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Effects of six-week sprint interval or endurance training on calculated power in maximal lactate steady state

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ABSTRACT: The purpose of the study was to evaluate and compare the influence of sprint interval training (SIT) and endurance training (ET) on calculated power in maximal lactate steady state (PMLSS) (influenced by the maximal lactate production rate ($\dot{V}La_{max}$) and maximal oxygen uptake ($\dot{V}O_{2max}$)). Thirty participants were randomly assigned to the a) SIT, b) ET, or c) control group (n = 10 each). Each session consisted of four to six repetitions of 30 s all-out effort Wingate anaerobic tests (SIT) or 60 min cycling at 1.5 to 2.5 mmol·L^{-1} blood lactate (analysed every 10 min). Both groups performed training on three days per week, over a period of six weeks. To measure $\dot{V}La_{max}$ and $\dot{V}O_{2max}$, and to calculate PMLSS, sprint and ramp tests were performed at baseline and after two, four and six weeks of intervention. While SIT resulted in a significant reduction of $\dot{V}La_{max}$ (-0.08 ± 0.05 mmol·L^{-1}·s^{-1}, p=0.003) after two weeks and remained subsequently stable, $\dot{V}O_{2max}$ (+2.6 ± 2.4 ml·min^{-1}·kg^{-1}, p = 0.044) and PMLSS (+25 ± 14 W, p=0.002) increased, but not before six weeks of SIT. After two weeks of ET, $\dot{V}La_{max}$ remained unchanged, but $\dot{V}O_{2max}$ increased by increased by +2.9 ± 2.4 ml·min-1·kg-1, p=0.03, and after six weeks by 5.6 ± 3.5 ml·min^{-1}·kg^{-1}. The increase of PMLSS was significant after four weeks of ET (+16 ± 14 W, p=0.036) and increased to +32 ± 17 W after six weeks. Comparison of SIT and ET revealed no significant differences for $\dot{V}La_{max}$, $\dot{V}O_{2max}$ or PMLSS after six weeks. The control group remained stable in all parameters. In both exercising groups there was a significant improvement of the calculated PMLSS due to different influences of $\dot{V}La_{max}$ and $\dot{V}O_{2max}$.

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INTRODUCTION

In the past, endurance training (ET) [1] was defined as lengthy exercise sessions of low intensities. Recent studies have demonstrated that high-intensity physical training, such as sprint interval training (SIT), conducted over a short time interval, leads to a comparable improvement in endurance performance [2]. Due to the time-efficient strategy, SIT may be considered more effective than ET [3].

Most studies to date demonstrate the effectiveness of SIT and ET for the development of maximal oxygen uptake ($\dot{V}O_{2max}$) [2] and power at different lactate thresholds [4]. These parameters have been used to approximate the power in maximal lactate steady state (PMLSS). Mader [5, 6] and Bleicher et al. [7] have suggested that the same lactate-performance curve may result from different combinations of $\dot{V}O_{2max}$ and maximal lactate production rate ($\dot{V}La_{max}$). Furthermore, the shift of a lactate-performance curve could also be achieved by changing $\dot{V}O_{2max}$ or $\dot{V}La_{max}$ separately. This confirms, therefore, that identical maximal lactate steady state (MLSS) could originate by completely different combinations of $\dot{V}O_{2max}$ and $\dot{V}La_{max}$ values. Using either $\dot{V}O_{2max}$ or $\dot{V}La_{max}$ alone, it is not possible to explain the differences in PMLSS between two athletes or the effects of training on the MLSS.

To understand the reasons for an improvement in MLSS as a physiological parameter of endurance exercise, it is necessary to understand the physiological origin of MLSS at the level of muscle cells [6]. Mader and Heck [8] published a mathematical description of the metabolic response based on measured values, specifically for a single muscle cell. They focussed on activation of glycolysis (as the lactate production system) and on oxidative phosphorylation (as the combustion system for lactate). Mader and Heck [8] argued that, on the basis of Michaelis-Menten kinetics, it would be possible to simultaneously calculate the rate of lactate formation by glycolysis and the rate of lactate elimination by oxidative phosphorylation, depending on a constant workload. The authors subsequently defined

PMLSS as the crossing point at which the lactate formation exactly equates to the maximal elimination rate of lactate.

A recent study [9] explained in detail the ten equations used in the calculation of PMLSS. This study showed a strong correlation between the calculated and experimental PMLSS, as measured by 30 min constant load tests. Below, the training effect of sprint and endurance training on $\dot{V}O_{2max}$ and its influence on $\dot{V}La_{max}$ is discussed. To the best of our knowledge, no studies exist yet to prove this hypothesis empirically. Basic research documents the variation of enzyme activity of phosphofructokinase as a key enzyme of glycolysis in high-intensity training, resulting in an improvement in maximal glycolytic power capacity [10, 11]. Therefore, an increase in $\dot{V}La_{max}$ by SIT might be supposed. Gibala et al. [12, 13, 14] found that ET induces improvements in muscle oxidative capacity, muscle buffering capacity, and exercise performance after two weeks. Additionally, this implies a decrease in $\dot{V}La_{max}$. Based on the theoretical model of Mader et al. [5, 8], the aim of this study was to investigate the influence of SIT and ET on $\dot{V}La_{max}$ and $\dot{V}O_{2max}$, and the calculated PMLSS. It was hypothesized that SIT and ET lead to an increase in PMLSS on the basis of different influences of $\dot{V}La_{max}$ and $\dot{V}O_{2max}$.

MATERIALS AND METHODS

Subjects

Thirty healthy male participants were recruited to take part in this study (Table 1). The participants were young, healthy amateur cyclists (physical education students) who were recreationally active in sport, but not specifically trained for endurance or sprint cycling (61.45 ± 7.55 $ml \cdot min^{-1} \cdot kg^{-1}$, 0.75 ± 0.17 $mmol \cdot L^{-1}$). Participants were informed about the experimental procedures and potential risks associated with the study before giving written informed consent. Approval for the study's procedures was granted by the Ethics Committee.

Procedure

Prior to baseline measurements, subjects were familiarized with the testing procedures and training devices.

$\dot{V}La_{max}$ test: Participants initially performed a sprint test ($\dot{V}La_{max}$ test) to calculate $\dot{V}La_{max}$ [9]. Participants started with a warm-up session consisting of 12 min pedalling at a power of 1.5 $W \cdot kg^{-1}$ body mass on an electronically braked cycle ergometer (Lode Excalibur Sport, Lode, Groningen, Netherlands). In the middle of this period, a short sprint attempt of 5 s was interposed. It was followed by 10 min cycling, at 50 W, to mitigate the increased lactate concentration. Directly after finishing the warm-up phase, two blood samples (20 μl) were obtained from the earlobe in order to measure the lactate concentration before the test (La_{Pre}) and to minimize measurement errors. The capillary was stored in pre-filled 'Safe-Lock' reaction cups (1000 μl) and used for determination on a BIOSEN C-line lactate analyser.

Thereafter, participants were instructed to accelerate as fast as possible to a speed of 130 revolutions per minute (rpm). At this speed, the automatic breaking power of the cycle ergometer held the rpm constant, resulting in an isokinetic modus. After 15 s sprinting at a maximal level (t_{test}), the automatic braking power reduced the speed to 40 rpm and stopped the test immediately. Participants were encouraged to peak at a maximal level by means of vocal motivation. Every 0.1 s, the Lode ergometer registered the power per round. During the 15 s of maximal power, the standard deviation of power per round (SD_{p15}) was calculated. A blood sample was taken to assess the maximum blood lactate concentration after maximum exertion ($La_{maxPost}$), both after the sprinting session and every minute until the end of the 9th minute. The maximal lactate production rate was calculated from La_{Pre}, $La_{maxPost}$, alactic time interval (t_{alac}) and t_{test} using equation 1. The time interval from the beginning of the sprint session to the time, when maximum power

TABLE 1. Baseline characteristics.

	SIT (n = 10)	ET (n = 10)	CG (n = 10)	p-value
Age [years]	27.9 ± 1.8	26.7 ± 2.2	27.5 ± 1.7	0.199
Weight [kg]	73.43 ± 4.84	75.52 ± 11.66	77.25 ± 6.51	0.153
Height [cm]	181.4 ± 4.3	180.6 ± 6.6	181.0 ± 6.7	0.907
Body mass index [$kg \cdot m^{-2}$]	22.32 ± 1.4	23.89 ± 1.4	23.57 ± 1.4	0.610
$\dot{V}La_{max}$ [$mmol \cdot L^{-1} \cdot s^{-1}$]	0.76 ± 0.18	0.75 ± 0.18	0.75 ± 0.18	0.990
$\dot{V}O_{2max}$ [$ml \cdot kg^{-1} \cdot min^{-1}$]	62.56 ± 8.75	61.03 ± 4.83	60.76 ± 9.04	0.856
PMLSS [W]	259.7 ± 67.6	269.1 ± 52.0	260.8 ± 65.9	0.934

Note: Values are expressed as mean ± standard deviation. Baseline characteristics of the three groups were compared with a one-way ANOVA (p-value). Abbreviations: CG denotes control group, ET endurance training, PMLSS power in calculated maximal lactate steady state, SD standard deviation, SIT sprint interval training, $\dot{V}La_{max}$ maximal lactate production rate, $\dot{V}O_{2max}$ maximum oxygen consumption at maximum load.

had decreased by 3.5%, was defined as the end of the alactic time interval.

$$\dot{V}La_{max} = \frac{La_{maxPost} - La_{Pre}}{t_{test} - t_{alac}}$$

EQUATION 1: Calculation of maximal glycolytic rate [15]:
Abbreviations: $La_{maxPost}$ = maximum post-exercise blood lactate, La_{Pre} = blood lactate previous to test start, t_{test} = test duration = 15 s, t_{alac} = alactic time interval, $\dot{V}La_{max}$ = maximal glycolytic rate.

$\dot{V}O_{2max}$ test: After a rest period of 60 min, a ramp test ($\dot{V}O_{2max}$ test) was performed (using a modified protocol published by Craig et al. [9, 16]) to assess $\dot{V}O_{2max}$. Oxygen consumption ($\dot{V}O_2$) and carbon dioxide production ($\dot{V}CO_2$) were measured breath-by-breath using an Oxycon PRO (Erich Jäger, Höchberg, Germany). Ten-minute warm-up at a constant power of 1.5 W·kg^{-1} body mass was followed by 2 min at a constant load of 50 W. The workload at the beginning of the test was set to 50 W for 2 min and was increased by 25 W every 30 s. The test finished when participants were physically exhausted or complained of shortness of breath, dizziness or other physical complaints that kept them from proceeding with the test [17]. The maximal oxygen uptake was averaged from the highest 30 s. Reliability of both the $\dot{V}La_{max}$ test and the $\dot{V}O_{2max}$ test has been shown previously [18].

Calculation of PMLSS: The results of the $\dot{V}La_{max}$ test, $\dot{V}O_{2max}$ test and body weight were used to calculate the PMLSS for all participants with a previously described model using ten algebraic equations [5, 8, 9]. The model, background and validity of the methodology used to estimate the PMLSS are explained in detail by Hauser et al. [9].

Training: After all participants were familiar with the exercise regimes they were randomized (1:1:1-ratio) into three study groups: one group performing SIT, one group performing ET, and one control group (CG). Each group consisted of 10 participants (Table 1). The participants in the exercising groups started with the supervised SIT and ET, two to four days after the baseline test, respectively. The sprint interval training started with a warm-up session, consisting of 10 min pedalling at a power of 1.5 W·kg^{-1} body mass, followed by 30 seconds all-out effort Wingate anaerobic tests [19] against a resistance equivalent to 0.075 kg/kg body mass on the same cycle ergometer. The number of Wingate tests performed during each training session increased from four during the first and second week to five tests during the third and fourth week, and six tests during the fifth and sixth week. Between the Wingate tests, a recovery interval (cycled against 30 W with cadence below 50 rpm) was fixed at 4.5 min. Therefore, a complete training session would take 30 min in the first two weeks, 35 min in the middle term and 40 min in the last two weeks.

Endurance training consisted of 60 min of cycling at 1.5 to 2.5 mmol·L^{-1} blood lactate without increase over the study period.

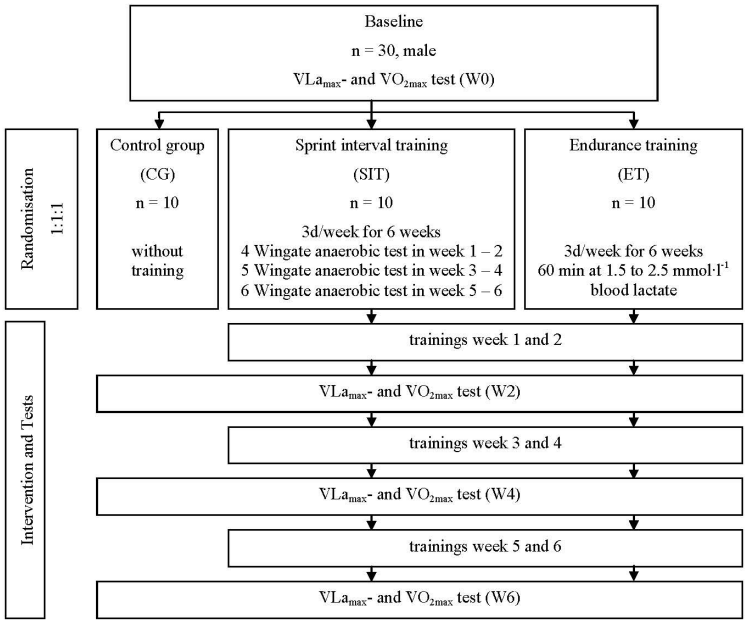

FIG 1. Study flow chart

A blood sample was taken to assess blood lactate concentration every 10 min. Both groups participated three days per week for six weeks.

Participants assigned to CG completed all test days without additional training and were encouraged to carry out activities of daily living without starting new fitness programmes (or finishing existing ones) over the study period. All participants were instructed to maintain their regular diet and physical activity throughout the intervention, but to refrain from alcohol and exercise for 48 h before each test. Sprint and ramp tests to determine $\dot{V}La_{max}$ and $\dot{V}O_{2max}$ (used to calculate the PMLSS) were performed in all study groups at baseline (W0), and after week two (W2), four (W4) and six (W6) of intervention. These data were used to measure the training effects of SIT and ET, in comparison to each other and to CG. The study flowchart is given in Figure 1.

Statistical analysis

Data were analysed with IBM SPSS Statistics, Version 25 and described by mean ± standard deviation (SD). The Shapiro-Wilk *W* test, Levene's test and Mauchly test, respectively, showed that the obtained data met the assumptions of normality, homogeneity of variance and sphericity. Baseline characteristics of the three groups were compared with a one-way ANOVA. A two-way ANOVA with repeated measurements was used to examine the impact of exercise training (time-effect) within each group, and to compare the intervention effects between the groups (2 group *4 time-effect). A p value of less than 0.05 was considered significant. Effect size quantifies the size of the difference between two measurements (W2, W4 and W6 in comparison to W0), and may therefore be said to be a true measure of the significance of the difference (Cohen's d for rating of effect intensity <0.2 trivial; $0.2 \leq |d| < 0.5$ small; $0.5 \leq |d| < 0.8$ moderate; $|d| \geq 0.8$ large effect size).

RESULTS

SIT

Sprint interval training resulted in a significant reduction of $\dot{V}La_{max}$ (-0.08 ± 0.05 mmol·L^{-1}·s^{-1}) and $La_{maxPost}$ (-1.22 ± 0.97 mmol·L^{-1}) and difference of $La_{maxPost}$ and La_{Pre} (La_{Diff}) (-1.12 ± 0.91 mmol·L^{-1}) and SD_{p15} (-19 ± 17 W) after two weeks and La_{pre} (-0.18 ± 0.16 mmol·L^{-1}) after four weeks. These parameters subsequently remained stable. Following training, $\dot{V}O_{2max}$ (+2.6 ± 2.4 ml·min^{-1}·kg^{-1}) and PMLSS (+25 ± 14 W) increased, but not before six weeks of intervention (Figure 2).

ET

Endurance training did not influence $\dot{V}La_{max}$, but significantly increased $\dot{V}O_{2max}$ (+2.8 ± 2.4 ml·min^{-1}·kg^{-1}) after two weeks. During the intervention $\dot{V}O_{2max}$ increased further, by 5.7 ± 3.5 ml·min^{-1}·kg^{-1}. A similar increase was noted in PMLSS (+16 ± 14 W) after four weeks, and increased to +32 ± 17 W after six weeks of intervention. Further baseline and follow-up parameters of $\dot{V}La_{max}$ and $\dot{V}O_{2max}$ are given in Table 2.

Comparison of SIT, ET and CG

Comparison of SIT and ET revealed no significant differences for $\dot{V}La_{max}$, $\dot{V}O_{2max}$ and PMLSS after six weeks. The control group remained stable in all parameters (Table 2).

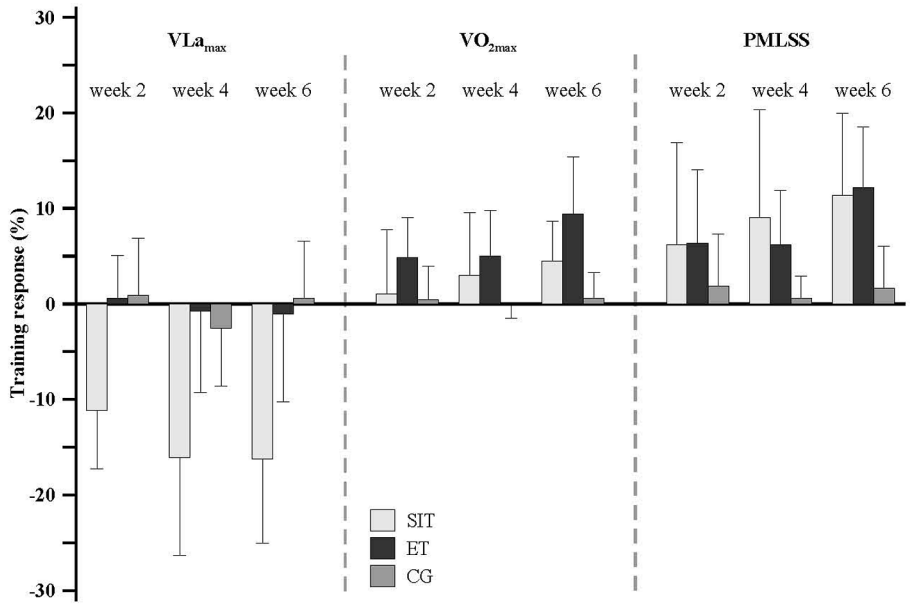

FIG 2. Training response to SIT, ET and CG for VLa_{max}, VO_{2max} and PMLSS.
Note: Inter-participant variability is large for all groups and all parameters. But all participants of the SIT respond with reduction of VLa_{max} (left). All participants of the ET respond with increase of VO_{2max} (middle) and ET and SIT respond with increase of PMLSS after six weeks (right). Abbreviations: CG denotes control group; ET endurance training; PMLSS power in calculated maximal lactate steady state; SIT sprint interval training ; VLa_{max} maximal lactate production rate; VO_{2max} maximum oxygen consumption at maximum load.

TABLE 2. Study results from baseline (W0) to follow-ups (W2 to W6).

	week	SIT (n = 10)			ET (n = 10)			CG (n = 10)		
		mean ± SD	p-value	d	mean ± SD	p-value	d	mean ± SD	p-value	d
$\dot{V}La_{max}$ [mmol·L^{-1}·s^{-1}]	W0	0.76 ± 0.18			0.75 ± 0.18			0.75 ± 0.18		
	W2	0.67 ± 0.17	0.01	-0.48	0.76 ± 0.18	0.99	0.01	0.75 ± 0.18	0.99	0.02
	W4	0.63 ± 0.17	0.01	-0.71	0.74 ± 0.17	0.99	-0.06	0.73 ± 0.18	0.99	-0.10
	W6	0.63 ± 0.15	0.01	-0.78	0.74 ± 0.17	0.99	-0.08	0.75 ± 0.21	0.99	0.03
La_{Pre} [mmol·L^{-1}·s^{-1}]	W0	1.04 ± 0.46			1.19 ± 0.6			1.12 ± 0.34		
	W2	0.94 ± 0.55	0.99	-0.21	1.11 ± 0.56	0.99	-0.13	0.97 ± 0.21	0.54	-0.54
	W4	0.86 ± 0.37	0.04	-0.44	1.02 ± 0.62	0.52	-0.28	0.94 ± 0.31	0.64	-0.53
	W6	0.85 ± 0.21	0.04	-0.56	0.92 ± 0.56	0.05	-0.48	1.11 ± 0.42	0.99	-0.03
$La_{maxPost}$ [mmol·L^{-1}·s^{-1}]	W0	9.05 ± 2.42			9.21 ± 2.14			9.43 ± 2.24		
	W2	7.82 ± 1.91	0.02	-0.56	9.30 ± 1.92	0.99	0.04	9.44 ± 2.30	0.99	0.01
	W4	7.57 ± 2.16	0.01	-0.65	8.92 ± 2.2	0.99	-0.14	9.03 ± 2.37	0.99	-0.17
	W6	7.48 ± 1.55	0.01	-0.79	8.75 ± 1.99	0.99	-0.22	8.99 ± 2.08	0.99	-0.20
La_{diff} [mmol·L^{-1}]	W0	8.01 ± 2.09			8.02 ± 1.91			8.31 ± 2.09		
	W2	6.89 ± 1.57	0.02	-0.61	8.18 ± 1.85	0.99	0.09	8.48 ± 2.18	0.99	0.08
	W4	6.71 ± 1.85	0.01	-0.66	7.90 ± 1.86	0.99	-0.06	8.08 ± 2.33	0.99	-0.10
	W6	6.63 ± 1.44	0.01	-0.78	7.83 ± 1.76	0.99	-0.10	7.88 ± 1.79	0.99	-0.22
t_{alac} [s]	W0	3.84 ± 0.37			4.45 ± 0.61			4.14 ± 0.72		
	W2	3.83 ± 0.53	0.99	-0.02	4.36 ± 0.49	0.99	-0.15	4.01 ± 0.60	0.79	-0.20
	W4	4.07 ± 0.50	0.29	0.52	4.41 ± 0.47	0.99	-0.07	4.09 ± 0.65	0.99	-0.08
	W6	3.77 ± 0.38	0.99	-0.21	4.34 ± 0.57	0.99	-0.18	4.05 ± 0.69	0.99	-0.13
P_{max} [W]	W0	1066 ± 138			943 ± 180			1039 ± 170		
	W2	1036 ± 157	0.14	-0.21	951 ± 190	0.99	0.05	1017 ± 172	0.51	-0.13
	W4	1035 ± 178	0.99	-0.19	948 ± 200	0.99	0.03	1004 ± 168	0.75	-0.21
	W6	1018 ± 164	0.33	-0.32	958 ± 202	0.99	0.08	1025 ± 176	0.99	-0.08
SDp15 [W]	W0	160.5 ± 40.2			139.5 ± 25.0			154.2 ± 43.0		
	W2	141.6 ± 36.2	0.04	-0.50	134.5 ± 26.7	0.99	-0.19	148.4 ± 41.4	0.99	-0.14
	W4	127.8 ± 44.0	0.01	-0.78	134.7 ± 30.0	0.99	-0.18	146.5 ± 45.0	0.35	-0.18
	W6	128.6 ± 35.4	0.01	-0.85	135.6 ± 29.9	0.99	-0.14	146.1 ± 44.5	0.99	-0.18
$\dot{V}O_{2max}$ [ml·kg^{-1}·min^{-1}]	W0	62.6 ± 8.8			61.0 ± 4.8			60.8 ± 9.0		
	W2	62.8 ± 6.6	0.99	0.03	63.9 ± 4.2	0.03	0.63	60.8 ± 7.5	0.99	0.01
	W4	64.0 ± 6.4	0.99	0.19	64.0 ± 4.5	0.05	0.63	60.7 ± 8.9	0.99	0.00
	W6	65.2 ± 7.9	0.04	0.32	66.7 ± 4.8	0.01	1.17	61.0 ± 8.2	0.99	0.03
PMLSS [W]	W0	259.7 ± 67.6			269.1 ± 52.0			260.8 ± 65.9		
	W2	271.1 ± 54.7	0.87	0.19	283.6 ± 46.8	0.09	0.29	263.6 ± 60.8	0.99	0.04
	W4	278.1 ± 56.0	0.24	0.30	284.6 ± 53.2	0.04	0.29	261.9 ± 64.5	0.99	0.02
	W6	284.7 ± 58.7	0.01	0.40	300.8 ± 58.4	0.01	0.57	263.6 ± 61.5	0.99	0.04

Note: Plus-minus values are means ± standard deviation. Abbreviations: CG denotes control group, d Cohen's d for rating of effect intensity of week two (W2), four (W4) and six (W6) in comparison to baseline (W0) (<0.2 trivial; 0.2 ≤ |d| <0.5 small; 0.5 ≤ |d| <0.8 moderate; |d| ≥ 0.8 large effect size), ET endurance training, La_{diff} $La_{maxPost}$ – La_{Pre}, $La_{maxPost}$ maximum post exercise blood lactate, La_{Pre} blood lactate previous to test start, p p-values for comparisson of W0 with W2, W4 and W6, P_{max} maximum physical power, PMLSS power in calculated maximal lactate steady state, SD standard deviation, SD_{p15} standard deviation of power per round over the 15 s sprint test, SIT sprint interval training, t_{alac} alactic time interval, $\dot{V}La_{max}$ maximal lactate production rate, $\dot{V}O_{2max}$ maximum oxygen consumption at maximum load.

DISCUSSION

This study examined the influence of SIT and ET, performed three times per week over six weeks, on $\dot{V}O_{2max}$ and $\dot{V}La_{max}$, and the calculated PMLSS using these values. Sprint interval training resulted primarily in reduced $\dot{V}La_{max}$, while ET led particularly to higher $\dot{V}O_{2max}$. These results indicate different changes in metabolic or physiologic endurance parameters according to the different training methods. In the control group, results of all $\dot{V}O_{2max}$- and $\dot{V}La_{max}$ tests revealed no relevant variation.

Tests to measure maximal aerobic capacity are widely accepted [20, 21]. In contrast, it is not possible to directly assess maximal anaerobic lactacid performance [15]. Using the $\dot{V}La_{max}$-equation (equation 1) allows for an approximation of maximal anaerobic lactacid performance [22]. Basic research studies document the variation of enzyme activity of phosphofructokinase as a key enzyme of glycolysis by high-intensity training resulting in improvement of maximal glycolytic power capacity [10, 11]. Therefore an increase in $\dot{V}La_{max}$ by SIT and a decrease by ET might be supposed.

In contrast to the hypotheses of the presented study, $\dot{V}La_{max}$ had already decreased significantly in the SIT group after two weeks (by -0.08 ± 0.05 $mmol \cdot L^{-1} \cdot s^{-1}$) and remained stable in the further weeks of the intervention. Only the maximum blood lactate concentration after maximum exertion and, therefore, the difference of rest lactate and maximal post-stress lactate showed significant changes during the study period. Accordingly, the significant changes of $\dot{V}La_{max}$ are mainly due to a reduction of lactate production and increase of lactate elimination. Kim et al. [23] identified a significant reduction of maximal and post-stress lactate after 8 weeks of SIT, using a step test. Oxygen is crucial to the metabolism of lactate. Therefore, transport of oxygen has to be sustained [24]. In the present study, maximal blood lactate values of 21.8 $mmol \cdot L^{-1}$ were measured in training sessions. High lactate concentrations result in a decrease in pH. This change in pH influences enzyme activity and leads to disruption of muscle activity [1]. To counteract this effect, lactate has to be eliminated promptly. Accordingly, the increased elimination of lactate results in elevated decomposition of lactate within mitochondria [24]. The elimination of blood lactate may be affected by lactate flow, metabolic capacity of oxidative muscle fibres (OMF), and lactate transport. After six weeks of SIT, with four to six repetitions of Wingate sprints, an increase in OMF of up to 25% was detected [12]. In addition, OMF reduces lactate production and may, therefore, also provoke a decrease in $\dot{V}La_{max}$. Storage capacity for glycogen increased by 7.6%, and resting muscle glycogen content improved by 28% [24]. Due to OMF, glycogenolysis diminished by 42% after six-week SIT, along with a simultaneous increase in lipometabolism [13].

Beyond this, the decrease in $La_{maxPost}$ and inferring from this $\dot{V}La_{max}$ may be a result of muscular economization and improvement of coordinative exposure through SIT. This is supported by our values of SD_{p15}, which show the standard deviation of power per round over 15 s. Sprint interval training resulted in a significant reduction in SD_{p15} (-21.9 ± 14.8 W), parallel to the reduction in $\dot{V}La_{maxPost}$ from the second week on. In comparison to SIT, after six weeks of ET, no significant change in $\dot{V}La_{max}$ was observed. A continuous decrease in La_{Pre} and $La_{maxPost}$ was noted during the intervention. Therefore, we postulate that six weeks of ET may be too short to provoke significant changes.

In contrast to $\dot{V}La_{max}$, six weeks of ET improved aerobic capacity to an extent comparable to other studies [13, 25]. While ET significantly improved $\dot{V}O_{2max}$ after two weeks, this effect remained active for up to six weeks when using SIT. Compared to previous studies, the significant improvement of $\dot{V}O_{2max}$ of 4.5 ± 4.1% after six weeks of SIT is within a lower range. Past studies described an improvement in $\dot{V}O_{2max}$ of 7.3% to 11.5% after a six-week SIT [2]. However, the relatively high baseline performance level ($\dot{V}O_{2max}$ 61.45 ± 7.55 $ml \cdot min^{-1} \cdot kg^{-1}$) could have affected the magnitude of effect sizes recorded in the present study. It might be supposed that sportive participants had more interest in participating in the study and increasing their fitness by training. Despite modest effect sizes, the exercise training protocols were successful in improving $\dot{V}O_{2max}$.

To assess the influence of $\dot{V}La_{max}$ and $\dot{V}O_{2max}$ on MLSS Mader and Heck [8] published a mathematical model. In this model, they explain the theoretical background of maximal lactate formation at steady state. Their model integrates maximal performance of both glycolysis and respiration. Changes in $\dot{V}La_{max}$ and $\dot{V}O_{2max}$ cause variations in the dependent parameter PMLSS. In both types of exercise training, a significant increase in PMLSS was noted. A significant reduction in $\dot{V}La_{max}$ was associated with an improvement of PMLSS by 11 ± 22 W, despite stable $\dot{V}O_{2max}$ after two weeks of SIT. Together with a significant increase in $\dot{V}O_{2max}$, a significant improvement in PMLSS was noted after six weeks of SIT. The significant reduction in $\dot{V}La_{max}$ after two weeks of SIT might be interesting for endurance athletes and may be used as a short-term training option before a competition. However, using ET, a significant increase in PMLSS after four weeks (and with a further increase after six weeks) was calculated, in the context of a stable $\dot{V}La_{max}$ and significantly improved $\dot{V}O_{2max}$. The improvements in PMLSS by 25 ± 14 W after six weeks of SIT and 32 ± 17 W, after six weeks of ET, are comparable to the results of other studies using threshold concepts [26, 27]. These changes show that both oxygen uptake and lactate are necessary to interpret PMLSS, power differences between subjects, and training methods [8, 9]. A combination of SIT and ET might to be useful to achieve optimal training results. However, the combination of the two strategies needs further investigation.

Limitations

Our study has several limitations. First, the inter-participant variability is large for all groups and all parameters. But all participants of the SIT or ET responded with a reduction in $\dot{V}La_{max}$ or increase in $\dot{V}O_{2max}$ after six weeks, respectively. Furthermore, all participants of ET and SIT responded with an increase in PMLSS. Additionally, the effect size confirmed the significance of the differences between the measurements. Second, we point to the relatively high baseline

performance level ($\dot{V}O_{2max}$ 61.45 ± 7.55 ml·min^{-1}·kg^{-1}), which may have affected the effect sizes (4.5 ± 4.1%) in our study. Third, it might be supposed that SIT is not practical for all populations, since it requires high levels of motivation and often also requires supervised training facilities. Despite modest effect sizes, the exercise training protocols were successful in improving $\dot{V}O_{2max}$.

CONCLUSIONS

The most striking finding of this study provides an answer to a pertinent question raised through the growing interest of researchers in different types of training (SIT and ET), and the subsequent effects on PMLSS (influenced by single parameters ($\dot{V}O_{2max}$ representing the maximal performance of the aerobic system and $\dot{V}La_{max}$ representing the maximal performance of the anaerobic lactic system)). While SIT primarily affects $\dot{V}La_{max}$, ET has an increasing effect on $\dot{V}O_{2max}$. It appears that both types of training significantly improved the calculated PMLSS by differently influencing $\dot{V}La_{max}$ and $\dot{V}O_{2max}$. Given the markedly lower training volume required, sprint interval training is indeed a time-efficient strategy to improve the PMLSS. Further research is needed to find the optimal combination of ET and SIT in different sports.

Conflict of interest

The authors declare that they have no conflict of interest.

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Ethical standards

The experiments comply with the current laws of the country. Ethics Commission proved the study.

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