Heart Rate Variability and training:

The example of world number one in Fencing

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Terminology

- Training
- Adjustment
- Recovery
- Periodisation
- Overwork/Overreaching
- Overtraining Syndrome
Recovery

- Nutrition and hydration
- Adequate alternation of load/unload
- Quality of sleep
- Relax and Emotional support
- Supporting Methodologies: massages, saunas, physiotherapy, postural control and so on.

Inadequate Recovery = Fatigue
Periodisation

Performance ability =

Inherent ability +
Accumulated Fitness - Accumulated Fatigue
Overwork/Overreaching

• Acute training period when workload (its intensity or volume) is increases significantly

• Short-term deterioration of performance

• Usually < 2 weeks
Indicators of Inadequate Recovery

- **Increase in HR at rest**
- Evaluation of mood (POMS)
- Decreased Free Testosterone/Cortisol Ratio
  - Anabolic/Catabolic balance
    > 30% decrease from baseline
- **Decrease in HRV**
Overtraining Model

- Performance
- Overreaching
- Supercompensation
- Overtrained

Time
HRV

• HR: Average Value /minute

• Time lapse between an heart beat and the following one, in other words between two subsequent R-R peaks, it's not a constant value as it changes every time.
Heart rate variability HRV

The Heart Rate Variability (HRV) is an electro cardiac non-invasive marker used to measure and analyze the variability of heart rate, which is the \textit{R-R time lapse} reflecting the activity of \textbf{parasympathetic} and \textbf{sympathetic} components of CNS. HRV is correlated to the interaction between Sympathetic and Parasympathetic Nervous System and to the comprehensive influence of ANS on both electrical and contractile heart activities. It's a \textit{clinical context's} derived method of investigation: in that context it's currently seen as a prognostic factor for heart diseases and used for their outcome, as well.
HRV

- there is a natural variability in heart rate due to reaction to many factors such as the rhythm of breath, the emotional status, and in case of anxiety, stress, anger, relaxation, worries and so on.
The practical implementation of HRV analysis is based upon rules set by the Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology (1996), based upon Russians studies and upon the respect of some general rules set by experience and useful to avoid errors that may compromise results, while performing the analysis.

Recommendations are that athletes should take care of:
1) to avoid assumption of nervine substances close to the test;
2) to wait about 2 hours from most recent meal, if possible.

Standard protocol requires 5 minutes test, with the subject lying down in supine position (clinostatism) in a room with constant temperature. It must be repeated over time keeping similar conditions and at the same time of the day. In any case, the best possible condition is in the morning, just after waking up, before breakfast.
Figure 1  Circadian rhythm of the hourly means of heart rate (A), f-QRS duration (B), ln HF (C), and ln LF/HF (D) in 20 subjects. Solid lines represent curves fitted to the data by the single cosinor method. LF and HF, low and high frequency components, respectively, of heart rate variability; LF/HF, LF to HF ratio.
Quick, easy and not invasive execution of test and related analysis

Hosand's MINIcardio PRO is commonly used for short time measurement (5 Minutes)

An acoustic signal is given at the end of the test and switches it off.
DETECTION ➔ TACHOGRAM

A graphical record as obtained from a normal ECG by charting the sequence of heartbeats on the abscissa and **their length on the ordinate** (calculated from R-R peak)

![Tachogram Graph](image)

ELABORATION OF DETECTION:

- **TIME DOMAIN**

- **FREQUENCY DOMAIN**
TIME DOMAIN

TIME DOMAIN

IT IS A STATISTICAL ELABORATION OF TIME LAPSE EXTRAPOLATED FROM TACHOGRAM

MOST IMPORTANT STATISTICAL PARAMENTERS IN HR VARIABILITY:

• **RMSSD**: root mean square successive differences in adjacent RR intervals. It is a reflection of short term variance of HR. It's connected to the parasympathetic activation. **It is not affected by circadian rhythm**

• **pNN50**: Percentage of intervals longer than 50 msec. compared to all measured R-R intervals

• **SDRR**: Total standard deviation. It is a reflection of all components, including the HRV’s circadian rhythm included. **It's more relevant in long term detection**
Many biological systems show rhythmic oscillations with a wide range of frequencies that vary from seconds to years. The ability to swing rhythmically seems able to determine advantages for a system in terms of efficiency and precision of its control. Analysis on rhythmic swing had been performed both in the short (5 min.) and in the long-term (24 hours) tests. The discrete Fourier transform makes it possible to switch from time domain to frequency domain, thus enabling the analysis of density and spectral power of the signal. The spectral analysis describes periodical oscillations of HRV signal and allows to break it down into different frequencies and amplitudes.

High frequency waves (HF)  ➔  vagal activity

Low frequency waves (LF)  ➔  vagal and sympathetic activity

LR/HR ratio  ➔  Sympathetic-vagal balance index
1) VLF (0.01 e 0.04 Hz) The VLF band is partially due to the activity of the Sympathetic Nervous System, but also to changes in thermoregulation and, in the psychological area, where the hypotheses are that it's influenced by worry and rumination. It's the marker for physical activity.

2) LF (0.04 e 0.15 Hz) The LF band is considered as mainly due to the activity of Sympathetic Nervous System and of baroreceptors.

3) HF (0.15 e 0.4 Hz). The HF band is considered as an expression of the activity of Parasympathetic Nervous System and of the Vagal. This area of frequencies is strongly influenced by rhythm and depth of breath. Both parameters express the overall level of heart rate variability, in other word the total activity of Sympathetic+ Parasympathetic. The connection between Sympathetic and Parasympathetic can also be measured using the LF/HF ratio eventually using normalized measure units,
SIGNAL PROCESSING in the TIME DOMAIN
SIGNAL PROCESSING in the FREQUENCY DOMAIN
HRV and Cardiac Autonomic Tone Modulation

- **Fast variations**: reflect parasympathetic (vagal)

- **Slower variations**: reflect a combination of both parasympathetic and sympathetic modulation and non-autonomic factors
Correlations between HRV Measures

• Highly correlated measures
  – SDNN, SDANN ➔ Total power
  – rMSSD, pNN50 ➔ HF power

• LF/HF ratio does not strongly correlate with any other HRV measures
HOW TO DEFINE A VALUE OF REFERENCE FOR HF?

A POSSIBLE METHODOLOGY

- By monitoring and recording HF's values during the last 7 days just before the beginning of training, with a complete absence of physical exercise. Then tracking and recording HF's values during the first 3 days of workout, during the days of physical testing (anaerobic threshold, VO2max, Lower limbs power and so on).

- A total recording of 10 days.

- Calculate average and standard deviation of HF of recorded values.

- By subtracting standard deviation from the mean average, we have reference and alert values for HF that would allow us, when having values below that and continuously taking into account LF and total spectral power, to eventually decide to modify the training program.

- It may be useful to proceed the very same way for RMSSD in time domain.

Kiviniemi-Hautala-Kinnunen-Tulpo

“Endurance training guided by daily heart rate variability measurement”

(Accepted 2007)
THE METHODOLOGY

Fig. 1 Heart rate variability (HRV)-guided training scheme. The basic idea was to lower the training intensity whenever decreased high-frequency (HF) oscillation of R–R intervals was observed. Maximum two consequent high-intensity exercises (*) and resting days (†) were allowed. Resting day was prescribed after nine consequent training days despite the daily HF power. Low = exercise at 65% of maximal heart rate; High = exercise at 85% of maximal heart rate; Rest = resting day; HRV+ = increased or not changed HRV; HRV− = decreased HRV

Kiviniemi-Hautala-Kinnunen-Tulpo
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POSSIBLE PERFORMANCE OF SPECTRAL DENSITY, BEFORE AND AFTER WORKOUTS OR COMPETITIONS

Before workout or competition

24 hours later

48 hours later

72 hours later
POSSIBLE EFFECTS OF AEROBIC WORKOUT: TIME DOMAIN

**Table I.** Heart rate variability parameters in the time domain obtained from ten control (sedentary) individuals and ten aerobically-trained athletes. Values are mean ± standard deviation (reproduced from Aubert et al.,[27] with permission)

<table>
<thead>
<tr>
<th></th>
<th>Mean NN (ms)</th>
<th>SDNN (ms)</th>
<th>rMSSD (ms)</th>
<th>pNN50 (%)</th>
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</thead>
<tbody>
<tr>
<td><strong>Supine</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>880.7 ± 263.8</td>
<td>69.7 ± 37</td>
<td>45.5 ± 26.8</td>
<td>21.8 ± 19.7</td>
</tr>
<tr>
<td>Aerobic</td>
<td>1100.3 ± 158.5*</td>
<td>97.9 ± 15.7*</td>
<td>73.5 ± 23.7*</td>
<td>40.1 ± 16.6*</td>
</tr>
<tr>
<td><strong>Standing</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>749.7 ± 165.6</td>
<td>65.4 ± 38.9</td>
<td>30.6 ± 16.9</td>
<td>10.5 ± 12.4</td>
</tr>
<tr>
<td>Aerobic</td>
<td>947.7 ± 108.8</td>
<td>92.9 ± 30.9</td>
<td>47.2 ± 11.1*</td>
<td>22.4 ± 8.9*</td>
</tr>
</tbody>
</table>

**NN** = normal-to-normal interval; **pNN50** = percentage of successive interval differences larger than 50ms; **rMSSD** = square root of the mean squared successive differences between adjacent RR intervals; **SDNN** = standard deviation of the NN interval; * p < 0.05.
CHANGES IN DENSITY AND SPECTRAL POWER AFTER 6 MONTHS OF AEROBIC TRAINING

Fig. 5. (a) Tachogram and power spectral density of a recording in a young sedentary individual before training (HF = 812.3 ms²); and (b) the same individual after a 6-month aerobic training programme (HF = 1878.4 ms²). HF = high frequency; LF = low frequency; PSD = power spectral density.
Date of recording: Monday 7th of May 2012 at 9.00 after the Week end

<table>
<thead>
<tr>
<th>RMSSD</th>
<th>VLF</th>
<th>LF</th>
<th>HF</th>
<th>TOTAL P</th>
<th>RAP LF\HF (n.u.)</th>
<th>RAP LF\HF (ln)</th>
</tr>
</thead>
<tbody>
<tr>
<td>54,1</td>
<td>172,93</td>
<td>153,98</td>
<td>545,55</td>
<td>872,46</td>
<td>0,28</td>
<td>0,80</td>
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</table>
Date of recording: Tuesday the 8th of May 2012

Previous sessions: **Morning**: lower limbs strength contrasts  **Afternoon**: technique + 4 attacks

<table>
<thead>
<tr>
<th>RMSSD</th>
<th>VLF</th>
<th>LF</th>
<th>HF</th>
<th>TOTAL P</th>
<th>RAP LF\HF (n.u.)</th>
<th>RAP LF\HF (ln)</th>
</tr>
</thead>
<tbody>
<tr>
<td>78,4</td>
<td>608,47</td>
<td>740,97</td>
<td>721,75</td>
<td>2071,20</td>
<td>1,03</td>
<td>1,00</td>
</tr>
</tbody>
</table>
Date of recording: Wednesday the 9th of May 2012

Previous sessions: **Morning**: push ups on bench press (power) + chins+ 4x1000  **Afternoon**: technique

<table>
<thead>
<tr>
<th>RMSSD</th>
<th>VLF</th>
<th>LF</th>
<th>HF</th>
<th>TOTAL P</th>
<th>RAP LF\HF (n.u.)</th>
<th>RAP LF\HF (ln)</th>
</tr>
</thead>
<tbody>
<tr>
<td>44,2</td>
<td>1225,98</td>
<td>168,29</td>
<td>341,89</td>
<td>1736,17</td>
<td>0,49</td>
<td>0,88</td>
</tr>
</tbody>
</table>
Date of recording: Thursday the 10th of May 2012

Previous sessions: **Morning**: lower limbs strength training  
**Afternoon**: technique

<table>
<thead>
<tr>
<th>RMSSD</th>
<th>VLF</th>
<th>LF</th>
<th>HF</th>
<th>TOTAL P</th>
<th>RAP LF\HF (n.u.)</th>
<th>RAP LF\HF (ln)</th>
</tr>
</thead>
<tbody>
<tr>
<td>48,4</td>
<td>537,91</td>
<td>293,72</td>
<td>319,93</td>
<td>1151,57</td>
<td>0,92</td>
<td>0,99</td>
</tr>
</tbody>
</table>
Date of recording: Friday the 11th of May 2012

Previous sessions: **Morning** Intermittent 1 min work 30 rec. speed = VAM **Afternoon:** 3 attacks

<table>
<thead>
<tr>
<th>RMSSD</th>
<th>VLF</th>
<th>LF</th>
<th>HF</th>
<th>TOTAL P</th>
<th>RAP LF\HF (n.u.)</th>
<th>RAP LF\HF (ln)</th>
</tr>
</thead>
<tbody>
<tr>
<td>38,8</td>
<td>738,96</td>
<td>529,33</td>
<td>288,48</td>
<td>1156,77</td>
<td>1,83</td>
<td>1,11</td>
</tr>
</tbody>
</table>
Evidence of recovery from workload of previous microcycle. This allows to approach the World Cup Competition (Winner) with no situation of fatigue in the short term.

date of recording: Monday the 14th of May after the weekend.
RECORDING THE SAME COMPETITION IN 2011 AND IN 2012
Il presente materiale è protetto dalle norme sulla proprietà intellettuale, l’uso, anche parziale è consentito solo previa autorizzazione dell’autore. L’uso, anche parziale, non autorizzato sarà perseguito secondo la normativa vigente.
Recent literature

Recently, a meta-analysis on 34 studies was published; it refers to HR and HRV parameters of agonistic athletes before and after a period of increased workload. Result of the analysis is, that after a short period (≤ 2 weeks) of a more intense training that generates a status of overreaching, we measure an increase of the LF\HF ratio and a trend of decreasing value of LF+HF.

As a result of longer periods of intensified workload (≥ 2 weeks) which is a potential cause to overtraining, there are no substantial changes in HRV parameters.

From these data it seems possible to consider an alteration of sympathetic vagal balance (LF/HF ratio) as a marker of fatigue in the short term.
An **increase or a maintenance of steady state levels of HF** should be considered as an indicator of **effective recovery** from previous training loads. A **decrease in HF component** below base values should be considered as an indicator of **state of fatigue** and a recommendation of avoid **intense training sessions**. (A. M. Kiviniemi, A. J. Hautala, H. Kinnunen, e M. P. Tulppo, «Endurance training guided individually by daily heart rate variability measurements», *Eur. J. Appl. Physiol.*, vol. 101, n° 6, pagg. 743-751, Dic 2007.)[22] (L. Bosquet, S. Merkari, D. Arvisais, e A. E. Aubert, «Is heart rate a convenient tool to monitor over-reaching? A systematic review of the literature», *Br J Sports Med*, vol. 42, n° 9, pagg. 709-714, Set 2008).[23]
Six months of training at moderate intensity lead to an increase in parasympathetic and to a decrease of sympathetic (Iellamo and others 2002).

Three weeks of intense training in the almost final stage of a training plan, generate a collapse of parasympathetic regulation and a sharp increase of the sympathetic one (Iellamo et al. 2002).

A workout focused on increasing the VO2max generates a reduction in heart rate and increase of the sympathetic component.
Findings

- Overtraining is often preceded by a period of excessive workload or by inadequate recovery or both, and always by an inadequate training plan. Short-term fatigue has to be monitored letting the athlete have pauses from trainings also to allow adaptation.

- To prevent overtraining and most of all to allow the athlete to adapt with success, it can be useful to measure HRV and to carefully evaluate the balance between sympathetic and parasympathetic activity of ANS.
Grazie per la vostra attenzione