Research Article

Delayed Increase in Blood Lactate Concentration after a Short, Intense CrossFit® Workout

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Abstract

CrossFit®, the most successful concept for high-intensity interval training (HIIT), consists of constantly varied training loads und and is usually performed as Workouts Of the Day (WOD) with a length of 6 minutes and more. However, regular CrossFit® training concepts also include shorter WODs, the physiology responses have rarely been investigated yet. In this Study we wanted to analyze the blood lactate concentration (LAC) after ultra-short, high-intensive CrossFit® workout and investigate whether the kinetics of LAC is related to heart rate (HR) or the ratings of perceived exertion measured by borg-scale (borg-RPE). To determine whether CrossFit® workouts induces increased LAC levels after the exercise load, ten participants (n= 10; 8 males; 2 females) volunteered in the study. The participants completed a WOD consisting of 30/20 Calories AirBike and ten repetitions Devil Press with 10 kg/5 kg dumbbell (men/female). LAC, HR, and borg-RPE were measured immediately after, until 12 min after the WOD. The lactate turning points (LTP1 /LTP2) were previously determined using a bicycle ergometer performance diagnostic. The LAC values increased immediately after the WOD by 2.3 ± 1.4 fold (mean ± SD) of the LTP2 up to the maximum by 3.9 ± 0.96- fold during the post-workout observation period.

Our results shows that a CrossFit® WOD induced delayed increased LAC levels, but this effect is not associated with borg-RPE. So the first time a time-delayed increase of LAC up to 4 times of LTP2 was observed after ultra-short, high-intensive CrossFit® workout as before only reported from short sprints.

Keywords: CrossFit® workout; Sport performance; Blood lactate; High-intensity interval training; Training load; Physical fitness

1. Introduction

The assumption that lactate (LAC) accumulates as a toxic waste product of the anaerobic metabolism due to an oxygen debt is omnipresent so that LAC is considered a fatigue agent throughout the first half of the last century [1]. However, the current state of research shows that LAC is much more than a waste product and performs various functions in the organism [2-7]. The ideas of the "cell-cell shuttle-theory" and the "intracellular lactate shuttle-theory" describe the functions of LAC as a gluconeogenic precursor [6]. LAC is a high-energy intermediate used in the anaerobic glycolysis for short-term high-energy turnovers [8]. Following these results, LAC is a relevant energy carrier for oxidative energy production and a precursor for gluconeogenesis [9]. LAC is transported back and forth between different cells, tissues, and organs via LAC shuttle mechanisms, a differentiation now is established between the "cell-cell shuttle" and the "intracellular lactate shuttle" [8].

In contrast, LAC also acts as a signaling molecule like a "pseudo-hormone" regulating protein and gene expression [10]. However, unawareness of the role of LAC has been associated with many negative effects in amateur athletes in the past and remains today. Sports science also assumes that increased LAC levels in the muscles lead to lactic acidosis, though it is still well accepted [11, 12]. In the traditional theory, it is assumed that LAC -induced acidosis promotes muscular fatigue and that the increased concentration of H(+) consequently limits muscle function [9]. However, the postulated mechanisms have not yet been verified under physiological temperatures. Current research results show only a temporary correlation between LAC values and blood pH values [13, 14].

Nevertheless, there is no direct causal relationship, and LAC causes no acidosis [15, 16]. However, the following syndrome is known, which includes the symptoms of nausea, malaise, general fatigue as well as possible vomiting and occurs within a period of 10 minutes after the completed training. Therefore, it is essential that the athlete feels a perceived exertion continues high or even increases after the physical exercise are over. Scientifically, this effect has not yet been defined more clearly, so there are only far documented case reports. In several online articles of specific endurance training for American football with a weight prowler, this symptom is also described as "Prowler Flu" [17]. An increased LAC level is supposed as a causal agent [18]. Achauer also assumes that the LAC -induced decreasing blood pH value results in vomiting. A fact that is also known as load-induced lactic acidosis [11]. Lactic acidosis symptoms include nausea, vomiting, heavy breathing, and general weakness, which coincide with the described effects. However, the assumption that increased LAC levels through glycolysis are responsible for a decreased pH-value, as already mentioned, is meanwhile contradicted [16]. The new trend sport CrossFit® is particularly well suited to investigate the factors that induce the feeling of an ongoing load after the finished exercise. CrossFit®, as varied, high-intensity interval training (HIIT), includes exercises from the main elements of gymnastics, weightlifting exercises, and cardiovascular activities.

CrossFit® training is usually performed as the "Workout of the day" (WOD), with the focus on constantly varying functional movements [19]. In the training sessions, highly intensive exercises are performed quickly, repetitively, and with little or no recovery time between sets [20]. Especially with short and high-intensity WOD (e.g., FRAN), many CrossFit® athletes report the symptoms described above after the training [21]. Considering that the CrossFit® area is permanently working with high intensities, this effect seemed not to be noticed unless vomiting occurs. The CrossFit® community also described it with the expression "Meeting Pukie" [11]. For rating the severity of these effects, the borg scale is a suitable method. The original Borg scale was developed to measure the Ratio of Perceived Exertion (borg-RPE) as a metric for physical strength [22]. The constant load of CrossFit® in the high-intensity range is known to result in increased LAC values shown by Tibana, 2018 [21]. The increased LAC levels under physical exertion are also used in LAC -based performance diagnostics. Specific intensity ranges can be identified based on the lactate curve (LC) determined by performance diagnostics. Many approaches exist to this purpose, some of which are based on severely obsolete perspectives on the role of LAC in the human organism [23]. The systematic application of lactate shuttle-theory shows that the temporal LC course is three-phase. LC implies three specific phases of energy delivery and, consequently, two turning points, respectively, the first (LTP1) and the second (LTP2) lactate turning point [24-26].

However, scientific evidence on how increased LAC concentrations affect CrossFit effectiveness is still missing, despite CrossFit® being the most successful HIIT approach. The few studies available have all examined typical WODs with a length of 6 minutes and more, usually how they are commonly performed [21, 27]. However, because the CrossFit® training concept consists of constantly varied training loads, regular CrossFit® training also includes WODs of much shorter duration, that have not yet been analyzed scientifically. To better understand the success of CrossFit, we wanted to analyze LAC concentration after an ultra-short, intensive CrossFit® workout with an average duration of fewer than 2 minutes and observe whether increased RPE can be induced by these WODs. It is known from 400 m runners or rowers that LAC increases sharply after exercise, so we wanted to know if ultra-short, intensive CrossFit® workouts can also lead to similarly high LAC concentrations [28]?.

2. Materials and Methods

2.1 Study design

To investigate the role of LAC on heightened RPE after completion of a CrossFit® workout, blood LAC, HR, and borg-RPE using borg scale were measured. To correlate the measured LAC concentration with the borg-RPE values, LPT1 and LTP2 were determined previously using an ergometer performance diagnostic.

2.2 Participants

Eight health men (25.9 ± 2 body mass index (BMI)) and two females (22.6; 22.8 BMI) with a minimum of 6-month CrossFit® training experience (24 ± 22 months) participated in the present study (23 ± 2.4 years). The CrossFit® workload varied between 2 and 6 training units per week (4 ± 2 units/week). The participants also performed other sports, including swimming, running, and soccer (3 ± 2 units/week). The inclusion criteria were as follows: No muscle, joint, or bone injuries, no diseases at the time of the study, no smoking, and signed the written informed consent document.

2.3 Experimental design

The subjects participated in two different investigations, with 3 to 14 days apart. To determine the LTP1/LTP2, the first approach involved performance diagnostics on a bicycle ergometer on measures of LAC and HR. In the second trial, the participants performed a CrossFit® workout, and subsequently, the LAC, the borg-RPE, and HR were measured up to 12 minutes after completion.

2.4 Performance diagnostics

All subjects performed an incremental exercise test using an electromagnetically braked cycle ergometer (Assault Fitness, California, U.S). The exercise intensity was increased in a stepwise manner, with an initial level of 25 W/15W and increments of 25 W/15 W added every 60 s until the intensity limit of each individual was reached (male/female). The intensity limit was reached by the participants unable to maintain a frequency of minimum 60 rpm and a maximum 80 rpm. From the hyperemized ear lobe, capillary blood samples were taken at rest, after the 3-min warm-up, at the end of each load step, and at the end of the ergometric test to determine LAC. HR was measured continuously over the entire period. LTP1/ LTP2 was calculated by means of linear regression breakpoint analysis, as shown previously [24, 29].

2.5 WOD

After a 3-minute warm-up on the AirBike (Assault Fitness, California, U.S.) with individual intensity, the participants complete the WOD shown in Figure 1.

The WOD consisted of reaching as soon as possible 30/20 calories on the AirBike, followed by ten repetitions of the exercise Devil Press with one 10/5 kg dumbbell per hand (male/female). After warm-up, LAC levels from capillary blood samples and borg-RPE were determined at rest, after warm-up, immediately after and 1,3,5,7,9,11 min after completing the workout. The test protocol is also shown in Figure 1. In addition, the borg-RPE was measured every minute after the end of the training session, and the HR was measured continuously during the training session.

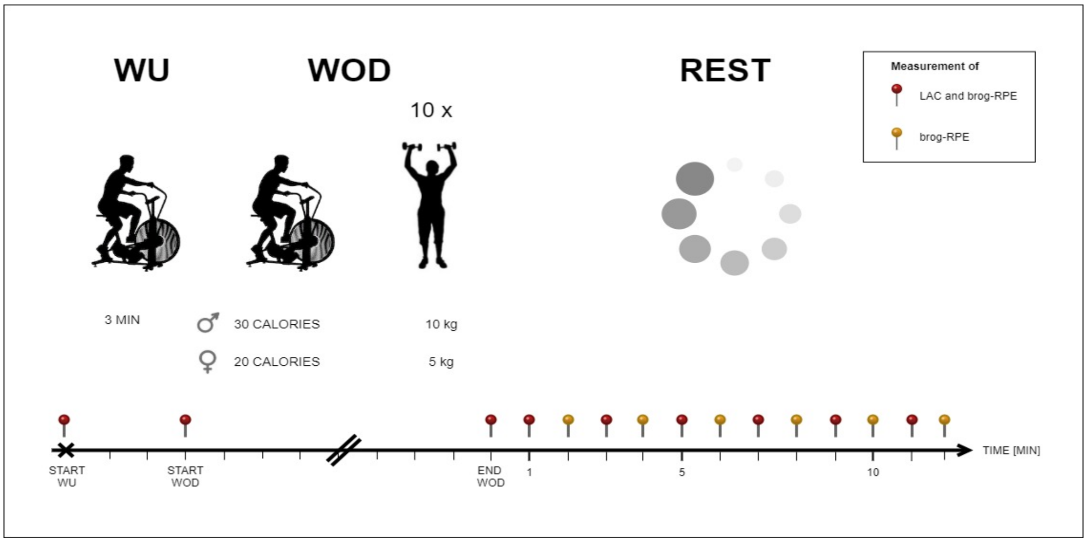

Figure 1: Performance of the CrossFit® Workout of the Day (WOD). Warm-Up (WU): 3 min AirBike at an individual intensity. WOD: as soon as possible reach 30/20 calories on the AirBike, followed by ten repetitions of the devil press with 10/5 kg dumbbell per hand (male/female). Test protocol of the time points blood lactate (LAC) and rate of perceived exertion by borg scale (borg-RPE) were measured after completing the WOD.

2.6 Blood lactate concentration (LAC)

To measure the LAC levels at the time points of testing protocol shown in Figure 1, capillary blood samples were taken from the ear lobe by using Gases and 70% alcohol for asepsis and a lancet to puncture the lateral pulp. A blood drop was inserted in the center of the test zone of the reactive tape by using the portable device "Lactate Scout+ "(SensLab GmbH, Leipzig, Germany).

2.7 Heart rate analysis (HR)

HR was measured continuously by using the "H7 heart rate sensor" (Polar Electro GmbH, Büttelborn, Deutschland) linked via Bluetooth with an Android smartphone. To collect the HR data, the app "HRV Elite" (Elite HRV Inc, Version 4.2.3, North Carolina, U.S.) and for analysis, the software "Kubios HRV" (Kubios Oy, Version 3.1 Kuopio, Finland) was used.

2.8 Rating of perceived exertion by borg- scale (borg-RPE)

The Borg Scale was used to measure borg-RPE. The borg scale rated from 6 (no stress) to 20 (too heavy, no longer works) [22].

2.9 Statistical analysis

Data were presented as means with '±' for standard deviation (S.D.). IBM SPSS statistics version 26 (Somers, NY, USA) software was used for statistical analysis. Kolmogorov-Smirnov-Tests was applied to check for normal distribution of study variables. Correlations between the single measurements for LAC, borg-RPE, LAC/LTP2, and HR were assessed after Spearman. The Wilcoxon signed-rank test was used to compare samples. The 95% confidence intervals (95% CI) were calculated using bootstrapping.

3. Results

As part of the preparation, the individual lactate thresholds LTP1 and LTP2 were determined for each athlete using bicycle ergometry. The participants achieved LTP1 in mean at 139 W with a LAC concentration of 1.6 mmol/l and LTP2 at 250 W with LAC concentration of 3.7 mmol/l. Considered separately, the male participants achieved LTP1 at 156 W with a LAC concentration of 1.7 mmol/l and LTP2 at 273 W with LAC concentration of 3.9 mmol/l (Table 1).

On another day, the athletes completed the WOD, starting with a warm-up at the Assault-Bike. The WOD itself was a combination of 20/30 calories on the Assault bike and 10 Devil Press with 5/10 kg dumbbells (Figure 1). The average time for the WOD was 113 s. The athletes ended the warm-up with a mean heartrate (HR) of 126 bpm which increased up to a mean of 178 bpm after the WOD. 11 minutes later, the mean HR was still at 109 bpm. Direct after the WOD, participants indicated in mean a borg-RPE of 17.4, which corresponds to the state "You can no longer talk because your breathing is heavy". 11 minutes later, borg-RPE was down to 8.1. Before the warmup, the athletes had a mean LAC of 2.2 mmol/l, 95% CI [1.9, 2,7], which stayed with 2.0 mmol/l, 95% CI [1.4, 2.3], nearly unchanged after the warmup. Immediately after the WOD, the LAC increased significantly up to 8.4 mmol/l, 95% CI [4.47, 12.36], $Z(7) = 2.521$, $p = 0.012$, representing the 2.3-fold, 95% CI [1.18, 3.52] of the individual LTP2. Taking all points in time after the WOD into consideration, the maximum LAC was in the mean by 13.5 mmol/l, 95% CI [11.85, 15.85], $Z(9) = 2.80$, $p = 0.005$, which corresponds to 3.9, 95% CI [2.96, 4.77] times the LTP2 (Figure 2).

According to the Borg scale, the perceived strain was highest at the end of the WOD and then decreased continuously. It was the same with the HR. In contrast, LAC was lowest immediately after WOD and then increased continuously until 9 minutes afterward (Figure 3). The strongest correlation was found between borg-RPE and heartrate (r_s = .55, p<0.001). The correlation between borg-RPE and LAC was also significant (r_s = .27, p = 0.012) and got even better when the measured LAC concentrations were divided by the individual LTP2's (r_s = .34, p = 0.001). No correlations were found between HR and LAC concentrations (Table 2).

	Overall (n = 10)	**Males (n = 8)**	**Female 1**	**Female 2**
	Mean [95% CI]	**Mean [95% CI]**		
LTP1				
Watt (W)	139 [101, 176]	156 [120, 191]	72	72
LAC (mmol/L)	1.6 [1.28, 1.83]	1.7 [1.53, 1.90]	1.1	0.8
LTP2				
Watt (W)	250 [193, 307]	273 [213, 332]	140	176
LAC (mmol/L)	3.7 [2.88, 4.46]	3.9 [2.89, 4.84]	2.7	3.1
WOD time (sec)	113 [98, 127]	111 [92, 130]	105	131
0 min after WOD				
HR (bpm)	178 [167, 186]	177 [165, 188]	176	188
LAC (mmol/L)	8.8 [4.2, 13.4]	9.3 [3.8, 14.8]	5.7	12.4
LAC/LPT2 ratio	2.4 [1.0, 3.8]	2.5 [0.7, 4.2]	2.1	4.1
Borg-RPE	17.4 [16.3, 18.6]	17.3 [15.9, 18.8]	18	18
11 min after WOD				
HR (bpm)	109 [101, 116]	106 [99, 118]	110	127
LAC (mmol/L)	12.1 [9.8, 14.6]	12.7 [10.3, 15.2]	8.8	11.5
LAC/LPT2 ratio	3.5 [2.4, 4.1]	3.3 [2.2, 4.4]	3.2	3.8
Borg-RPE	8.1 [6.1, 10.2]	8.3 [5.9, 10.8]	7	7

Lactate Turning Points (LTP) of performance diagnostics are shown by means and SDs overall and by gender. Furthermore the table contains the values of the Heart rate (HR), Lactate-Concentration (LAC), and ratings of perceived exertion measured by borg-scale (borg-RPE) at the time of 0 min after completing the Workout of the Day (WOD) and 11 min after that.

Table 1: Lactate Turning points of performance diagnostics and physiological response after the CrossFit® workout given as means and 95% confidence interval (CI).

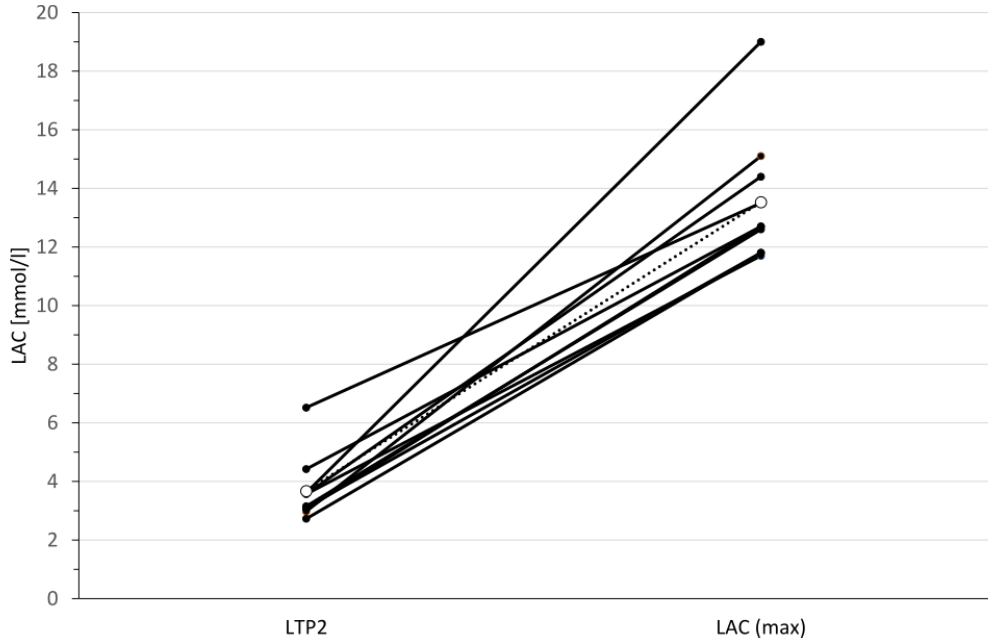

Figure 2: Comparison between the individual LPT2 and the maximum Lactate concentration 11 min after the WOD. Mean value is shown with the dotted line and the unfilled circles.

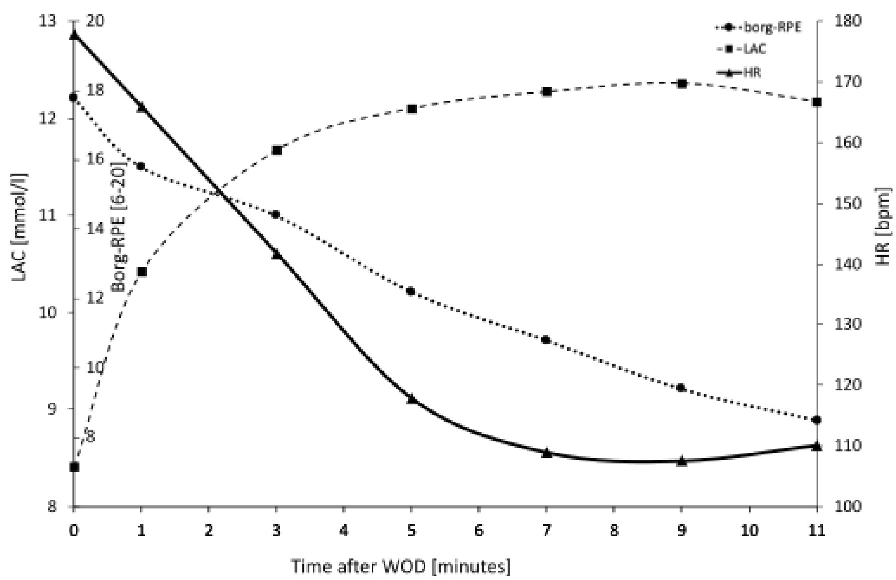

Figure 3: Means of Heart rate (HR), Lactate levels (LAC) and rate of perceived exertion by borg scale (borg-RPE) during 12 min after CrossFit® workout. After completion of the Workout of the Day (WOD) Borg-RPE and HR values decreased on average and LAC values increased.

	HR		**LAC**		**LAC/LTP2**	
	r_s (95% CI)	**p**	**r_s (95% CI)**	**p**	**r_s (95% CI)**	**p**
borg-RPE	0.55 (0.31-0.70)	<0.001	0.27 (0.03-0.46)	0.012	0.34 (0.13-0,52)	0.001
LAC/LPT2	-0.17 (-0.38-0.05)	0.121	-	-	-	-
LAC	-0.2 (-0.39-0.01)	0.066	-	-	-	-

Table 2: Spearman correlation of heartrate (HR), borg-RPE, lactate (LAC) and the ratio of LAC and LTP2 (LAC/LPT2). Correlation between heartrate (HR), borg-RPE, lactate (LAC) and the ratio of LAC and LTP2 (LAC/LPT2) are analyzed by Spearman (r_s). The 95% confidence interval (CI) and the p-value are demonstrated.

4. Discussion

The examined WOD belongs to the ultra-short CrossFit workouts with an average duration of fewer than 2 minutes. Until now, only WOD's with a length of 6 minutes and more were analyzed. It is known that these WODs lead to the highest LAC concentrations immediately after ending the WOD [1, 21]. Our results demonstrated for the first time that ultra-short, high-intense workouts can have delayed aftermath on LAC. Whereas LAC was at 8.4 mmol/l direct after ending the WOD, and it increased by 61% in the following minutes up to 13.5 mmol/l. Such a time-delayed effect is described, for example, for short sprints [28], but not for HIIT like CrossFit WODs. LAC concentration does not go inline with the HR after the WOD. For HR, the highest was measured immediately after ending the WOD and reduced by 12 bpm per minute for the next 7 minutes, where it finally levels off. The same happened for the perceived physical strain, measured according to Borg. Also, here, the highest exertion was reported immediately after ending the WOD. But unlike HR, a plateau initially formed at borg-RPE, which is probably also the reason why there was at least a weak correlation between LAC and borg-RPE. However, as the distance from the WOD increased, the participants also felt increasingly better. On the other hand, there was a strong correlation between borg-RPE and HR. This positive correlation between HR and borg-RPE is in accordance with previous research results, which partly justify the Borg scale [30]. To the best of our knowledge, this is the first study to investigate the effects of LAC Levels on borg-RPE after CrossFit® training. Previous studies have reported these single parameters, but only during the CF workout or separately, and in response to different training models [27, 31, 32].

In our study, LAC values with 13.5 mmol/l were far above LTP2. Such high levels beyond LTP2 are known for HIIT workouts. HIIT that evokes high levels of lactic acid production in the working muscle hormonally triggers specific responses and may elicit certain benefits, such as improving LAC tolerance, and is also a reason for considerable improvements in VO2max [33]. In summary, we demonstrated for the first time that also HIIT workouts can lead to the same effect as short sprints. After only two minutes of load, the LAC concentrations had reached the double-fold of LTP2, didn't reached its maximum, and instead went up to four-fold in the minutes after ending the WOD.

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