

# Recovery Analysis for Athletic Training Based on Heart Rate Variability

Firstbeat Technologies Ltd.

This white paper has been produced to describe a recovery analysis method based on heart rate variability developed by Firstbeat Technologies Ltd. Parts of this paper may have been published elsewhere and are referred to in this document.

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## SUMMARY

- The benefits of training are accomplished only through the recovery process
- Too much of body stress and lack of recovery results overloading, in contrast always perfect recovery may tell that training load is rather low resulting in suboptimal time management and/or inefficient training
- Recovery needs to be evaluated to optimize training load for optimal improvements in performance
- The Firstbeat method for analyzing recovery in athletic training is based on beat-by-beat heart rate measurement and advanced utilization of heart rate variability (HRV)
- The method can be applied for measuring overall stress and recovery balance over the day (24h), recovery during night's sleep or quick recovery tests during daytime
- The Firstbeat method has been shown to be very sensitive for changes in recovery status
- The method allows individual recovery monitoring systematically and repeatedly

## KEY TERMS

- **Recovery** = Period when physical capacity is regained. Physiologically reduced activation level of the body when parasympathetic (vagal) activation dominates the autonomic nervous system over sympathetic activity.
- **Training load** = Overall load or stress upon body originating from frequency and duration (volume), as well as intensity of all the training.
- **Overreaching** = Reversible, short-term state of decreased performance abilities due to high training load, stress and/or insufficient recovery.
- **Overttraining** = Severe long-term condition of decreased performance abilities due to high training load, stress, and/or insufficient recovery that may take months or years to recuperate.

## ATHLETIC TRAINING AND RECOVERY

### Importance of recovery for athletes

Hard training, balanced diet, and rest are the basic ingredients of every successful recipes in sports. Therefore, in precise and effective training management, an athlete and/or a coach should assess not only the load and effectiveness of training sessions but also monitor recovery from these sessions. Methods to measure training load and training effect have been described in other Firstbeat white papers [see 1-2]. The present white paper describes a Firstbeat method to assess the recovery of an individual athlete or a team, and represents the benefits of these easy-to-use recovery assessments.

In addition to high training load, recovery plays a crucial role in athletic training. There needs to be a balance between hard and easy training and rest both within a single training week and within longer training periods in order to optimize efforts put on development. When a hard training session or period eliciting significant disturbances in body's homeostasis is followed by sufficient recovery, performance improvements are likely to occur. The importance of recovery is due to the fact that performance improvements actually occur during recovery from training, not during workouts [3]. Finding a balance between training load and recovery is thus a fundamental factor in improving athletic performance.

Also periodization is central in training. Usually athletes have several very hard training periods each year, during which both the intensity and volume of training are very high. These kind of overreaching periods are very exhaustive but necessary for elite athletes to further improve their performance. However, performance can improve only if hard training is followed by adequate recovery [3].

Too hard training without sufficient rest may lead to overtraining condition, which is characterized by decreased performance and in the worst case also other harmful effects on health [4-12]. Recovery from overtraining may take from several weeks to months, but it is also possible that an athlete never reaches the previous performance level. Prevention of overtraining is therefore critical for an athlete. For preventing overtraining, systematic objective assessment of an athlete's recovery is highly beneficial [6, 10-12].

Another perspective for training is related to efficient time management. An athlete needs to know when to train hard and when to rest for optimizing the content of training. Excessively hard training may lead to overtraining, but on the other hand too easy training can result in inefficient time management, and this way into delayed development of an athlete. Therefore, recovery should be constantly evaluated for optimizing the stress on the body and for avoiding both over- and undertraining when seeking the most efficient programming of training.

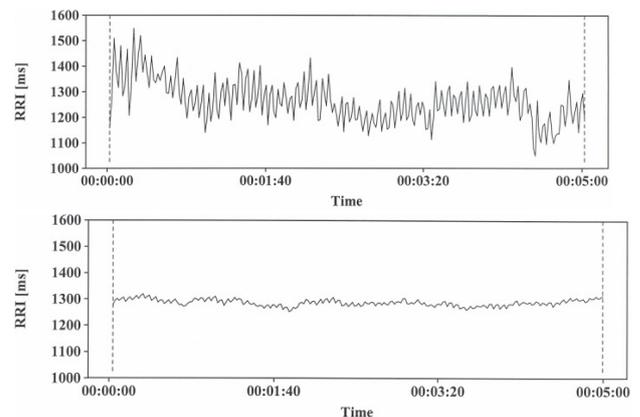
### Autonomic nervous system reflects recovery status

The autonomic nervous system (ANS) plays a major role in maintaining the body's homeostasis. The role of the ANS is to control the cardiovascular system as well as function of visceral organs without voluntary control. ANS is divided to sympathetic and parasympathetic nervous systems. From an anatomical point of view, sympathetic and parasympathetic nervous systems involve both central and peripheral nervous systems. The sympathetic nervous system prepares the body systems for challenging situations and is activated during e.g. physical activity and mental or cognitive tasks which we all encounter daily. The parasympathetic nervous system has the opposite role: increased parasympathetic activity enables recovery. This restores a resting state in body systems by for example allowing faster digestion of food [13].

Autonomic nervous system has the control over heart and its rate and stroke volume are constantly adjusted from heartbeat to heartbeat to enable appropriate flow of oxygenated blood and energy according to body's needs. The consequent fluctuations in heart rate level are called heart rate variability (HRV). HRV provides a powerful tool for observing the interplay between the sympathetic and parasympathetic nervous systems, and HRV is broadly accepted to reflect ANS activity [14]. When the body is

exposed to stress, such as physical exercise, sympathetic activation occurs and parasympathetic modulation decreases causing elevations in heart rate and stroke volume, and decreased HRV. During the recovery process parasympathetic activity increases, heart rate decreases, and HRV increases. Increased parasympathetic activity of the ANS is the fundamental characteristic of recovery and it shows that the body is able to reduce its physiological activation level.

If mental stress, high training load or other sources of stress (e.g. high altitude, jetlag, illness), or their combination lasts for prolonged periods without adequate rest, it is possible that a state of overtraining or exhaustion develops. Before the actual overtraining syndrome develops, it is possible to detect signs of inadequate recovery. This is shown by increased sympathetic nervous system activity and decreased parasympathetic activity even during periods when an athlete should be recovered and free from all stress factors (e.g. during sleep) [e.g. 7, 11]. Figure 1 represents an example of HRV in normal and overtraining state [9].



**Figure 1.** Two different beat-by-beat HR data collections (in supine position with controlled breathing) from a female long distance runner: Well trained and well recovered (upper chart) and overtrained (lower chart). The RR-intervals (RRI) fluctuate significantly, i.e. HRV is high, when the athlete is well recovered. On the contrary, there is hardly any variation in RR-intervals when the athlete is in overtrained state despite the same HR level (48 in well recovered and 47 bpm in overtrained condition). HRV data can be used in assessing overtraining. [Modified from 9]

### Factors affecting recovery

In addition to physical training, there are various other factors which can cause stress or increased need for recovery. The most important sources of stress are listed below. Some are highly personal as people perceive stress in different situations whereas some are universal stress factors for each of us. The underlying causes of stress should always be taken into account when adjusting the training and interpreting the recovery status of an athlete.

- Illness
- Lack of sleep or poor sleep quality

- Medication
- Jetlag
- High Altitude
- Adaptation to new environment (e.g. hot climate)
- Hard training session or race performed late in the evening
- Alcohol or “hangover”
- Work-related stress factors
- Social stress factors
- Emotional stress factors

It is also possible that athlete’s performance is decreased due to training-induced tension or soreness in musculature. This is not necessarily revealed by the ANS and HRV-based methods as monotonous training or some new (unfamiliar to the athlete) type of exercises may have led to decreased neuromuscular performance even without significant effects on the ANS function [15].

**Table 1.** Comparison of different methods to assess an athlete’s recovery status.

Method	Physiological and scientific basis	Advantages	Limitations
<b>Lactate measurements</b>	<ul style="list-style-type: none"> <li>• Lactate is formed in anaerobic metabolism</li> <li>• Observations have been made about reduced lactate levels in fatigued state, usually when the muscles are emptying of glycogen</li> </ul>	<ul style="list-style-type: none"> <li>• Relatively easy to measure</li> <li>• Inexpensive</li> </ul>	<ul style="list-style-type: none"> <li>• Cannot distinguish between overreaching and overtraining</li> <li>• Requires control exercise</li> <li>• Usually needs to be combined with information on subjective feelings</li> <li>• Mainly measures short term recovery after a single training session or a few sessions and is related to muscle glycogen level</li> </ul>
<b>Hormonal, immunological and biochemical measurements</b> (e.g. catecholamines, and glucocorticoids such as cortisol)	<ul style="list-style-type: none"> <li>• Poor recovery, overreaching and overtraining may be detected by observing hormonal, immunological and/or biochemical markers</li> </ul>	<ul style="list-style-type: none"> <li>• Specificity: Possible to locate the physiological mechanism precisely if changes in these markers are detected</li> </ul>	<ul style="list-style-type: none"> <li>• Not sensitive enough for the measurement of daily training status</li> <li>• Expensive</li> <li>• Possibly invasive</li> <li>• Instant feedback is not possible</li> </ul>
<b>Orthostatic test</b>	<ul style="list-style-type: none"> <li>• Cardiac reactivity to postural changes has been found to be associated with recovery state</li> </ul>	<ul style="list-style-type: none"> <li>• Inexpensive</li> <li>• Relatively easy and quick to perform</li> </ul>	<ul style="list-style-type: none"> <li>• Other factors, such as mental arousal or anxiety may confound results</li> <li>• Heart rate level may either increase or decrease due to high training load</li> </ul>
<b>Subjective feelings</b> (e.g. Profile of Mood States, other questionnaires or personal feelings of recovery or fatigue)	<ul style="list-style-type: none"> <li>• Training induced fatigue is linked to psychological factors</li> <li>• Experienced athletes can feel when they are recovered</li> </ul>	<ul style="list-style-type: none"> <li>• Inexpensive and easy to assess</li> </ul>	<ul style="list-style-type: none"> <li>• Not objective</li> </ul>
<b>Basic HRV-analysis</b> (e.g. HF power, RMSSD)	<ul style="list-style-type: none"> <li>• Single HRV indices have been found to detect excessive training load either alone or combined with orthostatic test</li> </ul>	<ul style="list-style-type: none"> <li>• Inexpensive</li> <li>• Relatively easy and quick to perform</li> </ul>	<ul style="list-style-type: none"> <li>• Necessary artefact correction requires signal analysis skills</li> <li>• If done awake, other factors such as mental arousal or anxiety may confound results</li> <li>• Traditional HRV indices are hard to interpret as such</li> </ul>
<b>Firstbeat Recovery Test</b>	<ul style="list-style-type: none"> <li>• <b>Based on advanced HRV analysis and physiological modeling of body functions</b></li> </ul>	<ul style="list-style-type: none"> <li>• <b>Very fast measurement, automated analysis and interpretation</b></li> <li>• <b>Has been found to be more sensitive than traditional HRV indices</b></li> </ul>	<ul style="list-style-type: none"> <li>• <b>If done awake, other factors such as mental arousal or anxiety may confound results</b></li> </ul>

## Different methods to analyze recovery

Different methods available for assessing recovery from training with their advantages and limitations are presented in the Table 1. Some methods are invasive, costly and time consuming and therefore these methods cannot be used frequently enough to support training and coaching optimally in the everyday life. Other challenges are related to insensitivity or invalidity for the given purpose as the recovery analysis should be easily applicable and accurate.

Firstbeat’s heartbeat based recovery analysis is easy to perform and gives valuable information on the function of the ANS, which has been shown to reflect the recovery state. The analysis is fast, and it reveals signs of accumulated stress and lack of recovery. The method can be utilized on a daily basis and this way recovery can be monitored all the time, which helps to prevent overtraining and development of harmful and severe consequences but also to increase training load if recovery seems to be constantly very good. This helps to make the training as efficient as possible.

## DESCRIPTION OF THE FIRSTBEAT RECOVERY ASSESSMENTS FOR ATHLETES

The Firstbeat's recovery analysis method has been designed to sensitively measure an athlete's recovery status. The method is based on analyzing HRV from beat-to-beat heart rate data, and thus reflects the ANS state which combines stress from different sources. In principle, the method recognizes the body's stress and recovery reactions, and the intensity of these reactions for accurate feedback.

### Detecting when the body is recovering

The Firstbeat method detects periods of stress, recovery, and physical activity from the HRV measurement. The detection of these states is based on the detection of sympathovagal reactivity of the heart that exceeds momentary metabolic requirements of the ANS. This means that during stressful situations or exercise, it is normal to utilize more sympathetic activation but during rest and relaxation, parasympathetic activity should be dominating the ANS state.

Stress state is defined as increased activation in the body, induced by external and/or internal stress factors (stressors), during which sympathetic nervous system activity is increased and parasympathetic (vagal) activity is decreased without the metabolic requirements from physical activity. In the analysis, stress is detected when HR is elevated and HRV is reduced and there are inconsistencies in the frequency distribution of HRV due to changes in respiratory period.

Recovery is defined as decreased activation in the body during relaxation, rest and/or peaceful working, related to lack of external and internal stress factors when parasympathetic (vagal nerve) activity is great and sympathetic activity is low. Recovery is detected when HR is close to individual resting level and HRV is great and regular according to the breathing rhythm. More information on the procedure for detecting different physiological states can be found in another Firstbeat white paper [16].

## Comprehensive recovery analysis during sleep and quick tests during daytime

Recovery analysis can be performed during sleep or daytime. In general, stress and recovery states during 24h or sleep (see Figure 2) can be used for a quick glance to see when the recovery starts to occur in the body. When the most accurate and reliable information on current recovery status compared to individual baseline values are needed, analysis of intensity of recovery reactions is suggested.

For the most reliable recovery analysis, sleep time is suggested as sleep is the natural state for relaxation typically free of confounding or disturbing external factors affecting the measurement. Night-time measurements are also the best condition for consistently following-up the progress of a person's recovery.

Quick recovery tests can be applied during awake time in cases when easily performable checks for recovery status are needed. Quick tests allow straightforward way of checking the recovery status of an individual athlete or a whole sports team. The tests can be conducted routinely each morning, before a training session or when preparing to a match. Quick tests are done by assessing the balance between sympathetic and parasympathetic effects on the heart, and calculating the strength of recovery reactions requiring only 1-10min of data. The challenge with quick tests are that external factors such as momentary stress, disturbing thoughts, and daily hassles may affect the results if the testing procedure is not standardized.

### Advantage: Individual interpretation

HRV values are very individual and to great extent also genetically defined [17-18]. These individual differences must be taken into account when interpreting the measured data. Therefore it is important to know the range of physiological parameters (heart rate and heart rate variability) of each individual for accurate recovery analysis.

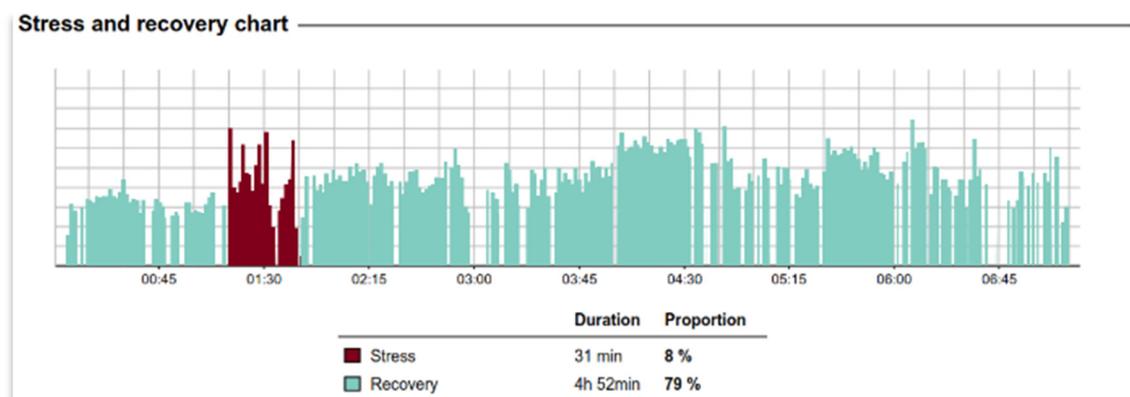


Figure 2. Example of detection of stress (red) and recovery (green) during sleeping.

The HRV-based method suits best for analyzing seasonal changes in athlete's recovery and stress parameters. It is preferred that reference values are always measured in good and poor recovery states, i.e. during both low and high stress / training load conditions and these personal references can thereafter be used to support interpretation of the results. These reference values should be updated whenever needed, for example between different training periods, if changes appear in the ANS function. Comparison between different individuals is not usually reasonable.

### Recovery Index: sensitive measure of recovery

A specific index (Recovery Index) is calculated by Firstbeat to describe the intensity of an athlete's recovery reactions. Recovery Index is calculated from HR level, HRV (low and high frequency power) and HRV-based respiration rate. The HRV measures are calculated second-by-second using the short-time Fourier Transform (STFT) method. Also data filtering is used to select the representative data periods to best describe the recovery status.

The values are then individually scaled based on user's measurement history and therefore the intensity of recovery is compared to the highest measurement in record. By this way, the results are highly individualized. For the sleep time, the method uses a 4-hour window starting 30 minutes after going to bed for determining the Recovery Index.

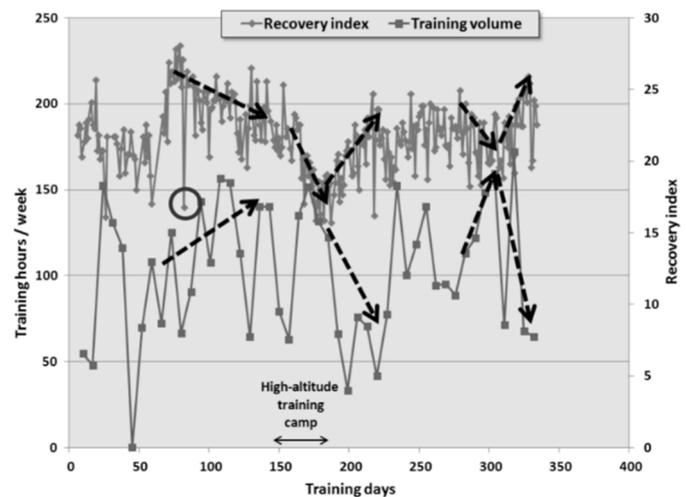
### Empirical results with the Firstbeat method

The described recovery assessment methods have been studied in individual athletes and sports teams [19-25]. It has been found that Recovery Index seems to be more sensitive to athlete's recovery status than basic HR or traditional high or low frequency powers of HRV in all conditions.

A 3-year follow up study with an international level endurance athlete (race walker) found that Firstbeat's method measured recovery state accurately both after single hard training day and after overreaching period [20]. The authors reported simultaneous increase in HR and decrease in HRV during sleep after a hard training session or a race resulting in decreased Recovery Index. The index responded to hard training sessions, and also the trends over longer periods seemed to follow the stress of training and the subsequent recovery periods.

The authors of the previous study made valuable conclusions about recovery assessments. They highlighted that 1) regular HRV analysis is needed to be able to react soon enough to undesirable changes in athlete's state of recovery, 2) the recovery analysis is of great help especially when the coach can't be present in e.g. high altitude training camp, 3) the athlete will learn to analyze the effects of different issues to

the readiness to train and compete based on measurements, 4) the training program should be adjusted according to the athlete's feelings together with the results of HRV-based recovery analysis to avoid "bad training days".



**Figure 3.** Example of recovery follow-up by the Recovery Index from an international level race walker containing a whole training year [modified from 20].

A recent study reported very interesting findings of recovery measurements from a top-level ice-hockey team (Jokerit in KHL). Those findings resulted in modifications of training to allow players to recover better [25]. The study concluded that: 1) it is extremely important what happens in the athlete's life between the games (being athlete 24/7), 2) the night after the game is the most crucial period for the recovery, 3) the recovery was delayed more after the away than home games (need to allow more time to recover when travelling), 4) there are big individual differences in recovery after the games (athletes need to learn how to recover), and 5) systematic recovery assessment is the key for better recovery (Firstbeat method was easy to use assessment tool) [25].

In addition, a recent study reported that higher Recovery Index values from night's sleep was associated with better aerobic fitness (higher  $VO_{2max}$ ) and with lower body mass index and body weight among men [26].

### HOW TO APPLY FIRSTBEAT RECOVERY ANALYSIS IN TRAINING?

Recovery measurements during sleep have been widely applied among international level athletes (e.g. in kayaking, swimming, cross-country skiing, ice-hockey). According to experiences, the analysis is easy-to-use, highly automated, quick to perform, and the measurement does not disturb sleep [see e.g. 25]. The analysis enables decision making immediately after awakening allowing immediate changes in training program when needed.

Regular recovery assessment is a key factor in successful training programming. In practice, more frequent recovery follow-up is recommended during harder training periods and especially to ensure recovery when it is supposed to occur. For effective time management, measurements can be done less frequently during periods of less demanding training when the risk of overtraining is small. Verification should be made both to assure the sufficiency of training load during hard training periods and to assure that the athlete really recovers during easy periods. Changes in recovery state are needed for training to be effective (see Table 2 and Figure 4).

### **Measure when the athlete is well recovered**

Recovery assessments should always be started before hard training periods. It is difficult to detect inadequate recovery if there is no reference level. It is even possible that inadequate recovery is not detected at all if recovery assessments are started when the athlete is already overreached or -trained.

### **Verify sufficiency of training load**

Recovery assessment is recommended even after a single hard training day; recovery status should be lower than normally during the subsequent night's sleep. Recovery intensity should move closer to baseline during the following nights if the athlete performs easier training or rests.

Overreaching periods are needed for a high level athlete to achieve performance increments. This means that training-related fatigue accumulates from a training session to another in such a manner that the athlete is actually exhausted at the end of the training period.

During an overreaching period recovery status should weaken towards the end of period. Recovery assessments should be made on night-by-night basis to quickly observe possible adverse effects of intensified training. If recovery status does not worsen during a hard training period then the training has probably been too easy and training should be reprogrammed by slightly intensifying the upcoming sessions compared to the predetermined plan. If hard training period has changed athlete's recovery status then the coming sessions can be performed as previously planned.

### **Prevent overtraining**

If training load is high for prolonged periods and a proper recovery is neglected, overtraining may occur. Therefore, easy training period is usually applied after harder training periods to assure recovery and performance increments. When training load is high, intensive recovery follow-up is the suggested way to notice whether the athlete has elevated risk of overtraining. Table 2 represents changes that occur in the body in different training states. The information can be

utilized in recognizing signs of excessive fatigue. With follow-up one can track whether it is safe to continue overreaching period or better to lighten up training.

During the subsequent easier training period recovery status should improve (more recovery state and improved intensity of recovery values). Thus, an athlete's recovery values should come closer to the reference values of well-recovered state. Intensive training should not be restarted before recovery values are at least close to those of well-recovered state.

### **Individualize training in team sports**

Varying training load during training sessions and matches for different team members, and varying capability of different individuals to recover from these exercises is a widely known challenge in team sports. Some individuals must put higher effort during team workouts and matches and some other may have reduced capability to recover due to e.g. previous injuries. If individual's recovery is incomplete it may lead to decreased personal performance which may even affect the whole team's performance.

In addition to the targeting of equal training load between team members, it is important to make sure that each athlete also recovers. The coach can either assess a few players who are suspected to have difficulties with recovery, or the coach can track the whole team. A recovery test for a whole team can be the solution. If necessary, training of the poorly recovered / exhausted individuals can then be reduced. Of course, some individuals may be very well recovered, for whom the training load can possibly be increased.

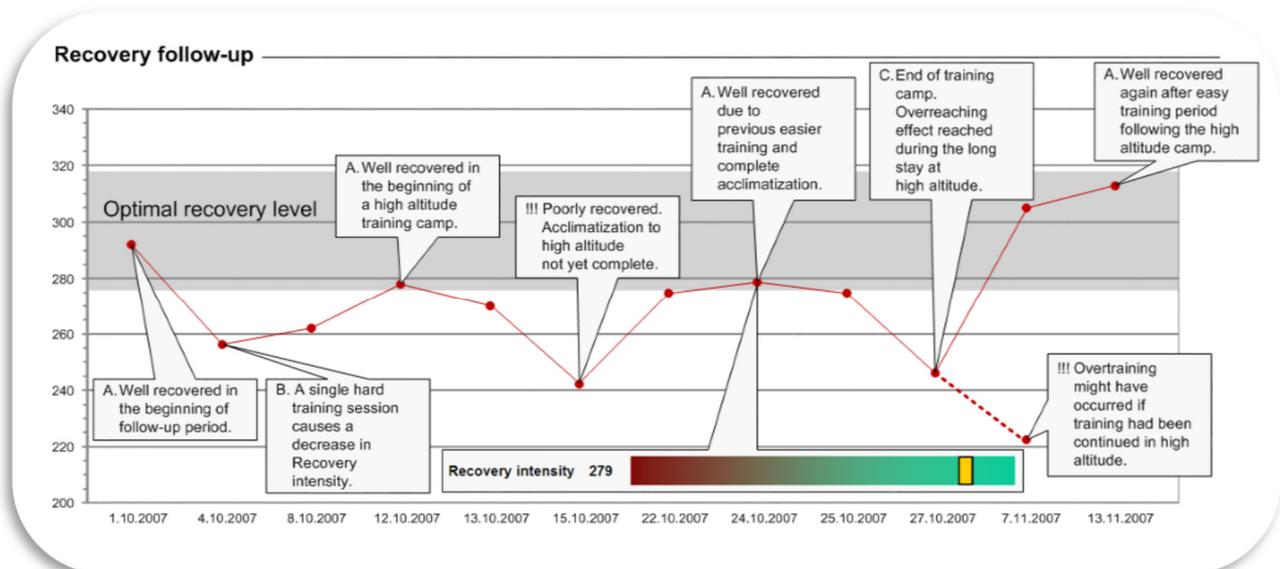
### **Follow physiological responses in special training periods (e.g. high altitude training)**

High altitude training is one of the issues in all types of sports where maximal oxygen uptake ( $VO_{2max}$ ) of an athlete plays a big role. High altitude training provides significant benefits whenever a match or race is arranged in high altitude but the benefits are more controversial when these events are arranged in altitudes close to sea level.

Acclimatization to high altitude causes always stress to a human body. When the acclimatization process is complete athlete's recovery and stress measures should reach near sea level values. Too hard training during the acclimatization period interacting with high altitude stress may delay or even inhibit reaching normal recovery state and spoil the whole training period. Thus, an intensified recovery follow-up is recommended during the whole high altitude residence. Same rules can be applied as during any intensive training period (see table 2), i.e. too hard training load (in interaction with high altitude stress) cannot be continued for too long periods.

**Table 2.** Effects of different training states on recovery measures (Recovery Index). Letters A-D refer to figure 4 which presents these different states in practice.

Training state	Physiological findings	Appearance in recovery analysis	Interpretation
<b>A. Well recovered. No training related fatigue.</b>	Low training related stress and high resources. Low level of sympathetic activity and high level of parasympathetic activity.	HR is low and HRV is great. High Recovery Index.	Harder training can be programmed or hard training can be restarted if easier training period has preceded the measurement.
<b>B. Not fully recovered from a single hard training session.</b>	Increased training-related stress and slightly reduced resources. Slightly increased sympathetic and decreased parasympathetic activity.	HR is higher and HRV lower than in a well recovered state. Recovery Index is slightly decreased.	Easier training is suggested until recovery index returns to a normal level unless you consciously aim for overreaching.
<b>C. High training-related fatigue after an overreaching period.</b>	High training-related stress and low resources. Symptoms of e.g. tiredness and cardiac tachycardia. Significantly increased sympathetic and reduced parasympathetic activity.	HR is significantly higher and HRV lower than in a well recovered state. Recovery Index is low.	Good body recovery should be allowed immediately after the overreaching period. Before restarting harder training, check that Recovery Index has returned to a normal level.
<b>D. Overtraining caused by a long period of hard training with inadequate recovery.</b>	Depleted body resources due to excessive long-term training stress. Near normal level of sympathetic activity and very low parasympathetic activity.	HR may be at normal level but HRV is diminished. Recovery Index is very low.	Rest or very light training is suggested until the Recovery Index returns to a normal level. It may take from weeks to several months.



**Figure 4.** Example of a cross-country skier's Recovery Follow-up. Successful training requires both hard training and a proper recovery.

## CONCLUSIONS

Training load of athletes should be adjusted by their recovery status as the benefits of training are accomplished only through the recovery process. Therefore, recovery status of an athlete needs to be assessed to optimize training programming.

If the overall training load and stress on the athlete is too high or lasts too long without adequate recovery the performance level deteriorates and the athlete may become overtrained. Overtraining is a severe condition, which potentially threatens an athlete's whole career. In contrast, always

unaffected recovery status may tell that training load is rather low resulting in suboptimal time management.

The present white paper described the Firstbeat method for analyzing recovery status in athletic training. The method is based on beat-by-beat heart rate measurement and advanced utilization of HRV, which is a non-invasive method for assessing autonomic nervous system activity (ANS). Increased parasympathetic activity of the ANS is the fundamental characteristic of recovery and it shows that the body is able to reduce its physiological activation level.

The Firstbeat method is applied for measuring stress and recovery over the day (24h), for comprehensive recovery analyses during night's sleep, and even quick recovery tests during daytime. The method has been shown to be very sensitive for changes in individual's recovery status. It allows recovery monitoring systematically, repeatedly, and accurately.

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