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Effect of sprint training: Training once daily versus twice every second day

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Abstract
This study compared training adaptations between once daily (SINGLE) and twice every second day (REPEATED) sprint training, with same number of training sessions. Twenty physically active males (20.9 ± 1.3 yr) were assigned randomly to the SINGLE (n = 10) or REPEATED (n = 10) group. The SINGLE group trained once per day (5 days per week) for 4 weeks (20 sessions in total). The REPEATED group conducted two consecutive training sessions on the same day, separated by a rest period of 1 h (2–3 days per week) for 4 weeks (20 sessions in total). Each training session consisted of three consecutive 30-s maximal pedalling sets with a 10-min rest between sets. Before and after the training period, the power output during two bouts of 30-s maximal pedalling, exercise duration during submaximal pedalling and resting muscle phosphocreatine (PCr) levels were evaluated. Both groups showed significant increases in peak and mean power output during the two 30-s bouts of maximal pedalling after the training period ($P < 0.05$). The groups showed similar increases in $\dot{V}O_{2\,max}$ after the training period ($P < 0.05$). The REPEATED group showed a significant increase in the onset of blood lactate accumulation (OBLA) after the training period ($P < 0.05$), whereas no change was observed in the SINGLE group. The time to exhaustion at 90% of $\dot{V}O_{2\,max}$ and muscle PCr concentration at baseline did not change significantly in either group. Sprint training twice every second day improved OBLA during endurance exercise more than the same training once daily.

Keywords: *Performance, exercise, training*

Introduction

Maximal anaerobic and anaerobic endurance capacities are important for sprinters and ballgame players (Duffield, Dawson, & Goodman, 2005; Lacour, Padilla-Magunacelaya, Barthélémy, & Dormois, 1990; Tomlin & Wenger, 2002), and sprint training is commonly performed by these athletes. Previous studies have reported that sprint interval training for 2–3 weeks significantly increases peak and mean power output during a 30-s maximal pedalling test (Astorino, Allen, Roberson, & Jurancich, 2012; Burgomaster, Hughes, Heigenhauser, Bradwell, & Gibala, 2005). The increases in peak and mean power output are partially due to augmented phosphocreatine (PCr) concentrations and buffering capacity in skeletal muscle (Bishop, Edge, Davis, & Goodman, 2004; Okudan & Gokbel, 2005; Weston et al., 1997; Yquel, Arsac, Thiaudière, Canioni, & Manier, 2002; Zuniga et al., 2012). In fact, Parra, Cadefau, Rodas, Amigó, and Cussó (2000) demonstrated that the muscle PCr concentration increased after 14 consecutive days of maximal sprint training. However, the peak and mean power output during a 30-s maximal pedalling test did not improve after the training period, suggesting that a recovery period between training sessions is essential for improving exercise capacity.

Growing evidence suggests that endurance training twice every second day is more effective than endurance training once daily (Croft et al., 2009; Hansen et al., 2005; Hulston et al., 2010; Yeo et al., 2008). Hansen et al. (2005) reported that endurance training twice every second day (with a 2-h rest period between training sessions on the same day) for 10 weeks resulted in greater increases in the time

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to exhaustion during incremental exercise compared with endurance training once daily in healthy, sedentary adults. Yeo et al. (2008) attempted to confirm the effect of endurance training twice every second day (1- to 2-h rest period between training sessions on the same day) on endurance-trained cyclists, and they found that the muscle glycogen concentration increased in subjects who trained twice every second day, but not in subjects who trained once daily. Furthermore, the fat oxidation rate during a 60-min submaximal pedalling test was markedly improved only in the subjects who trained twice every second day. These findings suggest that endurance training twice every second day with a 1- to 2-h rest between bouts results in greater improvement in endurance capacity compared with the same training once daily.

Although several reports have examined effects of endurance training twice every second day on exercise performance and muscle adaptation, whether sprint training twice every second day has beneficial effects on improvements in exercise capacity remains uncertain. Although the lack of a recovery day during a strenuous sprint training period impedes the improvement of anaerobic power output despite a marked increase in intramuscular PCr concentration (Parra et al., 2000), sprint training twice every second day may lead to greater improvement in exercise performance compared with sprint training once daily, which is the traditional training approach. Therefore, this study compared the effects of sprint training on exercise performance between sprint training twice every second day and sprint training once daily, with the same total number of training sessions. We hypothesised that sprint training twice every second day would result in further improvements in maximal anaerobic power output and anaerobic endurance capacity compared with sprint training once daily.

Methods

Subjects

Twenty physically active males were participated. Although the subjects were familiar with recreational sports activities, they were not participating in regular strenuous training programmes at the start of this study. All subjects were informed about the possible risks of all procedures and the purpose of the study, and written informed consent was subsequently obtained. This study was approved by the Human Ethics Committee of the Ritsumeikan University, Japan.

Experimental design

An overview of the experimental design is shown in Figure 1. All subjects were assigned randomly to either the once-daily training group (SINGLE; n = 10; age: 20.4 ± 0.8 yr, height: 73.6 ± 8.3 cm, body weight [BW]: 63.9 ± 13.6 kg, body mass index [BMI]: 21.0 ± 2.9 kg/m^3, $\dot{V}O_{2\,max}$/BW: 47.7 ± 4.8 mL/min/kg, maximum heart rate (HR): 194 ± 8 bpm) or the twice-every second day training group (REPEATED; n = 10; age: 21.3 ± 1.6 yr, height: 174.9 ± 4.5 cm, BW: 67.9 ± 6.7 kg, BMI: 22.2 ± 1.8 kg/m^3,

A

DAY	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SINGLE	•	•	•	•	•			•	•	•	•	•		
REPEATED		••		••				••		••		••		
DAY	15	16	17	18	19	20	21	22	23	24	25	26	27	28
SINGLE	•	•	•	•	•			•	•	•	•	•		
REPEATED		••		••				••		••		••		

B

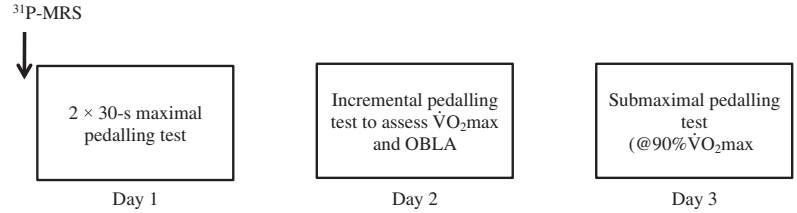

Figure 1. Experimental design (A) and measurement schedule before and after the training period (B). The training consisted of two 14-day cycles. A indicates the daily training schedule in each group. Measurements before and after the training period were performed over 3 days (days 1–3). SINGLE: training once daily; REPEATED: training twice every second day with a 1-h interval between each training session. (•) Training session (three sets of 30-s maximal pedalling).

$\dot{V}O_{2\,max}$/BW: 46.8 ± 6.3 mL/min/kg, maximum HR: 195 ± 10 bpm) to match physical fitness levels between the groups. No significant differences in body composition or physical fitness levels were observed between the groups before the training period.

The SINGLE group conducted a sprint training session once daily 5 days per week for 4 weeks. By contrast, the REPEATED group conducted two consecutive training sessions on the same day, with a rest period of 1 h. On the following day, the subjects did not perform any training (rest day). The 1-h rest period between training sessions on the same day was determined in accordance with Hansen et al. (2005) and Yeo et al. (2008). The training in the REPEATED group was performed 2–3 days per week for 4 weeks. Thus, the total number of training sessions was exactly the same between the two groups (20 training sessions over 4 weeks, Figure 1A).

Each training session in both groups consisted of three consecutive 30-s maximal pedalling bouts with a 10-min rest between each set. Training was performed on an electromagnetically braked cycle ergometer (Power max VIII, Combi, Nigata, Japan) with a resistance equivalent to 5.0% of the subject's BW. In the REPEATED group, the subjects rested for 1 h after the first training session, and the second training session was subsequently conducted. Power output during each bout of training was recorded over the training period in both groups. All training sessions were performed in the morning (8:00 am–12:00 am) following an overnight fast. The subjects were allowed to consume only water during each training session. Immediately after completing the last training session on each day, the subjects consumed a 45-g carbohydrate gel (180 kcal) to facilitate muscle glycogen recovery.

Measurements before and after the training period

Repeated two bouts of 30-s maximal pedalling, incremental pedalling and submaximal pedalling were carried out before and after the training period (Figure 1B). Each exercise test was prepared to evaluate different power output capacities among ATP-PC, glycolytic and aerobic systems. All tests before the training period were performed 3–7 days before the first training session and were started 72 h after the final training session in both groups. The PCr concentration in the quadriceps femoris muscle at rest was also measured before and after the training period.

Repeated 30-s maximal pedalling test

Subjects performed two bouts of 30-s maximal pedalling with a 10-min rest between bouts. The resistance was set at 5.0% of each subject's pre-training BW. Subjects were instructed to begin pedalling as fast as possible and were verbally encouraged to maintain power output. Power output during 30-s maximal pedalling was recorded by a computer (Edge E420/E520, Lenovo, Beijing, China) to determine power output per 0.1 s using specially designed software (Konami, Tokyo, Japan). Peak power output, mean power output and percentage decrease in power output between the two bouts were calculated from these data.

Incremental pedalling test

An incremental pedalling test was conducted to determine the maximal oxygen consumption ($\dot{V}O_{2\,max}$) and peak aerobic power output on an electromagnetically braked cycle ergometer (AEROBIKE 75XLIII, Combi, Nigata, Japan). The test began at 80 W and the load was increased continuously in 30-W increments every 2 min until exhaustion. The test was terminated when the subjects failed to maintain the prescribed pedalling frequency of 80 rpm or reached a VO_2 plateau. Respiratory gases were collected and analysed using an automatic gas analyser (AE300S, Minato Medical Science, Tokyo, Japan) to determine VO_2, carbon dioxide output, minute ventilation and the respiratory exchange ratio. These data were averaged every 30 s. Appropriate calibrations of the O_2 and CO_2 sensors and the volume transducer were conducted before the start of exercise. The HR was measured continuously using a wireless HR monitor (Acculex Plus, Polar Electro, Kempele, Finland).

During the incremental exercise, fingertip blood was collected to evaluate the time-course changes in blood lactate concentrations. Blood lactate concentrations were measured using an automatic lactate analyser (lactate Pro2 LT-1730, Arkray, Kyoto, Japan). The workload corresponding to 4 mmol/L blood lactate concentration (onset of blood lactate accumulation; OBLA) was calculated from the data using software (MEQNET LT Manager, Arkray, Kyoto, Japan).

Submaximal pedalling test

A submaximal pedalling test corresponding to 90% of $\dot{V}O_{2\,max}$ was performed before and after the training period to evaluate anaerobic endurance capacity. The pedalling frequency was set to 80 rpm. The exercise was terminated when pedalling frequency was <70 rpm for a consecutive period of 5 s. Time to exhaustion was measured to evaluate anaerobic endurance performance.

Muscle PCr concentration

Following an overnight fast, the PCr concentration in the quadriceps femoris muscle at rest was measured by ^{31}P-magnetic resonance spectroscopy (^{31}P-MRS) before and after the training period. ^{31}P-spectra (25.852 Hz, spectral width 3000 Hz) were collected with a SignaHDt 1.5T (GE Healthcare UK, Buckinghamshire, England). After being inserted into the magnet, an 8-inch diameter surface coil (Takashima Seisakusho, Kanagawa, Japan) was located on the middle of the right thigh. The field was shimmed using the proton signals from the intramuscular H_2O. After switching to ^{31}P, the receiver gain for ^{31}P was set to maximise the PCr signal acquired from the muscle and was maintained at an adequate level throughout the experiment. The data for 256 scans were averaged to produce a single spectrum. The absolute intramuscular PCr concentrations were calculated using the PCr: β-ATP ratio assuming that the peak area of β-ATP was 8.2 mM (Kemp, 2008). PCr measurements were repeated three times by the same investigator, and the mean values were adopted.

Statistical analysis

Exercise performance and muscle PCr concentration data before and after the training period were compared using a two-way (group × training period) repeated-measures analysis of variance (ANOVA) to determine the interaction or main effect. When the ANOVA revealed a significant difference, the Tukey–Kramer test was used for *post hoc* analyses. Time-course changes in power output during the 30-s maximal pedalling test over 20 training sessions were also analysed using a two-way (group × training session) repeated-measures ANOVA followed by a *post hoc* analysis. All values are expressed as means ± standard deviations (SDs). A value of $P < 0.05$ was considered to indicate a significant difference.

Results

Time-course changes in power output over the training period

We recorded the time-course changes in peak and mean power output while subjects pedalled maximally for 30 s (first set) relative to pre-training values during the training period. No significant interaction (group × training session) or main effects (groups, training session) for peak power output were observed. However, a significant interaction (group × training session) and a main effect for training session were observed for mean power output ($P < 0.05$). The REPEATED group showed significant ($P < 0.05$) increases in the change in the mean power output relative to the pre-training value during sessions 13 (4.6 ± 2.6%) and 19 (4.3 ± 3.9%), whereas the relative mean power output in the SINGLE group did not increase during the training period. The relative change in the mean power output relative to the pre-training value was significantly ($P < 0.05$) higher in the REPEATED (4.6 ± 2.6%) group than that in the SINGLE (1.8 ± 2.7%) group in session 13.

Repeated 30-s maximal pedalling test

Table I shows peak and mean power output during two repeated bouts of 30-s maximal pedalling before and after the training period. Peak and mean power output during the first and second bouts of 30-s maximal pedalling increased significantly after the training period in both groups ($P < 0.05$). No significant differences in peak or mean power output were observed between the two groups after the training period. Before the training period, peak and mean power output during the second bout of 30-s maximal pedalling test were significantly lower than those in the first bout ($P < 0.05$). However, peak power output during the second bout of 30-s maximal pedalling did not differ significantly compared with that during the first bout of exercise in either group after the training period. Mean power output during the second bout of exercise was significantly lower compared with that during the first bout of exercise in both groups.

The decrease in power output between the first and second bouts of 30-s maximal pedalling before was compared with that after the training period. The results showed that the peak power output decrease between the first and second bouts of 30-s maximal pedalling was reduced significantly after the training period in both groups (Figure 2A). However, the mean power output decrease between the first and second bouts of 30-s maximal pedalling was reduced significantly only in the REPEATED group ($P < 0.05$), whereas no change was observed in the SINGLE group (Figure 2B).

Incremental pedalling test

$\dot{V}O_{2\,max}$ and the maximal aerobic power output increased significantly after the training period in both groups ($P < 0.05$, Table I). However, no significant difference was observed between the two groups after the training period.

Figure 3 shows the OBLA during the incremental pedalling test before and after the training period. Before the training period, no significant difference was observed in OBLA between the two groups. OBLA increased significantly after the training period in the REPEATED group (130 ± 26 vs. 156 ± 47 W,

Table I. Performances during the repeated 30-s maximal pedalling test and the incremental pedalling test before and after the training period

	SINGLE		REPEATED	
	Before	After	Before	After
Repeated 30-s maximal pedalling test				
Bout 1				
Peak power output (W)	610 ± 131	633 ± 130*	648 ± 64	665 ± 67*
Mean power output (W)	482 ± 98	503 ± 103*	495 ± 47	521 ± 48*
Bout 2				
Peak power output (W)	579 ± 126**	632 ± 129*	609 ± 74**	664 ± 65*
Mean power output (W)	456 ± 93**	490 ± 95*,**	465 ± 52**	511 ± 51*,**
Incremental pedalling test				
$\dot{V}O_{2\,max}$ (mL/min)	2872 ± 420	3271 ± 512*	3159 ± 362	3425 ± 236*
$\dot{V}O_{2\,max}$/BW (mL/min/kg)	47.7 ± 4.8	51.6 ± 6.4*	46.8 ± 6.3	50.1 ± 5.1*
Maximal aerobic power (W)	254 ± 49	272 ± 45*	254 ± 42	287 ± 36*
Maximal HR (bpm)	194 ± 8	191 ± 9	195 ± 10	191 ± 12

Values are means ± SDs.
*$P < 0.05$ vs. before; **$P < 0.05$ vs. bout 1.

$P < 0.05$) but not in the SINGLE group (147 ± 21 vs. 152 ± 28 W).

Submaximal pedalling test

The time to exhaustion at 90% of $\dot{V}O_{2\,max}$ was not significantly different between the SINGLE (464 ± 266 s) and REPEATED (406 ± 100 s) groups before the training period. No significant change in time to exhaustion at 90% of $\dot{V}O_{2\,max}$ was observed after training in either group (SINGLE, 480 ± 104 s; REPEATED, 446 ± 144 s).

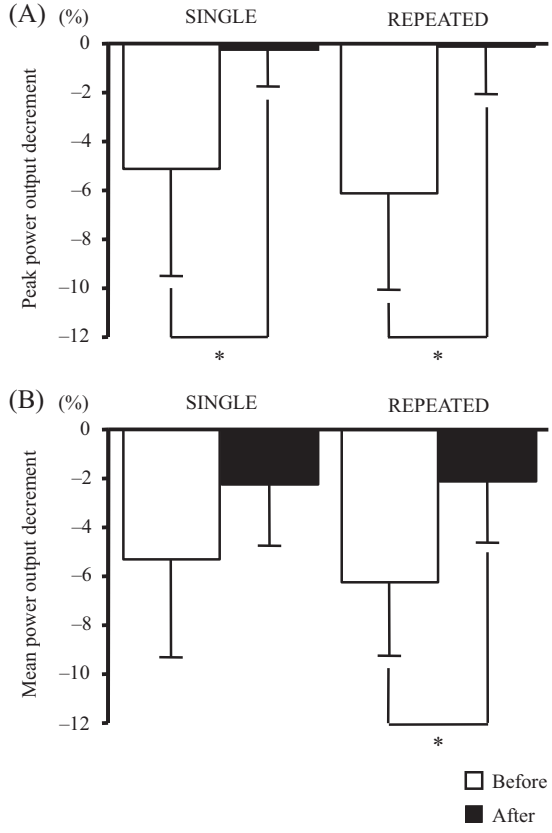

Figure 2. The peak (A) and mean (B) power decrements between the first and second bout of the 30-s maximal pedalling test before and after the training period. Values are means ± SDs. *$P < 0.05$.

Muscle PCr concentration

We evaluated muscle PCr concentration by ^{31}P-MRS before and after the training period. No significant difference in muscle PCr concentration was observed between the SINGLE (36.0 ± 4.4 mM) and the REPEATED (38.0 ± 6.5 mM) groups before the training period. Muscle PCr concentration did not change significantly after the training period in either the SINGLE (39.0 ± 4.5 mM) or REPEATED (42.1 ± 5.1 mM) group.

Discussion

This study was designed to compare the effects of sprint training between sprint training twice every second day (REPEATED) and sprint training once

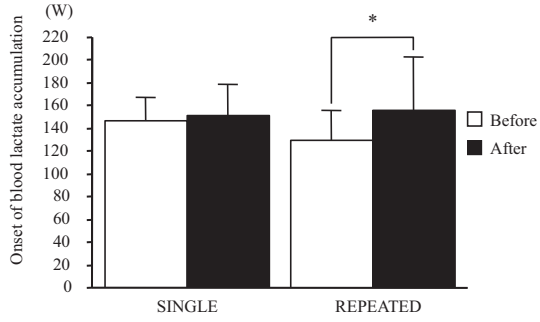

Figure 3. OBLA during the incremental pedalling test before and after the training period. Values are means ± standard SDs. *$P < 0.05$.

daily (SINGLE), with the same number of training sessions over 4 weeks. The main finding of this study was that the OBLA during the incremental pedalling test was improved significantly only in the REPEATED group, suggesting enhanced exercise capacity during submaximal exercise. Moreover, the REPEATED group showed a significant reduction in the mean power output decrease between the first and second bouts of 30-s maximal pedalling. Although previous studies have demonstrated further increases in muscle glycogen and endurance capacity after endurance training twice every second day, this is the first report to show that maximal anaerobic training twice every second day has some beneficial effects on adaptations to exercise performance.

Although endurance exercise twice every second day (with a 1- to 2-h rest between training sessions) has been shown to augment adaptations by endurance training (Croft et al., 2009; Hansen et al., 2005; Hulston et al., 2010; Yeo et al., 2008), sprint training is generally performed once daily due to the strenuous stress involved in intensive exercise with maximal effort. Moreover, Parra et al. (2000) reported that 14 consecutive days of sprint training increased the intramuscular PCr concentration markedly. Somewhat surprisingly, however, the peak and mean power output during the 30-s maximal pedalling test did not change after the training period. The findings suggest that consecutive sprint training sessions within a short period impede improvement in exercise performance. Therefore, we postulated that sprint training twice every second day would enhance anaerobic and endurance exercise capacities more than a traditional training programme performed once daily.

Both groups showed similar increases in peak and mean power output during two bouts of 30-s maximal pedalling test after the training period. The increase in power output may be due to augmented muscle PCr concentrations (Okudan & Gokbel, 2005; Yquel et al., 2002; Zuniga et al., 2012), as sprint training increases muscle PCr concentrations (Parra et al., 2000; Rodas, Ventura, Cadefau, Cussó, & Parra, 2000). However, this hypothesis was not supported by our results because muscle PCr concentrations did not change significantly in either group after the training period. Although the increases in the peak and mean power output during the 30-s maximal pedalling test were similar in the two groups, the temporal changes in the power output over 20 training sessions were significantly different. The relative mean power output compared with the pre-training value was significantly higher at session 13 in the REPEATED group than that in the SINGLE group, suggesting that the increase in mean power output during 30-s maximal pedalling occurred earlier in the week in the REPEATED group.

A unique component of the present study was that the subjects performed two successive 30-s maximal pedalling bouts before and after the training period. As a result, the percentage decrease in peak power output between the two bouts of 30-s maximal pedalling was significantly reduced after the training period in both groups. Moreover, the percentage decrease in the mean power output between the two bouts of 30-s maximal pedalling was reduced significantly only in the REPEATED group, although the difference in the training effect between the two groups was relatively small. Several studies have reported that repeated sprint performance is associated with muscle PCr resynthesis ability (Bogdanis, Nevill, Boobis, & Lakomy, 1996; Trump, Heigenhauser, Putman, & Spriet, 1996;) and $\dot{V}O_{2\,max}$ (Cooke, Petersen, & Quinney, 1997; Haseler, Hogan, & Richardson, 1999; Takahashi et al., 1995). Sprint training also improves muscle PCr resynthesis ability (Forbes, Slade, & Meyer, 2008). In our study, $\dot{V}O_{2\,max}$ increased significantly in both groups after the training period. This result is supported by previous reports (Burgomaster et al., 2005; Gibala, Little, Macdonald, & Hawley, 2012; Hazell, Macpherson, Gravelle, & Lemon, 2010), which demonstrated that sprint training stimulates mitochondrial biogenesis (Little, Safdar, Bishop, Taropolsky, & Gibala, 2011). Furthermore, improvements in muscle buffering capacity and lactate clearance might account for the attenuation of power output decrease between two successive 30-s maximal pedalling bouts (Bickham, Bentley, Le Rossignol, & Cameron-Smith, 2006; Gibala et al., 2006).

The OBLA increased significantly after training in the REPEATED group only. Although OBLA is a marker of lactate metabolic capacity, it mainly reflects lactate oxidation capacity (Kindermann, Simon, & Keul, 1979). Sprint training increases monocarboxylate transporter 1 (MCT1) content, which plays a role in lactate uptake by skeletal muscle (Bickham et al., 2006; Green et al., 2002). Therefore, a plausible mechanism for the improvement of OBLA in the REPEATED group may involve up-regulation of MCT1. Unfortunately, no studies have examined the effects of training twice every second day on lactate metabolism.

Short-term sprint training increases time to exhaustion during the submaximal pedalling test (Burgomaster et al., 2005; Burgomaster, Heigenhauser, & Gibala, 2006; Little, Safdar, Wilkin, Taropolsky, & Gibala, 2010). However, time to exhaustion at 90% of $\dot{V}O_{2\,max}$ did not change significantly after the training period in either group. The reason for the inconsistent results between the studies may be due to different experimental settings. A previous study (Little et al., 2010) assessed the submaximal pedalling test using the same absolute intensity before and after the

training period, whereas we used the same relative intensity after the training period.

Based on the improvement in OBLA with sprint training twice every second day, our findings are applicable to athletes who undertake intensive training to improve lactate metabolic capacity (e.g. sprinters and team sports players). However, caution is necessary because the findings supporting this idea are based on the results of a laboratory-based experiment rather than on more practical observations of actual sports training situations. Furthermore, the adequacy of a training programme consisting of sprint training twice every second day with a 1-h rest between sessions should be discussed carefully. Currently, we cannot assess the effect of sprint training twice daily. Additionally, all of the training sessions in this study were carried out under fasting conditions, and further investigations to determine the influence of diet may be necessary.

In conclusion, our results indicated that sprint training twice every second day improved the OBLA more than sprint training once daily in physically active males. However, improvements in peak and mean power output during 30-s maximal pedalling and anaerobic endurance capacity were similar between the groups.

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