Monitoring Training Load in Sprint Interval Exercises

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ABSTRACT

Current methods for assessing sprint training such as stopwatch timing and monitoring the athlete's perceived exertion, heart-rate recovery and blood lactate measurements are useful tools, but none provide unambiguous measures of training load. The purpose of this three-part study was to investigate the validity of different training load descriptors, including a new model for measuring training load in sprint interval exercises (SIEs) and over the course of a training period. The author compares data collected from single sprints of various intensities performed on separate days by eight athletes, from SIEs performed over the course of three months by 16 athletes and from the training of a single athlete in two eight-week periods. He concludes that a combination of methods is best for accurately monitoring training load but coaches and athletes should be aware of individual physiological responses, since similar training may not give similar adaptations for each individual. In addition, he finds that the index of sprint training load provided by the new model has certain practical advantages as it is non-invasive and does not require expensive devices yet correlates well to the other measures studied.

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Introduction

The ultimate goal of any sports coach and athlete is to improve the athlete's performance, producing a win or a personal best at a specific competition. The prescription of the training required to achieve this goal is based on years of coaching experience and a thorough knowledge of the athlete. The role of scientific research in the process is becoming more important in order to prescribe optimal training programmes preventing both under- and over-training as well as injuries.

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

The training load of endurance exercises 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[4,5]. In turn, BANISTER[2] proposed a training impulse (TRIMP) method to quantify the training load of endurance exercises using a person's heart-rate response to exercise and duration. In an attempt to simplify the quantification of training load, FOSTER[7] introduced the use of session RPE instead of using heart-rate data or having to measure the intensity of exercise.

Sprint interval exercises (SIEs) differ substantially from endurance training due to the higher intensity, shorter duration and interval nature of the exercise. In SIEs the intensity is often greater than the velocity at maximal oxygen uptake (VO_2 max), suggesting that oxygen uptake and heart-rate during the exercise are not valid methods to describe training load. In practice, coaches assess training load in SIEs with a stopwatch and by monitoring the athlete's RPE, blood lactate measurements and heart-rate recovery. All these methods are useful but none of them provide objective and unambiguous measures of the training load. In speed endurance sports, such as running distances from 100m to 800m, there is a need for an objective method that can be used to measure training load of a SIE.

The aim of the present study was to investigate the validity and suitability of different methods currently used to describe training load in SIEs. A secondary aim was to investigate the validity of a novel model for measuring the training load in SIEs and over the course of a training period.

Methods

Single sprints

This study was divided into three parts. In the first, three female and five male sprinters performed three to eight single sprints on separate days (Table 1). The sprints were 200m, 300m and 600m performed at 65-92% of the athlete's personal best time (PB). All the runs were timed and heart-rate was recorded (Suunto t6, Suunto Oy, Vantaa, Finland) from beat-to-beat with RR intervals (the peak between

Table 1: Description of female and male sprinters in the single sprints and sprint interval exercises

	Single Sprints		**Sprint Interval Exercises**	
	Women (n = 3)	Men (n = 5)	Women (n = 7)	Men (n = 9)
Age (years)	25.7 ± 4.9	25.8 ± 5.1	24.7 ± 2.6	25.8 ± 5.1
Height (m)	1.69 ± 0.02	1.85 ± 0.03	1.71 ± 0.06	1.87 ± 0.04
Body mass (kg)	55.0 ± 1.0	78.5 ± 3.0	60.4 ± 7.2	83.1 ± 4.8
Maximal heart-rate (bpm)	198 ± 6	197 ± 2	196 ± 5	197 ± 4
PB in 100 m (s)	12.64 ± 0.72	11.44 ± 0.45	12.37 ± 0.68	11.17 ± 0.46
PB in 200 m (s)	25.24 ± 1.66	22.54 ± 0.68	24.90 ± 1.23	22.15 ± 0.80
PB in 400 m (s)	56.58 ± 3.75	50.60 ± 3.37	56.55 ± 3.10	50.47 ± 2.62

Table 2: Rating of perceived exertion (RPE) scale used in the present study

0	Nothing at all
0.5	Extremely easy
1	Very easy
2	Easy
3	Moderate
4	
5	Hard
6	
7	Very hard
8	
9	
10	Extremely hard
10+	Absolute maximum

one R wave and the next in the electrocardiogram) during the sprints and a 2 min recovery in standing position. RPE was recorded after the sprints using a 0 - 10+ scale (Table 2). To measure blood lactate concentration, 20µl fingertip blood samples were taken immediately and at 3 min after each sprint and analysed (Biosen S_Line Lab+, EKF Diagnostic GmbH, Magdeburg, Germany).

Sprint interval exercises (SIEs)

In the second part of the study, seven female and nine male sprinters participated, (Table 1). In total, 95 different SIEs were performed over a three-month period. Running and recovery times for each SIE were measured with a stopwatch, while heart-rate was recorded with RR intervals from the beginning of the exercise until at least 2 min after the exercise using the same devices as for the single sprints. Similar to part one, RPE and blood lactate concentration levels were measured and recorded (Table 2).

Sprint training period

In the third part of the study, the training of a female sprinter (Age: 28yrs, Height: 170cm, Body mass: 56kg, PB in 400m: 52.27 sec) was monitored during two eight-week training periods separated by a four-week indoor competition season. The first training period was successful, with the athlete going on to record a personal best time in the 400m indoors. During the second training period, her performance decreased significantly and she was unable to recover completely during the following three-month outdoor competition season. The athlete recorded details of each interval training session in her training diary. The recorded data included the distance and time of each sprint, the recovery times between the sprints and RPE (0-10+) for each training session.

Furthermore, a maximal 30m speed test with a running start and a maximal anaerobic running test (MART) were conducted in November and April, after the first and second eight-week training periods, respectively. The MARTs were performed on a 200m indoor track and consisted of 10 x 150m with a 100 sec recovery between the runs[12]. The desired running velocity was determined for the first nine 150m runs with a light rabbit (Naakka Ltd., Lappeenranta, Finland), in which red lights at intervals of four meters were switched on according to preset velocities. The velocity of the first run was 3.94 m/sec and thereafter the velocity of the light rabbit was increased by 0.41 m/sec for each consecutive run until the last run, performed at maximal effort. Before the MARTs, 40 sec after each run and 2.5, 5 and 10 min after the last run, fingertip blood samples were taken and the blood lactate concentrations were analysed (Biosen S_Line Lab+, EKF Diagnostic GmbH, Magdeburg, Germany).

Analyses

Average velocity and relative running velocity (% of the PB) were calculated for all the single sprints and all the sprints in the SIEs. Furthermore, the total distance, total running and exercise times (exercise time = running time + recovery time) for the SIEs were also calculated. The

higher of the two lactate values after the single sprints or the SIEs was selected to represent blood lactate concentration of that particular sprint or SIE. The peak heart-rate and heart-rate recovery value was determined 30, 60, 90 and 120 sec after the single sprints and SIEs.

Sprint training load

Training load was calculated for the single sprints and SIEs using a new method. In this model, running intensity, distance and individual performance profile were used to calculate the sprint load index of a single sprint (Figure 1A). With regards to the SIEs, in addition to running intensity and distance the cumulative training load and the time for recovery were included in the model to determine the training load value (Figure 1B).

Statistical analyses

All statistical analyses and comparisons 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. The Standard t-test was used to compare the two eight-week training periods. Statistical significance was set at $p < 0.05$.

Results

Single sprints

A total of 42 sprints by eight sprinters were measured (Table 3). Correlation analysis between RPE and different variables of the single sprints revealed that running intensity affected the training load of single sprints to a greater extent than running distance. The highest correlations were observed between RPE and blood lactate ($r = 0.764$, $p < 0.001$) 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

A total of 95 SIEs by 16 sprinters using different combinations of running distances from 100m to 600m at various intensities (from 46 to 99% of PB) and recovery periods were measured. Correlation analysis between RPE and SIE characteristics showed that running intensity (either absolute or relative velocity) was the most important factor determining training load, (Table 4) with blood lactate being the best marker for sprint training load ($r = 0.771$, $p < 0.001$). Unlike the single sprints, a high correlation between heart-rate recovery and RPE in the SIEs was observed (Table 4). In addition, a significant correlation was seen between blood lactate and the index of sprint training load ($r = 0.727$, $p < 0.001$).

Sprint training period

The data for the MARTs and 30m maximal speed test as well as the average training data for the two eight-week training periods before and after the indoor season are shown in Table 5. The average data indicates that the training during the first period was harder than the second, with the athlete experiencing a state of over-training in the second period. RPE and the index of sprint training load increased gradually during both periods as shown in Figures 2A and 2B, respectively. Figure 3 shows that in the first period similarly rated sprint interval exercises achieved a higher index of sprint training load than in the second. Correlation analysis regarding the relationship between RPE and the index of sprint training load was higher during the first ($r = 0.615$, $p < 0.001$) than the second ($r = 0.377$, $p = 0.037$).

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. The athlete's rating of perceived exertion was selected as a valid method to describe training load. 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 recognised as an integrated measure of the homeostatic disturbance during exercise[15]. The results from the single sprints indicated that blood lactate concentration and the

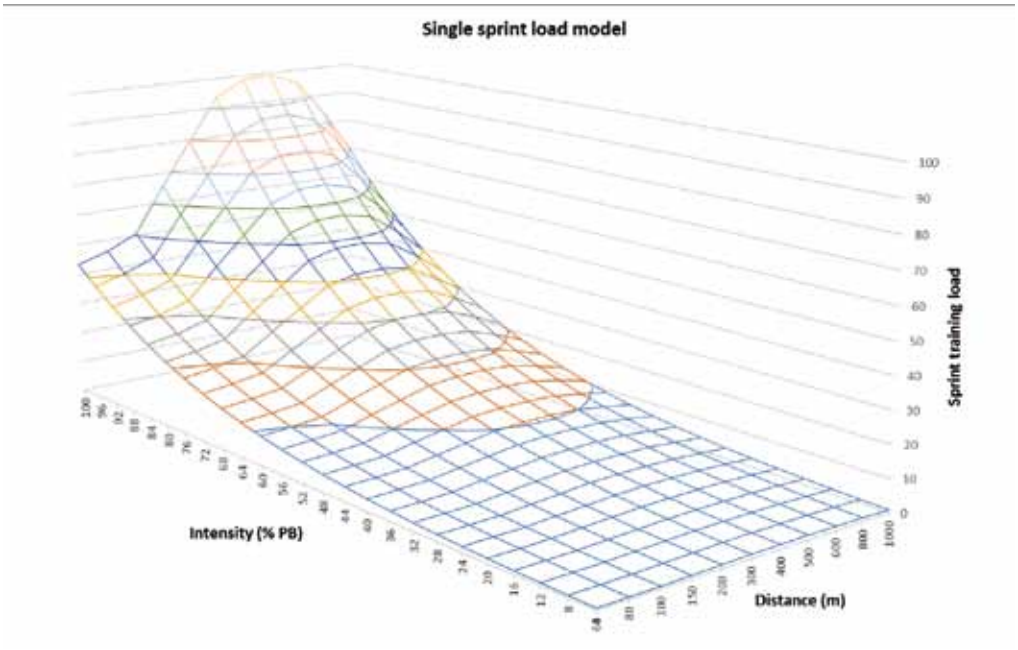

Figure 1A: The effect of running intensity (% PB) and distance on sprint training load

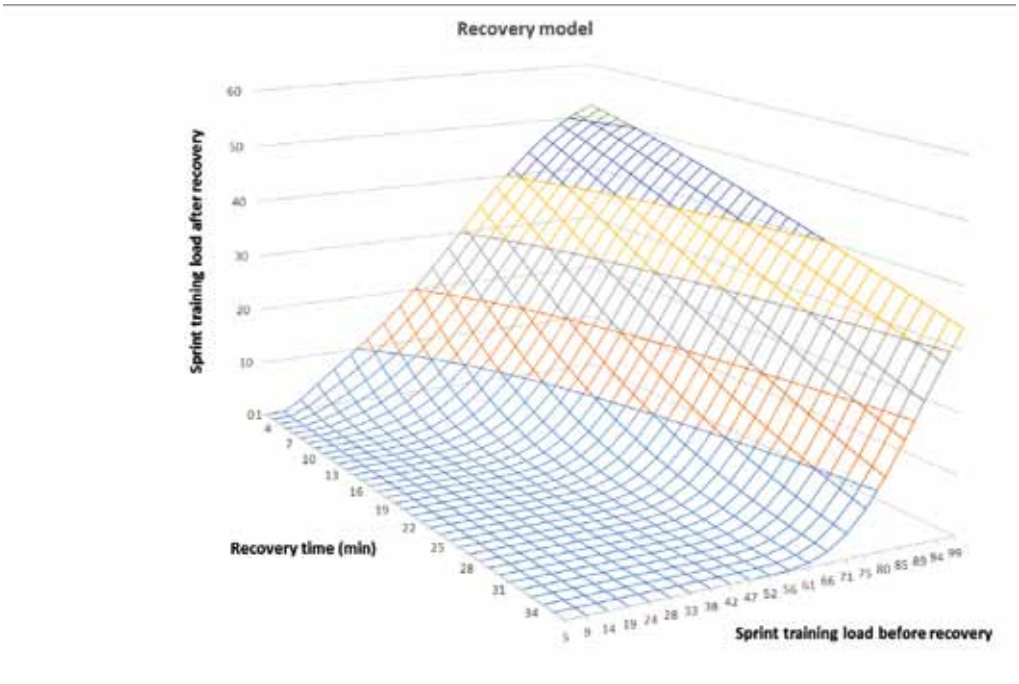

Figure 1B: The effect of recovery on sprint training load

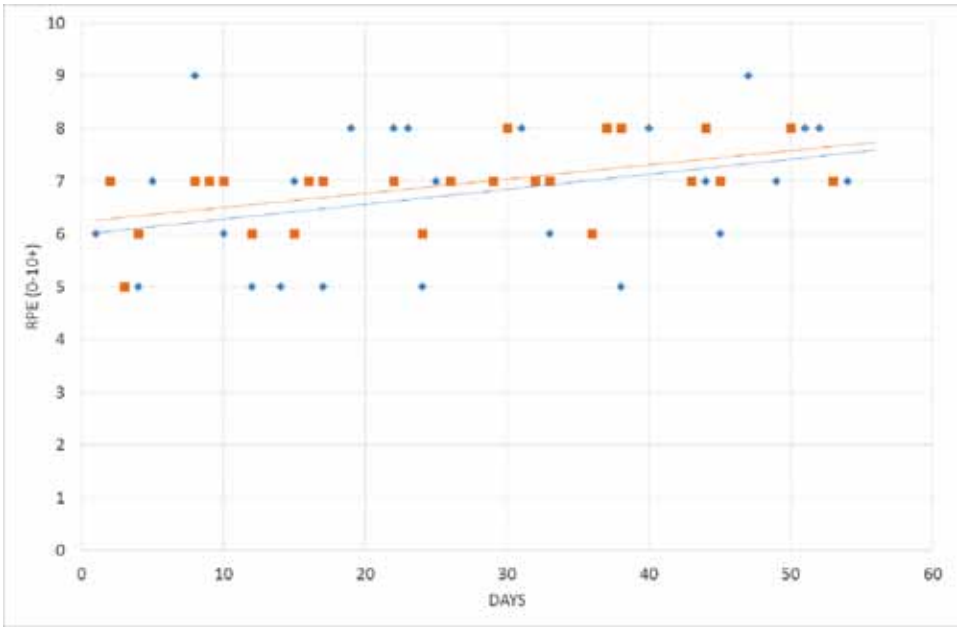

Figure 2A: RPE of sprint interval exercises during 8-week period before (blue) and after (red) the indoor season

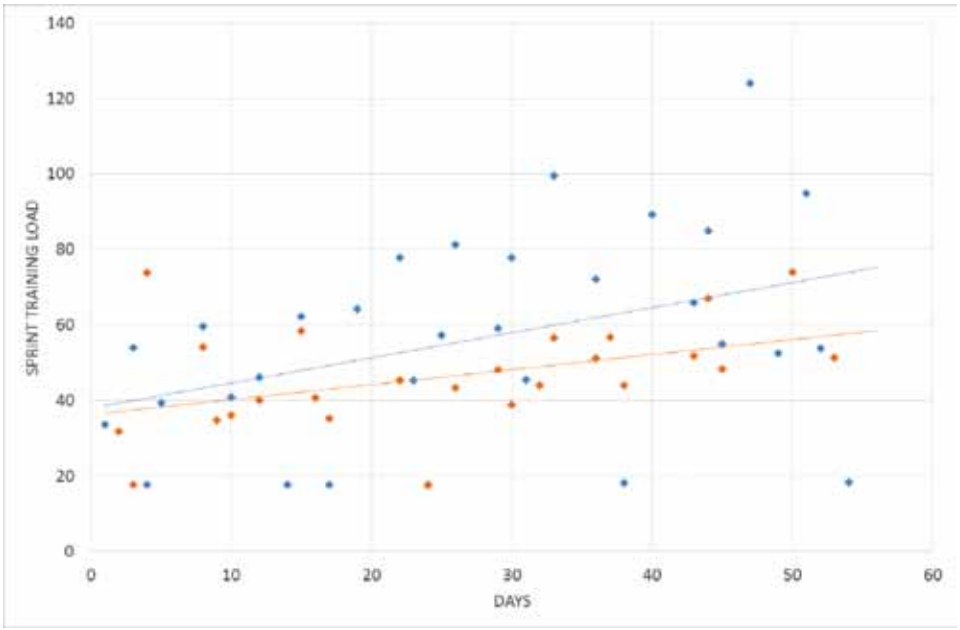

Figure 2B: Sprint training load of sprint interval exercises during 8-week period before (blue) and after (red) the indoor season

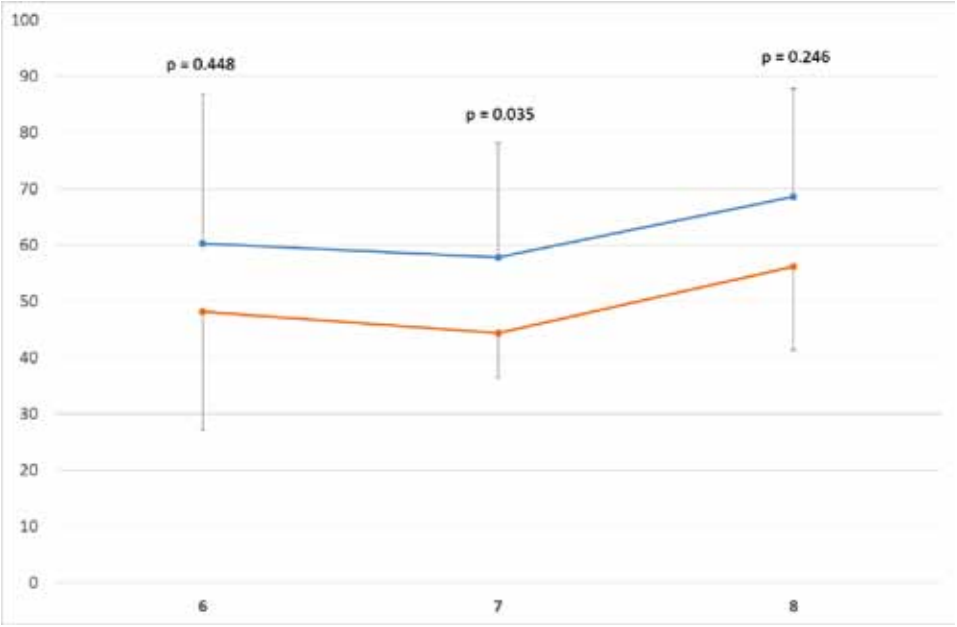

Figure 3: Similarly rated sprint interval exercises before (blue) and after (red) the indoor season

new index of sprint training load were the best methods to determine the training load in this activity. Blood lactate was the best method for determining the training load for the SIEs. Furthermore, the index of sprint training load and heart-rate recovery (HRR) were significantly related to RPE. Based on the current results, this relationship between HRR and RPE improved with the recovery time with the highest correlation value attained at 2 min of recovery.

Blood lactate

It was no surprise that a high correlation between blood lactate and RPE was observed both in single sprints and in the SIEs. Lactate is the end product of glycolysis, the anaerobic pathway used to produce energy during high intensity exercises. Glycolysis begins within the first few seconds after the initiation of high intensity exercise and contributes the bulk of energy during short-term high intensity exercises[3]. Blood lactate concentration is related to lactate production and concentration in a muscle[8]. The high correlation between RPE and blood lactate can be explained by the association of acidosis and fatigue[1].

The measurement of blood lactate concentrations has become easier and more practical with the development of portable measurement devices requiring only a drop of blood from a finger prick. Since blood lactate measure is invasive, however, it remains impractical to measure lactate during each sprint interval training session in order to quantify training load. Furthermore, improvements in training status and over-training have been associated with decreases in maximal and submaximal blood lactate concentration[10], which may lead to erroneous interpretations of lactate measurements and incorrect exercise prescriptions.

Table 3: Analysed variables of single sprints (n = 42) from eight sprinters and correlation coefficients (r) between RPE and different variables of the sprints

	Mean ± SD	Minimum	Maximum	r	p
RPE	3.6 ± 1.9	0.5	8.0	1.000	
Velocity ($m \cdot s^{-1}$)	5.81 ± 0.89	4.33	7.87	0.135	0.394
Velocity (% PB)	74.1 ± 7.9	64.0	91.7	0.732	< 0.001
Distance (m)	307 ± 160	200	600	0.455	0.002
Blood Lactate ($mmol \cdot l^{-1}$)	7.09 ± 2.65	3.88	13.78	0.764	< 0.001
Sprint training load index	31.0 ± 10.7	18.2	64.2	0.810	< 0.001
Heart-rate peak (bpm)	172 ± 11	145	192	0.438	0.004
HRR 30 s (% HRpeak)	92.4 ± 3.6	83.2	97.4	0.153	0.333
HRR 60 s (% HRpeak)	81.5 ± 6.2	61.6	91.3	0.294	0.059
HRR 90 s (% HRpeak)	74.5 ± 6.7	51.2	87.9	0.309	0.046
HRR 120 s (% HRpeak)	70.8 ± 6.3	47.0	86.8	0.316	0.042

Abbreviations: PB = personal best, HRR = heart rate recovery, HRpeak = peak heart rate during the exercise

Heart-rate recovery

Heart-rate recovery was calculated both for absolute and relative values. Percentage values from peak heart-rate of a single sprint or SIE are presented in the final results, and are highly 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[13]. Changes in the autonomic nervous system activity after exercise are affected by either improved endurance performance and/or over-training. Therefore, this may also be a practical and reliable marker of training load and fatigue providing information about training induced changes in performance.

In single sprint training, HRR (% of peak heart-rate) is not a reliable measure of load, since it is not strongly related to RPE. On the other hand, with regards to SIEs, peak heart-rate is more reliable. Since sprints increase the heart-rate, and this remains elevated during the recovery, less time is needed to attain the peak heart-rate. When measuring HRR, it is important that the athlete stays still during the recovery and in the same position every time. In the present study, the athletes were measured in the standing position approximately 2 min after the single sprints and after the SIEs. According to the results, the correlation between RPE and HRR increased with recovery time with the highest values recorded after 2 min of recovery for both the single sprints and the entire SIE. It should be noted that with single sprints, 90 sec was needed to attain a significant relationship with RPE while with the SIEs, 60 sec was enough to get a reliable measurement.

Table 4: Analyced variables of sprint interval exercises (n = 95) from 16 sprinters and correlation coefficients (r) between RPE and different variables of the exercises

	Mean ± SD	Minimum	Maximum	r	p
RPE	6.1 ± 1.8	2.0	10.0	1.000	
Average velocity ($m \cdot s^{-1}$)	6.39 ± 0.83	4.77	8.61	0.400	< 0.001
Average velocity (% PB)	76.6 ± 7.3	62.5	95.9	0.433	< 0.001
Distance (km)	1.92 ± 0.72	0.80	3.90	-0.018	0.300
Sprint time (min)	5.20 ± 2.31	1.61	11.82	-0.194	0.059
Total time (min)	30.48 ± 14.00	5.33	66.03	0.338	< 0.001
Blood Lactate ($mmol \cdot l^{-1}$)	14.30 ± 3.58	6.74	21.70	0.771	< 0.001
Sprint training load index	56.6 ± 21.6	16.9	102.2	0.506	< 0.001
HRpeak (bpm)	177 ± 11	151	194	0.025	0.810
HRR 30 s (% HRpeak)	95.1 ± 2.7	82.1	99.4	0.139	0.180
HRR 60 s (% HRpeak)	89.0 ± 4.7	74.2	98.9	0.278	0.006
HRR 90 s (% HRpeak)	81.5 ± 6.6	64.6	93.8	0.483	< 0.001
HRR 120 s (% HRpeak)	76.0 ± 7.3	58.1	92.2	0.546	< 0.001

Abbreviations: PB = personal best, HRR = heart rate recovery, HRpeak = peak heart rate during the exercise

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. A scale from 0 to 100 is used to measure the training load for single sprints and SIEs, with values sometimes exceeding 100 for the SIEs. These values are represented by a curvilinear relationship between sprint training load, intensity and distance. In the model, the highest load values attained for maximal intensity were between 400-500m. This is supported by a previous study[11], which observed that ATP resynthesis from glycolysis is highest in maximal exercises lasting 40-50 sec. Intensity in this model is a percentage value of the personal best result for the distance of the sprint. The above approach represents one way to individualise the model, with the other being the use of the performance profile of the athlete. With the SIEs, the determination of the training load of a single sprint and the effect of recovery on sprint training load needs to be determined. This is calculated by adding the effect of each recovery period to the index of sprint training load using the recovery model in Figure 1B. In this model, the cumulative training load of the previous sprint(s) and the recovery time are used to determine the final training load. In this context, the index of sprint training load had a greater correlation with RPE than blood lactate in single sprints. Furthermore, a significant correlation was observed between the sprint training load index and blood lactate value suggesting that the model is a valid method to measure training load in sprinting.

Table 5: MART and 30m maximal velocity test data of the female sprint runner and the respective training data of two 8-week training periods before and after the indoor season

	November	April
Maximal 30m ($m \cdot s^{-1}$)	8.96	8.77
Maximal 150m ($m \cdot s^{-1}$)	8.11	8.06
Peak B-La ($mmol \cdot l^{-1}$)	15.7	13.9
v10mM ($m \cdot s^{-1}$)	7.38	7.40
v5mM ($m \cdot s^{-1}$)	6.22	6.46
	Before indoor season	**After indoor season**
Number of all exercises	55	52
Number of SIE	31	25
Average velocity ($m \cdot s^{-1}$)	5.89 ± 1.39	6.03 ± 1.40
Average velocity (% PB)	75.1 ± 12.8	75.0 ± 11.6
Average distance (km)	2.12 ± 1.22	2.13 ± 1.10
Total SIE distance (km)	65.7	53.3
Average SIE time (min)	28.5 ± 8.2	32.9 ± 11.1
Average RPE all exercises	6.1 ± 1.4	6.0 ± 1.4
Average RPE in SIE	6.8 ± 1.3	6.9 ± 0.8
Sprint training load index	56.2 ± 27.2	46.4 ± 14.2

Abbreviations: B-La = blood lactate concentration, v10mM = velocity at 10 mmol · l^{-1} blood lactate level, v5mM = velocity at 5 mmol · l^{-1} blood lactate level, SIE = sprint interval exercise, PB = personal best

With regards to SIEs, the correlation between RPE and the index of sprint training load was lower than with blood lactate but is still significant and is also close to the correlation of HRR. Furthermore, a significant correlation was observed between the sprint training load index and blood lactate in SIE, suggesting that the sprint training load model is a valid method for determining the training load in SIEs. The advantage of the index over blood lactate or HRR is that it is non-invasive, and does not require expensive devices such as heart-rate monitors to determine sprint training load. All that is needed is a stopwatch to measure sprint and recovery times.

Sprint training period

In the present study, a case was presented in which the preparation for the indoor season was successful but in the following eight-week training period the athlete developed a state of over-training and was not able to attain her personal best during the subsequent outdoor season. Based on the training summary of the two eight-week training periods (Table 5) the training period before the indoor season was harder than the training period after the indoor season.

As concluded by BORRESEN & LAMBERT[4], there is currently no accurate and quantitative method with which to prescribe the pattern, du-

ration and intensity of exercise required to produce specific physiological adaptations. There is no single physiological marker that can be 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 measurable non-invasive physiological markers for physical fitness, training load or fatigue. This will help to improve the accuracy of performance by predicting and preventing under- and over-training. The relationship between training characteristics and the observed changes in physiological variables and performance are highly individual depending on numerous factors influencing an athlete's tolerance to a training load. Even the same exercise may have different physiological responses on the same individual at different times depending on the performance profile and state of training.

One of the aims of sprint interval training is to increase the ability of an athlete to run faster at the same blood lactate level. In this study, this was confirmed by the results for the MART (Table 5). However, if a decrease in maximal anaerobic performance, maximal running speed and peak blood lactate concentration occurs, this is indicative of an athlete reaching a state of over-reaching or over-training[10]. In the present study, this observation was confirmed with the athlete who was unable to achieve her personal best during the outdoor season.

The ratings of perceived exertion of SIE was at the same level and increased similarly during both eight-week training periods (Figure 2A), with the only difference being that the standard deviation of RPE was smaller after the indoor season. The RPE values after the indoor season were six to eight, with one SIE being rated as a five, whereas prior, the RPE values varied from five to nine. The slope of the increase of the index of sprint training load during the second eight-week training period was lower than the first (Figure 2B) confirming over-training, indicated by the lower SIE values post indoor season. Furthermore, the standard deviation of the index of sprint training load was smaller during the eight-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 athlete rated the SIEs with a lower training load similarly to the SIEs with a 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 a state of over-reaching in the post-indoor season.

The training data from this study suggests that a possible reason for overreaching after the indoor season was not enough variation in training load in the SIEs. In turn, other influences are possibly the unknown factors and stressors outside the exercises such as: psychological stressors, nutrition, rest and quality of sleep. Therefore, training and the ability to recover are significant factors in determining adaptation as well as assessing over-reaching or over-training.

The data of this case study confirms the conclusion of BORRESEN & LAMBERT[4] that there is currently no single accurate method that can be used to monitor both physiological adaptation and fatigue. Nevertheless, monitoring and combining different data from the athlete's training diary as well as physiological measurements will enable a coach to observe positive and negative changes related to a physiological adaptation and fatigue.

Conclusion and Recommendations

It can be concluded that intensity is the most important factor determining training load in SIEs. In addition to RPE, blood lactate concentration, heart-rate recovery and the index of sprint training load can also be used to determine training load. However, none of these methods alone are enough to accurately monitor the training load and fatigue. Therefore, a combination of these methods as suggested in this study provides a method to best monitor training data and different physiological responses in order to prevent under- or over-training in sprinters.

In training for sprints, the running velocity and intensity (% PB) in SIE are important factors to monitor for determining training load and adaptation. In order to calculate the index of sprint training load, running velocity, the intensity of the SIE, the distance sprinted and the recovery time 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 for the training adaptation and fatigue of a particular athlete. Coaches and athletes should be aware of the individual physiological responses to training, since similar training may not give similar adaptations for each individual. Based on the results of the present study RPE, blood lactate concentration, heart-rate recovery and the index of sprint training load are all valid and valuable measures to use in order to monitor physiological adaptation, training load and/or fatigue in SIEs.

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