A three year follow-up study of endurance performance and nocturnal HRV of an international level race-walker

Introduction

Endurance performance is known to be determined by the capacity to transport and utilize oxygen, economy, neuromuscular characteristics, and muscle power (Paavolainen et al. 1999). The highest level of aerobic metabolism is the maximal oxygen uptake (VO_{2max}) and the VO_{2max} of Olympic level endurance athletes seem to be between 70 and 85 $ml \cdot kg^{-1} \cdot min^{-1}$. During endurance race most of the race is performed under the speed associated to VO_{2max}, for example a marathon race is run at approximately 75-85 % of VO_{2max} (Joyner and Coyle. 2008). After many years of endurance training only minor improvements in VO_{2max} can be attained, but endurance performance may still be increased by improving movement economy and lactate threshold (Jones 1998).

To improve physical performance capacity, hard training is essential, but what is hard training for one, may be easy for another person (Midgley et al. 2006). According to the overload principle the training session has to be hard enough to disturb the homeostasis of the bodily functions and the recovery time has to be good and long enough to allow an increase in the determinants of performance, i.e. the training effect. If the disturbance is small, no training effect will occur (Rusko 2003). On the other hand, if the training is too demanding for the athlete, overtraining syndrome may develop (Meeusen et al. 2006; Rusko 2003). It has been difficult to estimate this disturbance of homeostasis, but estimating autonomic modulation could be useful, since changes in autonomic modulation may last even hours after an exercise session has been stopped (Furlan et al. 1993).

Autonomic nervous system activity can be estimated non-invasively with heart rate variability (HRV) measurements (Task Force 1996). Cumulative training effects on nocturnal HRV have been studied in endurance athletes and sedentary people during different training periods (Hautala et al. 2001; Hynynen et al. 2007; Pichot et al. 2000; Pichot et al. 2002). Pichot et al. (2000) found progressive decrease of up to 40 % in nocturnal HRV during the hard training period, followed by rebound during the relative resting week in middle-distance runners during their usual training cycle. Decrement in nocturnal HRV after an overreaching period has also been reported by Hynynen et al. (2007) in international level cross-country skiers. Recently, it was shown that also single endurance exercises can have remarkable effects on HRV during the following night sleep (Hynynen et al. 2010).

Taken these together, the purpose of this case study was firstly to describe the annual changes in the endurance performance characteristics of an international level endurance athlete, secondly to get information of training induced changes on autonomic modulation with the help of regular nocturnal HRV analysis and thirdly to study how the changes in endurance performance characteristics and nocturnal HRV are related to the changes in the result of 20K and 50K race-walking. In addition, immediate feedback from all the measurements was given to help the athlete and his coach to adjust the training program if needed.

Methods

Analysis of test results

The subject was tested on an indoor track (200 m) twice a year (1st time in December-January and 2nd time in March-April) and an average of these two tests was used as a representative value annually. This procedure was made to minimize the day to day variation in VO_2 determination, and was similar to previous study of Jones (Jones. 1998). Preceding each test, the subject's height and body mass was measured and the sum of four skinfolds was taken for body fat estimation (Durnin and Rahaman. 1967). The race-walking test consisted of 6×1000 m stages beginning from 3.05 $m \cdot s^{-1}$ (5 min 27 s per kilometer), and increased by 0.28 $m \cdot s^{-1}$ every stage until the sixth stage, which was a maximal time trial. Heart rate was measured with Suunto t6 heart rate monitor and respiratory gas exchange with Oxycon Mobile (Viasys Healthcare GmbH, Hoechberg, Germany) continuously, and 20 µl blood samples were taken for lactate analysis (Biosen S_line Lab+, EKF – diagnostic GmbH, Barleben, Germany) immediately after completing each stage. Respiratory gas exchange variables were determined as an average of the last minute each stage, except the VO_{2max}, which was determined as the highest minute of the test. The energy cost was determined as the VO_2 required to race-walk at 3.61 $m \cdot s^{-1}$ and at 3.89

$m \cdot s^{-1}$. The higher speed is associated with the average speed of the World Record in 50 km race-walking set by Denis Nizhegorodov in May 2008 (3:34:13).

Analysis of HRV

The subject recorded nocturnal RR-intervals with a Suunto t6 heart rate monitor (Suunto Ltd, Vantaa, Finland) having a sampling frequency of 1000 Hz. RR-interval recordings were started before going to bed for sleep and stopped after waking up in the morning. First 30 min after going to bed was excluded and the succeeding 4-hour section was analyzed. The 4 hour period was selected, because it has been used in previous studies (Hautala et al. 2001; Hynynen et al. 2006; Hynynen et al. 2007; Pichot et al. 2000), and to compare HRV measurements, the selected periods should be of the same length (Task Force 1996). Nocturnal RR-intervals were collected throughout the year, and yearly recordings consisted of 125/2007, 235/2008, and 301/2009 night recordings (on average 220 nights/year). Results from the last 2 nights before the National Championship race of 20 km and the main race of the year (50 km in World Championships 2007 and 2009, Olympic Games 2008), and the first night after the races for every year are provided in this study. All the erroneous RR-intervals, like movement artifacts, were first carefully excluded using automated software (Firstbeat Health, Firstbeat Technologies Ltd, Jyväskylä, Finland) and visual inspection. The same software was used to analyze the average HR and the following HRV indices with frequency domain (Short-time Fourier transformation) methods: low frequency power (LFP; 0.04–0.15 Hz), high frequency power (HFP; 0.15–0.40 Hz), and total power (TP; LFP + HFP). In addition, the software was used to calculate the ‘recovery index’ for the 4-hour sections. The recovery index is calculated from the RRI-data, and basically it increases when HRV is high and HR is low and vice versa (Kettunen and Saalasti 2004). Profile of HRV through the year is provided as a follow-up figure of the recovery index.

Analysis of training

The subject kept a training diary, including subjective description, amount and intensity of the training sessions, and perceived exertion of the training sessions. In this paper, sum of weekly training hours is used in order to describe the training.

The study procedures and the right to withdrawal from any measurements at any time without repercussion were explained to the subject, and the subject gave his written informed consent before the beginning of the measurements. In addition, the subject gave permission to publish his results in this paper.

Results

In the beginning of this study the subject was 23 years old. During the 3-year follow-up period there was only a little variation in the body mass and body fat (Table 1). Also VO_{2max} seemed to be stabilized, or to slightly decrease in the last year. Although no changes in VO_{2max} was observed, the maximal aerobic performance, measured as time trial on 1000 m, improved by 4 %.

Table 1. Changes in various physical and physiological measures over three years.

	2007	**2008**	**2009**
Height (m)	1.88	1.88	1.88
Body mass (kg)	73.2	74.5	73.2
Body fat (%)	8.9	8.5	8.7
VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$)	66.1	66.2	62.9
Time trial of 1km (min:s)	3:47	3:45	3:39
v_{max} ($m \cdot s^{-1}$)	4.38	4.42	4.55
BLa_{max} ($mM \cdot l^{-1}$)	10.6	10.7	11.3

VO_{2max}, maximal oxygen uptake; v_{max}, average velocity of maximal time trial; BLa_{max}, maximal blood lactate concentration after the time trial.

The economy of race-walking improved, as seen in decreasing trend of cost of walking at submaximal speeds (Figure 1). Decrease in consumed oxygen per 1000 m was found to be 7.0 % at the higher speed and 2.6 % at slower speed (Figure 1). In addition, personal best times decreased steadily annually in 50K, but in 20K only minor changes were observed (Figure 2).

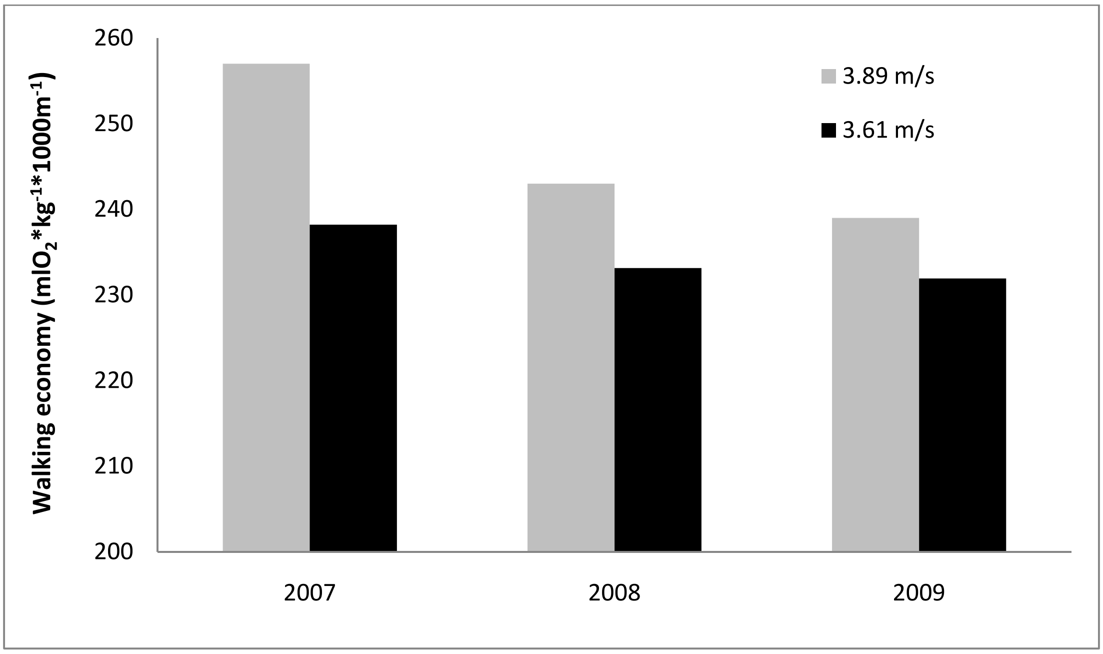

Figure 1. Cost of walking at 3.61 $m \cdot s^{-1}$ and 3.89 $m \cdot s^{-1}$ annually.

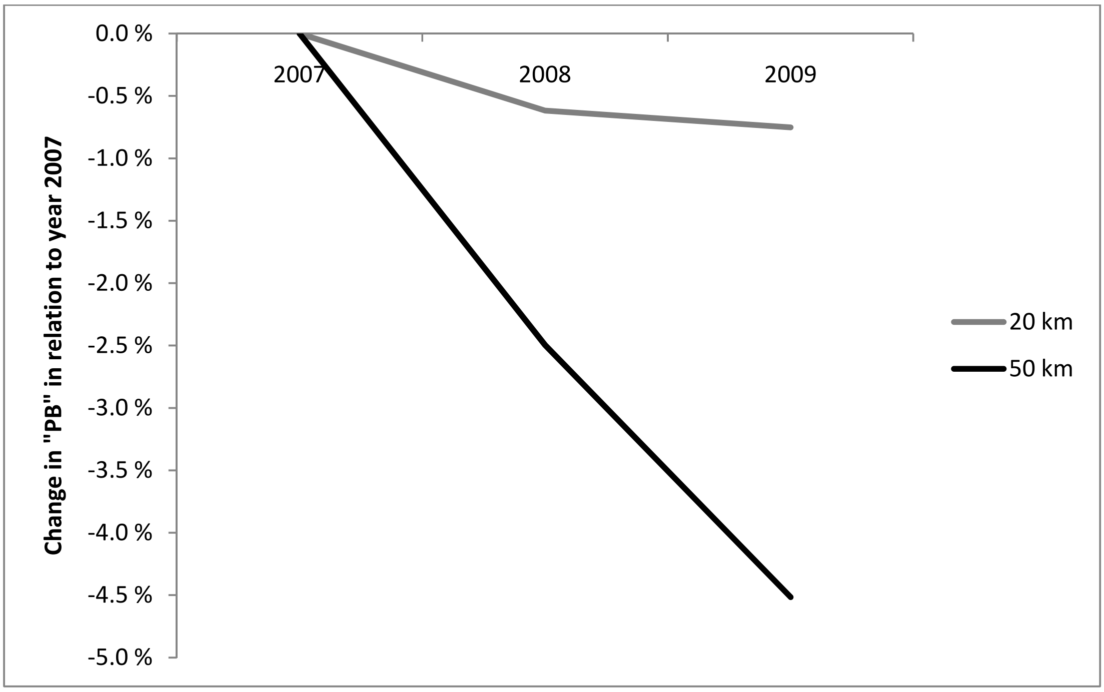

Figure 2. Improvement in personal best times (PB) in 20 km and 50 km races from 2007 to 2009.

The results from the national championship races of 20 km and from the international championship races of 50 km are presented in Table 2. The results of the 50 km races were new personal best times every year, but only the result of the 2008 race on 20 km was a new personal best time (at that time).

Table 2. Average heart rate and result of the national championship (20 km) and international championship (50 km) races annually (2007-2009). One HR value is missing due to technical problems in recording the HR data.

		2007	2008	2009
20 km	Result (h:min:sec)	1:29:24	1:25:56	1:27:30
	Average HR	-	186	172
50 km	Result (h:min:sec)	3:58:22	3:52:25	3:47:36
	Average HR	165	168	169

Table 3. Nocturnal HR and HRV before and after the national championship race (20 km) annually (2007 – 2009). The RR-interval data after the race in 2009 was too erroneous to be analyzed.

	2007		2008		2009	
	before	after	before	after	before	after
HRave (bpm)	55.8	62.7	49.5	64.7	51.1	-
LFP (ms^2)	9820	8424	7622	6456	5889	-
HFP (ms^2)	7281	3542	7393	3676	4104	-
TP (ms^2)	17101	11966	15015	10132	9994	-
Recovery index	162	109	196	101	165	-

HRave, average heart rate; LFP, low frequency power; HFP, high frequency power; TP, total power.

Table 4. Nocturnal HR and HRV before and after the 50 km competition annually (2007 – 2009).

	2007		2008		2009	
	before	after	before	after	before	after
HRave (bpm)	48.2	60.2	48.0	58.7	45.8	54.3
LFP (ms^2)	7361	6734	7160	8697	5237	8504
HFP (ms^2)	8946	3582	9782	5387	5901	7359
TP (ms^2)	16306	10316	16942	14084	11139	15862
Recovery index	219	120	222	134	209	164

HRave, average heart rate; LFP, low frequency power; HFP, high frequency power; TP, total power.

The dynamics in the nocturnal autonomic modulation through the whole training year are provided using recovery index as shown in Figures 3-5. Recovery index seemed to follow an opposite trend in comparison to weekly training hours, as pointed out with the arrows in the Figure 5. The lowest values of the recovery index, reflecting the highest cumulated training stress in the end of hard training periods, were found to be less than 150 (arbitrary units). If values less than 120 were found during the training season, they were associated to an infection, and in some cases, later a fewer. The additional stress of altitude on autonomic modulation was seen in lower values of recovery index, as highlighted in Figure 5. During competition season, values below 120 were sometimes found after a race, too (Table 3, Figures 3-5). In every year, a similar trend of increasing values of the recovery index was found during the last month preceding the main competition in the World Championships or the Olympic Games (Figure 6). It started from low values and ended up to values over 200 during the last week before the competition.

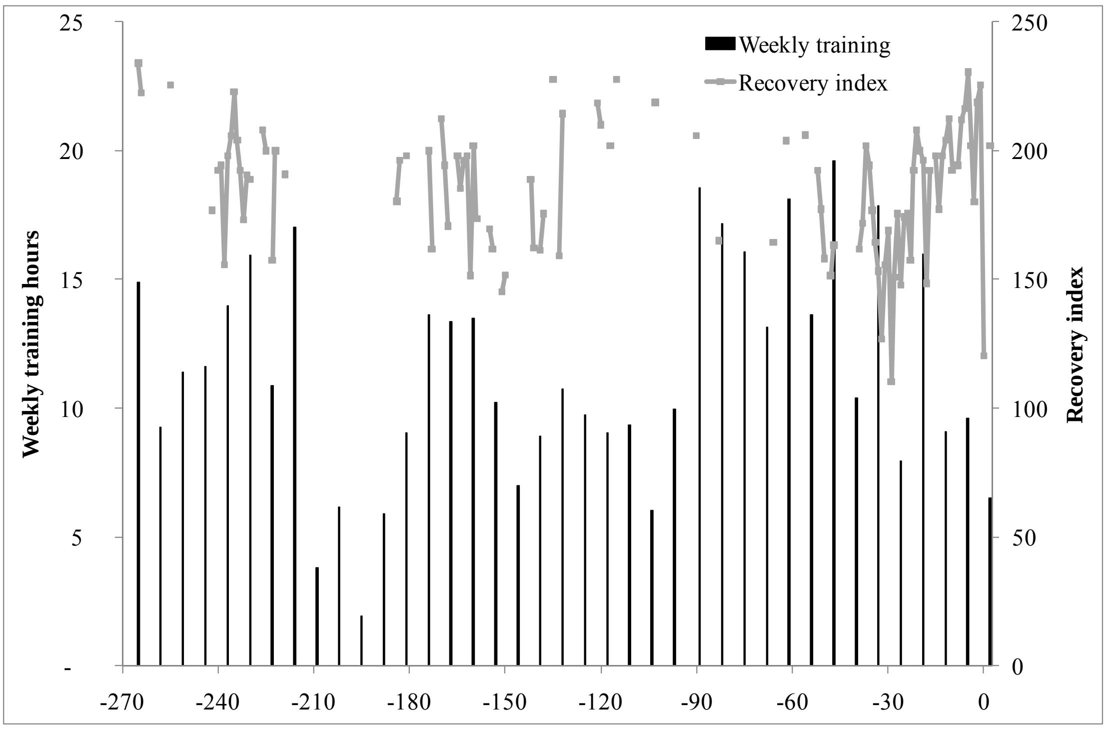

Figure 3. Recovery index through the training year 2007. Day 0 on the horizontal axis is the day of the main competition and the corresponding value of that day is from the very next night. The bar of the weekly training hours is located on Sundays.

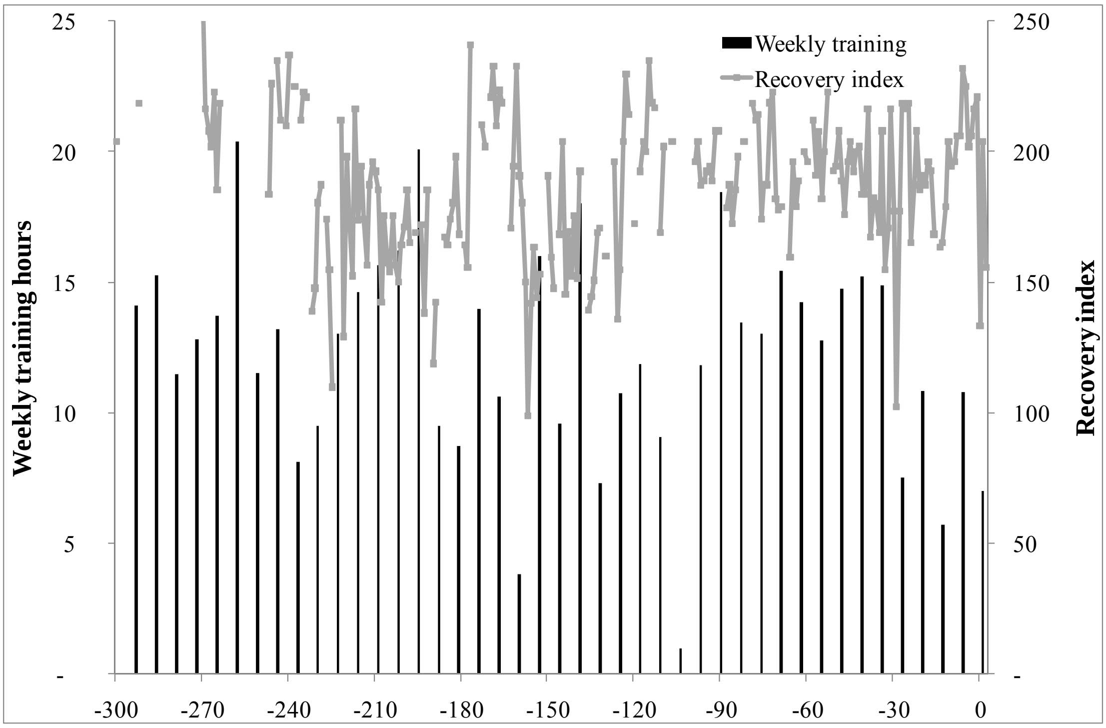

Figure 4. Recovery index through the training year 2008. Day 0 on the horizontal axis is the day of the main competition and the corresponding value of that day is from the very next night. The bar of the weekly training hours is located on Sundays.

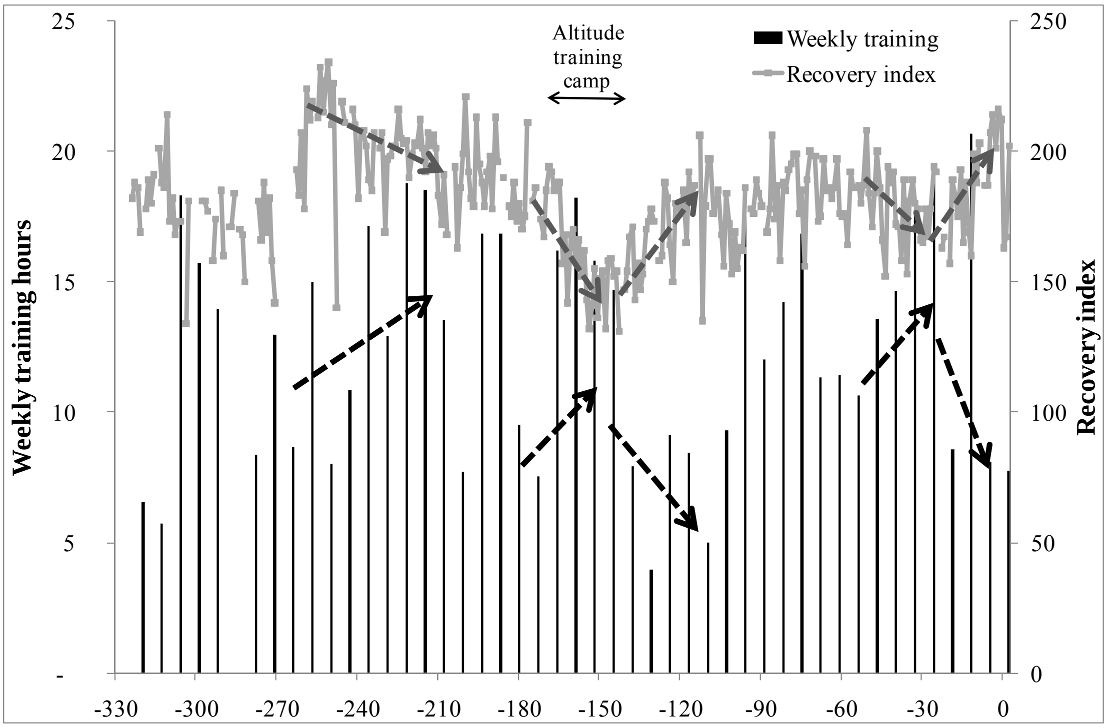

Figure 5. Recovery index through the training year 2009. Day 0 on the horizontal axis is the day of the main competition and the corresponding value of that day is from the very next night. The bar of the weekly training hours is located on Sundays. Additional arrows show opposite but simultaneous trends in training amount and recovery index.

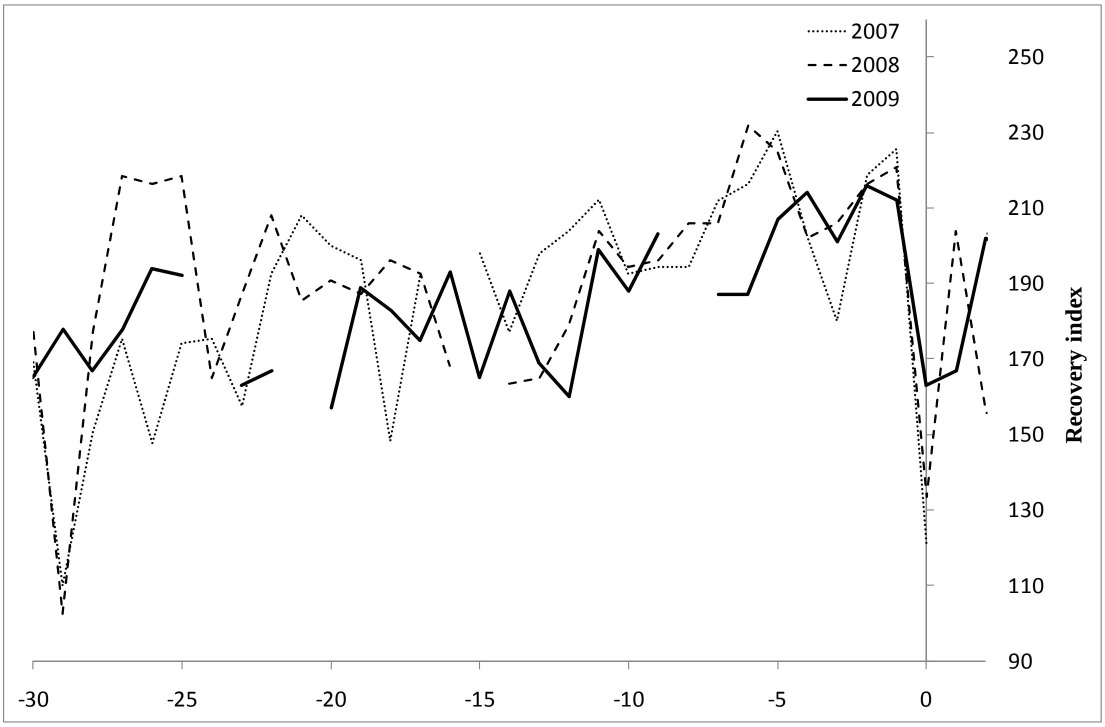

Figure 6. Recovery index based on nocturnal HR and HRV during the last 30 nights before the main competition.

Discussion

This study investigated the longitudinal changes in endurance performance characteristics and nocturnal HRV over a three-year period in an international level race walker. Simultaneously with a gradual improvement in the race-walking performance, there was a gradual improvement in walking economy, but practically no change in VO_{2max} was found during the follow-up period. Nocturnal HRV was found to be related to the stress of training, but no changes in HRV was found to be related to race-walking performance.

There was only a little variation in the body mass and body fat during the follow-up period. Although the maximal velocity in the 1000 m time trial improved 3.8%, there was no improvement in VO_{2max}. Simultaneously, energy cost of submaximal race-walking improved by 4.8 % and the race-walking performance in the main event, 50 km race, by 4.5 %. The energy cost of race-walking seemed to be similar to previous study of Brisswalter et al. (1998) even though the speed associated with the measurement was 1-2 km×h^{-1} higher in the present study. This finding of improved economy is in line with previous study of Jones (1998), where energy cost of running was found to decrease by 6.7 % with a simultaneous improvement of 2.6 % in the best time in 3000 m race during the last three year period of the five-year follow up of a world class female runner (Jones 1998). The association of improved running economy and race performance has been previously reported (Jones 1998; Maughan 2000) and the findings of this study complement the knowledge of endurance performance from the race-walking point of view. The subject in Jones study (1998) was only 17 years old at the beginning of the study and the physical growth and maturation may have complicated the interpretation of the results. However, the subject in the present study was 23 years old in the beginning of this study suggesting that growth and maturation had no effect on the improvement of the performance. As the top marathon runners have been reported to be on average close to 30 years old (Maughan 2000), one might expect the subject of our study to further enhance his performance for a few years. This development is supposed to happen via further improvements in the economy of race-walking and the ability to sustain higher percentage of his VO_{2max} for the time of approximately 3 h and 40 min.

The main finding from the nocturnal HRV measurements was that after a hard training session or a race, simultaneous increase in HR and decrease in HRV was found, which resulted in decreased recovery index. Not only the single values of recovery index after a hard training session, but also the trends over longer periods seemed to follow the stress of training and the subsequent recovery periods. Both the nocturnal HR and HRV are mainly related to the activity of parasympathetic branch of the autonomic nervous system, as it dominates usually during rest (Task Force 1996). Typically the training induced changes after a single exercise session (Hynynen et al. 2010), and a training period (Pichot et al. 2000; Pichot et al. 2002), are smaller in nocturnal HR than in HRV. The novelty of the HRV analysis used in this study was the combination of HR and HRV variables, the recovery index. As only one index was used as a follow-up measurement, it was easier to give feedback to the athlete from the training induced changes in nocturnal autonomic modulation. This method simplified the issue in a practical way, even though the formulas behind the index are proofed behind the patent (Kettunen and Saalasti 2004).

National Championship race on 20 km were held 3-4 weeks before the 50 km race every year and as the training program for the last month before the main race was very similar every year, it was also a “turning point” from training to taper. Interestingly, in 2008, nocturnal HRV analysis preceding the race showed high values when compared to HRV results in 2007 and 2009, where lower values of HRV suggested lower parasympathetic modulation than in 2008. This decrement in parasympathetic modulation may have been due to higher exertion from the preceding training periods and reflecting worse state of recovery. This interpretation of HRV results is further supported by the performance in the races, since in 2008 the result in the national championships was high and in relation to results in 2007 and 2009 races with time difference of 1.5 – 3.5 minutes in 20 km race. Also the effort in the 2009 race may have not been maximal, as seen in much lower average HR during that race in comparison to the 2008 race. During the final month preceding the 50 km race a reproducible ascending trend was found in nocturnal HRV measurements suggesting that the tapering phase was successful for the recovery of the body. The recovery index rose every year to values of 210-220 during the last week before the race. Also the recovery index preceding the national championship race in 2008 was close to the values seen before the main event, and the result of that race was a new personal best. Based on the experience of three years, for this individual athlete, recovery index value of approximately 200 or higher seems to be needed to be able to perform at high level.

Previously, Kiviniemi et al. (2007) suggested, that HRV measurements in the morning may be used to tailor the individual training program in a very successful way. They advised the recreational athletes in their study to do high intensity training only if the morning HRV was high. If the HRV was low, lower intensity or rest was suggested for the athlete (Kiviniemi et al. 2007). Similarly, the athlete in this study has used the nocturnal HRV measurements to adjust the training schedule especially during the high altitude training camps (no specific results shown here). However, as the group of Kiviniemi (2007) collected the individual database for the morning HRV, also the findings of this study suggest that the determination of the individual window of normal variation of nocturnal HRV is needed to be able to interpret the results of the HRV measurements. It seems that one divergent result is not always a “bad sign”, but if several consecutive nocturnal HRV measurements show unexpected results, there is a reason for them. This reason may be related to overreaching or some infection / other medical problem, and sometimes the cause of stress reactions may come from outside the sport. In any case, in order to decrease the relationship between stress and recovery and improve the performance, the cause of stress must be removed. If the stress is prolonged, undesirable results may follow.

In conclusion, this longitudinal study of an international level race-walker showed that performance increments in race times were associated to increments in the economy of race-walking, not to changes in VO_{2max}. Nocturnal HRV was found to be associated to the training and racing induced stress and an individual variation in recovery index was provided. In order to perform at high level in a competition, race-walker needs to be in a recovered state and parasympathetic dominance should be shown in nocturnal HRV analysis in pre-competition nights.

Recommendations

Regular physiological testing gives important and valid information on the athlete, that can’t be found from the results of competitions. In addition, regular nocturnal HRV analysis can give online feedback whether the athlete is recovered or stressed. Based on the experiences of the athlete and his coach, the following list of findings and recommendations concerning HRV measurements is provided:

- Regular HRV analysis is needed to be able to react soon enough to undesirable changes in athlete’s state of recovery.
- Great help especially when the coach can’t be present in e.g. high altitude training camp.
- The athlete will learn to analyze the effects of different issues to the readiness to train and compete.
- Avoid “bad training days” by adjusting the training schedule according to the athlete’s feelings together with the results of HRV analysis.
- Adjust the rhythm of training and rest individually with the help of HRV analysis, the common 3:1 is not the best for every athlete.

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