
Friday, November 2, 2018
11:00a – 12:30p
**Applied HRV Data Interpretation for the Clinician**
JP (Jack) Ginsberg, Ph.D.

Heart Rate Variability Biofeedback (HRVB) empowers clients to self-regulate emotions . HRVB professionals use quantitative and graphic analysis of heart rate (HR) to help clients understand their physiological status and the relationship between autonomic function and well-being.

This presentation will use actual pre-post HRV data from patients with PTSD and chronic pain to illustrate how acquisition of self-regulation through HRVB affects HR patterns and screen displays. 'Coherence' is the term used to refer to the 0.1 Hz HRV peak, which indicates optimum HRV and results from synchronization of respiration, HR, baroreflex and blood pressure. Methods and a new approach to quantifying Coherence from a tachygram will be explained. (NBCC, APA CE Hours 1.5-intermediate)


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"The more I know, the more I realize how little I know" — Socrates (b. 399 BCE)
"The more you know, the more you know you don't know." — Aristotle (b. 384 BCE)
"How Little I Know" – Buckminster Fuller, author of *Operating Manual for Spaceship Earth (1968), in The Saturday Review* (12 Nov 1966),

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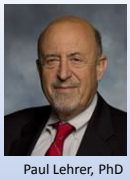
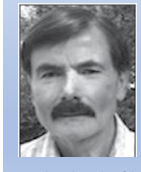
ACKNOWLEDGEMENTS

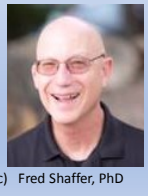

D.A. Powell, PhD (dec)

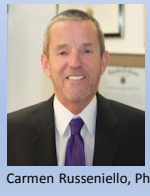

Rollin McCraty, PhD


Paul Lehrer, PhD

Rolland Parker, PhD (dec)


Wasyl Malyj, PhD (dec)


Fred Shaffer, PhD


Carmen Russeniello, PhD


Jan B. Newman, MD

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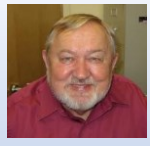

Evgeny G. Vaschillo, PhD

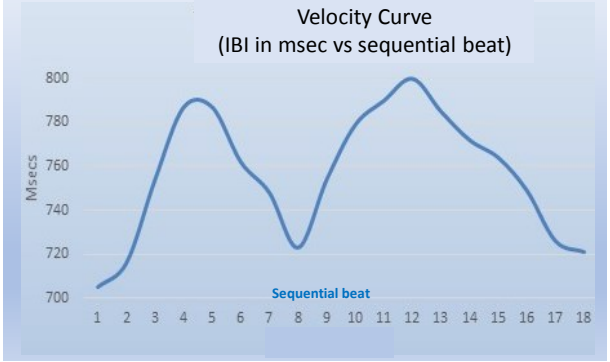
Disclaimer and Disclosure

- 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 welcomed
  - 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 |




Actual Interbeat Interval (IBI) Sample

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 705 | 716 | 754 | 787 | 787 | 762 | 748 | 723 | 754 |
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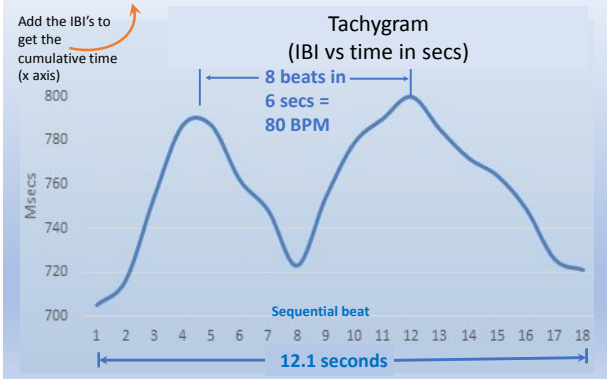
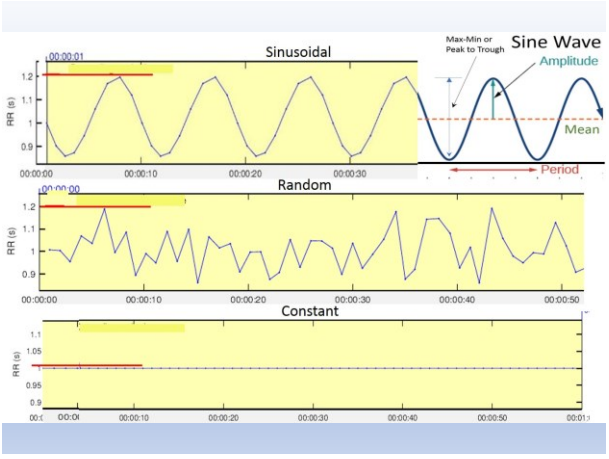
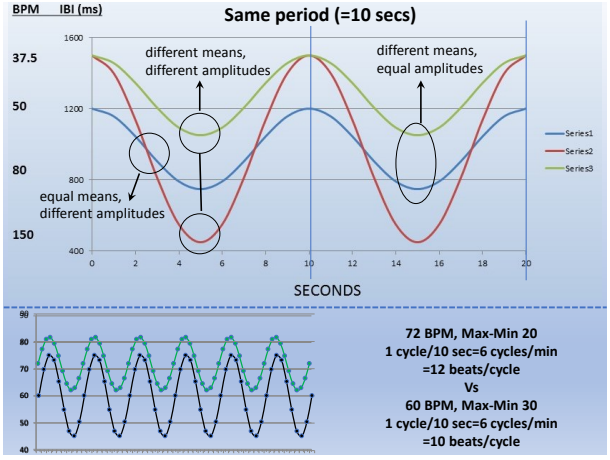


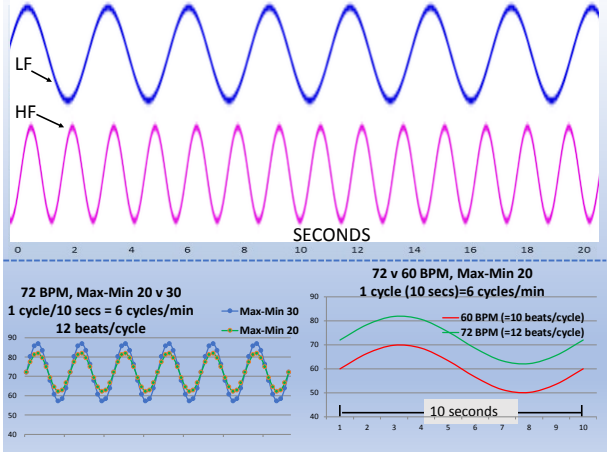


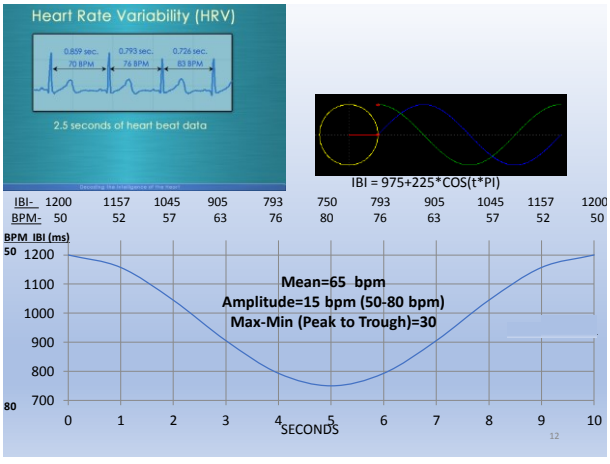
## Tachygram

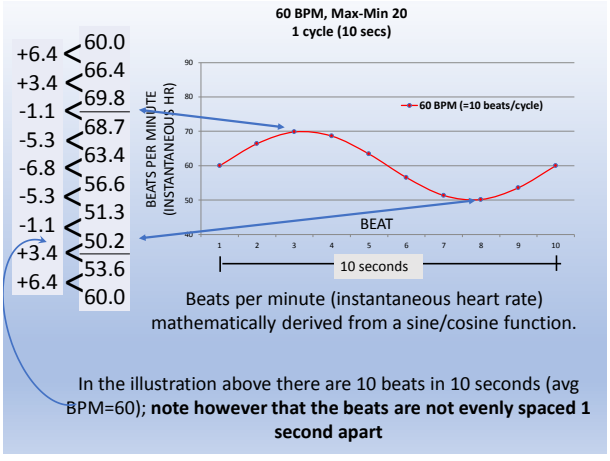
A tachygram is a graph of heart rate (HR), either as inter-beat interval (IBI) or as instantaneous HR (BPM), over a continuous time period. The illustrations above are IBI in msecs measured as RR.


Sinusoidal
Max-Min or Peak to Trough
Sine Wave
Amplitude
Mean
Period
Random
Constant
RR (s)


BPM IBI (ms)
Same period (=10 secs)
37.5
50
80
150
different means, different amplitudes
different means, equal amplitudes
equal means, different amplitudes
SECONDS
Series1
Series2
Series3
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

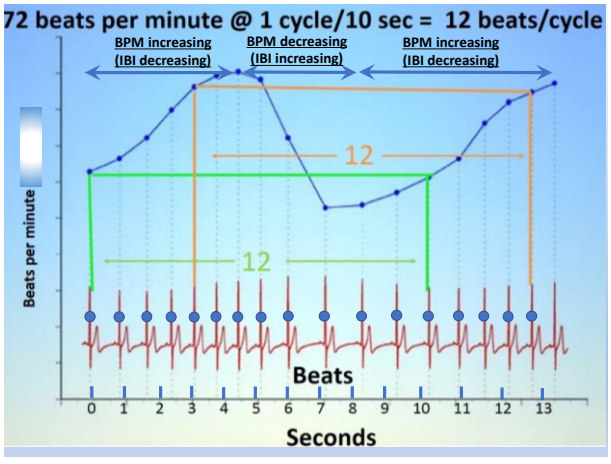

LF
HF
SECONDS
72 BPM, Max-Min 20 v 30
1 cycle/10 secs = 6 cycles/min
12 beats/cycle
Max-Min 30
Max-Min 20
72 v 60 BPM, Max-Min 20
1 cycle (10 secs)=6 cycles/min
60 BPM (=10 beats/cycle)
72 BPM (=12 beats/cycle)
10 seconds

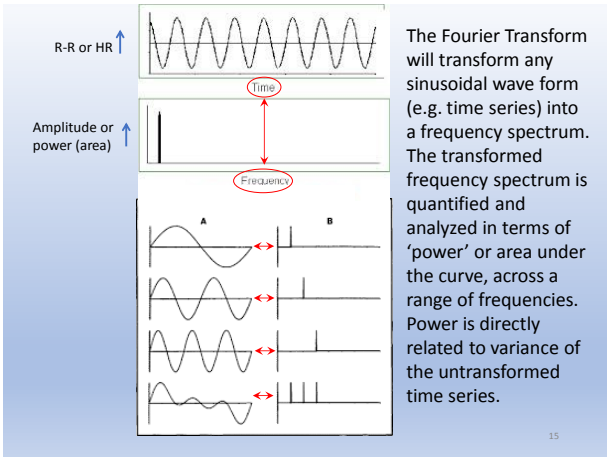

Heart Rate Variability (HRV)
2.5 seconds of heart beat data
IBI = 975+225*COS(t*PI)
IBI- 1200 1157 1045 905 793 750 793 905 1045 1157 1200
BPM- 50 52 57 63 76 80 76 63 57 52 50
BPM IBI (ms)
Mean=65 bpm
Amplitude=15 bpm (50-80 bpm)
Max-Min (Peak to Trough)=30
SECONDS



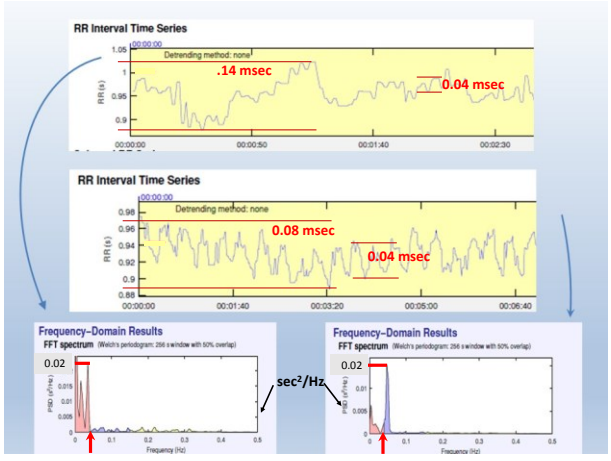

Beats per minute (instantaneous heart rate) mathematically derived from a sine/cosine function.

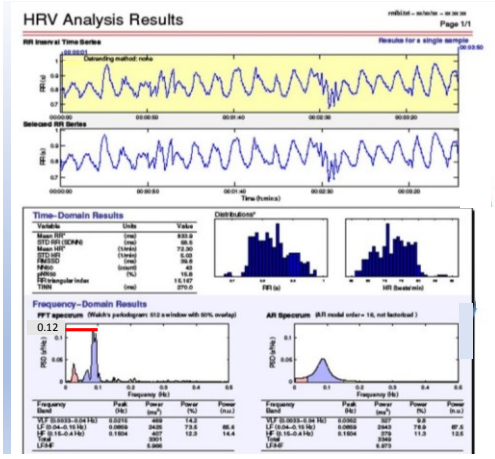
In the illustration above there are 10 beats in 10 seconds (avg BPM=60); **note however that the beats are not evenly spaced 1 second apart**




The Fourier Transform will transform any sinusoidal wave form (e.g. time series) 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.






Kubios HRV report

ULF: <0.0033 HZ=>300 secs/cycle

- Minimum > 24 hour recording
- Circadian
- Not commonly used in clinical assessments

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

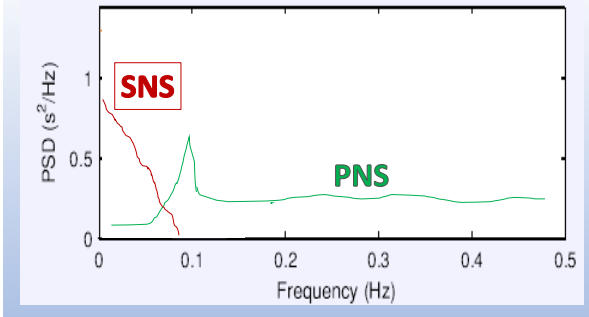
- **Minimum 5 minute recording (24 hour is best)**
- More strongly predictive of all-cause mortality and inflammation than the other bands
- Origins of VLF power unclear
  - **Intrinsic (pacemaker) and predominantly SNS activity**
  - Little PNS power

**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**
  - **No SNS above ~0.09 Hz**
  - **PNS dominant over 0.07 Hz**
  - **0.07-0.11 Hz is resonance frequency**
    - **Baroreflex activity**
    - **'Coherence'**

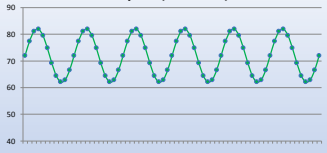
**HF: 0.15–0.40 Hz=(6.7-2.5) secs/cycle=(9-24) cycles/min**

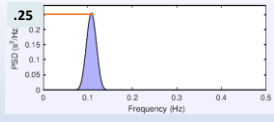
- **Minimum 1 minute recording**
- 'Respiratory band'
- **Parasympathetic activity**
- HR variations related to respiratory cycle may not reflect vagal tone.
- **Respiratory Sinus Arrhythmia (RSA)**




Idealized HRV power expected across frequency spectrum due to parasympathetic and sympathetic branches of the ANS. This hypothesized proposition has not been fully tested and validated.

**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 (ms²) | 0 |
| LF power (ms²) | 6959.0 |
| LF peak (Hz) | 0.1 |
| HF power (ms²) | 4 |

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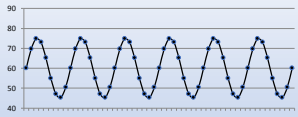
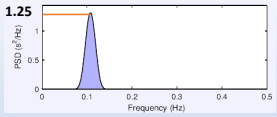
**60 BPM, Max-Min 30**
**1 cycle/10 secs, 10 beats/cycle**
**6 cycles (1 minute)**




| Idealized HRV parameters - 1 min recording | |
|---|---|
| Mean HR | 60.0 |
| Max-Min | 30.0 |
| SDNN (ms) | 187.1 |
| RMSSD (ms) | 130.6 |
| VLF power (ms)² | 0 |
| LF power (ms)² | 35379 |
| LF peak (Hz) | 0.1 |
| HF power (ms)² | 77 |

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| HRV parameters - 1 min recording, sinusoidal 10 second period | | | | |
|---|---|---|---|---|
| Mean HR | 72.0 | 60.0 | 72.0 | 60.0 |
| Max-Min | 20.0 | 20.0 | 30.0 | 30.0 |
| HR/(max-min) | **3.6** | **3.0** | **2.4** | **2.0** |
| SDNN (ms) | **83.9** | **120.8** | **129.6** | **187.1** |
| RMSSD (ms) | **47.0** | **83.4** | **72.1** | **130.6** |
| VLF power (ms)² | **0** | **0** | **0** | **0** |
| LF power (ms)² | **6959** | **14653** | **16443** | **35379** |
| LF peak (Hz) | 0.1 | 0.1 | 0.1 | 0.1 |
| HF power (ms)² | **4** | **16** | **19** | **77** |
| Total Power (ms)² | **6963** | **14669** | **16463** | **35456** |

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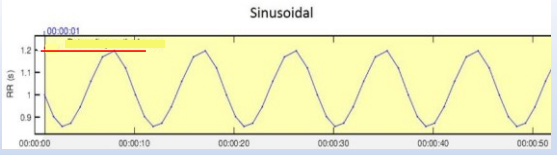
What parameters would Mean HR 72, Max-Min 24 (i.e. 72/24=3.0) have?

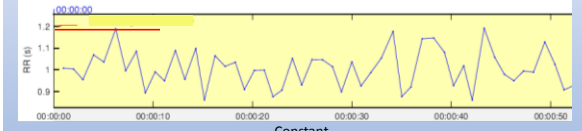
| Sinusoidal | | | | Random | | | | Constant | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 60.0 | 56.6 | 66.4 | 51.3 | 60.4 | 51.6 | 53.9 | 71.5 | 60.0 | 60.0 | 60.0 | 60.0 |
| 66.4 | 51.3 | 69.8 | 50.2 | 60.2 | 63.8 | 62.1 | 63.5 | 60.0 | 60.0 | 60.0 | 60.0 |
| 69.8 | 50.2 | 68.7 | 53.6 | 57.3 | 60.9 | 55.5 | 58.7 | 60.0 | 60.0 | 60.0 | 60.0 |
| 68.7 | 53.6 | 63.4 | 60.0 | 64.1 | 62.1 | 59.2 | 56.9 | 60.0 | 60.0 | 60.0 | 60.0 |
| 63.4 | 60.0 | 56.6 | 66.4 | 62.1 | 54.5 | 63.2 | 59.6 | 60.0 | 60.0 | 60.0 | 60.0 |
| 56.6 | 66.4 | 51.3 | 69.8 | 71.3 | 59.8 | 70.6 | 59.3 | 60.0 | 60.0 | 60.0 | 60.0 |
| 51.3 | 69.8 | 50.2 | 68.7 | 59.7 | 59.9 | 52.6 | 67.7 | 60.0 | 60.0 | 60.0 | 60.0 |
| 50.2 | 68.7 | 53.6 | 63.4 | 65.1 | 52.5 | 55.2 | 61.5 | 60.0 | 60.0 | 60.0 | 60.0 |
| 53.6 | 63.4 | 60.0 | 56.6 | 53.6 | 54.4 | 68.6 | 54.4 | 60.0 | 60.0 | 60.0 | 60.0 |
| 60.0 | 56.6 | 66.4 | 51.3 | 59.4 | 63.1 | 68.8 | 55.6 | 60.0 | 60.0 | 60.0 | 60.0 |
| 66.4 | 51.3 | 69.8 | 50.2 | 56.9 | 55.8 | 60.0 | 52.7 | 60.0 | 60.0 | 60.0 | 60.0 |
| 69.8 | 50.2 | 68.7 | 53.6 | 65.3 | 62.8 | 55.6 | 63.5 | 60.0 | 60.0 | 60.0 | 60.0 |
| 68.7 | 53.6 | 63.4 | 60.0 | 57.3 | 62.7 | 61.1 | 64.8 | 60.0 | 60.0 | 60.0 | 60.0 |
| 63.4 | 60.0 | 56.6 | | 65.9 | 60.8 | 51.6 | | 60.0 | 60.0 | 60.0 | |
| **Mean RR (ms)** | | **1013.9** | | | | **1013.9** | | | | **1000.0** | |
| **Mean HR (b/min)** | | **60.0** | | | | **59.9** | | | | **60.0** | |

60 BPM, Max-Min 20

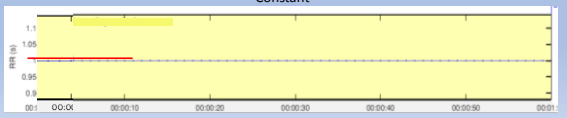
Sinusoidal




Random

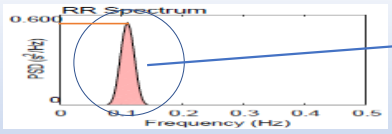



Constant



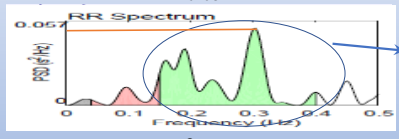
**60 BPM, Max-Min 20 (Amplitude 10), 10 sec/cycle**

Sinusoidal



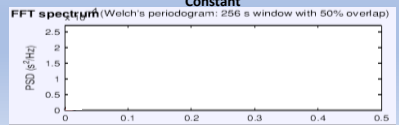

'Coherence' (discussed later)

Random




HR oscillations in HF band (0.15-0.40 Hz) are parasympathetically modulated

Constant

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| HRV parameters - 1 min recording | | | |
|---|---|---|---|
| | Sinusoidal | Random | Constant |
| Mean HR | **60.0** | **59.9** | **60.0** |
| Max-Min HR | **20.0** | **20.0** | **20.0** |
| HR/(Max-Min) | 3.0 | 3.0 | 3.0 |
| SDNN (ms) | **118.9** | **82.9** | **0.0** |
| RMSSD (ms) | **83.7** | **126.6** | **0.0** |
| VLF peak (Hz) | .03 | .03 | .04 |
| VLF power (ms)$^2$ | **10.1** | **100.9** | **0** |
| LF peak (Hz) | 0.10 | 0.15 | 0.15 |
| LF power (ms)$^2$ | **14814.0** | **603.9** | **0** |
| HF peak (Hz) | 0.22 | 0.30 | 0.38 |
| HF power (ms)$^2$ | **22.1** | **4191.1** | **0** |
| Total power (ms)$^2$ | **14846.2** | **4895.9** | **0** |

**Based on 24 hour recordings, SDNN < 50 unhealthy, 50-100 comprmised, > 100 healthy – however these values cannot be directly compared to short-term recordings**

**Note the SDNN:RMSSD ratio**

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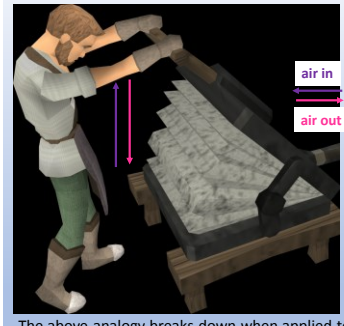
RMSSD and HF reflect PNS power; can concurrently have low or high SNS power

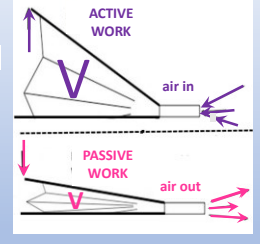
Physiological Bases of HRV

I. **Respiratory Sinus Arrhythmia (RSA)**
- Abdominothoracic Pump, Respiratory Pump, Cardio-respiratory Coupling, Cardiopulmonary Reflex, Lung-heart Pump
- **Results from interactions between respiration (rate, depth, volume) and**
  - **Oscillations in cardiac output**
  - **Vagal parasympathetic tone**
- **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

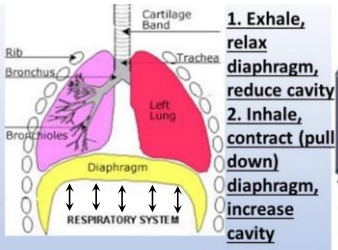
II. **Resonant Frequency Breathing (RFB)**
- **Occurs in LF, around 0.1 Hz=~6 BrPM**
- **Baroreceptor reflex (BR)**
- **Interrelations of respiration, HR, BR, BP, and vasomotor tone (VT)**
- **'Coherence'**

RSA: Respiration and Oscillations in Cardiac Output-I

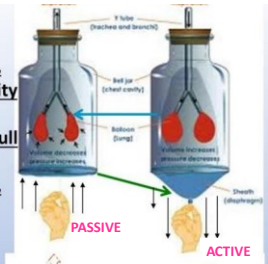


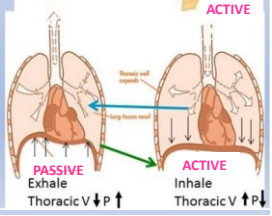

The above analogy breaks down when applied to breathing however, because the passive work of the bellows is due to the assist of gravity when it descends; in breathing the diaphragm does passive work when it ascends due to relaxation of the diaphragm muscle.




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

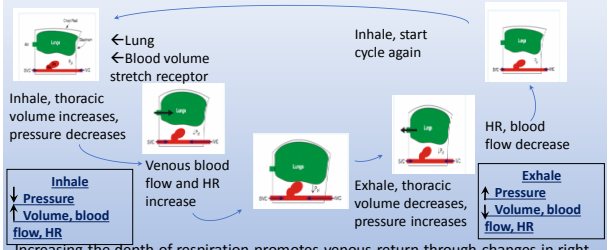



In Diaphragmatic Breathing inhalation increases thoracic cavity volume (draws air in) due to active contraction of diaphragm, decreases P; exhalation decreases cavity volume (expels air), increases P, and is passive.




RSA: Respiration and Oscillations in Cardiac Output-II

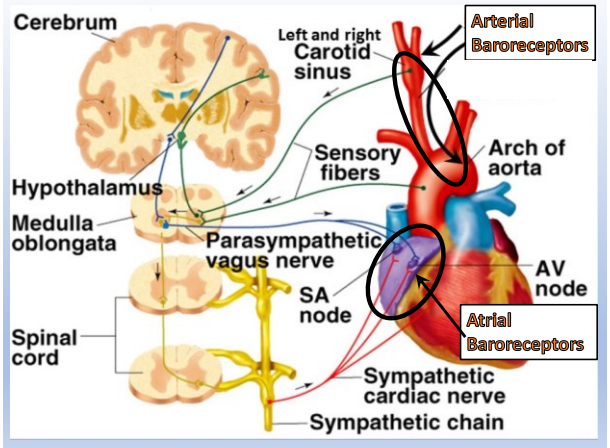
**Inhalation vs exhalation changes venous return**




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.

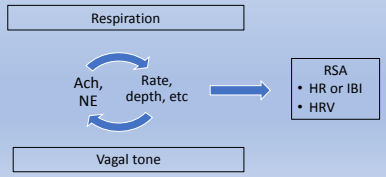
RSA: Respiration and Oscillations in Cardiac Output-III
(Intra-thoracic Pressure, Venous Return)

- **RSA is elicited by cardiovascular reflexes during normal respiration caused by pressure changes on venous filling of the heart**
- 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
- Changes in venous filling affect l**ow pressure atrial baroreceptors at veno-atrial junctions** of the heart ('cardio-pulomonary receptors') which are **innervated by myelinated vagal afferents** and respond to atrial filling and contraction. **On inhalation, right atrial expansion and reduced pressure increase venous return, blood volume stretch receptor discharge, and HR via activation of sympathetic outflow and withdrawal of vagal parasympathetic activity to the SA node ('Bainbridge' or 'Atrial Reflex'). On exhalation, right atrial contraction and increased pressure decrease stretch receptor discharge, venous return, and HR via sympathetic reduction and (re-)activation of vagal reflex.**



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 gas ($O_2$, $CO_2$) and 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**

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

- Respiration and HRV synchronize @RFB
  - 'Resonance'
  - Indicator of 'Coherence'

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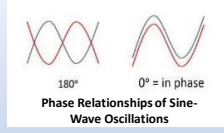
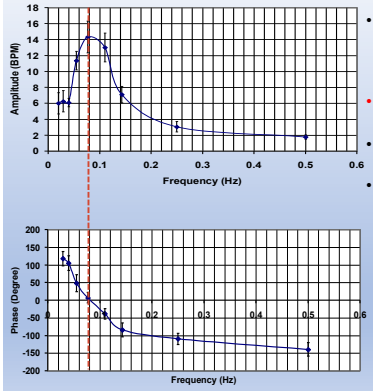
0º phase relationship between oscillations in respiratory and HR cycles



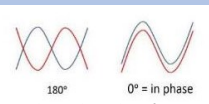
**Phase Relationships of Sine-Wave Oscillations**


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

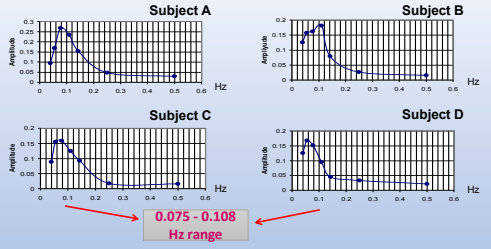



- Measured continuous HR in 5-min paced breathing periods of 0.5, 0.25, 0.143, 0.11, 0.077, 0.055, 0.04, 0.029, and 0.02 Hz
- Paced breathing (imposed) sinewave oscillations in HR
- Calculated avg $HR_{max}$- $Hr_{min}$ per respiratory cycle
- ***The highest amplitude of max-min and 0° phase occurred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

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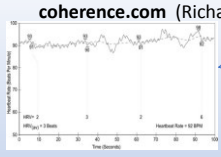
Coherence of Cardiac Rhythm: Effect of RFB on HRV

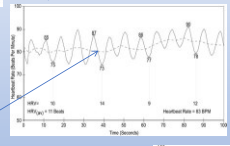
**coherence.com** (Richard Brown, MD and Stephen Elliott, Ph.D.)



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

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

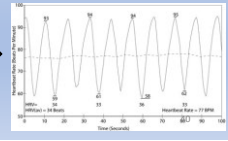
**5.5 BrPM (0.092 Hz), HRV(avg) = 34**



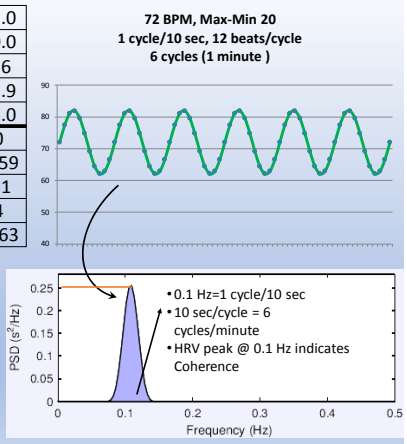
**Baroreflex activates resonance ('Coherence')**

**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 |




Respiration, HR, and BP are interrelated

BP: Sys/Dias, Pulse, Mean Arterial

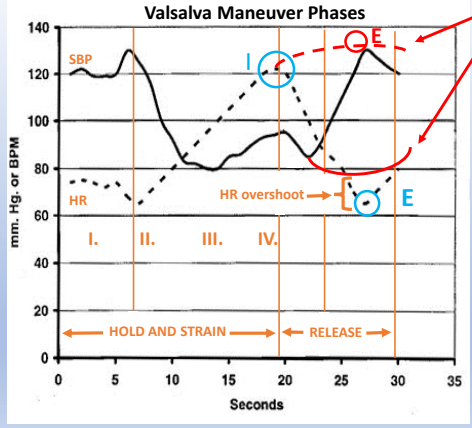
1. The Valsalva Maneuver
2. Traube-Hering and Mayer Waves
3. Baroreceptor Reflex (BR)
   a. HR goes down when blood pressure goes up, and HR goes up when blood pressure goes down
   b. The baroreflex amplifies HR oscillations at resonance frequency
   c. HRV Resonance @RFB → Coherence
   d. Includes complex relationship with vasomotor tone (VT)

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




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**

HR and BP: Traube-Hering and Mayer Waves

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

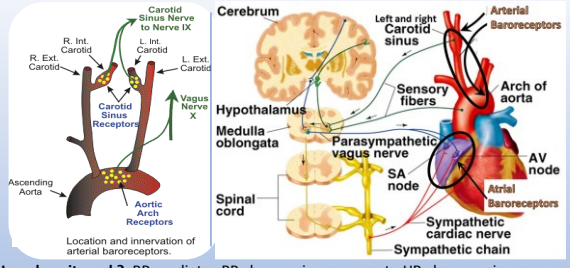
Taube-Hering

- 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)**



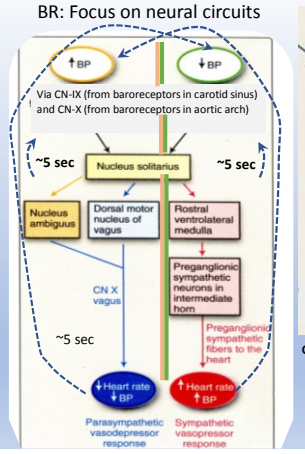

**How does it work?** BR mediates BP changes in response to HR changes via pressure receptors in the aortic arch and carotid arties. These arterial baroreceptors increase discharge rate when stretched by BP elevation caused by increased HR. This signal (through CNIX from carotid and CNX from aorta) goes 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.

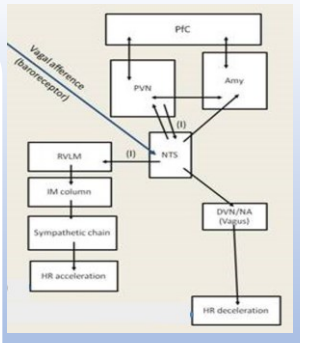
Resonance of HRV due to BR at RFB

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 |

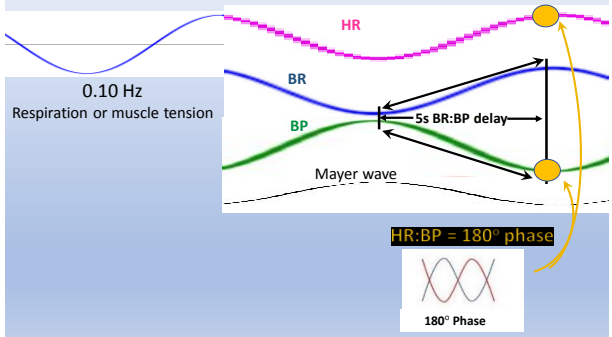
BR: Focus on neural circuits




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



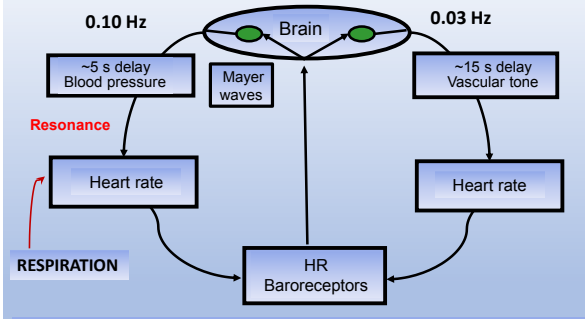

Baroreceptor reflex (BR)

- Respiration changes HR
- HR changes BR
- BR changes BP to maintain homeostasis
- @ RFB, HR amplitude resonates with Respiration and BP
  - 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
  - Includes SNS influences

'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.

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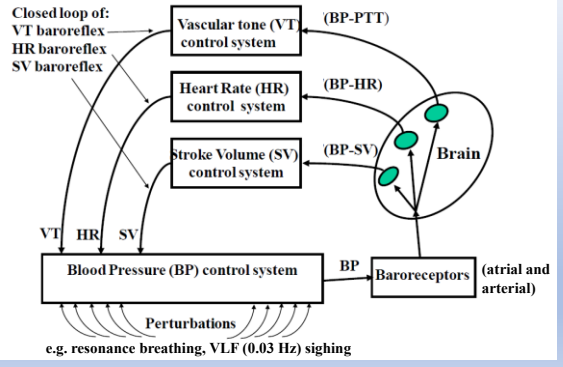
**Three Closed Loops Model of Baroreflex System**



Summary: RSA and BR at RFB work together to produce Coherent 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 (peak to trough) of HR in normal respiration cycle
     - Average HR may not change
   - Important in complex 0.03 Hz VT oscillations
   - HRVB reduces BP

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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

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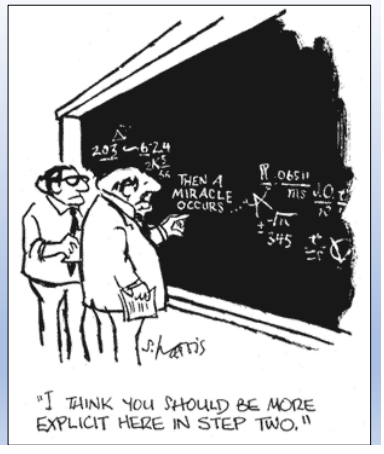
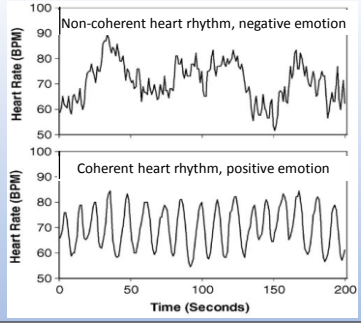
Attaining Coherence: HRV Biofeedback




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

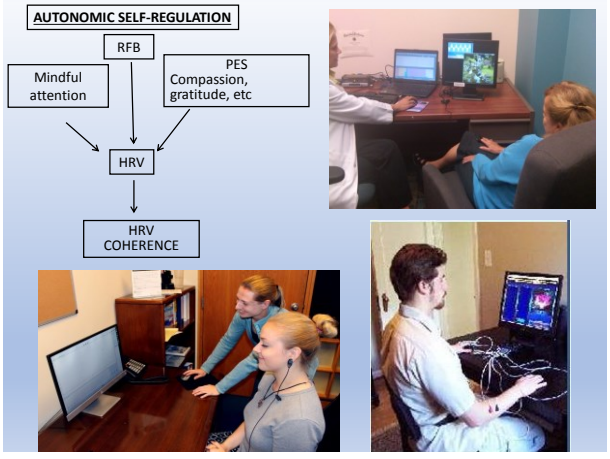
Three components of Autonomic Self-Regulation a

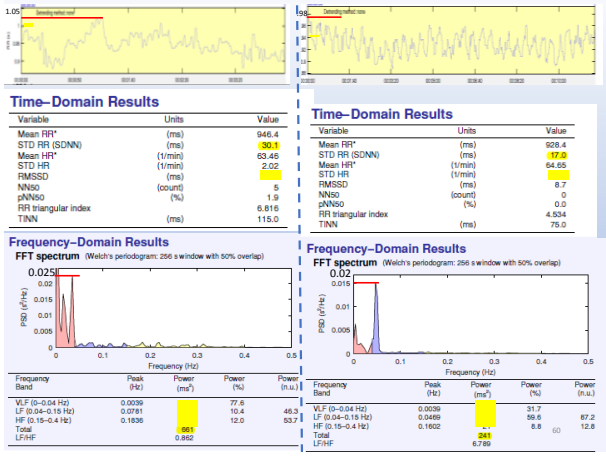
1. HRV Biofeedback = resonant frequency breathing
2. Mindful attention
3. Positive emotional state

## 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
- Positive emotional state (PES). Occupy the mind during the HRVB session with thoughts of compassion (including self-compassion), gratitude, appreciation, etc.

'COHERENCE'



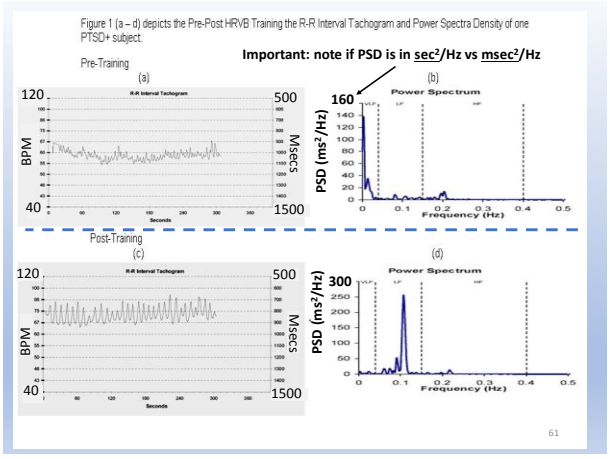
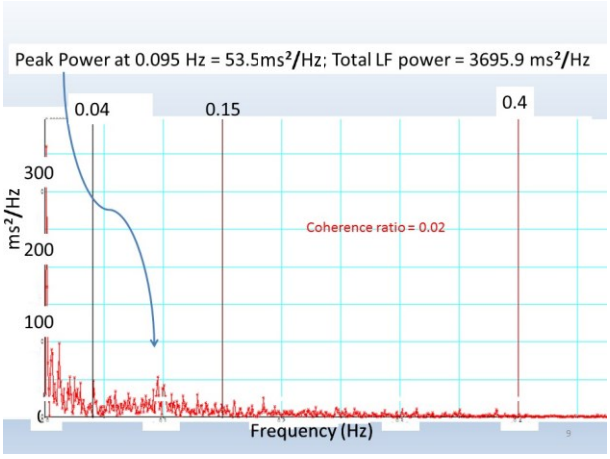
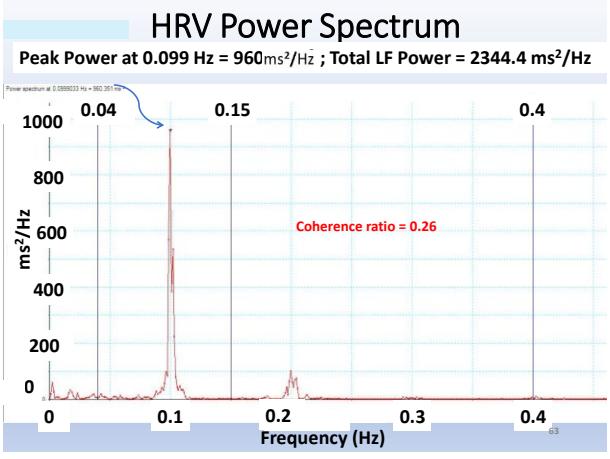
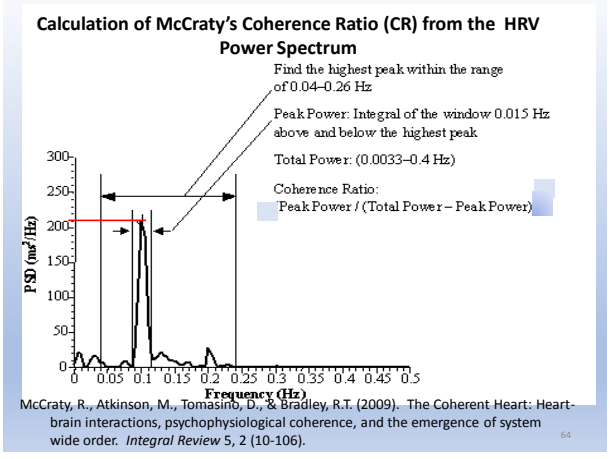


Figure 1 (a – d) depicts the Pre-Post HRVB Training the R-R Interval Tachogram and Power Spectra Density of one PTSD+ subject.
Pre-Training
Important: note if PSD is in sec²/Hz vs msec²/Hz
(a)
(b)
R-R Interval Tachogram
Power Spectrum
BPM
Msecs
PSD (ms²/Hz)
Frequency (Hz)
Seconds
Post-Training
(c)
(d)
120
40
500
1500
160
300
0.1
0.2
0.3
0.4
0.5
61


Peak Power at 0.095 Hz = 53.5ms²/Hz; Total LF power = 3695.9 ms²/Hz
0.04
0.15
0.4
300
200
100
ms²/Hz
Coherence ratio = 0.02
Frequency (Hz)
9


HRV Power Spectrum
Peak Power at 0.099 Hz = 960ms²/Hz ; Total LF Power = 2344.4 ms²/Hz
0.04
0.15
0.4
1000
800
600
400
200
0
ms²/Hz
Coherence ratio = 0.26
0
0.1
0.2
0.3
0.4
Frequency (Hz)
63


Calculation of McCraty's Coherence Ratio (CR) from the HRV Power Spectrum
Find the highest peak within the range of 0.04–0.26 Hz
Peak Power: Integral of the window 0.015 Hz above and below the highest peak
Total Power: (0.0033–0.4 Hz)
Coherence Ratio:
Peak Power / (Total Power – Peak Power)
PSD (ms²/Hz)
Frequency (Hz)
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).
64

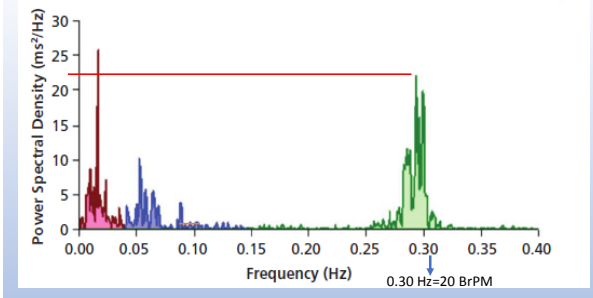
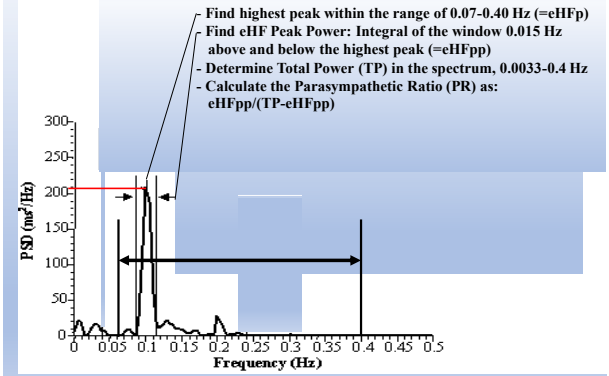



Figure 3 A typical heart rate variability (HRV) recording over a 15-minute period during resting conditions in a healthy individual

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**



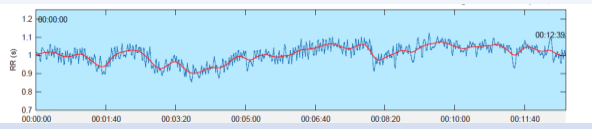

HRV(B) Case Data

Ginsberg, J. P., Berry, M. E., & Powell, D. A. (2010). Cardiac coherence and posttraumatic stress disorder in combat veterans. *Alternative Therapies in Health & Medicine*, *16*(4).

Berry, M. E., Chapple, I. T., Ginsberg, J. P., Gleichauf, K. J., Meyer, J. A., & Nagpal, M. L. (2014). Non-pharmacological intervention for chronic pain in veterans: a pilot study of heart rate variability biofeedback. *Global advances in health and medicine*, *3*(2), 28-33.

Dorn VA Medical Center
Columbia, SC

**PTSD 2 Pre-**

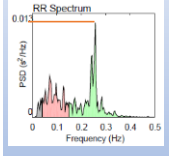



**Time-Domain Results**

| 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 |

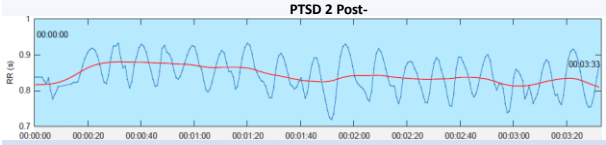
**Frequency-Domain Results** (FFT spectrum)

| 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-**

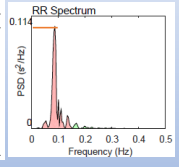



**Time-Domain Results**

| 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 |

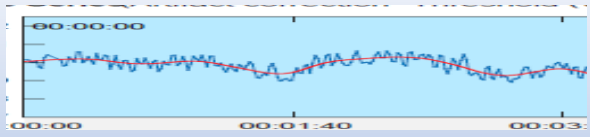
**Frequency-Domain Results** (FFT spectrum)

| 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) | - | | |

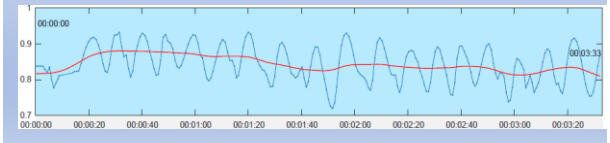



| Peak (0.04-0.26 Hz) | Peak Power | Total Power | CR |
|---|---|---|---|
| 0.09 | 1769.8 | 2229.3 | 0.86 |
| **Peak (0.07-0.40 Hz)** | **Peak Power** | **Total Power** | **PR** |
| 0.09 | 1769.8 | 2229.3 | 0.86 |

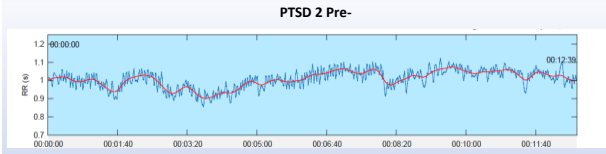
**PTSD 2 Pre-**




**PTSD 2 Post-**




**PTSD 2 Pre-**

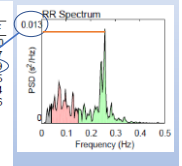



**Time-Domain Results**

| Variable | Units | Value |
|---|---|---|
| Mean RR* | (ms) | 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)

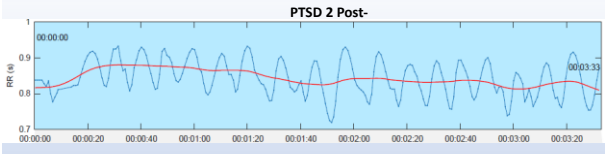
| Variable | Units | VLF | LF | HF |
|---|---|---|---|---|
| Frequency band | (Hz) | 0.00-0.04 | 0.04-0.15 | 0.15-0.40 |
| Peak frequency | (Hz) | 0.040 | 0.070 | 0.257 |
| Power | ($ms^2$) | 33 | 264 | 359 |
| Power | (log) | 3.507 | 5.575 | 5.885 |
| Power | (%) | 5.08 | 40.16 | 54.74 |
| Power | (n.u.)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

**Keys**
**eHFpp>LFpp**
**RMSSD>SDNN**

**PTSD 2 Post-**



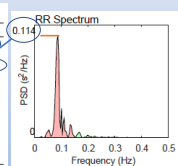

**Time-Domain Results**

| 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) | - | | |

+1812
- 214
+1572
4x

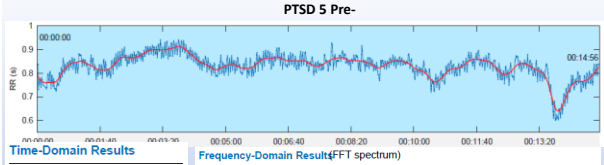



+11
+17.3
- 4.2

| 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 |

**Keys**
**eHFpp=LFpp**
**SDNN>RMSSD**

**PTSD 5 Pre-**

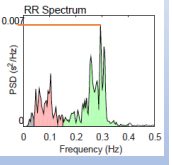


**Time-Domain Results**

| 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 |

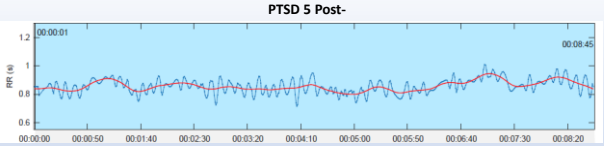
**Frequency-Domain Results** (FFT spectrum)

| 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-**

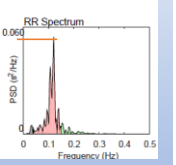


**Time-Domain Results**

| 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 |

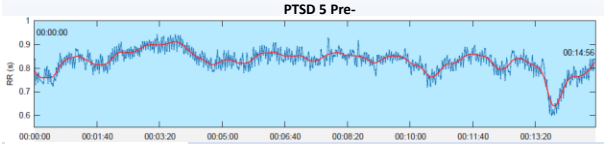
**Frequency-Domain Results** (FFT spectrum)

| 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-**

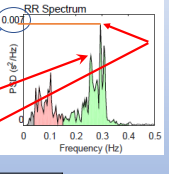


**Time-Domain Results**

| 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)

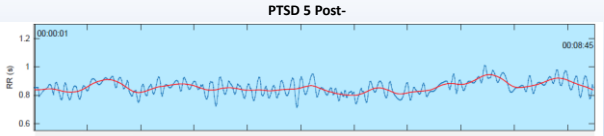
| Variable | Units | VLF | LF | HF |
|---|---|---|---|---|
| Frequency band | (Hz) | 0.00-0.04 | 0.04-0.15 | 0.15-0.40 |
| Peak frequency | (Hz) | 0.033 | 0.103 | 0.293 |
| Power | ($ms^2$) | 11 | 134 | 284 |
| Power | (log) | 2.439 | 4.895 | 5.647 |
| Power | (%) | 2.67 | 31.16 | 66.10 |
| Power | (n.u.)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

**Keys**
eHFpp>LFpp
RMSSD>SDNN

**PTSD 5 Post-**

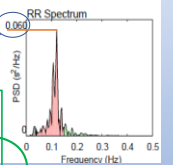


**Time-Domain Results**

| 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) | - | | |



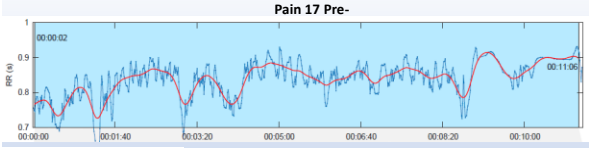

+1094
- 131
+1001
4x, 19x,

- 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 |

**Keys**
eHFpp=LFpp
SDNN>RMSSD

**Pain 17 Pre-**

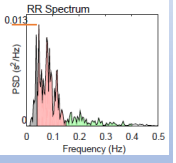


**Time-Domain Results**

| 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 |

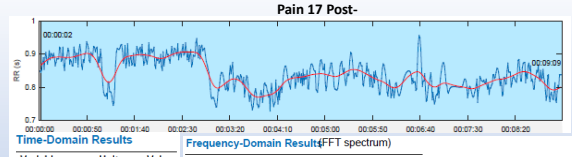
**Frequency-Domain Results** (FFT spectrum)

| 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-**

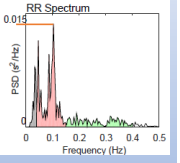


**Time-Domain Results**

| 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 |

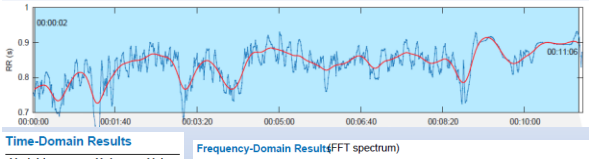
**Frequency-Domain Results** (FFT spectrum)

| 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-**

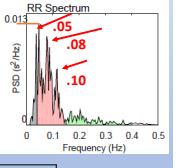


**Time-Domain Results**

| 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)

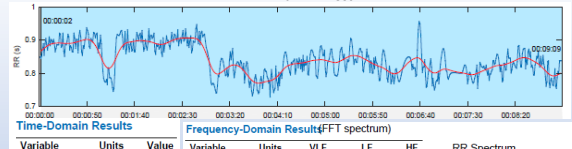
| Variable | Units | VLF | LF | HF |
|---|---|---|---|---|
| Frequency band | (Hz) | 0.00-0.04 | 0.04-0.15 | 0.15-0.40 |
| Peak frequency | (Hz) | 0.037 | 0.047 | 0.203 |
| Power | ($ms^2$) | 83 | 489 | 119 |
| Power | (log) | 4.417 | 6.193 | 4.775 |
| Power | (%) | 11.99 | 70.80 | 17.15 |
| Power |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

**Keys**
**LFpp>eHFpp**
**SDNN>RMSSD**

**Pain 17 Post-**

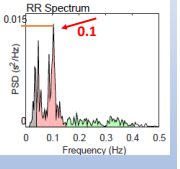


**Time-Domain Results**

| 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) | - | | |




0
- 0.6
+ 3.7

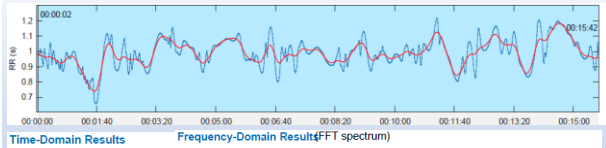
-58.8

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 |

**Keys**
**eHFpp>LFpp**
**SDNN>RMSSD**

**Pain 16 Pre-**

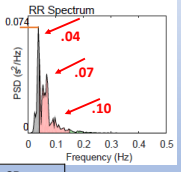



**Time-Domain Results**

| 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 |

**Keys**
**LFpp>eHFpp**
**SDNN>RMSSD**

Summary: 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)

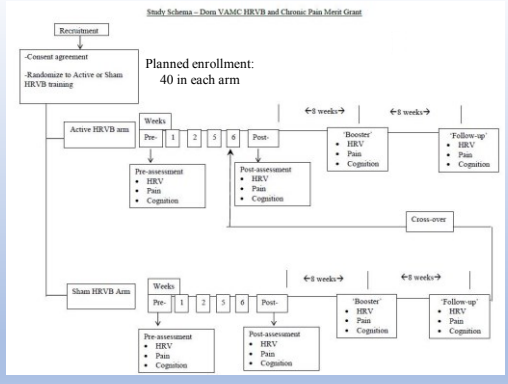
eHFpp≥LFpp and SDNN>RMSSD: PNS dominant (PR gt ~0.4)

PR and CR are useful for comparing intra-individual change

What are the predictive utilities of the CR *vs* PR?

Ginsberg, J., Arave, J., Muni, P., Fogo, W., Nagpal, M., Malphrus, R., . . . Gleichauf, K (2018) HRV Mediates Sensitized Chronic Pain Symptom Cluster (poster presentation at The Association of Applied Psychophysiology and Biofeedback. 49th Annual Scientific Meeting. April 13, Orlando, FL)

| | | |
|---|---|---|
| PI: **Ginsberg, Jay** | Title: HRV Biofeedback in Pain Patients: Pilot Intervention for Pain, Fatigue & Sleep | |
| Received: 09/08/2014 | FOA: CX14-006 | Council: 01/2015 |
| Competition ID: | FOA Title: CSR&D MERIT REVIEW AWARD FOR CLINICAL TRIALS | |
| **1 I01 CX001182-01A1** | Dual: | Accession Number: 3732973 |
| IPF: 10018661 | Organization: VETERANS HEALTH ADMINISTRATION | |
| Former Number: | Department: Mental Health | |
| IRG/SRG: CLNA | AIDS: N | Expedited: N |
| Subtotal Direct Costs (excludes consortium F&A)<br>Year 1: 198,078<br>Year 2: 149,913<br>Year 3: 149,932<br>Year 4: 149,935 | Animals: N<br>Humans: Y<br>Clinical Trial: N<br>Current HS Code: 20<br>HESC: N | New Investigator: N<br>Early Stage Investigator: N |
| *Senior/Key Personnel:* | *Organization:* | *Role Category:* |
| Jay Ginsberg Ph.D | WJB Dorn VA Medical Center | PD/PI |
| James Burch Ph.D | University of South Carolina | MPI |
| Alexander McLain Ph.D | University of South Carolina | Co-Investigator |
| Raouf Gharbo Ph.D | Hampton Roads Riverside Regional Medical Center | Consultant |
| James Hebert ScD | University of South Carolina | Consultant |
| Francis Spinale M.D. | WJB Dorn VA Medical Center | Consultant |
| Tarek Sobeih Ph.D | Dorn Research Institute | Other Professional-Recruitment Coordinator |




**Number of veterans screened or prescreened: 220**
**Number of veterans enrolled: 30**
**Number of veterans completed: 27**

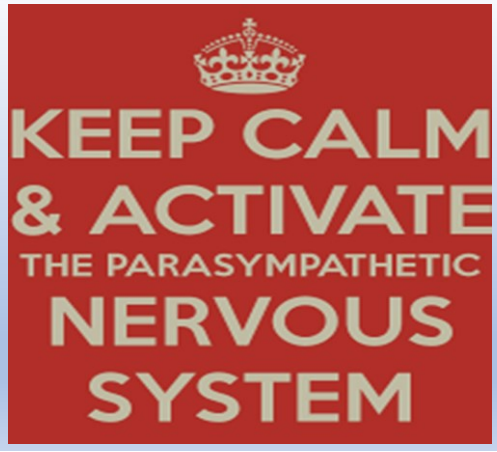
## Symptom Cluster Assessment

- ***STRESS***
  - ***Perceived Stress Scale (PSS)***
- ***DEPRESSION***
  - ***Beck Depression Inventory–II (BDI-II0***
- ***FATIGUE***
  - ***Multidimensional Fatigue Inventory (MFI)***
- ***PAIN***
  - ***Brief Pain Inventory (BPI)***
- ***SLEEP***
  - ***Insomnia Symptom Questionnaire***
- ***CATASTROPHIZING***
  - ***Pain Catastrophizing Scale (PCS)***

- ***COGNITION***
  - ***Psychomotor Vigilance Test (PVT)***
  - ***Paced Auditory Serial Addition Test (PASAT)***

| 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<br>Rho (Diff PR with Diff Outcome) vs Rho (Diff CR with Diff Outcome)<br>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 | | | |

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REFERENCES AND READINGS


Readings on RSA: Respiration and Vagal Tone

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

Grossman P. (2017). Comment on heart rate variability and cardiac vagal tone in psychophysiological research – recommendations for experiment planning, data analysis, and data reporting. *Front Psychol* 8:213. doi:10.3389/fpsyg.2017.00213

Grossman, P., & Kollai, M. (1993). Respiratory sinus arrhythmia, cardiac vagal tone, and respiration: Within-and between-individual relations. *Psychophysiology*, *30*(5), 486-495.

Grossman, P., & Taylor, E. W. (2007). Toward understanding respiratory sinus arrhythmia: relations to cardiac vagal tone, evolution and biobehavioral functions. *Biological psychology*, *74*(2), 263-285.

Laborde, S., Mosley, E., & Thayer, J. F. (2017). Heart rate variability and cardiac vagal tone in psychophysiological research–recommendations for experiment planning, data analysis, and data reporting. *Frontiers in psychology*, *8*, 213.

Shaffer, F., & Ginsberg, J. P. (2017). An overview of heart rate variability metrics and norms. *Frontiers in public health*, *5*, 258.

Readings on Traube-Herring and Mayer Waves

Halliburton, W.D. (1919). Traube waves and Mayer waves. King's College, London, https://physoc.onlinelibrary.wiley.com/doi/pdf/10.1113/expphysiol.1919.sp000262

Visscher, M., Rupp, A., and Scott, F.H. (1924). The respiratory wave in arterial blood pressure. Department of Physiology, University of Minnesota https://www.physiology.org/doi/pdf/10.1152/ajplegacy.1924.70.3.586

Davidson, N. S., Goldner, S., & McCloskey, D. I. (1976). Respiratory modulation of baroreceptor and chemoreceptor reflexes affecting heart rate and cardiac vagal efferent nerve activity. *The Journal of physiology*, *259*(2), 523-530. https://physoc.onlinelibrary.wiley.com/doi/pdf/10.1113/jphysiol.1976.sp011480

Eckberg, D. L., & Sleight, P. (1992). *Human baroreflexes in health and disease* (No. 43). Oxford University Press.

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).

Bernardi, L., Porta, C., Gabutti, A., Spicuzza, L., & Sleight, P. (2001). Modulatory effects of respiration. *Autonomic neuroscience*, *90*(1-2), 47-56.

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.

Julien, C. (2006). The enigma of Mayer waves: facts and models. *Cardiovascular research*, *70*(1), 12-21.

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.

<u>Readings on Baroreflex: RFB and Coherence</u>

Luecken, L. J., & Gallo, L. C. (2008). *Handbook of physiological research methods in health psychology*. Sage.

Vaschillo, E., Lehrer, P., Rishe, N., & Konstantinov, M. (2002). Heart rate variability biofeedback as a method for assessing baroreflex function: a preliminary study of resonance in the cardiovascular system. *Applied Psychophysiology and Biofeedback*, *27*(1), 1-27.

Vaschillo, E. G., Vaschillo, B., Buckman, J. F., Pandina, R. J., & Bates, M. E. (2010, January). The investigation and clinical significance of resonance in the heart rate and vascular tone baroreflexes. In *International Joint Conference on Biomedical Engineering Systems and Technologies* (pp. 224-237). Springer, Berlin, Heidelberg.

Vaschillo, E., Vaschillo, B., & Lehrer, P. (2004). Heartbeat synchronizes with respiratory rhythm only under specific circumstances. *Chest*, *126*(4), 1385-1386; author reply 1386-1387.

Yasuma, F., & Hayano, J.I. (2004) Respiratory snus arrhythmia: why does the heart beat synchronize with respiratory rhythm? *Chest 125*:683-690.