ABSTRACT

The purpose of the study was to investigate the validity of different methods to describe training load in sprint interval exercises. Since it is generally believed that athletes can inherently evaluate the physical stress of their bodies experience during exercise, RPE was selected as a valid method to describe training load. Sprint runners performed totally 45 single sprints (200-600 m) at the intensity of 65-92% and 95 different sprint interval exercises (SIE) with various combination of intensities and distances. The running times were taken from each single sprints and SIE as well as recovery times from SIE, heart rate was recorded during runs and recovery periods, RPE was asked after the exercise, and blood lactate concentrations were analyzed after the sprints and SIE. Furthermore, the training of one sprinter, who entered in the state of overreaching, was monitored from November to April during two 8-week training periods cut with the 4-week indoor season. Blood lactate concentration had the high correlation with RPE both in single sprints (r = 0.76, p < 0.001) and SIE (0.77, p < 0.001). The novel index of sprint training load and heart rate recovery had also significant correlations with RPE in single sprints and SIE. It was concluded, that blood lactate concentration, heart rate recovery and the novel index of sprint training load can be used to determine training load in sprint interval exercises. However, none of these methods seems not to be enough alone to monitor accurately training load and fatigue. There is currently not one method which can be used to monitor physiological adaptation and prevent overtraining in the training of sprint running.

INTRODUCTION

The ultimate goal of any sports coach and athlete is to improve performance in the particular sport and to produce a winning or personal best performance at a specific competition. The prescription of the training required to achieve this goal is based on years of coaching experience of that particular sport and thorough knowledge of the athlete. The role of scientific research in coaching process is becoming more important in order to prescribe optimal training programs that prevent both under- and over-training as well as injuries.

The intensity, duration and frequency of exercise all determines the training load and training effect. Furthermore, the training load is dependent on the exercise mode or sport, the muscles being used, individual factors like performance profile, training background and training state of the athlete and external conditions. Surprisingly little research, however, has been conducted into the quantification of training programs and their effects on training load, physiological adaptation and subsequent performance.

Training load of a constant load endurance exercise has been described by heart rate, oxygen consumption, blood lactate, rating of perceived exertion (RPE), excess post exercise oxygen consumption (EPOC) and exercise intensity and duration (Børsheim and Bahr 2003; Borresen and Lambert 2009). Banister (1991) proposed a training impulse (TRIMP) method to quantify training load of endurance exercises using person’s heart rate response to exercise and exercise duration. In attempt to simplify the quantification of training load, Foster (1998) introduced the use of session RPE instead of using heart rate data or having to measure the intensity of exercise of being performed.

Sprint interval exercises differ substantially from constant load endurance exercises due to high intensity, short duration and interval nature of the exercise. In sprint interval exercises the intensity is often higher than the velocity at maximal oxygen uptake (VO_{2max}) suggesting that oxygen uptake and heart rate during the exercise are not valid methods to describe training load. In practice, coaches use stop watch, athlete’s perceived exertion, blood lactate measurements and heart rate recoveries to assess training load in sprint
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interval exercises. All the methods are useful but none of them gives objective and unambiguous measure of the training load of sprint interval exercise. In speed endurance sports like running distances from 100 m to 800 m, there is a need for an objective method, which can be used to measure training load of a sprint interval exercise.

The aim of the present study was to investigate the suitability and validity of different methods to describe training load in sprint interval exercises. RPE was selected as a valid method to describe training load since it is generally believed that athletes can inherently evaluate the physical stress of their bodies experience during exercise. Another aim of the present study was to investigate the validity of the novel model to measure training load in sprint interval exercises and during interval training period.

METHODS

**Single sprints.** The present study had three separate parts. In the first part three female and five male sprint runners (Table 1) performed 3-8 single sprints on separate days. The sprints were 200 m, 300 m and 600 m at 65-92% of their personal best time (PB). All the runs were timed by stopwatch, heart rate was recorded with RR intervals from the beginning of the exercise to at least 2 min after the exercise using same devices as in single sprints. RPE was also asked after the exercise using the RPE scale from 0-10+ (Table 2). In order to analyze blood lactate concentration (Biosen S_Line Lab+, EKF Diagnostic GmbH, Magdeburg, Germany) 20 μl fingertip blood samples were taken immediately and 3 min after each sprint.

**Sprint interval exercises (SIE).** In the second part of the study, the subjects were seven female and nine male sprint runners (Table 1). The sprinters performed totally 95 different SIE within three months training period. From each SIE running and recovery times were taken by stopwatch, heart rate was recorded with RR intervals from the beginning of the exercise to at least 2 min after the exercise using same devices as in single sprints. RPE was also asked after the exercise using the RPE scale from 0-10+ as in single sprints (Table 2). Blood lactate concentrations were analyzed from 20 μl fingertip blood samples immediately and 3 min after the SIE.

**Sprint training period.** In the third part of the study, the training of female sprinter (Age 28, Height 170, Body mass 56 kg, PB in 400 m 52.27) was monitored from November to April during two 8-week training periods cut with the 4-week indoor season. The first training period was successful and she did her personal best time in 400 m indoor game. During the second training period her performance decreased significantly and she could not recover completely during the following 3-month competitive season. The sprinter recorded details of each interval training sessions in her training diary. The recorded data was the distance and time of each sprint, the recovery times between the sprints and RPE (0-10+) of each training sessions. Furthermore, she performed maximal 30-m speed test with a running start and Maximal Anaerobic Running Test (MART) on November and April after the second training period. The MART was performed on a 200-m indoor track and it consisted of 10 times 150-m runs with a 100-s recovery between the runs (Nummela et al. 2007). Before the MART, 40 s after each run and 2.5, 5 and 10 min after the last run fingertip blood samples were taken and blood lactate concentrations were analyzed using Biosen S_Line Lab+ analyzer (EKF Diagnostic GmbH, Magdeburg, Germany). The velocity of the first run was 3.94 m ∙ s⁻¹ and thereafter the velocity of the treadmill was increased by 0.41 m ∙ s⁻¹ for each consecutive run until the last run, which was performed at maximal effort. The desired running velocity was guided during the first nine 150-m runs by the so-called light rabbit (Naakka Ltd., Lappeenranta, Finland), in which red lights at the intervals of four meters were switched on according to the preset velocities.

**Analyses.** Average and relative running speed (% of the PB) was calculated for all the single sprints and all the sprints in SIE. Furthermore, in SIE the total distance, total running and exercise time (exercise time = running time + recovery time) were also calculated. The higher of the two lactate values after the single sprint or SIE was selected to represent blood lactate concentration of the particular sprint or SIE. The peak
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heart rate and heart rate recovery value was determined after 30, 60, 90 and 120 s after single sprints and after SIE.

**Sprint training load.** Training load was calculated for single sprints and SIE using a novel method. In the new model, running intensity and distance as well as individual performance profile determines the sprint load index of a single sprint (Figure 1A). In SIE not only running intensity and distance but also the cumulative training load and the time for recovery determines the training load value (Figure 1B).

**Statistical analyses.** All statistical comparisons and analysis were done by the SPSS / PC+™ program (SPSS Inc. Chicago, USA). Standard statistical methods were used to calculate means, standard deviations and coefficients of correlations. Standard t-test was used to compare the two 8-week training periods. Statistical significance was set at p < 0.05.

**RESULTS**

**Single sprints.** Totally 42 sprints were measured from eight different sprinters (Table 3). Correlation analysis between RPE and different variables of single sprints revealed that running intensity affected more training load of single sprints than running distance. The highest correlations were observed between RPE and blood lactate correlation (r = 0.764, p < 0.001) and the new index of sprint training load (r = 0.810, p < 0.001). Furthermore, a significant correlation was observed between blood lactate and the new index of sprint training load (r = 0.910, p < 0.001).

**Sprint interval exercises.** Totally 95 sprint interval exercises with different combinations of running distances from 100 m to 600 m at various intensities (from 46 to 99% of PB) and recovery periods were measured from 16 sprinters. Correlation analysis between RPE and SIE characteristics showed that running intensity (either absolute or relative speed) is the most important factor determining training load in SIE (Table 4). The best marker of sprint training load was blood lactate (r = 0.771, p < 0.001). Unlike in single sprints also heart rate recovery had high correlations with RPE in SIE (Table 4). In addition, a significant correlation was observed between blood lactate and the new index of sprint training load (r = 0.727, p < 0.001).

**Sprint training period.** MART and 30-m maximal speed test data as well as the average training data of two 8-week training period before and after the indoor season is shown on Table 5. The average training data showed that the training during the first 8-week period was harder than during the second 8-week period, but the sprinter entered in the state of overreaching during the second 8-week period. RPE and the index of sprint training load increased gradually during both 8-week training periods as shown in Figures 2A and 2B, respectively. Figure 3 shows that in the first 8-week training period similarly rated sprint interval exercises got higher index of sprint training load than in the second 8-week training period. Correlation analysis showed that the relationship between RPE and the index of sprint training load was higher during the first 8-week period (r = 0.615, p < 0.001) than during the second one (r = 0.377, p = 0.037).

**DISCUSSION**

The aim of the present study was to investigate whether simple and user-friendly methods can be used to describe training load in sprint interval exercises. RPE was selected as a valid method to describe training load since it is generally believed that athletes can inherently evaluate the physical stress of their bodies experience during exercise. Although RPE may be influenced by psychological factors it has been strongly correlated with heart rate and blood lactate measurements in a variety of populations and is widely recognized as an integrated measure of the homeostatic disturbance during exercise (Scherr et al. 2013, Eston 2012). The results from single sprints showed that blood lactate concentration and the novel index of sprint training load were the best methods to describe training load in single sprints. Blood lactate was the
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best method also in SIE to describe training load. Furthermore, the index of sprint training load and heart rate recovery (HRR) had significant relationship with RPE. Based on the current results, the relationship between HRR and RPE improved with the recovery time attaining the highest correlation at 2 min of recovery.

**Blood lactate.** It was not a surprise that blood lactate has the highest correlation with RPE both in single sprints and in SIE. Lactate is the end product of glycolysis, the anaerobic pathway to produce energy during high intensity exercises. Glycolysis begins within the first seconds after the initiation of high intensity exercise and contributes the provision of energy during short term high intensity exercises (Boobis et al. 1983; Hultman and Sjöholm 1983). Blood lactate concentration is related to lactate production and concentration in a muscle (Hirvonen et al. 1992). The high correlation between RPE and blood lactate can be explained by the association of acidosis and fatigue (Ament and Verkerke 2009).

The measurement of blood lactate concentrations has become easier and more practical with the development of portable measurement devices and requiring the collection of only one drop of blood from a finger prick. Since blood lactate measure is invasive, it remains impractical to measure lactate from each sprint interval training session in order to quantify sprint training load. Furthermore, both improvements in training status and overtraining have been associated with decreases in maximal and submaximal blood lactate concentration (Jeukendrup and Hesselink 1994), which may lead to erroneous interpretation of lactate measurements and incorrect exercise prescription.

**Heart rate recovery.** Heart rate recovery was calculated in the present study with both absolute and relative values. Percentage values from peak heart rate of single sprint or SIE were presented in the final results, since they were best correlated to RPE values. The heart rate response to the cessation of exercise is governed by the autonomic nervous system, specifically parasympathetic reactivation and sympathetic withdrawal (Pierpoint and Voth 2004; Savin et al. 1982). Changes in autonomic nervous system activity after the exercise is affected by improved endurance performance and overtraining. Therefore, it may also be practical and reliable marker of training load and fatigue and provide information about training induced changes in performance.

In single sprint HRR was not strongly related to RPE. Peak heart rate measured in a short term exercise is not reliable measure and it is not related to training load of a single sprint. Therefore, neither the HRR (% of peak heart rate) is a reliable measure. On the contrary, in SIE peak heart rate is more reliable, since previous sprints increase heart rate in sprints and heart rate stays elevated during recovery and therefore less time is needed to attain the peak heart rate. When measuring HRR, it is important that athlete stays still during the recovery and in the same position every time. In the present study, the sprinters were in standing position two minutes after the single sprints and after the exercises. According to the present results, the correlation between RPE and HRR increased with recovery time attaining highest values after two minutes recovery both in single sprints and whole SIE. In single sprints, 90 s is needed to attain a significant relationship with RPE and in SIE 60 s is enough to get a reliable measure.

**Index of sprint training load.** The index of sprint training load is affected by the intensity and length of the sprint as shown in Figure 1A. The scale from 0 to 100 is used in the sprint training load of single sprints but in SIE values above 100 are possible to reach. There is a curvilinear relationship between the sprint training load and both the intensity and distance. In the model, the highest sprint training load values are attained in 400-500 m sprints at maximal intensity. This is supported by previous study (Kinderman and Keul 1977), which has shown that the ATP resynthesis from glycolysis is highest in maximal exercises lasting 40-50 s. The intensity is presented in the model as percentage value of the personal best result of the used sprinting distance. This is one way to individualize the model. The other way is to use the performance profile of the sprinter. In SIE, not only the determination of training load of a single sprint but also the effect of recovery
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on sprint training load is needed to determine. In order to calculate sprint training load, the effect of each recovery period is added to the index using the recovery model presented in Figure 1B. In the model, the cumulative training load of the previous sprint or sprints and time for recovery determine the final sprint training load.

The index of sprint training load had even higher correlation with RPE than blood lactate in single sprints. Furthermore, a significant correlation was observed between sprint training load index and blood lactate value suggesting that the model is a valid method to measure training load in sprint running.

In SIE, the correlation between RPE and the index of sprint training load was lower than the correlation of blood lactate but it was still significant and close to the correlation of HRR. Furthermore, a significant correlation was observed between sprint training load index and blood lactate in SIE suggesting that sprint training load model is also a valid method to determine training load in sprint interval exercises of sprint runners. The advantage of the index to blood lactate or HRR is that it is non-invasive and does not need any expensive devices as heart rate monitors to determine sprint training load. All you need is stopwatch for measuring sprint and recovery times.

Sprint training period. In the present study, a sprint training case was presented in which the preparation to indoor season was successful but in the following 8-week training period the sprinter entered in the state of overreaching and she could not attain her personal best during the following outdoor season. Based on the training summary of the two 8-week training period before and after the indoor season (Table 5), the 8-week training period before the indoor season was harder than the 8-week training period after the indoor season. Nevertheless, after the indoor season she entered in the state of overreaching. Even the average values of RPE and the index of sprint training load showed that the 8-week period before the indoor season was harder than the period after the season.

As concluded by Borresen and Lambert (2009) there is currently no accurate and quantitative methods with which to prescribe the pattern, duration and intensity of exercise required to produce specific physiological adaptations. There is no single physiological marker which can used to quantify the performance effects and training load or fatigue responses to exercise or predict performance with accuracy. As such, more research and innovations are needed to find easily measurable physiological markers of physical fitness and training load or fatigue to improve the accuracy the performance can be predicted and under- and overtraining can be prevented. The relationship between training characteristics and the observed changes in physiological variables and performance are highly individual and depends on numerous factors that influence an athlete’s tolerance of a training load. Even the same exercise has different physiological responses on the same individual at different time depending on the performance profile and state of training.

Then, how could we say that the sprinter entered in the state of overreaching at the end of the 8-week training period on April. One of the aims of the sprint interval training is that one can run faster at the same blood lactate level as shown in the results of MART in Table 5. But if at the same time maximal anaerobic performance, maximal running speed and peak blood lactate concentration decrease, it is a sign of overreaching or overtraining (Jeukendrup and Hesselink 1994). To confirm this interpretation the sprinter in the present study could not reach her personal best level throughout the outdoor season.

The ratings of perceived exertion of SIE was at the same level and increased similarly during the both two 8-week training periods (Figure 2A). The only difference was that the standard deviation of RPE was smaller after the indoor season. The RPE values were from 6 to 8, only one SIE was rated as 5, after the indoor season, whereas before the season the RPE values varied from 5 to 9. Moreover, the slope of the increase of the index of sprint training load during the second 8-week training period was lower than during the first 8-week training period (Figure 2B). This means that the objectively measured training load of SIE during the
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8-week period after the indoor season was lower than during 8-week training period before it. Furthermore, the standard deviation of the index of sprint training load was smaller during the 8-week training period after the indoor season than before it. The combined RPE and index of sprint training load data indicates that after the indoor season the sprinter rated the SIE with lower training load similarly as the SIE with higher training load before the indoor season (Figure 3). Moreover, the difference between the training periods increased toward the end of the periods suggesting that the sprinter gradually entered in the state of overreaching during the 8-week training period after the indoor season.

The only possible reason from the training data for the overreaching after the indoor season was that there was not enough variation in training load in sprint interval exercises after the indoor season. The more probable reason for the overreaching is the unknown factors and stressors outside the exercises. An athlete must be an athlete 24/7, since not only the training but also the recovery is important factor in the adaptation process. Therefore, the factors outside the exercises like psychological stressors, nutrition, rest and quality of sleep are significant when assessing the reasons for overreaching or overtraining.

The data of this case study confirms the conclusion of Borresen and Lambert (2009) that there is currently no single accurate method which can be used to monitor both physiological adaptation and fatigue. Nevertheless, monitoring and combining different data from training diary and physiological measurements from an athlete it is possible to find out the positive and negative changes in physiological adaptation and fatigue.

CONCLUSIONS

It can be concluded that the intensity is the most important factor determining training load in sprint interval exercises. In addition to RPE, blood lactate concentration, heart rate recovery and the index of sprint training load can be used to determine training load in sprint interval exercises. However, none of these methods seems not to be enough alone to monitor accurately training load and fatigue. In order to prevent under- or overtraining in sprint running you need to monitor training data and different physiological responses.

RECOMMENDATIONS

In the training of sprint running the running speed and intensity (% PB) in sprint interval exercises is an important factor to monitor, since it is the most important factor determining training load and causing adaptation in sprint running. In order to calculate the index of sprint training load, not only the running speed and intensity of SIE but also sprinting distance and time of recovery are needed. Therefore, it is recommended to record the details of sprint interval exercises in the training diary.

Training data alone does not give enough information of the training adaptation and fatigue of a particular sprinter. Coaches and athletes should also know the individual physiological responses to training, since similar training does not give similar adaptation for each individual. Based on the results of the present study RPE, blood lactate concentration, heart rate recovery and the novel index of sprint training load are all valid and valuable measures to monitor physiological adaptation and training load or fatigue in sprint interval exercises.

REFERENCES

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