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HERZ-KREISLAUF-FORSCHUNG E.V.

What is Heart Rate and How do we Measure Heart Rate Variability?

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Content

1. Heart Rate

Any Definition of Heart Rate?

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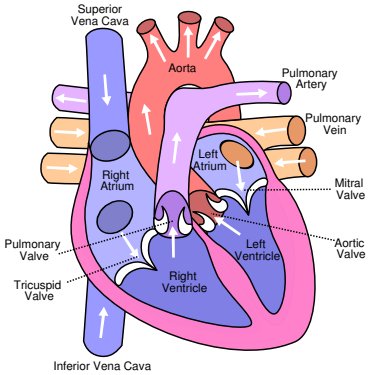
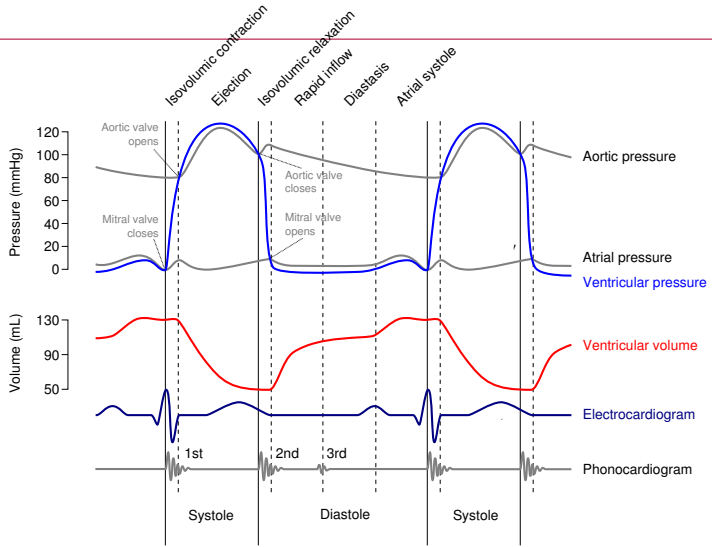
Some Definitions of Heart Rate?

"Heart rate is the speed of the heartbeat measured by the number of contractions (beats) of the heart per minute (bpm)."
Wikipedia, "Heart Rate", Edited on 21 March 2019, at 09:53 (UTC), Article

"The number of heartbeats per unit of time, usually per minute. The heart rate is based on the number of contractions of the ventricles (the lower chambers of the heart)". *MedicineNet, "How the heart works",* Article

Cardiac Cycle





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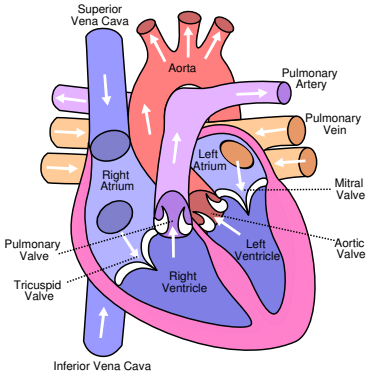
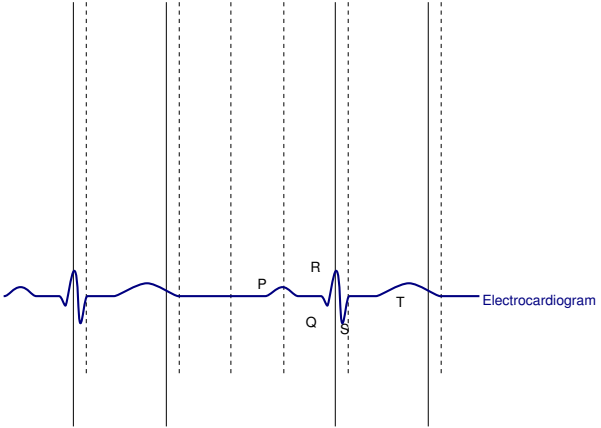
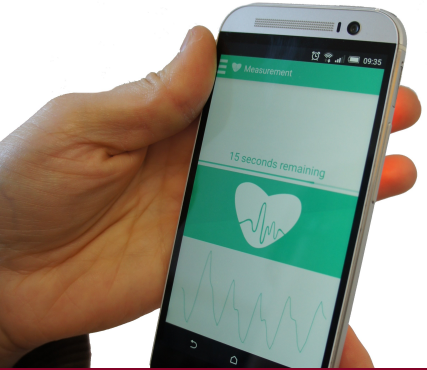




Smart Measurment: Photoplethysmography

Messung des Plethysmogramms mittels Durchleuchtung des Fingers über den Blitz eines Smartphones.



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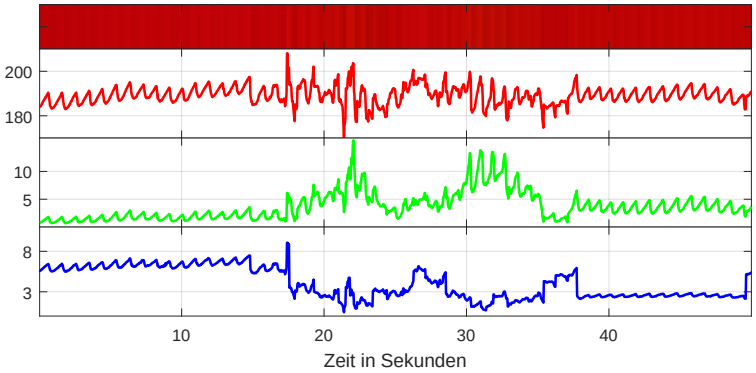


Easy Heart Rate Assessment

How to take your pulse

Although you may be able to feel your blood pumping in a number of places—your neck, the inside of your elbow, and even the top of your foot—your wrist is probably the most convenient and reliable place to get a good pulse.

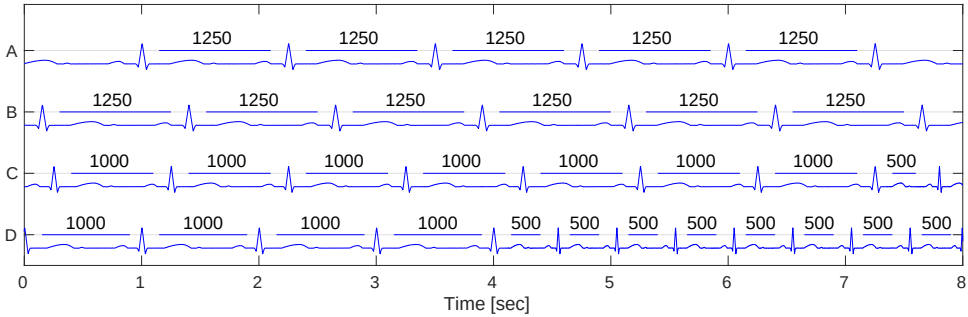
Press your index and middle fingers together on your wrist, below the fat pad of your thumb. Feel around lightly until you detect throbbing. If you press too hard you may suppress the pulse. You can probably get a pretty accurate reading by counting the number of beats in 15 seconds and multiplying that number by four, Dr. Johnson says.

The best time to get your resting heart rate is first thing in the morning, even before you get out of bed. To gauge your maximum heart rate, take your pulse immediately after exercising as vigorously as possible.

From Harvard Health Publishing, "What your heart rate is telling you", Article

Computing the Heart Rate – How?

Imagine these four scenarios with 8 seconds short ECG data and Inter-Beat-Intervals. There are four methods I make clear for you to compute the heart rate.

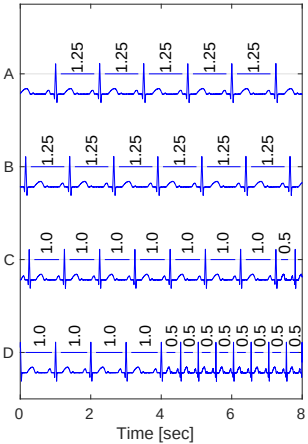


Computing the Heart Rate – How?

I Counting

Count the number of beats in the interval and project to a 60 seconds interval

- A: 6 beats $\rightarrow$ HR $= 60\,\text{s} \cdot \frac{6}{8\,\text{s}} = 45\,\text{bpm}$
- B: 7 beats $\rightarrow$ HR $= 60\,\text{s} \cdot \frac{7}{8\,\text{s}} = 52.5\,\text{bpm}$
- C: 9 beats $\rightarrow$ HR $= 60\,\text{s} \cdot \frac{9}{8\,\text{s}} = 67.5\,\text{bpm}$
- D: 12 beats $\rightarrow$ HR $= 60\,\text{s} \cdot \frac{12}{8\,\text{s}} = 90\,\text{bpm}$



Computing the Heart Rate – How?

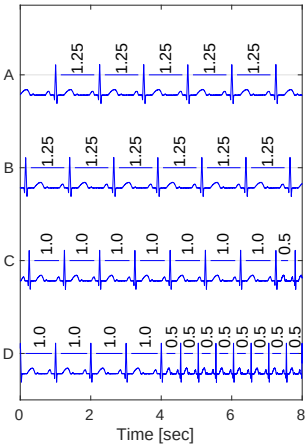
II Averaging Inter-beat-Intervals (IBI)

Average all observed IBIs and convert to a heart rate: $\frac{60}{\frac{1}{n}\sum_{i=1}^{n} IBI_i}$, n – number of IBIs

- A: $HR = \frac{60\,s}{1.25\,s} = 48\,bpm$
- B: $HR = \frac{60\,s}{1.25\,s} = 48\,bpm$
- C: $HR = \frac{60\,s}{\frac{1}{8}7.5\,s} = 64\,bpm$
- D: $HR = \frac{60\,s}{\frac{1}{12}8\,s} = 90\,bpm$

Kubios standard www.kubios.com/about-hrv/

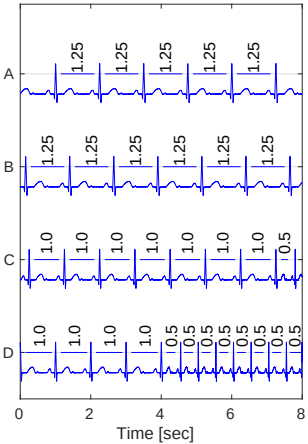
HRVTool standard HRV.m



Computing the Heart Rate – How?

III Averaging local heart rates

Convert all IBIs to a local heart rate and form the average: $\mathrm{HR} = \frac{1}{n}\sum_{i=1}^{n} HR_i$, $HR_i = \frac{60}{IBI_i}$, n – number of IBIs



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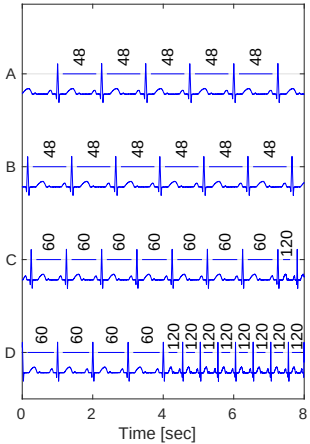
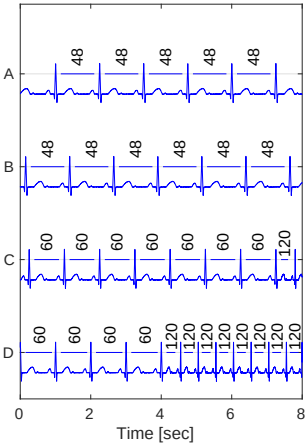


Computing the Heart Rate – How?

III Averaging local heart rates

Convert all IBIs to a local heart rate and form the average: $\mathrm{HR} = \frac{1}{n}\sum_{i=1}^{n} HR_i$, $HR_i = \frac{60}{IBI_i}$, n – number of IBIs

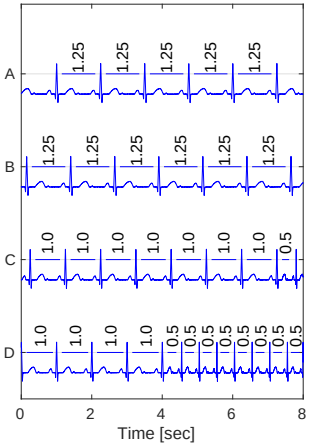
- A: $\mathrm{HR} = \frac{48+\ldots+48}{5} = 48\,\mathrm{bpm}$
- B: $\mathrm{HR} = \frac{48+\ldots+48}{6} = 48\,\mathrm{bpm}$
- C: $\mathrm{HR} = \frac{7\cdot 60+120}{8} = 67.5\,\mathrm{bpm}$
- D: $\mathrm{HR} = \frac{4\cdot 60+8\cdot 120}{12} = 100\,\mathrm{bpm}$



Computing the Heart Rate – How?

IV Spectral Analysis

Compute the power spectrum using Fourier transformation and search for the frequency with the maximum amplitude

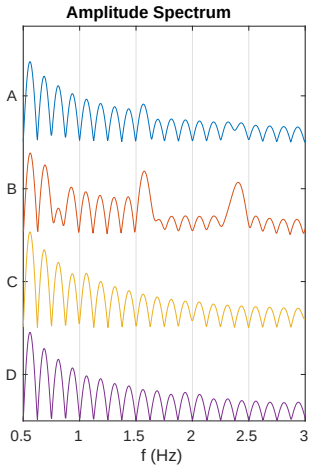


Computing the Heart Rate – How?

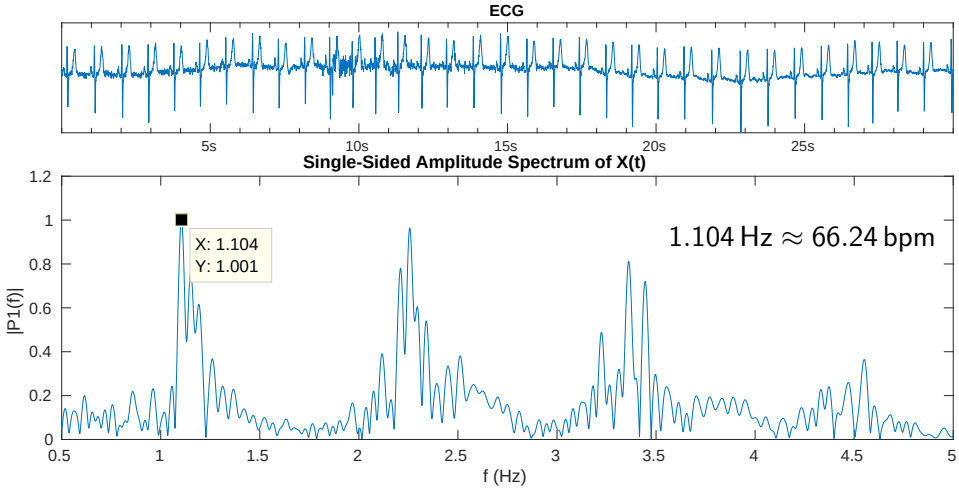
IV Spectral Analysis

Compute the power spectrum using Fourier transformation and search for the frequency with the maximum amplitude

Due to its strong periodicity of the shown artificial examples, there is unfortunately no clear peak.
Using real ECG data its quite accurate and convenient.



Computing the Heart Rate – How?



Any directive?

To the best of my knowledge

There is no guideline/standard/directive on heart rate computation!

Pathophysiological mechanisms

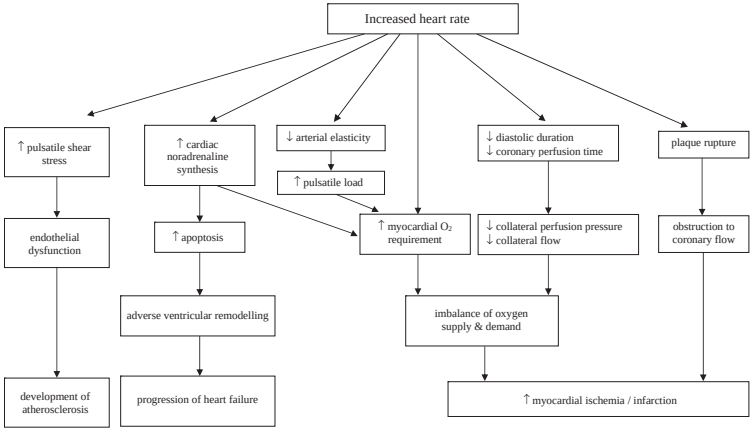


Figure 1) *Pathophysiological mechanisms promoted by increased heart rate*

From Arnold et al. [1]

2. Heart Rate Variability

Any Definition of Heart Rate Variability?

?

Some Definitions of Heart Rate Variability

Heart Rate Variability (HRV) is a physiological marker of autonomic activity of the heart.

Translated from "Herzfrequenzvariabilität im Sport"[2]:

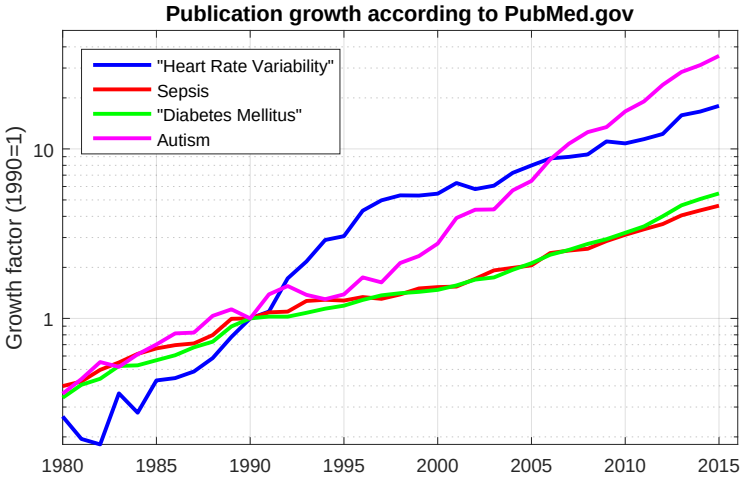
- [HRV] describes the ability of the heart to continuously change the time interval from heartbeat to heartbeat regardless of strain in order to adapt quickly to changing requirements.

Some Definitions of Heart Rate Variability

Definitions from Shaffer and Ginsberg [3]:

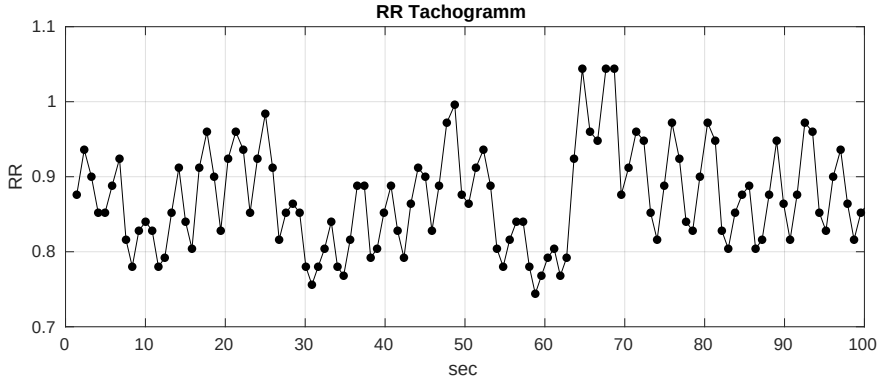
- HRV is the fluctuation in the time intervals between adjacent heartbeats.
- HRV indexes neurocardiac function and is generated by heart-brain interactions and dynamic non-linear autonomic nervous system (ANS) processes.
- HRV is an emergent property of interdependent regulatory systems which operate on different time scales to help us adapt to environmental and psychological challenges.

HRV – An Emerging Field?



RR Intervals | Inter-Beat-Intervals (IBIs)

- **Inter-Beat-Interval (IBI)** – timely distance from one heart beat to the next beat
- **RR Interval** – timely distance from R peak to R peak
- **NN Interval** – distance between *normal* R peaks (no artifacts or arrhythmic beats)



HRV – What measures are available?

Parameter	Unit	Description
SDNN	ms	Standard deviation of NN intervals
SDRR	ms	Standard deviation of RR intervals
SDANN	ms	Standard deviation of the average NN intervals for each 5 min segment of a 24h recording
SDNN index (SDNNI)	ms	Mean of the standard deviations of all NN intervals for each 5 min segment of a 24h recording
pNNx	%	Percentage of successive RR intervals that differ by more than x ms
RMSSD	ms	Root mean square of successive RR intervals
HRV triangular index		Integral of the density of the RR interval histogram divided by its height
TINN	ms	Baseline width of the RR interval histogram

HRV – What measures are available?

Parameter	Unit	Description
ULF power	ms^2	Absolute power of the ultra-low-frequency band ($\leq$0.003 Hz)
VLF power	ms^2	Absolute power of the very-low-frequency band (0.0033 to 0.04 Hz)
LF peak	Hz	Peak frequency of the low-frequency band (0.04 to 0.15 Hz)
LF power	ms^2	Absolute power of the low-frequency band (0.04 to 0.15 Hz)
LF power	nu or %	Relative power of the low-frequency band (0.04 to 0.15 Hz)
HF peak	Hz	Peak frequency of the high-frequency band (0.15 to 0.4 Hz)
HF power	ms^2	Absolute power of the high-frequency band (0.15 to 0.4 Hz)
HF power	nu or %	Relative power of the high-frequency band (0.15 to 0.4 Hz)
LF/HF	%	Ratio of LF-to-HF power

HRV – What measures are available?

Parameter	Unit	Description
S	ms	Area of the ellipse which represents total HRV
SD1	ms	Poincaré plot standard deviation perpendicular the line of identity
SD2	ms	Poincaré plot standard deviation along the line of identity
SD1/SD2	%	Ratio of SD1-to-SD2
ApEn		Approximate entropy, which measures the regularity and complexity of a time series
SampEn		Sample entropy, which measures the regularity and complexity of a time series
DFA $\alpha 1$		Detrended fluctuation analysis, which describes short-term fluctuations
DFA $\alpha 2$		Detrended fluctuation analysis, which describes long-term fluctuations
D_2		Correlation dimension, which estimates the minimum number of variables required to construct a model of system dynamics

Standard Maesures

pNNx

$$P\left(|\mathrm{RR}_{i+1} - \mathrm{RR}_i| > x \text{ ms}\right)$$

Standard Maesures

pNNx

$P\left(|\mathrm{RR}_{i+1} - \mathrm{RR}_i| > x \text{ m}\right.$

SDNN

$$\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(\mathrm{RR}_i - \overline{\mathrm{RR}}\right)^2}$$

Standard Maesures

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SDNN

$$\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(\mathrm{RR}_i - \overline{\mathrm{RR}}\right)^2}$$

RMSSD

$$\sqrt{\frac{1}{n-1}\sum_{i=1}^{n-1}\left(\mathrm{RR}_{i+1} - \mathrm{RR}_i\right)^2}$$

Standard Maesures

Time domain measures [4]

- Easy to use
- Influenced by outliers and artifacts
- Affected by the heart rate

pNNx

$P\left(|\mathrm{RR}_{i+1} - \mathrm{RR}_i| > x \text{ m}\right.$

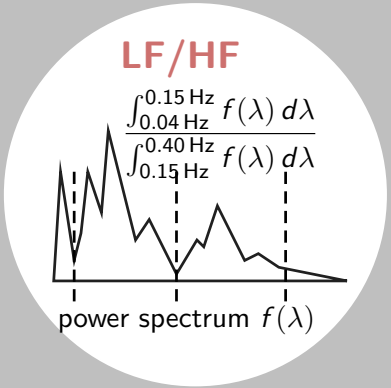
SDNN

$$\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(\mathrm{RR}_i - \overline{\mathrm{RR}}\right)^2}$$

RMSSD

$$\sqrt{\frac{1}{n-1}\sum_{i=1}^{n-1}\left(\mathrm{RR}_{i+1} - \mathrm{RR}_i\right)^2}$$

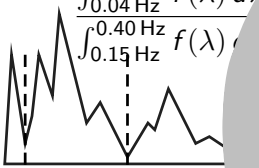
Standard measures



Standard measures

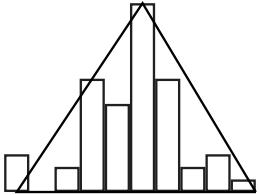
LF/HF

$$\frac{\int_{0.04\,\mathrm{Hz}}^{0.15\,\mathrm{Hz}} f(\lambda)\,d\lambda}{\int_{0.15\,\mathrm{Hz}}^{0.40\,\mathrm{Hz}} f(\lambda)\,d\lambda}$$



power spectrum $f($

TINN



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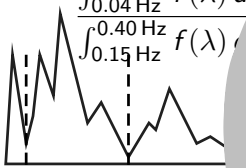
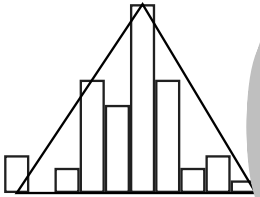


power spectrum $f($

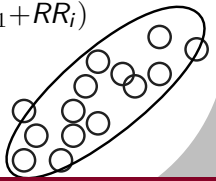
TINN



$M - N$

SD1/SD2

$$\frac{\sigma(RR_{i+1} - RR_i)}{\sigma(RR_{i+1} + RR_i)}$$



Standard measures

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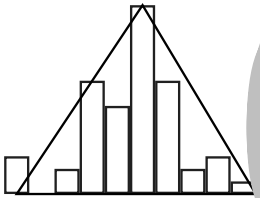
power spectrum $f($

TINN

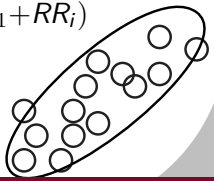


$M - N$

Geometrical and spectral measures

- harder to understand
- Influenced by outliers and artifacts
- Affected by the heart rate
- Spectrum: dealing with missing values?
- TINN: bar width unclear

$$\overline{\sigma(RR_{i+1}+RR_i)}$$



Alternative measures – rrHRV

Relative RR intervals rr_i are defined as a weighted difference [5]:

$$rr_i := \frac{RR_i - RR_{i-1}}{\frac{1}{2}(RR_i + RR_{i-1})} \quad , \; i \in \{2, \ldots, n\}$$

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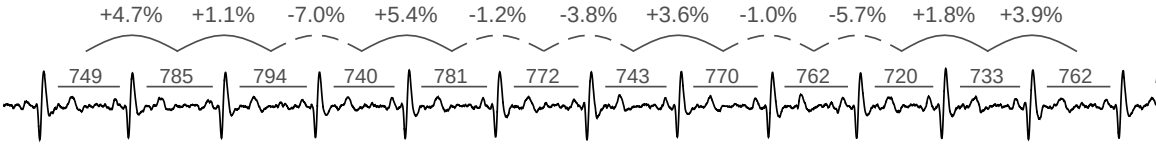

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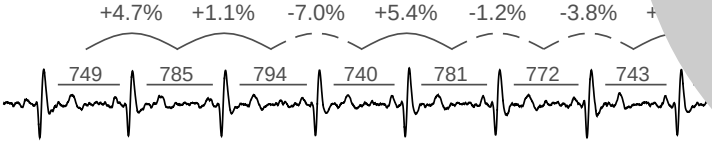

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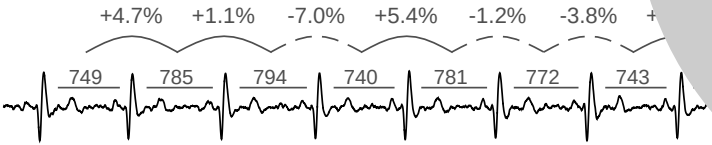

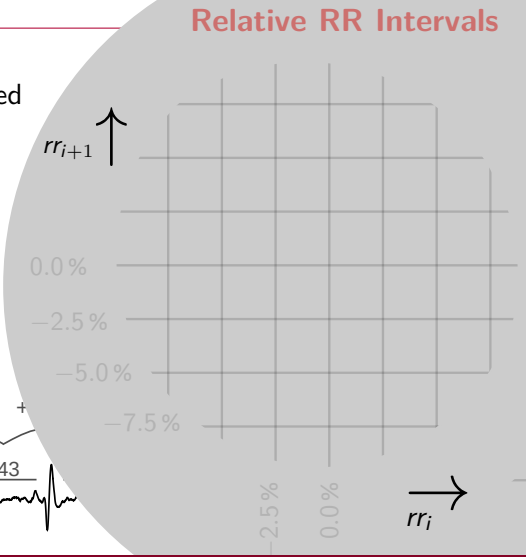

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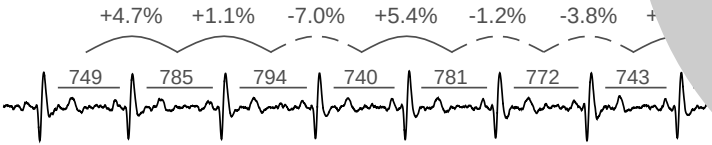
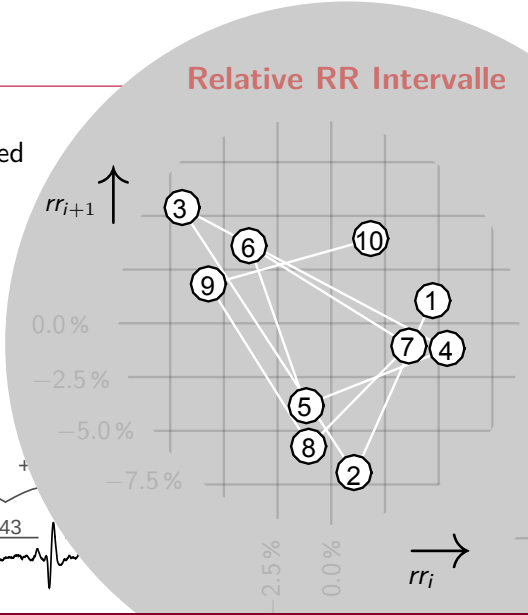


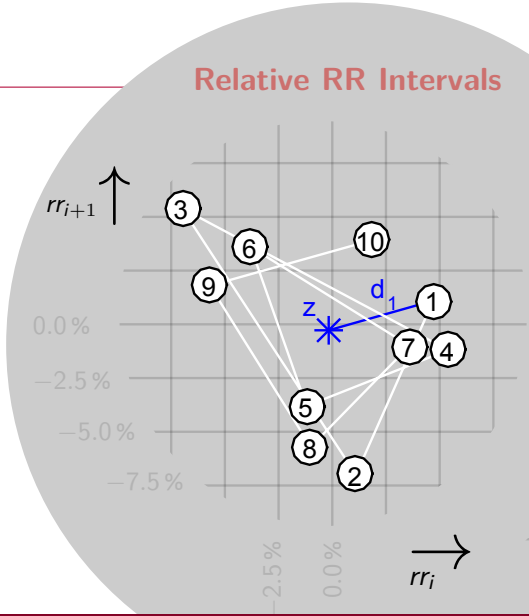


Alternative measures – rrHRV

The heart rate variability *rrHRV* is defined by the Euclidean distance to the center of the scatter cloud [5]:

$$\text{rrHRV} := \text{median}\left(\|(rr_i, rr_{i+1}) - z\|_2\right)$$

$$\text{rrHRV} = \text{median}\left(\{d_i\}_{i\in\{2,\ldots,n\}}\right)$$



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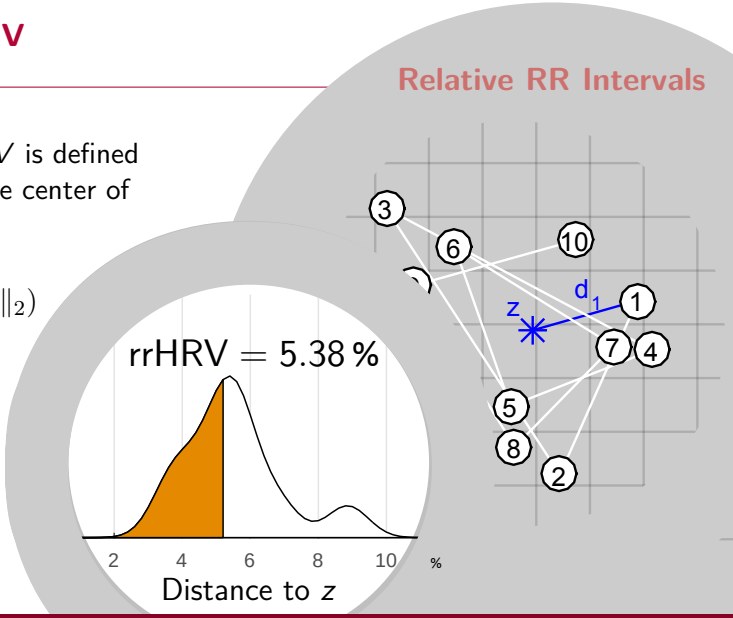
$$\text{rrHRV} := \text{median}\left(\|(rr_i, rr_{i+1}) - z\|_2\right)$$

$$\text{rrHRV} = \text{median}\left(\{d_i\}_{i\in\{2,\ldots,n\}}\right)$$



Special Mathematical Properties

rrHRV is invariant against

- Scaling
- Time-dependent scaling
- Mirroring
- Artifacts
- Missing values
- Segment length

HRV Measures and Invariance

Measure	Translation	Scaling	Time dependent scaling	Mirroring	Artifacts	Missing Values
SDNN, RMSSD, pNN50	✓	✗	✗	✓	✗	✓
TRI, TINN	(✓)*	✗	✗	✓	✓	✓
SD1/SD2 ratio	✓	✓	✗	✓	✗	✓
LF/HF ratio	✗	✗	✗	✗	✗	✗
DFA	✓	✓	✗	✗	✗	(✓)**
ApEn	✓	✓	✗	✓	✓	(✓)**
CD/D_2	✓	✗	✗	✓	✓	✓
rrHRV	✗	✓	✓	✓	✓	✓

* Small deviations possible due to fixed bar width

** In principle also computable with missing values

Recommendation for Parameter Usage

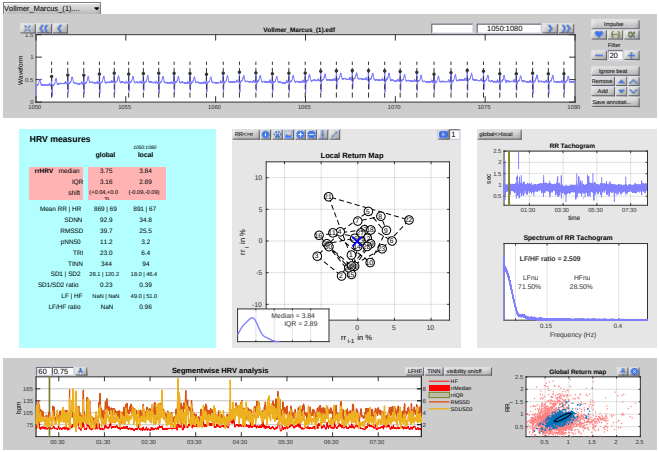
Measure	Ultra short term < 5 min	Short term $5-20$ min	Long term > 20 min
SDNN, RMSSD, pNN50	✓	(✓)	✗
TRI, TINN	✗	(✓)	✗
SD1/SD2 ratio	✓	(✓)	✗
LF/HF ratio	✗	✓	✓
DFA	(✓)	✓	✓
ApEn	(✓)	✓	✓
CD/D_2	✗	✓	✓
rrHRV	✓	✓	✓

✓ recommended for use

(✓) recommended under certain circumstances (e.g. resting state)

✗ not recommended or not computable

HRVTool – An Interactive User Interface for MATLAB



GitHub Project Matlab File Exchange

Remarks welcome!

3. Appendix

Literature I


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Image Sources

Heart illustration: Wikimedia Commons | Wapcaplet
Cardiac cycle: Wikimedia Commons | DestinyQx/DanielChangMD