ORIGINAL ARTICLE

Blood lactate, ammonia and kinematic indices during a speed-endurance training session in elite sprinters

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Abstract

Introduction. The analysis of both athletic performance and individual response to exercise helps control the training process. In order to fulfill these needs, various blood biomarkers, along with physiological and biomechanical parameters are tested using modern technology. **Aim of Study.** The aim of this study was to evaluate athletes' response to the performed speed-endurance training session during the pre-competition phase. **Material and Methods.** The study sample comprised male sprinters competing in the 100 m, 200 and 4 × 100 m events at the national and international level. During training, blood samples were taken, which were analyzed regarding ammonia and lactate concentrations. Kinematic parameters were analyzed using the Catapult OptimEye S5 system. **Results.** In all athletes, maximum blood ammonia (176-181 µmol/l) and lactate concentrations (18.0-20.3 mmol/l) were observed three minutes after the last run during the main part of the training session. At the 30th minute of cool down, blood ammonia concentration was similar to the level before warm up, and lactate concentration was still increased. During the main part of the session, sprinters achieved maximum velocity 10.3-10.4 m/s. **Conclusions.** In highly-trained sprinters, a speed endurance training session causes a strong and prolonged exercise response, manifested by extremely high blood ammonia and lactate concentration as well as maximal heart rate. Kinematic indices help to individually optimize athletes' exercise loads.

KEYWORDS: sprinters, blood ammonia, lactate, speed endurance, monitoring training session.

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What is already known on this topic?

Changes in blood lactate and ammonia as a response to exercise in athletes have been analyzed in different studies. There is limited data available on these biomarkers measured during real workout in highly-trained sprinters. An evaluation of kinematic characteristics using the Catapult OptimEye S5 system was performed in team sports athletes, in particular, but not yet in sprinters.

Introduction

An important factor which helps athletes achieve higher results in sports is control over the training process. Conscious and planned implementation of training loads, appropriate training methods as well as recovery time allows athletes to peak at the most important competitions [1].

There are three main phases in a sprinter's annual training plan: preparatory, competition and transition [2, 3]. The realization of certain tasks depends on the competitions in which the athlete will participate in. In each phase, the training is focused on specific aspects to prepare the athlete for competition. In the first phase, the most important aspect is anatomical adaptation (body composition), tempo training, and maximum strength training; in the second phase - power, maximum speed, and speed maintenance. In the last phase, the focus is on active rest and recovery along with gradual preparation for the preparatory phase once again [3, 4, 5]. According to Winckler [6], most coaches understand the quality of speed endurance to be the athlete's ability to maintain

high speed over extended sprint distances. Thus, a 100 m sprinter must work at an intensity of 95-l00% of his maximum velocity over distances of 60-150 m [7]. A classic method for developing speed endurance is the so-called "anaerobic lactic training", resulting in high blood lactate concentration. In practice, coaches plan interval training sessions, consisting of maximal- or submaximal-intensity sprints, separated by relatively short recovery periods to stimulate anaerobic energy sources.

Before the main competition, coaches and athletes use a tapering phase. A taper can be defined as a period of reduced training volume in order to optimize competition performance [8]. The aim of the pre-competition preparation is to bring athletes to their highest potential, in similar conditions to those that will take place during the main competition. There are many studies verifying the efficacy of a taper, especially in swimming, running and triathlon [9]. A very important part during a tapering period is the appropriate decrease in training load, realized by adjusting the training volume, intensity, and frequency [10]. It is also important to enhance recovery during this period. Stress and fatigue induced by training must be rapidly minimized. Recovery is an integral component in optimizing performance [1].

The analysis of both athletic performance and individual response to exercise helps to control the training process. In order to fulfill these needs, various blood biomarkers are tested along with physiological and biomechanical indices, using modern technology. Monitoring the levels of blood biomarkers fulfills an informative function necessary to control the training process and to assess the impact of exercise on the body [11]. Taking into account the level of a biomarker, it is possible to estimate training status, muscle damage, hydration status, oxidative fatigue, and overtraining. The analysis of biomarker concentration and its application in training planning helps to optimally increase performance in elite sprinters. The most commonly evaluated biomarkers used in sports training are lactate and ammonia in blood [12]. Accumulation of lactic acid and ammonia is the factor limiting work efficiency during moderate and high-intensity exercise [13].

Blood lactate increases when phosphate sources, derived mainly from phosphocreatine, are reduced. Lactic acidosis will progress when lactate production exceeds its clearance [14]. Lactate concentration in blood offers valuable information not only about glycolytic changes, but also the ability of athletes to work anaerobically [11]. Lactate is used to assess the anaerobic potential of athletes and serves to determine exercise intensity and time needed for post-exercise recovery [15].

Blood ammonia accumulation in athletes is dependent on the type and intensity of exercise [16]. During high-intensity exercise, the main source of ammonia production in blood is adenosine monophosphate deamination [17, 18]. Blood ammonia concentration can indirectly indicate the adenosine triphosphate content in muscles [18]. It also affects the central nervous system and muscle function [17, 19]. This is why the analysis of ammonia concentration in sports training provides additional support in appropriate planning of training loads.

Technological advances and the development of complex monitoring systems for athletes allow recording a great deal of kinematic, physiological and biomechanical data during exercise, as well as between training sessions. Monitoring fatigue and exercise capacity is desired to achieve better performance. It helps to optimize the training process and minimize unplanned fatigue [20]. The most advanced technological systems used to monitor sports training in athletes can measure such characteristics as athlete's position, velocity and acceleration, heart rate (HR), and time spent in certain exercise intensity bands. For a coach, being able to visually follow each characteristic which illustrates an athlete's response to exercise in real time makes it possible to immediately adjust training loads accordingly.

First complex systems used for monitoring athletic activity started being used mainly in team sports. In field hockey [21], soccer [22], basketball [23], Australian rules football [24], and rugby [25] movement patterns, distance travelled, HR, acceleration, deceleration and the so-called Player Load were measured. GPS-based systems, however, have not been used yet to monitor and analyze sprinter training.

The aim of this study was to evaluate the response of highly-trained sprinters to a speed-endurance training session during the pre-competition phase, using the measurements of levels of blood ammonia, lactate and heart rate. Additionally, characteristics of speed endurance training, distance, time, velocity, and player load were evaluated.

Method

Participants

The study participants were three male sprinters competing in 100 m, 200 m and 4 × 100 m, at the national and international level, aged 23-29 years, with their competitive sport training experience of 6 to 12 years, body weight of 80.1-94.8 kg, body height of 184.5-189.0 cm,

Table 1. Basic characteristics of studied athletes

	Age [years]	Training experience [years]	Body height [cm]	Body mass [kg]	VO$_2$max [ml/min/kg]
Athlete 1	29	12	184.5	80.1	52
Athlete 2	29	12	188.0	93.6	48
Athlete 3	23	6	189.0	94.8	50

and maximal oxygen uptake (VO$_2$max) of 50-52 ml/ /kg/min. The basic characteristics of each athlete are presented in Table 1. The participants were informed of the procedures and gave their written consent to participate in the study. The study was approved by the Local Bioethical Committee at the Poznan University of Medical Sciences.

Speed-endurance training session
The study was carried out during a training camp in May in wind-free conditions and at the air temperature of 24ºC. The measurements were performed on a standard 400-m running track. The aim of the session, designed by a coach, was to develop speed endurance. The workout schedule was the same for each athlete and consisted of the the warm up, main part (four sprints: 120 m, 150 m, 120 m, 150 m), and cool down sections.

Blood ammonia and lactate measurement
During the training session, blood samples were taken from the athletes, to be analyzed for ammonia and lactate concentrations. Blood was taken before and after the warm-up, three minutes after each sprint performed in the main section, and on the 20th and 30th min of the cool-down.
To determine the concentration of blood ammonia, 20 µl of whole blood was applied on a test strip and analyzed with PocketChem BA (Arkray, Japan). To measure blood lactate accumulation, Biosen C-line (EKF Diagnostics, Germany) was used. In brief, 20 µl of whole blood was filled into the prefilled micro test tube using a capillary. L-lactate contained in the sample was converted enzymatically to pyruvate and hydrogen peroxide, which was detected by the electrode.

Kinematic evaluation
The evaluation of kinematic characteristics and HR was performed using the Catapult OptimEye S5 system (Catapult Sports, Melbourne, Australia). HR was measured with the use of POLAR monitors, Bluetooth and ANT. OptimEye S5 sensors were equipped with 10 Hz GPS, an integrated 100 Hz 3-axis accelerometer, a 100 Hz 3-axis gyroscope, and a 100 Hz 3-axis

magnetometer. During the session, total duration and distance covered, maximum and mean HR, and maximum velocity (Vmax) were measured. The so-called Total Player Load was also calculated. The Player Load is a resultant vector magnitude derived from tri-axial accelerometer data. It is expressed as the square root of the sum of the squared instantaneous rates of change in acceleration in each of the three vectors (X, Y and Z axis) and divided by 100 [24]. The calculation utilized a scaling factor of "100" to make the output data more applicable to use. It is reported in arbitrary units (au) using the formula:

$$Player\ Load = \sqrt{\frac{(a_{y1} - a_{y-1})^2 + (a_x - a_{x-1})^2 + (a_{z1} - a_{z-1})^2}{100}}$$

Note: a_y – antero-posterior acceleration; a_x – medio-lateral acceleration; a_z – vertical acceleration

Results
Figure 1 shows blood lactate and ammonia levels that were measured in the three athletes before, during, and after the training session. In the first athlete, before the warm-up, the ammonia concentration was 32 µmol/l, and then increased up to 138 and 176 µmol/l after the 3rd and 4th sprint, respectively. After 30 minutes of the cool-down, the blood ammonia concentration decreased to 33 µmol/l. Blood lactate concentration was 0.9 mmol/l before the warm-up and attained 18.0 mmol/l 3 minutes after the 150 m run (4th repetition). 30 minutes after the main section, the lactate concentration decreased to 10.8 mmol/l.
In the second athlete, before the warm-up, the blood ammonia concentration was 29 µmol/l. An increase in blood ammonia concentration was noted in the consecutive measurements. The maximal level of blood ammonia was observed after the 4th sprint (150 m), and it amounted to 181 µmol/l. The blood ammonia concentration decreased to 81 µmol/l after 20 minutes, and after 30 minutes of the cool down it decreased 41 µmol/l. The blood lactate concentration before the warm-up was 1.21 mmol/l and increased to 4.1 mmol/l after the warm-up. The maximal level (19.0 mmol/l)

was attained after the last sprint. Thirty minutes after the main section of the training session, the blood lactate concentration decreased to 13.3 mmol/l.

In the third athlete, before the warm-up, the blood ammonia concentration was 32 µmol/l. After the 3rd sprint, it increased to 153 µmol/l, and after the last run to 180 µmol/l. The blood ammonia level decreased to 81 and 41 µmol/l after 20 and 30 minutes of the cool down, respectively. Before the warm-up, the blood lactate concentration was 1.2 mmol/l, and after the warm-up it increased to 2.8 mmol/l. The maximal concentration of 20.3 mmol/l was reached 3 minutes after the 150-m sprint (4th repetition). 30 minutes after the main part of the training session, it decreased to 17.3 mmol/l.

Table 2 shows the characteristics recorded using the Catapult System with OptimEye S5 sensors. During the 2-hour training session, the first runner travelled a distance of 5700 m, with the Player Load of 507 au, maximal heart rate (HRmax) of 204 bpm, and Vmax of

10.4 m/s. In the main section of the training session, the HRmax and Vmax in consecutive sprints were 194 bpm and 10.0 m/s (120 m), 198 bpm and 10.2 m/s (150 m), 199 bpm and 10.4 m/s (120 m), and 204 bpm, and 10.0 m/s (150 m), respectively.

The second runner covered almost 5000 m during the 2-hour training session, with the Player Load of 377 au, HRmax was 204 bpm, and Vmax was 10.4 m/s. In the main section of the training session, the HRmax and Vmax in consecutive sprints amounted to 202 bpm and 9.7 m/s (120 m), 204 bpm and 9.8 m/s (150 m), 178 bpm and 10.4 m/s (120 m), and 178 bpm, and 10.0 m/s (150 m), respectively.

The third runner travelled almost 5300 m during the 2-hour training session. In the main section of the training session, his HRmax and Vmax in consecutive sprints were: 180 bpm and 10.3 m/s (120 m), 181 bpm and 10.2 m/s (150 m), 167 bpm and 10.2 m/s (120 m), and 177 bpm and 10.0 m/s (150 m), respectively.
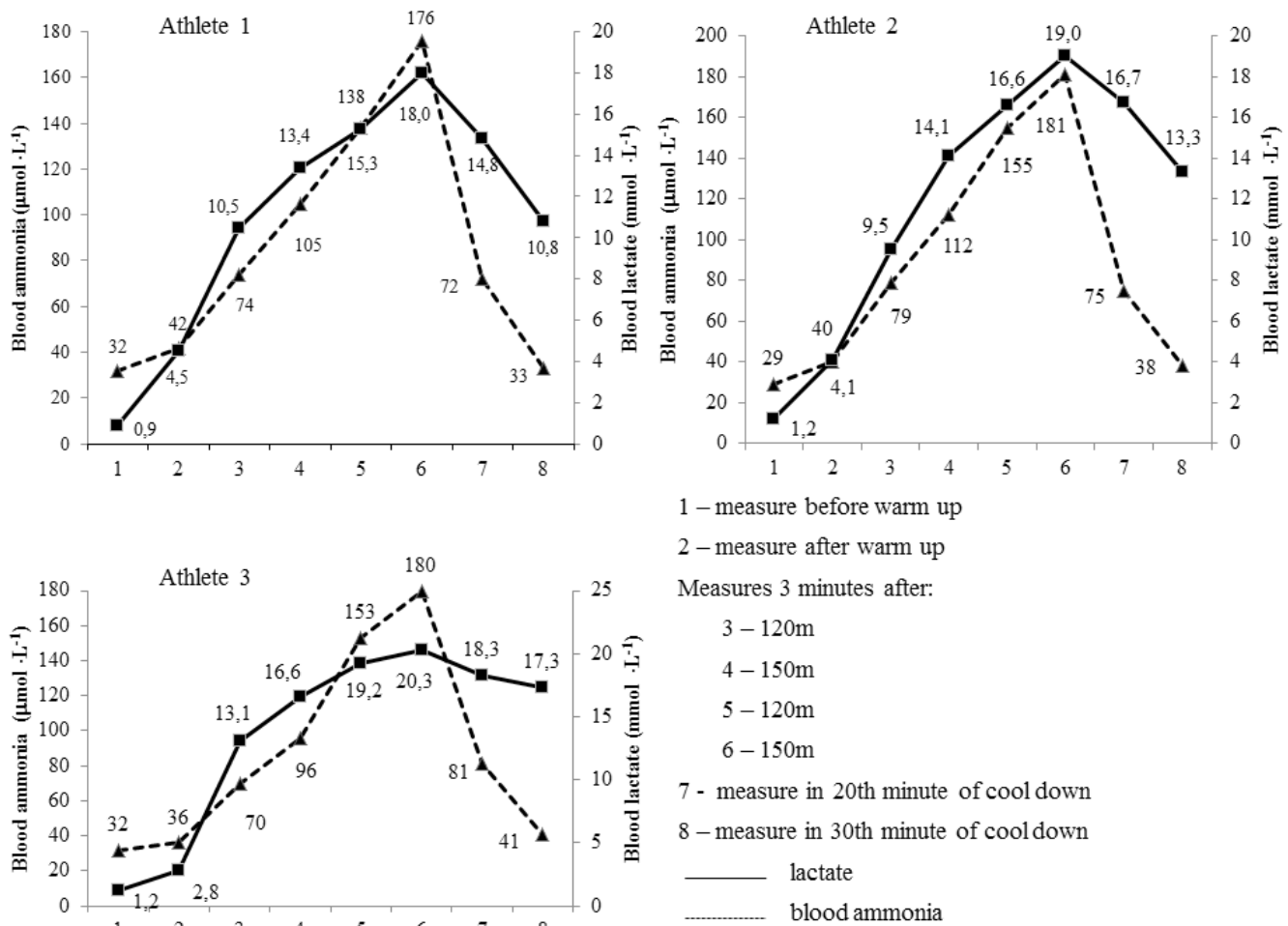

Figure 1. Blood lactate and ammonia concentrations in three sprinters before, during, and after the training session

Table 2. Characteristics recorded by the Catapult System using OptimEye S5 during the speed-endurance training session

	Session part	Total duration [min:s]	Total distance [m]	HRmax [beat/min]	HRmean [beat/min]	Vmax [m/s]	Total player load [au]
	Warm-up	47:49	3361	178	132	8.2	307
Athlete 1	Main part	47:07	2030	204	142	10.4	164
	Cool down	33:02	312	149	133	1.6	36
	Total	127:58	5703	204	135.7	10.4	507
	Warm-up	47:50	2928	183	109	8.6	236
Athlete 2	Main part	38:54	1639	204	124	10.4	117
	Cool down	34:22	220	190	117	2.0	24
	Total	121:06	4787	204	116.7	10.4	377
	Warm-up	47:49	2857	147	112	8.6	257
Athlete 3	Main part	45:36	2090	188	134	10.3	155
	Cool down	32:21	342	141	126	1.7	21
	Total	125:46	5289	181	124	10.3	433

Abbreviations: HRmax – maximal heart rate; HRmean – mean heart rate; Vmax – maximal velocity

Discussion

The aim of this study was to evaluate sprinters' response to training loads during a speed-endurance training session. Despite individual differences the studied athletes displayed a similar and consistent time course in their blood ammonia and lactate concentrations, HR, and kinematic indices in sprinters. The speed endurance training session caused a strong and prolonged exercise response, manifested by extremely high post-exercise blood ammonia and lactate concentrations as well as maximal heart rate.

During high-intensity exercise, energy is mainly obtained from anaerobic sources. The main source of ammonia is the deamination of adenosine monophosphate to inosine monophosphate through the purine nucleotide cycle [11, 26]. An increase in ammonia concentration occurs predominantly after high-intensity exercise, where ammonia aids in stimulating glycolysis [27]. In the athletes under study, the highest concentration of blood ammonia was observed after the last sprint repetition. The blood ammonia level was slightly higher 30 minutes after the main training part than before the warm-up.

Blood lactate concentration in all the athletes gradually increased during the session, reaching the maximum after the main part of the training session. In two athletes (1 and 2), 30 minutes after training the lactate concentration decreased by 30-40%. However, in the third athlete it was only 15% lower than the maximal

concentration. High levels of blood lactate during training session are typical for elite athletes, who tolerate high amounts of lactate during maximal exercise [28]. In the studied athletes, the maximal concentration of lactate produced was 18-20 mmol/l. In another study, a sprinter attained a slightly lower concentration of lactate after completing a training plan consisting of 60 m + 60 m + 100 m + 120 m runs (with recovery breaks of 5, 8, 8 min, respectively). After completing the runs, the athlete's lactate level was 16.2 mmol/l [29]. The lower lactate levels in that study were most likely due to shorter distances run in the training session compared to longer distances covered in the analyzed training session. Since both training sessions were performed at maximal or near-maximal intensity, and the time needed to perform each repetition was higher for the 120 m/150 m distances, more lactate was produced through anaerobic glycolysis.

An increase in blood ammonia and lactate concentrations during a training session in sprinters is a typical response to the training load [30]. In the present study, blood ammonia and lactate concentrations increased considerably in all the athletes through all the performed repetitions. A similar observation was made by Kantanista et al. [31], who examined sprinters and triathletes during an incremental exercise test, even though they were tested in laboratory conditions and not during a real track session. This shows that both biomarkers are effective as training load indicators in highly-trained sprinters. With increasing

fatigue, the levels of both biomarkers increase, reflecting the physiological status of the athlete. This information can then be used by coaches to plan or adjust training sessions according to the athlete's status; more fatigued athletes may need more recovery and reduced training load.

The Catapult OptimEye S5 system provided some additional characteristics, which produced information about the training session and its effects. The gathered data, i.e. total duration, total distance, HRmax, mean HR, Vmax, and Total Player Load, made it possible to optimize the performed training session. The system recorded characteristics at distances longer than 20-40 m in a straight line [32], so in this case the presented results can be considered reliable. HRmax in two athletes was 204 bpm, and in the third athlete it was 181 bpm, i.e. higher than during a standard incremental laboratory test. Kusy et al. [30] carried out a preliminary study on one highly-trained sprinter during a speed-endurance workout and the HRmax achieved was lower (174 bpm) after the last repetition (120 m) than that in laboratory conditions (194 bpm). This discrepancy may be connected with shorter distances analyzed by Kusy et al. During the main part of the training session, the athletes achieved Vmax of 10.3-10.4 m/s. Maćkała and Antti [33] compared the best performances in the 100 m during the World Championship final in Berlin 2009, and the two highest Vmax were 12.26 m/s and 11.80 m/s. It is typical of speed-endurance training sessions that athletes must work at their near-maximal speed, and their goal is to maintain that speed as long as possible and to minimize the decrease in speed. In the investigated session, the so-called Player Load was recorded, which gives additional information on the training load an athlete goes through in certain phases of the training session. The Player Load helps to modify the training load on the spot as well to plan/modify training periodization in a longer perspective (annual training cycle). Certain indices can help characterize an athlete's response to a given exercise bout and, when bouts are repeated throughout an annual plan or training phase, they can be analyzed and compared to other sessions.

Our study has certain strengths. The research was carried out in the pre-competition phase on highly-trained athletes. Additionally, the training load was registered by the reliable Catapult OptimEye S5. Unfortunately, it was not possible to compare our results with other reports, because it is, to the best of our knowledge, the first study which used this measuring system on sprinters. In the future, performing this type of research in all phases of an annual training cycle on larger groups of athletes would yield a more comprehensive image of the effects of speed endurance workout on biochemical and kinematic exercise response in highly-trained sprinters.

Conclusions
The obtained data show that a speed endurance training session causes a strong and prolonged exercise response in highly trained sprinters, manifested by extremely high blood ammonia and lactate concentration as well as maximal heart rate. Kinematic indices help to individually optimize the athletes' exercise loads.

What this study adds?
It is the first study to present blood ammonia and lactate levels as a response to exercise during a real speed-endurance workout in highly-trained sprinters. Additionally, the Catapult OptimEye S5 system was shown to be a useful tool to obtain additional characteristics. It allows monitoring training sessions and enables coaches to implement modifications in "live" conditions.

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