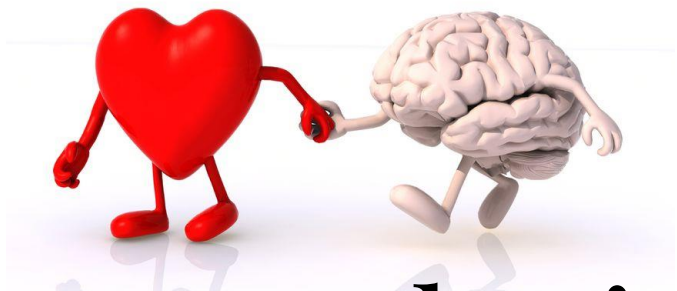


Herz und Hirn

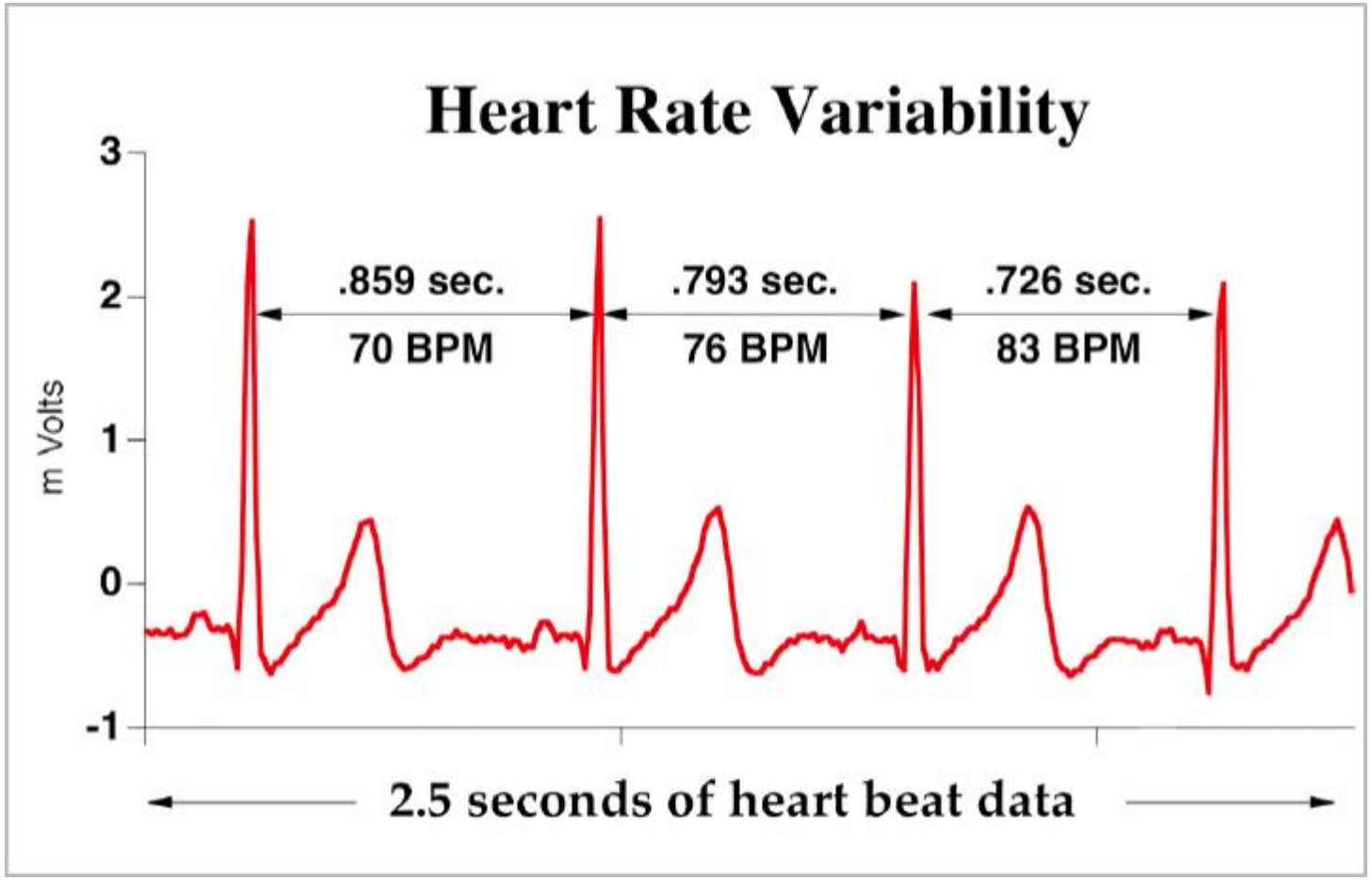
zur Physiologie, Psychologie & Auswertung der Herzfrequenzvariabilität

12. November 2015

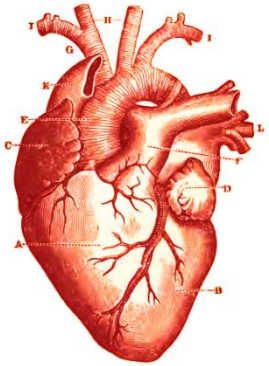
Michael Gaebler
(michael.gaebler@gmail.com)

Leipziger Forschungszentrum für Zivilisationserkrankungen (LIFE)
MPI für Kognitions- und Neurowissenschaften Leipzig

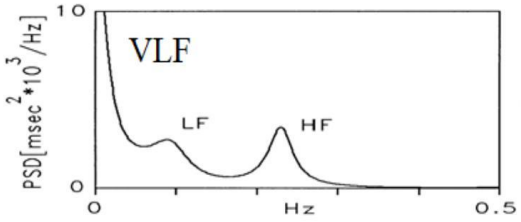
Was ist Herzfrequenzvariabilität?



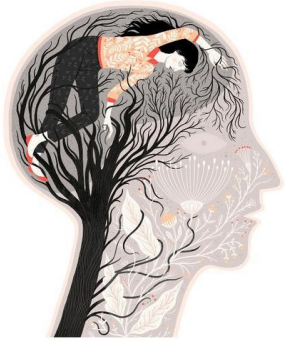
1. Nicht Mittel, sondern **Abweichung**
2. **Leicht** zu erheben
3. Je **höher**, desto besser
4. Index der **Herz-Hirn-Interaktion**



Physiologie der HFV



Auswertung der HFV

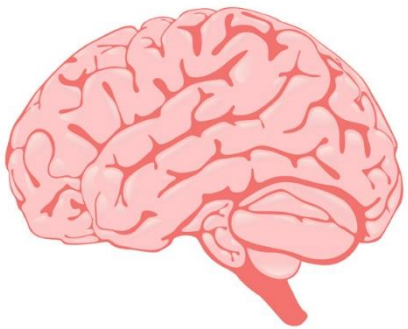


Psychologie der HFV

The nervous systems (Wikipedia)

Key:
- = Structure
- = Function

Central Nervous System (CNS)
- Brain and spinal cord
- Integrative and control centers



Peripheral Nervous System (PNS)
- Cranial nerves and spinal nerves
- Communication lines between the CNS and the rest of the body

Sensory (afferent) division
- Somatic and visceral sensory nerve fibers
- Conducts impulses from receptors to the CNS

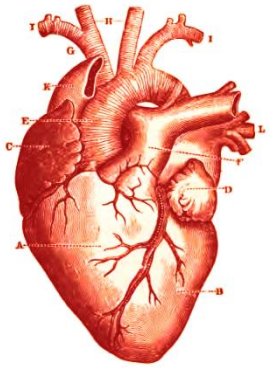
Motor (efferent) division
- Motor nerve fibers
- Conducts impulses from the CNS to effectors (muscles and glands)

Sympathetic division
- Mobilizes body systems during activity ("fight or flight")

Autonomic nervous system (ANS)
- Visceral motor (involuntary)
- Conducts impulses from the CNS to cardiac muscles, smooth muscles, and glands

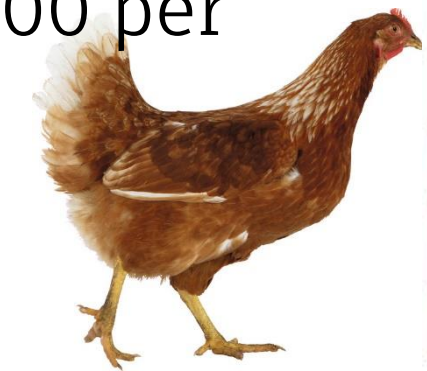
Somatic nervous system
- Somatic motor (voluntary)
- Conducts impulses from the CNS to skeletal muscles

Parasympathetic division
- Conserves energy
- Promotes "housekeeping" functions during rest

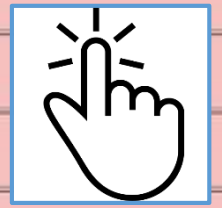


Fun facts

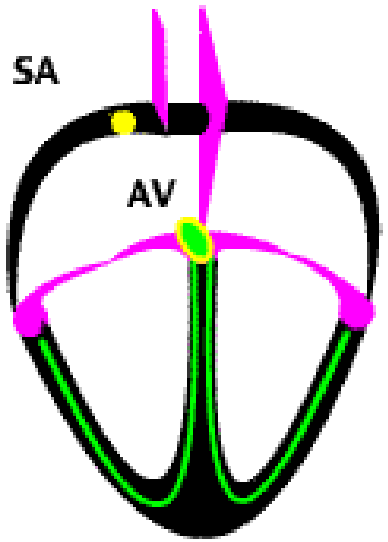
- Evolution: a function of first “brains” (500 Mio. years ago) was to control heartbeat
- Heart is about the size of a clenched fist
- 4,000/hour, 100,000/day, >2,000,000,000 per lifetime

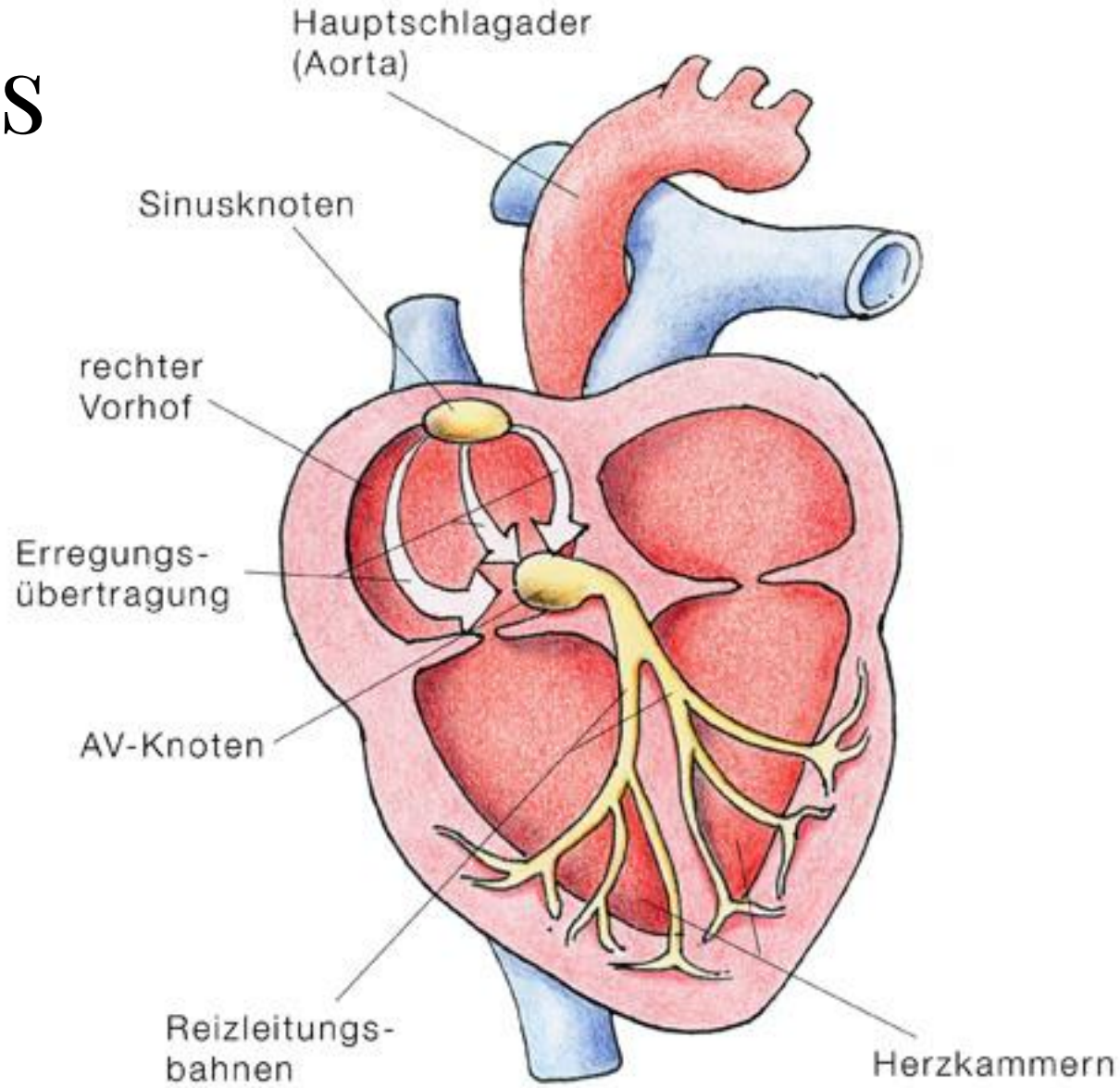


Lifetime Heartbeats and Animal Size					
	Weight	Heart Rate	Longevity	Product	Lifetime Heartbeats
Creature	(grams)	(/minute)	(years)		(billions)
Human	90000	60	70	4200	2.21
Cat	2000	150	15	2250	1.18
Small dog	2000	100	10	1000	0.53
Medium dog	5000	90	15	1350	0.71
Large dogs	8000	75	17	1275	0.67
Hamster	60	450	3	1350	0.71
Chicken	1500	275	15	4125	2.17
Monkey	5000	190	15	2850	1.50
Horse	1200000	44	40	1760	0.93
Cow	800000	65	22	1430	0.75
Pig	150000	70	25	1750	0.92
Rabbit	1000	205	9	1845	0.97
elephant	5000000	30	70	2100	1.1
giraffe	900000	65	20	1300	0.68
large whale	120000000	20	80	1600	0.84

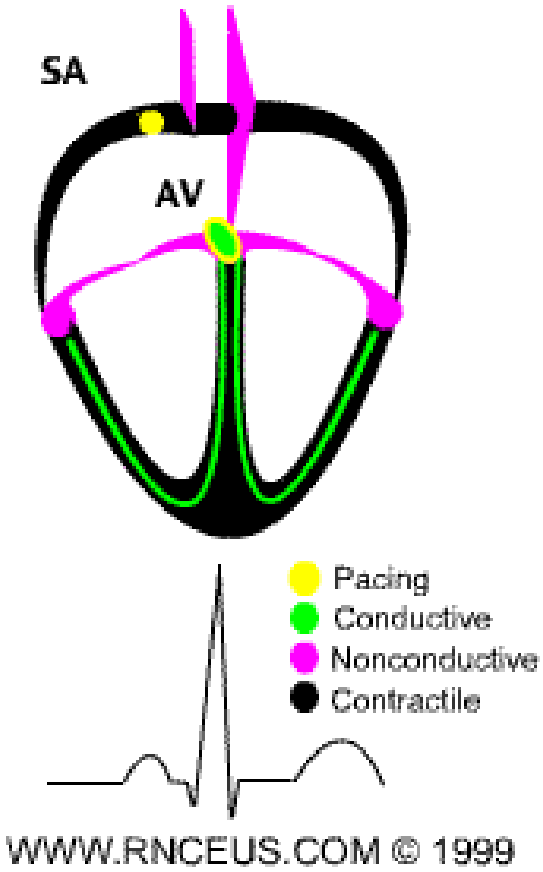


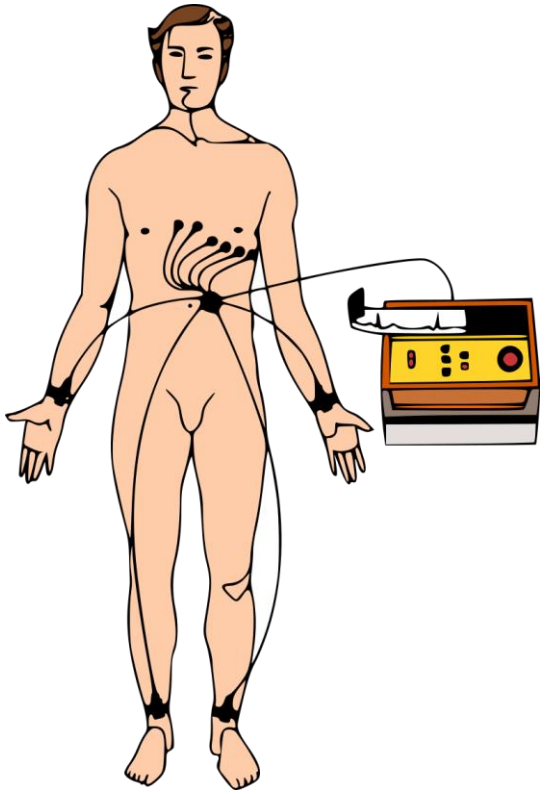
Aufbau des Herzens

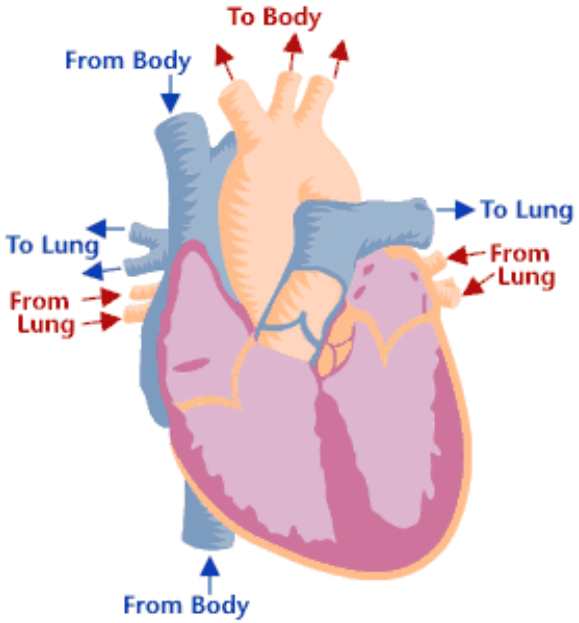




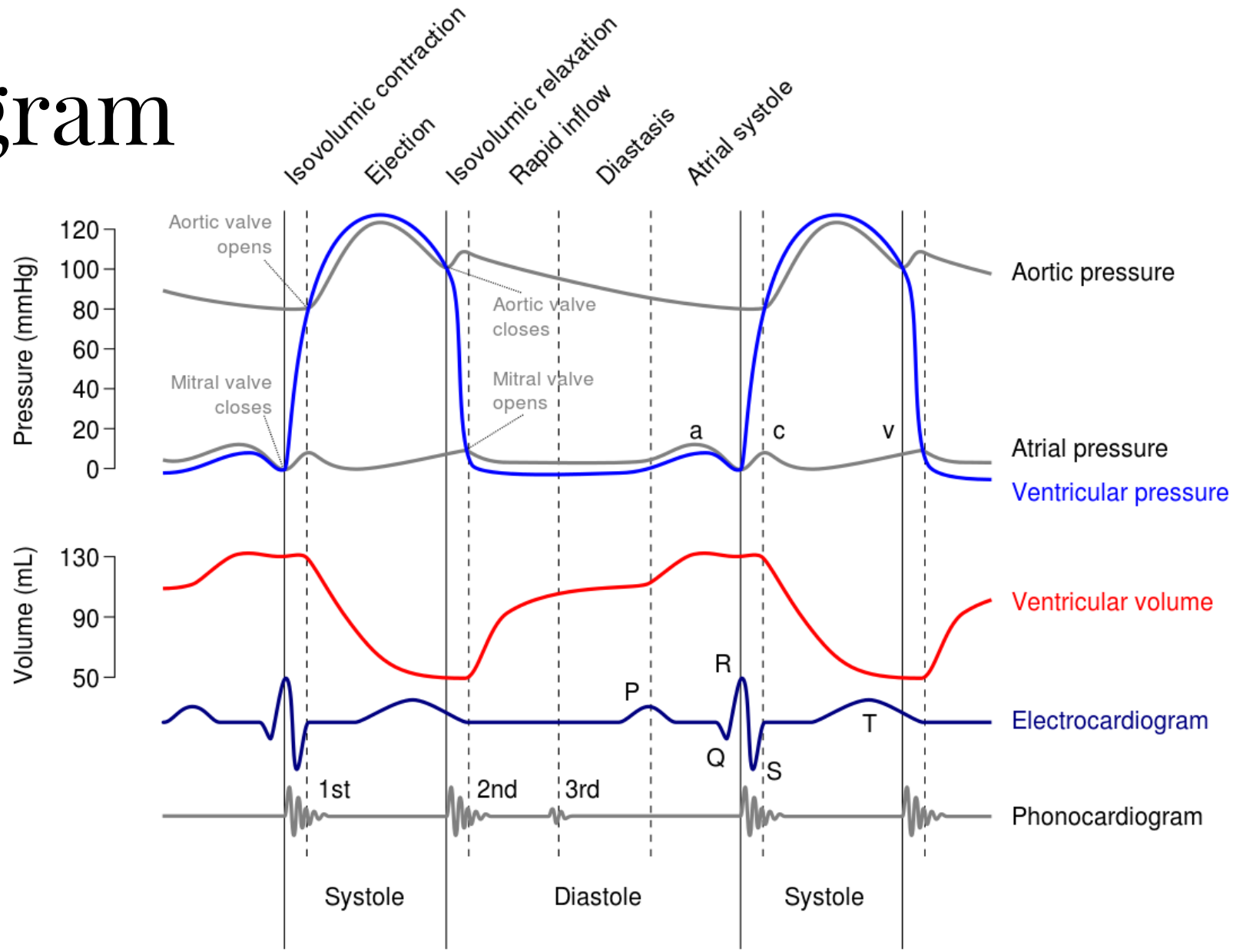
Das Herz als elektrische Pumpe







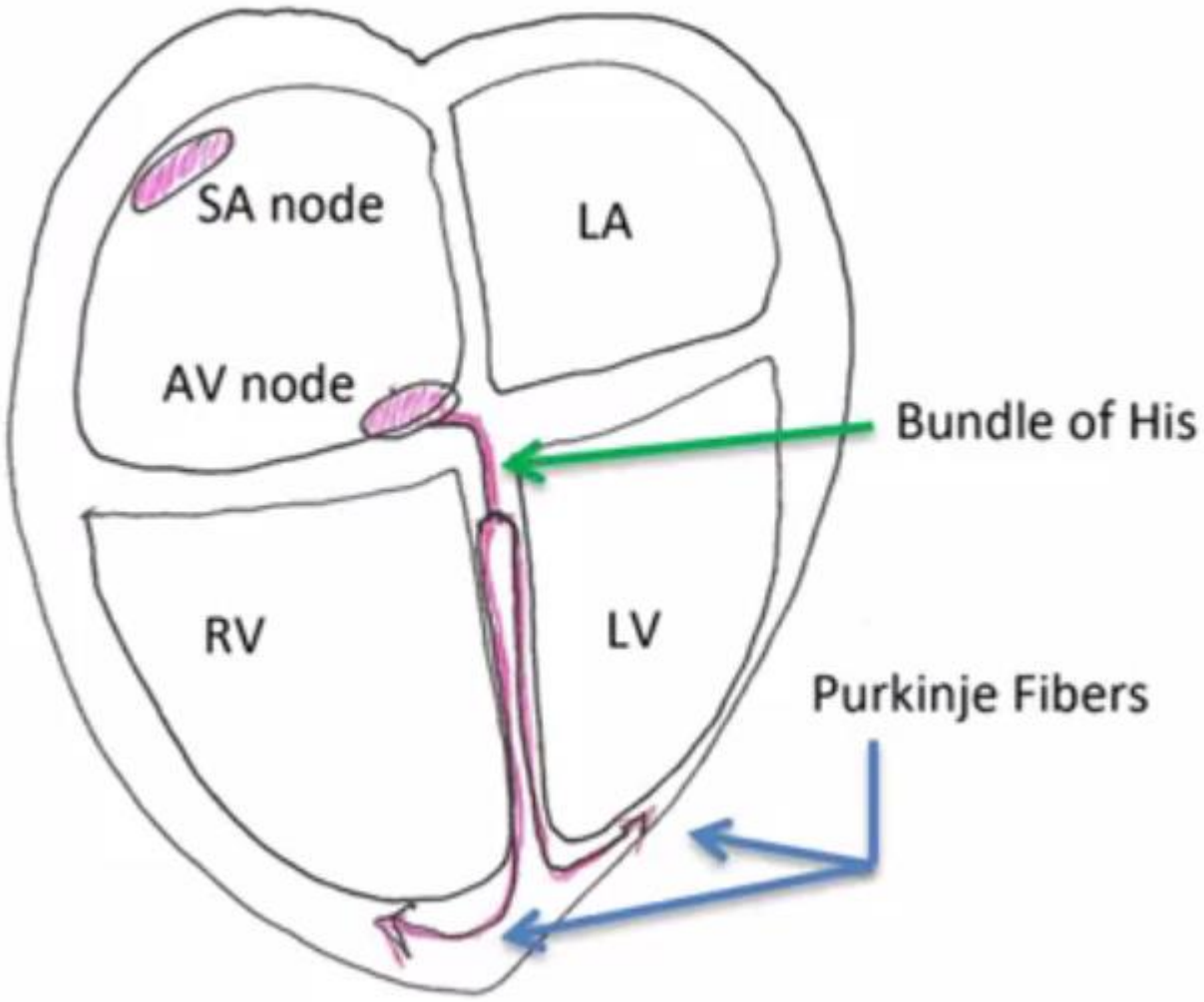
Wigger's diagram



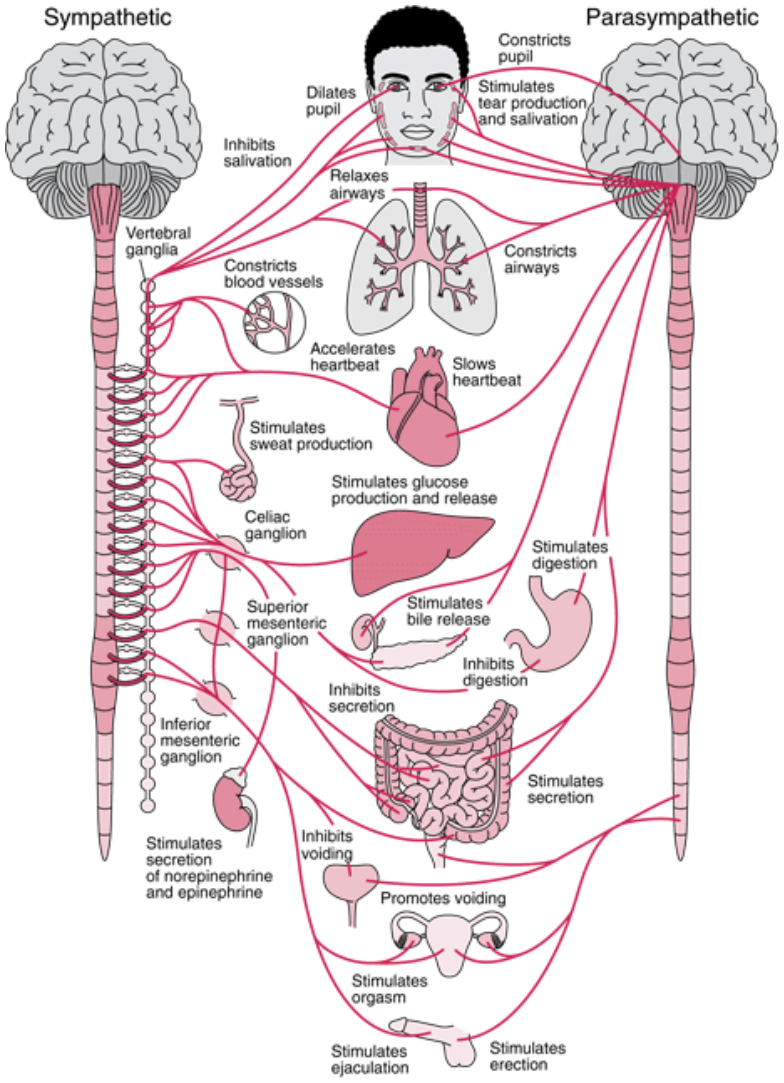
(Source: Wikipedia/Wikimedia)

Heart physiology

- Unidirectional blood flow:
  right → left
  atrium → ventricle
- Pacemakers:
  - **Sino-atrial** (SA) node (60-90 bpm)
  - **Atrial-ventricular** (AV) node (gateway, pauses signal, 40-60 bpm)
  - **Bundle of His** and **Purkinje** (25-45 bpm)



Autonomic nervous system (ANS)



(Source: merckmanuals.com)

sympathetic nervous system (SNS)

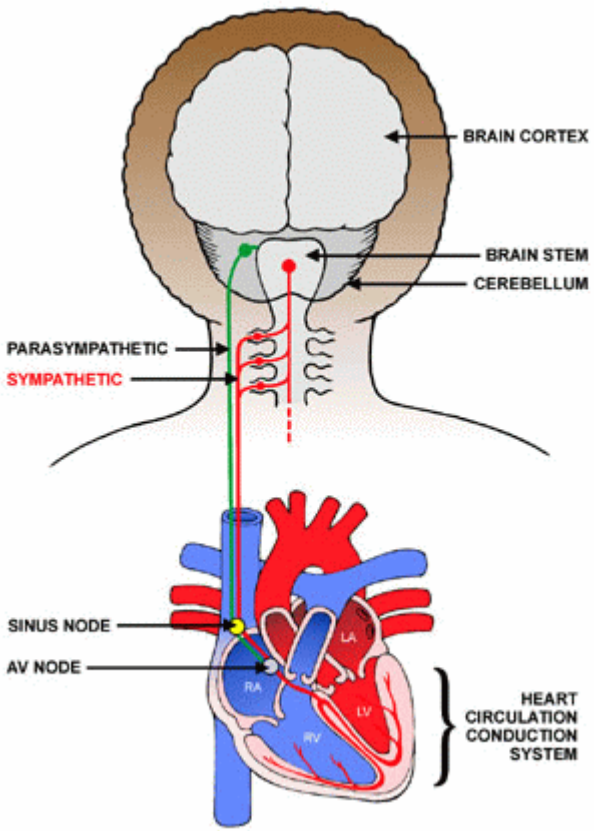
+

parasympathetic nervous system (PSNS)

→ HRV = fluctuations in ANS inputs

Physiology of HRV

dual innervation of the heart by the ANS:

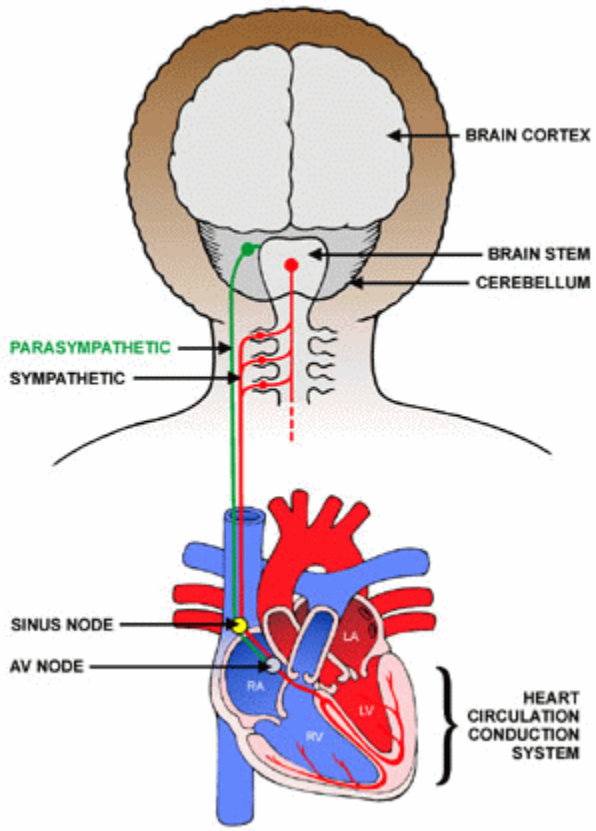


increase in **sympathetic** activity (slow, seconds, nor/epinephrine)

→ **HR increase** (shorter IBIs)

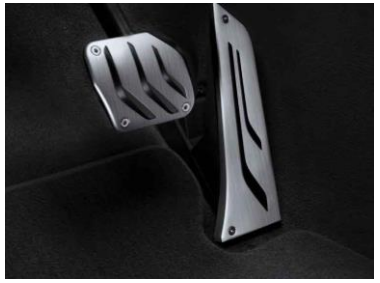
increase in **parasympathetic** activity (primarily vagal, fast, ms, acetylcholine)

→ **HR decrease** (longer IBIs)



Physiology of HRV – remarks

- At rest, HR is **balanced** by both sympathetic (SNS) and parasympathetic nervous system (PSNS)

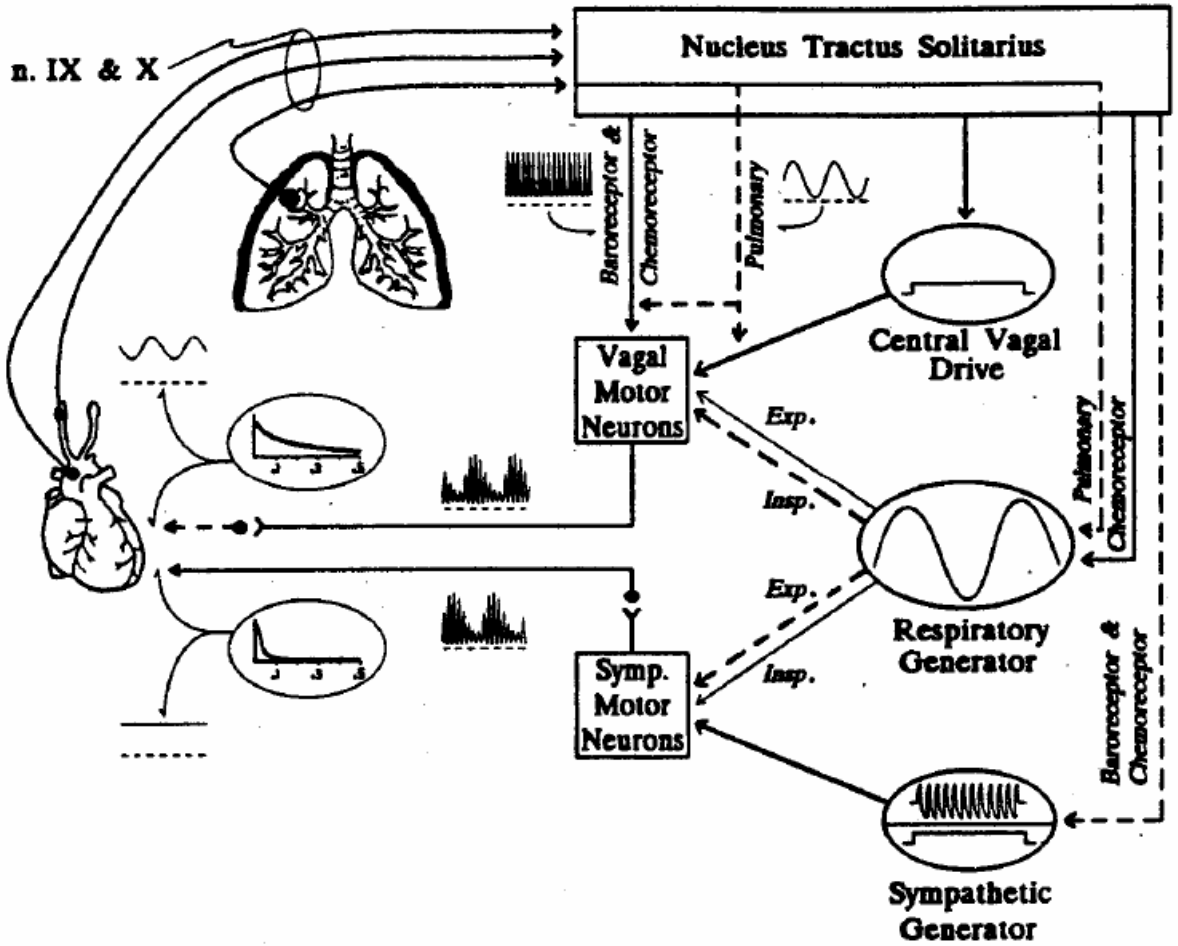


- Intrinsic HR is higher than HR_Rest → Heart is under **tonic inhibitory control** by PSNS (vagus)

- SNS influences are **slow** → high-frequency HRV (above 0.15 Hz) represents PSNS influences

Physiology of HRV – influences

1) reflex-related changes in **blood pressure**, **oxygen**, **carbon dioxide** levels detected by **baroreceptors** and **chemoreceptors**, resp.
2) Mechanical changes in **respiration**: IBI shortened during inspiration and prolonged during expiration → respiratory sinus arrhythmia (RSA)
3) Tonic and reflexive changes in **CNS activity** (mainly brainstem but also <u>cortex</u>)

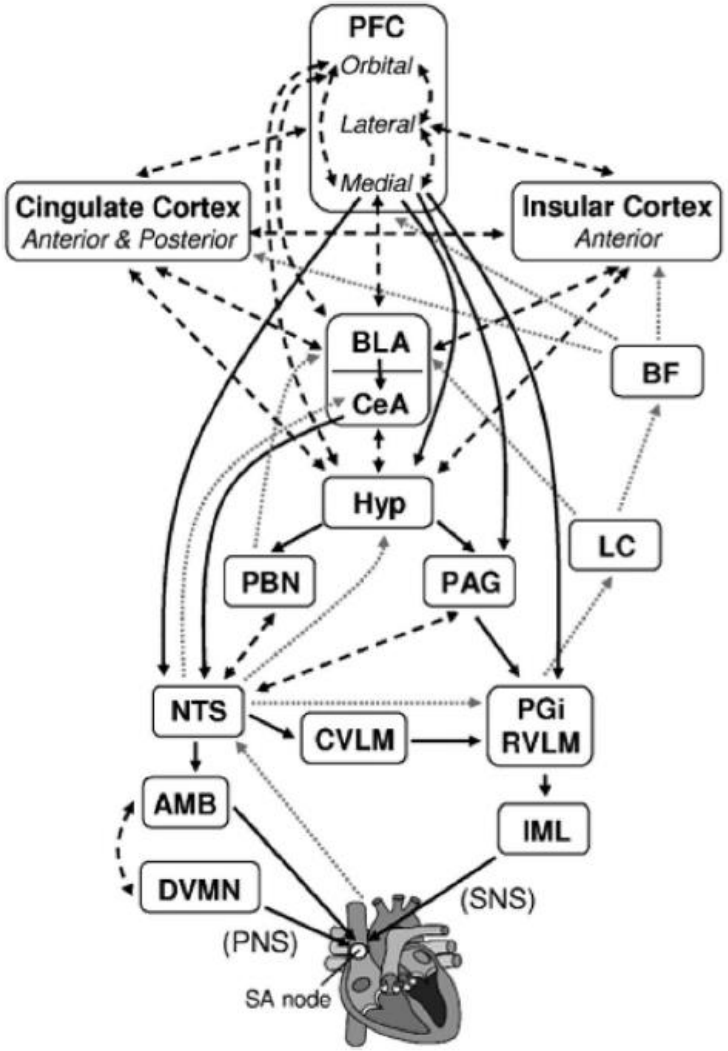


Heart & Brain: Neurovisceral integration

Claude Bernard (1867): mutual action and reaction between brain and heart

Thayer & Lane (2000, 2009): inhibition is critical to effective functioning in a complex environment

→ **cortical activity tonically inhibits brainstem cardioacceleratory circuits**

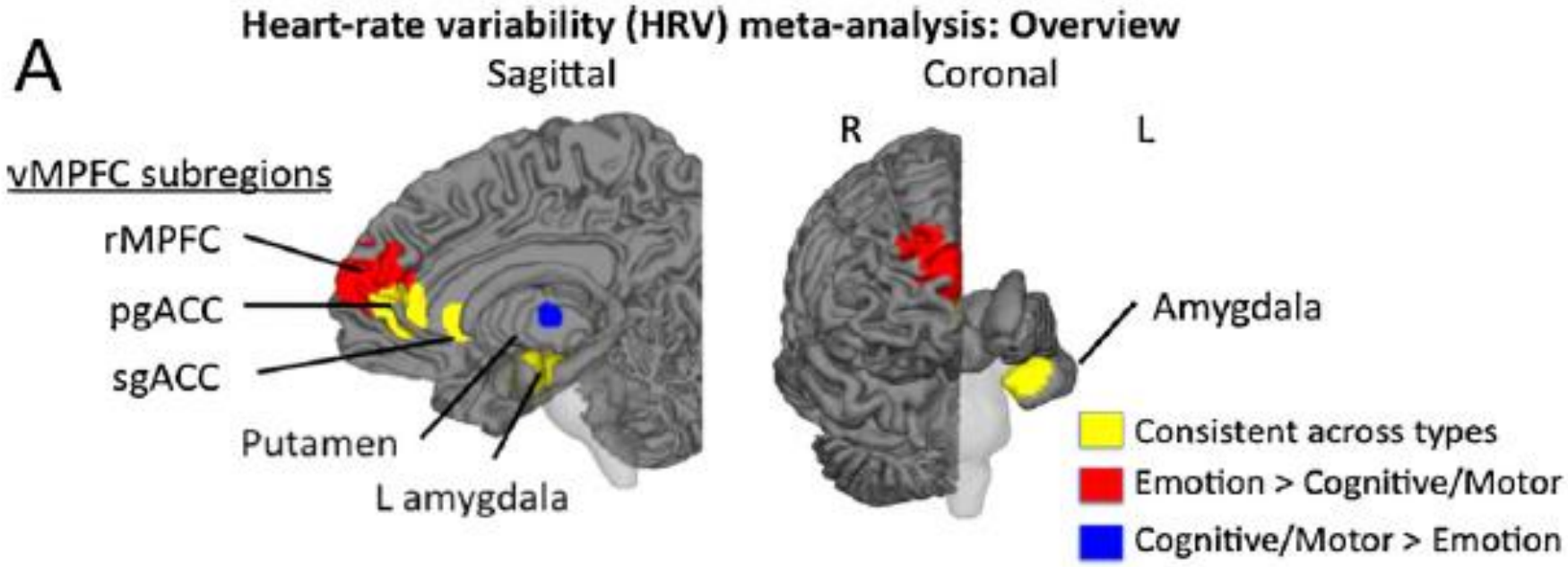


Park et al., 2012

Heart & Brain: Cortical cardioregulation

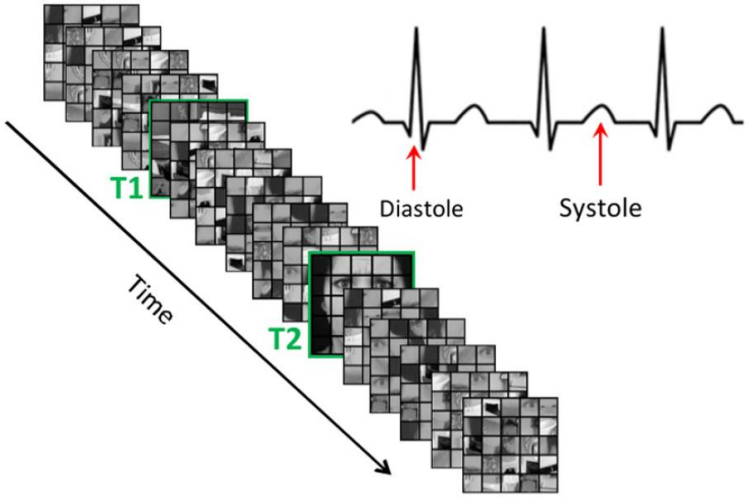
MPFC/ACC (& AMY) connected to (task-related) HRV

- Meta-analysis w/ 5 fMRT (n=61) and 3 PET (n=133) studies (Thayer et al., 2012)



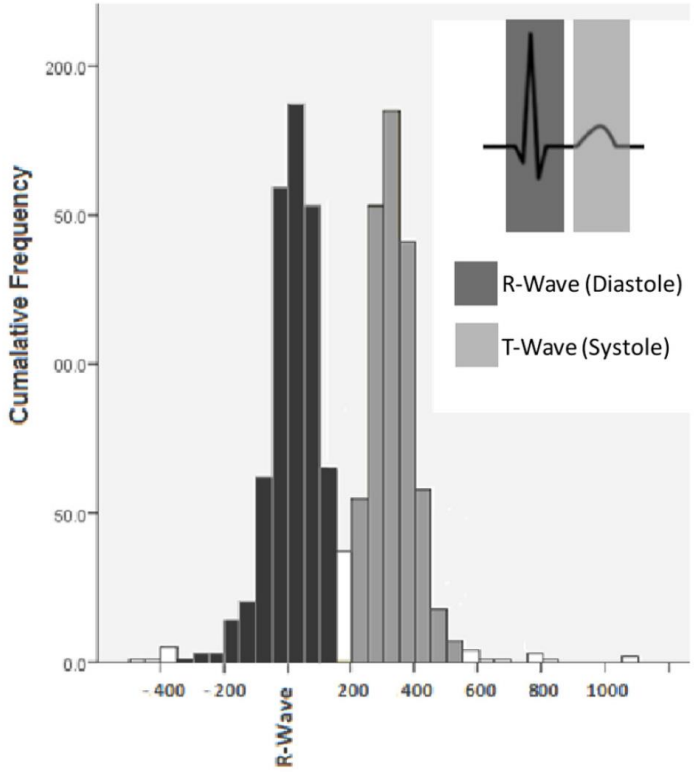
Heart-brain interactions (Garfinkel et al., 2014)

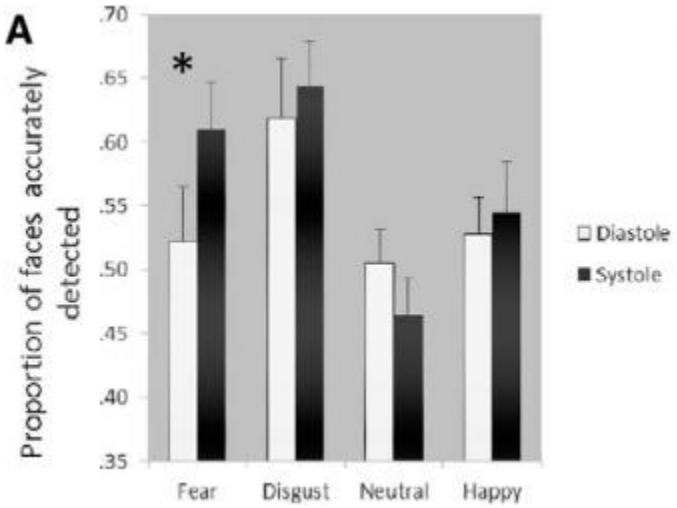
B Emotional Attentional Blink

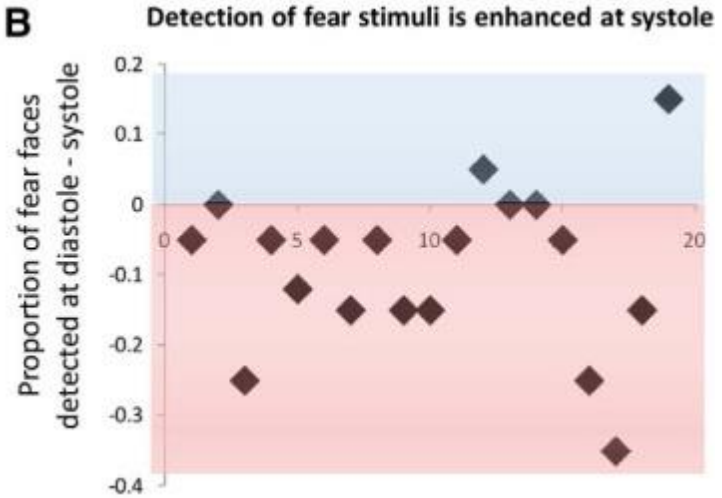


Forced choice test:

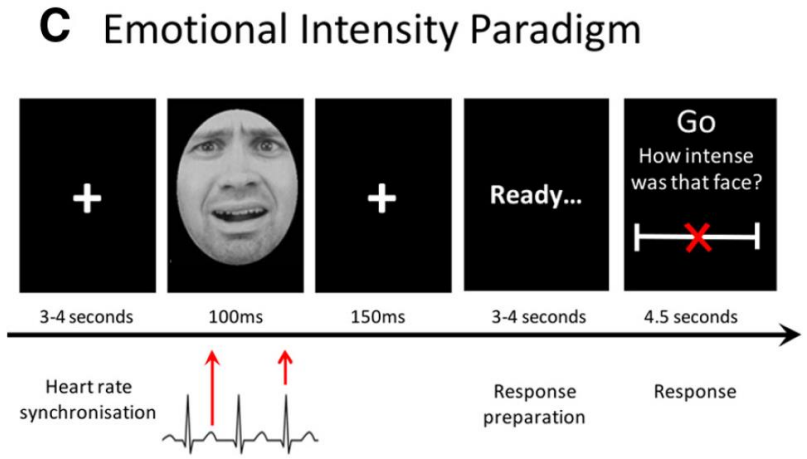
A Histogram detailing stimulus presentation during cardiac cycle

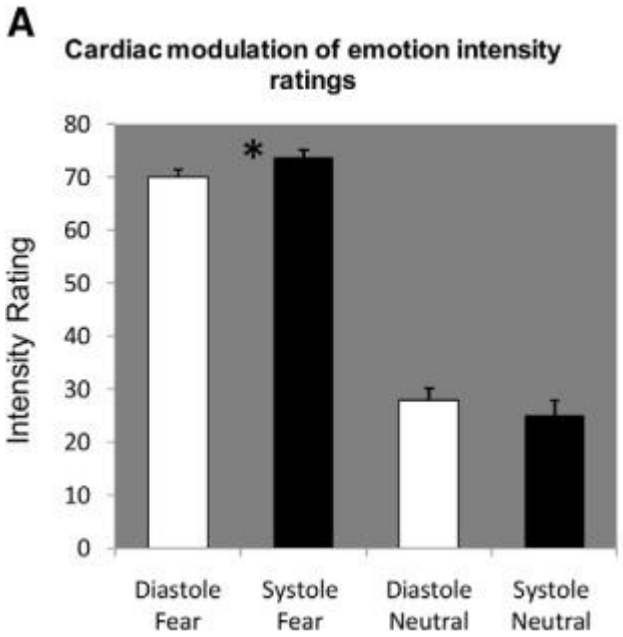


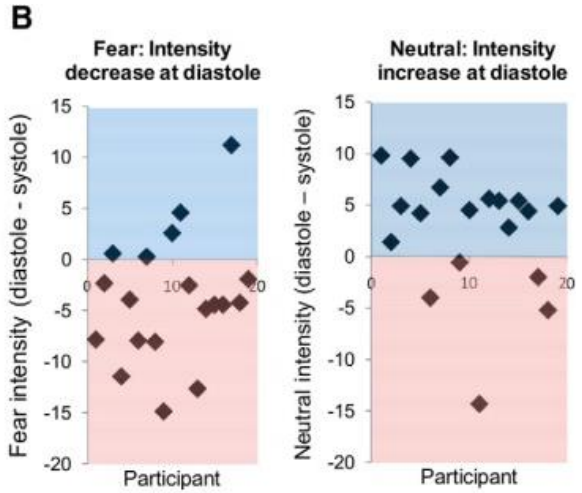


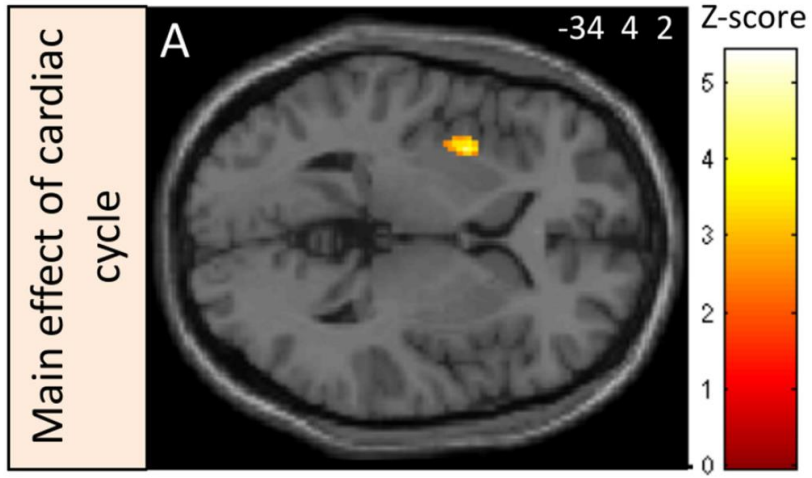


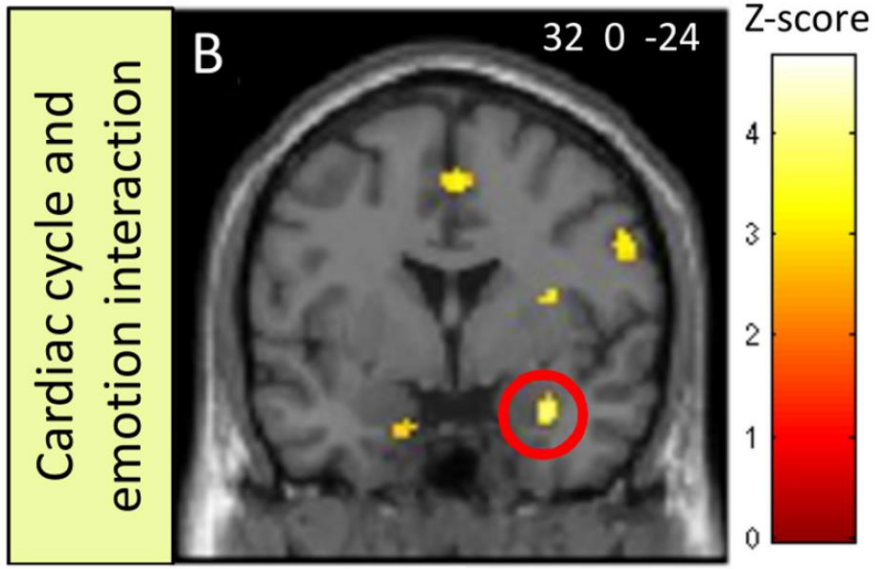
Heart-brain interactions (Garfinkel et al., 2014)





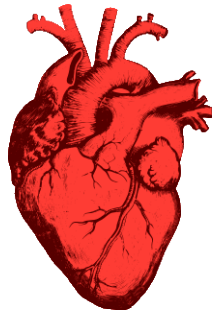


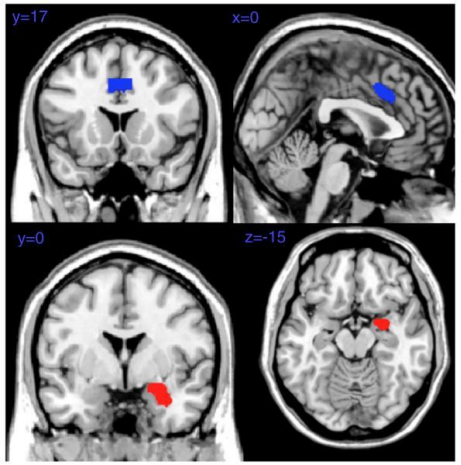


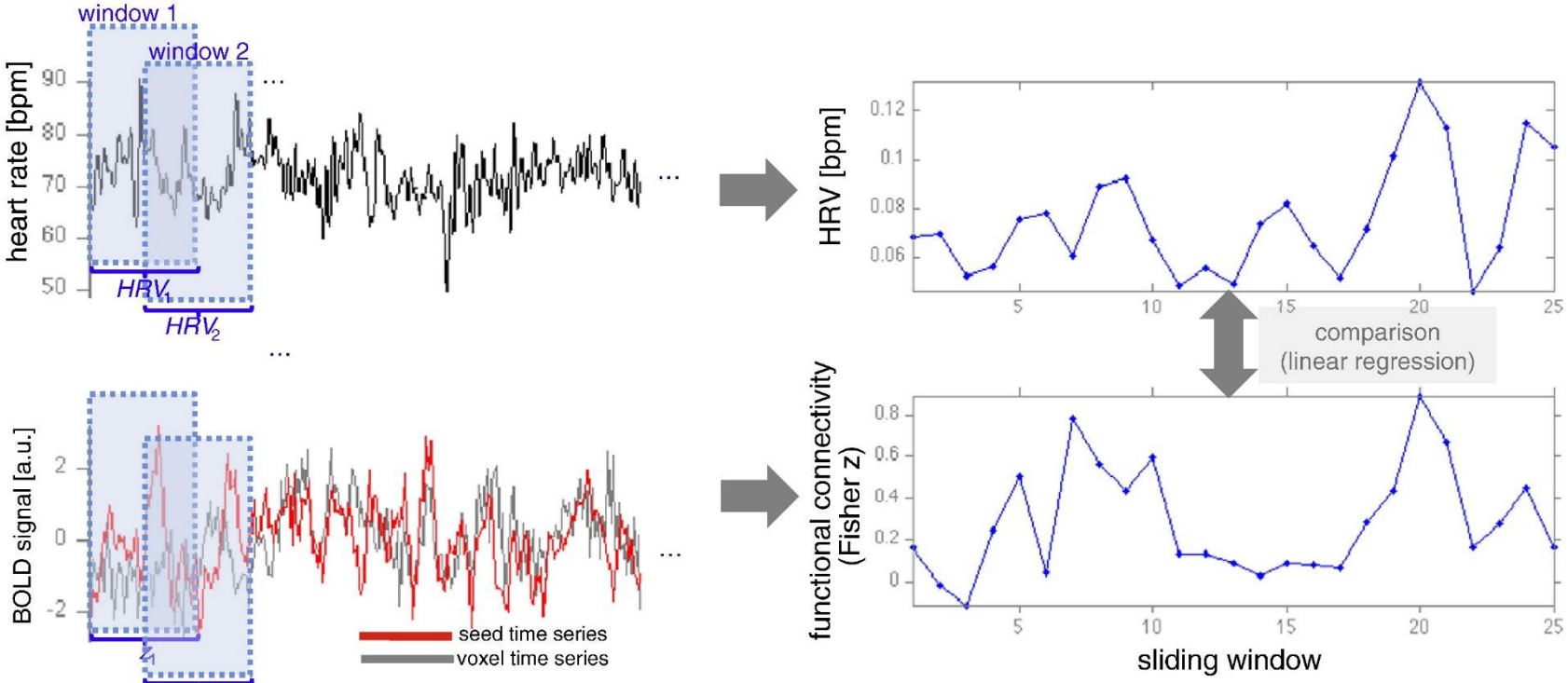


Heart & Brain: Cortical cardioregulation 2

Chang et al., 2013: Resting-state fMRI and (resting) HRV

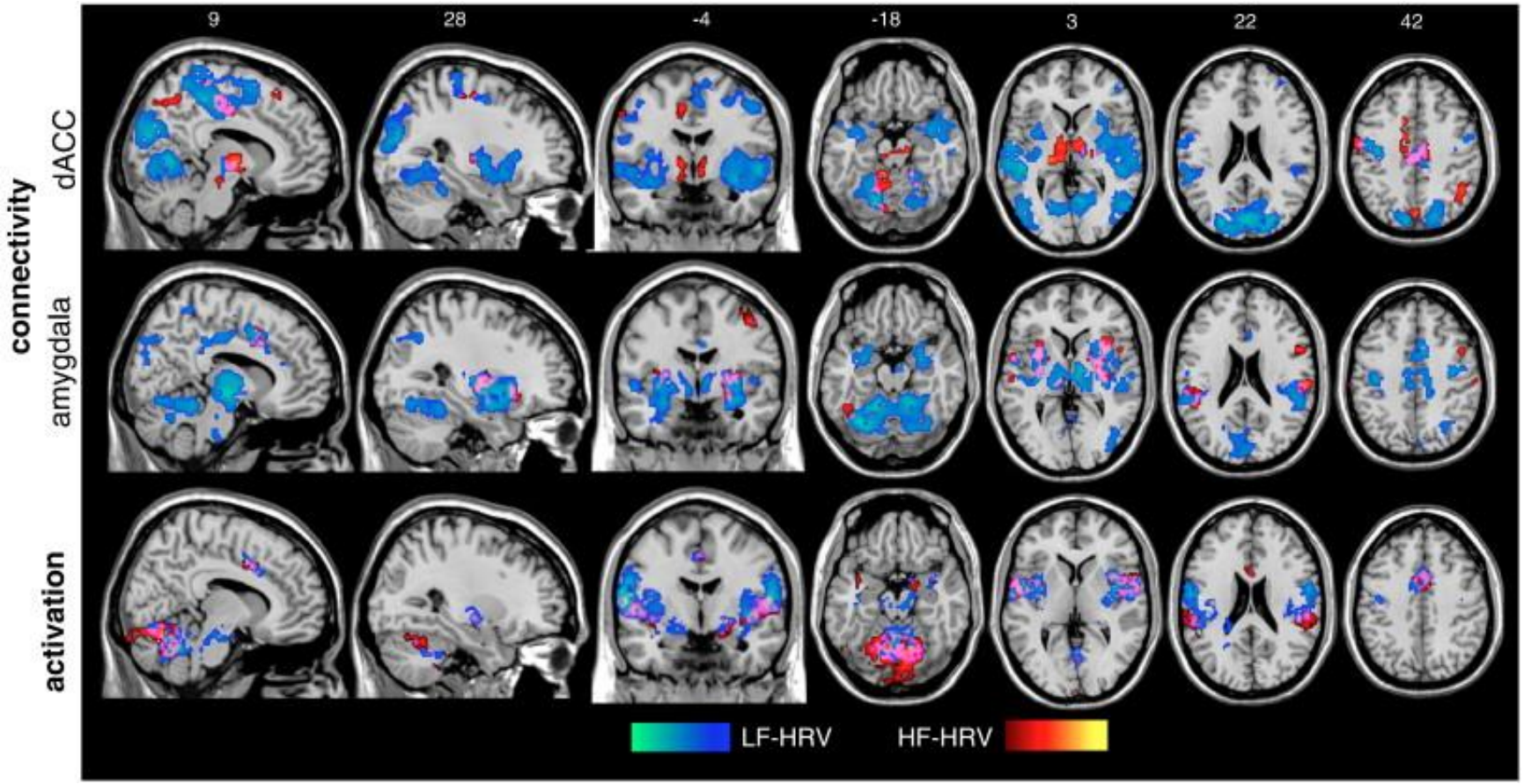


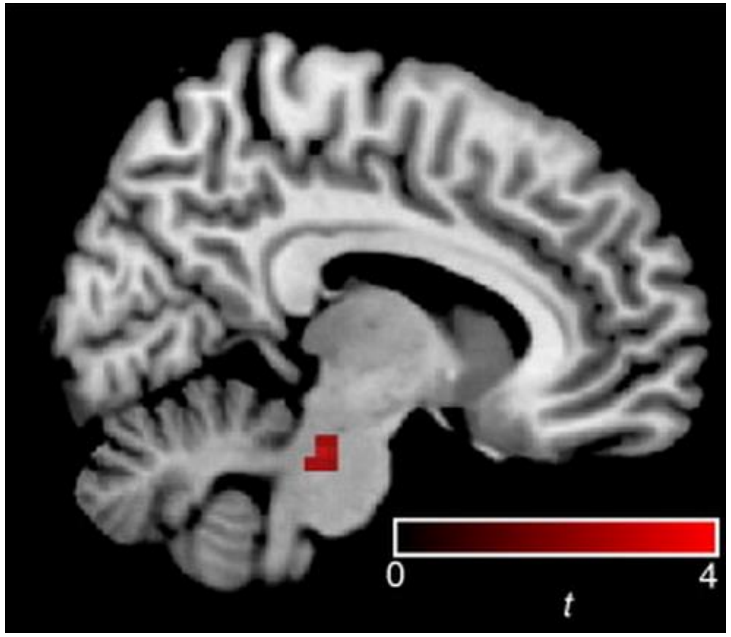




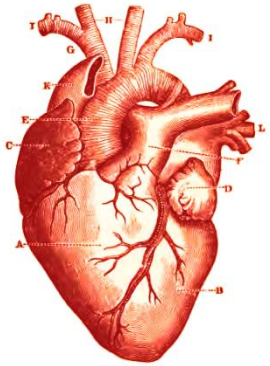
Heart & Brain: Cortical cardioregulation 2

Chang et al., 2013: Resting-state fMRI and (resting) HRV

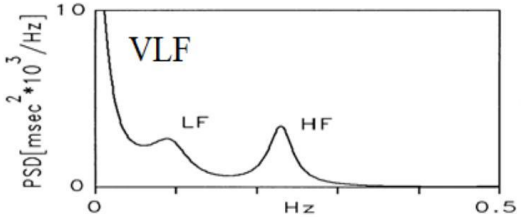




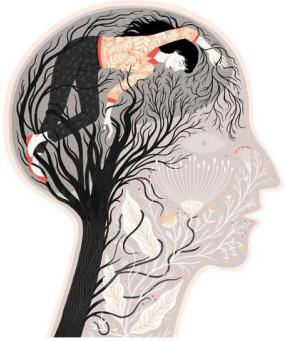
Specific to HF-HRV



Physiologie der HFV



Auswertung der HFV



Psychologie der HFV

Die Herzfrequenz & ihre Variabilität (HFV)

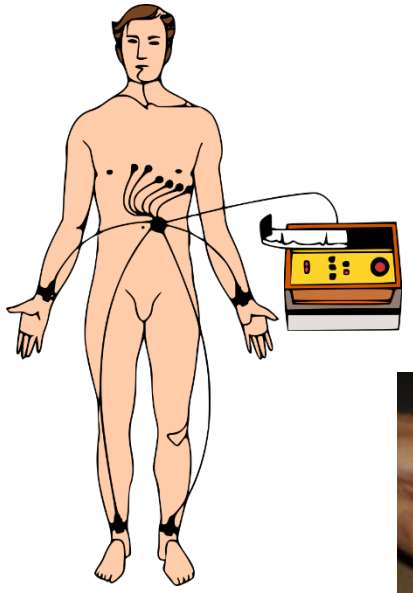
- **Herzfrequenz (HF) oder "heart rate"** (HR): Anzahl der Herzschläge pro Minute (bpm) → vgl. Puls

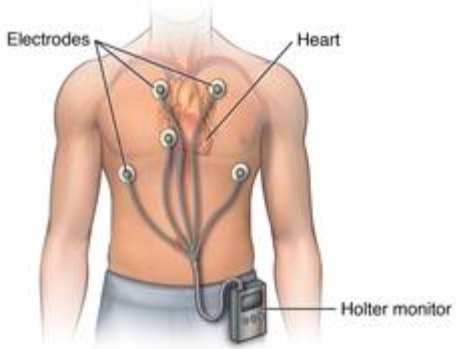
- **Ruhe-Herzfrequenz**: Person ruhend und wach (60-80 bpm)

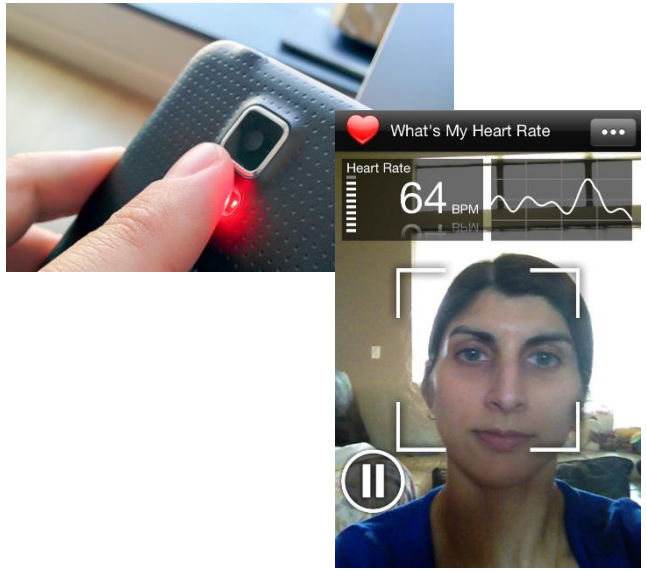
- **HF-Variabilität** (HFV): Variationen in den "beat-to-beat" oder "interbeat" Intervallen (IBI, auch: RR oder NN)

Wie wird HF(V) gemessen?

- **Kontinuierliche** Messung der IBIs (HF) über einen gewissen Zeitraum
- Normale Atmung
- **Sampling rate**: min. 100, eher 250-500 Hz (Task Force)

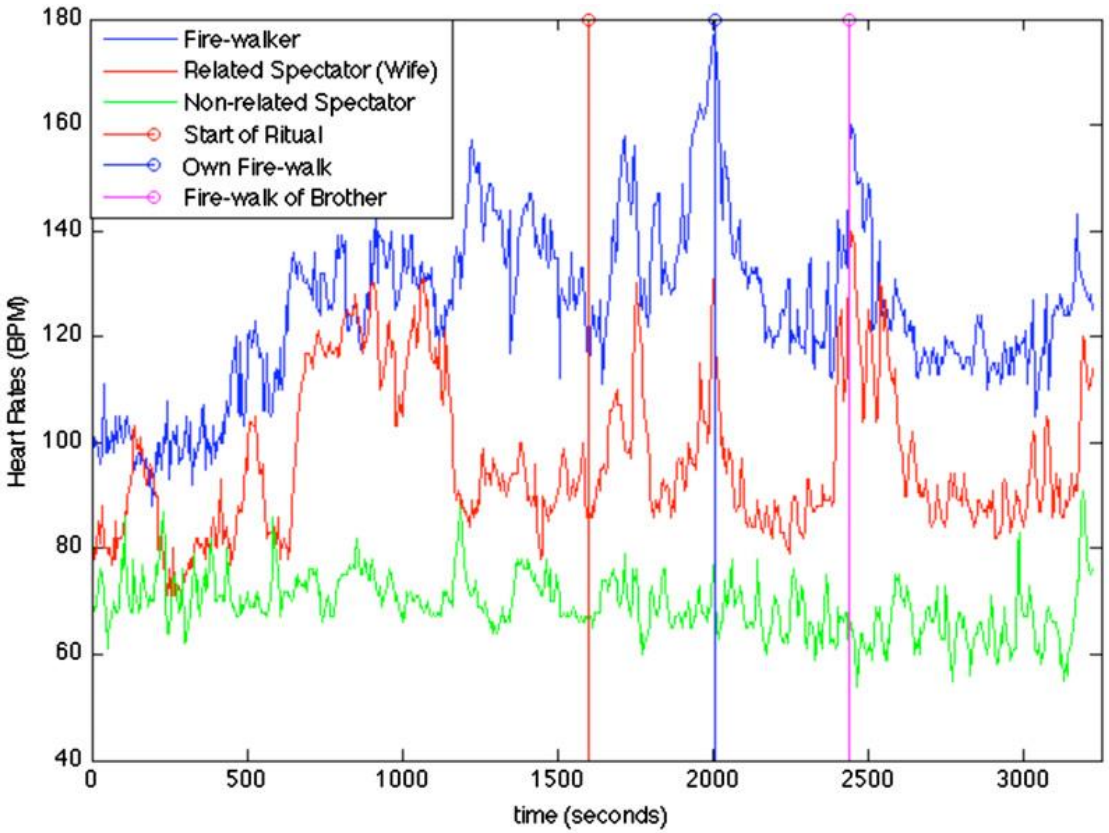






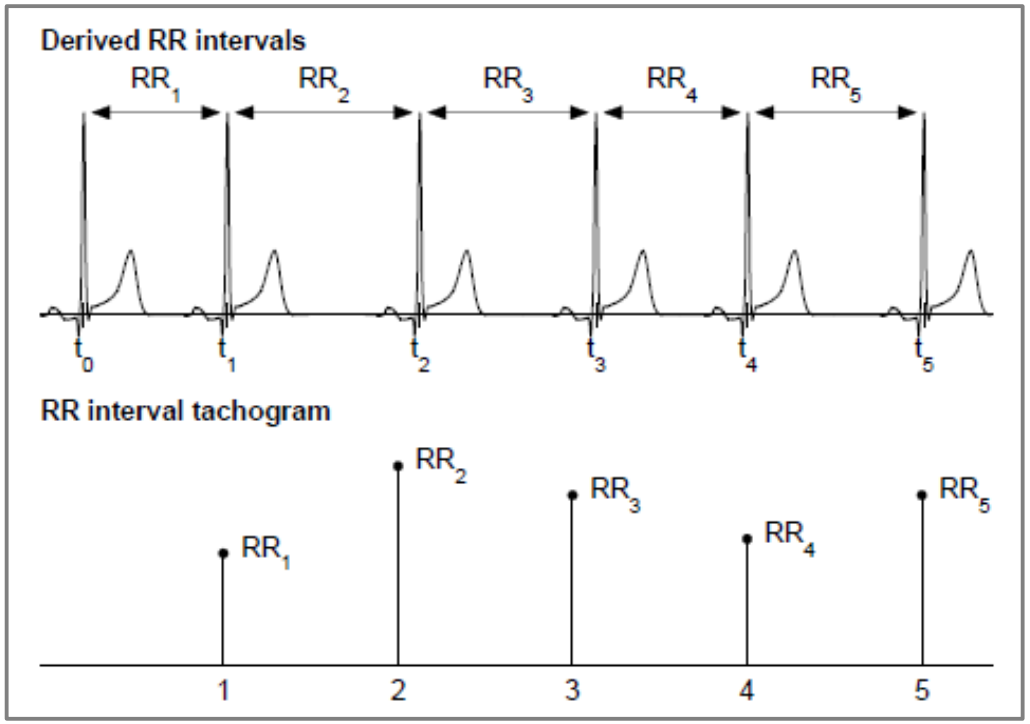
Ecological heart rate recordings

Konvalinka et al. (2011) Synchronized arousal between performers and related spectators in a fire-walking ritual. *PNAS*.



Measures of HR/V– time-domain

NN/RR/IB intervals; time domain = best for long-term (24h) recordings



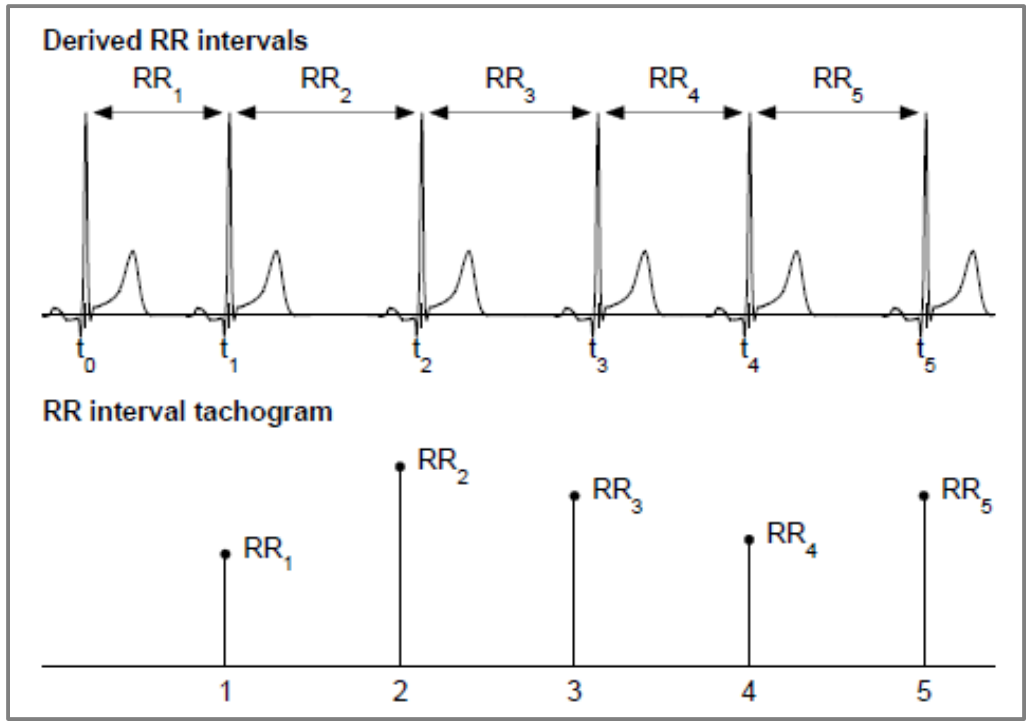
- Mean NN, mean HR, difference between shortest and longest NN
- Sqrt(var) = SD of NN intervals (**SDNN**) → estimate of overall HRV
- Sqrt of mean squared difference of successive NN intervals (**RMSSD**) → short-term components of HRV
- Number (**NN50**) and proportion (**pNN50**) of pairs of adjacent NN intervals with diff > 50ms

RMSSD, (p)NN50 = PSNS-mediated HRV

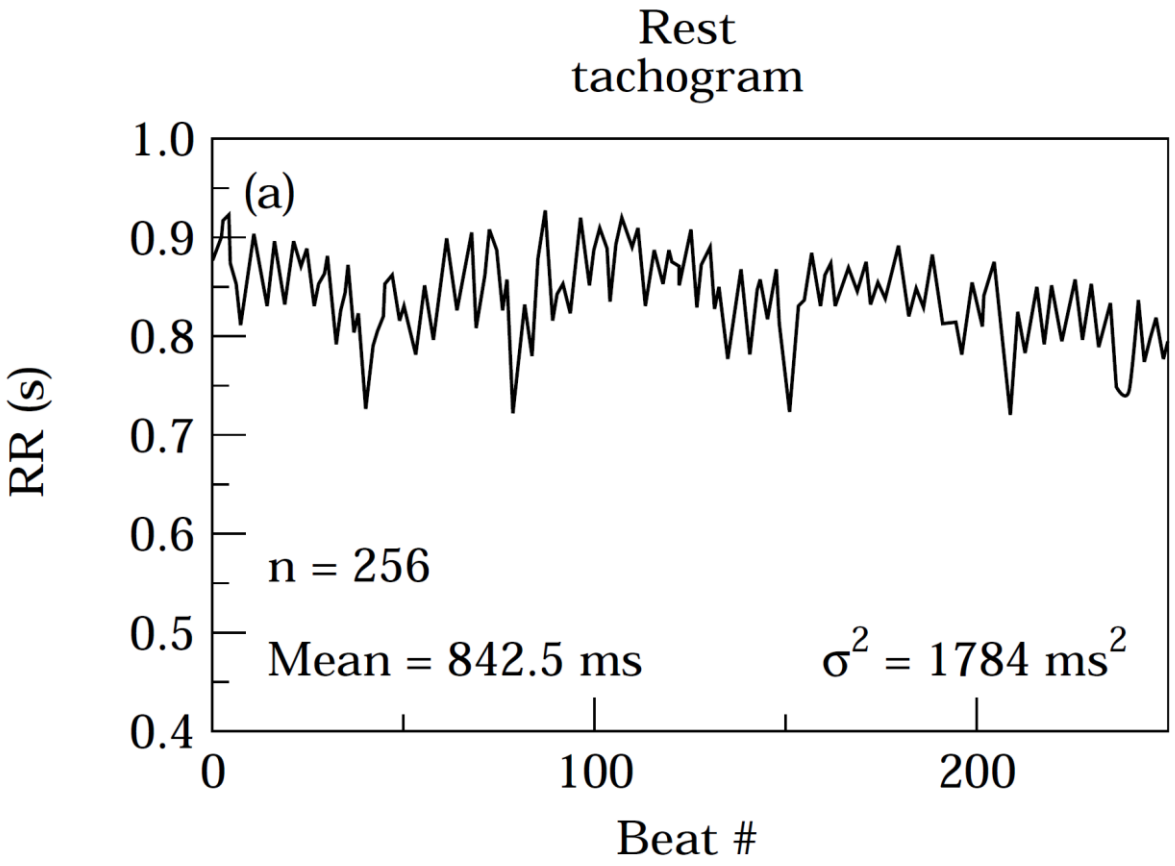
- NB: total variance of HRV increases with recording length

Measures of HR/V– time-domain

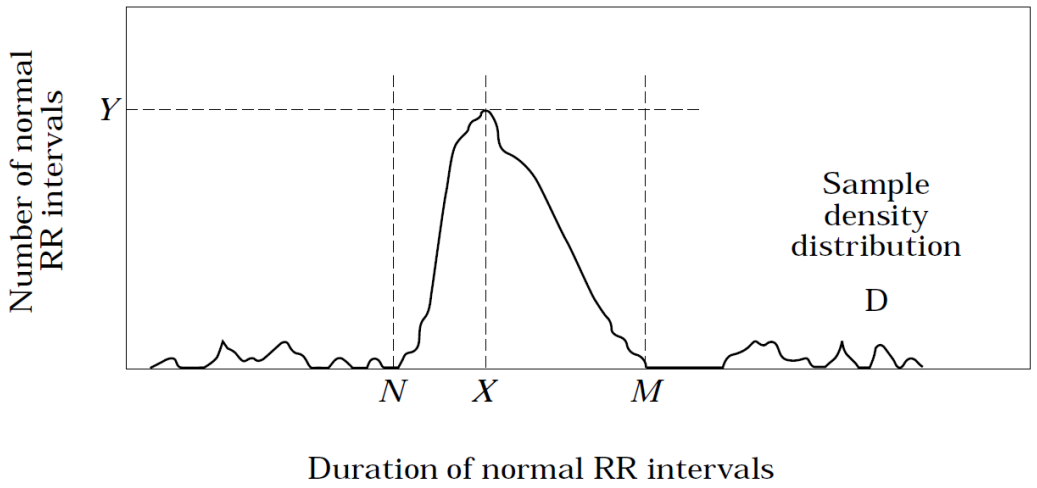
Discrete event series (DES)



RR interval tachogram

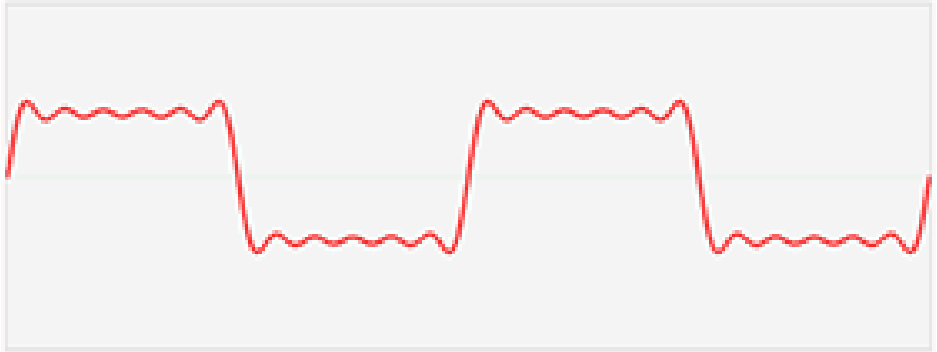


Geometrical and nonlinear measures



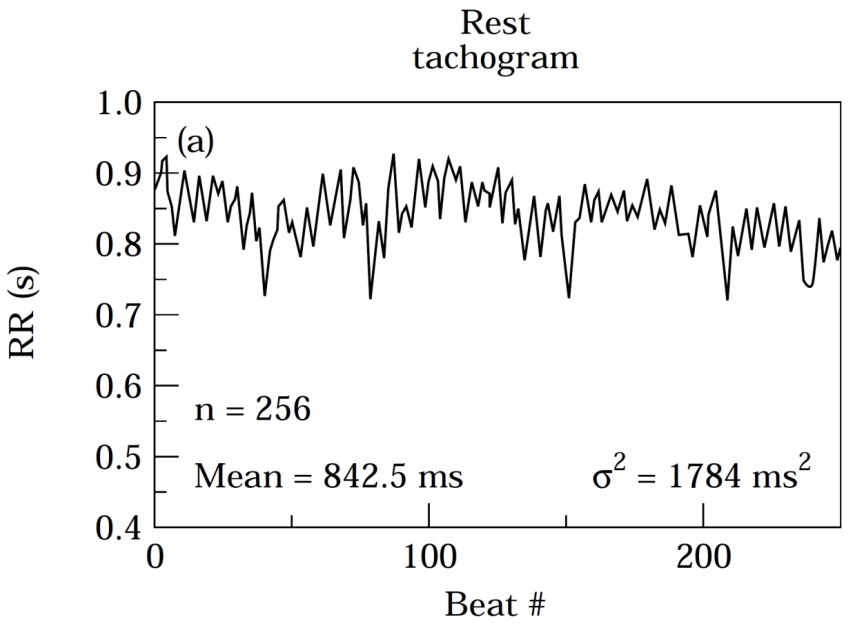
- **Geometrical** measures: on NN interval histogram – HRV **triangular index** and **triangular interpolation** of NN interval histogram → recordings of at least 20 min (preferably 24h)
- **Nonlinear** measures: e.g., **Poincaré plots** and **approx. entropy** (ApEn) → difficult to interpret (physiologically)

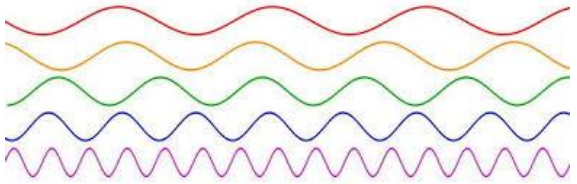
Fourier Transform: time ↠ frequency

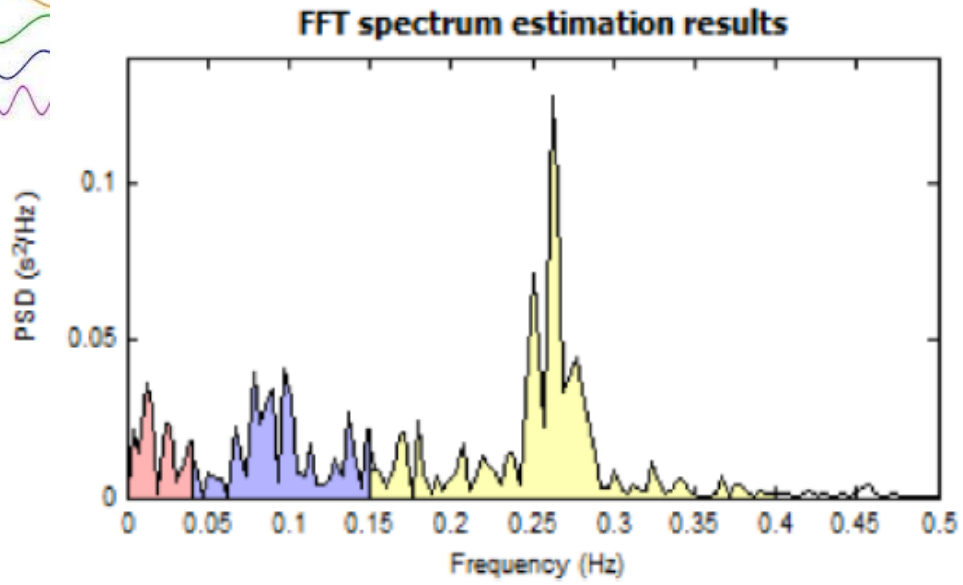


Source: Wikipedia/Wikimedia (also cf. youtube)

Fourier Transform: time ↠ frequency







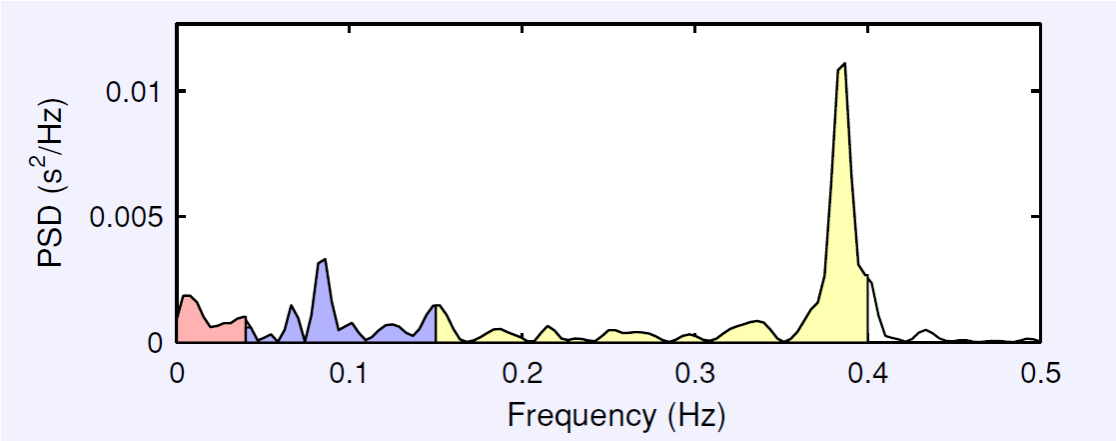
Power spectral (density; PSD) analysis of heart rate fluctuations (Akselrod, 1981)

Measures of HR/V– frequency-domain

power in frequency bands (FFT or AR):

- Very low Frq (**VLF**): 0-0.04 Hz (NB: not for short-term recordings of 5 min or less)
- Low Frq (**LF**): 0.04-0.15 Hz (~3-9 times / minute) → PSNS + SNS
- High Frq (**HF**): 0.15-0.4 Hz (9-24 times / minute) → PSNS (vagal)
- LF/HF ratio (careful!)

→ absolute values (ms^2) or normalized units (n.u.) → Normalization emphasizes balancing of SNS and PSNS (but always also report absolute values)



Physiological evidence

- Total **autonomic blockade** nearly eliminates all HRV
- **HF-HRV** modulated by **PSNS antagonists** or **vagotomy** (abolished) and **electrical vagal stimulation** (increased)
- **LF-HRV** reduced with either **SNS or PSNS antagonists**

→ NB: HF-HRV (PSNS) more clearly understood physiologically; central and peripheral contributions

HFV-Auswertung

Articles

Heart Rate Variability

Standards of Measurement, Physiological Interpretation, and Clinical Use

Task Force of the European Society of Cardiology the North American Society of Pac

Correspondence to Marek Malik, PhD, MD, Chairman, Writing Committee of the Task Force, Department of Cardiological Sciences, St George's Hospital Medical School, Cranmer Terrace, London SW17 0RE, UK.

This Article

Circulation. 1996;93:1043-1065
doi: 10.1161/01.CIR.93.5.1043

- Extract *Free*
- Figures Only *Free*
- » Full Text *Free*
- PPT Slides of All Figures

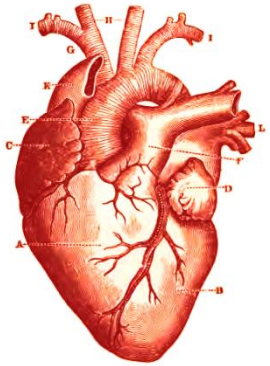
Psychophysiology, 34 (1997), 623–648. Cambridge University Press. Printed in the USA.

COMMITTEE REPORT

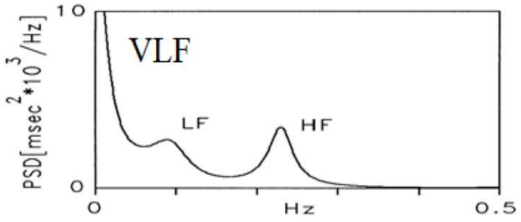
Heart rate variability: Origins, methods, and interpretive caveats

GARY G. BERNTSON,[a] J. THOMAS BIGGER, JR.,[b] DWAIN L. ECKBERG,[c] PAUL GROSSMAN,[d] PETER G. KAUFMANN,[e] MAREK MALIK,[f] HAIKADY N. NAGARAJA,[g] STEPHEN W. PORGES,[h] J. PHILIP SAUL,[i] PETER H. STONE,[j] AND MAURITS W. VAN DER MOLEN[k]

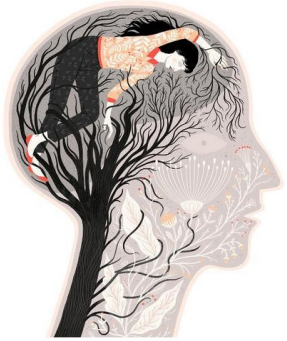
- HFV ist nicht gleich HFV (Vielzahl an **Maßen**)
- HFV verschiedener **Messdauer** nicht direkt vergleichbar
- Liegend versus stehend
- Verlässliche **R-Zacken Detektion** benötigt (z.B., Kubios)
- Extrasystolen und andere Arrythmien, fehlende Daten und Rauschen beeinflussen HFV-Maße → **Interpolation** und **Korrektur** (Kubios)



Physiologie der HFV



Auswertung der HFV



Psychologie der HFV

Trait HFV (in Ruhe) ↠ höher = besser

HFV als **individuelles Maß physischer und psychischer Gesundheit** → Messung: 5 Minuten in **Ruhe**

- HFV verringert bei kardiologischen aber auch nicht-kardiologischen Patienten, z.B. mit **Guillain-Barré Syndrom** (Flachenecker et al., 1997)
- HF-HFV prädiziert **Überleben nach Herzinfarkt** (e.g., Kleiger et al. 1987)
- Niedrige HFV als **Risikofaktor für Herz-Kreislauf-Erkrankungen** (32-45% erhöht nach Meta-Analyse von Hillebrand et al., 2013) und ***generelle*** **Mortalität** (z.B. Liao et al., 2002)

HFV und Schlaganfall

- **EKG-Änderungen** nach Schlaganfall
  - Akut (Dimant & Grob, 1977; Orlandi et al., 2000)
- **HFV-Änderungen** nach Schlaganfall
  - Nach 4-12 Wochen (Lakusiv et al., 2003)
  - Nach 6 Monaten (besonders bei Insel-Läsionen; Korpelainen et al., 1999)
  - Unklar nach 9 Monaten (McLaren et al., 2005, aber Kouakam et al., 2000)

→ Veränderungen in HFV nach Schlaganfall

→ Aber: Wenige Studien + versch. Maße und Messdauern

HFV und Psychopathologie

Verringerte HFV bei:

- **Depression** (Meta-Analyse: Kemp et al., 2010)
- **Angststörungen**
  - Sozialphobie (z.B. Gaebler et al., 2013)
  - PTBS (z.B. Wahbeh & Oken, 2013)

  → Meta-Analyse (Chalmers et al., 2014)

→ **NB**: Medikationseinfluss (Kemp et al., 2010)

HFV als unabhängige Variable

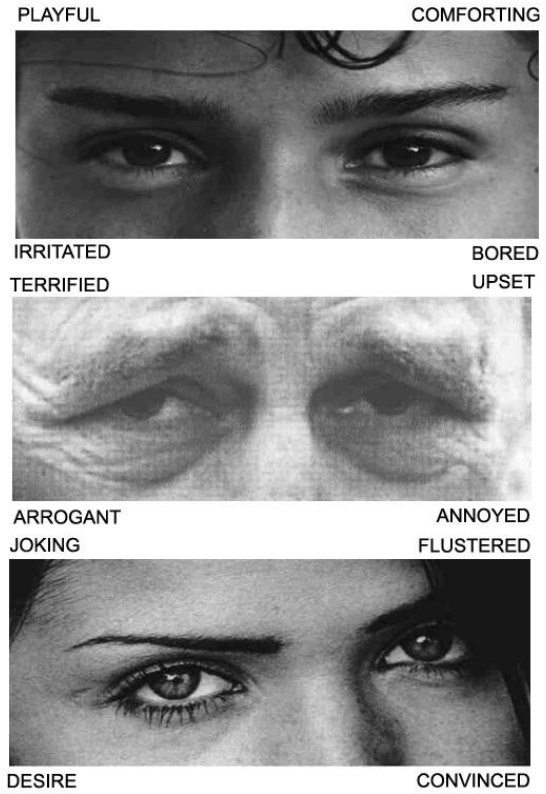
HFV als Messparameter in **Versuchsaufbauten**

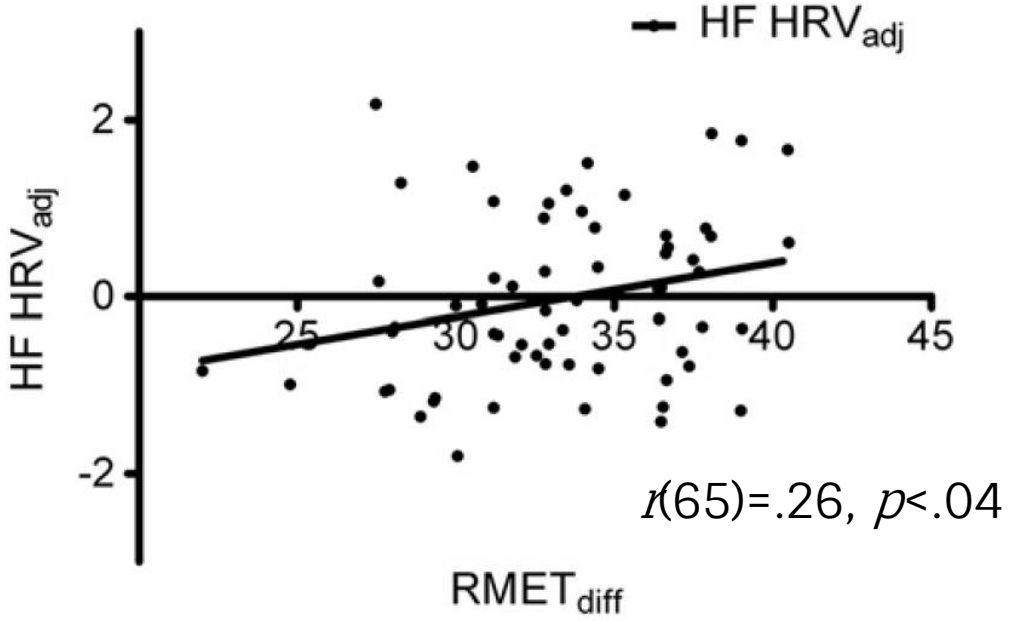
→ **Flexibilität** im Verhalten und **Aufmerksamkeit/Beschäftigung** mit der Umgebung (Thayer & Lane 2000, 2009; Porges, 2001, 2003)

- **Emotionsverarbeitung**: Emotionserleben und Emotionsregulation
- **Soziale Kognition** und **Aufmerksamkeit**
- **Stress**
- ...

individuals with higher HF-HRV at rest…

…perform better on a test of **social cognition** and **emotion recognition** (Quintana et al. 2012)

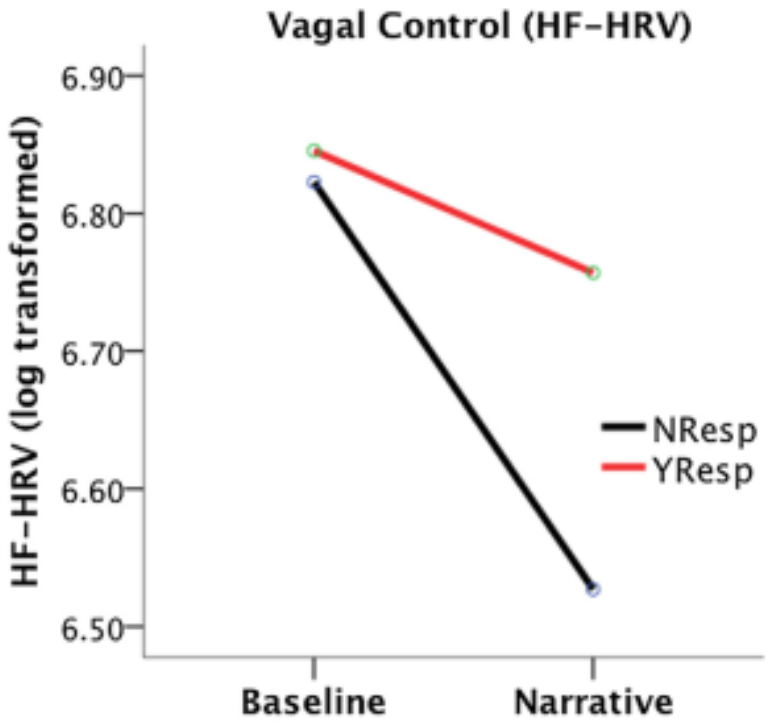




Prosocial behavior and HRV

Barraza et al., 2015

- 100 s **video** of father with a 2yo son who's dying of brain cancer
- **Donors** (red) vs **non-donors** (black)
- subjectively: more **distress** and **concern** in donors than non-donors
- Logistic regression: **HF-HRV predictive of donor status**



HRV and attention

- individuals with higher HF-HRV at rest **inhibit unnecessary processing of affective information** more efficiently (Park et al. 2012).

- However, **on-task HRV** inversely related to **attentional functioning** (Duschek et al., 2009)

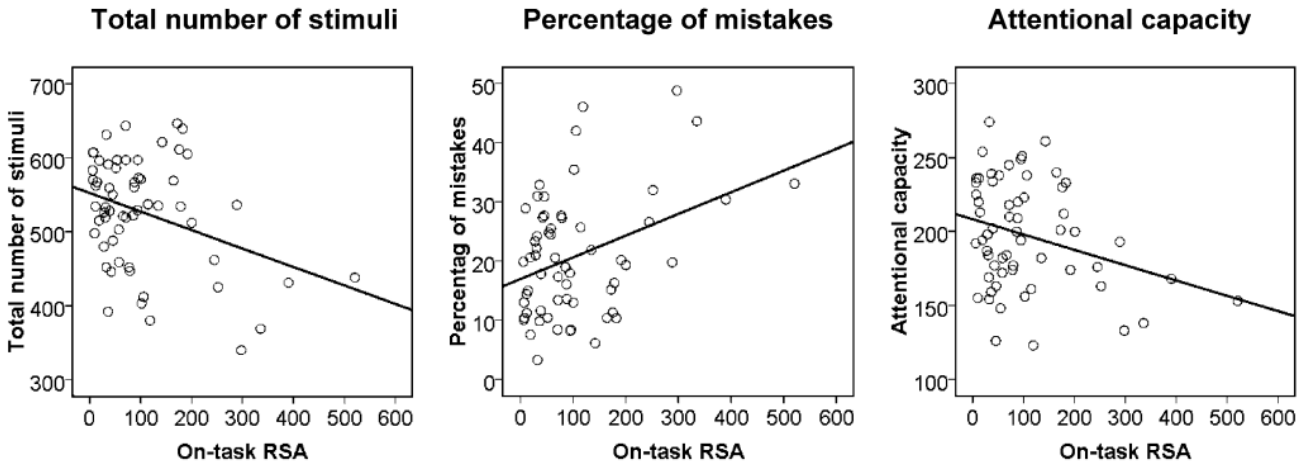
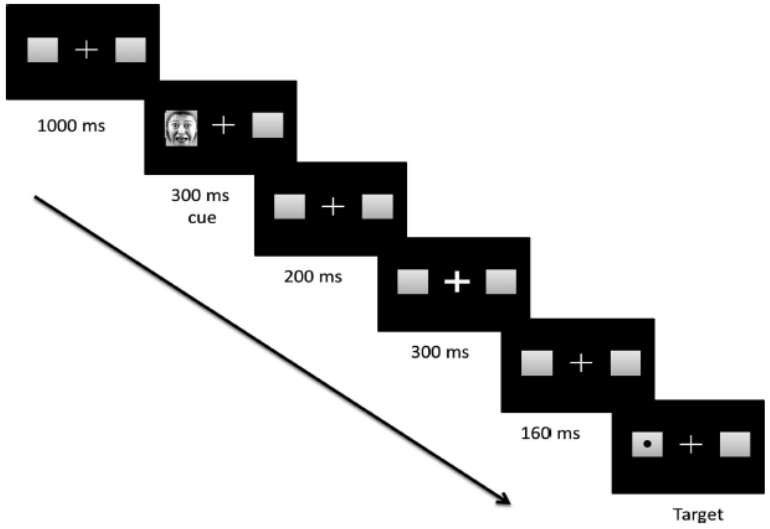


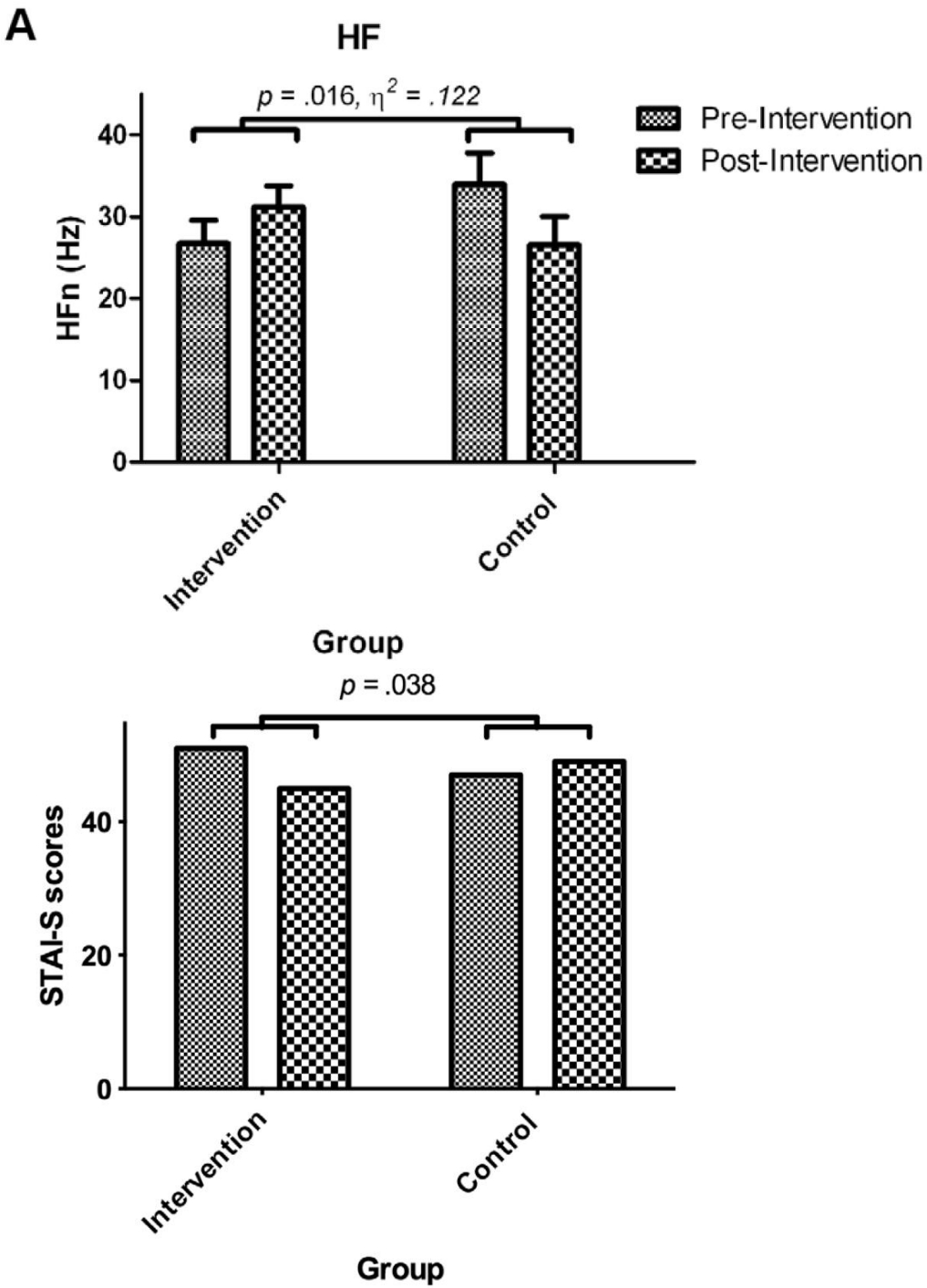
Fig. 2. Scatter plots for the relationships between on-task RSA and the indices of the Test d2.



HRV and acute stress

Wells et al., 2012

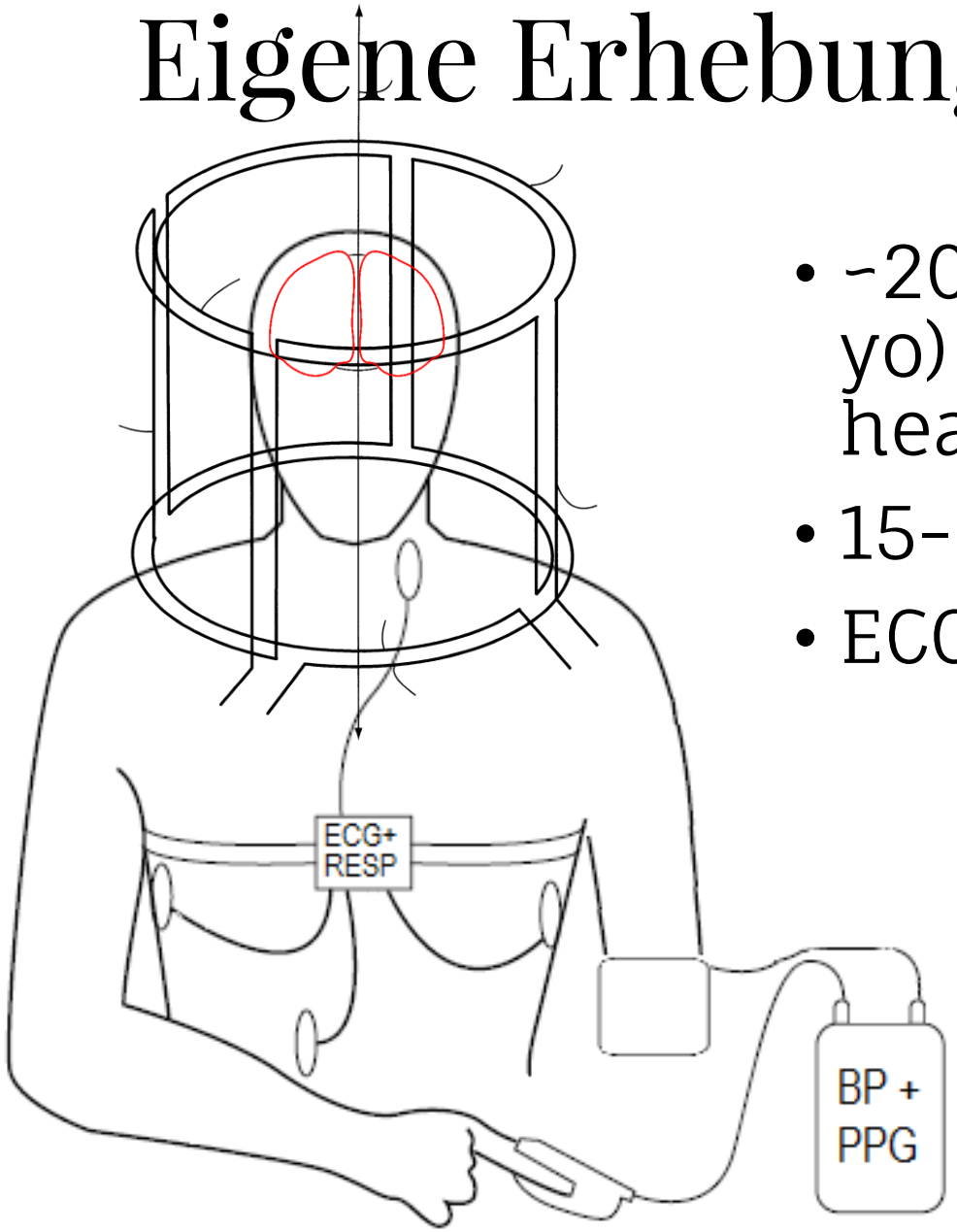
- 42 musicians
- Performance anxiety
- Single 30-min session of HRV biofeedback and slow breathing



More chronic stress ~ lower HRV

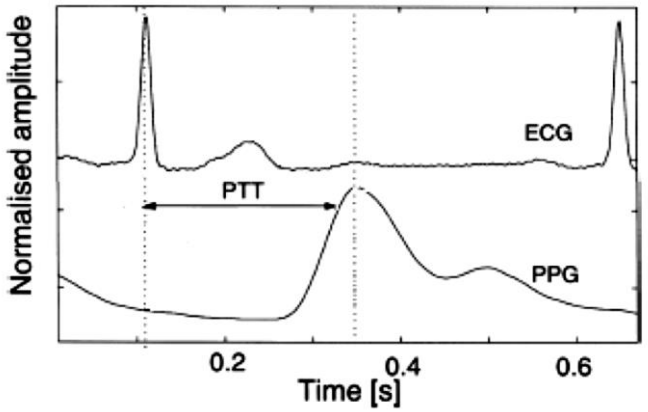
- Greater perceived **emotional stress** during past week - **lower HRV** (HF) at rest (Dishman et al., 2000; n = 92)
- Greater **work stress** - **lower HRV** (HF) at rest (Chandola et al., 2008; n = 10,308)
- Greater **work stress** - **lower HRV** (HF) during 24-h on a work day (Clays et al., 2010; n = 653)

Eigene Erhebungen & Auswertungen



- ~200 younger (20-35 yo) and older (60-75 yo) healthy adults
- 15-min resting-state
- ECG + PPG (+ BP + MRI)

LEMON
LEIPZIG COHORT FOR MIND-BODY-EMOTION INTERACTIONS



PWV = predictor of **incident hypertension** (Najjar et a., 2008) and **cardiovascular mortality** (Blacher et al., 1999)

Eigene Erhebungen & Auswertungen

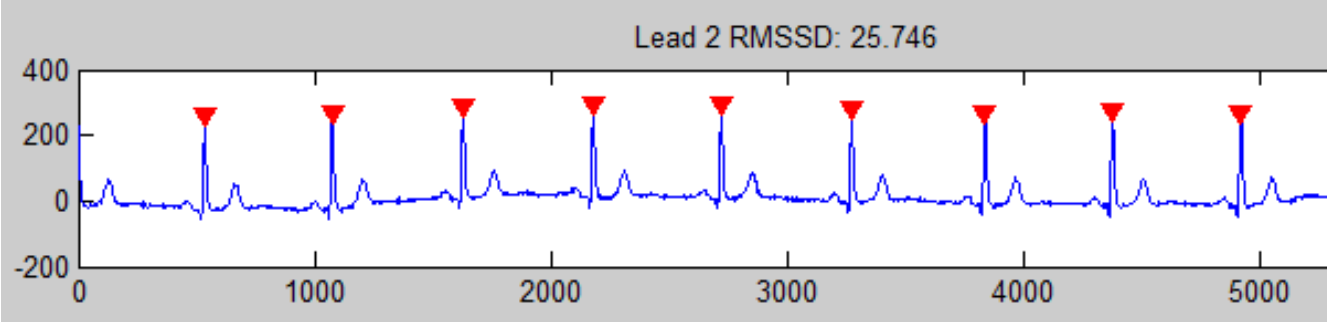
Leipziger Forschungszentrum für Zivilisationserkrankungen (LIFE)

N = ~1,500

Trierer Inventar zur Erfassung von **chronischem Stress** (TICS; Schulz & Schlotz, 1999)

10-s 12-Kanal-Ruhe-EKG (“ultrashort”)

(+ MRT: T1 und resting-state fMRI)



Eigene Erhebungen & Auswertungen

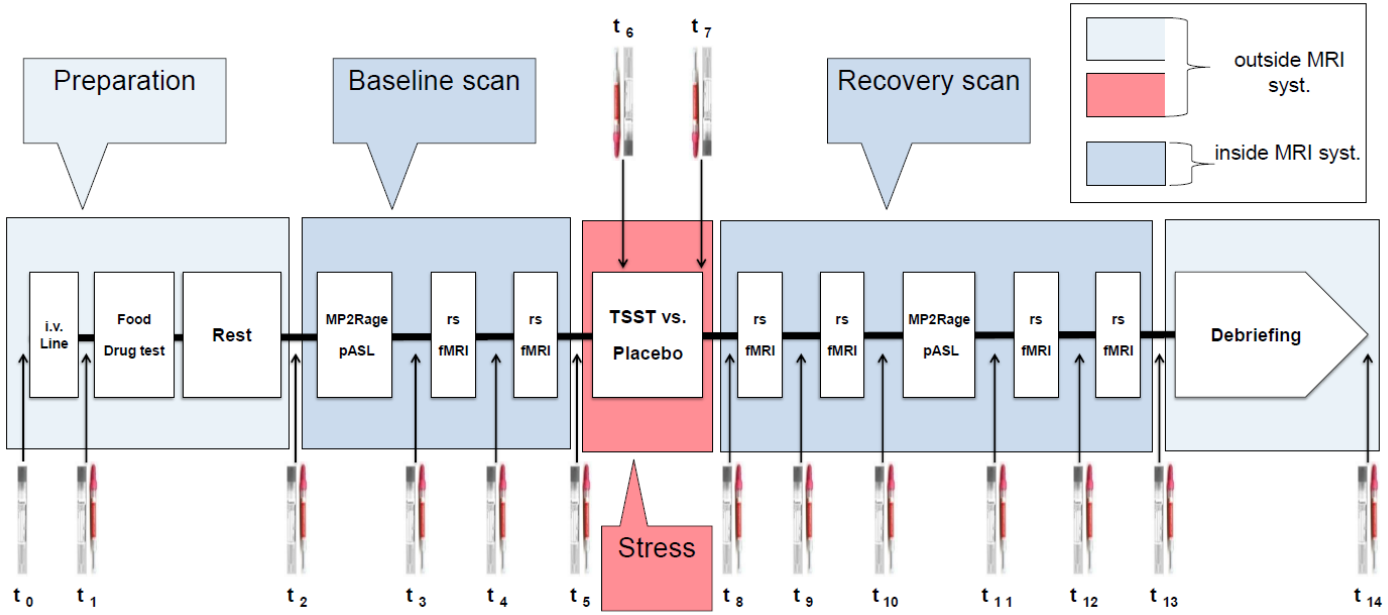
“The physiology and experience of chronic stress in post-meno-pausal women and men in the same age-group”

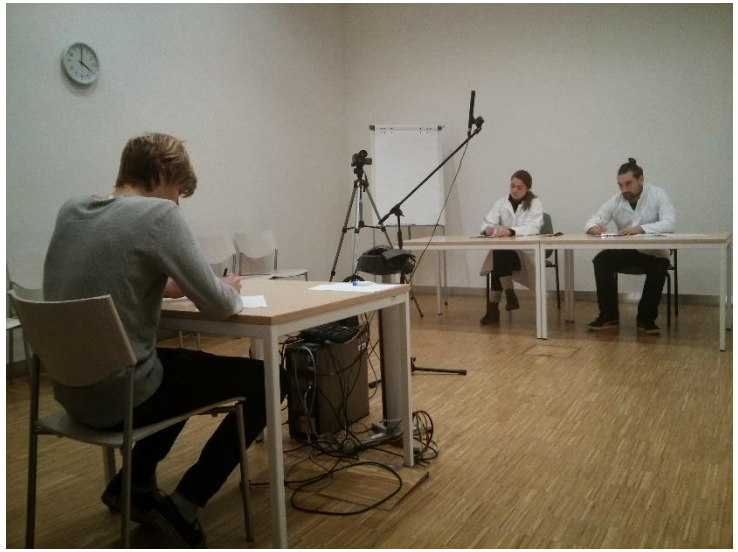
- N = 30
- Ältere Frauen & Männer (60-70 Jahre)
- **7 Tage Dauer-EKG** und stündliche Abfragen (Stress im Alltag)

Eigene Erhebungen & Auswertungen

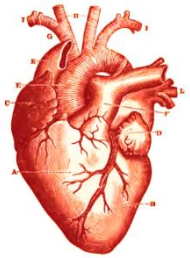
"**Ne**ural **Co**nsequences of **S**tress" (NECOS)

- ~60 gesunde junge Männer
- Trier Social Stress Test (TSST; Kirschbaum et al., 1993)

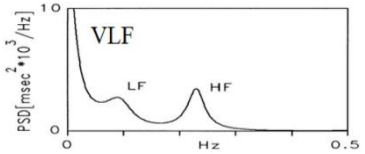




Zusammenfassung



Physiologie: HFV als Maß **parasympathischer Kardioregulation → Herz-Hirn-Interaktion** (Hirnstamm und Großhirn)



Auswertung: Vergleichbarkeiten der Maße (Zeit/Frequenz) und Messdauern

Psychologie: “Trait” und “State” Maß

- Körperliche und geistige Gesundheit
- Aufmerksamkeit, soziale und Emotionsverarbeitung → **Stress**

Europäische Union

Europa fördert Sachsen.
ESF
Europäischer Sozialfonds

LIFE

UNIVERSITÄT LEIPZIG
Medizinische Fakultät

Vielen Dank für Ihre Aufmerksamkeit!

MAX PLANCK INSTITUTE FOR HUMAN COGNITIVE AND BRAIN SCIENCES LEIPZIG

BERLIN SCHOOL OF MIND AND BRAIN

HUMBOLDT-UNIVERSITÄT ZU BERLIN

LEMON
LEIPZIG COHORT FOR MIND-BODY-EMOTION INTERACTIONS

How to augment your HRV?

- Drugs (beta-adrenergic blockade, antiarrhythmic)
- Biofeedback and meditation
- Psychotherapy
- Vagus nerve stimulation
- Physical exercise

→ clinical intervention studies are missing!