Load Characteristics of Sprint Interval Training According to 400 m Running Performance: Competitive Level Comparison

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This study aimed to compare the load characteristics of sprint interval training (SIT) according to 400-m sprint performance. Eight elite sprinters and ten sub-elite sprinters were separated according to 400-m sprint performance and participated in this study (age: 21.0 ± 2.5 years, height: 176.0 ± 4.0 cm, and body mass: 67.0 ± 5.3 kg). All subjects performed two different SIT protocols on a cycle ergometer. The SIT protocols consisted of two bouts of 20-s maximal sprints interspersed with either 30-s rest (R-30s) or 60-s rest (R-60s). Mean power output over both sprints in R-60s was significantly greater than in R-30s in both groups ($p < 0.001$). In the elite group, blood lactate did not significantly differ between R-30s and R-60s even though different mean power output was recorded. However, in the sub-elite group, blood lactate from the R-60s condition was significantly greater than from the R-30s condition ($p < 0.05$). These results indicate different physiological responses to SIT depending on 400-m sprint capabilities. To enhance anaerobic adaptations, it is suggested that elite 400-m sprinters should utilize SIT with very short recovery periods, while sub-elite 400-m sprinters should utilize relatively longer recovery periods.

Keywords: recovery duration, blood lactate, anaerobic energy

1. Introduction

The 400-m race is the longest sprint in track and field, thus it requires speed endurance in order to achieve and maintain high running velocities throughout the event (Schiffer, 2008). The duration of the event, which is primarily supported by the anaerobic energy system, lasts approximately one minute and the physiological demands result in decreased sprint velocity towards the end of the race. Previous studies have demonstrated that the anaerobic energy contribution during 400-m sprinting is approximately 70% and represents the key factor in achieving high performance (Hill, 1999; Numera and Rusko, 1995; Reis and Miguel, 2007). Moreover, Weyand et al. (1994) mentioned that it was possible to predict 400 m sprint time based on the anaerobic endurance capacity of athletes. Ac-

cordingly, coaches and athletes tend to focus on improving the anaerobic energy system through speed endurance training.

Sprint interval training (SIT) that involves repeated sprint running or cycling bouts completed with all-out effort interspersed with short recovery time has been demonstrated to enhance anaerobic performance (Burgomaster et al., 2006; Hazell et al., 2010). From a physiological and biochemical perspective, increased accumulated O_2 deficit, blood lactate concentration, and low intracellular pH as well as power output induced by the SIT are considered to be key components needed to develop the anaerobic energy system (Reis and Miguel, 2007). Therefore, SIT represents a potentially effective training approach for improving anaerobic capacity in 400 m sprinters. It is well known that recovery duration dramatically influences these parameters

with several previous studies examining the effects of manipulating work-to-rest ratios during SIT (Buchheit et al., 2009, Glaister et al., 2005). Buchheit et al. (2009) suggested that increased recovery duration leads to the higher lactate accumulation and anaerobic energy supply. In addition, it has been demonstrated that 30-s of recovery after an exhaustive exercise bout is insufficient to allow for full phosphocreatine (PCr) resynthesis; however, this resynthesis process is exponential and appears to be complete following 60-s of recovery (Bogdanis et al., 1995). Accordingly, power output during subsequent exercise bouts should differ according to the duration of the recovery interval even in a small increment (e.g. 30-s and 60-s). The use of longer recovery durations during SIT supports PCr resynthesis and enhancement of the glycolytic pathway (Bogdanis et al., 1995, Bogdanis et al., 1998, Buchheit et al., 2009). Therefore, coaches and athletes often adopt SIT protocols involving some number of 20-30-s maximal sprints interspersed with very short recovery periods, from 30-s to 60-s to enhance anaerobic energy expenditure (Saraslanidis et al., 2009).

While the previous studies have demonstrated the effects of recovery duration on the physiological response during SIT (Bogdanis et al., 1995 and 1998, Buchheit et al., 2009), differences among athletes of different competitive levels has not been fully examined. Since it is known that the anaerobic capacity is well developed in superior 400-m sprinters (Weyand et al., 1994), the training effect of SIT should differ according to the performance capabilities of the athlete. Hanon et al. (2011) suggested the possibility that athletes with different competitive levels demonstrate different physiological responses with respect to their individual anaerobic energy capacities. Thus, competitive level and physiological capacity may be important considerations to optimize adaptations to SIT. Accordingly, more comprehensive knowledge of the influence of recovery duration on intermittent exercise will assist in the design of training programs for competitive athletes, and the identification of potential differences in training requirements of elite versus sub-elite sprinters is needed.

Therefore, we aimed to (a) compare two SIT sessions with different recovery duration (30-s vs. 60-s) and (b) identify the difference in load characteristics during SIT depending upon the competitive level of

400 m sprinters (elite vs. sub-elite). We hypothesized that (1) mean power output during the protocol with a 30-s rest (R-30s) would be greater than that of the protocol with a 60-s rest (R-60s), and (2) the change in power output and physiological response between the R-30s and the R-60s would be affected by the competitive level of 400-m performance.

2. Methods

2.1. Subjects

Eighteen subjects including elite ($n=8$) and sub-elite ($n=10$) 400 m sprinters participated in this study (**Table 1**). The elite sprinters participated in national level competition with two of the athletes having international competitive experience in 400 m events (Personal Record = 45.87-s and 46.56-s, respectively). The sub-elite sprinters had participated in only regional level competition. The International Association of Athletics Federations (IAAF) scores in the elite level sprinters and sub-elite sprinters were 1047 ± 40 and 845 ± 69 points, respectively, and these were equivalent to the scores of the 30th (1040 points) and 850th (859 points) ranked Japanese athletes, respectively. All athletes were asked to maintain their normal diet and training throughout the study except for being required to consume no food or beverages (other than water) 2 h before testing, and to refrain from alcohol consumption and vigorous exercise in the 24 h before testing.

This study was approved by the Human Subjects Committee of the Tsukuba University, in accordance with the Declaration of Helsinki. Written informed consent was obtained from all subjects prior

Table 1 Characteristic of and differences between the elite and sub-elite group.

	elite group ($n=8$)	sub-elite group ($n=10$)	
Age (y)	22.1 ± 3.4	20.1 ± 0.7	N.S.
Height (cm)	174.4 ± 5.3	176.5 ± 3.1	N.S.
Body mass (kg)	66.8 ± 5.5	67.2 ± 5.4	N.S.
400 m time (s)	46.97 ± 0.60	50.24 ± 1.18	$p < 0.001$
IAAF Score	1047 ± 40	845 ± 69	$p < 0.001$

Values are means $\pm$ SD.

$p < 0.001$; the significant differences between groups.

N.S.; the non-significant difference between groups.

to their participation in this study.

2.2. Procedures

An electromagnetically braked cycle ergometer (Powermax-VII, Combi Wellness, Tokyo, Japan) was used in the present study. A standardized warm-up protocol was completed which involved 3-min cycling at a rate of 90 rpm with 1.0 kp workload followed by two 5-s maximal sprints with 30-s recovery duration under submaximal effort. After the warm-up, subjects spent 20-min at chair rest to prepare for the experiment. Thereafter, the subjects performed two different types of SIT. These protocols consisted of two bouts of 20-s maximal sprints interspersed with either 30-s rest (R-30s) or 60-s rest (R-60s). The experimental setting of R-60s was based on a study by Sarasilanidis et al., (2009), whilst the R-30s was selected so that phosphocreatine resynthesis would be incomplete during the recovery period between sprint bouts (Bogdanis et al., 1995). The resistance of each SIT protocol was set to 0.075 kp of body weight. Since all subjects were well-familiarized with the equipment, maximal sprint cycling, and testing procedures prior to the experiment, there was complete confidence in reaching an all-out effort from a stationary start. Furthermore, all subjects were highly motivated and verbally encouraged during exercise and instructed to cycle with maximum effort in every session. The two testing sessions were separated by >48 h and conducted within 1 week, and the SIT protocols were completed in a randomized order. All tests were performed at the same time of day to minimize the influence of diurnal variations on the measured variables.

2.3. Measurements

The power output data produced during cycling were sampled at 10 Hz on a personal computer (INSPIRON1300, Dell, Texas, USA) using the ergometer software. Peak power was determined as the highest achieved power output during each SIT protocol. Mean power was determined by averaging the power for each 20-s sprint bout and over the entire SIT protocol. Blood samples were taken from the fingertips at rest and 1, 3, 5, and 7 min after each test. Blood lactate concentrations were measured using an automated lactate analyzer (Lactate

Pro2 LT-1730, Arkray, Kyoto, Japan). The peak blood lactate values (PBLa) were used to evaluate glycolytic metabolism during SIT protocols.

2.4. Statistical analyses

The mean and standard deviation (SD) of each measure were calculated for descriptive analyses. Independent-sample *t* tests were used to compare the descriptive and performance characteristics of the elite and sub-elite sprinters. Pearson's correlation coefficient was used to examine the relationship between IAAF scores and mean power outputs. A three-way [recovery (30-s vs 60-s) x sprint (1st vs. 2nd) x competitive level (elite vs. sub-elite)] analysis of variance (ANOVA) with repeated measures was used to compare the peak and mean power output (relative to body mass) during the SIT protocols. A two-way [recovery (30-s vs 60-s) x competitive level (elite vs. sub-elite)] ANOVA with repeated measures was used to compare PBLa. When there was a significant *F*-value, Bonferroni adjusted comparison were used for post-hoc analyses. The Cohen's *d*-value effect size was calculated based on mean and SD to show practical significance and interpreted as trivial (<0.19), small (0.20-0.59), moderate (0.60-1.19), large (1.20-1.99), and very large (2.0-4.0) (Hopkins et al., 2009). Statistical significance was set at $p < 0.05$. All statistical analyses were performed using SPSS version 22 for Windows (IBM SPSS Statistics, IBM, USA).

3. Results

Mean power output during the entire SIT protocol was significantly greater in the R-60s compared to the R-30s ($p < 0.001$, $d = 0.80$). As shown in **Figure 1**, IAAF scores were significantly correlated with mean power output during the entire SIT protocol for both the R-30s ($p < 0.01$, $r = 0.68$) and the R-60s ($p < 0.01$, $r = 0.69$) conditions.

A significant recovery x sprint interaction ($F_{1,16} = 45.31$, $p < 0.001$) was shown for mean power with no difference found between SIT protocols during the first sprint ($p = 0.98$, $d = 0.01$), and the R-30s being greater than the R-60s during the second sprint ($p < 0.001$, $d = 0.94$). A significant sprint x competitive level interaction ($F_{1,16} = 7.20$; $p < 0.05$) was shown for mean power with elite sprinters demonstrating greater values than sub-elite sprinters

Table 2 Power output and blood lactate of Ex-30s and Ex-60s in elite and sub-elite group.

	elite group (n = 8)	sub-elite group (n = 10)	p	Cohen's d	95% CI
R-30s					
Peak Power (W/kg)	13.7 ± 0.7	12.8 ± 0.7	<0.05	1.37	0.25–1.62
Mean Power (W/kg)					
Total	10.1 ± 0.4	9.7 ± 0.3	<0.05	1.19	0.06–0.76
1 st sprint	11.6 ± 0.6	10.9 ± 0.5	N.S.	—	—
2 nd sprint	8.7 ± 0.2	8.5 ± 0.4	N.S.	—	—
Peak blood lactate (mmol/L)	19.9 ± 1.2	17.6 ± 1.6	<0.05	1.67	0.91–3.74
R-60s					
Peak Power (W/kg)	13.7 ± 0.3	12.8 ± 0.5	<0.05	1.37	0.24–1.58
Mean Power (W/kg)					
Total	10.4 ± 0.3	10.0 ± 0.3	<0.05	1.34	0.09–0.66
1 st sprint	11.6 ± 0.5	10.9 ± 0.4	N.S.	—	—
2 nd sprint	9.2 ± 0.3	9.1 ± 0.2	N.S.	—	—
Peak blood lactate (mmol/L)	19.2 ± 2.4	19.0 ± 2.0	<0.05	0.10	–1.97–2.40

Values are means ± SD.

p < 0.05; the significant differences between groups.

N.S.; the non-significant difference between groups.

Figure 1 Relationship between IAAF scores and mean power during (A) R-30s and (B) R-60s. **Figure 2** Mean power output (A) and peak blood lactate (B) during R-30s and R-60s in elite and sub-elite groups. †Significantly different between groups (†; p < 0.05, ††; p < 0.01). *Significantly different between protocols (*; p < 0.05, ***; p < 0.001).

during the first sprint ($p < 0.01$, $d = 1.44$), and no differences were found between groups during the second sprint ($p = 0.452$, $d = 0.24$). Main effects for recovery ($F_{1,16} = 61.53$, $p < 0.001$; R-30s > R-60s) and sprint ($F_{1,16} = 463.03$, $p < 0.001$; first sprint > second sprint) were also noted.

No significant recovery $\times$ competitive level interaction was shown for peak power (**Fig. 2 A**); however, there was a main effect for competitive level ($F_{1,16} = 9.27$, $p < 0.01$) with the elite sprinters (mean = 13.7 ± 0.2 W/kg; 95% CI = 13.2 to 14.2 W/kg) exhibiting greater values than the sub-elite sprinters (mean = 12.8 ± 0.2 W/kg; 95% CI = 12.4 to 13.2 W/kg).

A significant recovery $\times$ competitive level interaction ($F_{1,16} = 6.53$, $p < 0.05$) was shown for PBLa (**Fig. 2B**), with significantly greater values following the R-60s compared to the R-30s in the sub-elite group ($p < 0.05$, $d = 0.69$) and no differences between SIT protocols for the elite group ($p = 0.24$, $d = 0.20$).

4. Discussion

Sprint interval training, consisting of repeated bouts of maximal sprint cycling interspersed with short recovery duration is used as a means to stress or “overload” the anaerobic energy system (Bickham et al., 2006), may be an effective training format aimed at improving anaerobic endurance for 400-m sprinters. One of the main findings in the present study was that power output during the R-60s protocol was significantly greater than that of the R-30s protocol and the difference occurred during the second sprint. Despite the relatively small difference in recovery duration, power output was sufficiently affected in this sample of 400-m sprinters. This result supported our first hypothesis that mean power output during the R-60s would be greater than that of the R-30s. Previous studies comparing SIT protocols with different recovery duration have focused on relatively larger differences of the recovery duration. Thus, the results in the present study highlighting SIT protocols with relatively shorter differences in recovery duration may support this unique training format. In addition, the lack of differences in power output during the first sprint between different SIT protocols provides verification that all subjects exerted similar effort between testing sessions, and that power output

difference in the second sprint was not dependent on pacing strategies.

This study classified the athletes into two groups based on 400-m performance in order to examine the load characteristics of SIT depending on competitive level. The greater power output generated during R-60s compared to R-30s in both groups suggests increased energy requirements during the SIT session with greater recovery durations. However, interestingly, we found divergent results between groups regarding blood lactate with PBLa significantly increased from the R-30s to the R-60s in the non-elite group and no differences between trials in the elite group. The elite athletes appear to have exhibited similar responses from the glycolytic system between experimental trials despite a higher energy requirement in the R-60s condition. For this reason, in the elite group, the ATP-PCr system and/or aerobic system must have supplied a higher amount of the energy during the R-60s condition compared to the R-30s condition. These results partially supported our second hypothesis; the change of the physiological response was different between elite and sub-elite groups. However, power output was changed in the same way between the R-30s and the R-60s conditions despite the different competitive levels of the groups, which may partially refute our second hypothesis.

Unfortunately, it was difficult to quantify exactly how much energy was supplied by the ATP-PCr and the aerobic energy systems during the R-60s condition in this study. While speculative, the similar PBLa response between conditions in the elite group despite differences in power output may be indicative of the enhanced ATP-PCr system and phosphocreatine resynthesis in these athletes during the longer duration recovery period. During the shorter recovery period, neither group of athletes appears to have been able to fully recover phosphocreatine stores, which is supported by previous time course evaluations of the ATP-PCr system following exhaustive exercise (Dawson et al., 1997; Bogdanis et al., 1995). Furthermore, while not significantly, the PBLa tended to decrease in the elite group during the R-60s condition. This result might show the possibility that the amount of the energy supply from the glycolytic system is decreased in SIT with relatively long recovery duration like 60-s. Therefore, in order to sufficiently stress the ATP-PCr energy system, it is recommended to design SIT

protocols with relatively short recovery duration periods particularly for elite 400 m sprinters.

For the sub-elite group, the PBLa in the R-30s condition was significantly lower than in the R-60s condition. This result might indicate that the 30-s recovery duration was insufficient to allow the transport of lactate from the muscle tissue to the capillaries for these athletes. In general, humans attempt to maintain intracellular pH by moving lactate from muscle tissue thereby continuing to support the ability to produce force (Juel, 1998; Weston et al., 1996). In the R-60s condition, the lactate was apparently buffered well enough; however, in the R-30s condition, the lactate likely remained within the muscle tissue when blood lactate was sampled after the second sprint. The remaining lactate would induce muscle dysfunction by decreasing the pH which would inhibit both the activity of phosphofructokinase and the muscle excitation-contraction coupling function inside of the muscle (Hultman and Sahlin, 1980). Accordingly, the resultant metabolic disturbance could be one of the possible reasons for the relatively lower PBLa and power output during the R-30s in sub-elite group. In addition, the results of the present study indicate that the ability to transport lactate to blood capillaries during SIT protocols with very short recovery differs between sprinters according to their competitive level. Maemura et al. (2004) mentioned that the capillary to muscle fiber ratio was well related to the anaerobic performance. Based on their argument, it could be speculated that the capillaries would be well developed in the elite group, allowing lactate to be more effectively buffered even with short recovery durations.

When developing training programs for athletics, coaches typically utilize SIT to improve the anaerobic energy system for 400-m sprinters; however, no consensus regarding the length of recovery duration between sprints has been established. Instead, coaches rely on “trial-and-error” which may hinder the development of anaerobic capacity. Based on the present study, we suggest that elite 400-m sprinters implement SIT protocols with relatively shorter rest durations to overload the anaerobic energy systems (ATP-PCr and/or glycolytic) compared to sub-elite 400 m sprinters. Alternatively, when utilizing similar recovery durations, extending exercise duration may provide an overload stimulus to improve anaerobic capacity for elite 400-m sprinters.

However, with this option, it must be noted that the intensity of exercise should be maintained. Furthermore, for non-elite 400-m sprinters who participate at the regional level, 30-s rest duration may be too short to maintain the anaerobic energy system and maximize the potential for adaptations to SIT. Based on this study, we also suggest that relatively longer rest durations or shorter exercise time may be helpful for sub-elite 400-m sprinters to provide anaerobic energy through SIT.

As a limitation, only the PBLa was used for quantifying the energy supply in the present study. Hence, neither the energy supply from ATP-PCr nor the aerobic system was quantified. Therefore, the measurement of other variables such as oxygen uptake and estimated PCr utilization would be beneficial to identify the load characteristics of SIT in more detail. The individual differences in the amount of energy supplied from the three energy systems is essential knowledge for coaches and trainers of high-level 400-m sprinters.

5. Conclusion

This study revealed that (1) differences in recovery duration during sprint interval training, even as short as 30-s, have an effect on subsequent exercise performance and (2) the contribution of anaerobic energy supply in sprint interval training varies by the competitive levels of the sprinters. These results suggest that elite 400-m sprinters may need to utilize SIT with very short recovery durations, while sub-elite 400-m sprinters may need to train with relatively longer recovery durations.

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