Measuring the embodied mind

Summer term 2015

Michael Gaebler
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Humboldt-Universität zu Berlin
Berlin School of Mind and Brain

Measuring the embodied mind
Session 7 – heart rate variability

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Approaching practicality: Laptops?

- Install Kubios (http://kubios.uef.fi/) and R + RStudio (instruction video)

- If you have time and are eager to learn data analysis: http://bit.do/embodiedmind

- Data repository (so far: mem1,2,4,5) on dropbox.

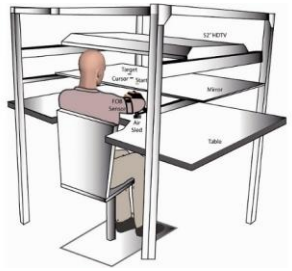
Organizational

Absent on July 1st (and potentially July 14th)

Alternatives:

- One or two extra sessions (doodle dates)
- Prolong remaining sessions by ~15 min each
  → practical sessions

Summary from last time

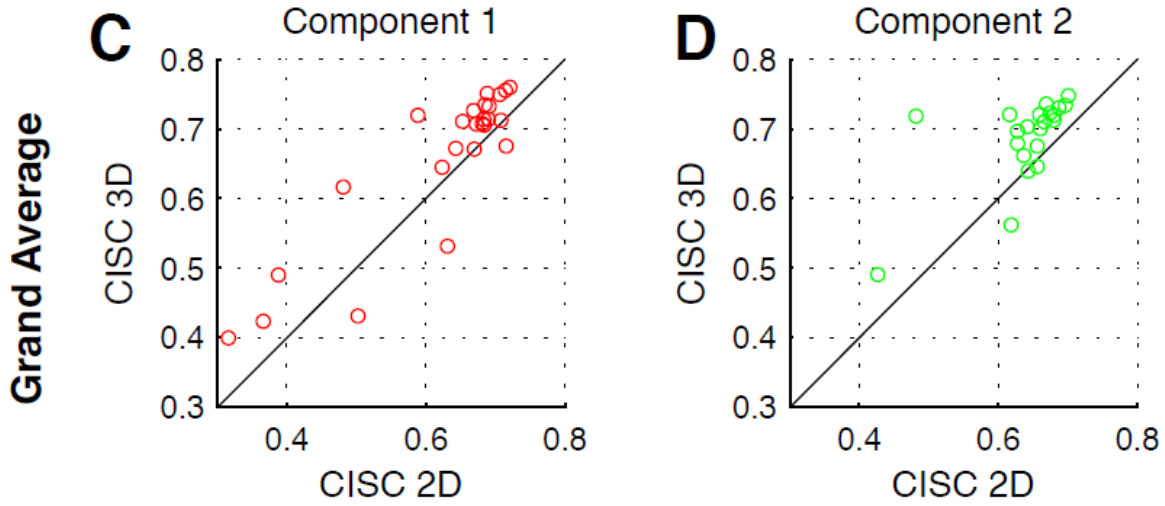


Experimental setup

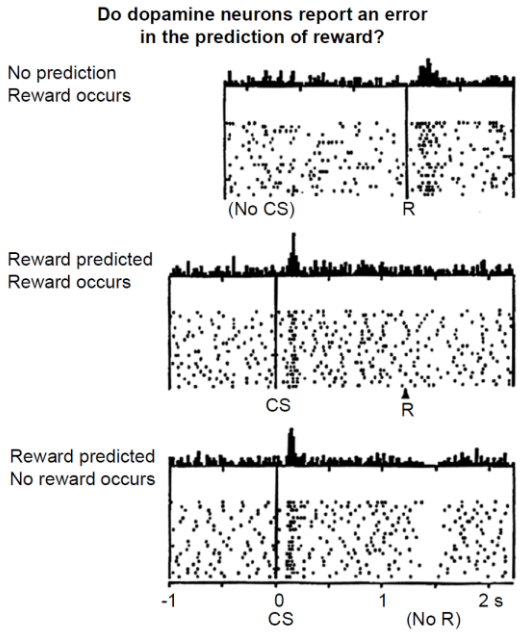
Embedded in

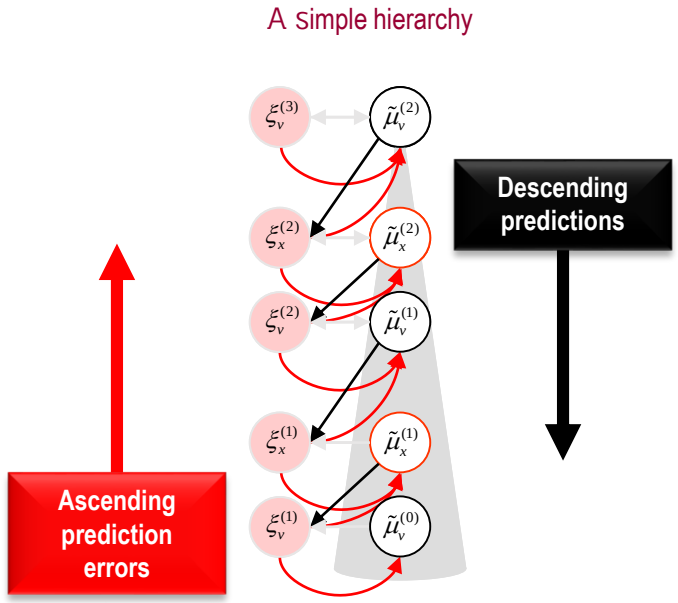
Approximates

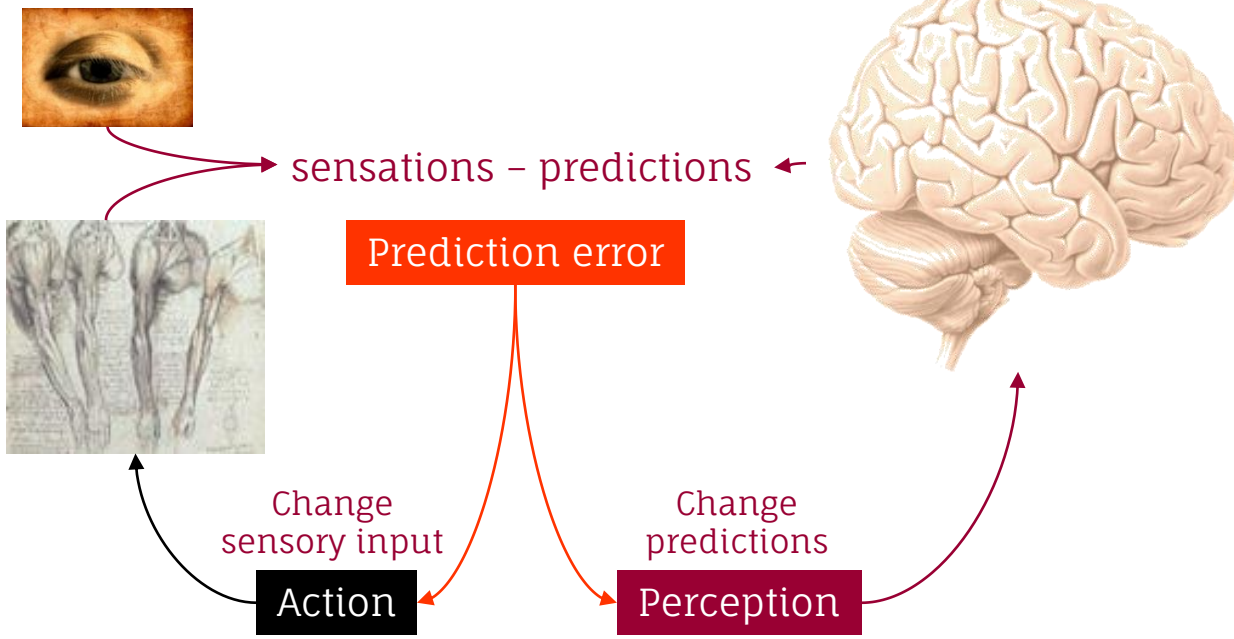
Everyday life



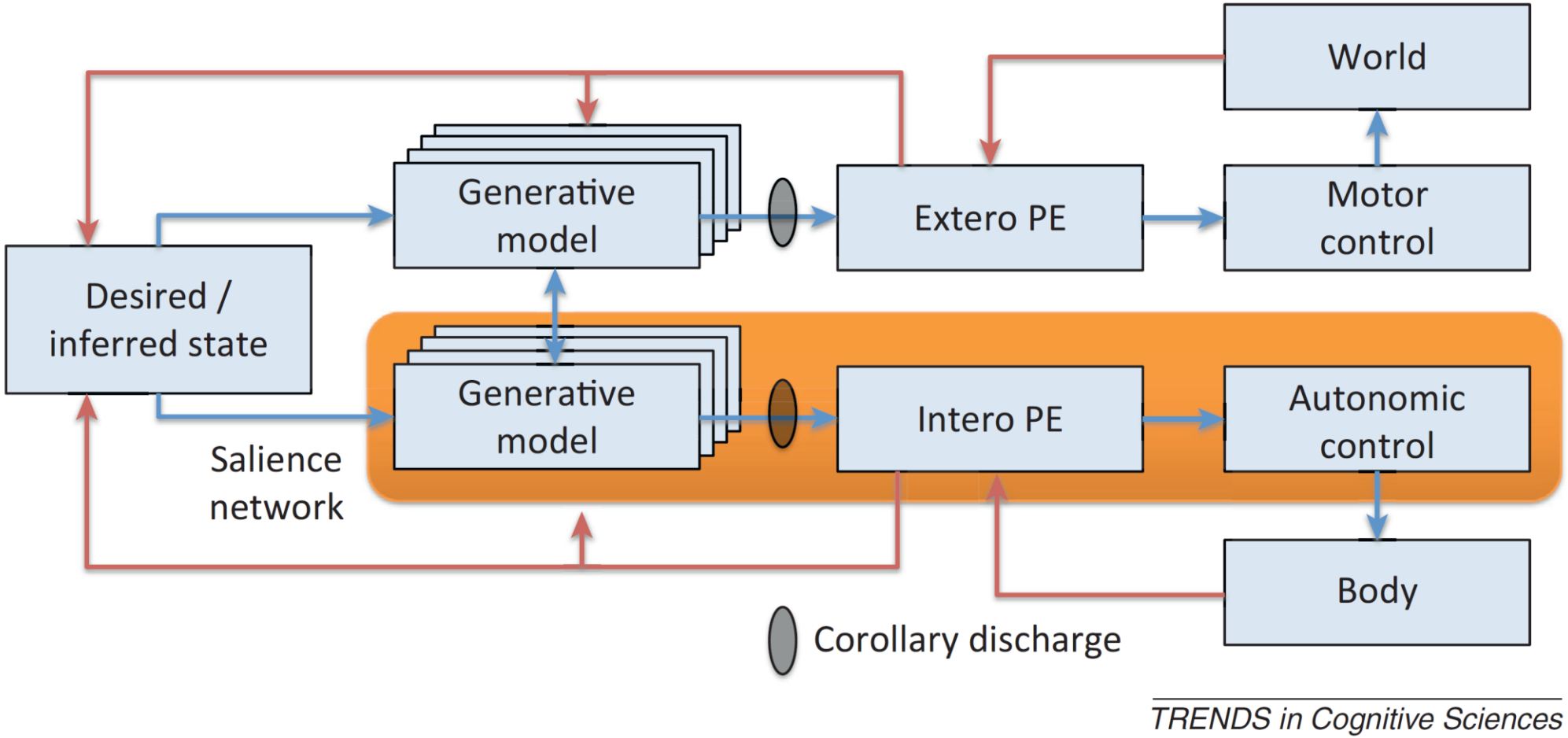
How can we minimize prediction error?



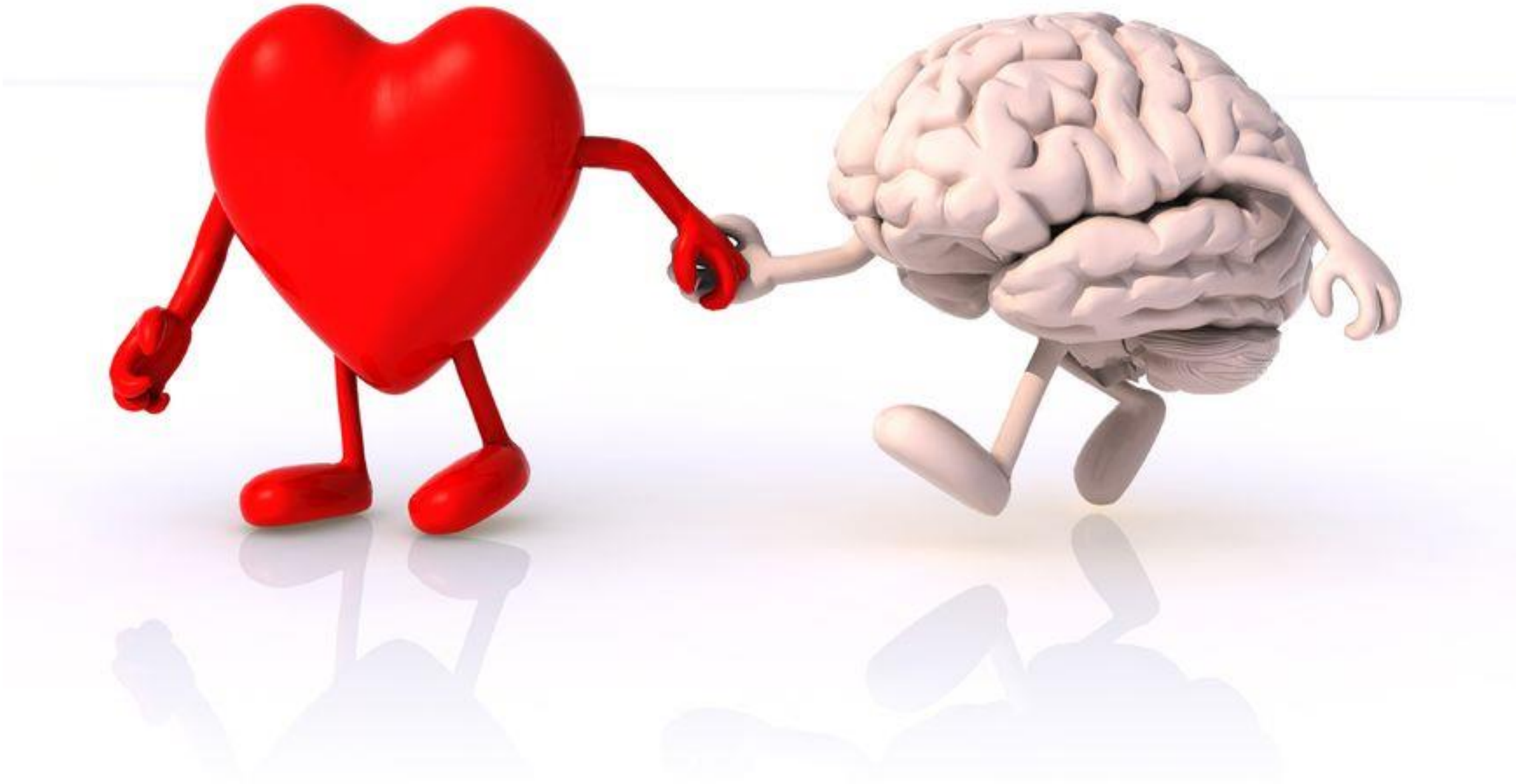




Interoceptive inference



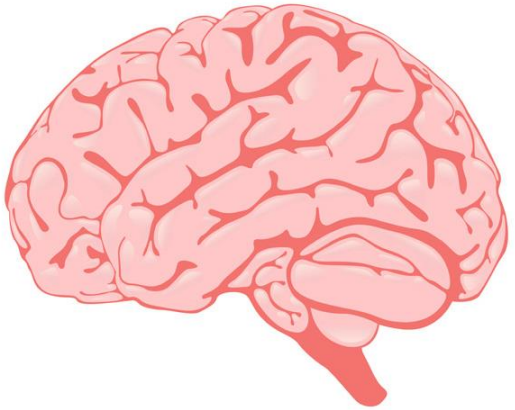
Seth, 2013



The nervous systems (Wikipedia)

Key:
- = Structure
- = Function

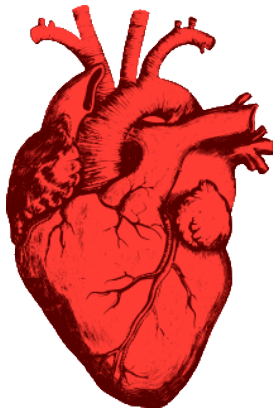
Central Nervous System (CNS)
- Brain and spinal cord
- Integrative and control centers



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")

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

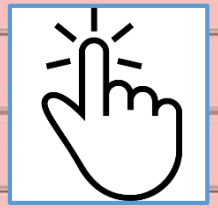
Autonomic nervous system (ANS)
- Visceral motor (involuntary)
- Conducts impulses from the CNS to cardiac muscles, smooth muscles, and glands

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

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 (cf. chicken)

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



Heart rate and its variability (HRV)

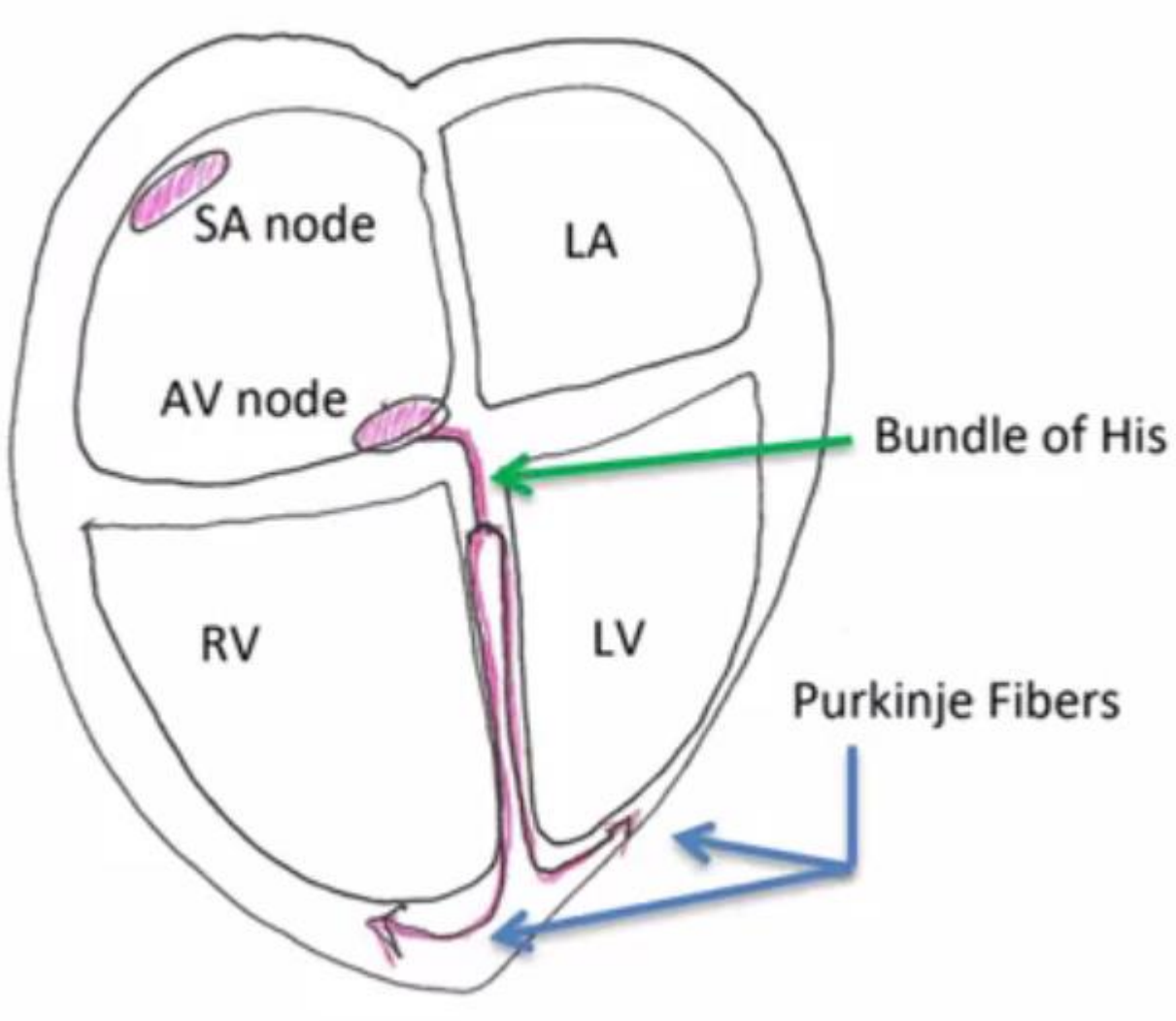
- **Heart rate** (HR): Number of heart beats per minute (bpm) → cf. pulse of the body

- **Resting heart rate** (HR_Rest): subject at rest and awake (typically 60-80 bpm)

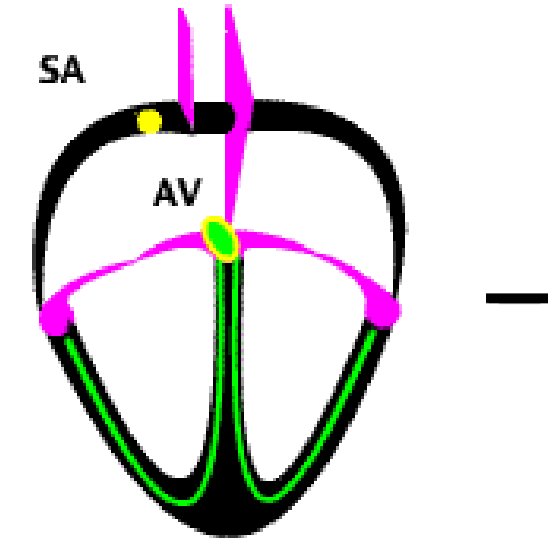
- **HR Variability** (HRV): variation in beat-to-beat or interbeat interval (IBI/RR/NN)
- "oscillation in the interval between consecutive heart beats" (Task Force, 1996)

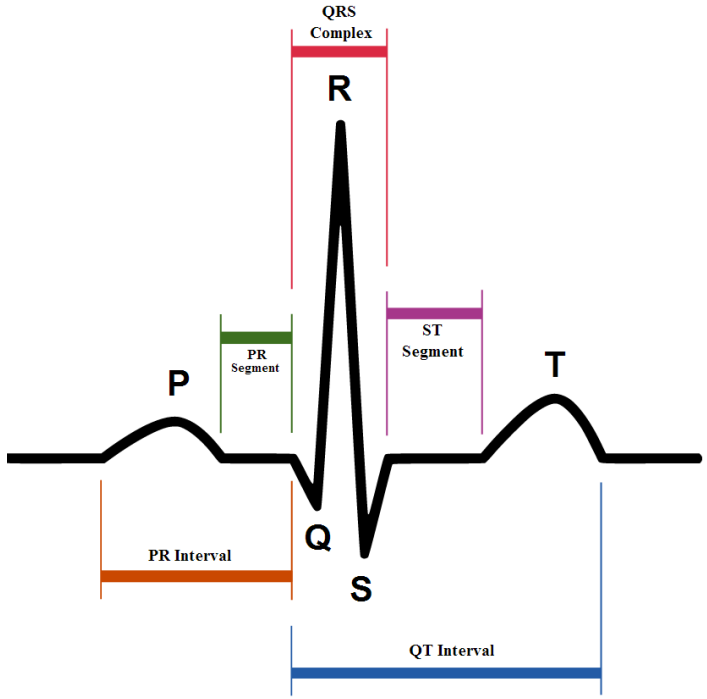
Heart anatomy

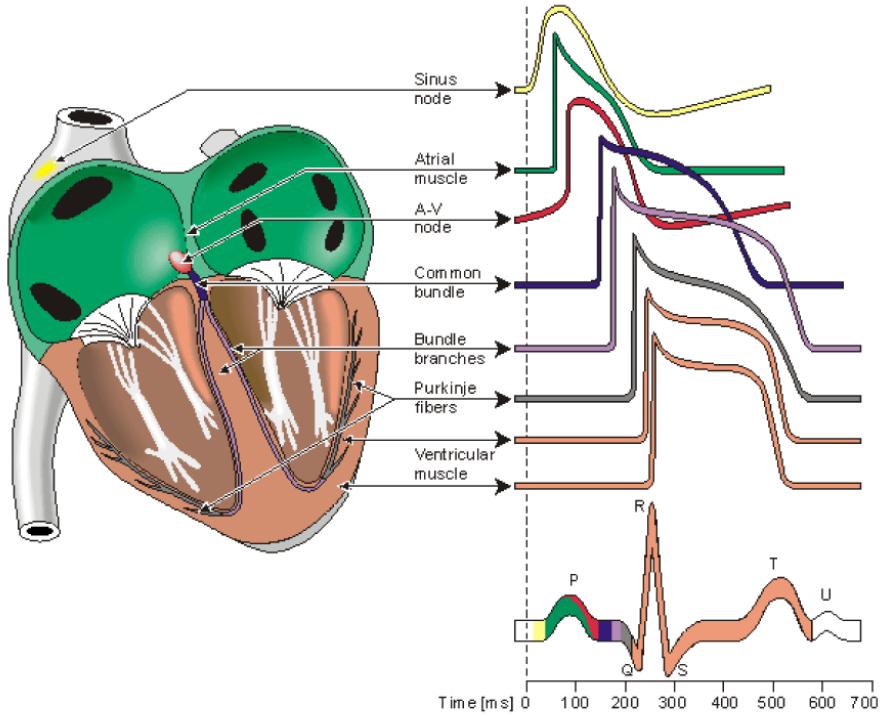
- Unidirectional blood flow:
  right → left
  atrium → ventricle
- Pacemakers:
  - **Sino-atrial** (SA) node (100 bpm)
  - **Atrial-ventricular** (AV) node (gateway, pauses signal, 40-60 bpm)
  - **Bundle of His** and **Purkinje** (25-45 bpm)



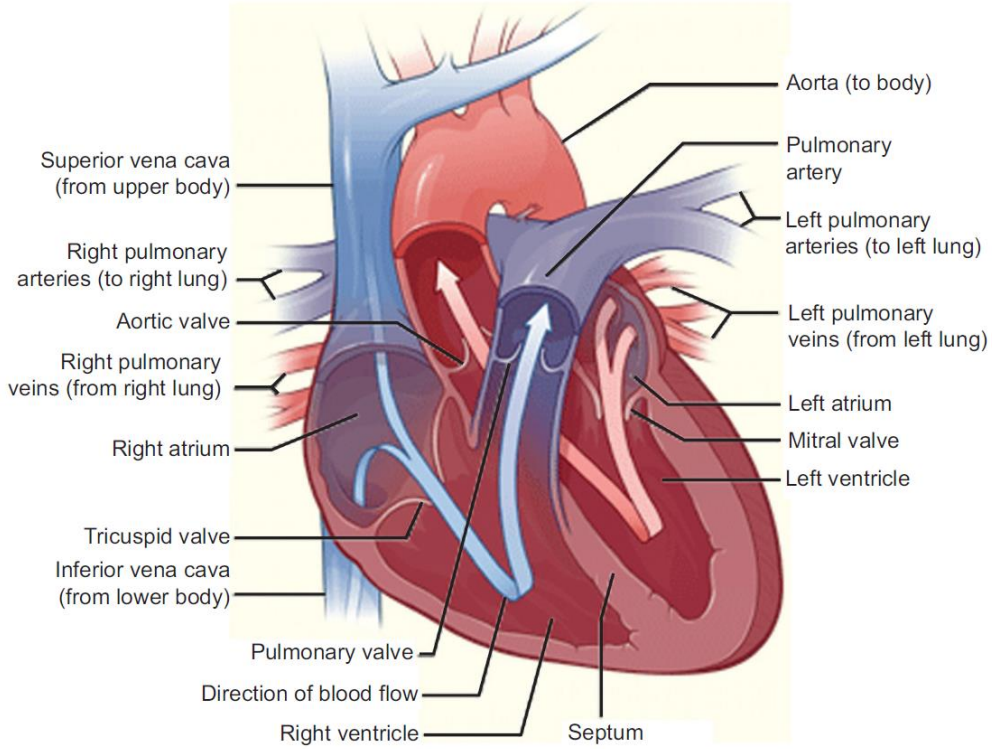
Physiology of the heart (electric pump) 1

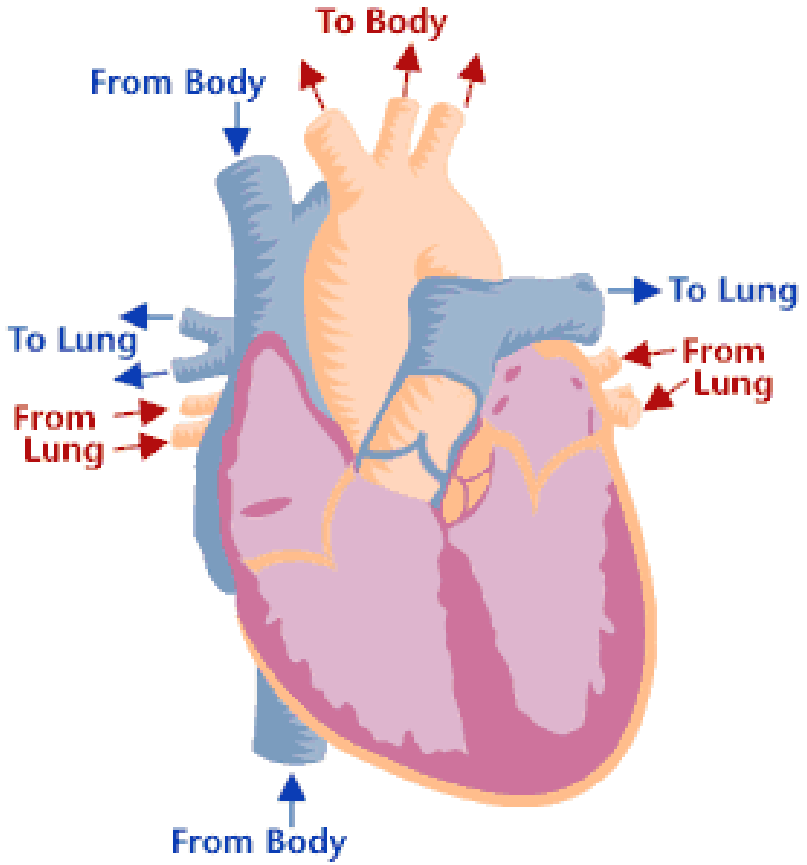




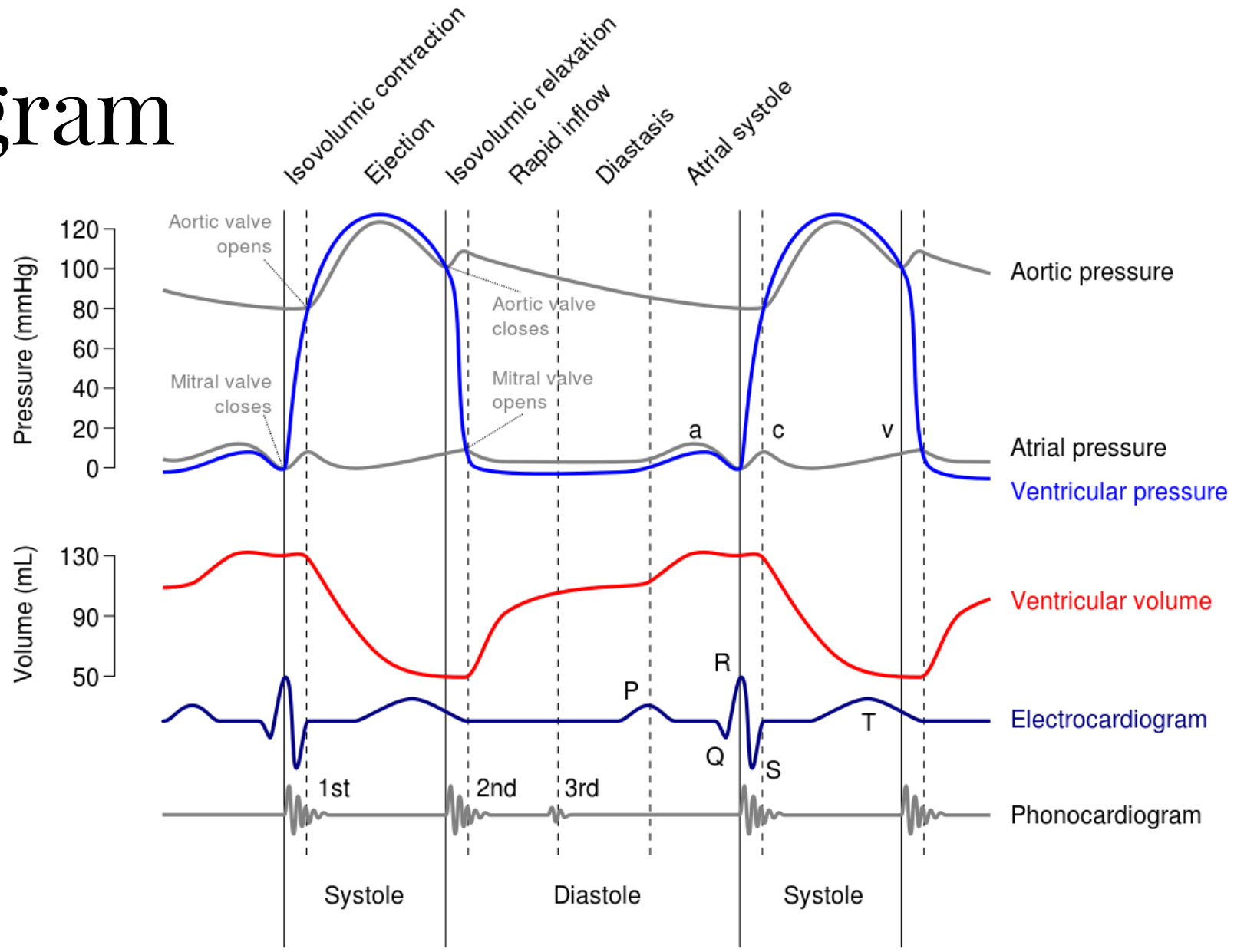


Physiology of the heart (electric pump) 2

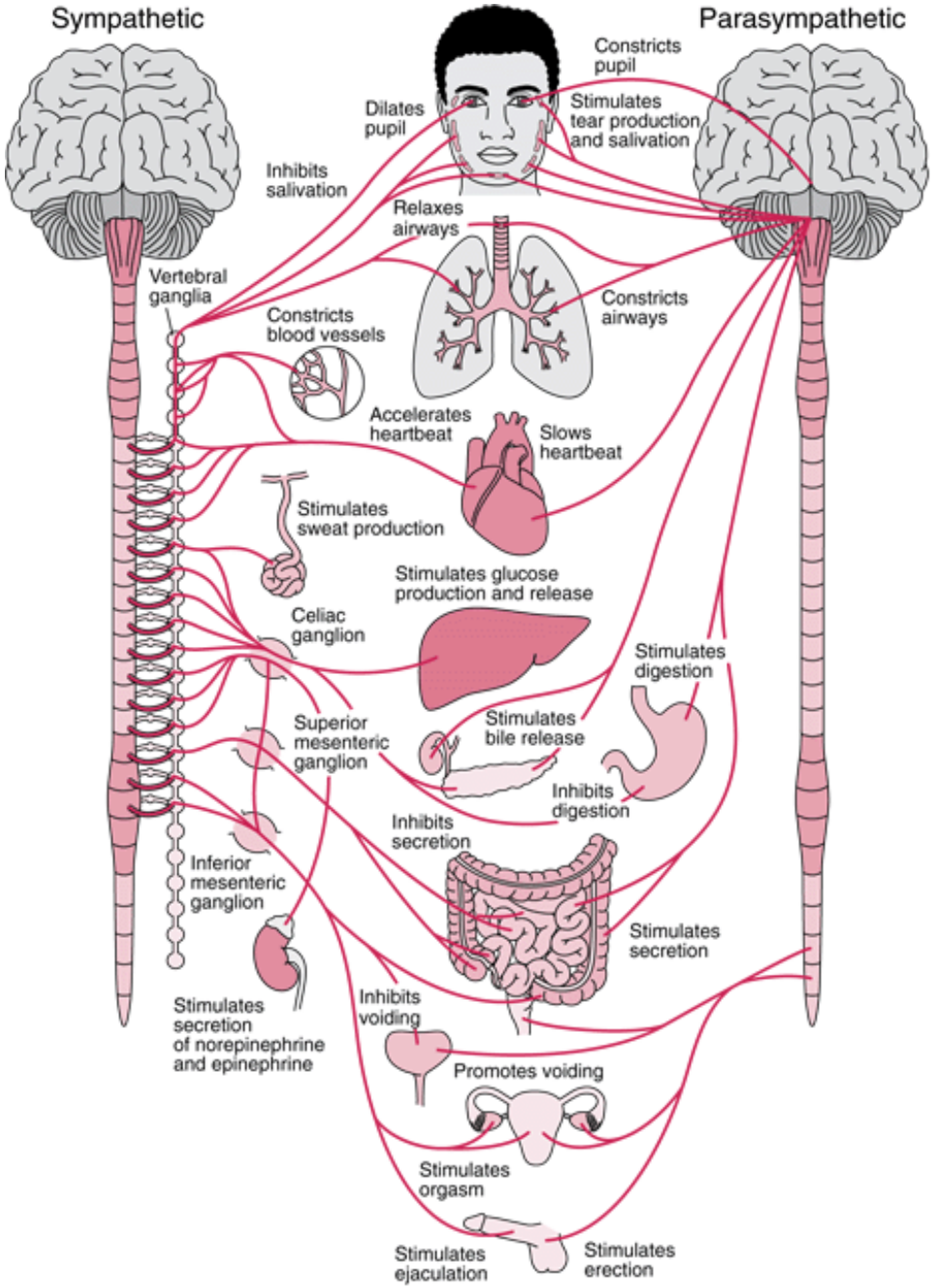




Wigger's diagram



(Source: Wikipedia/Wikimedia)



(Source: merckmanuals.com)

Autonomic nervous system (ANS)

ANS =

sympathetic nervous system (SNS)

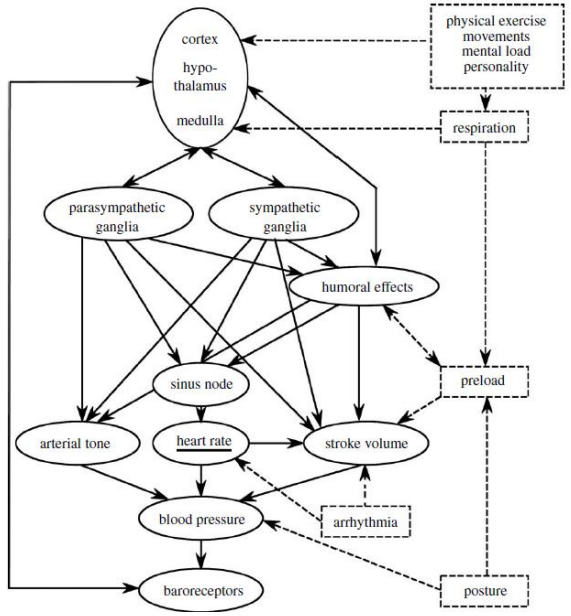
+

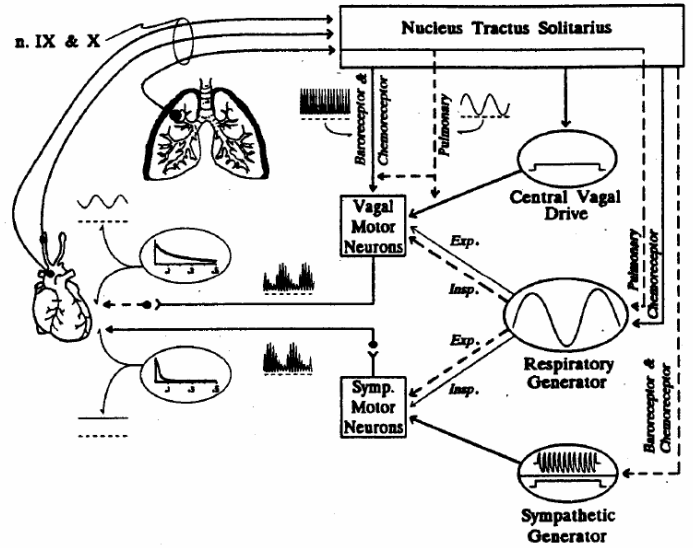
parasympathetic nervous system (PSNS)

→ HRV = fluctuations in ANS inputs

Physiology of HRV – influences

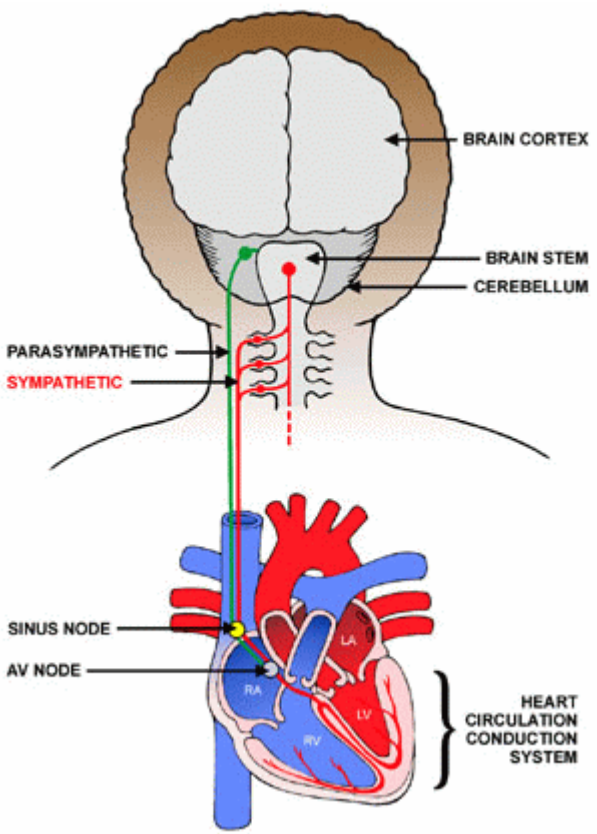
1) reflex-related changes in **blood pressure**, **oxygen**, **carbon dioxide** levels detected by **baroreceptors** and **chemoreceptors**, resp.
2) Mechanical changes in **respiration** (inspiration and expiration)
3) Tonic and reflexive changes in **CNS activity** (mainly brainstem but also cortex)





Physiology of HRV

dual innervation of the heart by the ANS:

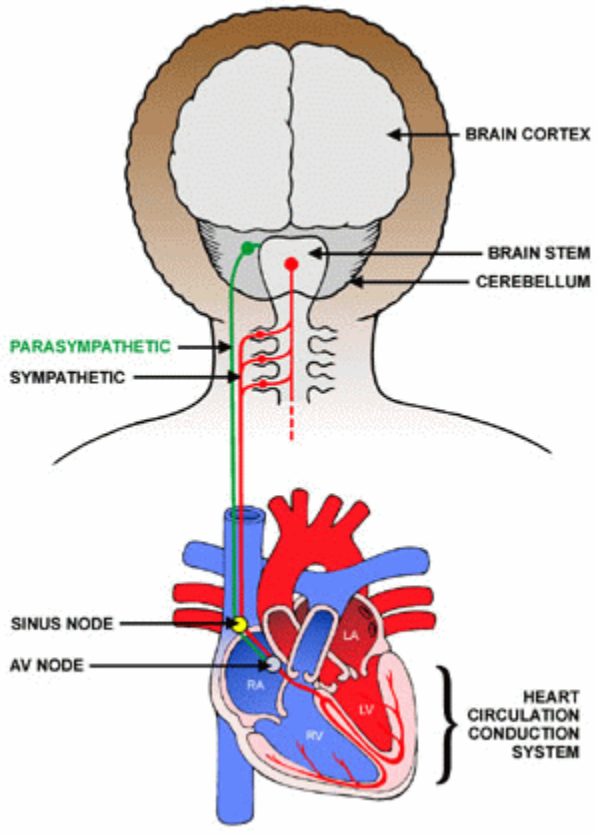


increase in **sympathetic** activity (slow, seconds, nor/epinephrine)

→ **HR increase** (shorter IBIs)

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

→ **HR decrease** (longer IBIs)



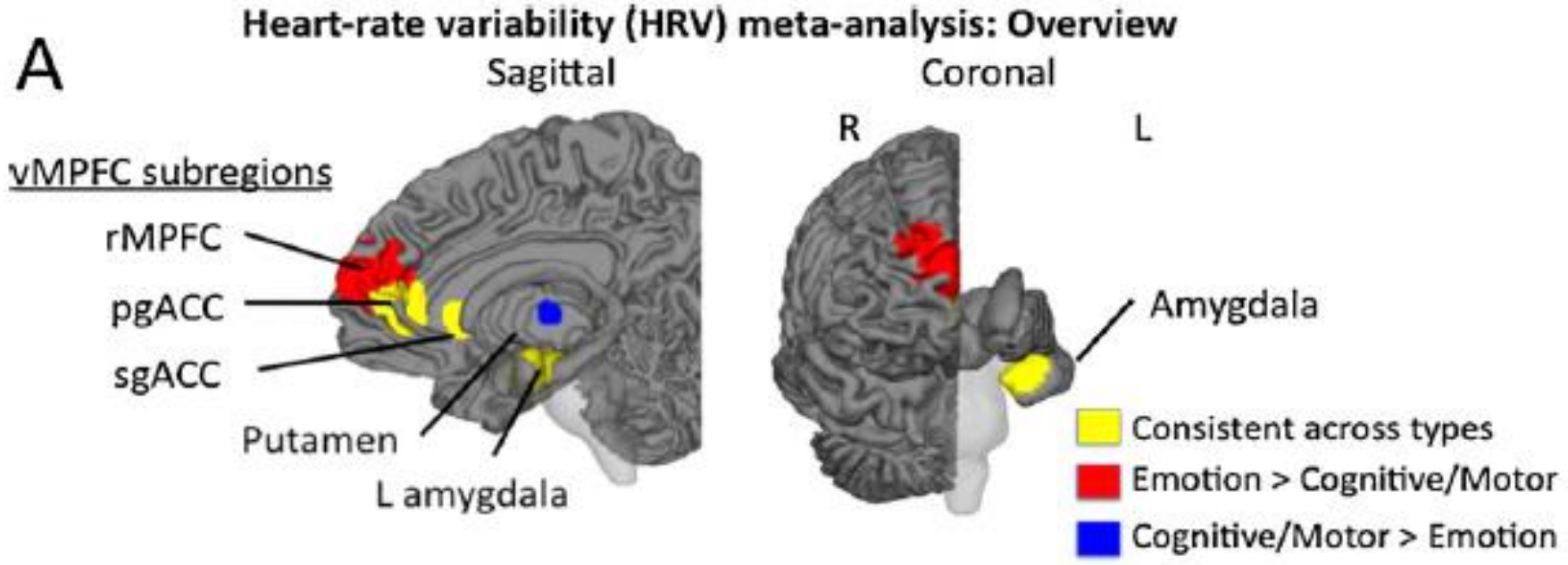
Physiology of HRV – remarks

- At rest, HR is **balanced** by both sympathetic (SNS) and parasympathetic nervous system (PSNS) → cf. car metaphor
- 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

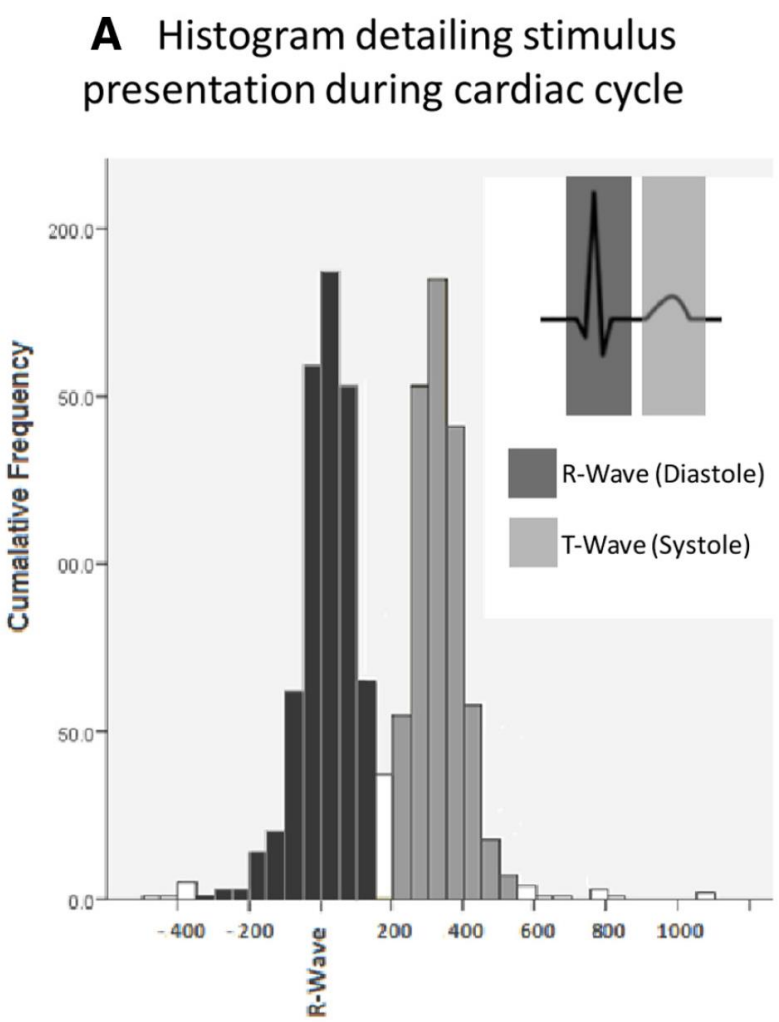
Heart & Brain: Cortical cardioregulation 1

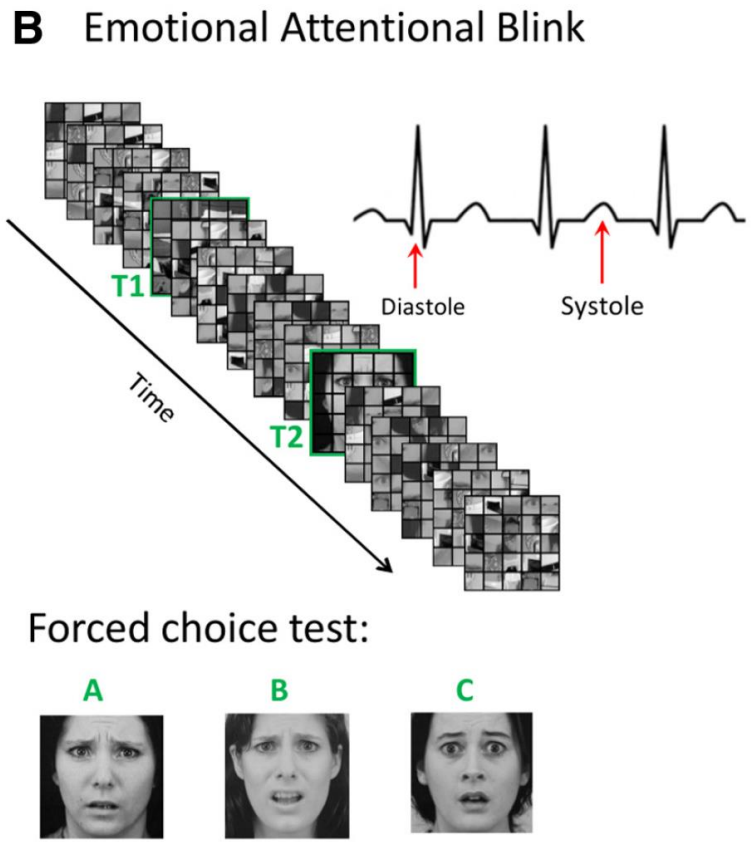
MPFC/ACC (& AMY) connected to (task-related) HRV

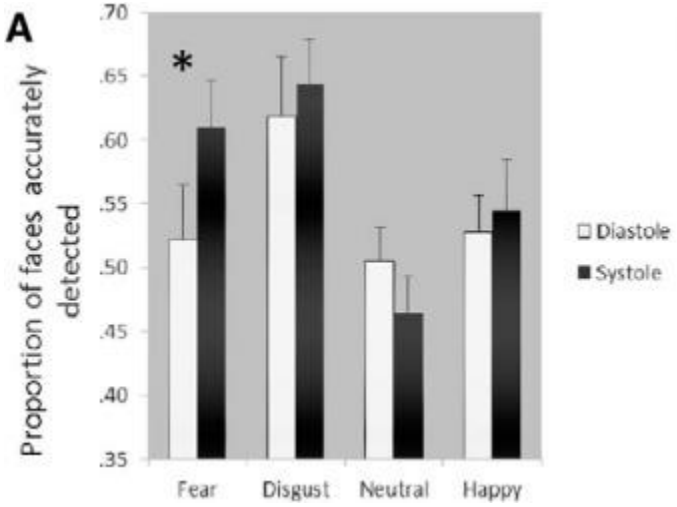
- Meta-analysis w/ 5 fMRT (n=61) and 3 PET (n=133) studies (Thayer et al., 2012)

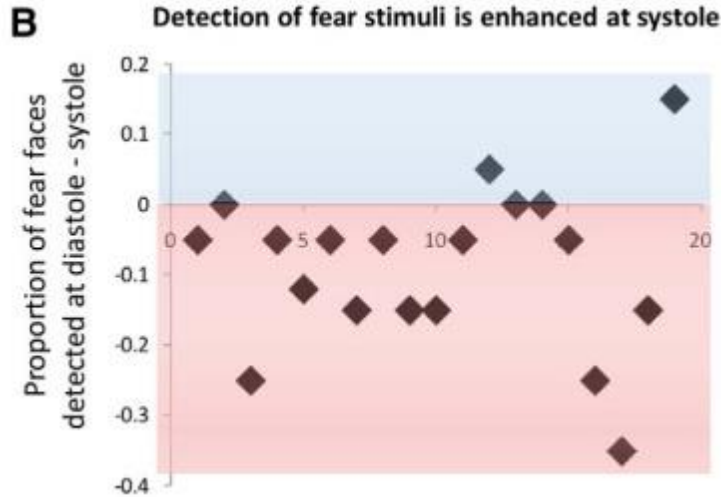


Heart-brain interactions (Garfinkel et al., 2014)









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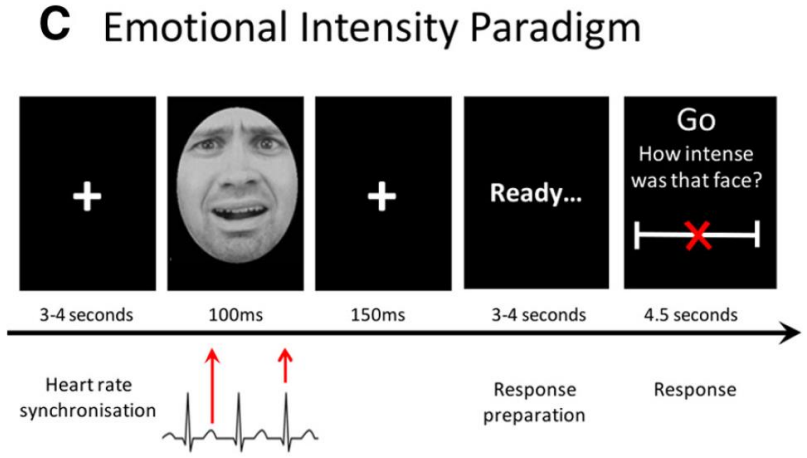
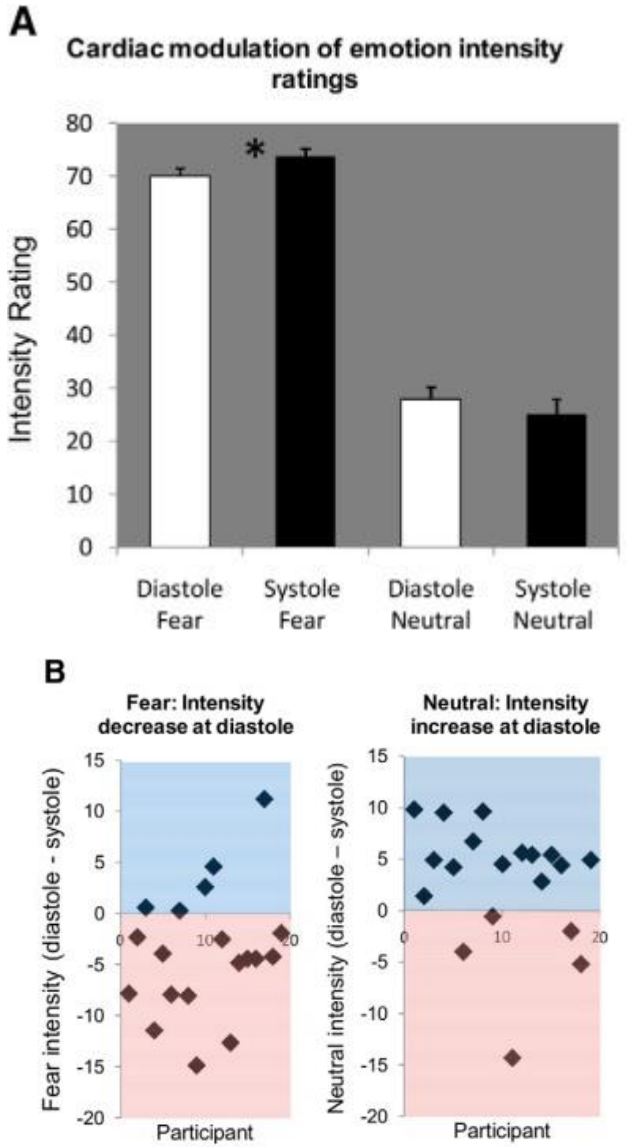
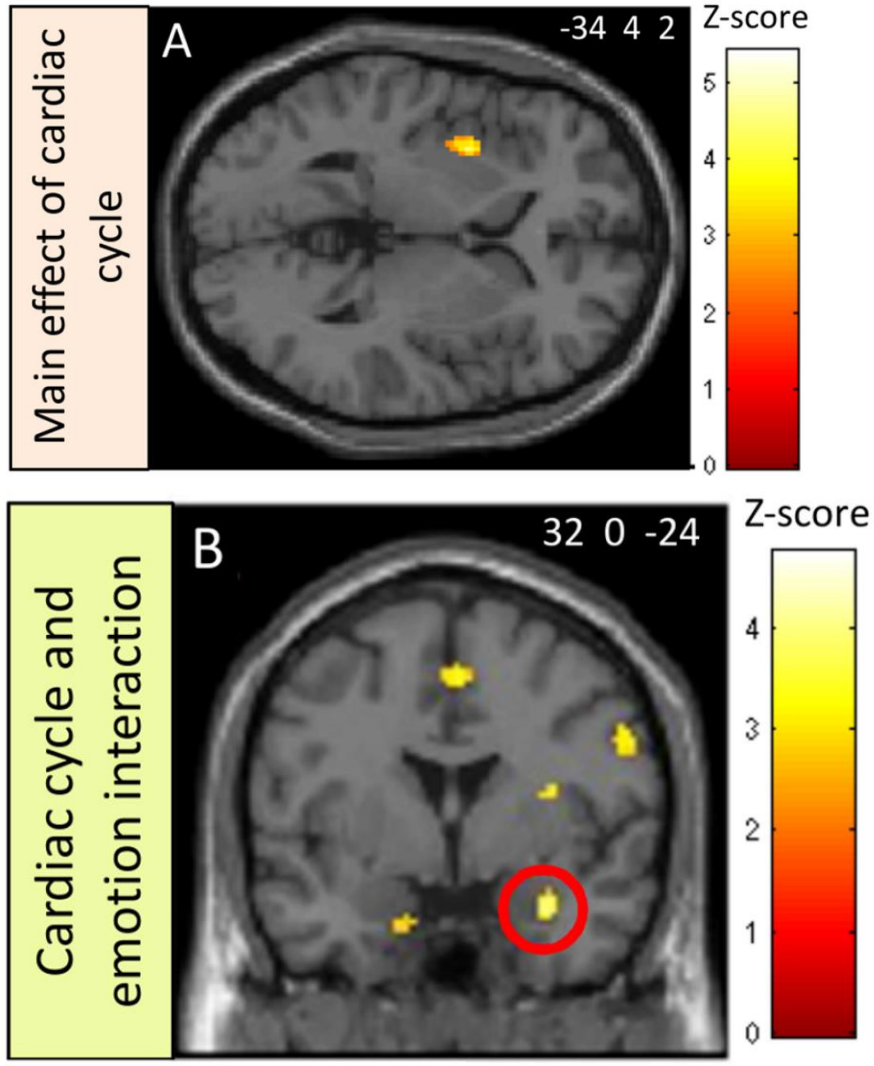
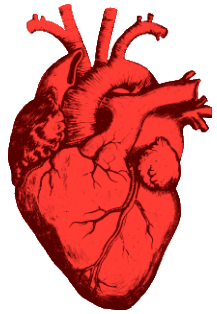


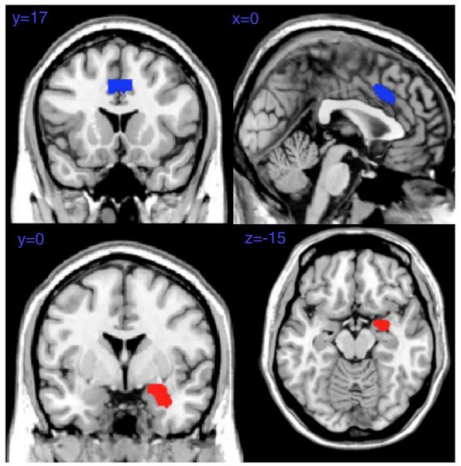


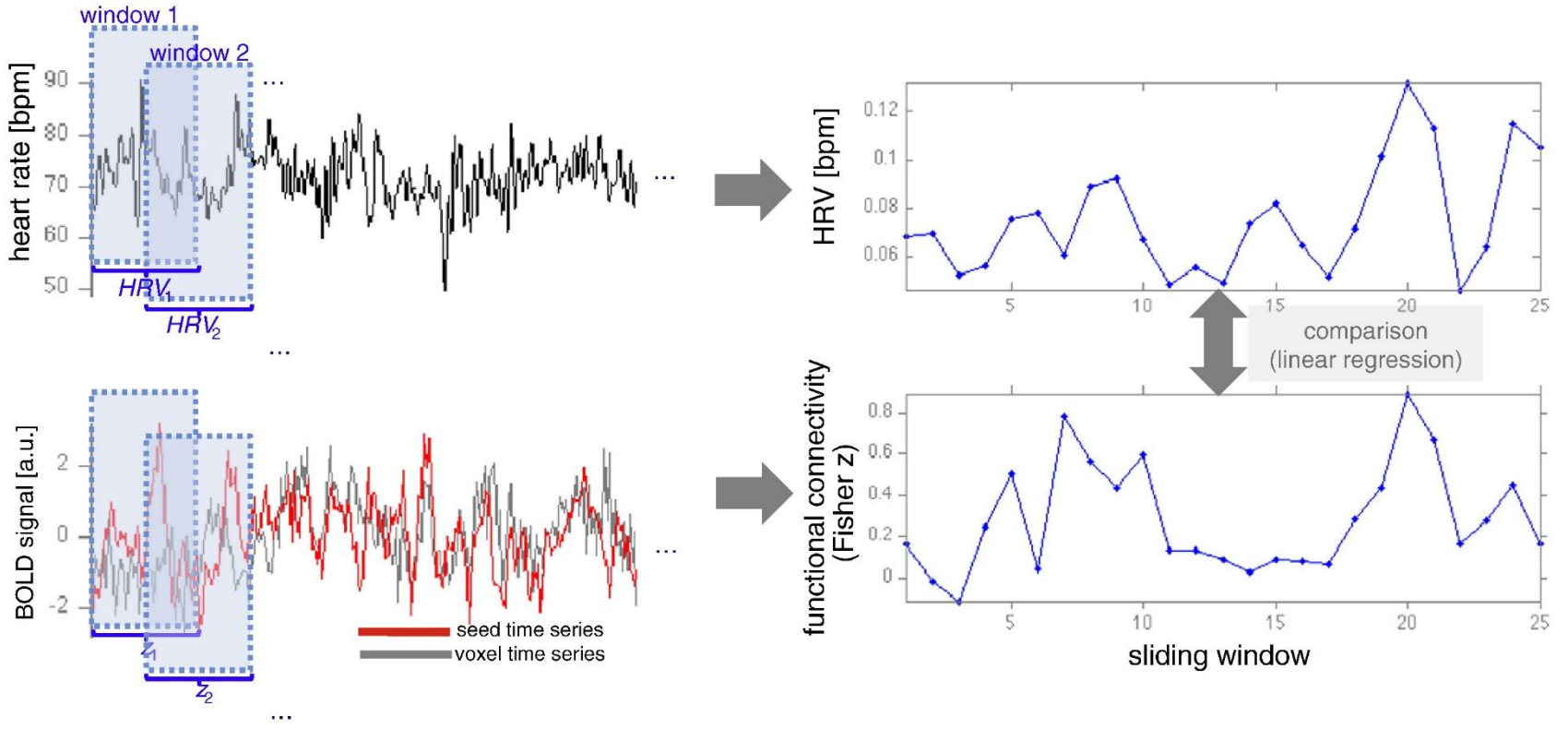


Heart & Brain: Cortical cardioregulation 2

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







Heart & Brain: Cortical cardioregulation 2

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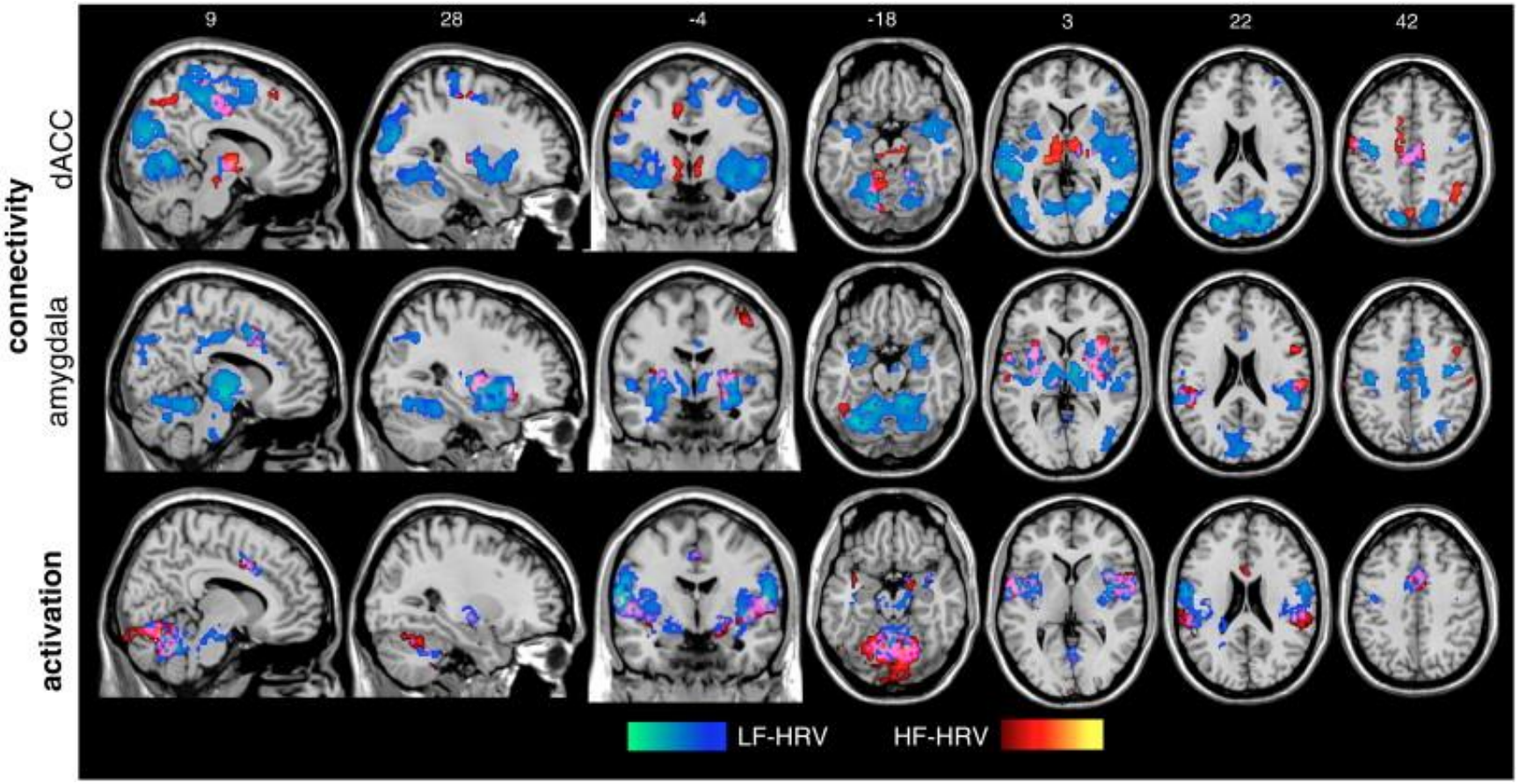

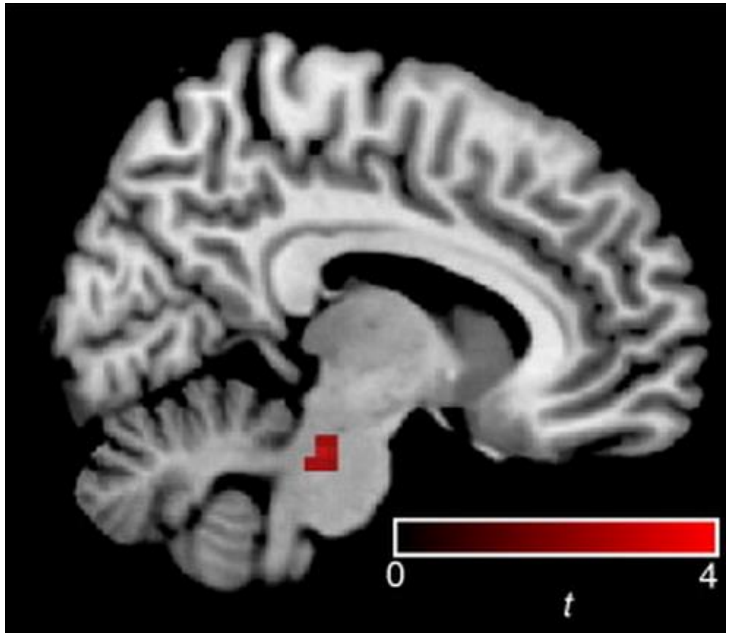

Specific to HF-HRV

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Session 7 – heart rate variability

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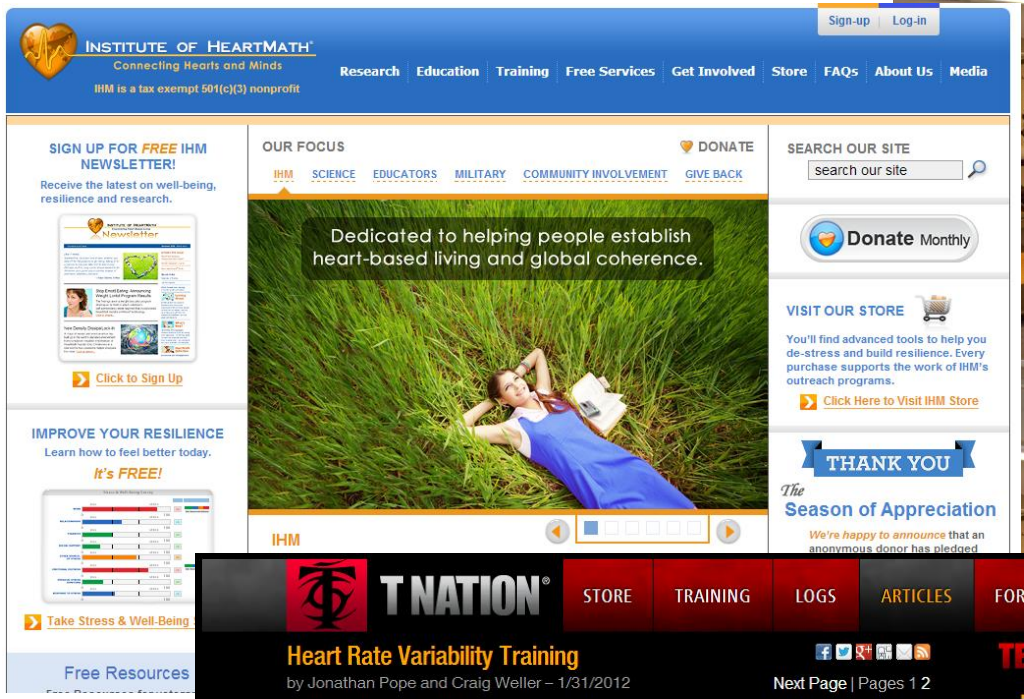
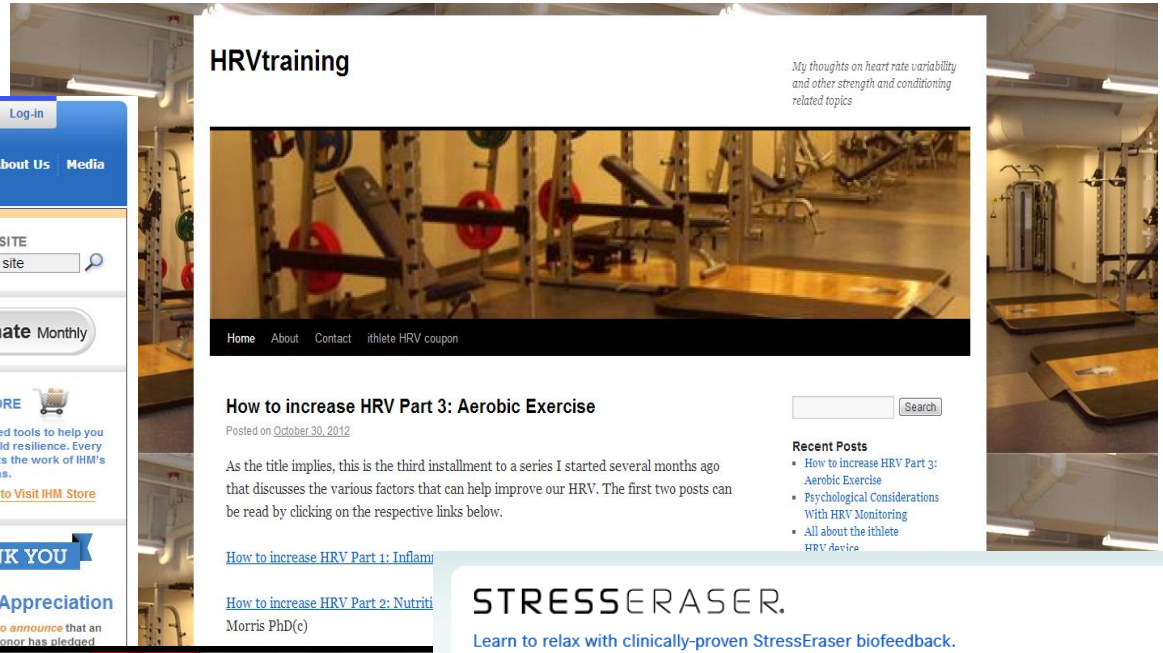
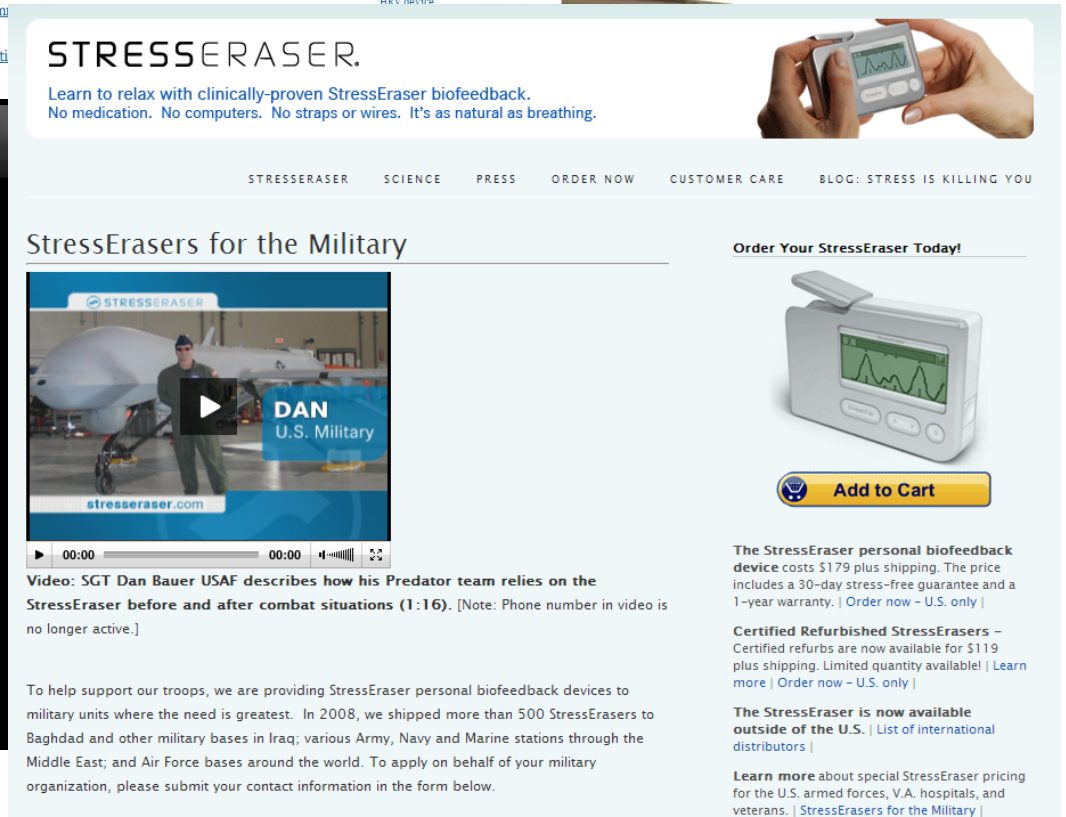
Less scientific HRV

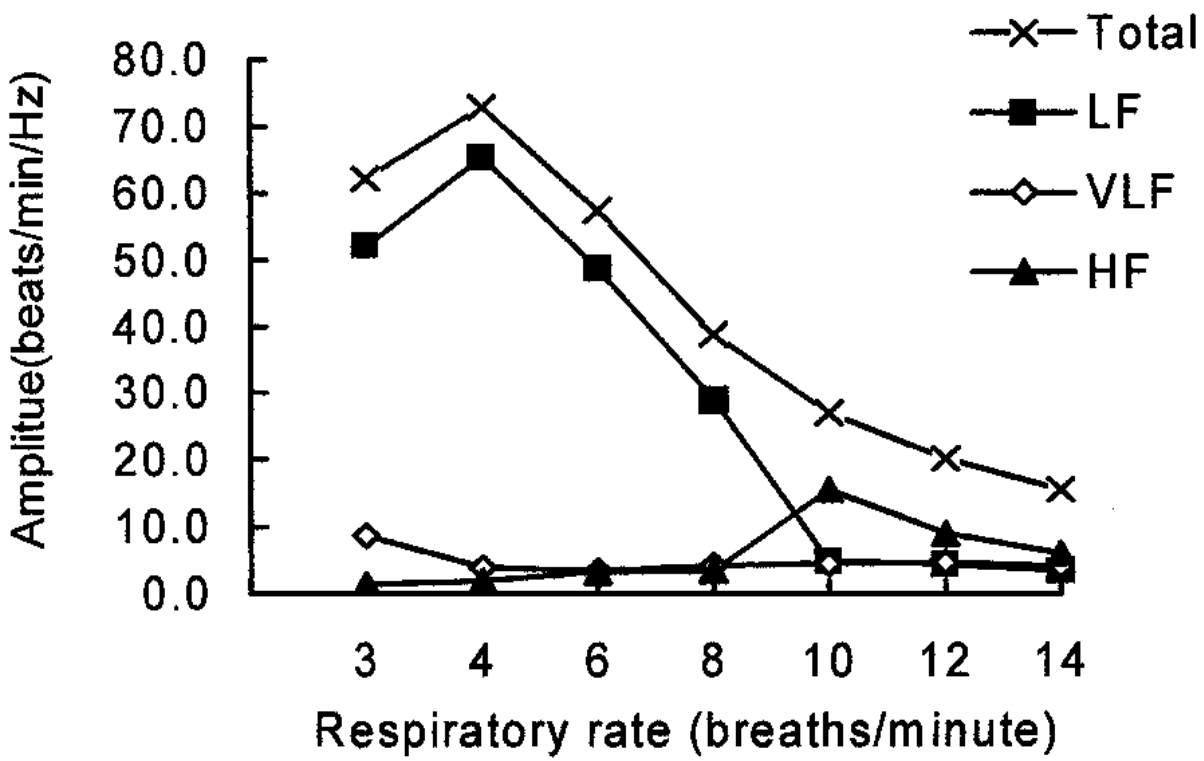






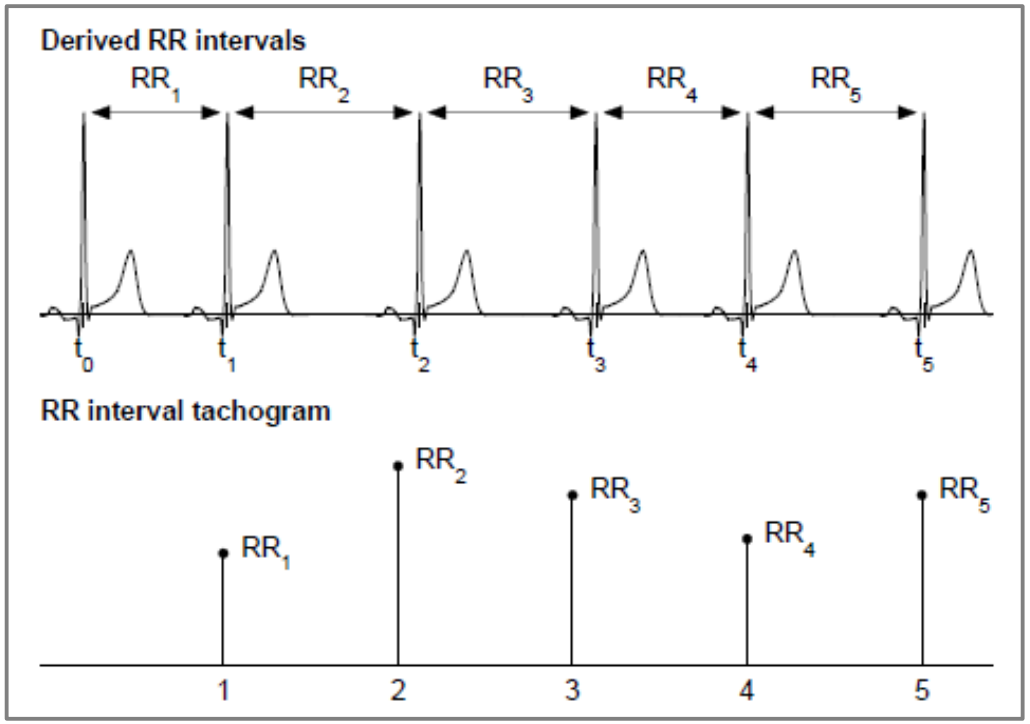
How to acquire HR(V)?

- **Continuous** recording of IBIs (HR) over time
- Normal **breathing** (rapid + shallow breaths decrease HRV) → respiration belt?
- **Sampling rate**: min. 100, rather 250-500 Hz (Task Force) → Polar H6/7: 1000 Hz



Measures of HR/V– time-domain

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



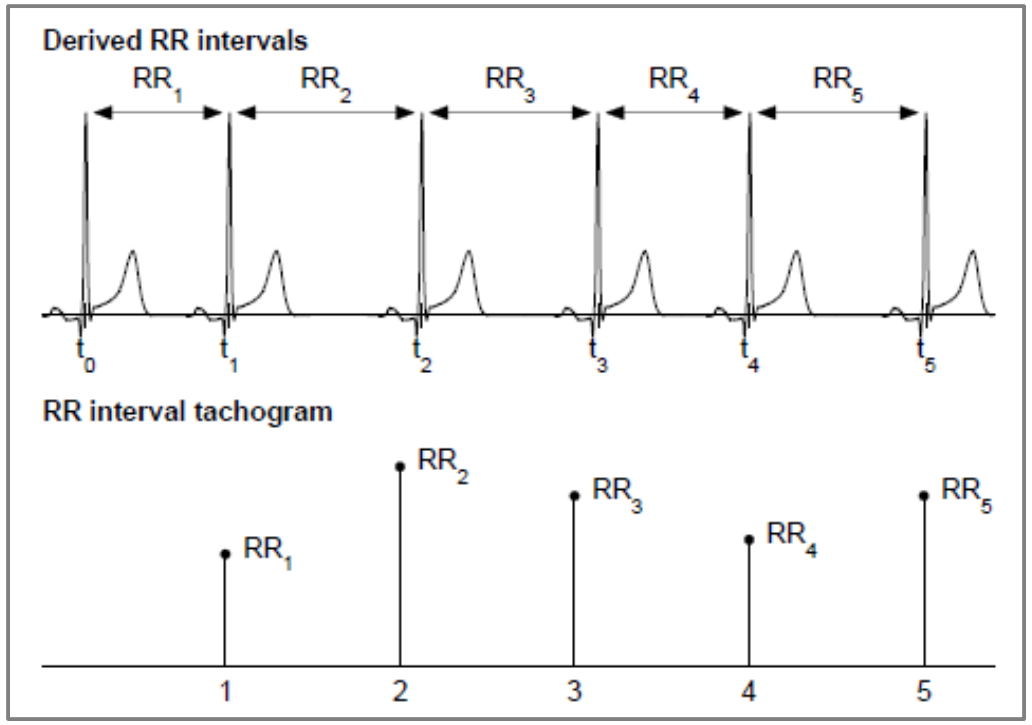
- Mean NN, mean HR, difference between shortest and longest NN
- Sqrt(var) = SD of NN intervals (**SDNN**) → estimate of overall HRV
- Sqrt of mean squared difference of successive NN intervals (**RMSSD**) → short-term components of HRV
- Number (**NN50**) and proportion (**pNN50**) of pairs of adjacent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

RMSSD, (p)NN50 = PSNS-mediated HRV

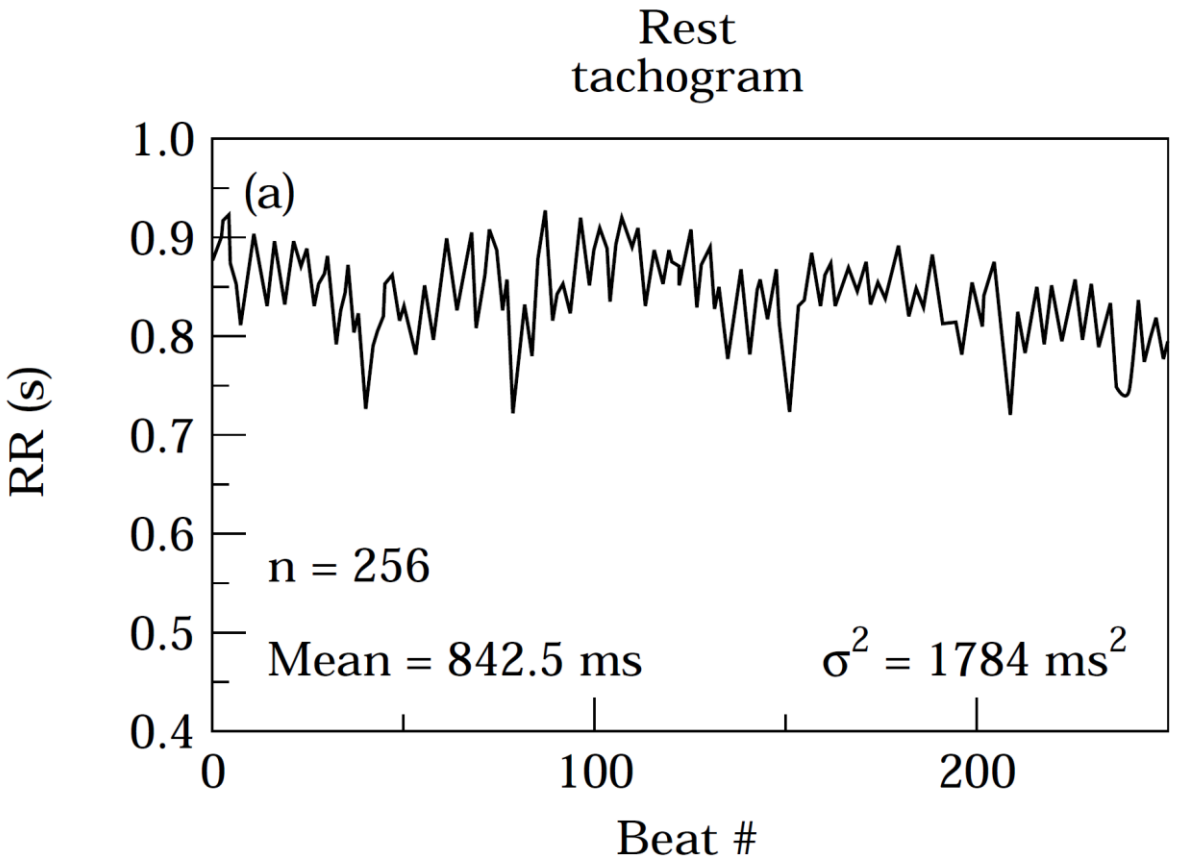
- NB: total variance of HRV increases with recording length

Measures of HR/V– time-domain

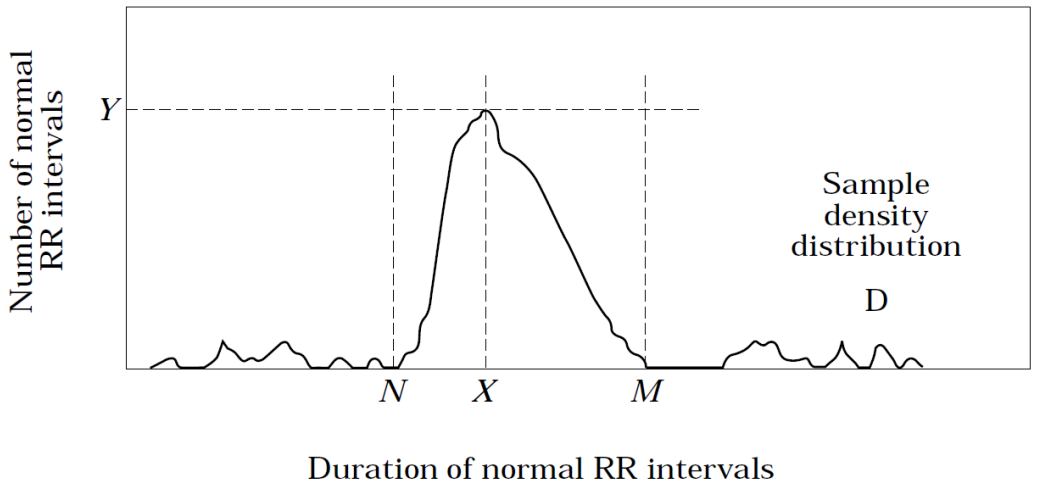
Discrete event series (DES)



RR interval tachogram

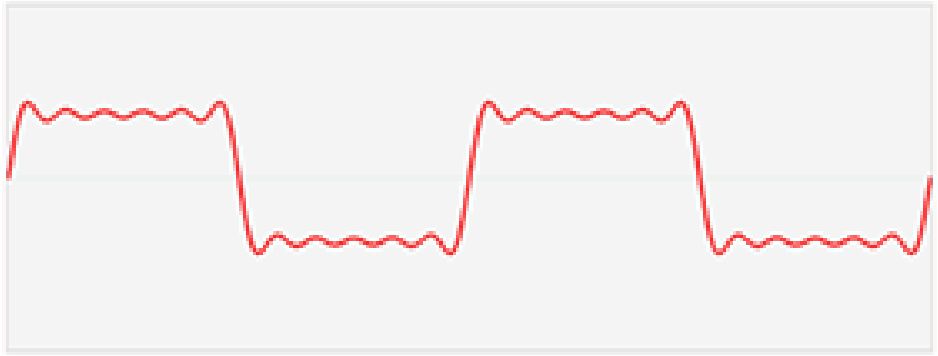


Geometrical and nonlinear measures



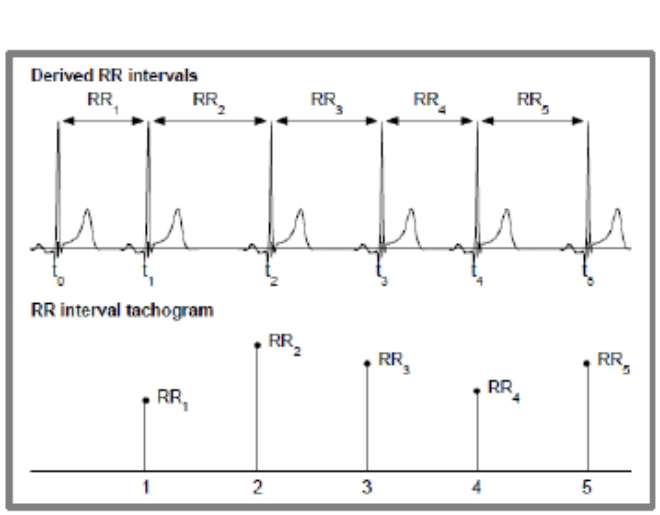
- **Geometrical** measures: on NN interval histogram – HRV **triangular index** and **triangular interpolation** of NN interval histogram → recordings of at least 20 min (preferably 24h)
- **Nonlinear** measures: e.g., **Poincaré plots** and **approx. entropy** (ApEn) → difficult to interpret (physiologically)

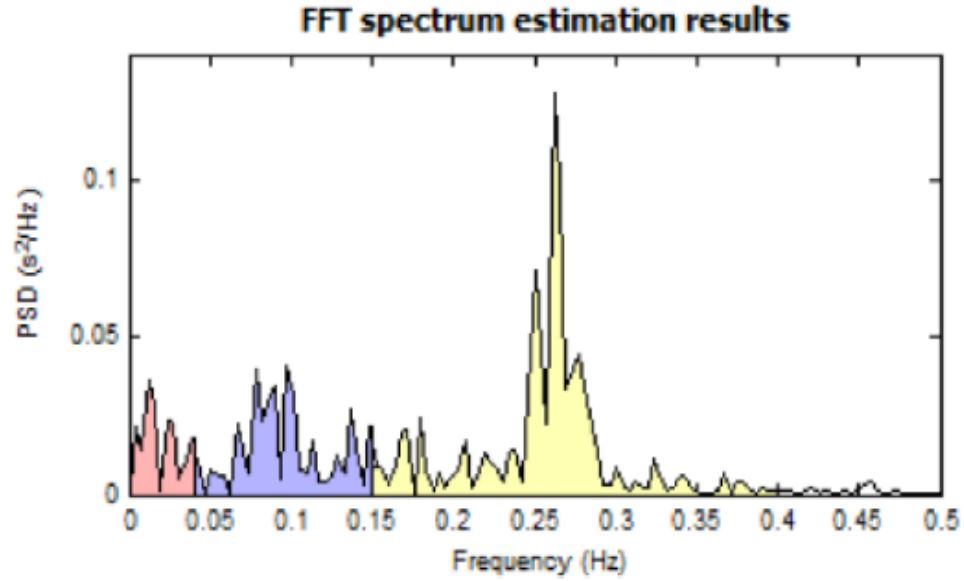
Fourier Transform: time ⇝ frequency



Source: Wikipedia/Wikimedia (also cf. youtube)

Fourier Transform: time ⇾ frequency





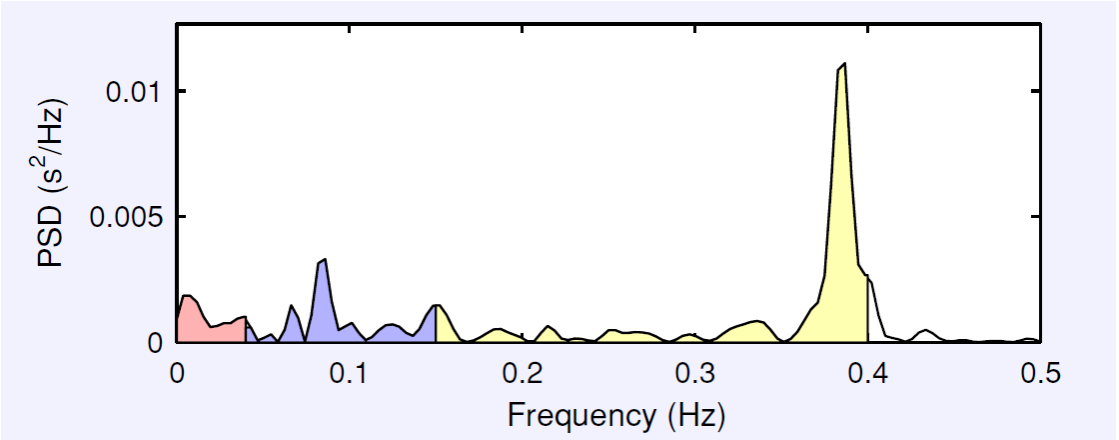
Power spectral (density; PSD) analysis of heart rate fluctuations (Akselrod, 1981)

Measures of HR/V– frequency-domain

power in frq. 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**

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

Tips (from Task Force, 1996)

- “It is inappropriate to compare time-domain measures obtained from recordings of **different duration**” (Task Force) → 5-min and 24-h
- “**frequency-domain** methods should be preferred to the time-domain methods when investigating **short-term recordings**.” (Task Force)
- Recording at least **10 times the wavelength of lower frq bound** of investigated component → 1 min for HF-HRV, 2 min for LF-HRV

HRV as a marker (psychology?) 1

1) **HRV as individual trait marker** (i.e., **at rest** → usually 5 min): mental & physical health

   Low HRV as risk-factor for psychopathology and all-cause mortality (Liao et al. 2002); e.g., HF-HRV predicts survival in post-myocardial infarction patients (e.g., Kleiger et al. 1987)

2) **HRV as response variable** in task settings → **behavioural flexibility** or **attentional engagement with the environment**

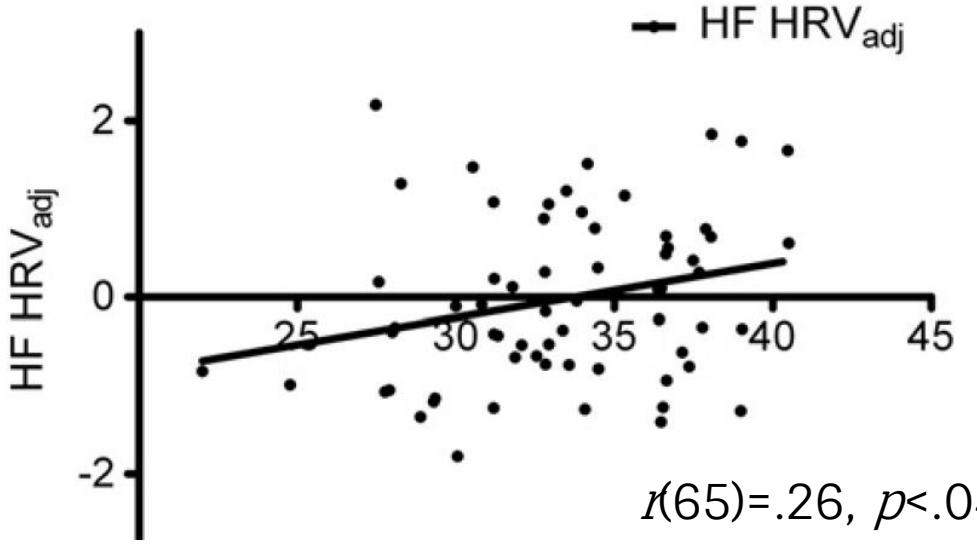
   HRV (HRV_Rest and task-related) as marker of emotional experience and emotion regulation (e.g., Appelhans & Luecken 2006); e.g., breathing exercise w/ HRV biofeedback decreases anxiety (Wells et al. 2012)

(cf. Thayer & Lane 2000, 2009; for review)

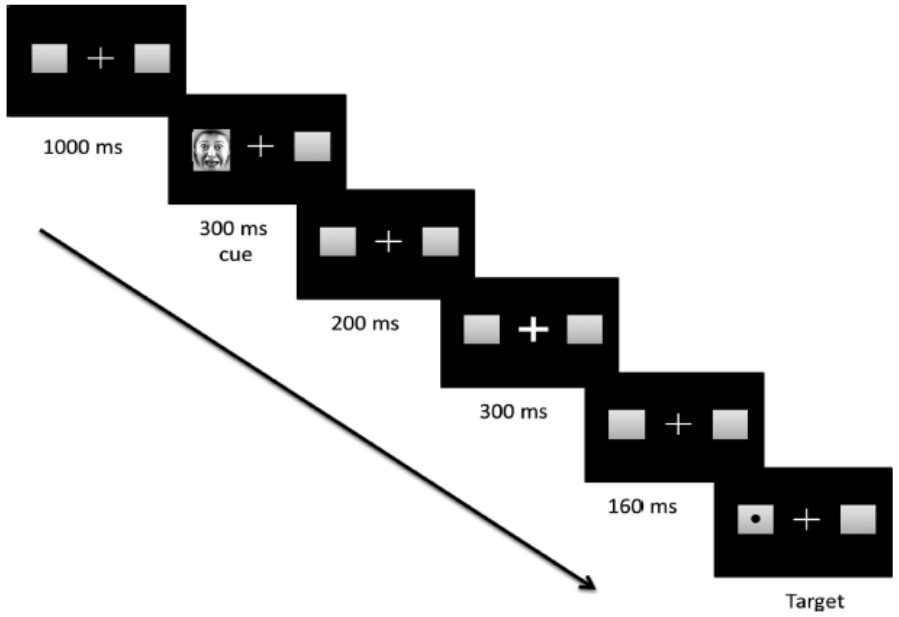
HRV as a marker (psychology?) 2

individuals with higher HF-HRV at rest

- perform better on a test of **social cognition** and **emotion recognition** (Quintana et al. 2012)
- and **inhibit unnecessary processing of affective information** more efficiently (Park et al. 2012).



$r(65)=.26$, $p<.04$



HRV as a marker (psychology?) 3

- Reduced HRV in several **cardiological and non-cardiological diseases**: diabetic neuropathy, cardiac transplantation, myocardial dysfunction, tetraplegia, but also in depression, anxiety disorders, etc.

- Intuitive/simplistic interpretation for **mental disorders**: less flexibility in the face of changing environments leads to increased stress and fear (or vice versa)

How to influence your HRV?

Interventions to augment HRV:

- Drugs (beta-adrenergic blockade, antiarrhythmic)
- Physical exercise
- Biofeedback and meditation → see Boris next week
- Psychotherapy