10/2/2018 11:00am **Spotlight on Pain Management**

Applied HRV Data Interpretation for the Clinician

Ginsberg, JP (Jack)

Heart Rate Variability Biofeedback (HRVB) professionals regularly use quantitative and graphic methods of analysis of heart rate to understand the physiological and emotional status of pain patients. This presentation will use actual pre-post HRVB data from Veterans with PTSD and chronic pain to illustrate how acquisition of the skill of self-regulation through HRVB affects heart rate patterns and screen displays and is related to reduced symptoms and improved level of function.

JP (Jack) Ginsberg, PhD

Licensed Clinical Psychologist/Neuropsychologist
and Principal Investigator,
Dorn VA Medical Center
Basic Science Research Assistant Professor
University of South Carolina, School of Medicine,
Dept of Pharmacology, Physiology & Neuroscience
Columbia, SC
jay.ginsberg@va.gov
803.776.4000 x6644

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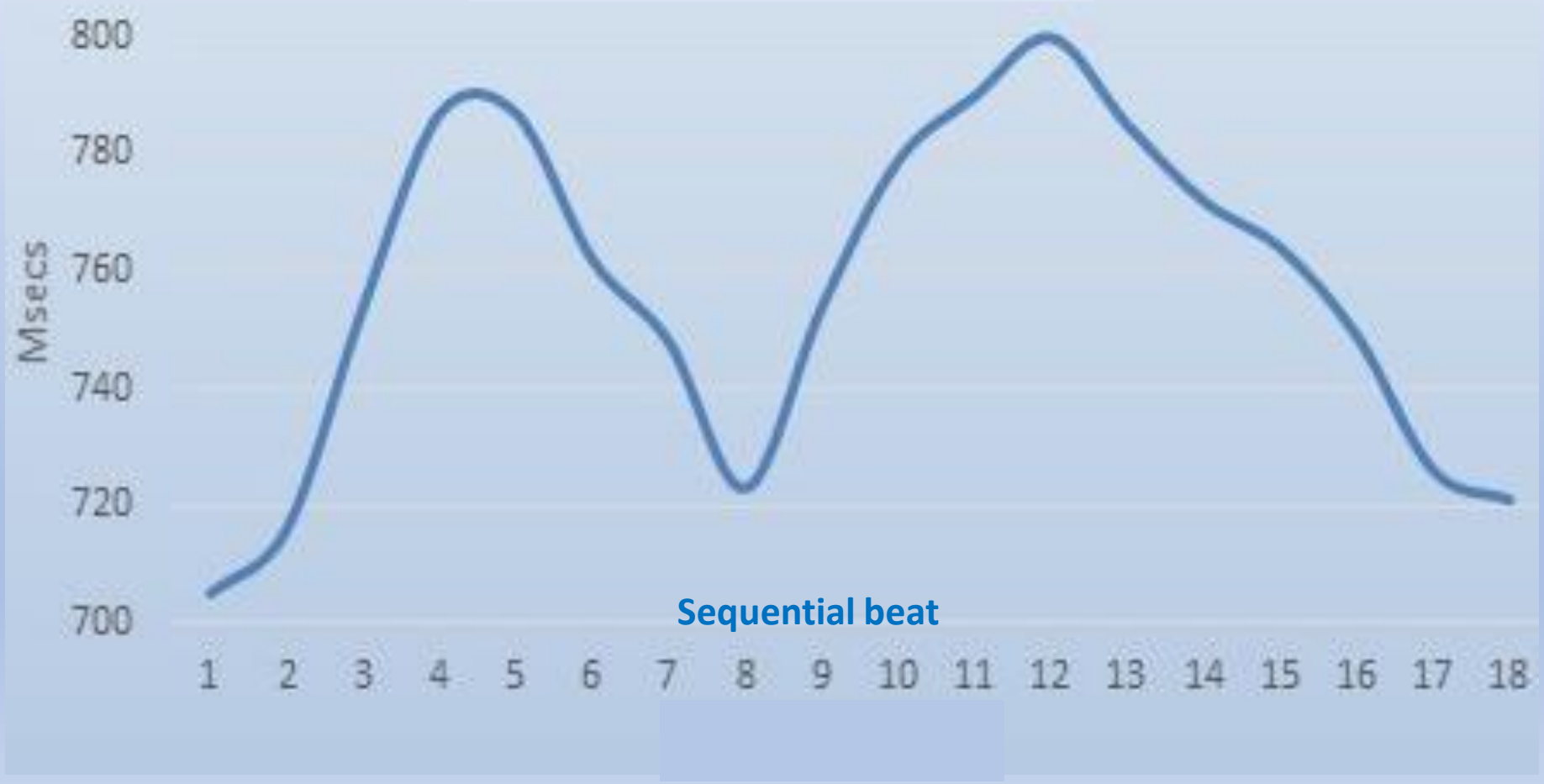
- Neuropsychologist, interest in PTSD and cognitive psychophysiology
  - Not expert in cardiology, physiology, medication, or pain
- No conflict of interest, affiliations, or product endorsement
- Slides are original, available on internet, or acknowledged
  - Not copyrighted but please acknowledge
- Some portions presented previously
- Models are didactic and heuristic
  - Correct only as far as they go
    - Referenced and consistent with current scientific literature
    - Corrections, revisions, expansions, updates are appreciated
  - Sketchy, incomplete, simplified, and not elaborated in context
  - Not writing medical cardiovascular physiology textbook or research proposal

Materials that are included in this presentation may include interventions and modalities that are beyond the authorized practice of mental health professionals. As a licensed professional, you are responsible for reviewing the scope of practice, including activities that are defined in law as beyond the boundaries of practice in accordance with and in compliance with your professions standards.

Actual Sample of Interbeat Intervals (IBI)

705	716	754	787	787	762	748	723	754
779	790	800	785	772	764	749	726	721

Velocity Curve
(IBI vs sequential beat)



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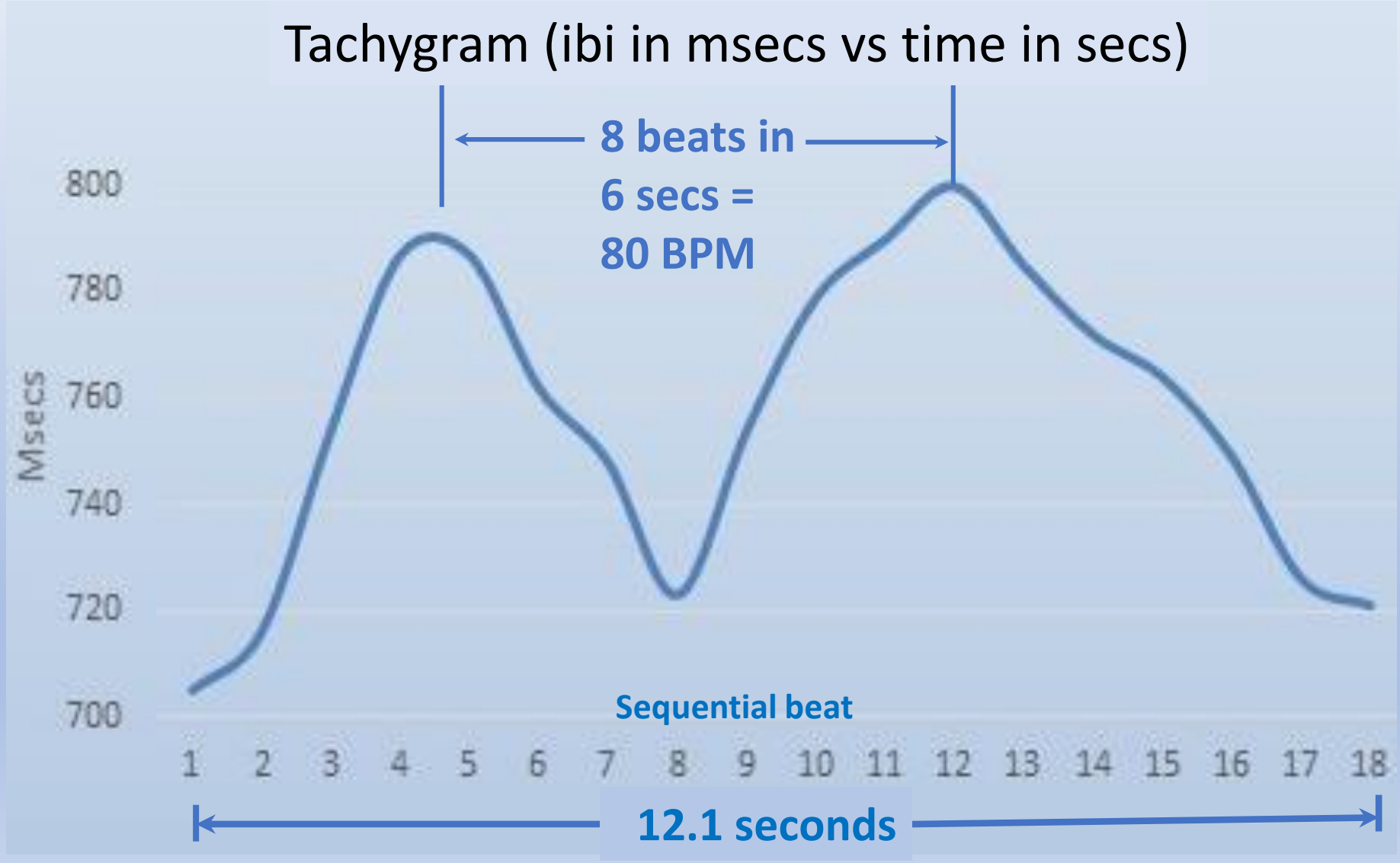
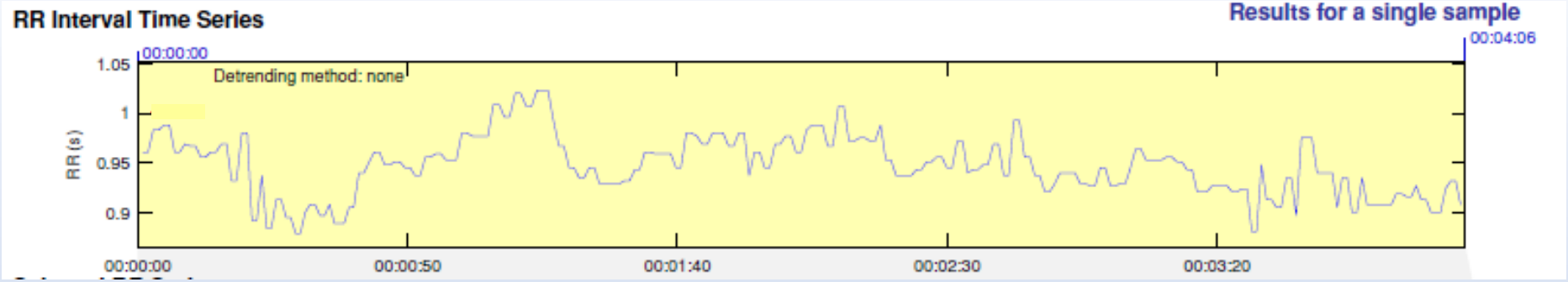
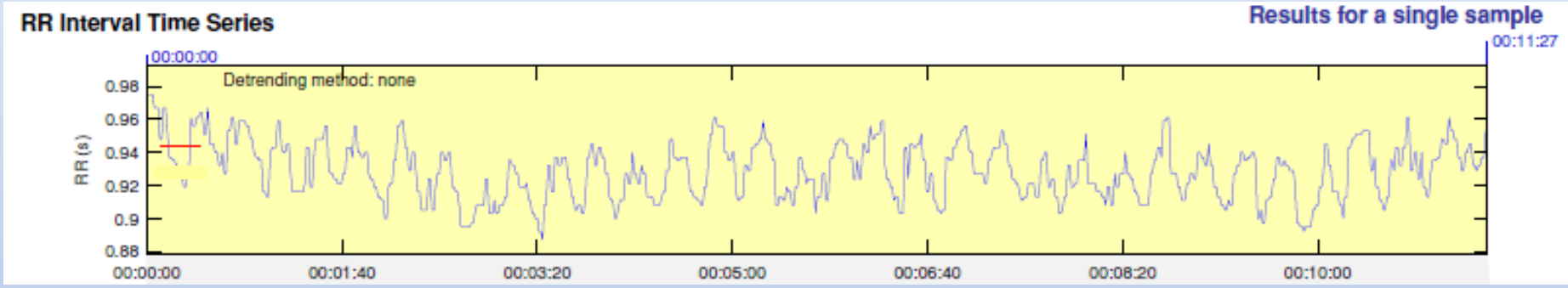


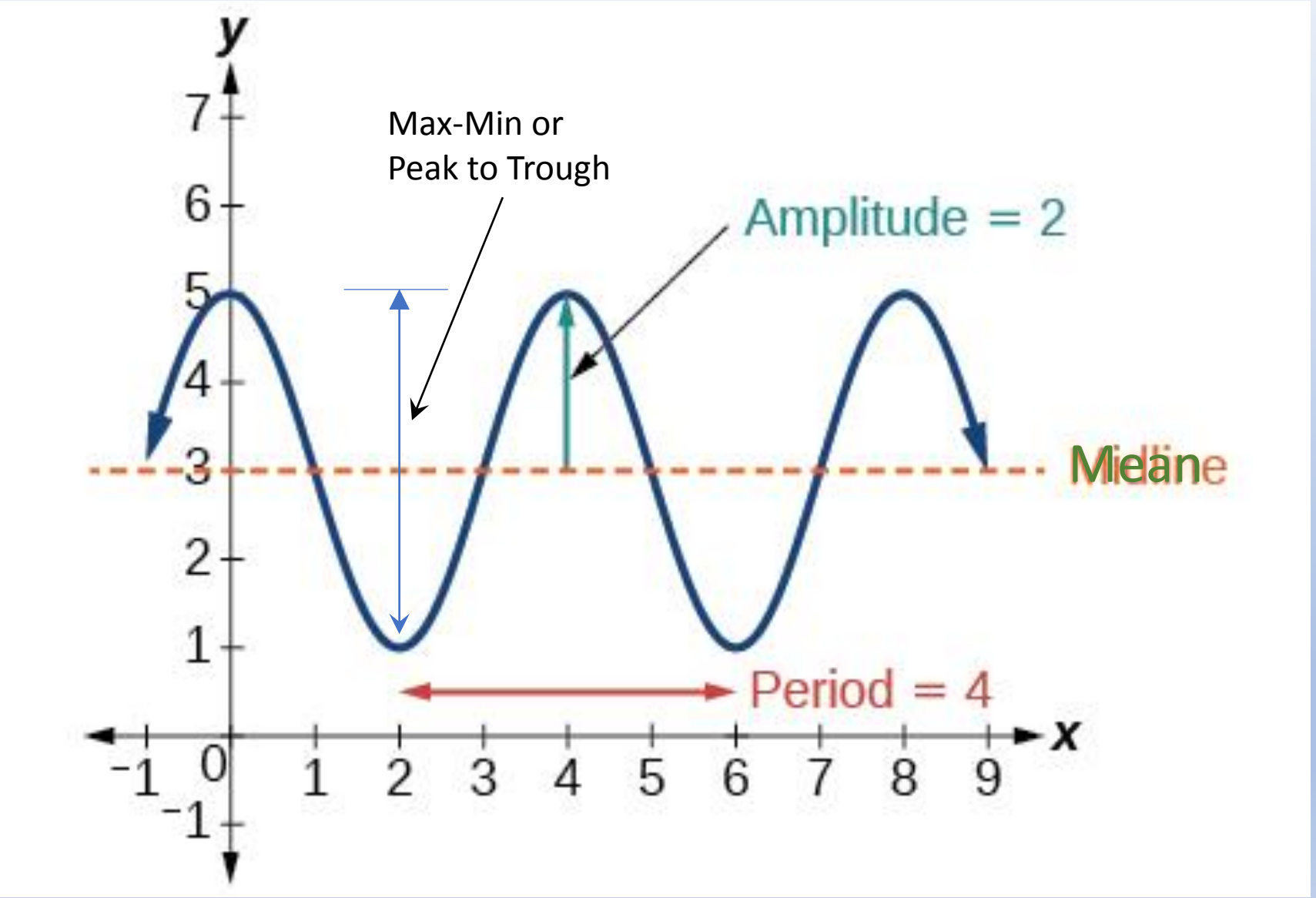




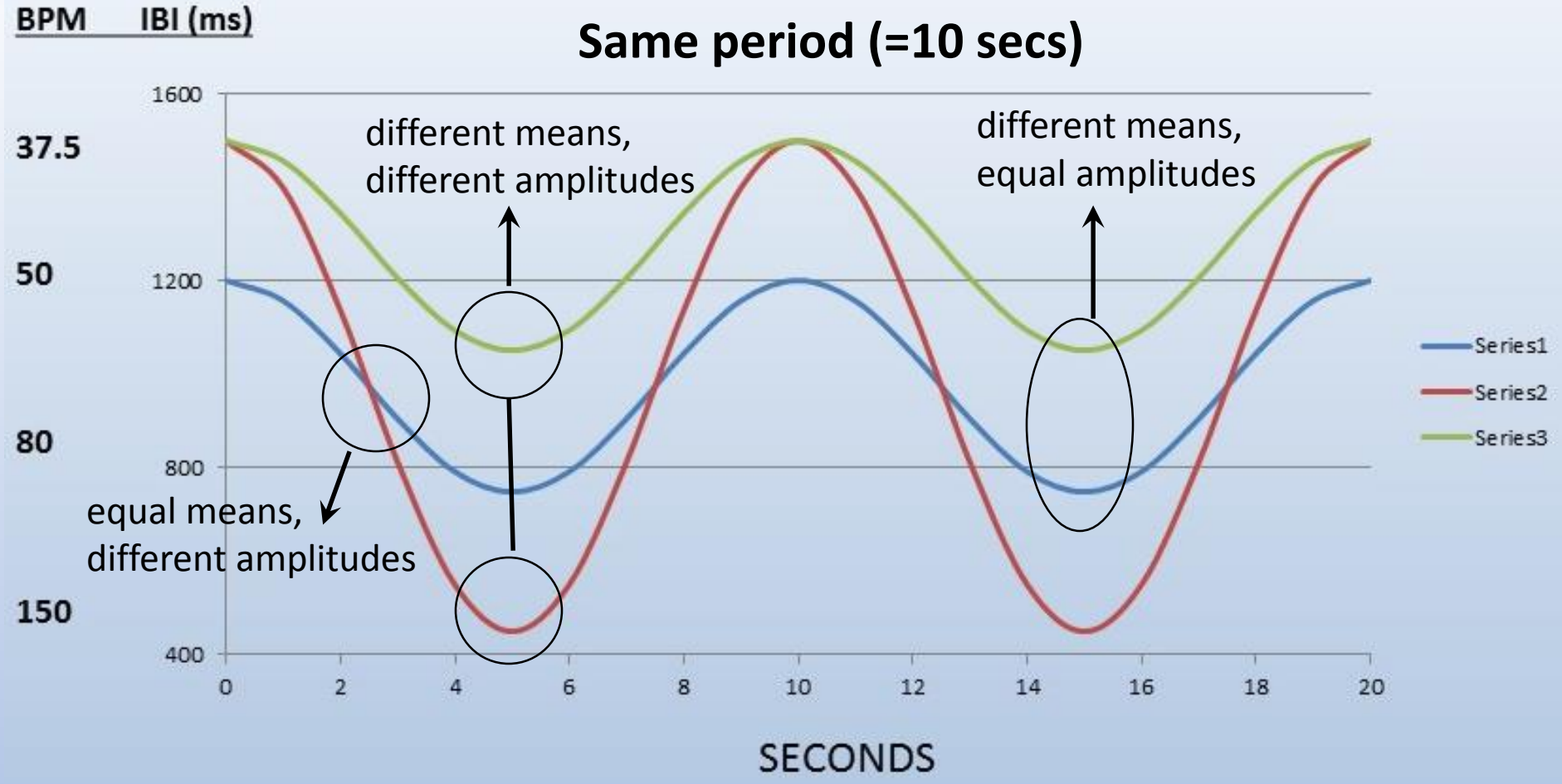
Tachygram

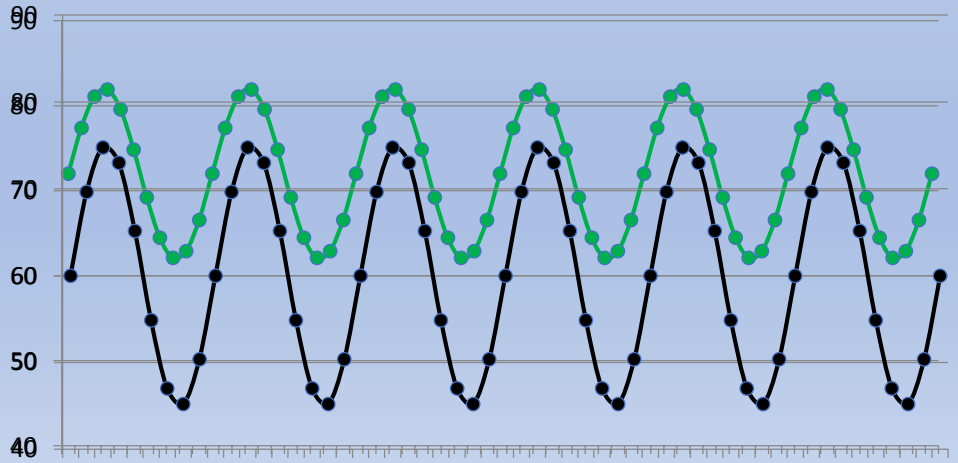
A tachygram is a graph of heart rate (HR), either as inter-beat interval (IBI) or as instantaneous HR (BPM), over a continuous time period. The illustrations above are IBI in msecs measured as RR.

Sine Wave

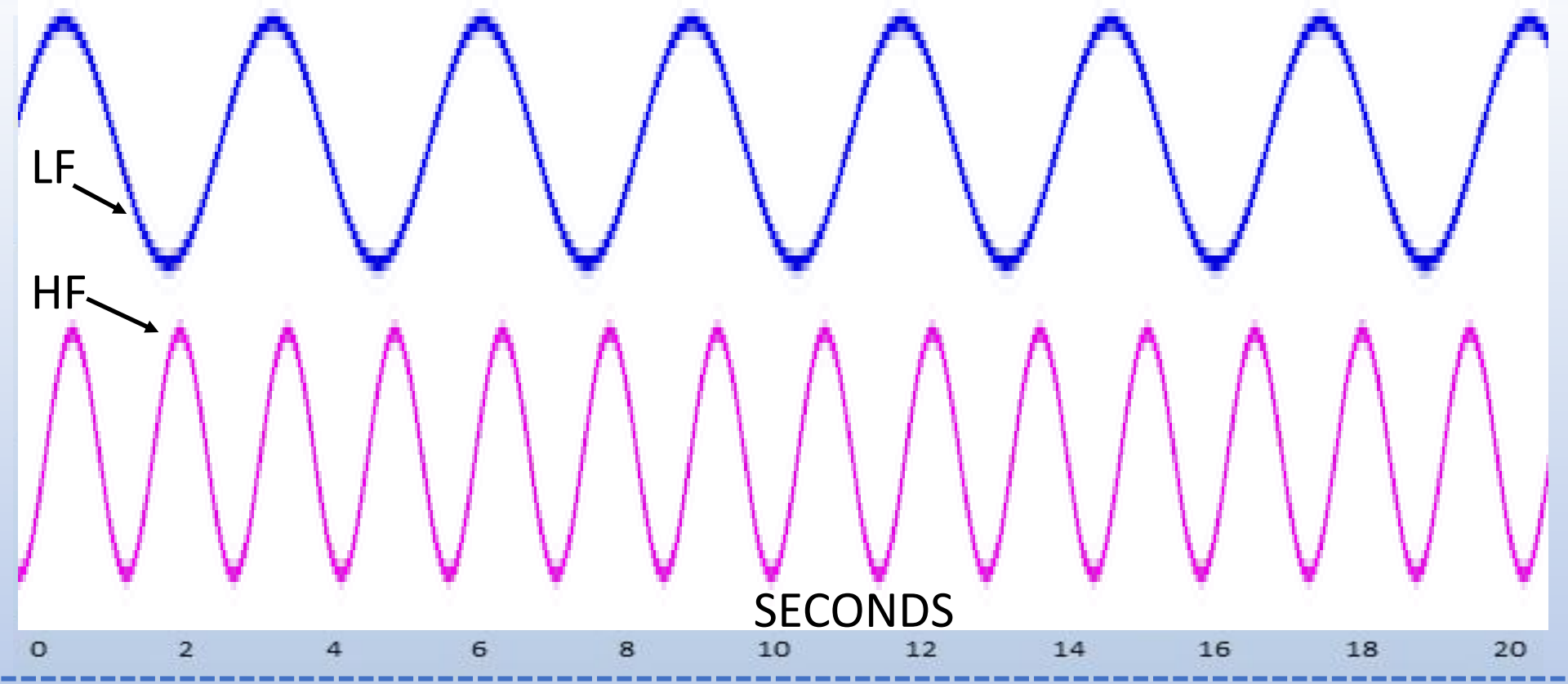

y
x
Max-Min or
Peak to Trough
Amplitude = 2
Mediane
Period = 4
7
6
5
4
3
2
1
-1
0
1
2
3
4
5
6
7
8
9

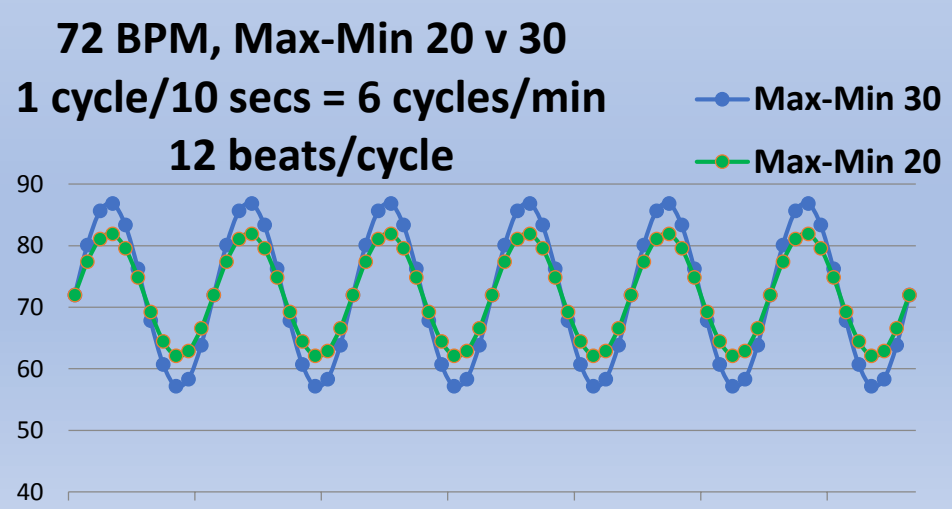
Same period (=10 secs)

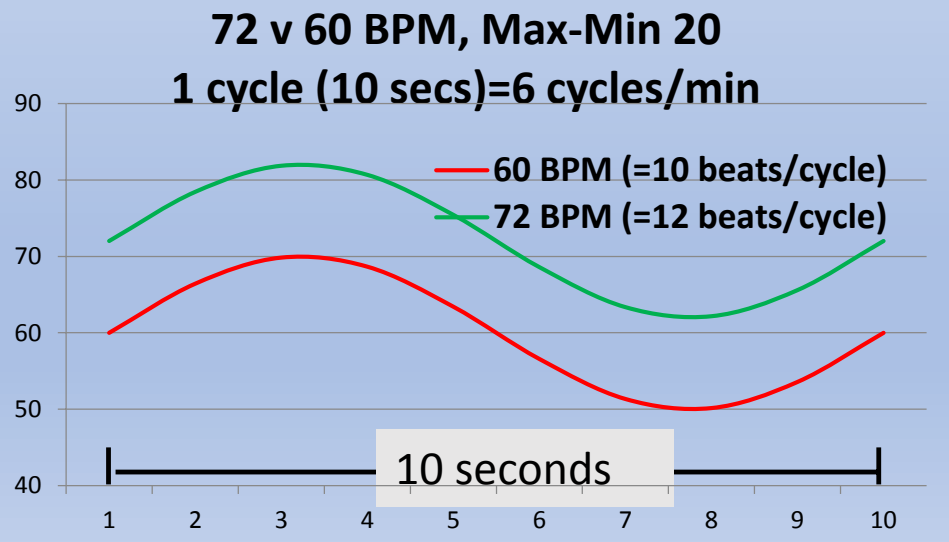


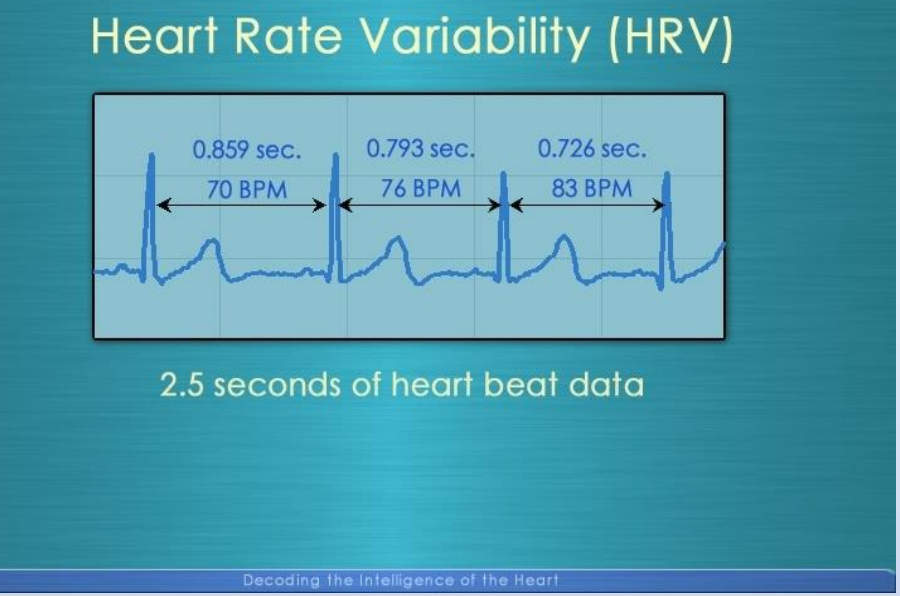


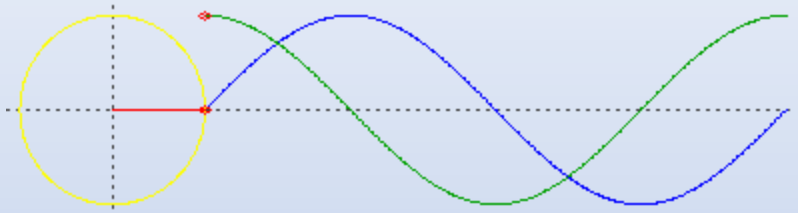
72 BPM, Max-Min 20
1 cycle/10 sec=6 cycles/min
=12 beats/cycle
Vs
60 BPM, Max-Min 30
1 cycle/10 sec=6 cycles/min
=10 beats/cycle


LF
HF
SECONDS
0
2
4
6
8
10
12
14
16
18
20


72 BPM, Max-Min 20 v 30
1 cycle/10 secs = 6 cycles/min
12 beats/cycle
Max-Min 30
Max-Min 20
90
80
70
60
50
40

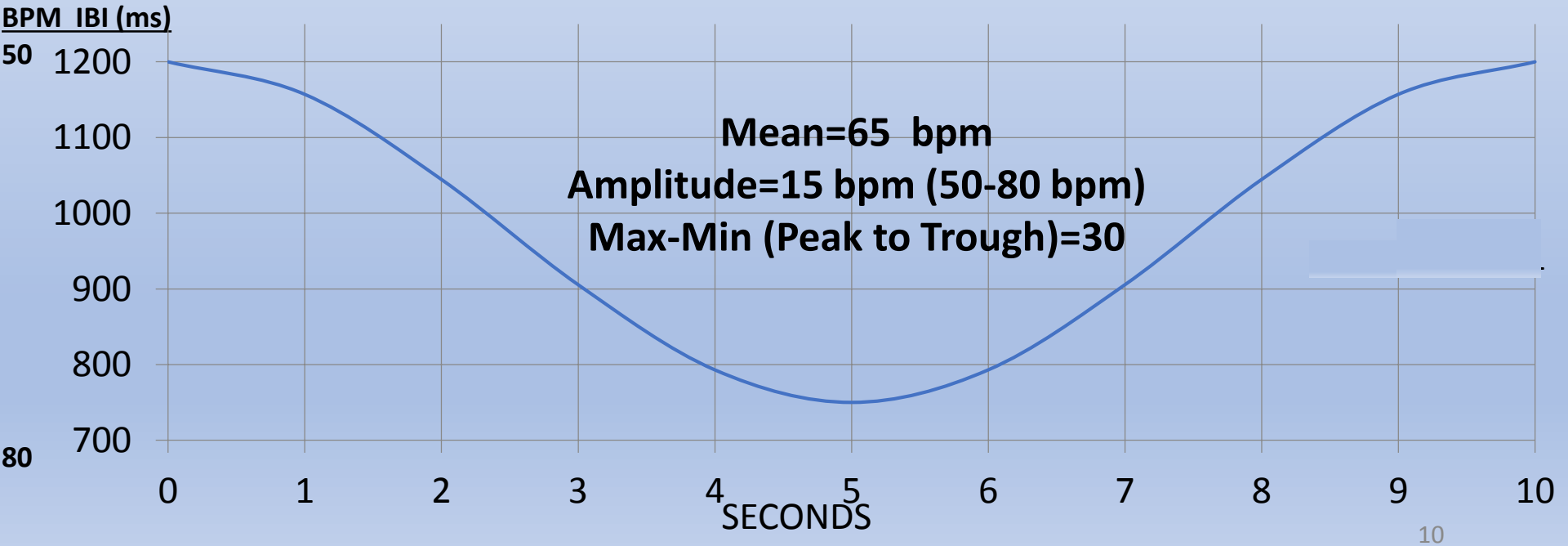

72 v 60 BPM, Max-Min 20
1 cycle (10 secs)=6 cycles/min
60 BPM (=10 beats/cycle)
72 BPM (=12 beats/cycle)
10 seconds
90
80
70
60
50
40
1
2
3
4
5
6
7
8
9
10



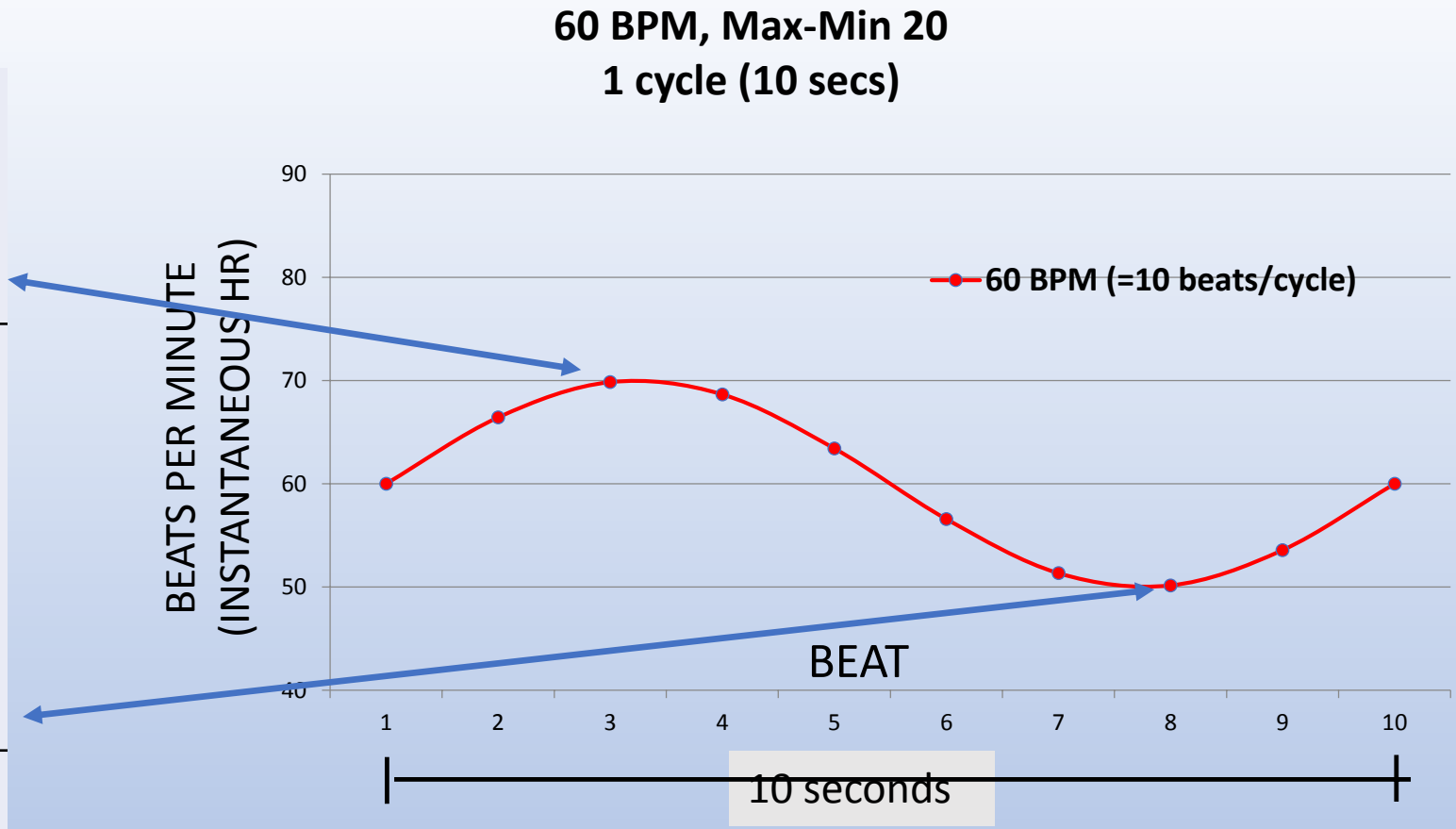


IBI = 975+225*COS(t*PI)

IBI-	1200	1157	1045	905	793	750	793	905	1045	1157	1200
BPM-	50	52	57	63	76	80	76	63	57	52	50

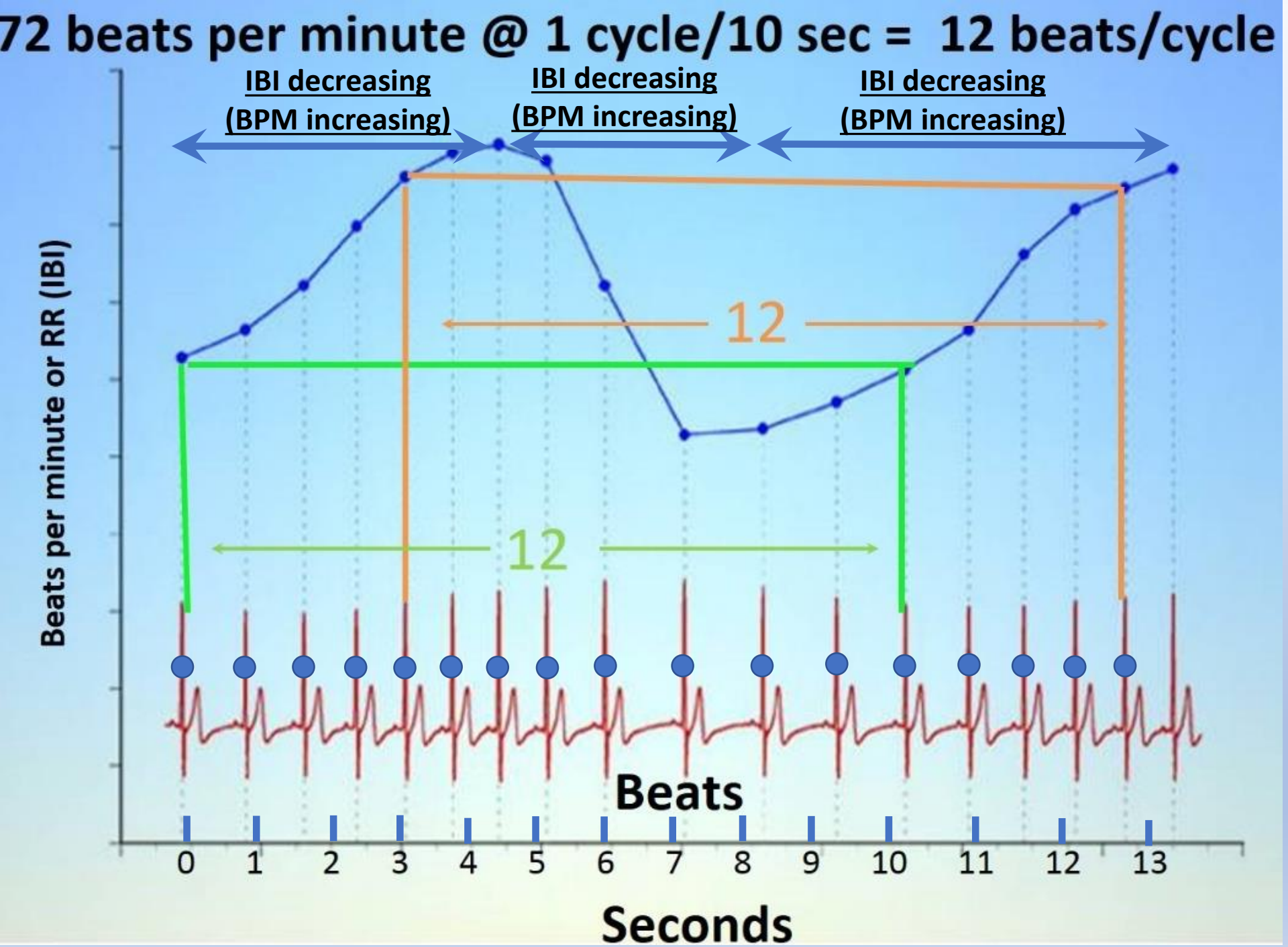


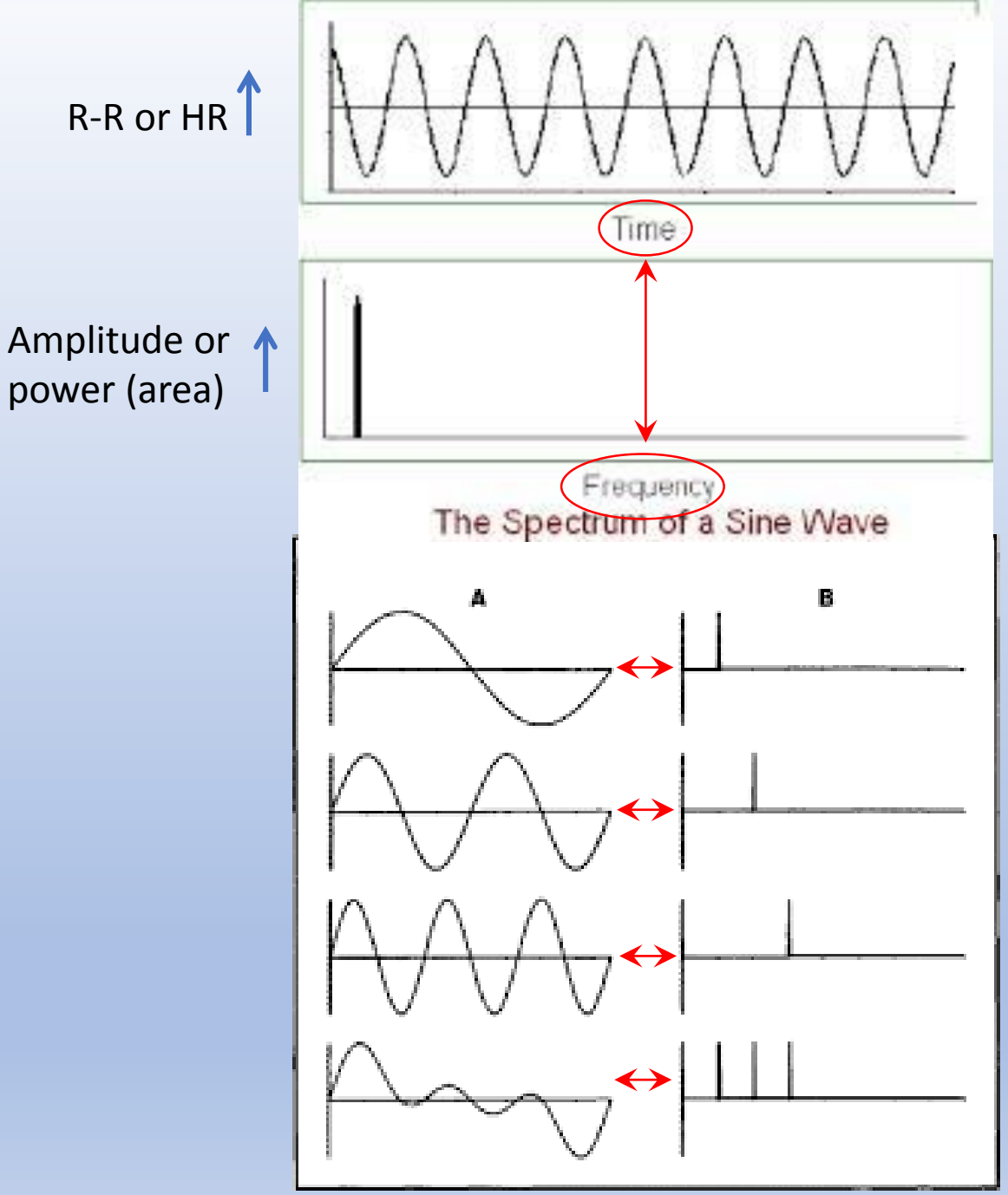
60.0
66.4
69.8
68.7
63.4
56.6
51.3
50.2
53.6
60.0



Beats per minute (instantaneous heart rate) mathematically derived from a sine/cosine function.

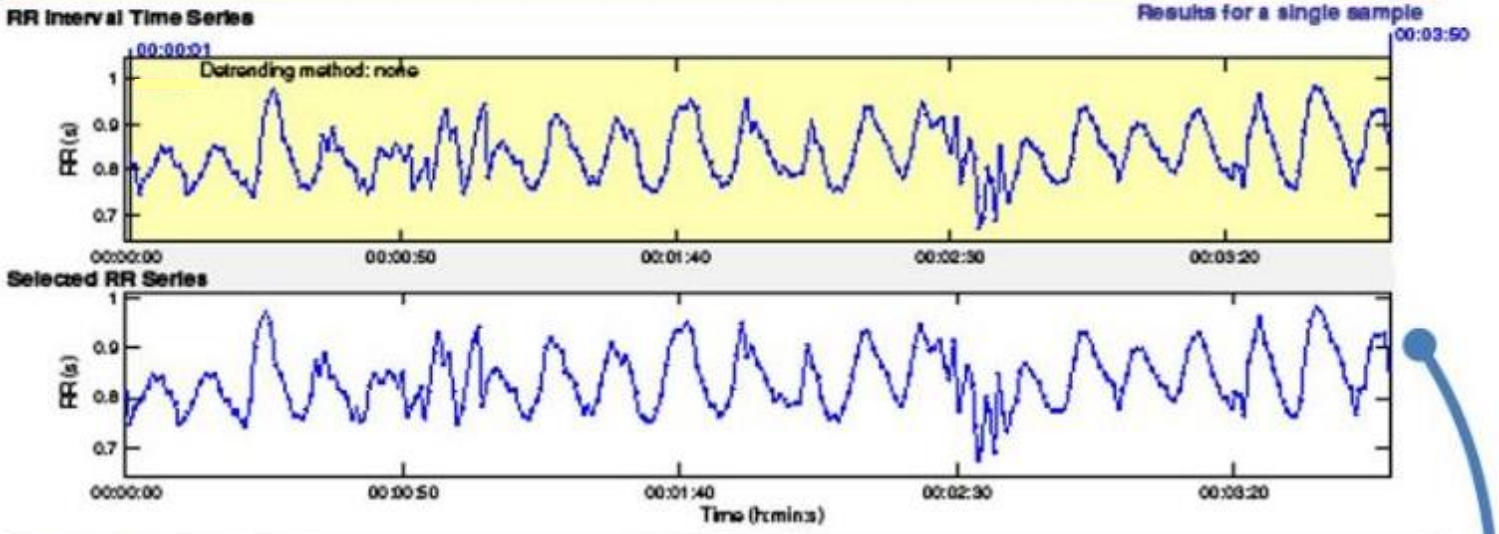
In the illustration above there are 10 beats in 10 seconds (avg BPM=60); **note however that the beats would not be not evenly spaced 1 second apart**


72 beats per minute @ 1 cycle/10 sec = 12 beats/cycle
IBI decreasing (BPM increasing)
IBI decreasing (BPM increasing)
IBI decreasing (BPM increasing)
12
12
Beats per minute or RR (IBI)
Beats
0 1 2 3 4 5 6 7 8 9 10 11 12 13
Seconds



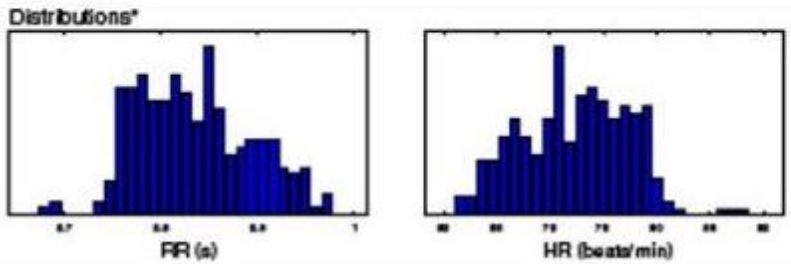
The Fourier Transform will transform any sinusoidal wave form into a frequency spectrum. The transformed frequency spectrum is quantified and analyzed in terms of ‘power’ or area under the curve, across a range of frequencies. Power is directly related to variance of the untransformed time series.

HRV Analysis Results



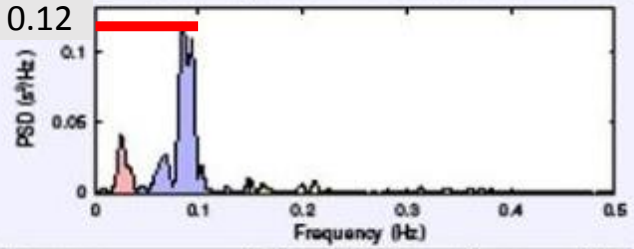
Time–Domain Results

Variable	Units	Value
Mean RR*	(ms)	833.9
STD RR (SDNN)	(ms)	56.5
Mean HR*	(1/min)	72.30
STD HR	(1/min)	5.03
RMSSD	(ms)	39.8
NN50	(count)	43
pNN50	(%)	15.8
RR triangular index		15.167
TINN	(ms)	270.0



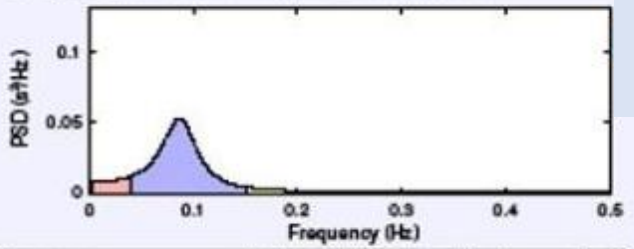
Frequency–Domain Results

FFT spectrum (Welch's periodogram: 512 s window with 50% overlap)



Frequency Band	Peak (Hz)	Power (ms²)	Power (%)	Power (n.u.)
VLF (0.0033–0.04 Hz)	0.0215	469	14.2	
LF (0.04–0.15 Hz)	0.0859	2425	73.5	85.6
HF (0.15–0.4 Hz)	0.1504	407	12.3	14.4
Total		3301		
LF/HF		5.966		

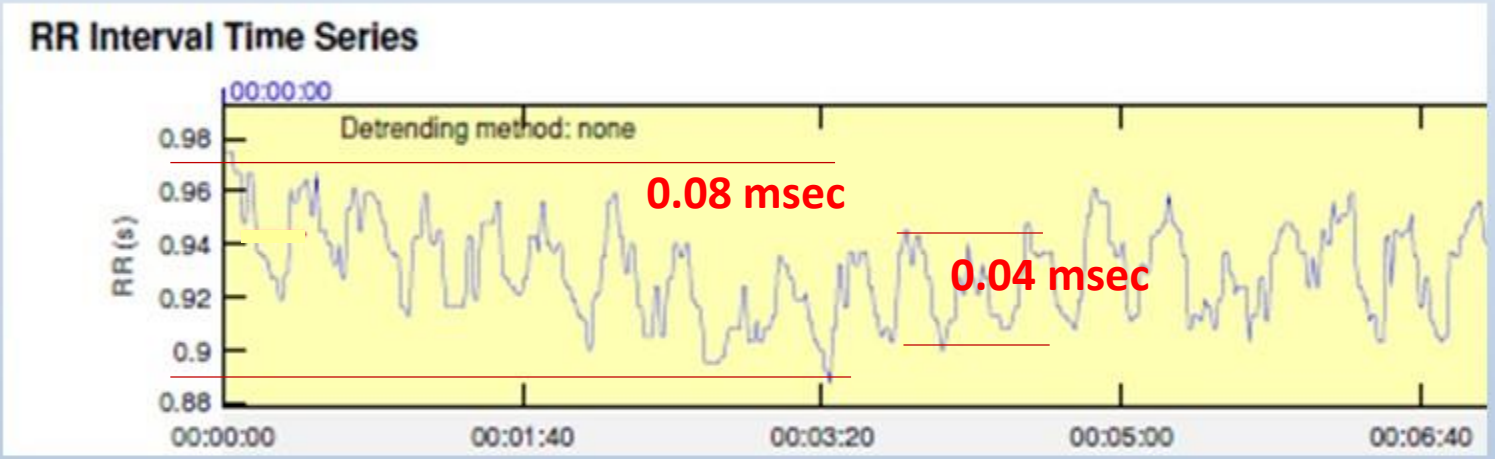
AR Spectrum (AR model order = 16, not factorized)

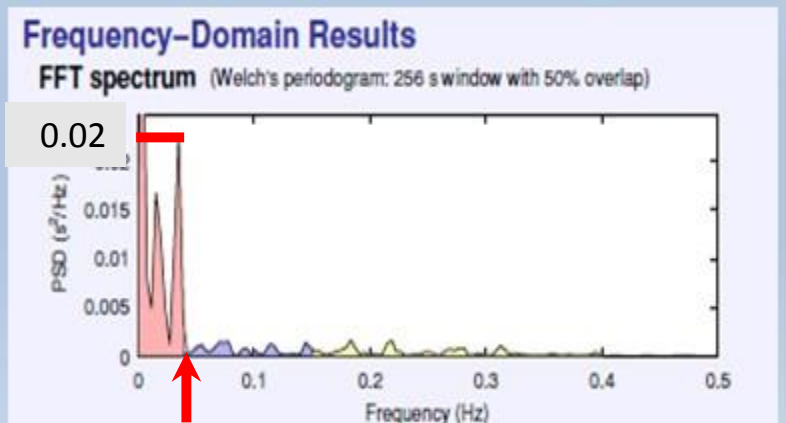


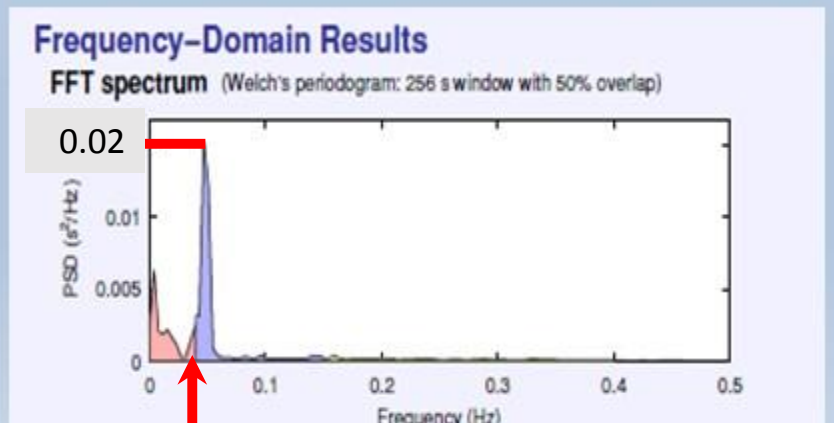
Frequency Band	Peak (Hz)	Power (ms²)	Power (%)	Power (n.u.)
VLF (0.0033–0.04 Hz)	0.0352	327	9.8	
LF (0.04–0.15 Hz)	0.0859	2643	78.9	87.5
HF (0.15–0.4 Hz)	0.1504	379	11.3	12.5
Total		3349		
LF/HF		6.973		

Kubios HRV report


RR Interval Time Series
00:00:00
Detrending method: none
.14 msec
0.04 msec
RR (s)
1.05
1
0.95
0.9
00:00:00
00:00:50
00:01:40
00:02:30


RR Interval Time Series
00:00:00
Detrending method: none
0.08 msec
0.04 msec
RR (s)
0.98
0.96
0.94
0.92
0.9
0.88
00:00:00
00:01:40
00:03:20
00:05:00
00:06:40


Frequency–Domain Results
FFT spectrum (Welch's periodogram: 256 s window with 50% overlap)
0.02
PSD (s²/Hz)
0.015
0.01
0.005
0
0
0.1
0.2
0.3
0.4
0.5
Frequency (Hz)


Frequency–Domain Results
FFT spectrum (Welch's periodogram: 256 s window with 50% overlap)
0.02
PSD (s²/Hz)
0.01
0.005
0
0
0.1
0.2
0.3
0.4
0.5
Frequency (Hz)

VLF: 0.0033-0.04Hz=(300-25) secs/cycle=(0.2-2.4) cycles/min

- Minimum 5 minute recording (24 hour is best)
- More strongly predictive of all-cause mortality and inflammation than the other bands
- Origins of VLF power unclear
  - Intrinsic (pacemaker)
  - Predominantly SNS activity however low PNS power also present

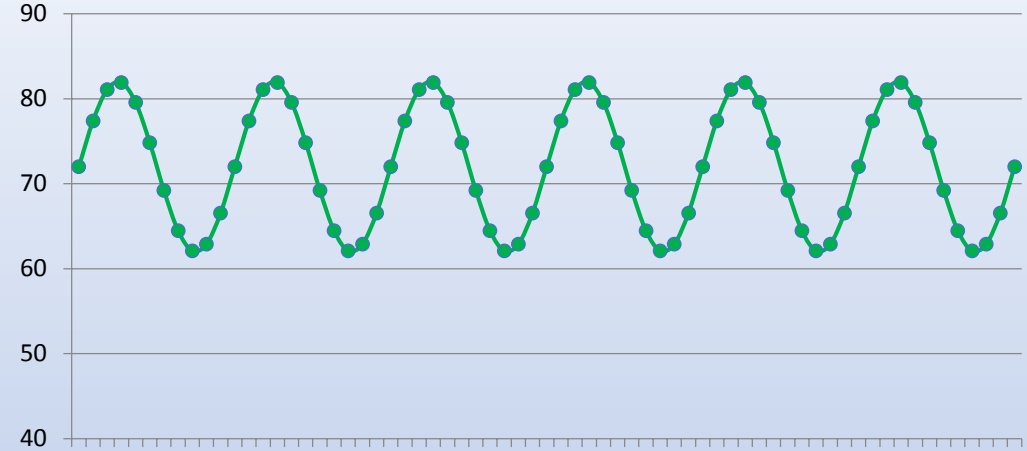
LF: 0.04–0.15 Hz=(25-6.7) secs/cycle=(2.4-9) cycles/min

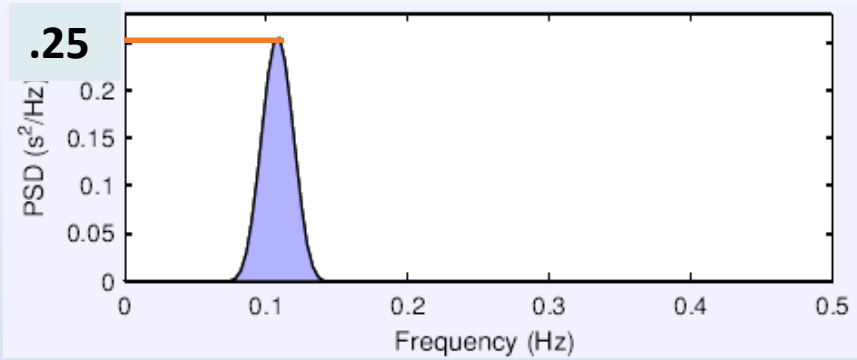
- Minimum 2 min recording
- 'Baroreceptor range' during rest
- Power from SNS, PNS, and baroreceptors
  - SNS not above ~0.1 Hz
  - PNS dominant >0.07 Hz

HF: 0.15–0.40 Hz=(6.7-2.5) secs/cycle=(9-24) cycles/min

- Minimum 1 minute recording
- 'Respiratory band'
- PNS power

72 BPM, Max-Min 20
1 cycle/10 sec, 12 beats/cycle
6 cycles (1 minute)





Idealized HRV parameters - 1 min recording	
Mean HR	72.0
Max-Min	20.0
SDNN (ms)	83.9
RMSSD (ms)	47.0
VLF power (ms^2)	0
LF power (ms^2)	6959.0
LF peak (Hz)	0.1
HF power (ms^2)	4

Kubios v. 2.0

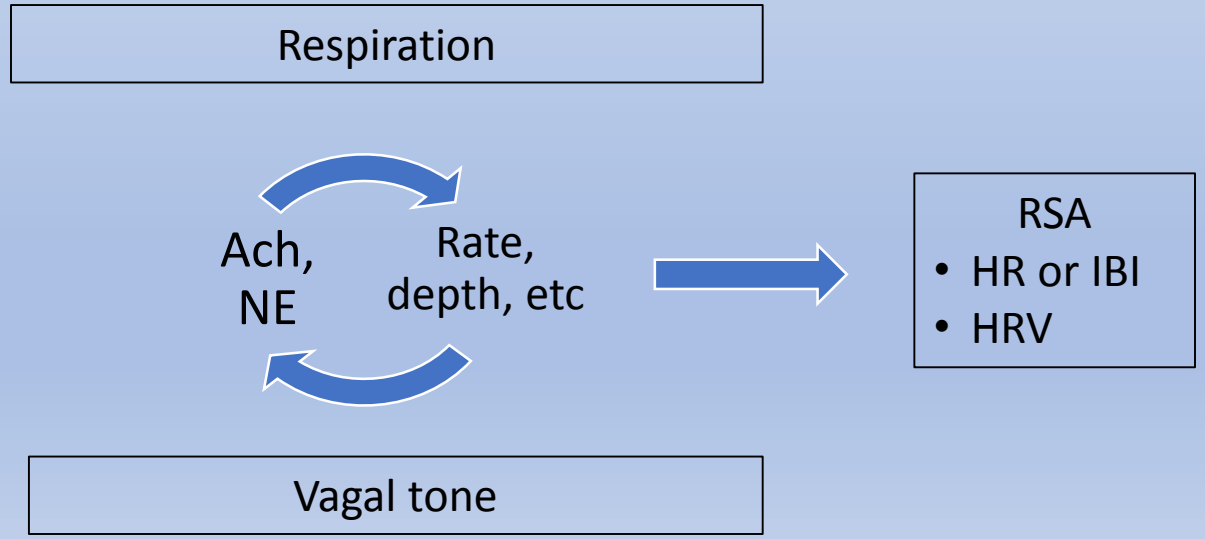
Physiological Bases of HRV

I. Respiratory Sinus Arrhythmia (RSA)
- Abdominothoracic Pump, Respiratory Pump, Cardio-respiratory Coupling, Cardiopulmonary Reflex, Lung-heart Pump
- Results from interactions of
  - Respiration (e.g. rate, depth, volume, effort)
  - Vagal parasympathetic tone
  - Oscillations in cardiac output
- Occurs at normal respiration rate
  - 0.15-0.4 Hz=9-14 BrPM
- May be measured as either instantaneous HR or IBI
  - Max-min ('peak to trough') over a single respiratory cycle or averaged over many respiratory cycles
  - HRV indices
- A higher resting vagal tone may be adaptive
  - Energy reserve capacity for active states

II. Resonant Frequency Breathing (RFB)
- Occurs in LF, around 0.1 Hz=~6 BrPM
- Baroreceptor reflex (BR)
- Interrelations of respiration, HR, BR, BP, and vasomotor tone (VT)
- 'Coherence'

RSA: Respiration and Vagal Parasympathetic Tone-I

- Normal Respiration produces rhythm of cardiac acceleration and deceleration
  - Cardiac acceleration on inhalation
  - Cardiac deceleration on exhalation
- Synchronization of respiratory and cardiovascular processes and regulation of energy exchange
- Vagal tone is measured by HR responses to cholinergic and adrenergic stimulation and blockade

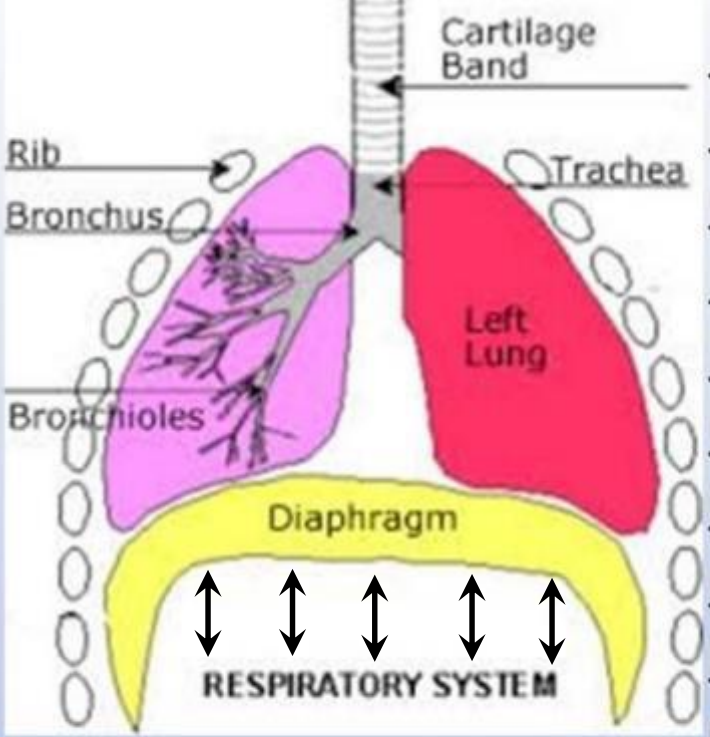


RSA: Respiration and Vagal Tone-II

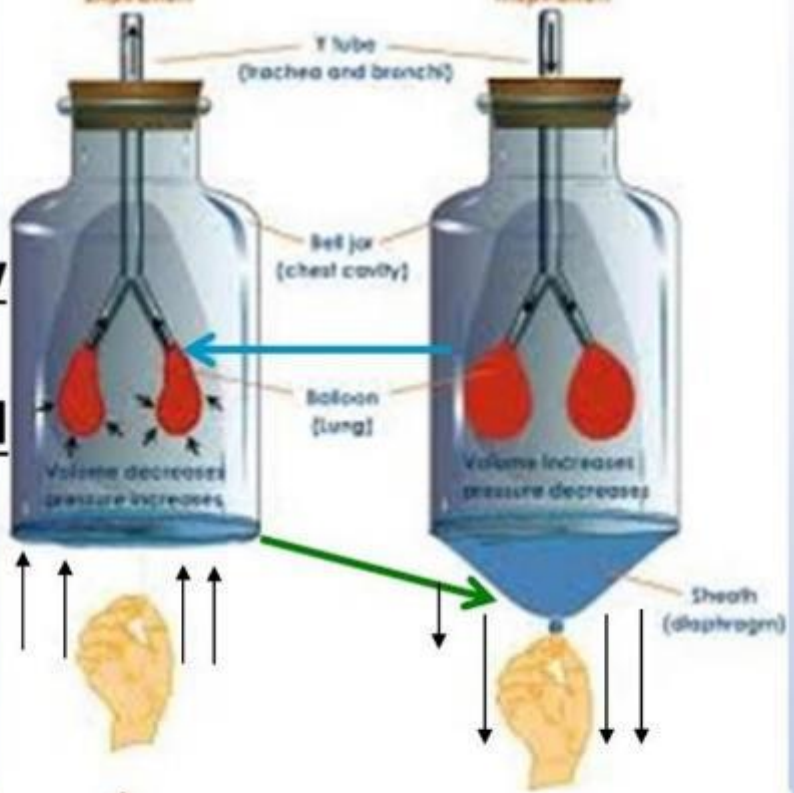
- RSA magnitude is affected by respiration and vagal tone separately
- Vagal tone reflects oscillations of cardiac vagally modulated parasympathetic (cholinergic) effects upon the sinoatrial node and, therefore, HR
- Respiratory parameters (e.g. rate, volume or depth) affect or confound the function linking RSA and vagal tone
  - RSA due to respiration rate and cardiac vagal tone can dissociate
- RSA magnitude more closely related to changes in respiratory parameters than to changes in cardiac vagal tone
  - Greater tidal volume, lower breath rate increase RSA with constant vagal tone
- HR max-min is sensitive to respiration rate independent of vagal tone
- HF power changes may not be accompanied by changes in HR
- HF power and RSA do not represent vagal tone
- RSA magnitude is affected by vagal tone and beta-adrenergic status
  - Vagolytic agents (e.g. atropine, muscarinic cholinergic antagonists) block Ach and increase beta-2 adrenergic activity
    - Decrease RSA, increase HR, no BP change
    - Abolish LF and HF power
      - Blocks SA Ach released by vagus
      - Does not alter HR in absence of vagal nerve activity
  - Beta-adrenergic blockade (e.g. propranolol, atenolol)
    - Increase RSA, decrease HR and BP

RSA: Respiration and Oscillation in Cardiac Output (Intra-thoracic Pressure, Venous Return)

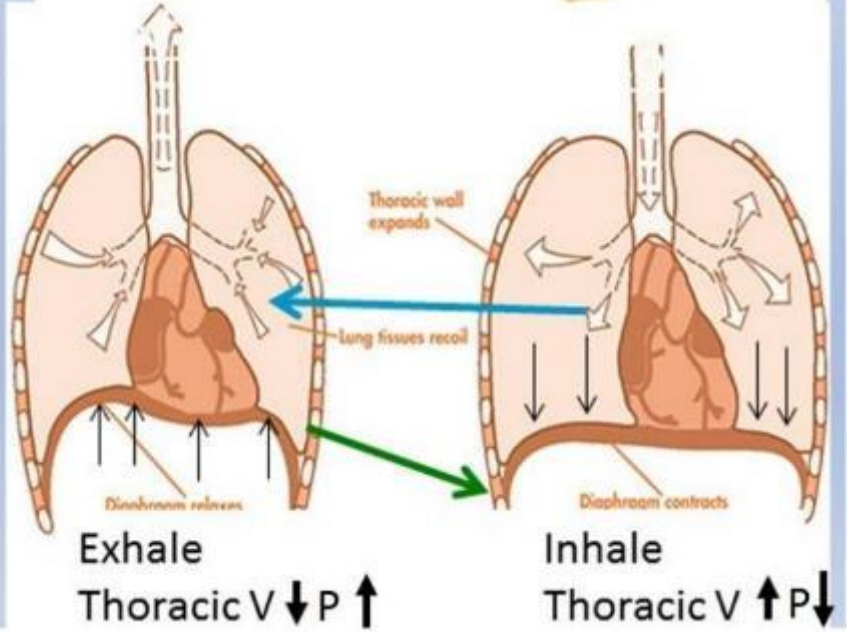
- RSA is also elicited by cardiovascular reflexes due to changes in venous filling of the heart during normal respiration
- Respiratory activity influences venous return to the heart. Inspiration expands the right atrium, lowers intra-pleural pressure, enhances venous return, increases HR
- Increasing the depth of inhalation promotes venous return (like pulling out on a bellows or syringe), enhances cardiac output, and increases HR
    - Cardiac output = stroke volume x HR
- Low pressure arterial baroreceptors at veno-atrial junctions of the heart ('cardio-pulomonary receptors') are innervated by myelinated vagal afferents and respond to atrial filling and contraction. During inhalation, right atrial expansion and reduced pressure increase venous return, blood volume stretch recptors, and HR via withdrawal of vagal parasympathetic activity to the SA node (Bainbridge Reflex). During exhalation, right atrial contraction and increased pressure decrease stretch receptors which decreases venous return and HR via activation of vagal reflex.



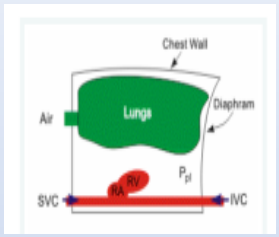
1. Exhale, relax diaphragm, reduce cavity
2. Inhale, contract (pull down) diaphragm, increase cavity



In Diaphragmatic Breathing inhalation increases thoracic cavity volume (draws air in) due to active contraction of diaphragm, decreases P; exhalation decreases cavity volume (expels air), increases P, and is passive.



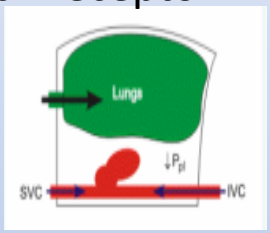
RSA is affected by inhalation vs exhalation changes in venous return and cardiac output



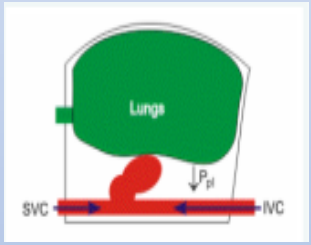
←Lung
←Blood volume stretch receptor

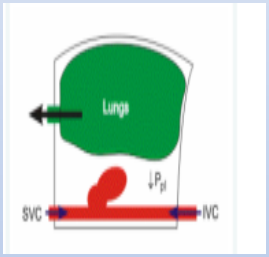
Inhale, start cycle again

Inhale, thoracic volume increases, pressure decreases



Venous blood flow and HR increase





Exhale, thoracic volume decreases, pressure increases

HR, blood flow decrease

Inhale
↓ **Pressure**
↑ **Volume, blood flow, HR**

Exhale
↑ **Pressure**
↓ **Volume, blood flow, HR**

Increasing the depth of respiration promotes venous return through changes in right atrial (chest cavity) pressure. During inspiration, the chest wall expands as the diaphragm descends, causing right atrial pressure to fall which facilitates venous return.. As pressure falls and venous return flow rises, cardiac rate accelerates… During expiration, the opposite occurs.. Increasing right atrial pressure impedes venous return and slows HR… Increasing the depth of ventilation increases the range of HR over the respiratory cycle.

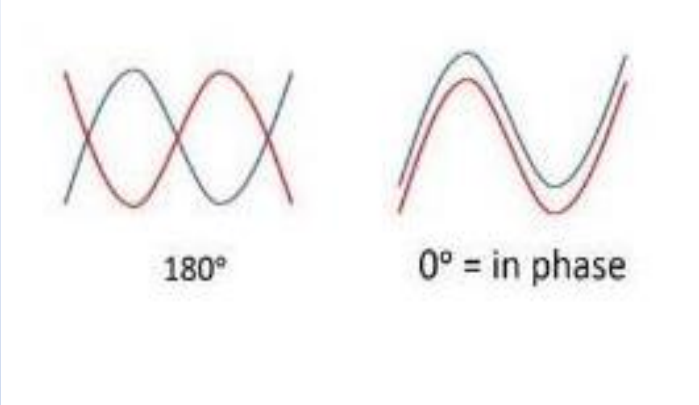
Resonance Frequency Breathing (RFB)

- HRV is related to frequency of respiratory cycle

- At ~ 6 breaths/minute =10 seconds per breath=0.1 Hz
  = 0.1 cycles/second
  = 1 cycle/10 seconds
  = 6 cycles/60 seconds
  = 6 cycles/minute

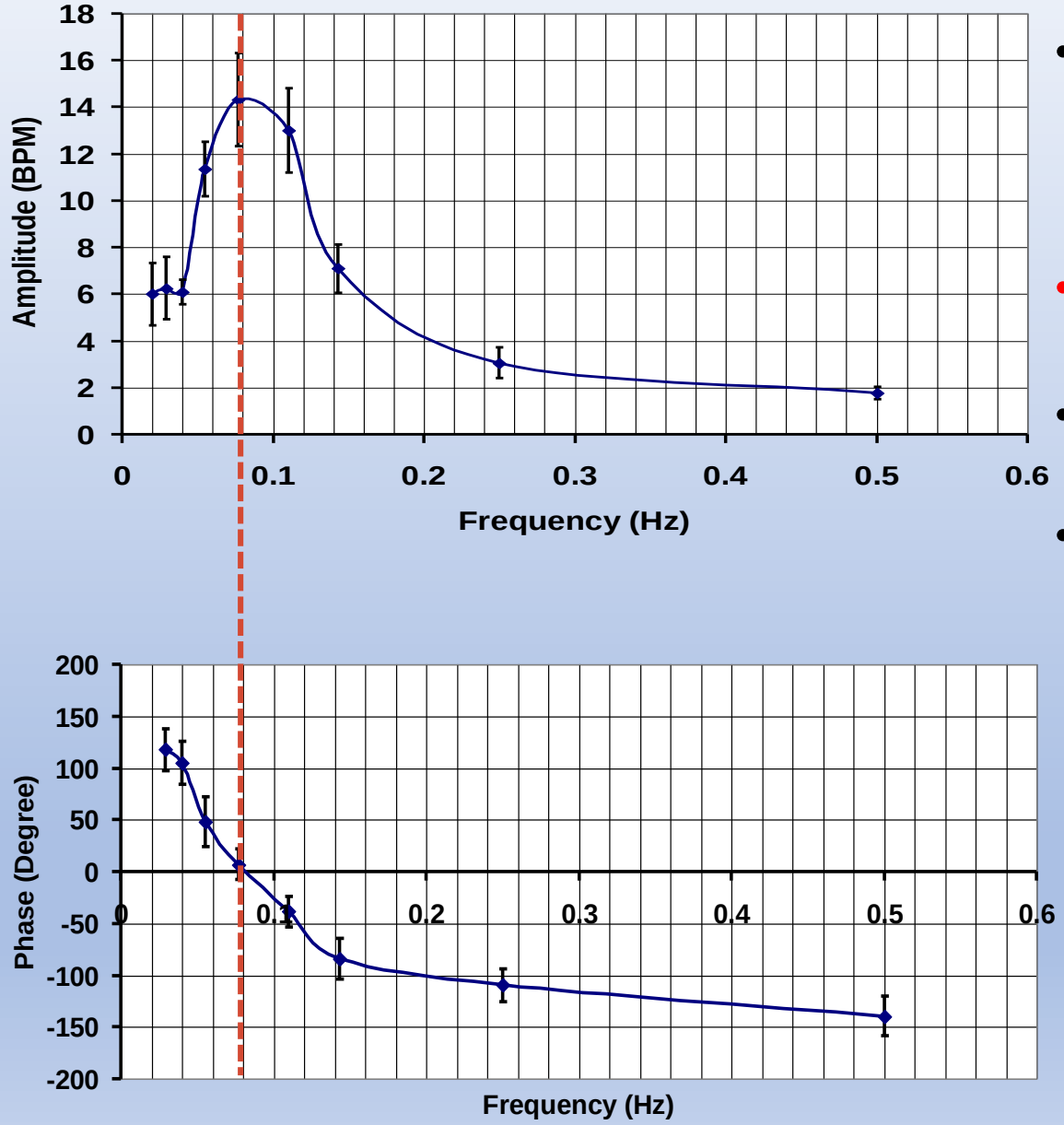
- @RFB, respiration and HRV synchronize
  - 'Resonance'
  - Indicator of 'Coherence'

0º phase relationship between oscillations in respiratory and HR cycles

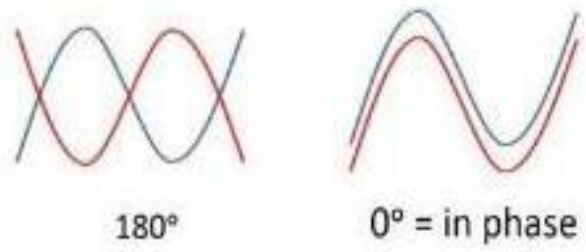


When HRV and respiration are synchronized, a spectral peak occurs at the RFB, ~0.1 Hz, due to resonance of HRV amplitude.

Resonance Frequency Breathing: Effect of Various Respiration Frequencies on HRV Averaged RSA Amplitude and Phase Frequency Characteristics

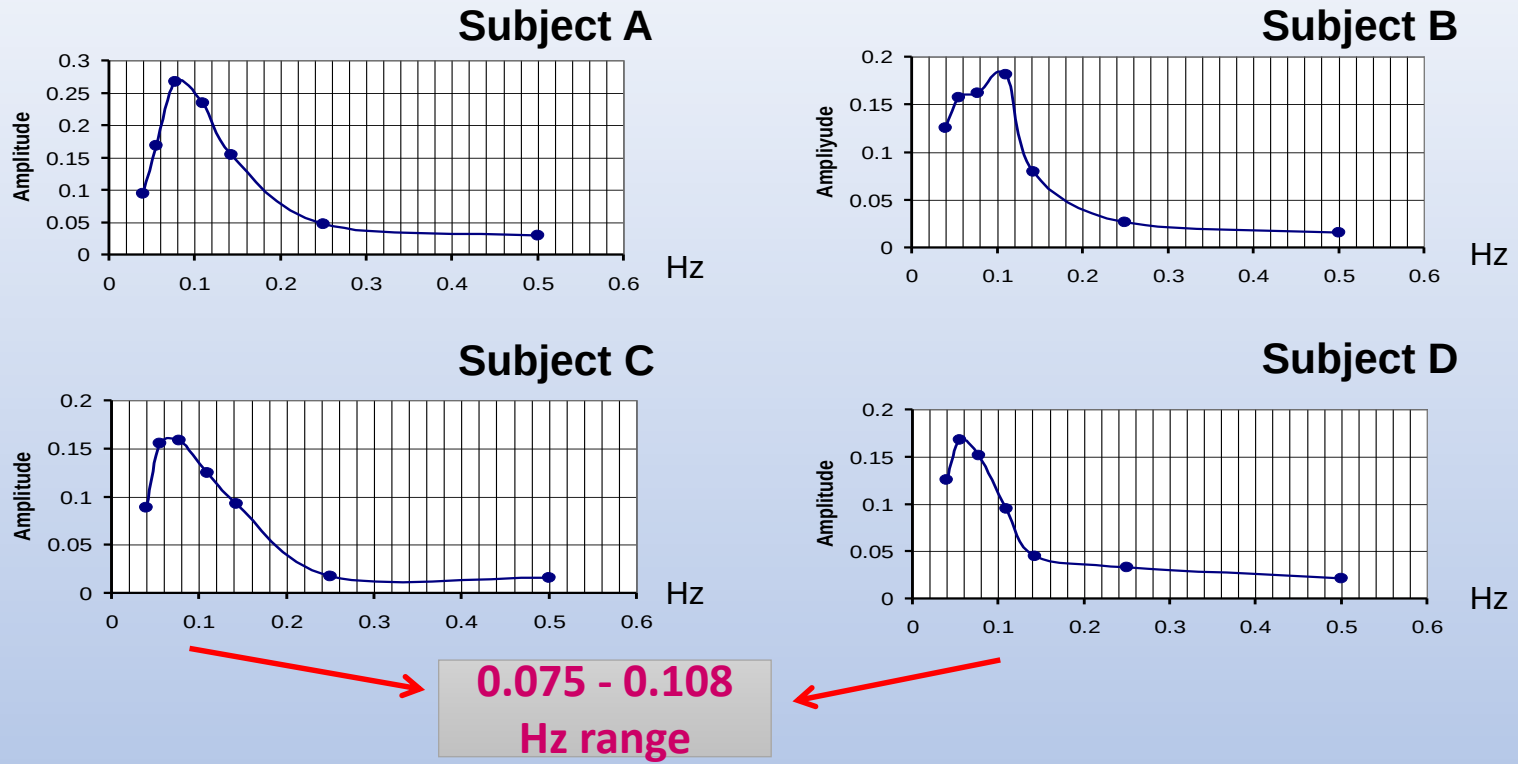


- Measured continuous HR in 5-min paced breathing periods of 0.5, 0.25, 0.143, 0.11, 0.077, 0.055, 0.04, 0.029, and 0.02 Hz
- Paced breathing (imposed) sinewave oscillations in HR
- Calculated avg HR_{max}- Hr_{min} per respiratory cycle
- ***The highest amplitude of max-min and 0° phase occurred at same frequency of breathing, ~0.1 Hz***



Phase Relationships of Sine-Wave Oscillations

RSA (HR max-min) Differs between People but all have max ~0.1 Hz



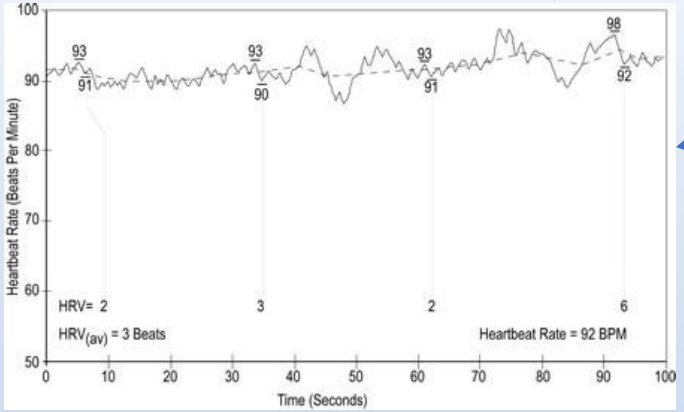
- Breathing ~0.1Hz caused highest HR oscillation amplitude for all Ss
- HR always synchronized with breathing at this frequency (phase=0°).
- Peak HR amplitudes at ~0.1 Hz (resonance in CVS) at this frequency.
- Peak HR amplitude found in range of *0.075–0.108 Hz (=4.5-6.5 BrPM)*

Resonance is the tendency of a system to oscillate with greater amplitude at some frequencies than at others. Relative maximum frequency of oscillation is the system's **resonance frequency**. At these resonance frequency, even small periodic driving forces can produce large amplitude oscillations

Pushing a person in a swing is an example of resonance. Pushing a swing in time with its resonant frequency will make the swing go higher and higher (maximum amplitude), while attempts to push it at a faster or slower tempo results in smaller arcs.

Coherence of Cardiac Rhythm: Effect of RFB on HRV

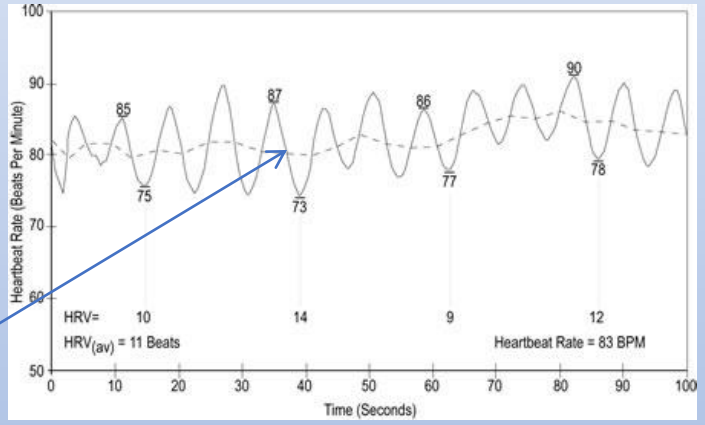
coherence.com (Richard Brown, MD and Stephen Elliott, Ph.D.)



30 BrPM (0.5 Hz) , HRV(avg) = 2

7.5 BrPM (0.125 Hz), HRV(avg) = 11

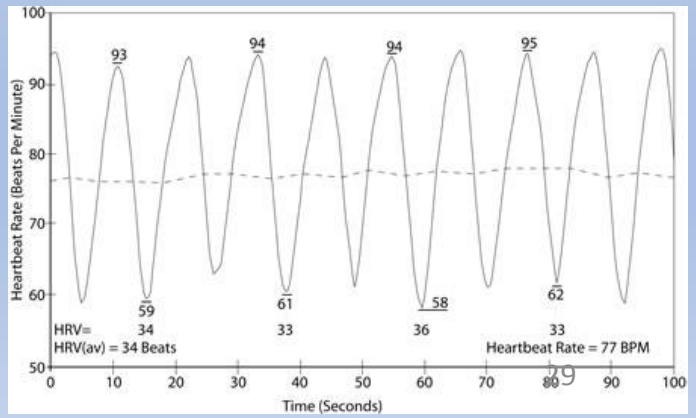
5.5 BrPM (0.092 Hz), HRV(avg) = 34



Baroreflex activates resonance ('Coherence')

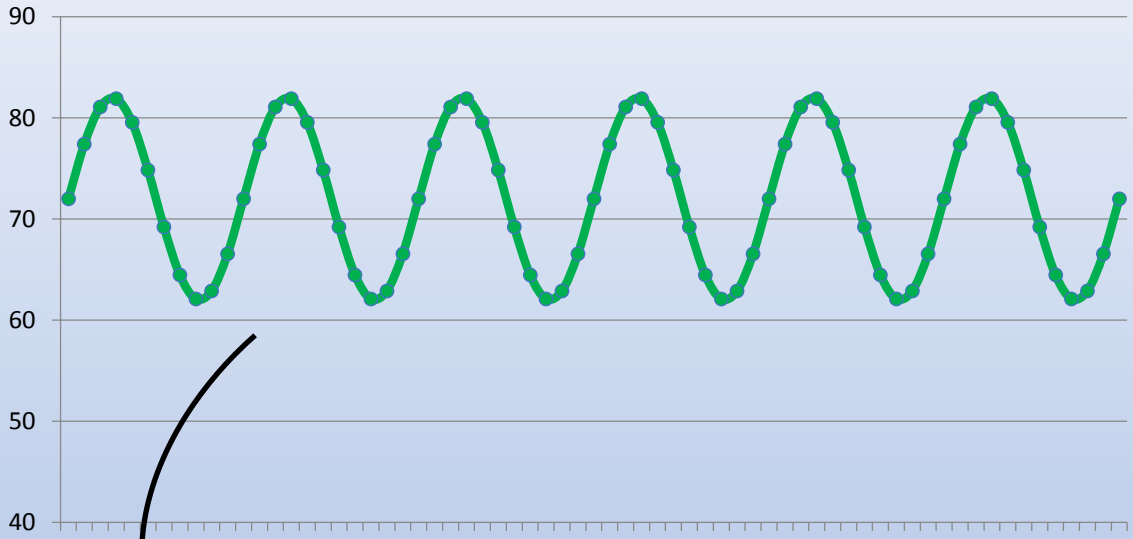
The difference between the max and min HR for each cycle is shown along the center; averaging across consecutive cycles yields HRV(avg), one of the many measures of HRV.

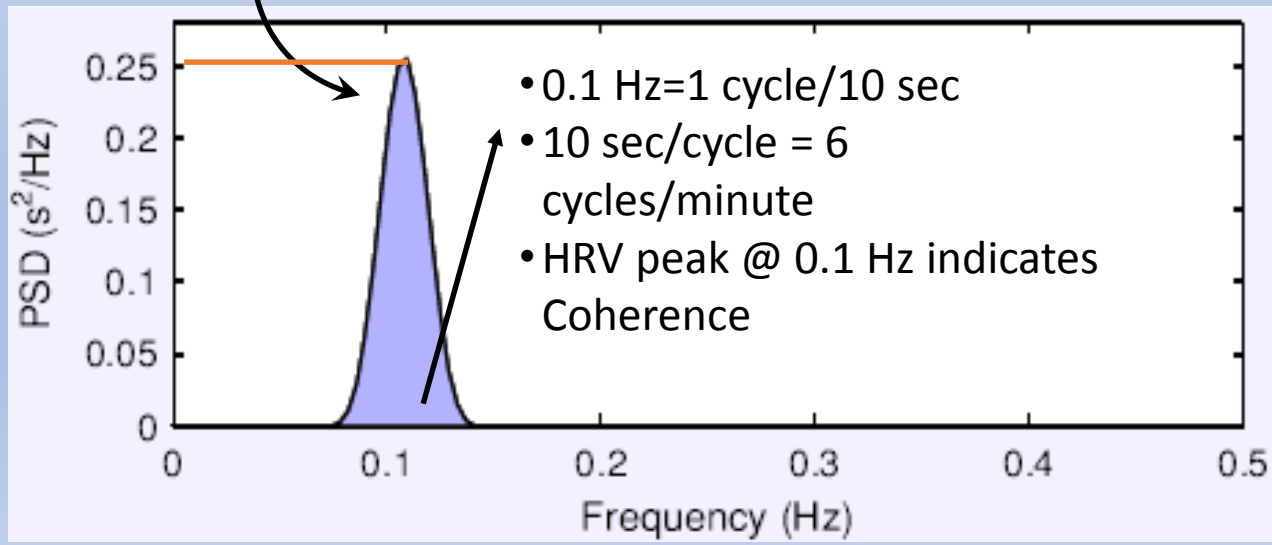
RFB →



Mean HR	72.0
Max-Min	20.0
HR/(max-min)	3.6
SDNN (ms)	83.9
RMSSD (ms)	47.0
VLF power [(ms)^2]	0
LF power [(ms)^2]	6959
LF peak (Hz)	0.1
HF power [(ms)^2]	4
Total Power [(ms)^2]	6963

72 BPM, Max-Min 20
1 cycle/10 sec, 12 beats/cycle
6 cycles (1 minute)





Respiration, HR, and BP are interrelated

BP: Sys/Dias, Pulse, Mean Arterial

1. The Valsalva Maneuver
2. Traube-Hering and Mayer Waves
3. Baroreceptor Reflex (BR)
   a. HR goes down when blood pressure goes up, and HR goes up when blood pressure goes down
   b. The baroreflex amplifies HR oscillations at its resonance frequencies
   c. HRV Resonance @RFB→Coherence

The Valsalva Maneuver

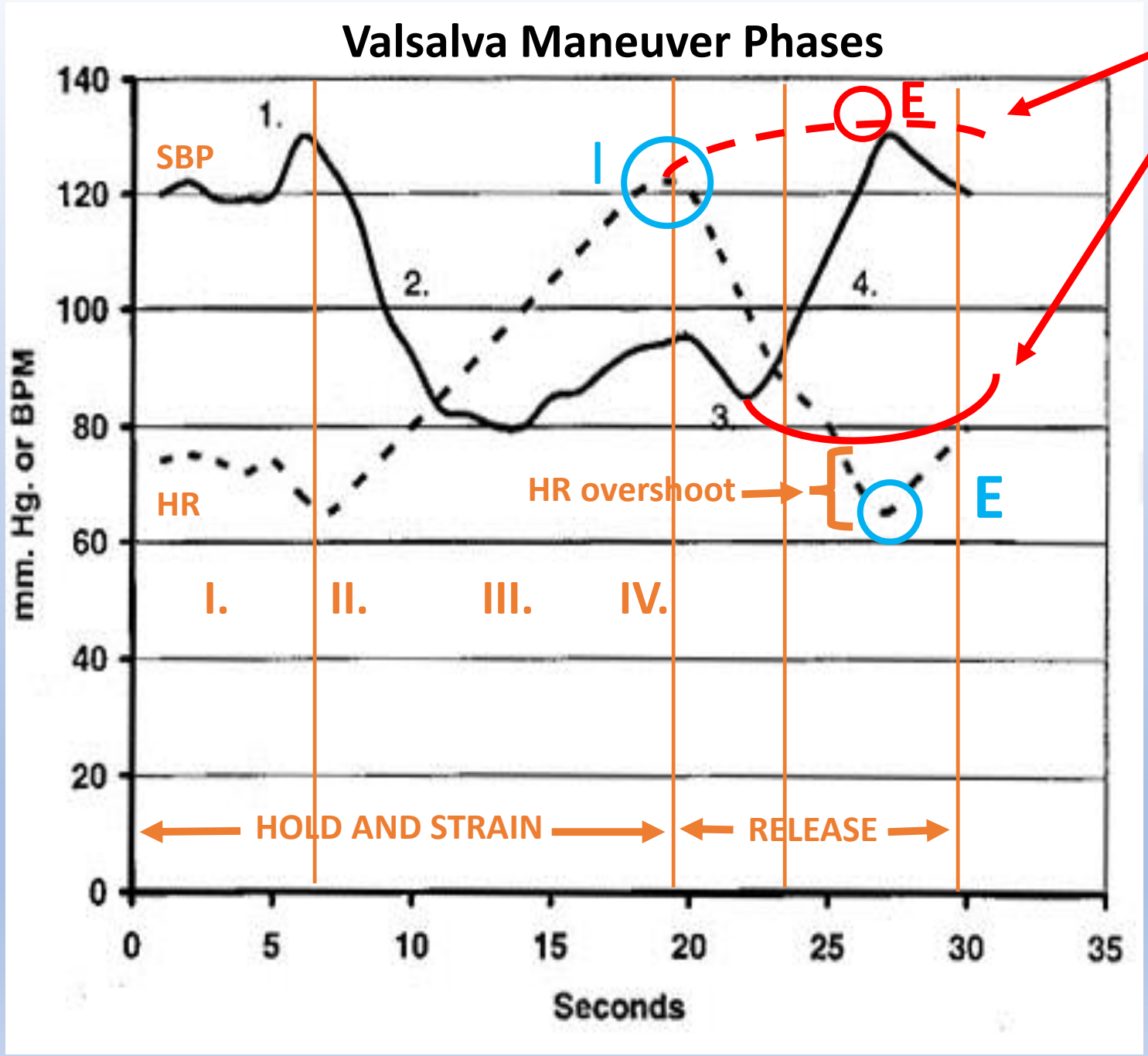
- Real-time blood pressure and heart rate responses to deep breathing provide autonomic information
- RSA and Valsalva maneuver share a BP and HR linking mechanism
- In a normal Valsalva maneuver, BP and HR both normalize. In autonomic failure, HR remains high and BP stays low
- Quantified by the Expiratory/inspiratory (E/I) or Valsalva ratio =

  Longest R-R interval (phase IV) /

  Shortest R-R interval (phase II)
  - E/I ratio reflects PNS afferent (baro-receptor) and PNS and SNS efferent (parasympathetic and sympathetic) relation
  - E/I > 1.20 is normal, <= 1.20 is abnormal

Procedure for the Valsalva Maneuver

1. While continuously recording BP and HR:
2. Take a deep breath, pinch your nose, and keep your mouth closed.
3. Try to exhale moderately forcefully for 10 to 15 seconds, as if inflating a balloon.
4. Gently release after about 15 seconds and breathe normall
5. Produces 4 stages of HR and BP changes


Valsalva Maneuver Phases
Autonomic Failure
In this example, the E/I ratio for normal (black line) is about 0.97/0.50= 1.9; for autonomic failure E/I is about 0.45/0.50= 0.9
mm. Hg. or BPM
140
120
100
80
60
40
20
0
SBP
HR
1.
2.
3.
4.
I
E
HR overshoot
I.
II.
III.
IV.
HOLD AND STRAIN
RELEASE
0
5
10
15
20
25
30
35
Seconds

HR and BP: Traube-Hering and Mayer Waves

- Named for Ludwig Traube, Karl Konstantin Hering, and Siegmund Mayer

Taube-Hering

- Rhythmical variations in blood pressure with a frequency varying from 6 to 10 cycles per minute (0.10 to 0.16 Hz)
- Related to variations in vasomotor tone
- Discovered in 1865 by Traube
- Confirmed in 1869 by Hering

Mayer

- Oscillations similar to Taube-Hering waves observed in 1876 by Mayer
  - Thought they might be a separate entity than Traube-Hering
- **Frequency ~0.1 Hz (10-second waves), correlated with HRV**
- **Due to oscillating sympathetic vasomotor tone (VT) of arterial blood vessels**
- **Cyclic waves in arterial blood pressure**
- Waves in arterial blood pressure brought about by *oscillations in baroreceptor and chemoreceptor reflex* control systems.
- Vasodilation due to action on alpha adrenergic receptors
- Abolished or attenuated by blockade of alpha-adrenergic receptors Seen both in ECG and continuous blood pressure
- Arterial blood pressure linear frequency coupling with SNS
- Low frequency and non-synchronous with ventilatory pattern
- Frequency does not depend on gender, age or posture
- Shift to lower frequency may be associated with risk of hypertension

Baroreceptor Reflex (BR)

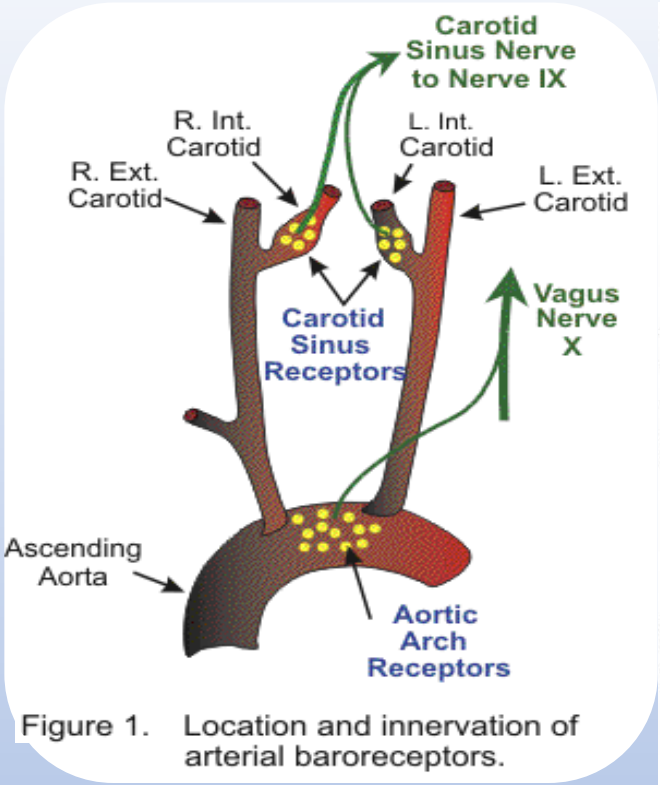
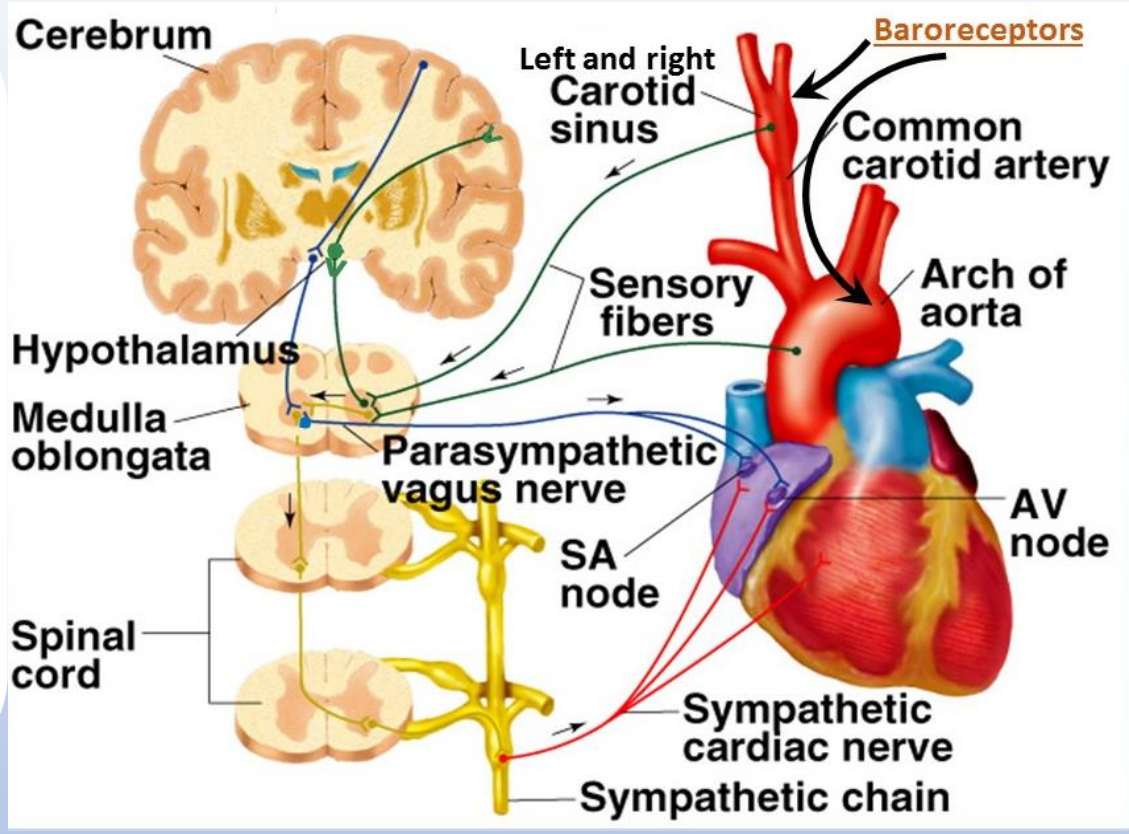


Figure 1. Location and innervation of arterial baroreceptors.



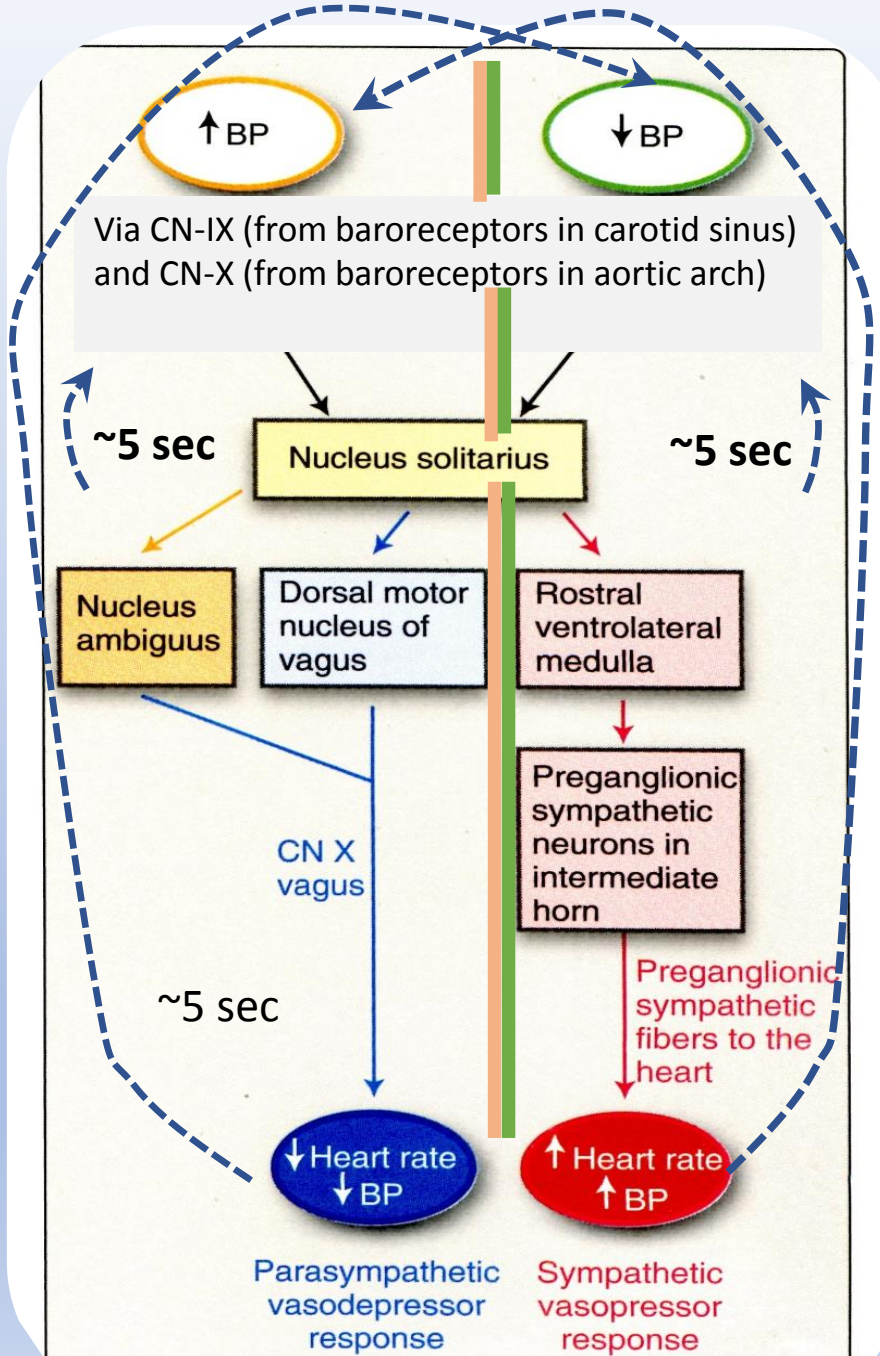
How does it work? BR mediates BP changes in response to HR changes via pressure receptors in the aortic arch and carotid arties. These baroreceptors increase discharge rate when stretched by BP elevation caused by increased HR. This signal (through CNIX from carotid and CNX from aorta) goes to the cardiovascular control center in medulla which then decreases vasomotor SNS and dilates vessels and increases cardiac vagal PNS, so that HR decreases. When BP falls, BR lower discharge leads to vasomotor SNS increase and vessel constriction, cardiac SNS increase and PNS withdrawal, and results in HR acceleration.

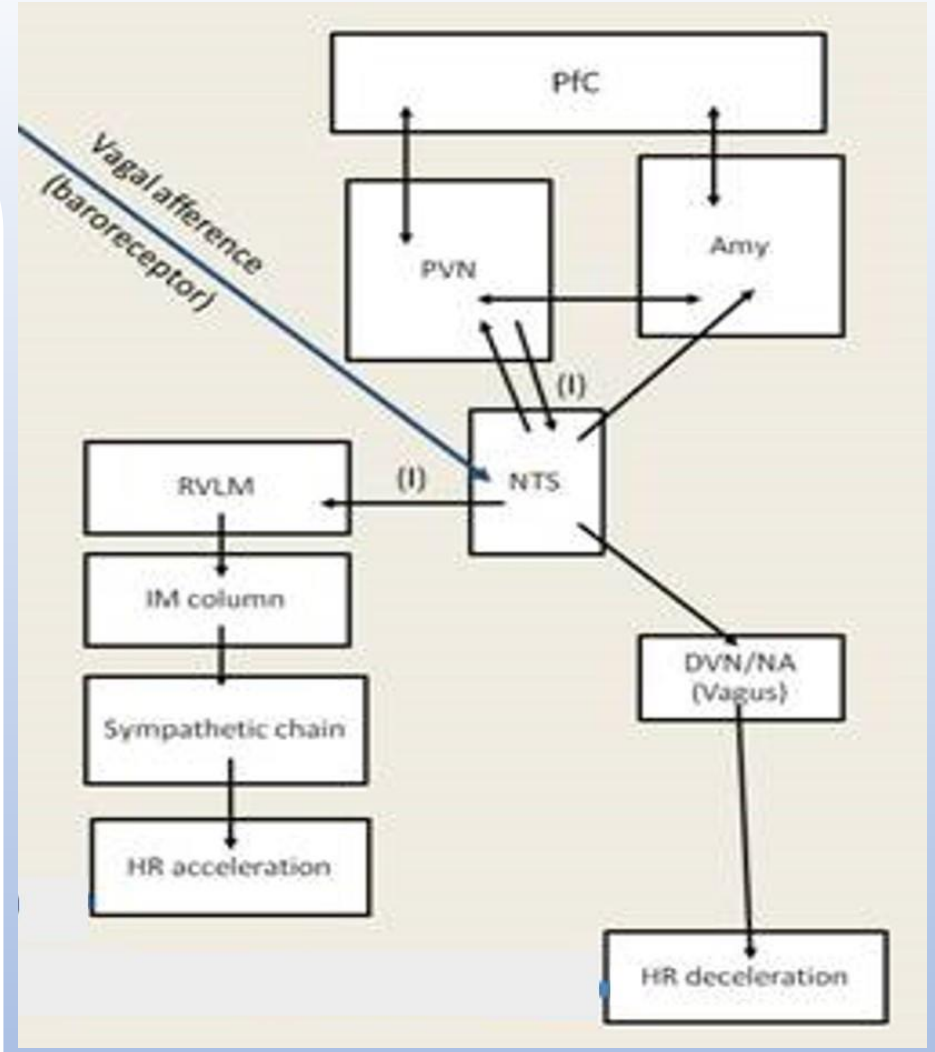
Resonance of HRV due to BR at RFB

At RFB (0.07-0.11 Hz, and corresponding to Mayer waves), the BR-mediated BP oscillatory period is 180° out of phase with HR oscillations. HR oscillations are thus amplified at resonant frequency. Maximal BP is reached after ~5 second delay from the previous cycle of BR-mediated BP increase and therefore occurs at the same time that HR reaches a minimum, which lowers HR even further; conversely, minimal BP occurs as HR reaches maximum and increases HR even more.

~ 5 sec time delay in BR produces arterial pressure oscillation resonance with HRV				
@RFB	→	**HR and respiration periods synchronize; BR + 5 second delay→BP 180° out of phase with HR; resonance of HRV;**	→	Coherence

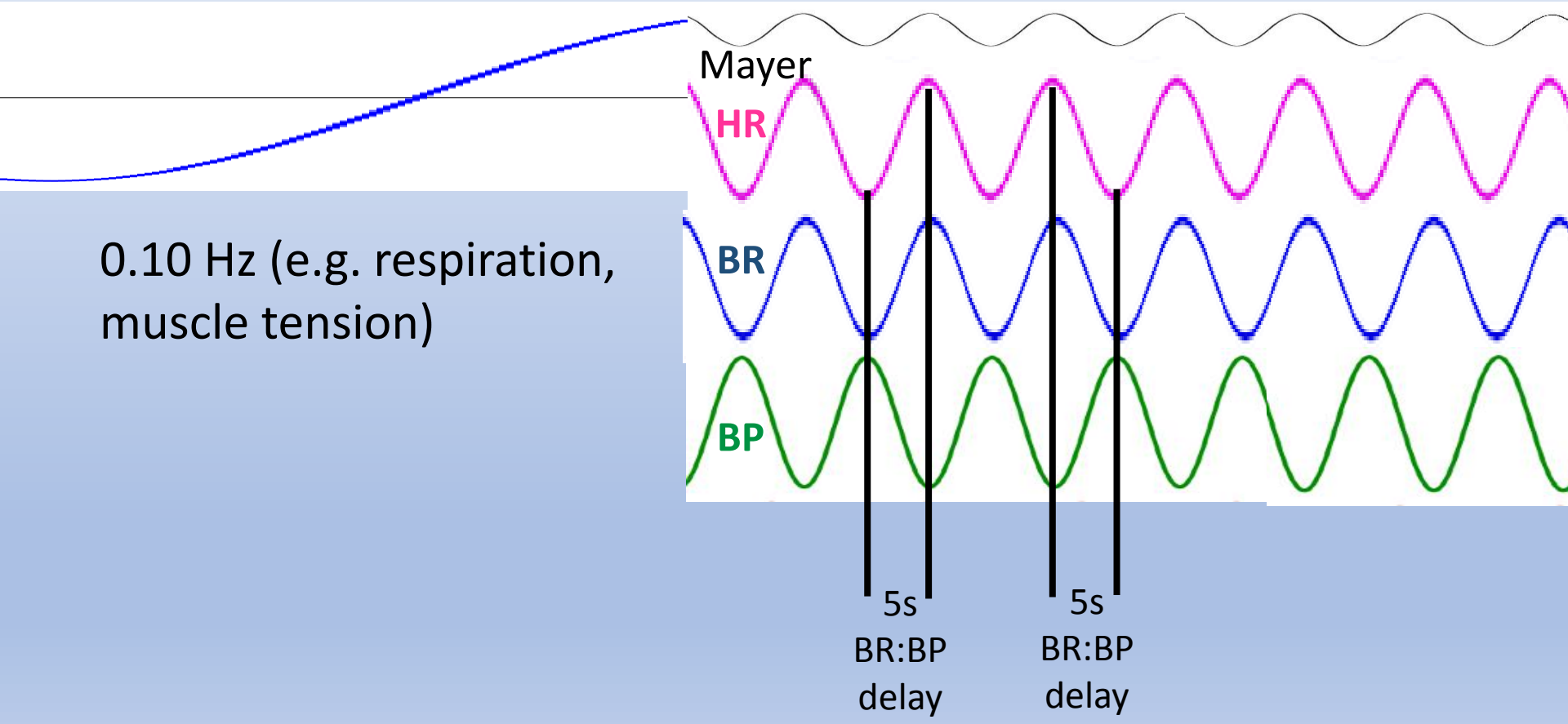
BR: Focus on neural circuits





Ginsberg, J. P., & Nagpal, M. (2016). Disruption of Bradycardia During Vigilance: Autonomic Cardiac Dysregulation is Prelude to Disinhibition, Hyperarousal, and Attention Bias in Combat Veterans with PTSD. In *A Multidimensional Approach to Post-Traumatic Stress Disorder-from Theory to Practice*. InTech.

HR Amplitude Resonance due to BP Phase Frequency Shift from BR 5-second delay creates the sharp 0.1 Hz peak characteristic of Coherence



0.10 Hz (e.g. respiration, muscle tension)

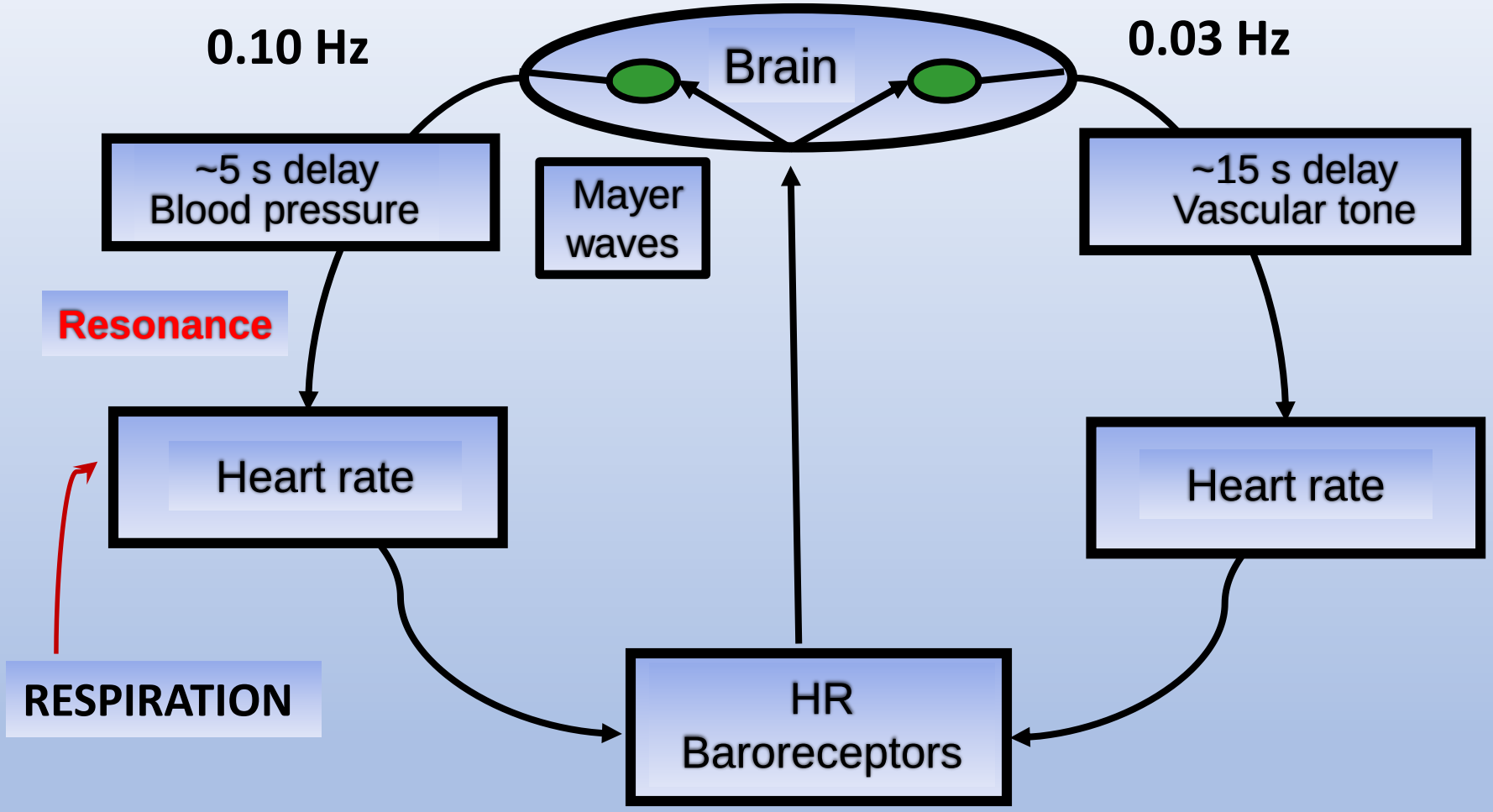
Baroreceptor reflex (BR)

- HR changes in response to Respiration
- BR changes in response to HR to maintain homeostasis
- BP changes in response to BR
- HR amplitude resonates with BP at RFB
  - Fixed time delay ~5 sec in BR produces 0.1 Hz arterial pressure oscillation that resonates HR amplitude at 0.1 Hz
- RFB synchronizes respiration, HR, BR, BP
- BR also important in 0.03 Hz VT oscillations
  - Complex relationship between HR and 0.03 Hz VT oscillations

'Coherence'

- Uncertainty whether Mayer waves are independent of BR
  - ?Central oscillator?
  - ?Additive to resonance?

Schematic Model of HR, Baroreflex, BP, and Vascular Tone Systems Based on Vaschillo and Lehrer



Triggered by respiration @`0.1 Hz, BR links HR and BP via CNS, produces HRV resonance, and maintains BP homeostasis. 0.03 Hz oscillations of VT also influence HR and BR.

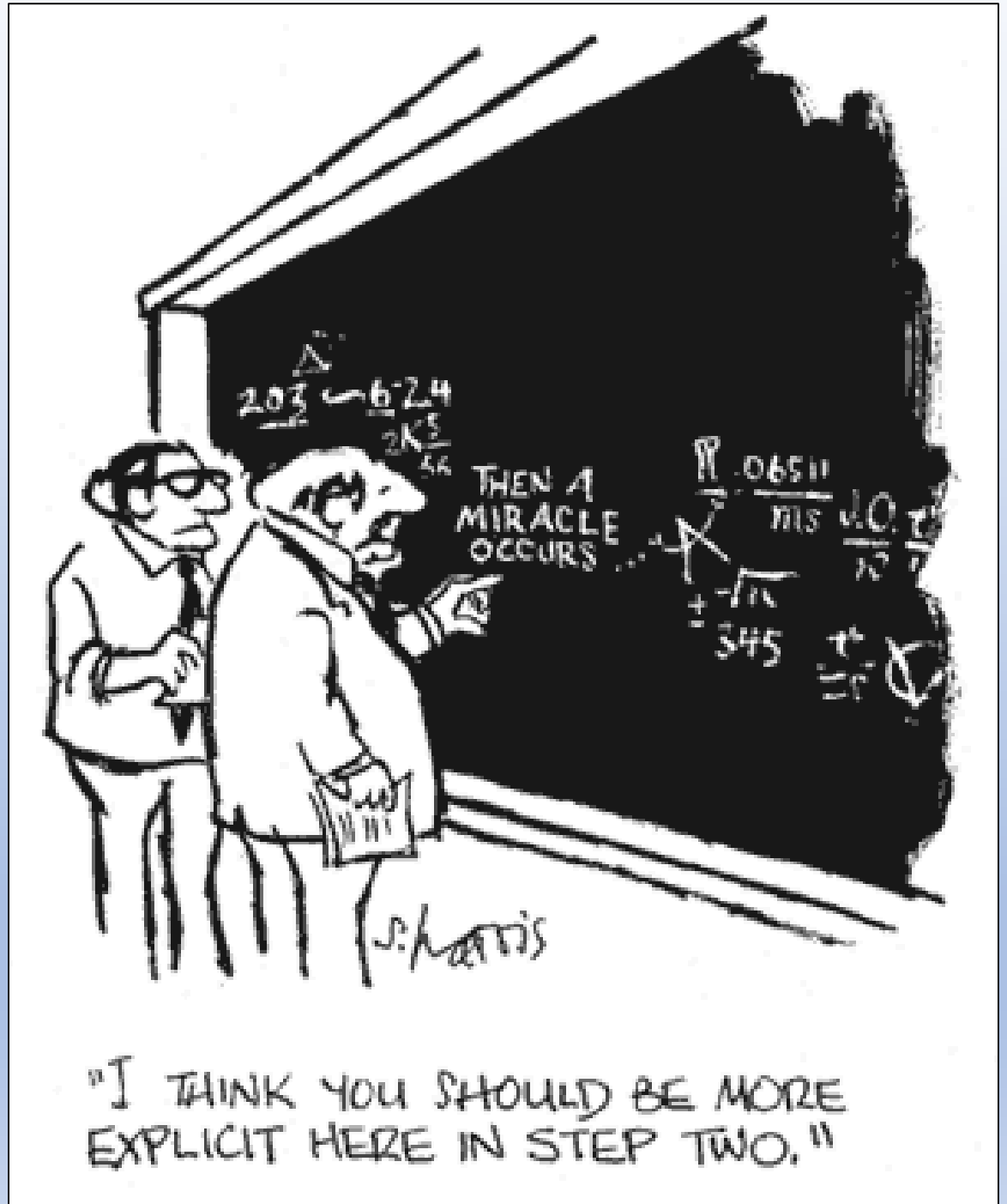
Properties of HRV Coherence

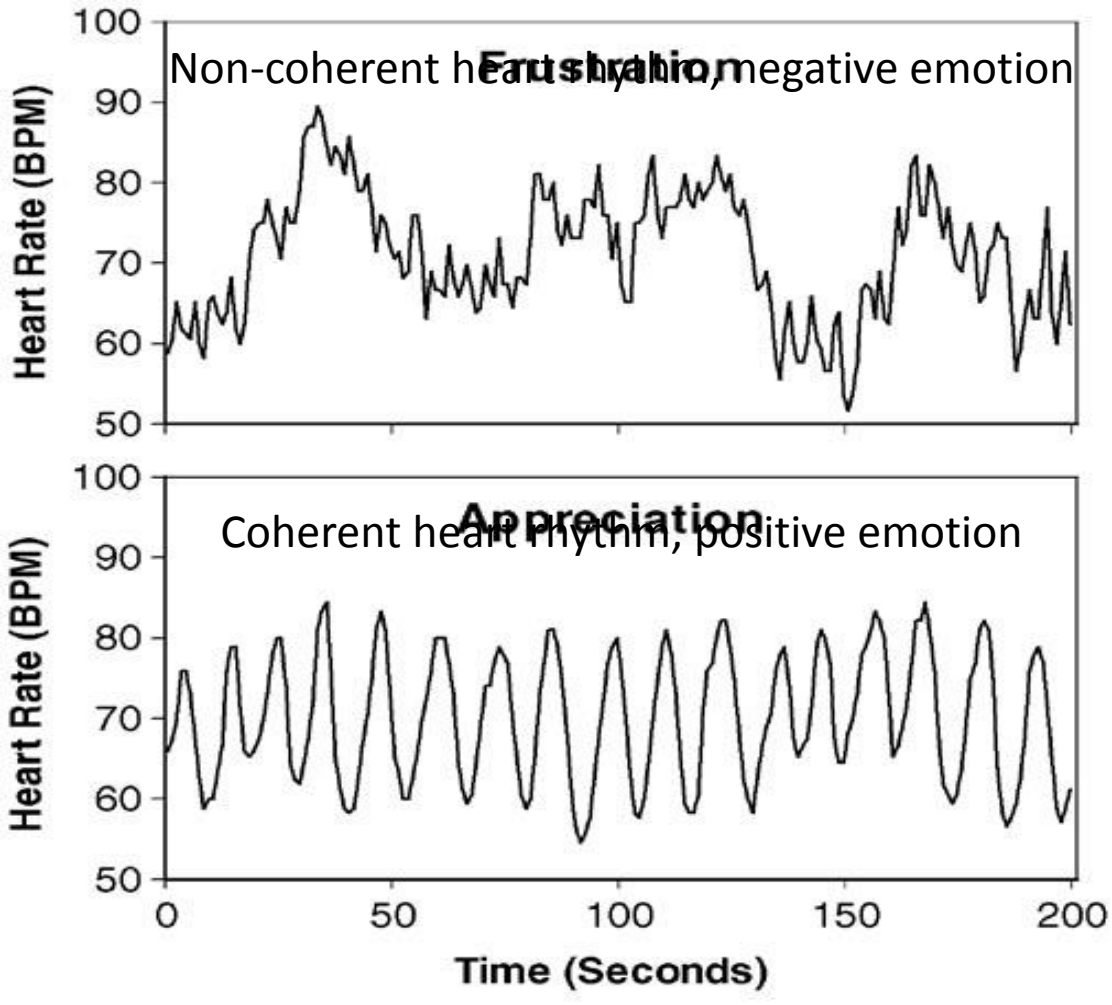
- Produced by resonant frequency breathing (RFB)
- RFB occurs ~0.1 Hz (=6 cycles/minute=10 sec/cycle=10 sec/ period)
- Produced by HRV Biofeedback
- Also produced by other stimuli at 0.1 Hz frequency (e.g. rhythmical muscle tension, chanting, picture presentation, etc.)
- Due to interactions between cycles of respiratory sinus arrhythmia (RSA) and baroreflex feedback control of vasomotor tone
- 0° phase between respiratory and sinusoidal HR cycles
- 180° phase between baroreflex and sinusoical HR cycles
- Associated with maximum RSA (max-min HR over respiratory cycle)
- Discrete sharp peak in power spectrum at resonant frequency
- Associated with improved adaptive behaviors
    - alertness, responsiveness
    - emotional self-regulation
    - cognitive function
- distinct from "relaxation"
- Healthy people do not have Coherence during non RFB periods
- Extended high coherence may be a sign of inflexibility of cardiac adjustment

Summary: RSA and BR work together to produce HRV

1. RSA
   - Relatively small amplitude HR oscillations
   - Frequency range of normal respiration
     - ~10-24 breaths/minute= 0.17Hz-0.40Hz
   - HR accelerates on inspiration (SNS)
   - Returns to resting HR on exhalation (PNS)
   - Oscillations of cardiac output
     - Affects intra-thoracic pressure and venous return→HR
   - Smaller BP oscillations (Traube-Hering waves?)
   - Hypertension reduces RSA and vagal tone
2. BR
   - BP changes in response to HR for homeostasis (?Mayer waves?)
   - RFB synchronizes respiration, HR, BR, BP→**'Coherence'**
   - Larger amplitude HR oscillations than RSA
     - Can be very large
   - Frequency range of ~4.2-7.5 breaths/minute (= 0.07-0.12 Hz),
   - Increases max and min of HR compared to slow respiration cycle
     - Average HR may not change
   - Important in 0.03 Hz VT oscillations
   - HRVB reduces BP

Attaining Coherence: HRV Biofeedback





Low HRV(av)

High HRV(av)

The heart rhythm pattern shown in the top graph is characterized by its erratic, irregular pattern (incoherence), and associated with negative emotions such as anger or frustration. The bottom graph shows a coherent heart rhythm pattern, observed when an individual is experiencing sustained, modulated positive emotions such as gratitude or happiness.

Three components of Autonomic Self-Regulation a

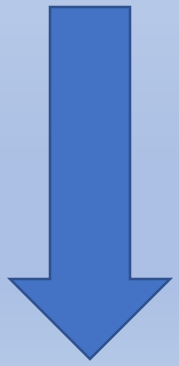
1. HRV Biofeedback = resonant frequency breathing
2. Mindful attention
3. Positive emotional state

ASR coaching essential elements

- Paced breathing at resonant frequency and the production of HRV Coherence through HRV Biofeedback

- Mindfulness or imagery focused on breathing and the heart. Focused attention on air entering and exiting the chest and passing thorough the heart

- Positive emotional state (PES). Occupy the mind during the HRVB session with thoughts of **compassion**, gratitude, apreciation, etc.



'COHERENCE'

AUTONOMIC SELF-REGULATION

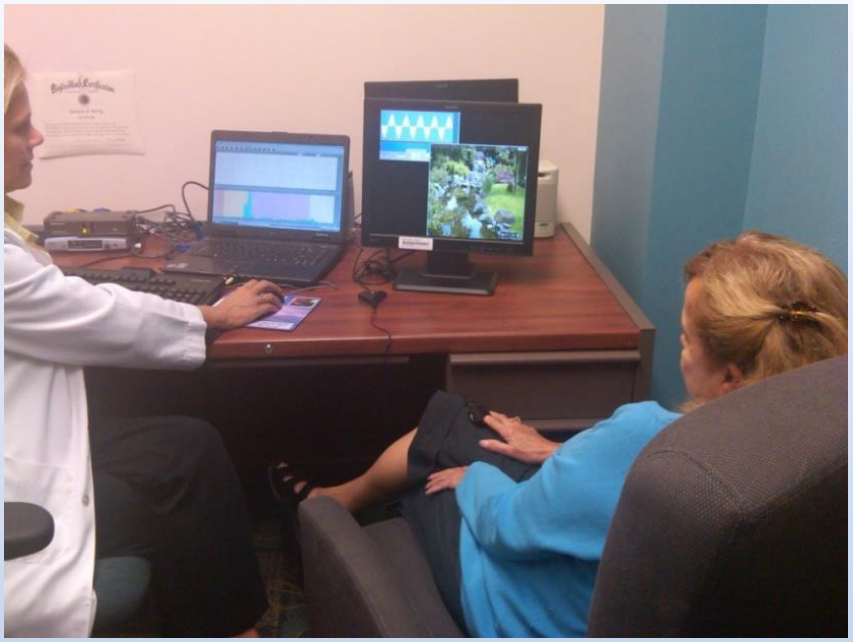
RFB

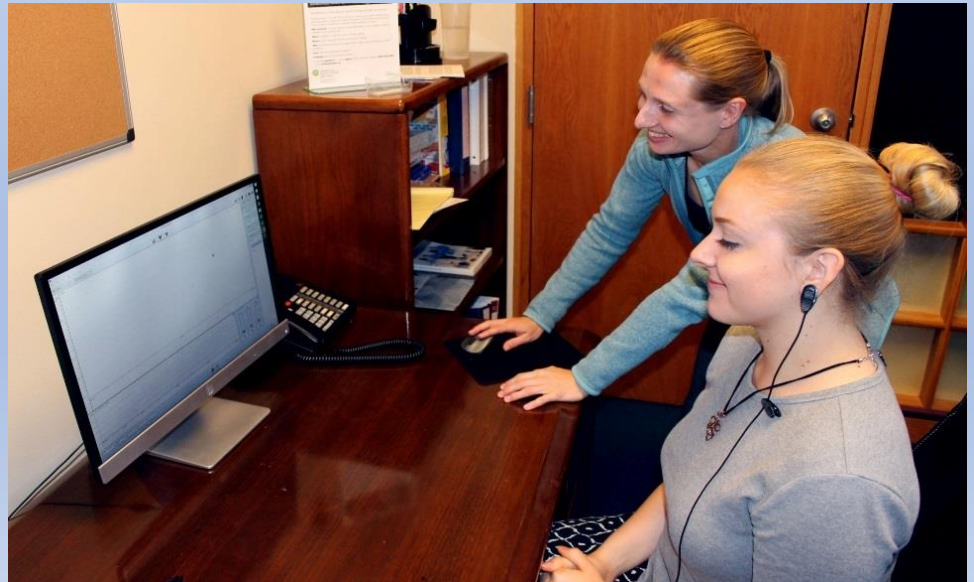
Mindful attention

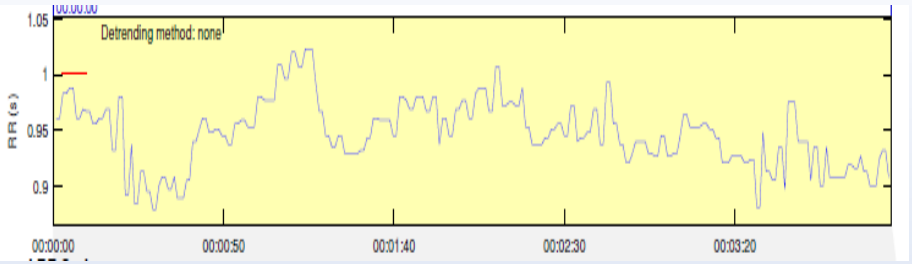
PES
Compassion, gratitude, etc

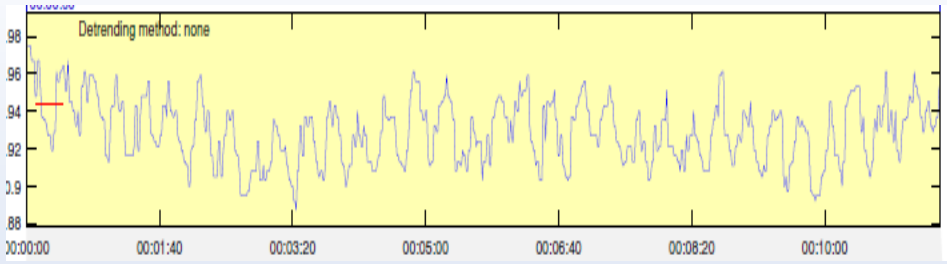
HRV

HRV COHERENCE









Time–Domain Results

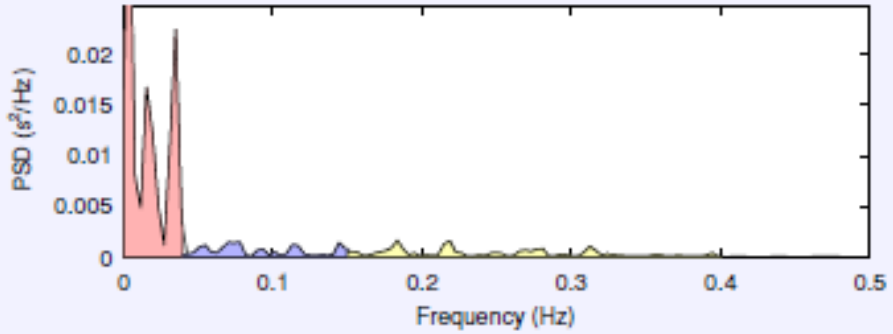
Variable	Units	Value
Mean RR*	(ms)	946.4
STD RR (SDNN)	(ms)	30.1
Mean HR*	(1/min)	63.46
STD HR	(1/min)	2.02
RMSSD	(ms)	17.1
NN50	(count)	5
pNN50	(%)	1.9
RR triangular index		6.816
TINN	(ms)	115.0

Time–Domain Results

Variable	Units	Value
Mean RR*	(ms)	928.4
STD RR (SDNN)	(ms)	17.0
Mean HR*	(1/min)	64.65
STD HR	(1/min)	1.18
RMSSD	(ms)	6.7
NN50	(count)	0
pNN50	(%)	0.0
RR triangular index		4.534
TINN	(ms)	75.0

Frequency–Domain Results

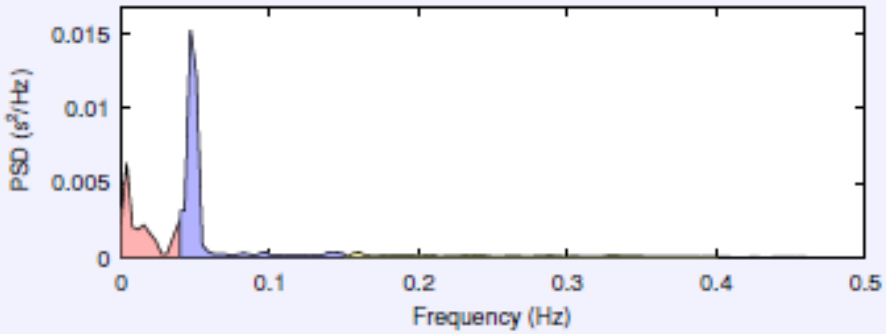
FFT spectrum (Welch's periodogram: 256 s window with 50% overlap)



Frequency Band	Peak (Hz)	Power (ms²)	Power (%)	Power (n.u.)
VLF (0–0.04 Hz)	0.0039	512	77.6	
LF (0.04–0.15 Hz)	0.0781	69	10.4	46.3
HF (0.15–0.4 Hz)	0.1836	80	12.0	53.7
Total		661		
LF/HF		0.862		

Frequency–Domain Results

FFT spectrum (Welch's periodogram: 256 s window with 50% overlap)

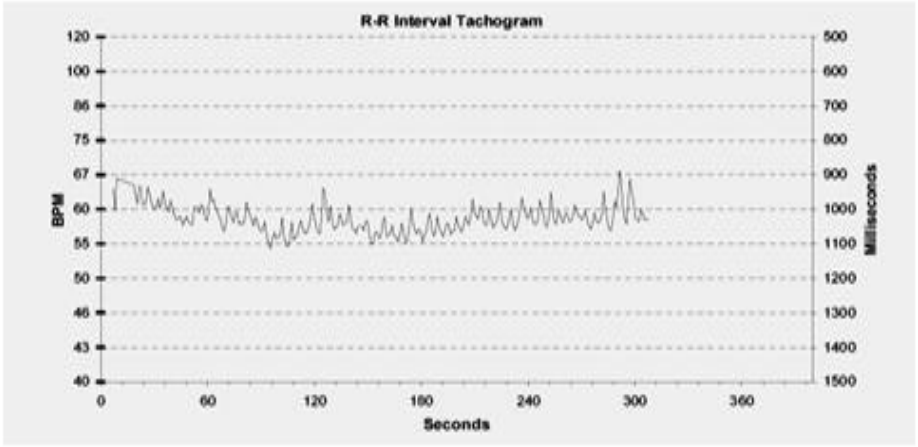


Frequency Band	Peak (Hz)	Power (ms²)	Power (%)	Power (n.u.)
VLF (0–0.04 Hz)	0.0039	76	31.7	
LF (0.04–0.15 Hz)	0.0469	144	59.6	87.2
HF (0.15–0.4 Hz)	0.1602	21	8.8	12.8
Total		241		
LF/HF		6.789		

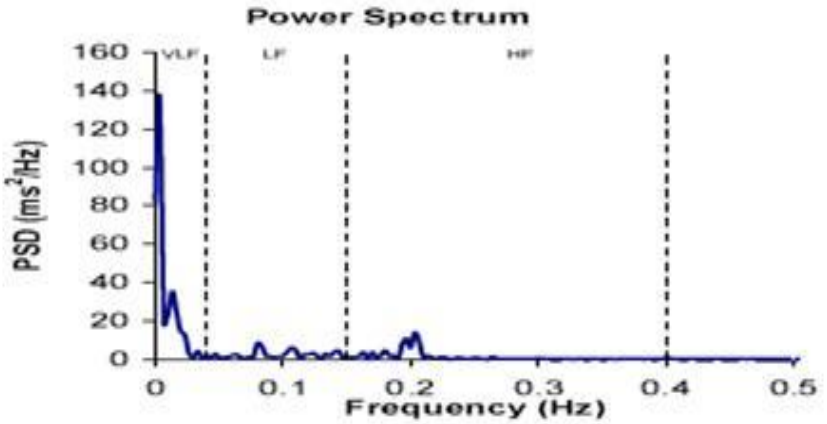
Figure 1 (a – d) depicts the Pre-Post HRVB Training the R-R Interval Tachogram and Power Spectra Density of one PTSD+ subject.

Pre-Training

(a)

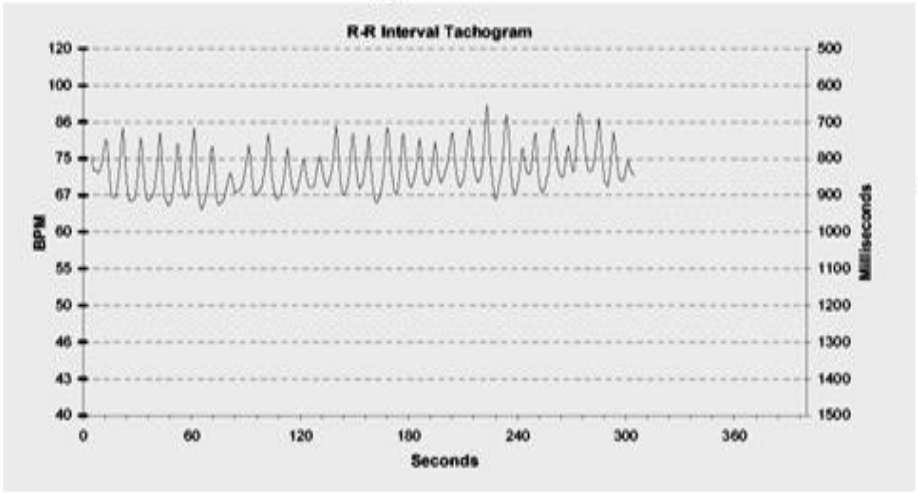


(b)

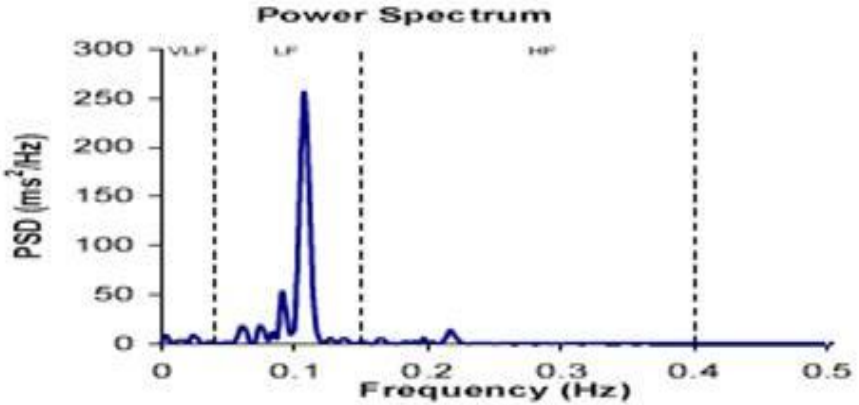


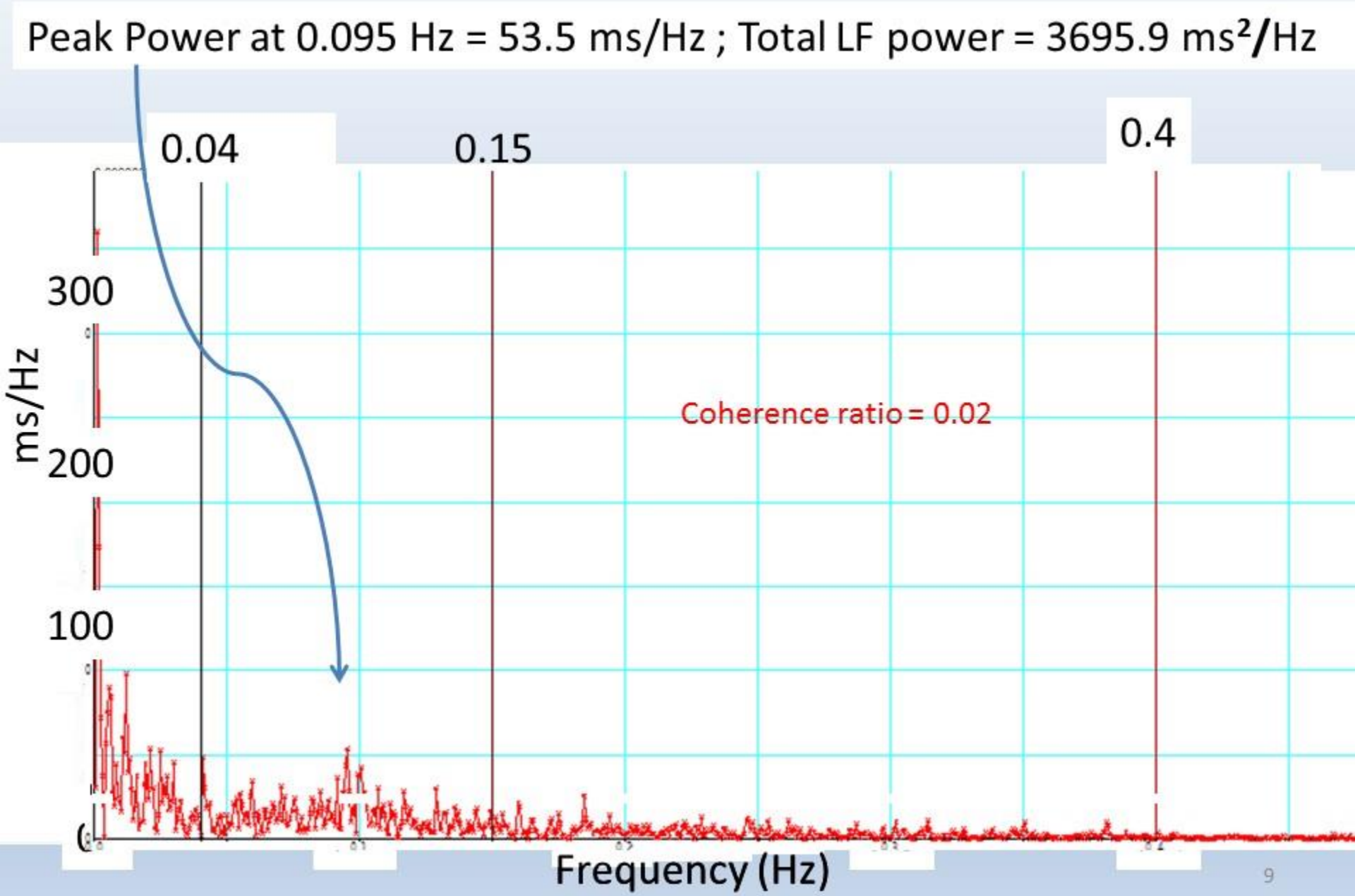
Post-Training

(c)



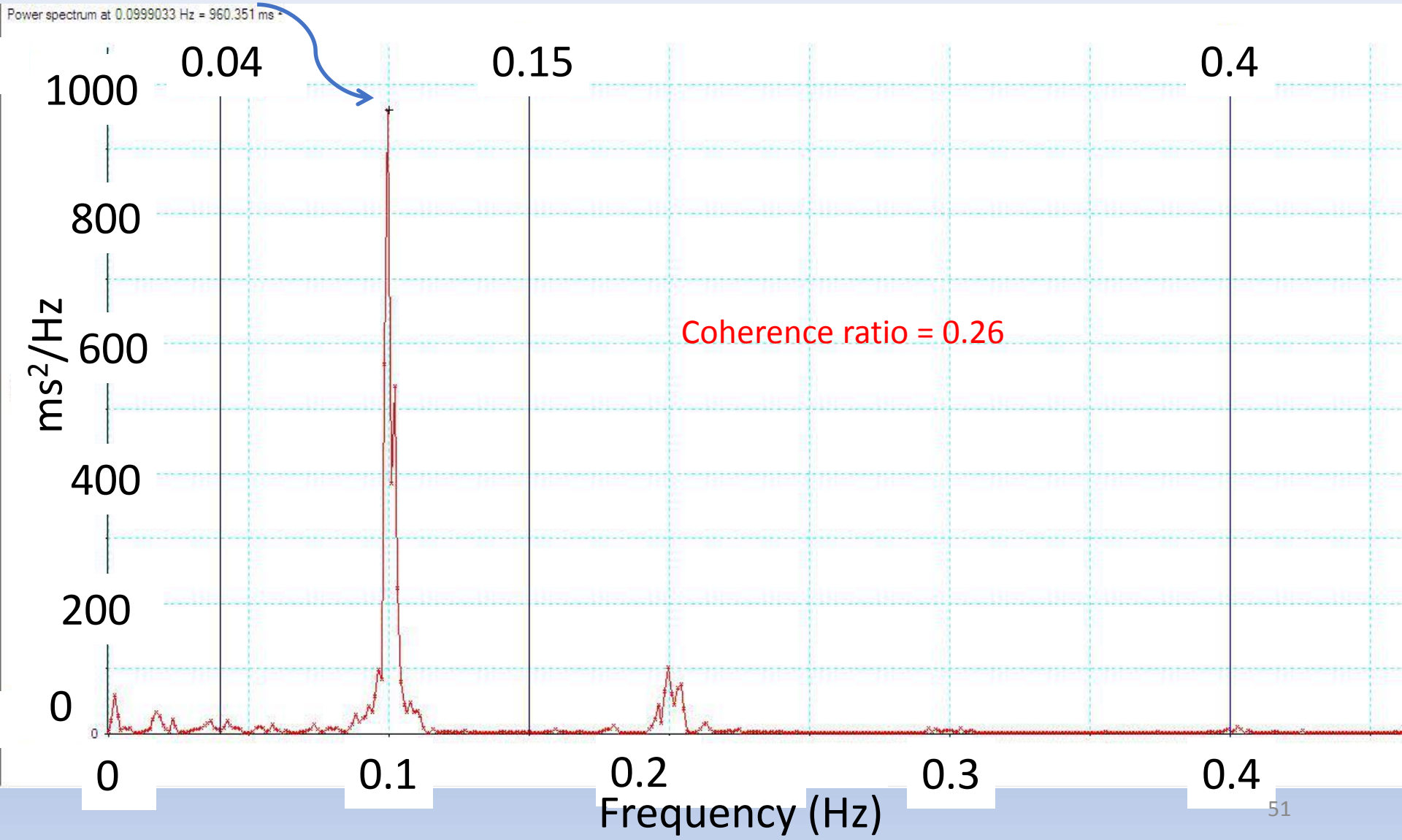
(d)



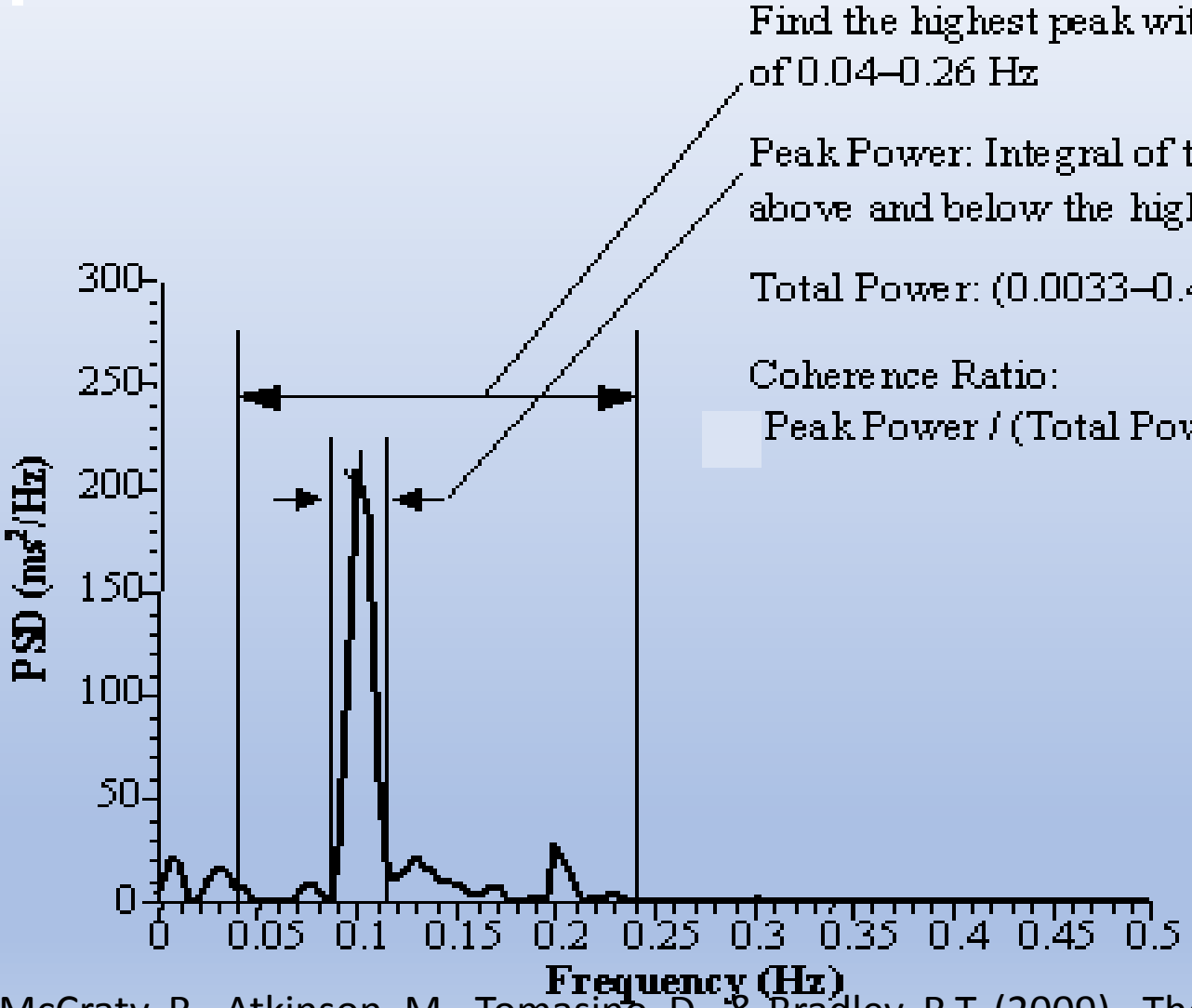

Peak Power at 0.095 Hz = 53.5 ms/Hz ; Total LF power = 3695.9 ms²/Hz
0.04
0.15
0.4
300
200
100
ms/Hz
Coherence ratio = 0.02
Frequency (Hz)

HRV Power Spectrum

Peak Power at 0.099 Hz = 960.4 ms^2 ; Total LF Power = 2344.4 ms^2/Hz



Calculation of McCraty's Coherence Ratio (CR) from the HRV Power Spectrum



McCraty, R., Atkinson, M., Tomasino, D., & Bradley, R.T. (2009). The Coherent Heart: Heart-brain interactions, psychophysiological coherence, and the emergence of system wide order. *Integral Review* 5, 2 (10-106).

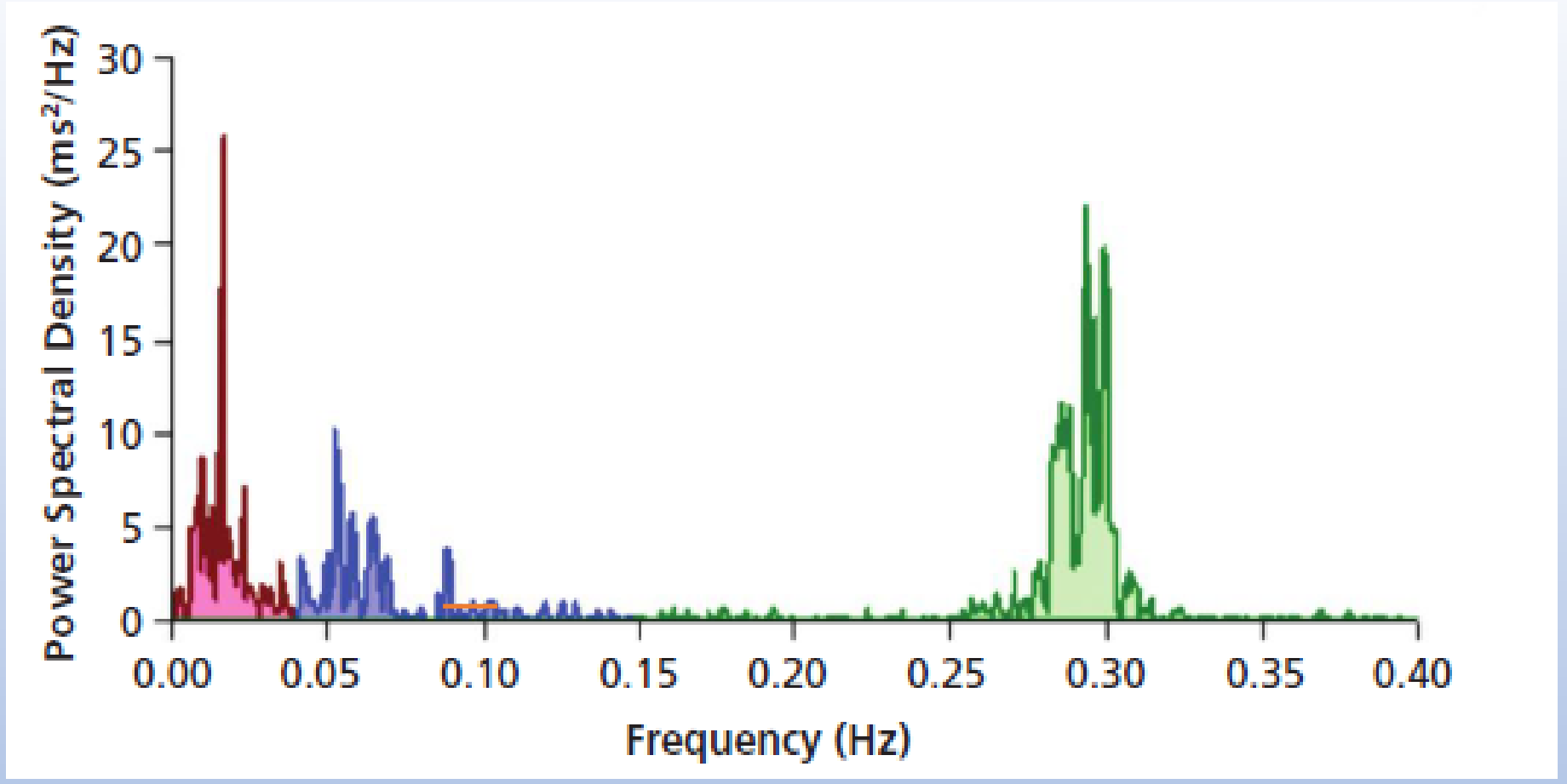
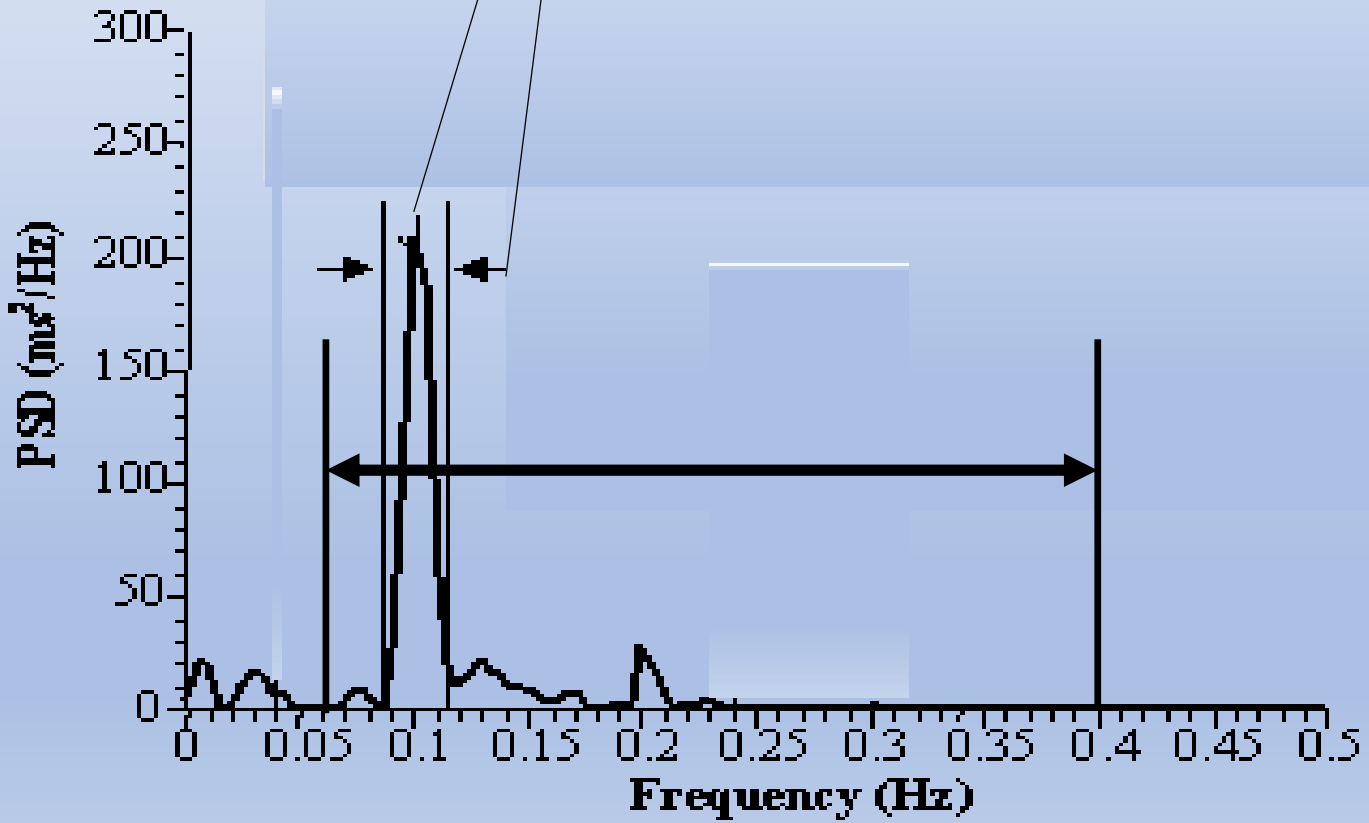


Figure 3 A typical heart rate variability (HRV) recording over a 15-minute period during resting conditions in a healthy individual

McCraty, R., & Shaffer, F. (2015). Heart rate variability: new perspectives on physiological mechanisms, assessment of self-regulatory capacity, and health risk. *Global Advances in Health and Medicine*, *4*(1), 46-61.

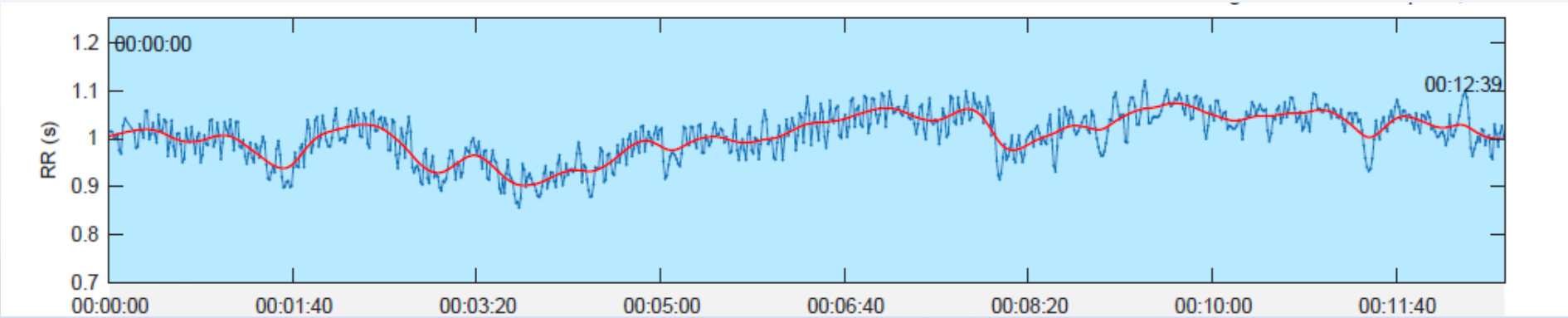
Beyond Coherence?
Calculation of the Parasympathetic Ratio (PR) from the HRV Power Spectrum

- Find highest peak within the range of 0.07-0.40 Hz (=eHFp)
- Find eHF Peak Power: Integral of the window 0.015 Hz above and below the highest peak (=eHFpp)
- Determine Total Power (TP) in the spectrum, 0.0033-0.4 Hz
- Calculate the Parasympathetic Ratio (PR) as: eHFpp/(TP-eHFpp)



HRV(B) Case Data

PTSD 2 Pre-



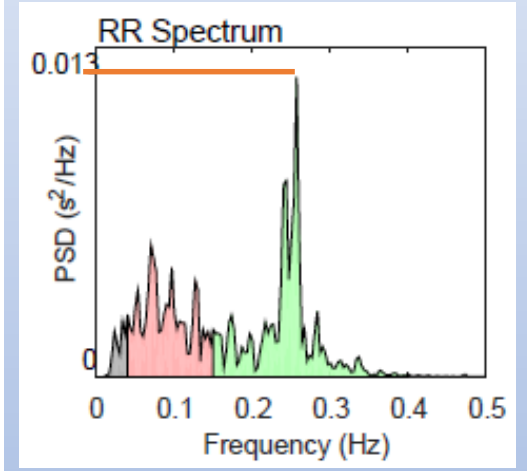
Time-Domain Results

Variable	Units	Value
Mean RR*	(ms)	1005
Mean HR*	(bpm)	60
Min HR	(bpm)	54
Max HR	(bpm)	70
SDNN	(ms)	26.3
RMSSD	(ms)	28.7
NN50	(beats)	72
pNN50	(%)	9.54
RR triangular index		8.89
TINN	(ms)	135.0
Stress Index (SI)		13.7

Frequency-Domain Results (FFT spectrum)

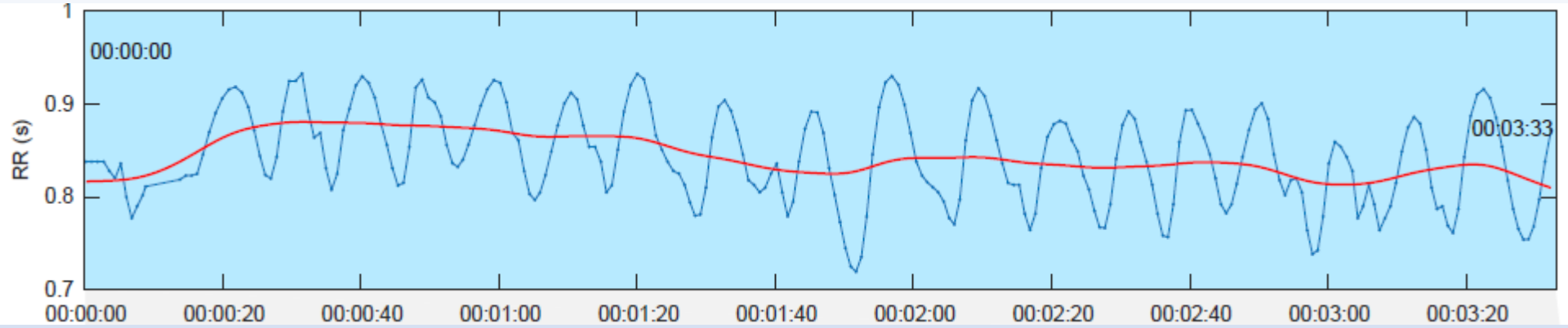
Variable	Units	VLF	LF	HF
Frequency band	(Hz)	0.00-0.04	0.04-0.15	0.15-0.40
Peak frequency	(Hz)	0.040	0.070	0.257
Power	(ms^2)	33	264	359
Power	(log)	3.507	5.575	5.885
Power	(%)	5.08	40.16	54.74
Power	(n.u.)		42.31	57.66

Total power	(ms^2)	657		
Total Power	(log)	6.487		
LF/HF ratio		0.734		
EDR	(Hz)	-		



Peak (0.04-0.26 Hz)	Peak Power	Total Power	CR
0.26	153.2	656.5	0.23
Peak (0.07-0.40 Hz)	**Peak Power**	**Total Power**	**PR**
0.26	153.2	656.5	0.23

PTSD 2 Post-



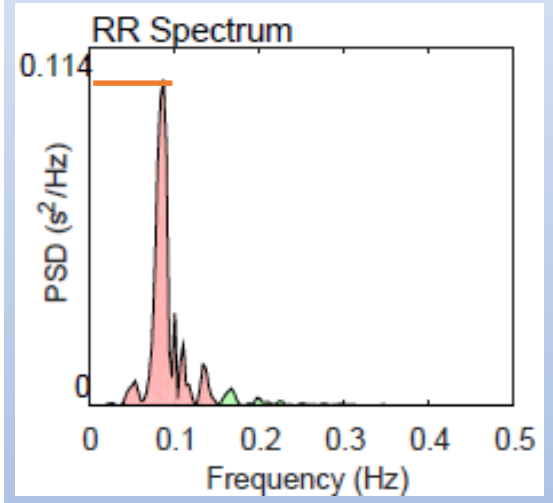
Time-Domain Results

Variable	Units	Value
Mean RR*	(ms)	841
Mean HR*	(bpm)	71
Min HR	(bpm)	64
Max HR	(bpm)	83
SDNN	(ms)	43.6
RMSSD	(ms)	24.5
NN50	(beats)	8
pNN50	(%)	3.24
RR triangular index		10.33
TINN	(ms)	201.0
Stress Index (SI)		10.4

Frequency-Domain Results (FFT spectrum)

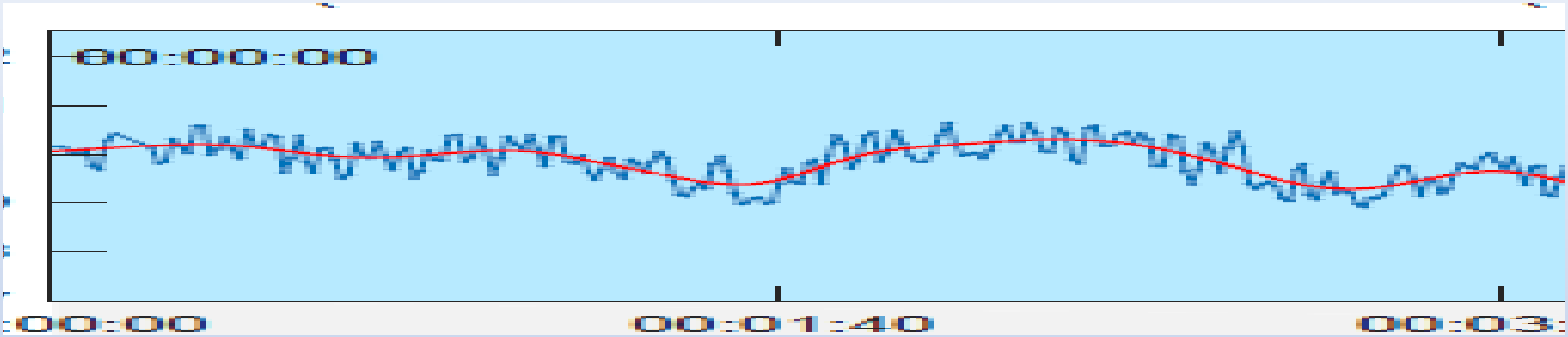
Variable	Units	VLF	LF	HF
Frequency band	(Hz)	0.00-0.04	0.04-0.15	0.15-0.40
Peak frequency	(Hz)	0.040	0.087	0.167
Power	(ms^2)	9	2076	145
Power	(log)	2.207	7.638	4.974
Power	(%)	0.41	93.11	6.49
Power	(n.u.)		93.49	6.51

Total power	(ms^2)	2229		
Total Power	(log)	7.709		
LF/HF ratio		14.354		
EDR	(Hz)	-		

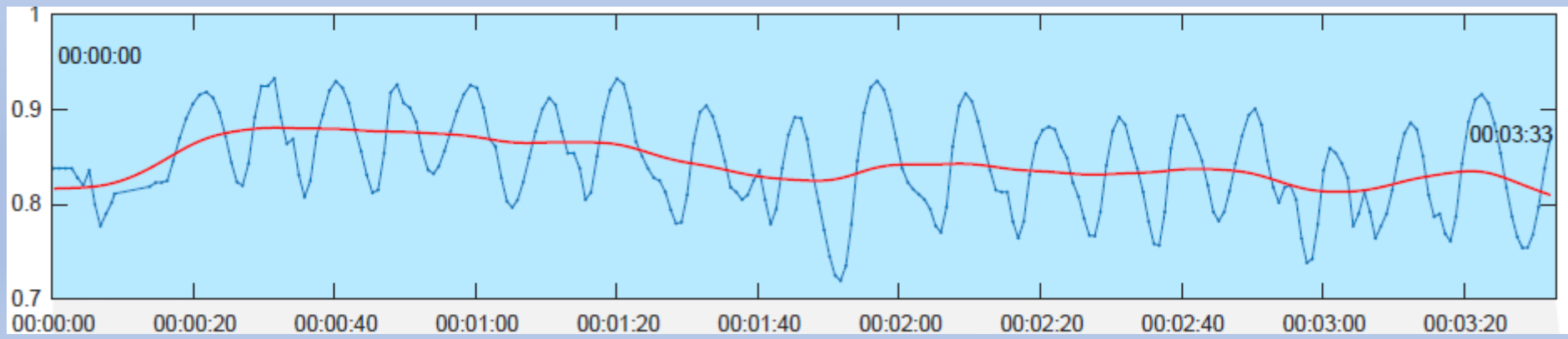


Peak (0.04-0.26 Hz)	Peak Power	Total Power	CR
0.09	1769.8	2229.3	0.86
Peak (0.07-0.40 Hz)	**Peak Power**	**Total Power**	**PR**
0.09	1769.8	2229.3	0.86

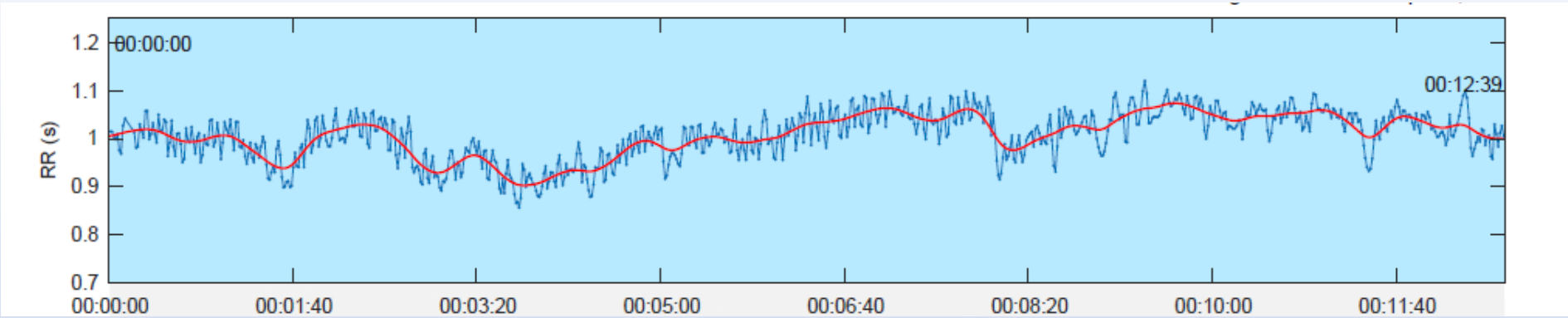
PTSD 2 Pre-



PTSD 2 Post-



PTSD 2 Pre-



Time-Domain Results

Variable	Units	Value
Mean RR*	(ms)	1006
Mean HR*	(bpm)	60
Min HR	(bpm)	54
Max HR	(bpm)	70
SDNN	(ms)	26.3
RMSSD	(ms)	28.7
NN50	(beats)	72
pNN50	(%)	9.54
RR triangular index		8.89
TINN	(ms)	135.0
Stress Index (SI)		13.7

Frequency-Domain Results (FFT spectrum)

Variable	Units	VLF	LF	HF
Frequency band	(Hz)	0.00-0.04	0.04-0.15	0.15-0.40
Peak frequency	(Hz)	0.040	0.070	0.257
Power	(ms^2)	33	264	359
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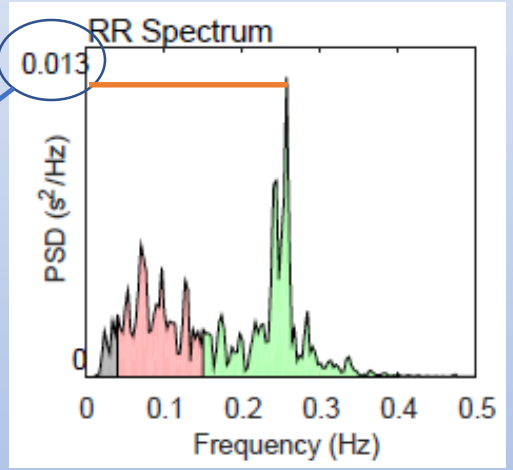
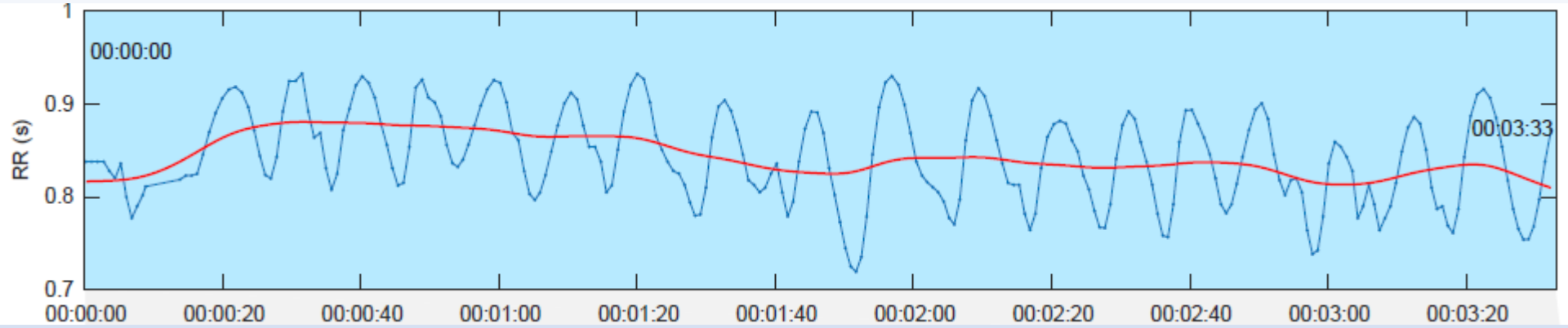
Total power	(ms^2)	657		
Total Power	(log)	6.487		
LF/HF ratio		0.734		
EDR	(Hz)	-		



Peak (0.04-0.26 Hz)	Peak Power	Total Power	CR
0.26	153.2	656.5	0.23
Peak (0.07-0.40 Hz)	**Peak Power**	**Total Power**	**PR**
0.26	153.2	656.5	0.23

eHFpp>LFpp
RMSSD>SDNN

PTSD 2 Post-



Time-Domain Results

Variable	Units	Value
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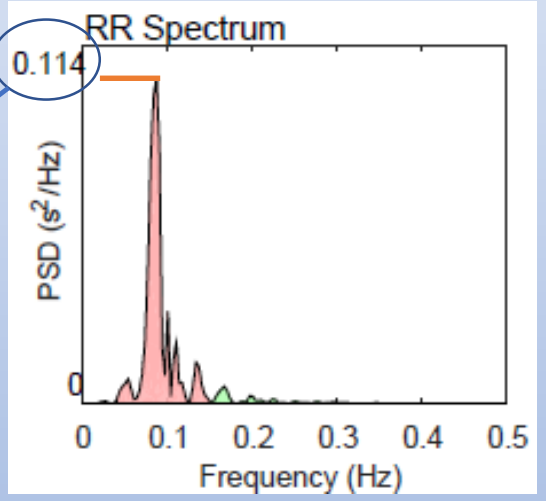
Mean HR*	(bpm)	71
Min HR	(bpm)	64
Max HR	(bpm)	83
SDNN	(ms)	43.6
RMSSD	(ms)	24.5
NN50	(beats)	8
pNN50	(%)	3.24
RR triangular index		10.33
TINN	(ms)	201.0
Stress Index (SI)		10.4

Frequency-Domain Results (FFT spectrum)

Variable	Units	VLF	LF	HF
Frequency band	(Hz)	0.00-0.04	0.04-0.15	0.15-0.40
Peak frequency	(Hz)	0.040	0.087	0.167
Power	(ms^2)	9	2076	145
Power	(log)	2.207	7.638	4.974
Power	(%)	0.41	93.11	6.49
Power	(n.u.)		93.49	6.51

Total power	(ms^2)	2229		
Total Power	(log)	7.709		
LF/HF ratio		14.354		
EDR	(Hz)	-		

+1812
- 214
+1572
4x

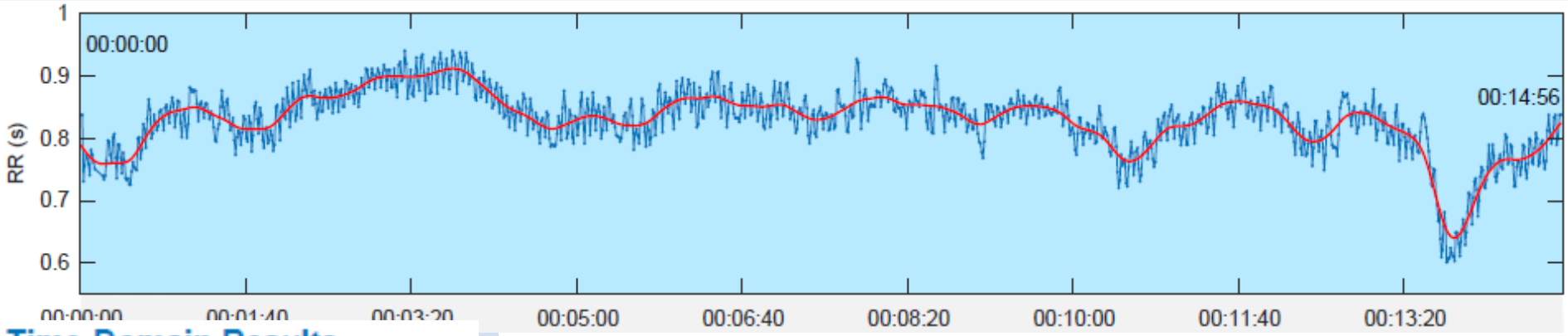


+11
+17.3
- 4.2

Peak (0.04-0.26 Hz)	Peak Power	Total Power	CR
0.09	1769.8	2229.3	0.86
Peak (0.07-0.40 Hz)	**Peak Power**	**Total Power**	**PR**
0.09	1769.8	2229.3	0.86

eHFpp=LFpp
SDNN>RMSSD

PTSD 5 Pre-



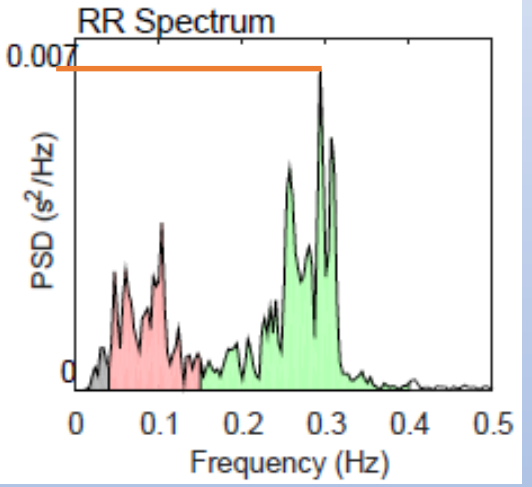
Time-Domain Results

Variable	Units	Value
Mean RR*	(ms)	826
Mean HR*	(bpm)	73
Min HR	(bpm)	64
Max HR	(bpm)	100
SDNN	(ms)	22.2
RMSSD	(ms)	24.1
NN50	(beats)	23
pNN50	(%)	2.13
RR triangular index		7.11
TINN	(ms)	116.0
Stress Index (SI)		17.4

Frequency-Domain Results (FFT spectrum)

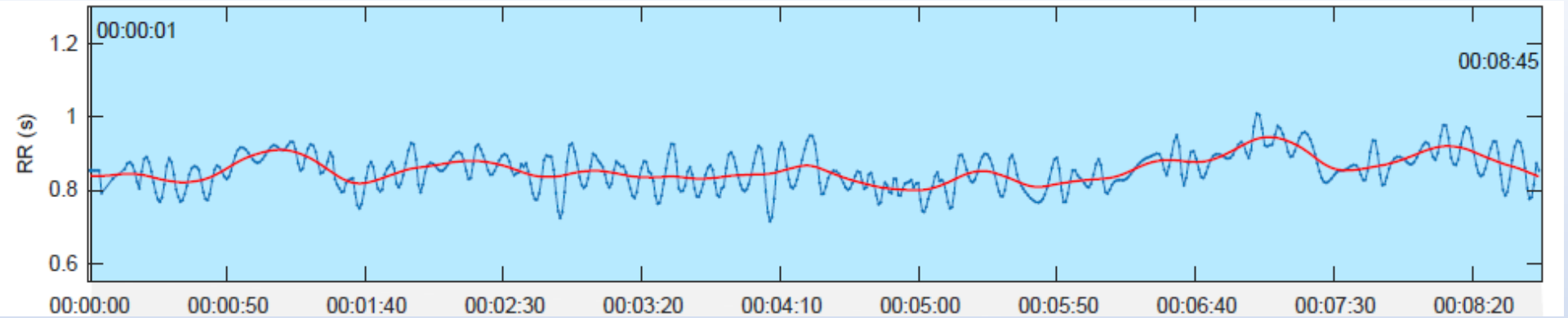
Variable	Units	VLF	LF	HF
Frequency band	(Hz)	0.00-0.04	0.04-0.15	0.15-0.40
Peak frequency	(Hz)	0.033	0.103	0.293
Power	(ms^2)	11	134	284
Power	(log)	2.439	4.895	5.647
Power	(%)	2.67	31.16	66.10
Power	(n.u.)		32.01	67.92

Total power	(ms^2)	429		
Total Power	(log)	6.061		
LF/HF ratio		0.471		
EDR	(Hz)	-		



Peak (0.04-0.26 Hz)	Peak Power	Total Power	CR
0.26	45.7	428.6	0.12
Peak (0.07-0.40 Hz)	**Peak Power**	**Total Power**	**PR**
0.29	91.7	428.6	0.27

PTSD 5 Post-



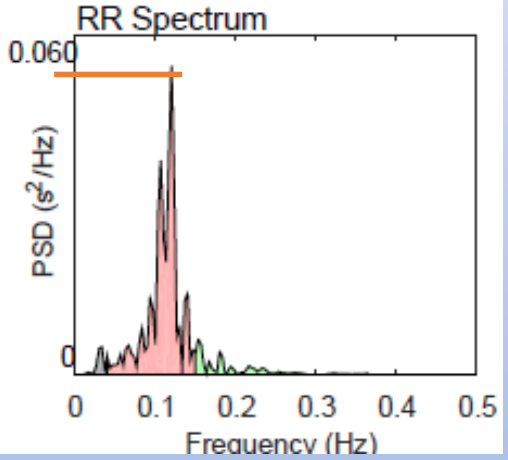
Time-Domain Results

Variable	Units	Value
Mean RR*	(ms)	854
Mean HR*	(bpm)	70
Min HR	(bpm)	59
Max HR	(bpm)	84
SDNN	(ms)	36.4
RMSSD	(ms)	23.5
NN50	(beats)	25
pNN50	(%)	4.15
RR triangular index		10.79
TINN	(ms)	186.0
Stress Index (SI)		10.7

Frequency-Domain Results (FFT spectrum)

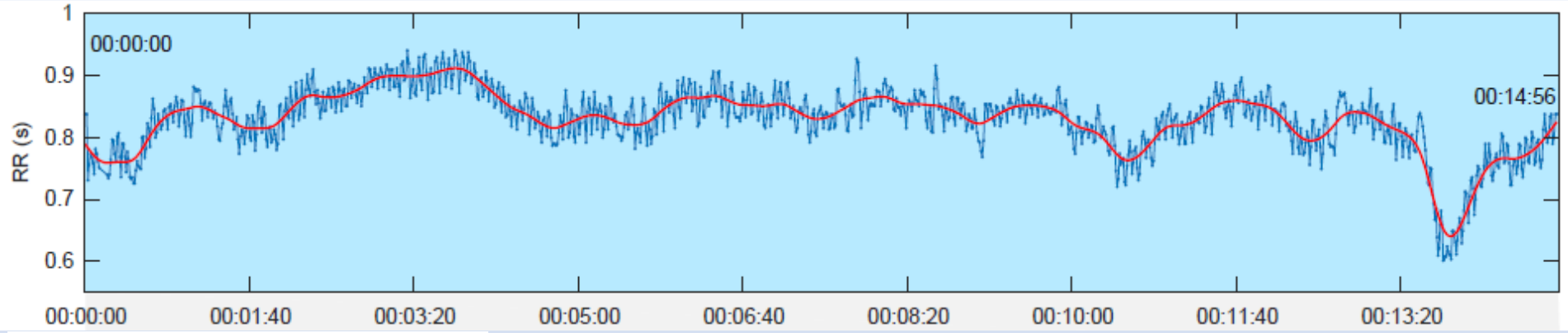
Variable	Units	VLF	LF	HF
Frequency band	(Hz)	0.00-0.04	0.04-0.15	0.15-0.40
Peak frequency	(Hz)	0.033	0.120	0.153
Power	(ms^2)	48	1228	153
Power	(log)	3.875	7.113	5.032
Power	(%)	3.37	85.90	10.72
Power	(n.u.)		88.90	11.10

Total power	(ms^2)	1430		
Total Power	(log)	7.265		
LF/HF ratio		8.011		
EDR	(Hz)	-		



Peak (0.04-0.26 Hz)	Peak Power	Total Power	CR
0.12	739.2	1429.7	1.07
Peak (0.07-0.40 Hz)	**Peak Power**	**Total Power**	**PR**
0.12	739.2	1429.7	1.07

PTSD 5 Pre-



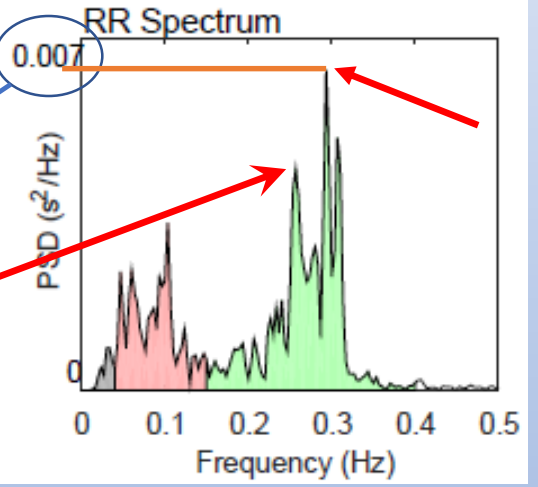
Time-Domain Results

Variable	Units	Value
Mean RR*	(ms)	826
Mean HR*	(bpm)	73
Min HR	(bpm)	64
Max HR	(bpm)	100
SDNN	(ms)	22.2
RMSSD	(ms)	24.1
NN50	(beats)	23
pNN50	(%)	2.13
RR triangular index		7.11
TINN	(ms)	116.0
Stress Index (SI)		17.4

Frequency-Domain Results (FFT spectrum)

Variable	Units	VLF	LF	HF
Frequency band	(Hz)	0.00-0.04	0.04-0.15	0.15-0.40
Peak frequency	(Hz)	0.033	0.103	0.293
Power	(ms^2)	11	134	284
Power	(log)	2.439	4.895	5.647
Power	(%)	2.67	31.16	66.10
Power	(n.u.)		32.01	67.92

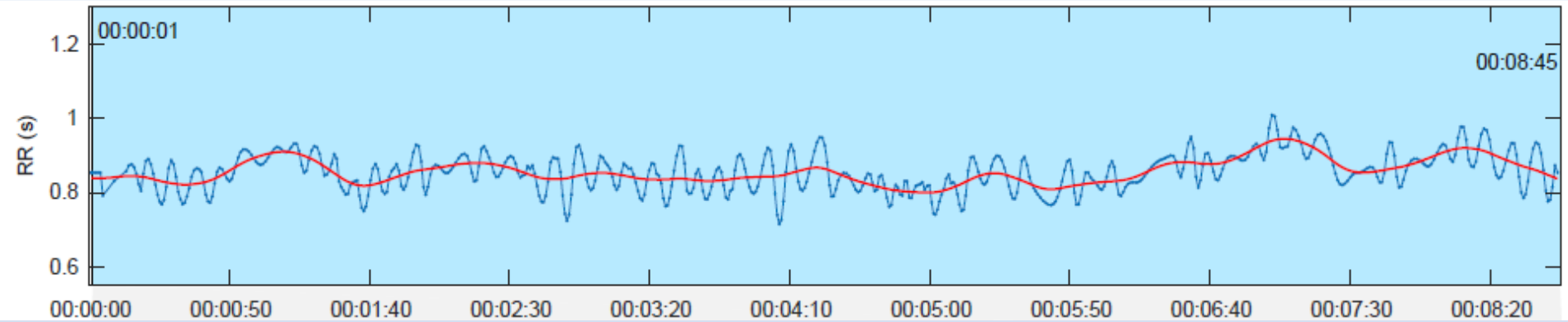
Total power	(ms^2)	429		
Total Power	(log)	6.061		
LF/HF ratio		0.471		
EDR	(Hz)	-		



Peak (0.04-0.26 Hz)	Peak Power	Total Power	CR
0.26	45.7	428.6	0.12
Peak (0.07-0.40 Hz)	**Peak Power**	**Total Power**	**PR**
0.29	91.7	428.6	0.27

eHFpp>LFpp
RMSSD>SDNN

PTSD 5 Post-

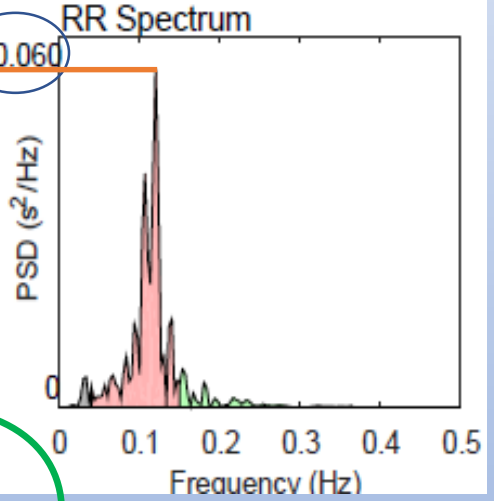


Time-Domain Results

Variable	Units	Value
Mean RR*	(ms)	854
Mean HR*	(bpm)	70
Min HR	(bpm)	59
Max HR	(bpm)	84
SDNN	(ms)	36.4
RMSSD	(ms)	23.5
NN50	(beats)	25
pNN50	(%)	4.15
RR triangular index		10.79
TINN	(ms)	186.0
Stress Index (SI)		10.7

Frequency-Domain Results (FFT spectrum)

Variable	Units	VLF	LF	HF
Frequency band	(Hz)	0.00-0.04	0.04-0.15	0.15-0.40
Peak frequency	(Hz)	0.033	0.120	0.153
Power	(ms^2)	48	1228	153
Power	(log)	3.875	7.113	5.032
Power	(%)	3.37	85.90	10.72
Power	(n.u.)		88.90	11.10
Total power	(ms^2)	1430		
Total Power	(log)	7.265		
LF/HF ratio		8.011		
EDR	(Hz)	-		



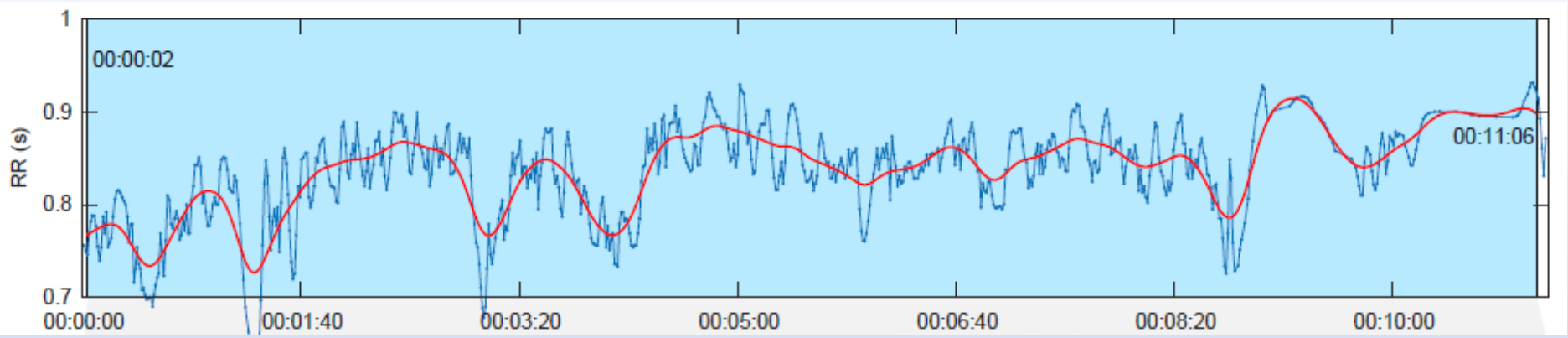
+1094
- 131
+1001
4x, 19x

- 3
+14.2
- 0.6

Peak (0.04-0.26 Hz)	Peak Power	Total Power	CR
0.12	739.2	1429.7	1.07
Peak (0.07-0.40 Hz)	**Peak Power**	**Total Power**	**PR**
0.12	739.2	1429.7	1.07

eHFpp=LFpp
SDNN>RMSSD

Pain 17 Pre-



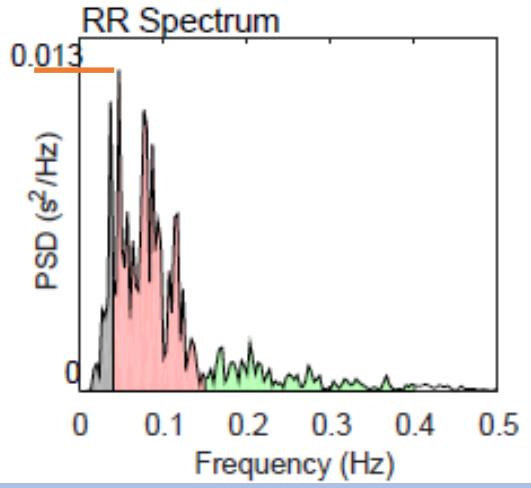
Time-Domain Results

Variable	Units	Value
Mean RR*	(ms)	833
Mean HR*	(bpm)	72
Min HR	(bpm)	64
Max HR	(bpm)	96
SDNN	(ms)	27.5
RMSSD	(ms)	19.4
NN50	(beats)	13
pNN50	(%)	1.80
RR triangular index		6.94
TINN	(ms)	154.0
Stress Index (SI)		13.1

Frequency-Domain Results (FFT spectrum)

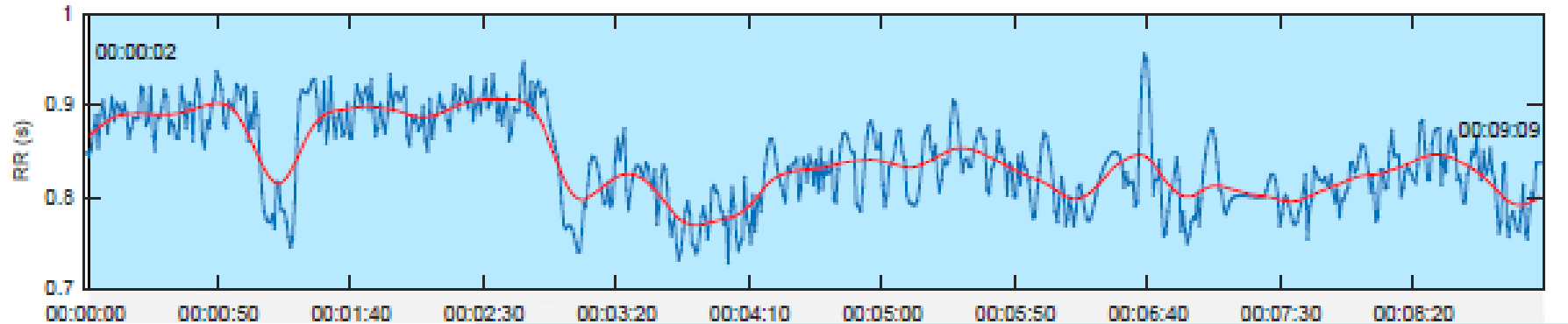
Variable	Units	VLF	LF	HF
Frequency band	(Hz)	0.00-0.04	0.04-0.15	0.15-0.40
Peak frequency	(Hz)	0.037	0.047	0.203
Power	(ms^2)	83	489	119
Power	(log)	4.417	6.193	4.775
Power	(%)	11.99	70.80	17.15
Power	(n.u.)		80.44	19.49

Total power	(ms^2)	691		
Total Power	(log)	6.538		
LF/HF ratio		4.128		
EDR	(Hz)	-		



Peak (0.04-0.26 Hz)	Peak Power	Total Power	CR
.05	181.9	690.5	0.36
Peak (0.07-0.40 Hz)	**Peak Power**	**Total Power**	**PR**
.08	69.2	690.5	0.10

Pain 17 Post-



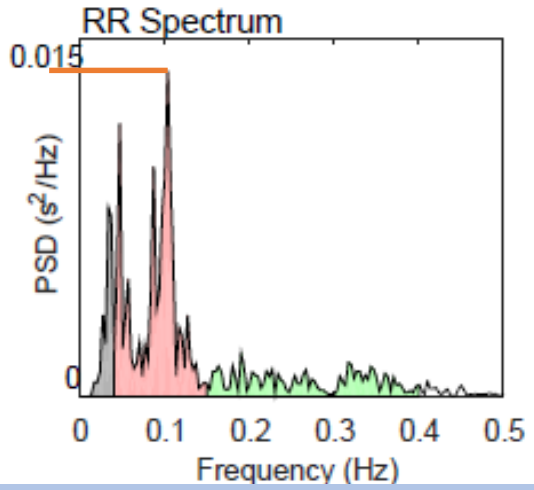
Time-Domain Results

Variable	Units	Value
Mean RR*	(ms)	837
Mean HR*	(bpm)	72
Min HR	(bpm)	63
Max HR	(bpm)	82
SDNN	(ms)	26.9
RMSSD	(ms)	23.1
NN50	(beats)	32
pNN50	(%)	4.90
RR triangular index		7.79
TINN	(ms)	152.0
Stress Index (SI)		13.9

Frequency-Domain Results (FFT spectrum)

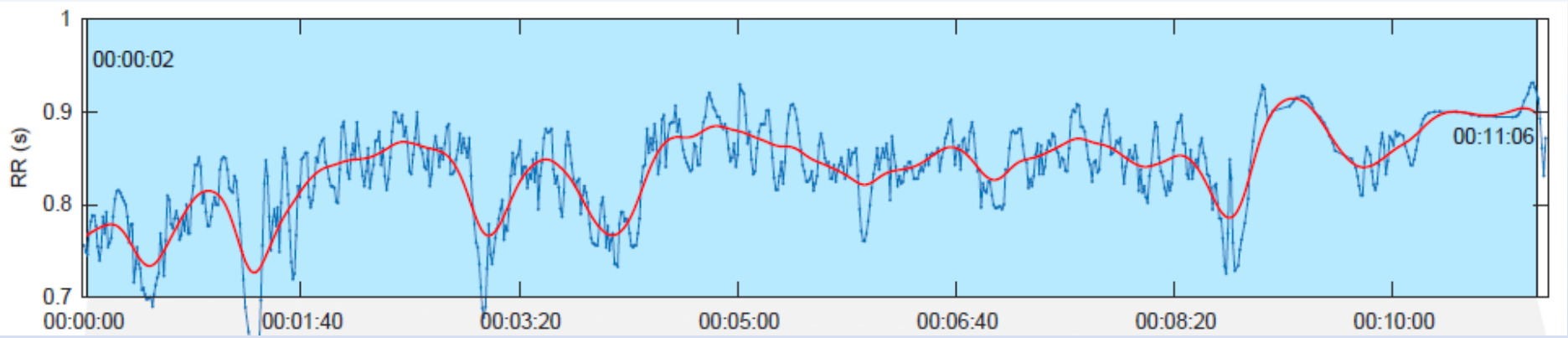
Variable	Units	VLF	LF	HF
Frequency band	(Hz)	0.00-0.04	0.04-0.15	0.15-0.40
Peak frequency	(Hz)	0.033	0.103	0.190
Power	(ms^2)	78	395	158
Power	(log)	4.356	5.979	5.062
Power	(%)	12.34	62.53	24.99
Power	(n.u.)		71.33	28.50

Total power	(ms^2)	632		
Total Power	(log)	6.449		
LF/HF ratio		2.503		
EDR	(Hz)	-		



Peak (0.04-0.26 Hz)	Peak Power	Total Power	CR
0.10	202.5	631.7	0.47
Peak (0.07-0.40 Hz)	**Peak Power**	**Total Power**	**PR**
0.10	202.5	631.7	0.47

Pain 17 Pre-

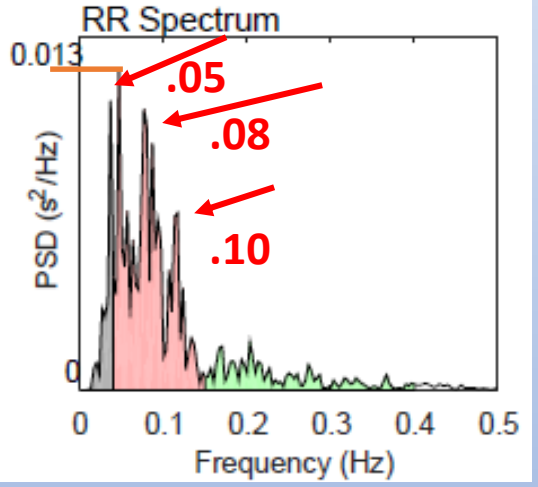


Time-Domain Results

Variable	Units	Value
Mean RR*	(ms)	833
Mean HR*	(bpm)	72
Min HR	(bpm)	64
Max HR	(bpm)	96
SDNN	(ms)	27.5
RMSSD	(ms)	19.4
NN50	(beats)	13
pNN50	(%)	1.80
RR triangular index		6.94
TINN	(ms)	154.0
Stress Index (SI)		13.1

Frequency-Domain Results (FFT spectrum)

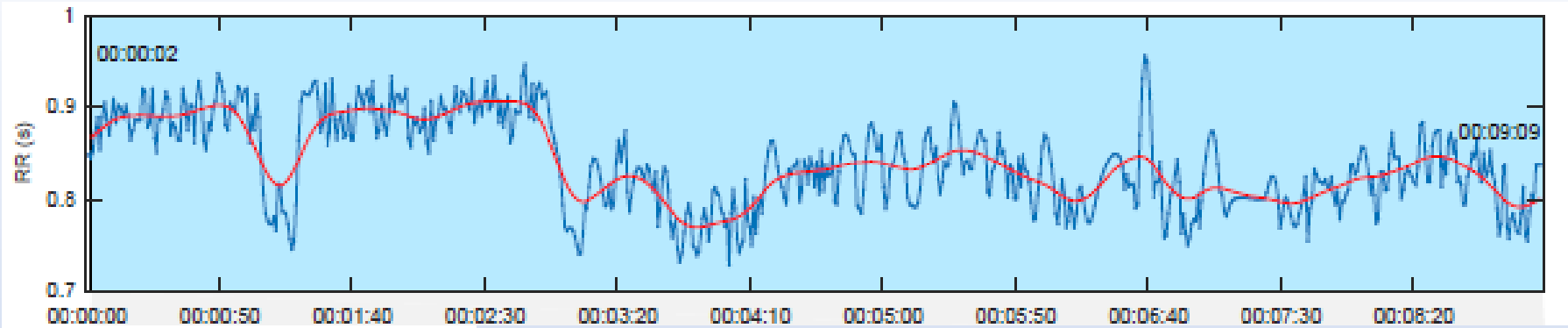
Variable	Units	VLF	LF	HF
Frequency band	(Hz)	0.00-0.04	0.04-0.15	0.15-0.40
Peak frequency	(Hz)	0.037	0.047	0.203
Power	(ms^2)	83	489	119
Power	(log)	4.417	6.193	4.775
Power	(%)	11.99	70.80	17.15
Power	(n.u.)		80.44	19.49
Total power	(ms^2)	691		
Total Power	(log)	6.538		
LF/HF ratio		4.128		
EDR	(Hz)	-		



Peak (0.04-0.26 Hz)	Peak Power	Total Power	CR
.05	181.9	690.5	0.36
Peak (0.07-0.40 Hz)	**Peak Power**	**Total Power**	**PR**
.08	69.2	690.5	0.10

LFpp>eHFpp
SDNN>RMSSD

Pain 17 Post-

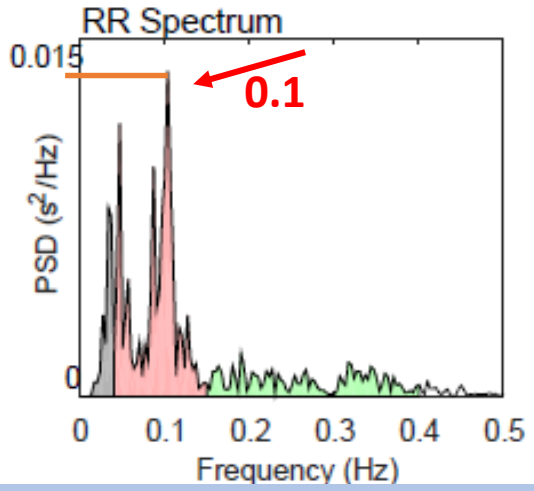


Time-Domain Results

Variable	Units	Value
Mean RR*	(ms)	837
Mean HR*	(bpm)	72
Min HR	(bpm)	63
Max HR	(bpm)	82
SDNN	(ms)	26.9
RMSSD	(ms)	23.1
NN50	(beats)	32
pNN50	(%)	4.90
RR triangular index		7.79
TINN	(ms)	152.0
Stress Index (SI)		13.9

Frequency-Domain Results (FFT spectrum)

Variable	Units	VLF	LF	HF
Frequency band	(Hz)	0.00-0.04	0.04-0.15	0.15-0.40
Peak frequency	(Hz)	0.033	0.103	0.190
Power	(ms^2)	78	395	158
Power	(log)	4.356	5.979	5.062
Power	(%)	12.34	62.53	24.99
Power	(n.u.)		71.33	28.50
Total power	(ms^2)	632		
Total Power	(log)	6.449		
LF/HF ratio		2.503		
EDR	(Hz)	-58.8-		



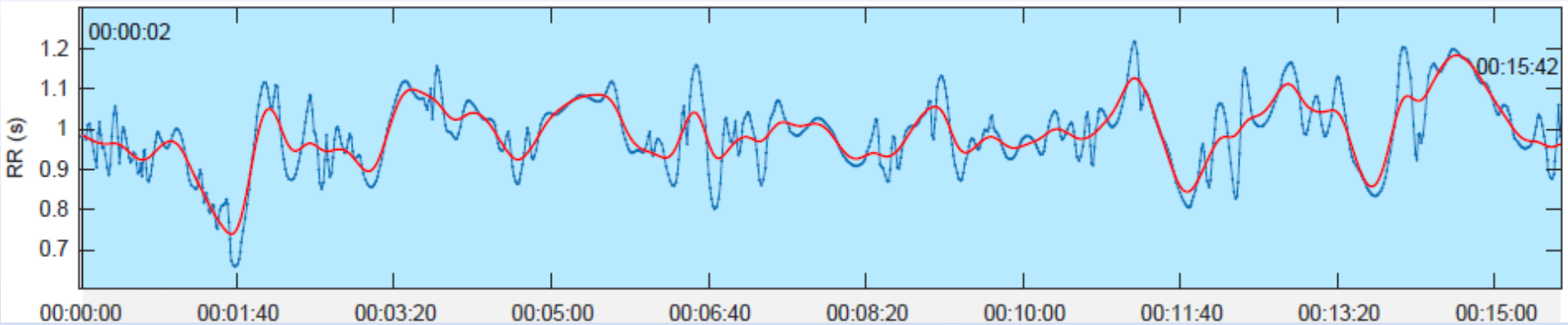
0
- 0.6
+ 3.7

4x, 1.3

Peak (0.04-0.26 Hz)	Peak Power	Total Power	CR
0.10	202.5	631.7	0.47
Peak (0.07-0.40 Hz)	**Peak Power**	**Total Power**	**PR**
0.10	202.5	631.7	0.47

eHFpp>LFpp
SDNN>RMSSD

Pain 16 Pre-

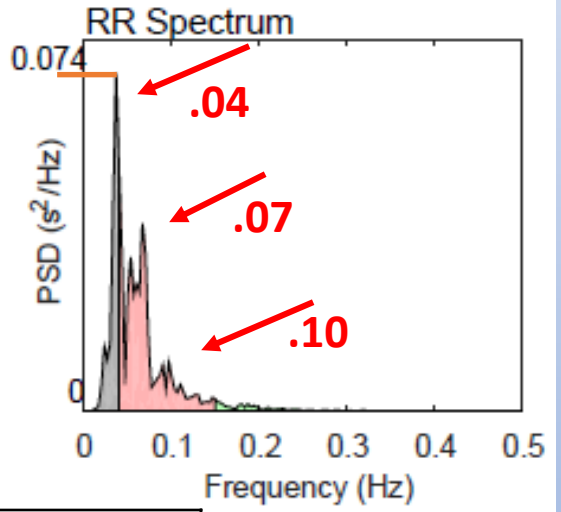


Time-Domain Results

Variable	Units	Value
Mean RR*	(ms)	987
Mean HR*	(bpm)	61
Min HR	(bpm)	49
Max HR	(bpm)	91
SDNN	(ms)	43.2
RMSSD	(ms)	20.1
NN50	(beats)	32
pNN50	(%)	3.41
RR triangular index		10.11
TINN	(ms)	223.0
Stress Index (SI)		9.1

Frequency-Domain Results (FFT spectrum)

Variable	Units	VLF	LF	HF
Frequency band	(Hz)	0.00-0.04	0.04-0.15	0.15-0.40
Peak frequency	(Hz)	0.037	0.040	0.150
Power	(ms^2)	581	1206	76
Power	(log)	6.365	7.095	4.326
Power	(%)	31.21	64.73	4.06
Power	(n.u.)		94.10	5.90
Total power	(ms^2)	1863		
Total Power	(log)	7.530		
LF/HF ratio		15.941		
EDR	(Hz)	-		



Peak (0.04-0.26 Hz)	Peak Power	Total Power	CR
0.04	893.0	1863.0	0.92
Peak (0.07-0.40 Hz)	**Peak Power**	**Total Power**	**PR**
0.07	570.4	1863.0	0.44

LFpp>eHFpp
SDNN>RMSSD

Empirical keys of HRV profiles

LFpp>eHFpp: excessive SNS (PR<0.4)

eHFpp>LFpp and RMSSD>SDNN: excessive SNS with PNS (PR le ~0.4)

eHFpp≥LFpp and SDNN>RMSSD: PNS dominant (PR gt ~0.4)

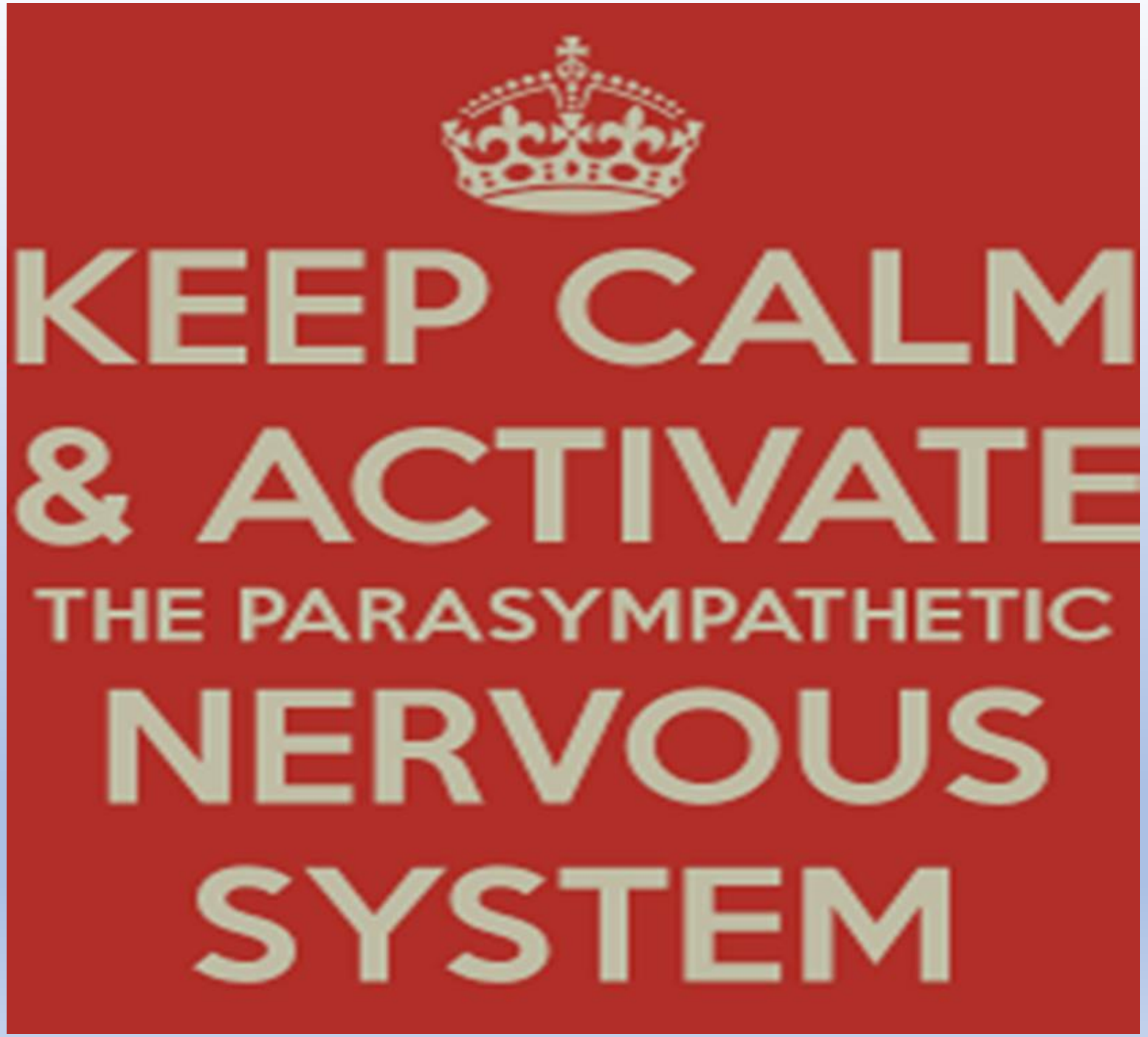
PR and CR are useful for comparing intra-individual change

CR vs PR after HRVB in a Sample of Veterans with Chronic Pain				
	Pre-n	Post-n	TP2 PR-TP2 PR (SE) 'Diff CR'	TP2 CR-TP1 CR1 (SE) 'Diff PR'
Active	26	22	0.53 (0.23) [1]	0.62 (0.22)[1]
Sham	29	19	0.06 (0.03) [2]	0.05 (0.05) [2]
[1]p< .005 [2]ns				

Predictive Strength of CR vs PR			
Active HRVB Group Rho (Diff PR with Diff Outcome) vs Rho (Diff CR with Diff Outcome) 4% change in variance cutoff (bold means changed ns to significant)			
Minutes weekly practice	**GT**	Perceived Stress Scale	ND
Minutes HM coherence	**GT**	BPI Severity	ND
CRP	**GT**	BPI Interference	ND
PASAT	**GT**	Pain Catastrophizing	ND
PVT Reaction Time	GT (-)	Physical Fatigue	ND
Reduced Motivation	GT (-)	Mental Fatigue	ND
List Learning	ND	Total Fatigue	ND
Beck Depression	ND		
GT=Greater Than; ND=No Difference			

Take-aways

- HRV from resting HR tachygram can be quantified in a number of ways
- SNS HRV power above 0.07 Hz is minimal and becomes negligible by 0.1 Hz
  - PNS power below 0.07 Hz is minimal
- HRV power below 0.07 Hz is common in clinical populations and may indicate pathology
  - Reflected by eHF peak power vs LF peak Power
- Interpretation of a single tachygram requires both graphic display and several indices
- Intra-person comparisons are generally informative
  - Coherence and Parasympathetic Ratios are both promising
- Inter-person comparisons require both graphic display and several indices
  - eHFpp vs LFpp and SDNN vs RMSSD
  - Parasympathetic Ratio may be more predictive


KEEP CALM
& ACTIVATE
THE PARASYMPATHETIC
NERVOUS
SYSTEM


time for questions

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Readings on RSA: Respiration and Vagal Tone

Eckberg, D. L. (1997). Sympathovagal balance: a critical appraisal. *Circulation*, *96*(9), 3224-3232. (republished March 2018)

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Karemaker, J. M. (1999). Autonomic integration: the physiological basis of cardiovascular variability. *The Journal of physiology*, *517*(2), 316-316.

Blood pressure (BP) and heart rate (HR) are continually varying. The nervous mechanisms behind this variability have been studied extensively in non-human animal models (for reviews, see Eckberg & Sleight, 1992). Since the 1980s, the combined availability of non-invasive blood pressure measurement by the Peñáz-Wesseling Finapres, and more and more powerful computers in the laboratory, have revived research into prevalence and physiological meaning of this variability in humans. When Fourier analysis was applied to analysis of BP variability (BPV) and HR variability (HRV), two frequency peaks stood out: one around the respiratory frequency and one around 0.1 Hz, or one oscillation in 10 s. These frequencies had been observed in blood pressure recordings before, actually over 130 years ago: Traube-Hering waves (coupled to respiration) and Mayer waves, the 0.1 Hz and slower oscillations. In the earlier research it had been established that oscillating sympathetic activity causes the Mayer waves in blood pressure. The respiration-coupled blood pressure oscillations were partly explained by mechanical effects of respiration and possibly by the vagally induced heart period oscillations coupled to respiration, known as respiratory sinus arrhythmia (RSA) (Eckberg & Sleight, 1992).

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Respiration is a powerful modulator of heart rate variability, and of baro- and chemoreflex sensitivity. Abnormal respiratory modulation of heart rate is often an early sign of autonomic dysfunction in a number of diseases. In addition, increase in venous return due to respiration may help in maintaining blood pressure during standing in critical situations. This review examines the possibility that manipulation of breathing pattern may provide beneficial effects in terms not only of ventilatory efficiency, but also of cardiovascular and respiratory control in physiologic and pathologic conditions, such as chronic heart failure. This opens a new area of future research in the better management of patients with cardiovascular autonomic dysfunction.

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Mayer waves are oscillations of arterial pressure occurring spontaneously in conscious subjects at a frequency lower than respiration (~0.1 Hz in humans). Mayer waves are tightly coupled with synchronous oscillations of efferent sympathetic nervous activity and are almost invariably enhanced during states of sympathetic activation. For this reason, the amplitude of these oscillations has been proposed as a surrogate measure of sympathetic activity, although in the absence of a clear knowledge of their underlying physiology. Some studies have suggested that Mayer waves result from the activity of an endogenous oscillator located either in the brainstem or in the spinal cord. Other studies, mainly based on the effects of sino-aortic baroreceptor denervation, have challenged this view. Several models of dynamic arterial pressure control have been developed to predict Mayer waves. In these models, it was anticipated that the numerous dynamic components and fixed time delays present in the baroreflex loop would result in the production of a resonant, self-sustained oscillation of arterial pressure. Recent analysis of the various transfer functions of the rat baroreceptor reflex suggests that Mayer waves are transient oscillatory responses to hemodynamic perturbations rather than true feedback oscillations. Within this frame, the amplitude of Mayer waves would be determined both by the strength of the triggering perturbations and the sensitivity of the sympathetic component of the baroreceptor reflex.

Readings on Baroreflex: RFB and Coherence

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