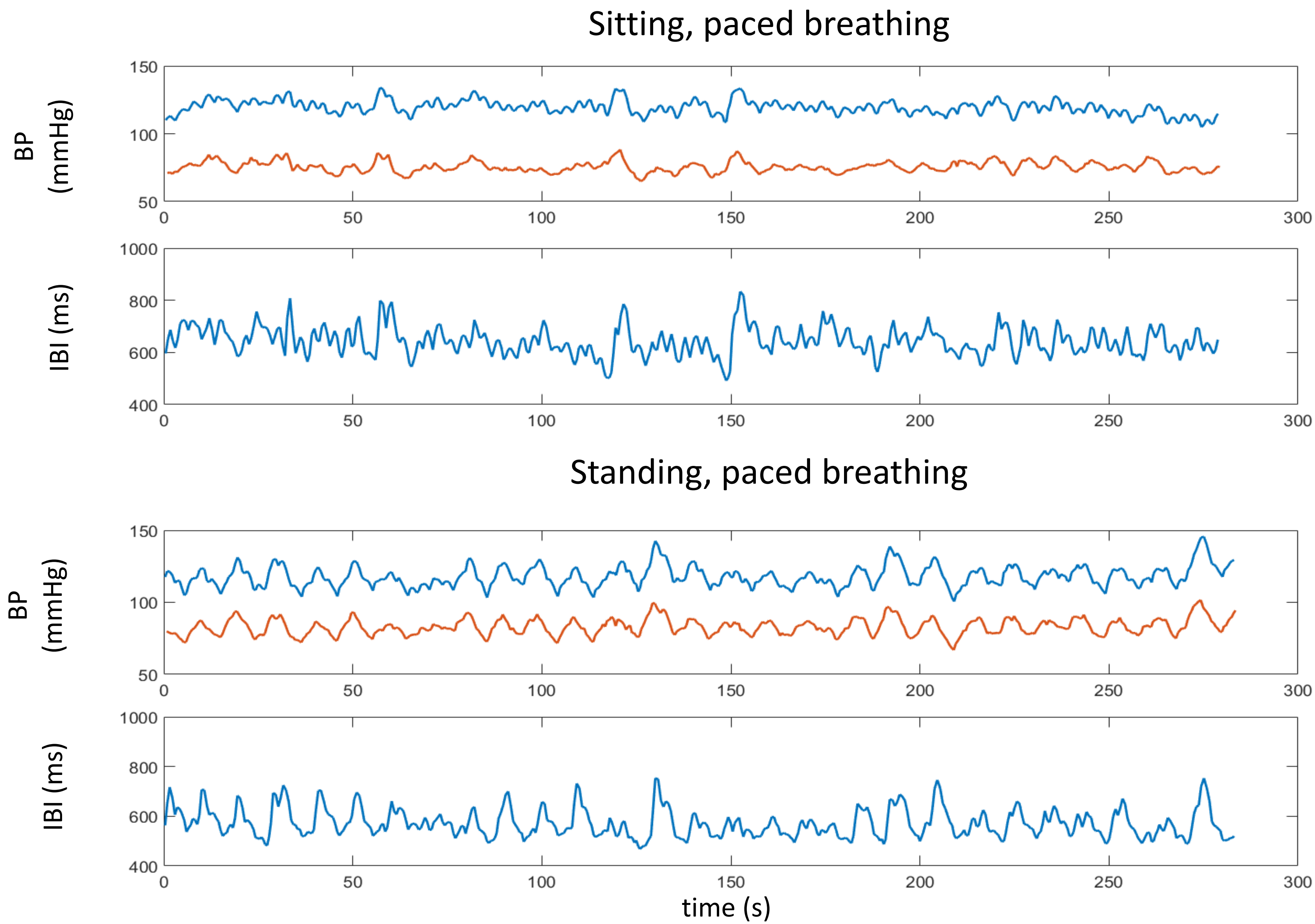
Disadvantages of methods

- Only sinus rhythm without ectopic beats can be analysed
- Long recording >5min, stationary signal
- BRS is a parameter of cardiac baroreflex function, information about vascular part of baroreflex is missing
- Causality of RR-SBP is neglected

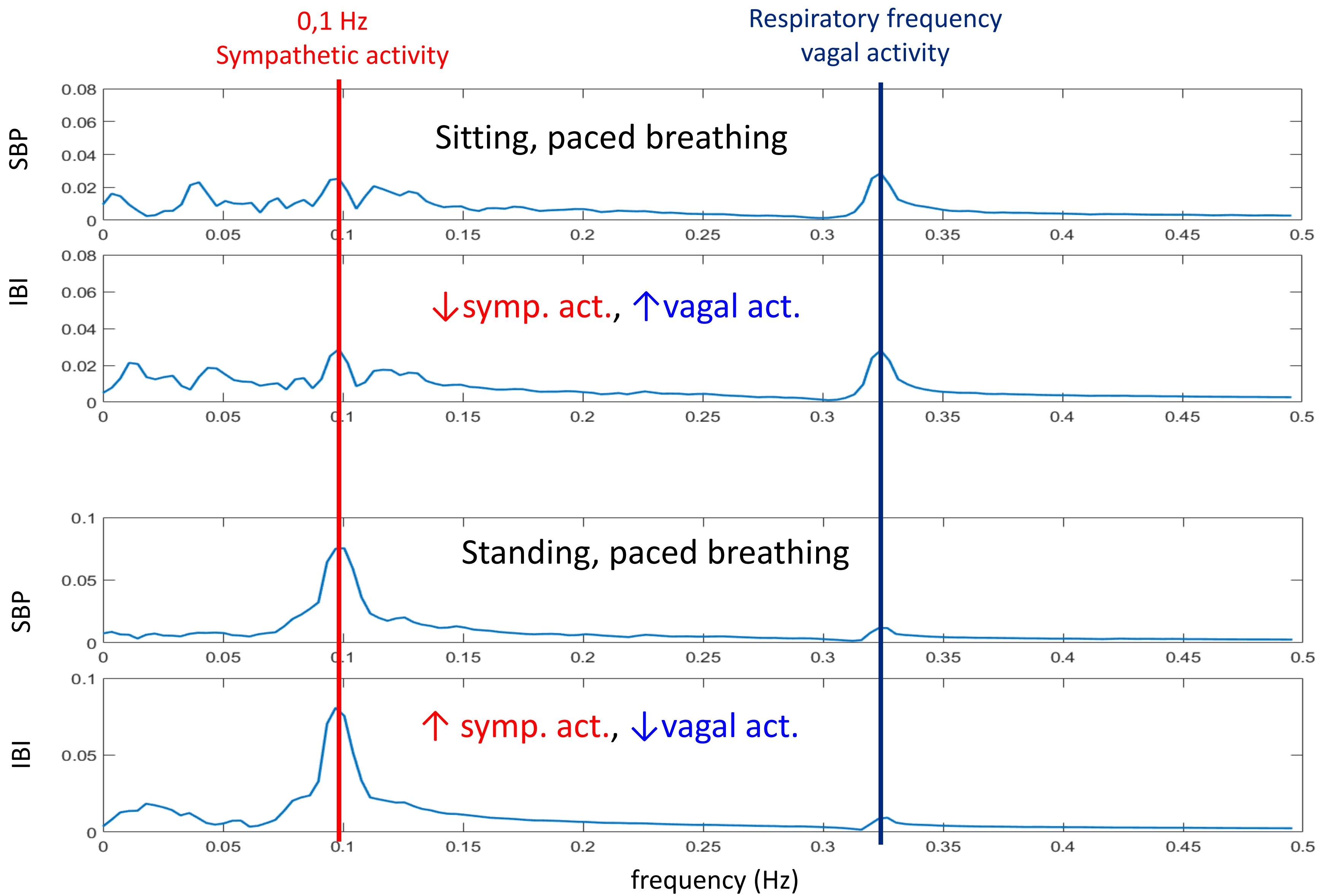
Blood pressure signal (270 s) - example



sequentions of SBP, DBP and inter-beat intervals (IBI) - example

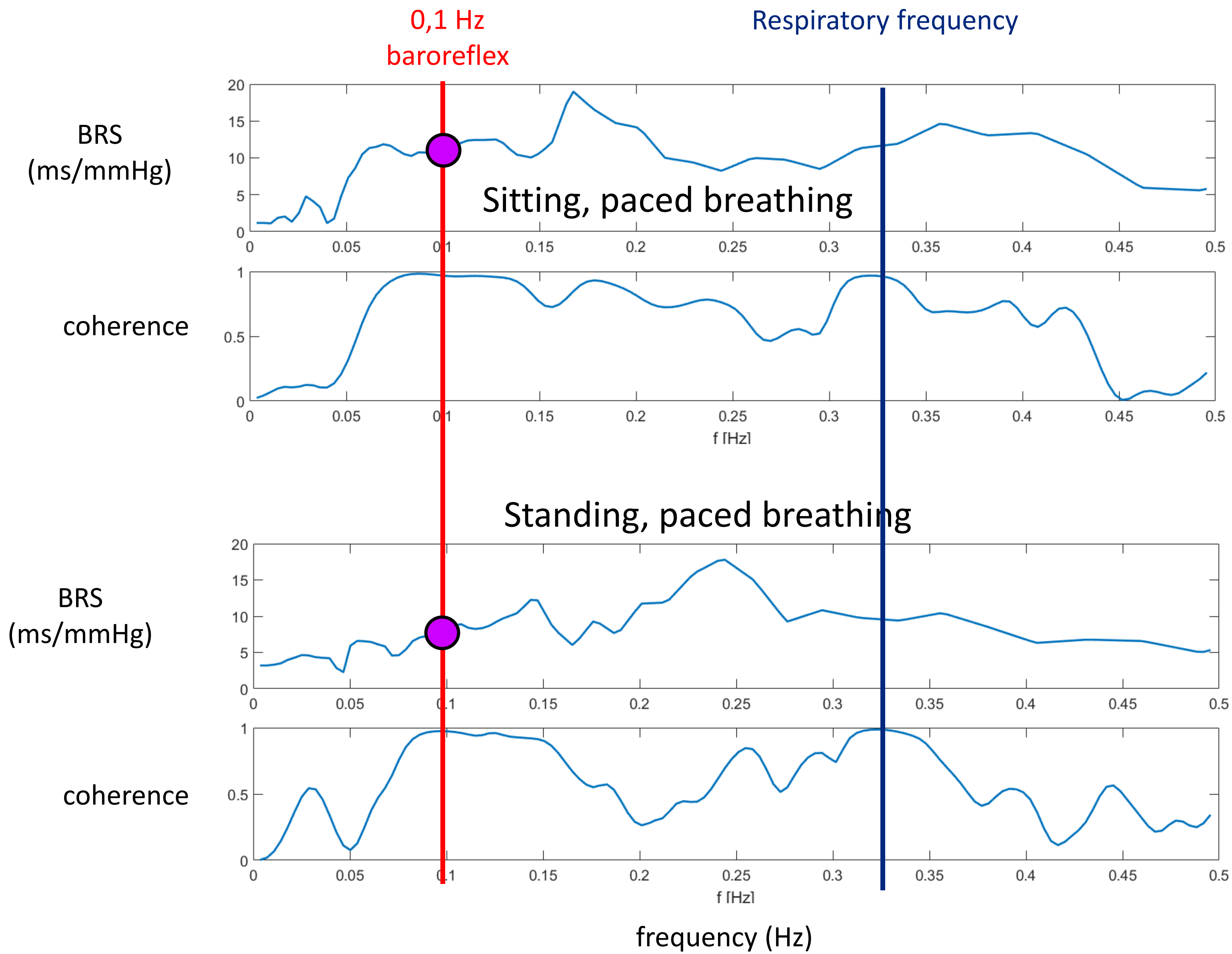


Spectra of SBP and IBI - example



Coherence a BRS - example

coherence: synchronization between signals (correlation on particular frequency)



Take home message 1

- Variability of cardiovascular signals contain information about regulatory mechanisms
- Analysed signals: time series
  - ECG: beat-to-beat RR intervals, heart rate (HR)
  - Continual record of blood pressure: beat-to-beat systolic pressures (SBP)
- Main methods of variability analysis
  - Standard deviations and derived parameters
  - Spectral analysis
- Analysis of RR-SBP interaction: baroreflex sensitivity
  (definition: change of RR caused by change of SBP by 1 mmHg)

Take home message 1

- **Heart rate variability (HRV) – assessment of ANS activity**
  - decreased – increased cardiovascular risk
- Blood pressure variability (less analysed)
  - increased – increased cardiovascular risk
- **Baroreflex sensitivity (BRS)**
  - normal(> 4 mmHg) – baroreflex function is OK
  - decreased (< 3 mmHg) – increased cardiovascular risk
    - Hypertension, diabetes, heart failure, stress
- Predictors od sudden cardiac death: zero values of BRS and HRV
- Spectra RR and SBP
  - Frequency bands (VLF, LF a HF)
    - **HF (0.15-0,5Hz): parasympathetic activity, respiration (in RR – respiratory sinus arhytmia)**
    - LF (around 0,1 Hz): sympathetic/parasym. activity, baroreflex
    - VLF (< 0,03): low changes in vascular system (hormones, TPR, RAS,…)

Thank you