# HEART RATE VARIABILITY & ATHLETE MONITORING

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Human Performance & Sport Physiology Laboratory
POWERFUL IDEAS | PROVEN RESULTS

## *Overview*

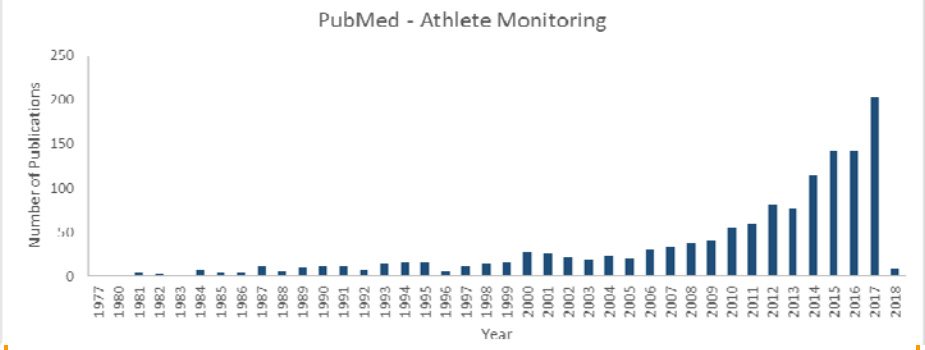
- Athlete monitoring
- Physiological aspects of HRV
- HRV measurement fundamentals
- Relevant Athletic Training HRV Literature
- Application of HRV to health, performance, and injury in baseball pitchers and firefighters

## *Athlete Monitoring*

- What is athlete monitoring?
- Monitoring what?
  - Training load, performance, injury
- For what purpose?
  - Reduce injury, improve recovery, optimize performance, avoid fatigue, minimize risk for overreaching and overtraining
- How?
  - Questionnaires, RPE, fatigue scales, heart rate, bar velocity, workload quantification, movement screens
  - Wearable technology

## *Athlete Monitoring*

- Is this a new concept or practice?
  - Yes……and no….and Why now?



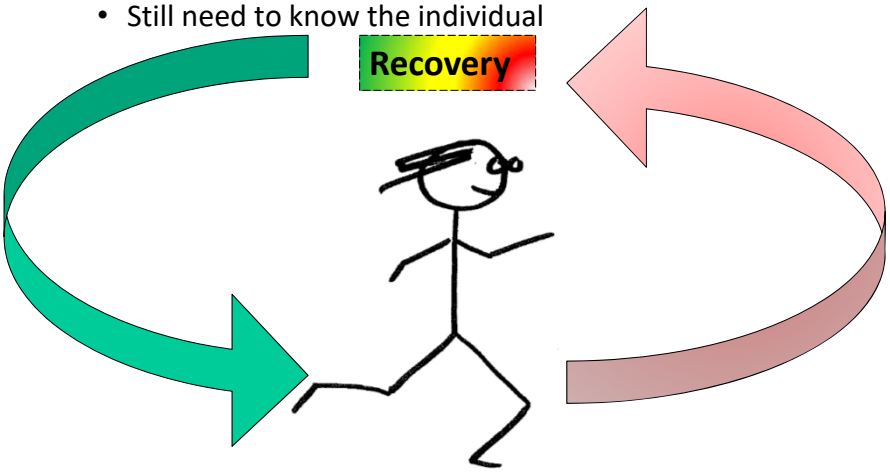

Bourdon et al (2017). Monitoring Athlete Training Loads: Consensus Statement. *International Journal of Sports Physiology and Performance.*

Gabbett et al (2017). The athlete monitoring cycle: a practical guide to interpreting and applying training monitoring data. *British Journal of Sports Medicine.*

Windt & Gabbett (2016). How do training and competition workloads relate to injury? The workload—injury aetiology model. *British Journal of Sports Medicine.*

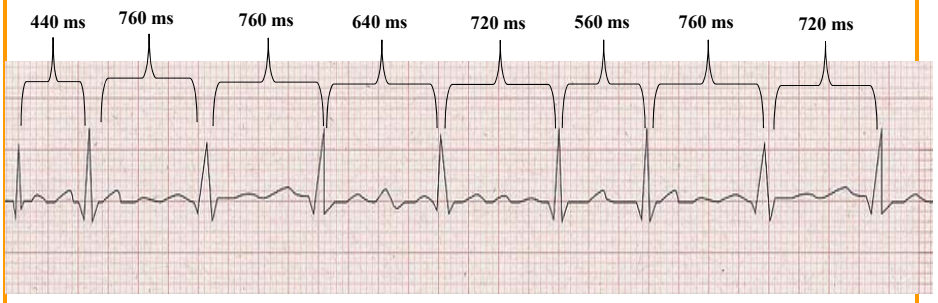
## Athlete Monitoring

- Growth of Sport Sciences
  - Dashboard of metrics
  - What are the inputs and outputs
  - Still need to know the individual




## What is HRV?

- Heart Rate
  - A simple average number of beats in a given time period
  - In figure below, 9 QRS complexes in 6 seconds * 10 = AVERAGE HR of 90 bpm
- Heart Rate Variability (HRV)
  - Quantifies the time (ms) between R-waves from consecutive QRS complexes
  - Inter-beat interval (IBI) or RR Interval (RR or RRi)



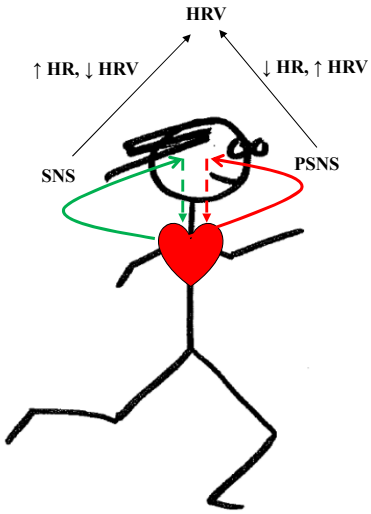

https://www.wikihow.com/Calculate-Heart-Rate-from-ECG

## HRV & The Autonomic Nervous System

- Nervous System
  - Central nervous system
    - Brain, spinal cord
  - Peripheral nervous system
    - Afferent division (sensory)
      - Somatic, visceral, special
    - Efferent division
      - Sympathetic (SNS)
      - Parasympathetic (PSNS)
      - Enteric
- ANS Features
  - Blood pressure, breathing, heart rate
  - SNS and PSNS constantly mediating essential functions to optimally match function with task demands

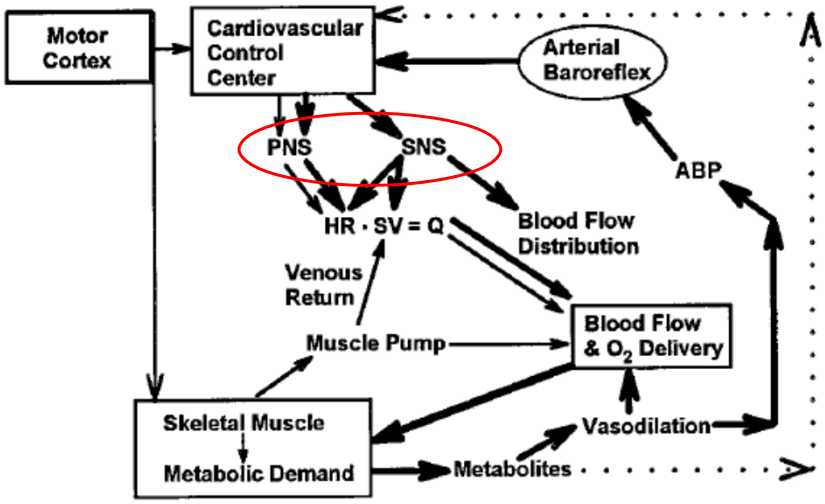
## HRV & The Autonomic Nervous System

- Autonomic Nervous System (ANS) influences cardiac control via two branches
  - Parasympathetic (PSNS)
    - Vagal Nerve input on the sinoatrial (SA) node
    - Resting State
    - Vagal Tone
    - Increases variability
  - Sympathetic (SNS)
    - Sympathetic nerve endings on myocardium
    - Fight or Flight
    - Decreases variability
- Autonomic Balance



## Multi-System Influence

Hughson et al (2001). Regulation of Oxygen Consumption at the Onset of Exercise.
*Exerc. Sport Sci. Rev.,* 29:129-133




## Multi-System Influence

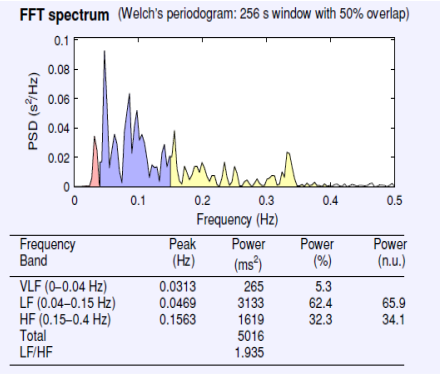
- Remember that HRV will have a multi system influence
  - Breathing
  - Digestion
  - Myocardial integrity
  - Blood pressure
  - Stress, anxiety, excitement
  - Fitness

## Quantifying HRV

- HRV is quantified with either time domain or frequency indices
- Time domain
  - SDNN
    - standard deviation of all NN Intervals (i.e. RRi)
  - RMSSD
    - square root of the mean of the sum of squares of differences between NN intervals
  - LnRMSSD
    - natural log of RMSSD
  - NN50
    - Number of pairs of adjacent NN intervals differing by more than 50ms (can be converted to pNN50)
- In general, Time Domain indices
  - Simple to calculate
  - Greater confidence with shorter time samples
  - Lower RMSSD would suggest less parasympathetic influence or greater sympathetic influence
  - Vagal Tone

## Quantifying HRV

- Frequency HRV Indices
  - Low Frequency (LF)
    - 0.04 to 0.15 Hz
  - High Frequency (HF)
    - 0.15 to 0.4 Hz
  - LF/HF
    - Ratio of the LF to HF
- In general, Frequency Domain indices
  - More difficult to calculate
  - May not be as stable during short time samples
  - Lower frequency values associated with less parasympathetic / greater sympathetic influence




| Frequency Band | Peak (Hz) | Power (ms²) | Power (%) | Power (n.u.) |
|---|---|---|---|---|
| VLF (0–0.04 Hz) | 0.0313 | 265 | 5.3 | |
| LF (0.04–0.15 Hz) | 0.0469 | 3133 | 62.4 | 65.9 |
| HF (0.15–0.4 Hz) | 0.1563 | 1619 | 32.3 | 34.1 |
| Total | | 5016 | | |
| LF/HF | | 1.935 | | |

European Guidelines for Heart Rate Variability, *European Heart Journal* (1996) 17, 354–381.

## Functional Relationship Between HR and HRV

**Heart Rate**

**HRV**

PNS

SNS

***Avoid the On/Off Switch Analogy***

## Measurement Tools

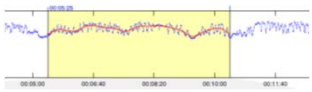
- Chest Strap and Watch Devices
  - Polar, Garmin
- Wrist Based Devices
  - TomTom Spark3, FitBit, LifeTrak Zoom HRV (arm, wrist, ankle)
- Smart Garments and Straps
  - Hexoskin
  - Zephyr/Medtronic
- Regardless of device, questions to consider include
  - Is this for individual or group/team measurements?
  - Does the device require a resting, non exercise position and state?
  - Is it really measuring HRV or is the device measuring pulse rate variability?
  - How are ectopic beats managed?
  - Do you need/have access to the raw data?

## *Measurement Considerations*

- Position
  - Supine vs. seated vs. standing vs. exercise
- Breathing
  - Paced vs. non-paced
- Time of Day
  - Upon waking, morning, mid-day
- Sample length
  - ≤1 min, 3 min, **5 mins**, >5mins
- Environment (Ecologically valid vs. Controlled Lab)
  - Quiet, music, mobile devices, talking, sleeping
- Methods references
  - Shaffer, F., & Ginsberg, J. P. (2017). An Overview of Heart Rate Variability Metrics and Norms. *Frontiers in Public Health*, 5, 258.
  - Ernst, G. (2017). Hidden Signals—The History and Methods of Heart Rate Variability. *Frontiers in Public Health*, 5, 265.
  - Bellenger, C.R., et al. (2016). Monitoring Athletic Training Status Through Autonomic Heart Rate Regulation: A Systematic Review and Meta-Analysis. *Sports Med,* 46, 1461.

## *Sample Data Collection Procedures*

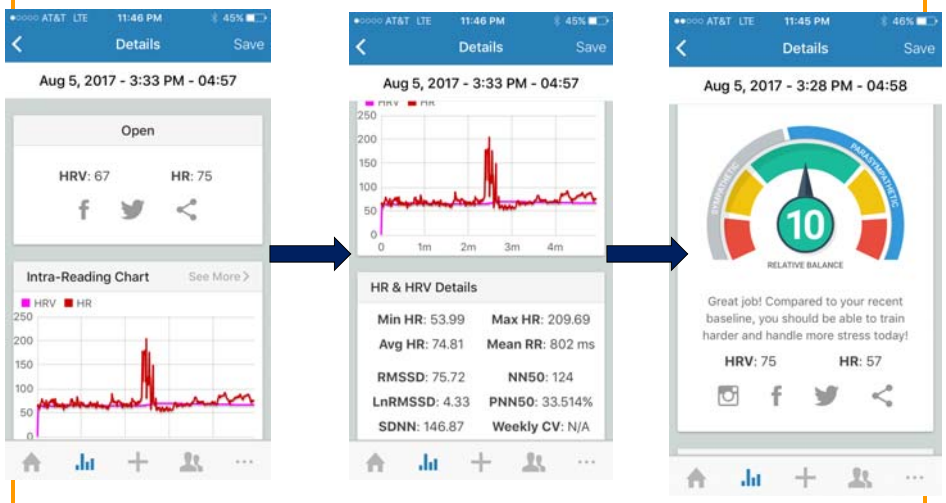
- 5 minute resting sample
  - Extract the RR file
  - Send RR file to Kubios HRV program
  - Clean and filter data
  - Analyze for time and frequency domain metrics
- Then what?
  - Do you have a "dashboard" to present the data, make day to day comparisons, evaluate trends
- The advantages of available programs
  - Omnisense (Zephyr/Medtronic)
  - Polar Flow
  - Available apps like Elite HRV



**Time–Domain Results**

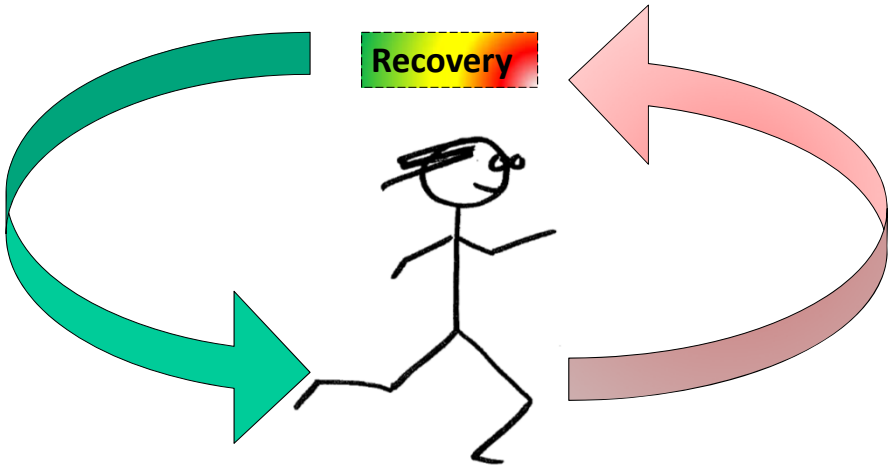
| Variable | Units | Value |
|---|---|---|
| Mean RR* | (ms) | 1177.7 |
| STD RR (SDNN) | (ms) | 158.5 |
| Mean HR* | (1/min) | 52.96 |
| STD HR | (1/min) | 10.32 |
| RMSSD | (ms) | 168.5 |

## *Sample Analysis Approach*



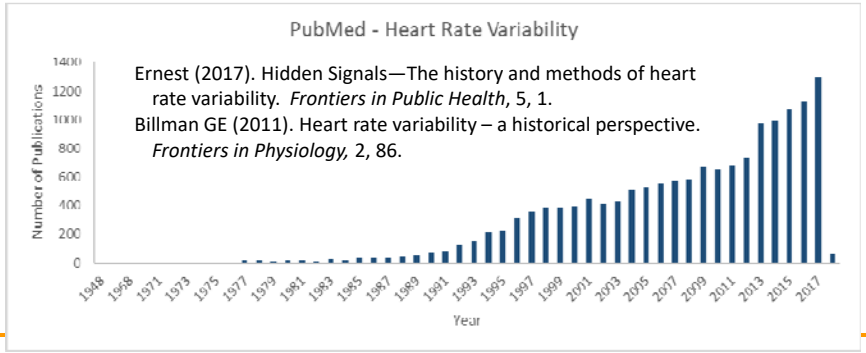

## *Before We Move On….*
## *Methodological Questions?*

# Applications of HRV to Athletic Training




## HRV Literature

- According to PubMed.com
  - The first published HRV paper was in 1925
  - From 1925/1948 to 2007, 10,581 papers were published
  - More papers (11,628) have been in the last 9 years than the first 76 years of HRV history
  - Yet, the literature related to HRV and other areas is just beginning to grow: sport (n=1,514), exercise (n=2,894), injury (n=520), concussion (n=22)



## HRV Applications

**Cardiovascular**

- Singh et al (1998). Reduced Heart Rate Variability and New-Onset Hypertension Insights Into Pathogenesis of Hypertension: The Framingham Heart Study. *Hypertension*, 32, 293
  - Lower HRV associated with greater risk of hypertension
- Lioa (2002). Lower Heart Rate Variability Is Associated With the Development of Coronary Heart Disease in Individuals With Diabetes. *Diabetes,* 51, 352.
- Routledge (2010). *Canadian Journal of Cardiology*
  - ↑ in HRV following exercise therapy (cardiovascular, diabetes, healthy)
- Besnier et al (2017). Exercise training-induced modification in autonomic nervous system: An update for cardiac patients. *Annals of Physical and Rehabilitation Medicine*, 60, 27.
  - "The sports science concept of the heart rate variability (HRV)-vagal index used to manage exercise sessions (for a goal of performance) could be implemented in cardiac rehabilitation to improve cardiovascular fitness and autonomic nervous system function."

## HRV Applications

**Concussion**

- Goldstein (1998). *American Journal of Physiology*
  - Following head trauma, HRV has been observed to be significantly lower than non-injured control subjects and inversely associated with long-term outcomes
- La Fountaine et al. (2009). *Autonomic Neuroscience: Basic and Clinical*
  - Decrease in HRV in concussed athletes
- Lagos et al. (2012). Heart rate variability biofeedback for postconcussion syndrome: Implications for treatment. *Biofeedback*, 4, 150.
  - Improvement in autonomic balance will result in decrease in post concussion S&S
- Conder and Conder (2017). Heart rate variability interventions for concussion and rehabilitation. *Frontiers in Physiology,* 5, 890.
  - Higher levels of baseline HRV associated with greater performance on complex neurocognitive tasks of
- Senthinathan et al. (2017). Heart rate variability of athletes across concussion recovery milestones: A preliminary study. *Clin J Sport Med,* 27, 288.
  - ANS dysfunction identified via HRV in athletes with concussion, even beyond return to play.

## HRV Applications

**Exercise Prescription**

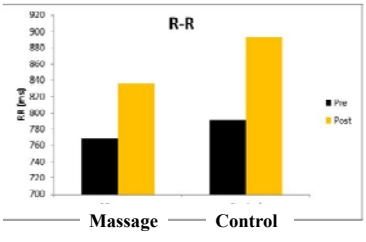
- Arai et al (1989). *American Journal of Physiology*
  - Progressive withdrawal of PSNS with progressive exercise intensity
- Kiviniemi et al (2010). *Medicine & Science in Sports and Exercise*
  - HRV is a beneficial tool in exercise prescription

**Training and Athletes**

- Hellard (2011). *Medicine & Science in Sports and Exercise*
  - ↑ in HF component at rest in swimmers associated with onset and presence of viral illness
- Chen (2011). *Journal of Strength & Conditioning Research*
  - Pre-competition anxiety identified in BMX athletes by ↑ in LF
- Di Michele et al (2012). *Journal of Strength & Conditioning Research*
  - HRV can be used to identify anaerobic threshold
- Kiviniemi et al (2014). Cardiac autonomic function and high-intensity interval training in middle-age men. *Med Sci Sports Exerc*
  - HIIT was a more effective short-term strategy to increase R-R interval variability than aerobic training

## Treatment Modalities

- **The Influence of Skeletal Muscle Massage on Heart Rate Variability**
  - Decrease ($p<0.05$) in HR from pre to post for the massage (80 ± 11 bpm vs. 74 ± 12 bpm) and control group (77 ± 9 bpm vs. 68 ± 9 bpm).
  - Increase ($p<0.05$) in RR from pre to post for the massage (768.7 ± 108 ms vs. 836.5 ± 152 ms) and control group (792 ± 102 ms vs. 893.4 ± 130 ms).
- Autonomic changes following a short-duration, skeletal muscle massage may not necessarily be due to the actual massage, but more related to the time spent in rest or preference for massage.


Ebersole, Conlon, Bartz, Meyer (2012). ACSM

## *HRV & Injury*

Inflammation

Cooper et al. (2015). *Brain Behav Immun*

- Heart Rate Variability Predicts Levels of Inflammatory Markers: Evidence for the Vagal Anti-Inflammatory Pathway

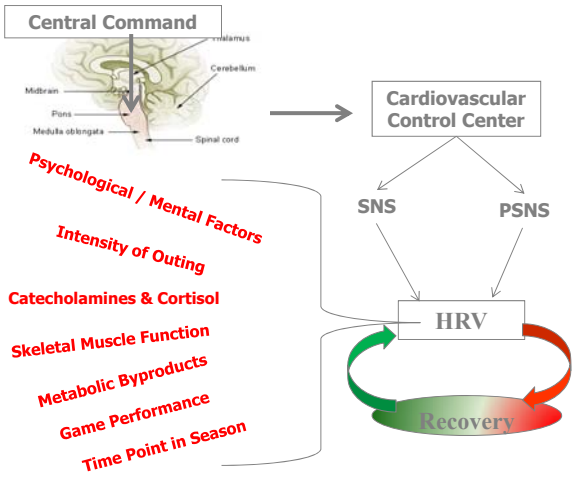
Injury

- Gisselman et al (2016). Musculoskeletal overuse injuries & heart rate variability: Is there a link? *Medical Hypotheses*, 87, 1-7.
  - Abnormal somatic tissue response to accumulating trauma may modulate ANS activity at the level of HRV.

## *Using HRV to Answer Health, Performance, and Injury Questions in Baseball Pitchers & Firefighters*

## Initial Recovery Model

- 2011 Model




NEW YORK

# The Glass Arm

**Inside the art and science (but mostly still art) of keeping pitchers from getting hurt.**

By Will Leitch Published Mar 17, 2013

Pitch counts and innings limits are probably a good idea, but no one knows exactly how much rest is necessary, Fleisig says. "Every person is different than every other person. That's humanity." The trick, he believes, is spotting when a pitcher is tired or hurting or getting him to tell you that—"human interaction," he says. Human

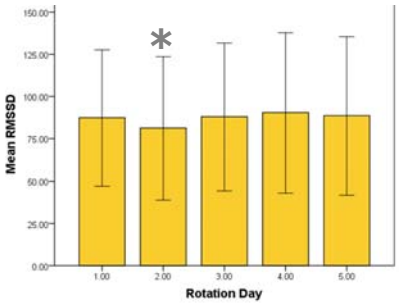
- But….how do you define fatigue?
  - In general, the only consistency in definition is the reference to "decline in performance"
  - Task dependency of fatigue emphasizes the need for ecologically valid approaches to study fatigue
  - Fatigue is a process, not a single point
  - Specific to the person

## *HRV & Baseball Pitchers*

- Data from 95 players across 4 years
- Over 11,000 days of resting HRV data
- Initially used the methods of Plews et al (2012, 2013, 2014) and Kubios
- Continuously refine process and analysis based on the data

## *Resting HRV vs Rotation Day*

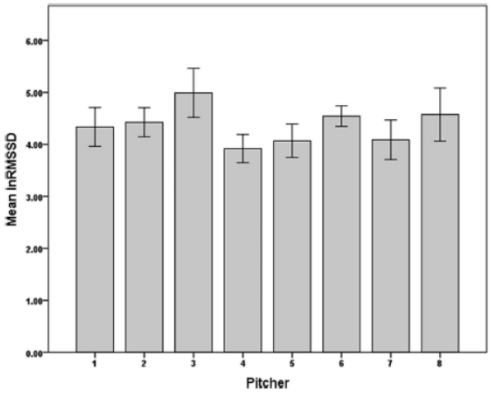
- A pitch outing may alter ANS function on day 2 and recovery should be expected by day 3.
- Increases in HRV in the weeks before the event, during the highest training loads, are likely associated with a positive performance outcome (Plews et al., 2012)




Cornell, Paxson, Caplinger, Seligman, Davis, & Ebersole (2017). Resting heart rate variability among professional baseball starting pitchers. *J Strength Cond Res* 31, 575–581.

## Group vs. Individual Data

- HRV is an individually specific biometric
- Each individual may have different "inputs" and "outputs" that account for day to day changes
- Plews et al (2013). Training Adaptation & HRV in Elite Endurance Athletes: Opening the Door to Effective Monitoring. *Sports Medicine*, 43, 773-781




Cornell, Paxson, Caplinger, Seligman, Davis, & Ebersole (2017). Resting heart rate variability among professional baseball starting pitchers. *J Strength Cond Res* 31, 575–581.

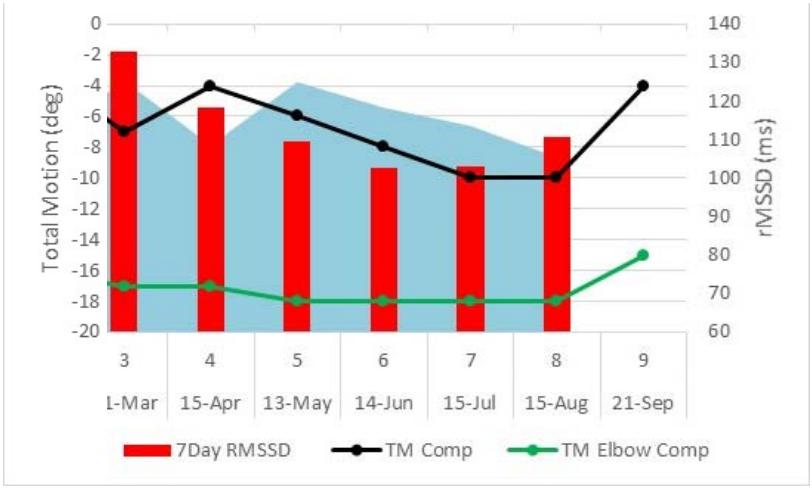
## ROM, HRV, Aggregate Data

- Exploring the model presented by Gisselman et al (2016) linking soft tissue injury to HRV
- Aggregate data reveals little relationship between HRV and ROM changes

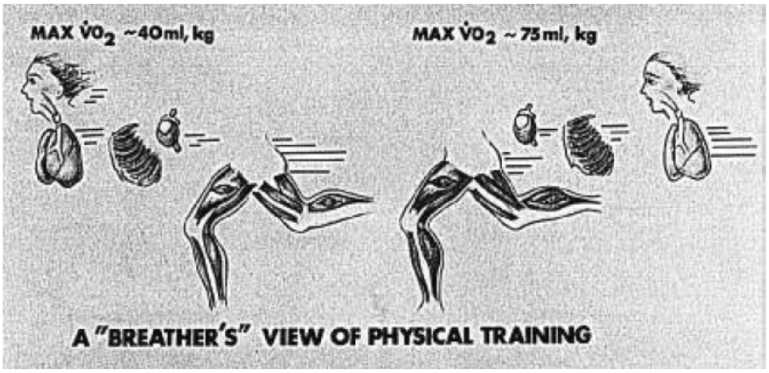
**Correlations**

| | | TM_COMP | TM_ELBOW_COMP | RMSSD_7_DAY | RMSSD_14_DAY |
|---|---|---|---|---|---|
| TM_COMP | Pearson Correlation | 1 | .402* | -.188 | -.189 |
| | Sig. (2-tailed) | | .023 | .302 | .301 |
| | N | 32 | 32 | 32 | 32 |
| TM_ELBOW_COMP | Pearson Correlation | .402* | 1 | -.009 | -.019 |
| | Sig. (2-tailed) | .023 | | .960 | .919 |
| | N | 32 | 32 | 32 | 32 |
| RMSSD_7_DAY | Pearson Correlation | -.188 | -.009 | 1 | .996** |
| | Sig. (2-tailed) | .302 | .960 | | .000 |
| | N | 32 | 32 | 32 | 32 |
| RMSSD_14_DAY | Pearson Correlation | -.189 | -.019 | .996** | 1 |
| | Sig. (2-tailed) | .301 | .919 | .000 | |
| | N | 32 | 32 | 32 | 32 |

## ROM, HRV, Individual Data




## Conditioning/Fitness Status Does Matter



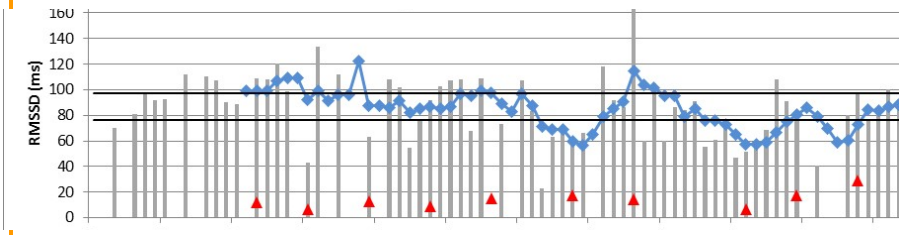

J.B. WOLFFE MEMORIAL LECTURE

**Is the lung built for exercise?**

Presented at ACSM Annual Meeting, 1985 (Published in MSSE, 1986)

## Resting HRV & Training Load

- Consecutive days of decreasing HRV can be corrected with a training load adjustment




## Re-Examination of Training Strategies?

The training-injury prevention paradox: should athletes be training smarter *and* harder?

Gabbett TJ. *Br J Sports Med* 2016;**0**:1–9.

- Gabbett suggested that physical hard training develops physical qualities which in turn protect against injuries
- In season adjustments to training load and intensity result in changes to HRV

## Firefighter Health & Performance

CO Firefighter/Medic Dies After Training Injury
OCT 31, 2016 SOURCE: FIREHOUSE.COM NEWS

NY Firefighter Dies After Completing Shift
FEB 9, 2017 SOURCE: FIREHOUSE.COM NEWS

WY Fire Chief Dies After Helping Remove Ice Jams
FEB 21, 2017 SOURCE: FIREHOUSE.COM

GA Firefighter Dies After Operating at House Fire
MAR 2, 2017

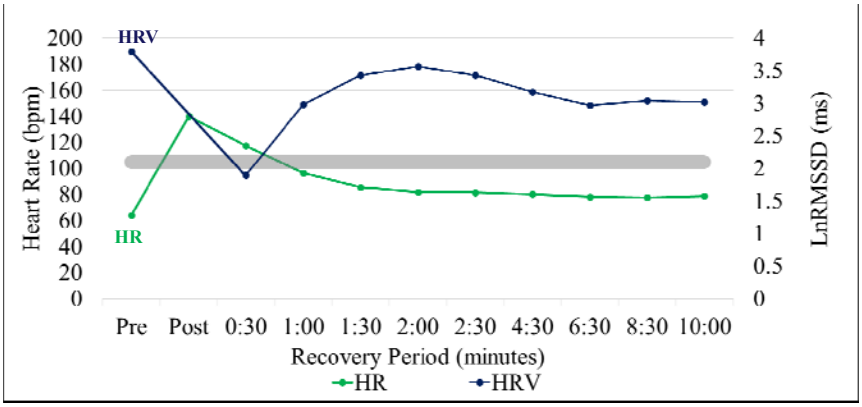
**Firefighter dies after battling flames in Watertown**
Updated: Mar 17, 2017 - 10:57 PM


AL Firefighter Dies After Completing Shift
MAR 24, 2017 SOURCE: FIREHOUSE.COM NEWS

OH Chief Dies After Completing Shift
APR 17, 2017 SOURCE: FIREHOUSE.COM NEWS

## Firefighter Health & Performance

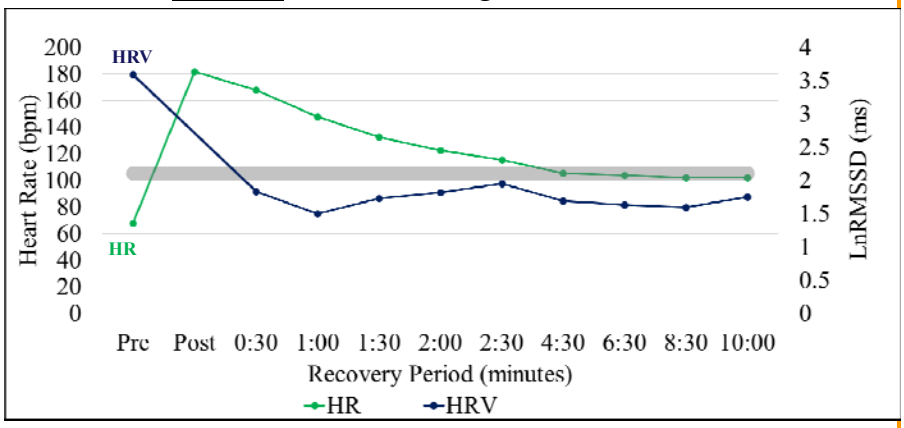
HRV After Submaximal Exercise Testing




Flees, Ebersole, Meyer, Zalewski (2017). Influence of submaximal and maximal exercise on the autonomic nervous system responses during recovery in firefighters. In Review.

## *Firefighter Health & Performance*

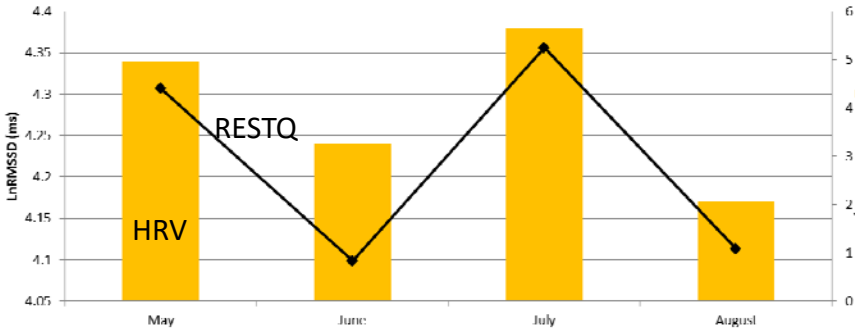
HRV After Maximal Exercise Testing




Flees, Ebersole, Meyer, Zalewski (2017). Influence of submaximal and maximal exercise on the autonomic nervous system responses during recovery in firefighters. In Review.

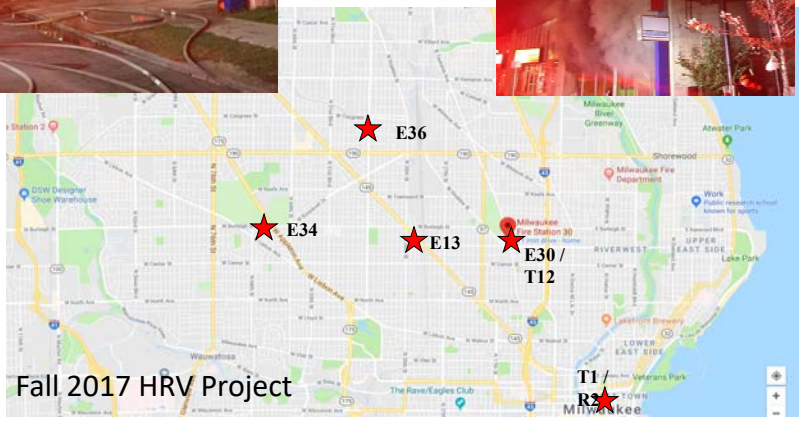
## *HRV & RESTQ*

- Monthly averages for daily HRV and weekly RESTQ scores in a firefighter. Reinforces the multi-system relationship for HRV.




Gorgas, Meyer, Ebersole (2017). Psychophysiological aspects of work load: A firefighter case study.

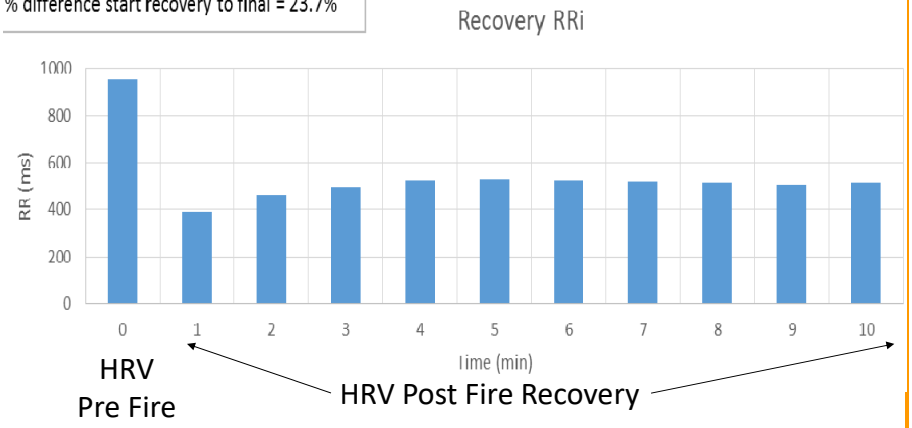
## Firefighter Health & Performance




## Firefighter Health & Performance

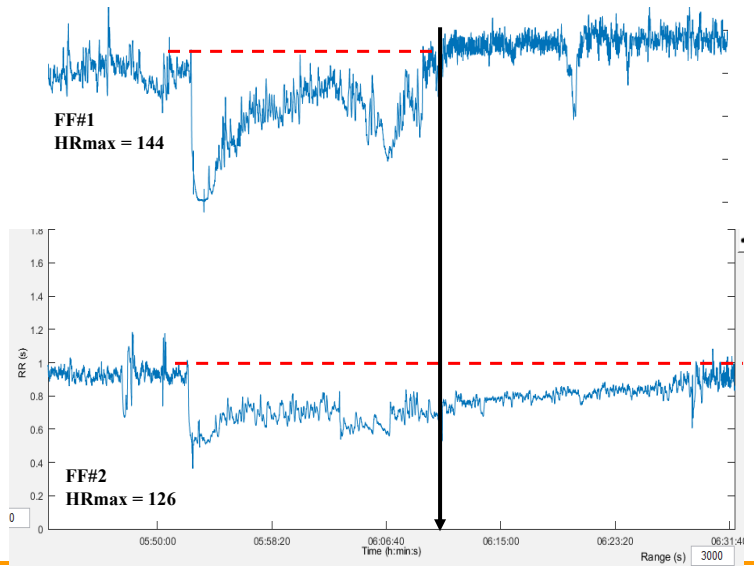
HRV response during recovery after fire

% difference rest to final = 85.3%
% difference start recovery to final = 23.7%



## *Firefighter Health & Performance*

HRV response during recovery after middle of night auto extrication




## *In Summary*

- Have clarity in your purpose for using HRV as a metric.
- Understand HRV is not an exact science and will not tell you exactly what is the mechanism of a change.
- HRV is a conversation starter that helps guide you in the right direction.
- Be aware of how an app or product is analyzing the data, how noise is managed.
- Use caution with aggregate data.

## *Acknowledgements*


- Milwaukee Brewers Baseball Club
- Milwaukee Fire Department, North Shore Fire Department
- UW-Milwaukee
  - Human Performance & Sport Physiology Lab
  - Laboratory for Sport Psychology & Performance Excellence



# THANK YOU!

**EBERSOLE@UWM.EDU**

Human Performance & Sport Physiology Laboratory
POWERFUL IDEAS | PROVEN RESULTS |