Heart rate variability and altitude: implications for training

Julien V Brugniaux

Department of Physiology and Biophysics
University of Calgary
Alberta, Canada

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University Paris 13

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**Oxygen transport**

- Pulmonary ventilation
- Alveolo-capillary transfer of oxygen
- Transport of oxygen by the blood
- Diffusion of oxygen to the tissues
- Aerobic production of energy

**Cardiovascular function**

**Hormonal control** (long-term regulation)
- Epinephrine
- Norepinephrine

**Nervous control** (short-term regulation)
- Sympathetic
- Parasympathetic
**Autonomic nervous system**

- Parasympathetic (ParaS)
- Sympathetic (S)

**HRV - Origin**

- Blood pressure variations during the respiratory cycle induces variability into HR

*respiratory sinus arrhythmia*

Mean R-R interval variability
What is HRV?

The duration between 2 heart beats (RR interval in msec) is not constant

HRV - Analysis

**Temporal analysis**
- Quantitative description of the paraS modulation
- Long-term monitoring

**Spectral analysis**
- Qualitative (and)
  - Exercise orthostatism
Spectral analysis

**Supine Standing**

0.15 – 0.40 Hz

**POWER SPECTRUM (msec/Hz)**

**VLF LF HF**

Supine  Standing position
**Physiological significance**

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Very Low Frequency</strong></td>
<td>Long term mechanisms of regulation</td>
</tr>
<tr>
<td><strong>Low Frequency</strong></td>
<td>Its physiological interpretation remains controversial</td>
</tr>
<tr>
<td></td>
<td>Reflects both sympathetic and parasympathetic modulations</td>
</tr>
<tr>
<td><strong>High Frequency</strong></td>
<td>Parasympathetic influence associated with breathing frequency (respiratory sinus arrhythmia)</td>
</tr>
<tr>
<td>LF/HF ratio</td>
<td><img src="https://via.placeholder.com/150" alt="Image" /> (or)</td>
</tr>
</tbody>
</table>

**Acute hypoxia**
Acute hypoxia

Hypoxia

Local vasodilation due to $\frac{P_aO_2}{PaO_2}$

$\text{Arch of Aorta}$

$\text{Carotid body}$

$\text{medulla}$

$\text{pulmonary afference}$

Sympathetic activity and HR

Noradrenaline

Epinephrine

Heart Rate (bpm)

P<0.05 vs. sea level

Mazzeo et al. 1994, Metabolism; 43:1226-32
Effect on HRV

- Decrease in HF
- Increase in LF (related to respiratory frequency)

- LF/HF ratio is usually increased, so is the sympathetic modulation

Decrease in total spectrum power of HRV
Exercise

- HRmax is decreased
- Submaximal HR is increased

Exercise

- Increase in HR is not limited by β-sympathetic or parasympathetic blockade
  - Potential role of the α1-adrenergic receptor stimulated by NAd
Chronic hypoxia

1. Hypoxia
2. Pulmonary afference
3. Carotid body
4. Medulla
5. Arch of Aorta
6. Blood Pressure
7. HR
8. Q
9. Peripheral Vasodilation

From Levine 2001, in: Handbook of clinical neurology; 75:258-80
Sympathetic activity

**Days in altitude**

- **H1**: 2 days at 4,350m
- **H2**: 13 days between 850 - 4,800m
- **H3**: 21 days at 4,800m

* P<0.05 vs. SL; ** P<0.01 vs. SL

**Mazzeo et al. 1998, J Appl Physiol;84:1151-7**

* P<0.05 vs. baseline (normoxia)
† P<0.05 vs. baseline (notmoxia)

**Richalet et al. 1988, J Appl Physiol;65:1957-61**
Cardiac receptors

\(\beta\)-adrenergic receptors \(\rightarrow\) Muscarinic receptors

Parasympathetic activity

Relative increase due to parasympathetic blockade is greater at altitude vs. seal level (109% vs. 86%, resp.)

Enhanced parasympathetic neural activity accounts for the lowering of HR

? Sea level Control
? Sea level Glycopyrrolate
? 5,260m Control
? 5,260m Glycopyrrolate
Heart Rate

*P<0.05 vs. sea level

Mazzeo et al. 1994, *Metabolism*;43:1226-32


**Effect on HRV**

Total spectrum power is increased

Parrini et al.
Exercise

- HRmax is decreased for altitudes above 3,500m, due to:
  - decreased response to catecholaminergic stimulation (β-adrenergic receptors)
  - increased parasympathetic tone

Power output (Watts)

![Graph: Heart rate (beats/min) vs. Power output (Watts) for 9 weeks at 5,260m](image)

* P<0.05 Sea Level vs. 5,260m Control
+ P<0.05 Sea Level vs. 5,260m Glycopyrrolate

Intermittent hypoxia

- HRmax is decreased for altitudes above 3,500m, due to:
  - decreased response to catecholaminergic stimulation (β-adrenergic receptors)
  - increased parasympathetic tone

![Intermittent hypoxia diagram](image)
**Intermittent hypoxia**

- Models of intermittent hypoxic exposure are multiple:
  - sleep apnea
  - altitude workers (Peru for example)
  - intermittent hypoxic training

- Intermittent hypoxic exposure is different from repeated acute exposures to hypoxia or discontinuous chronic hypoxia

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**Remnant effect of hypoxia**

- Remnant effects last longer after continuous than discontinuous hypoxia

### Remnant effect of hypoxia

<table>
<thead>
<tr>
<th>HR (beats/min)</th>
<th>SL</th>
<th>5,000 m</th>
<th>7,000 m</th>
<th>8,000 m</th>
<th>RSL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>62.9 ± 7.7</td>
<td>79.1 ± 11.0†</td>
<td>90.4 ± 13.7†</td>
<td>89.0 ± 11.3†</td>
<td>63.5 ± 10.0</td>
</tr>
</tbody>
</table>

† P<0.05 vs. baseline  
‡ P<0.05 vs. RSL  
+ P<0.05 hypoxia vs. hypercapnia

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From Boussuges et al. 2000, Am J Respir Crit Care Med; 161:264-70

† P<0.05 vs. SL  
‡ P<0.05 vs. RSL

**FiO2=0.12%**
“Acute” Exercise

Mechanisms

Greiwe et al. 1999, J Appl Physiol; 86:531-5

* P<0.05 vs. pre exercise
* P<0.05 untrained vs. trained
Kinetic

+ after:
Rapid drop in CSNA precedes HR decrease

− after:
Gradual decrease in HR with no change in CSNA

? mid to late:
Both CSNA and HR are elevated

HRV: methodological consideration

60% of PVO₂ max

70% of PVO₂ max

80% of PVO₂ max
HRV: methodological consideration

The major influence of ventilation challenges the validity of standard HRV indices for assessing autonomic control of heart rate during strenuous exercise.

Time course of recovery from exercise

HR (time constant) recovery from an acute exercise is faster in subjects with moderate training load, whatever their fitness level.

Early recovery depends on the intensity
Remnant effect of exercise

- The elevated resting HR post-exercise, associated with a high sympathetic modulation, can last for up to 24h.

- A parasympathetic rebound is observed between 24 and 48h post-exercise (long and intense).

Remnant effect of exercise - trained vs. untrained

- * P<0.05 vs. before training

- Control group

- Training groups
Remnant effect of exercise - trained vs. untrained

Correlation between baseline HF component and response to 8 wk of aerobic training

Endurance Training
Moderate intensity - total power of HRV

Neurovegetative activity, as represented by power spectrum (PSD), is greater in athletes than in sedentary individuals

Moderate intensity - sympathetic activity

Sympathetic component is decreased after training
*Moderate intensity – paraS activity and HR*

Parasympathetic component is increased after training

*High intensity – sympathetic activity*

Increase in the sympathetic component with high intensity training, rapidly reversible
High intensity - parasympathetic activity

- Decrease in the parasympathetic component with high intensity training

- Increase in the LF power

- Increase in HR associated with the conditioning period

"Over-reaching"

- Can be characterized by:
  - A decreased total power of HRV with a LF predominance
  - An increased supine HR
  - A slow cardiac recovery from exercise

- But has also been described as inducing paraS modulation

- Can be considered as normal fatigue and not necessary associated with a drop in performance

- Can be observed during conditioning period of training when “non-pathological”
“Over-training”

Can be characterized by:
- a large increase in total power of HRV with a high HF activity (endurance sports)
- a decreased supine HR
- a fast cardiac recovery from exercise

Is always associated with a decrease in performance even in the absence of autonomic symptoms

활동영역

<table>
<thead>
<tr>
<th>P &lt; 0.05</th>
<th>P &lt; 0.01</th>
</tr>
</thead>
</table>

"Over-training" can be associated with overtraining

Orthostatic hypotension

Athletes have a lower tolerance to Tilt test vs. sedentary (proportional to their training status)

This might be due to:
- structural training adaptations: ? arterial and venous compliance, ? cardiac compliance and hypertrophy, ? blood volume
- decrease in baroreflex sensitivity
- decrease in autonomic nervous system control on baroreflex, related to the parasympathetic modulation induced by training

Orthostatic hypotension can be associated with overtraining
HRV and Training Follow-up

**Normoxia**

Pre- and post-season differences

Performance is increased, but resting HR do not change

Gender differences seem to exist? Parasympathetic activity is greater in females than in males

<table>
<thead>
<tr>
<th></th>
<th>Females (n=6)</th>
<th>Males (n=8)</th>
<th>Entire group</th>
</tr>
</thead>
<tbody>
<tr>
<td>UO2 power (mW)</td>
<td>3.65 (3.07-3.96)</td>
<td>3.78 (3.44-4.16)</td>
<td>3.82 (3.50-4.18)</td>
</tr>
<tr>
<td>HRmax (bpm)</td>
<td>196 (180-209)</td>
<td>191 (180-209)</td>
<td>191 (180-209)</td>
</tr>
<tr>
<td>VO2max (ml/kg/min)</td>
<td>47.6 (46-48.6)</td>
<td>54.4 (50-58)</td>
<td>51.0 (47-55)</td>
</tr>
<tr>
<td>Rest time (min)</td>
<td>1.0 (0.5-2.5)</td>
<td>1.3 (1.0-3.5)</td>
<td>1.1 (0.5-2.5)</td>
</tr>
<tr>
<td>RR interval (7) (ms)</td>
<td>117 (110-122)</td>
<td>115 (110-122)</td>
<td>116 (110-122)</td>
</tr>
</tbody>
</table>

* P<0.05 test1 vs. test2
** P<0.01 test1 vs. test2
Pre- and post-season differences

- resting HR is decreased and performance is increased
- No alteration in sympathetic or parasympathetic markers
- Indirect marker of HR vagal reflex control could have been improved
  * P<0.05 between body position
  # P<0.05 pre vs. post
- Specific training adaptation (2 low blood volume and cardiac dimension is less in swimmers than in runners) may explain these divergences
- These discrepancies may reflect methodological limitation in the use of HRV for long-term variations

Training individualization

Low: 65% of HRmax, 40 min
High: 85% of HRmax, 30 min
+ warm-up/cool-down at 65%, 5 min

* Max 2 consequent high-intensity exercises
† Max 2 consequent resting days
Training individualization

HRV and Training Follow-up

Hypoxia

* P<0.05 between groups
† P<0.05 within the groups
### Summary - Hypoxia vs. Training

**Hypoxia**
- HR: Moderately low
- HRV: Low
- LF: Low
- HF: Low

**Training**
- HR: Moderately high
- HRV: High
- LF: High
- HF: High

### Altitude training - mild vs. moderate hypoxia

<table>
<thead>
<tr>
<th>Condition</th>
<th>Pre-trial</th>
<th>Test 1</th>
<th>Test 2</th>
<th>Post-trial</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\delta_{PO}$</td>
<td>1200m</td>
<td>$1.07 \pm 0.42$</td>
<td>$1.00 \pm 0.77^*$</td>
<td>$0.84 \pm 0.27^*$</td>
</tr>
<tr>
<td>$\delta_{PF}$</td>
<td>1200m</td>
<td>$0.02 \pm 0.21$</td>
<td>$1.00 \pm 0.10^*$</td>
<td>$2.62 \pm 2.03^*$</td>
</tr>
<tr>
<td>$\delta_{HF}^{PF}$</td>
<td>1200m</td>
<td>$2.40 \pm 1.32$</td>
<td>$2.31 \pm 1.34^*$</td>
<td>$1.22 \pm 1.38^*$</td>
</tr>
<tr>
<td>Time 2000m (s)</td>
<td>1200m</td>
<td>$2.07 \pm 2.05$</td>
<td>$1.02 \pm 1.31$</td>
<td>$2.02 \pm 2.45$</td>
</tr>
</tbody>
</table>

* $P<0.05$ vs. pre-trial; # $P<0.05$ 1,200m vs. 1,850m

- **Same relative training loads induce positive HRV adaptations ($\delta_{HF}^{PF}$ and $\delta_{HF}^{SF}$) at 1,200m and improve performance, but not at 1,850m.**
- **HF sensitivity may help predict performance alteration.**
What are the influences of the remaining effects of exercise and/or hypoxia?

LHTL - Remnant effects of exercise

Altitude does not affect intense-exercising remnant effects on HRV in a well-adapted population

Living in altitude does not impair the autonomic response to training
LHTL - Remnant effects of hypoxia

Altitude exposure counteracts aerobic training induced alterations in autonomic control, but does not prevent further enhancement at the end of the exposure.

\[ \text{P} \leq 0.05 \text{ vs. PRE} \]

Intermittent hypoxia - LHTL

LHTL can not be considered as repeated acute exposures to hypoxia.

This needs to be taken into account to controlling training with HR'V
**Take Home Message**

- HRV is more useful on a day to day basis than for long-term comparison.
- Overtraining being hard to diagnose, controlling training using HRV becomes very useful.
- Training follow up over altitude training is even more important.
- Few is known about the different models of intermittent hypoxia ("LH-TL", "LL-TH").