Influence of recovery duration during 6-s sprint interval exercise on time spent at high rates of oxygen uptake

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A B S T R A C T

Background/Objective: This study examined whether time spent at high rates of oxygen consumption (VO2) during 6-s sprint interval exercises (SIE) is a function of recovery interval duration.

Methods: In a randomised crossover study, thirteen male endurance runners performed 40 × 6-s all-out sprints interspersed with 15-s, 30-s and 60-s passive recovery intervals (SIE15, SIE30, and SIE60 trials respectively), and a work duration-matched Wingate-SIE (8 × 30-s all-out sprints with 4-min passive recovery, SIEWin trial). The accumulated exercise time at ≥ 80%, 85%, 90%, 95% and 100% of VO2max and maximum heart rate (HRmax) in the four trials were compared.

Results: During the 6-s SIEs, accumulated time spent at all selected high rates of VO2max increased as recovery time decreased, whilst the SIE work rate decreased (p < .05). In SIEWin, although the exercise lasted longer, the time spent at >90% VO2max (74 ± 16 s) was significantly less than that in SIE15 (368 ± 63 s, p < .05), yet comparable to that in SIE30 (118 ± 30 s, p > .05), and longer than that in SIE60 (20 ± 14 s, p < .05). The differences between the four trials in accumulated time at high percentages of HRmax were similar to those for VO2, although the temporal characteristics of the increases in HR and VO2 during the SIEs were different.

Conclusion: In conclusion, the duration of the recovery interval in 6-s SIE protocols appears to be a crucial parameter when sprint interval training is prescribed to enhance aerobic capacity. Further, the SIE30 protocol may represent a potential alternative to 30-s SIEWin in the development of time-efficient aerobic training intervention.

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Introduction

High-intensity interval training appears to be more effective than continuous training in raising athletes’ maximum oxygen uptake (VO2max) to the trainable limit, as it allows athletes to tolerate metabolic loading at or close to maximum for a prolonged period of time.1 Moreover, brief interval training regimes consisting of sprint interval exercises (SIE) are often adopted by athletes to enhance their endurance performance, and by recreationally active persons to improve cardiometabolic health including aerobic fitness, because of its time efficient.2 A typical SIE protocol consisting of repeating four 30-s Wingate sprints interspersed with 4- or 4.5-min recovery intervals has been shown to tax the cardiorespiratory functional capacity of active individuals at above 80% during each interval.3 It has been reported that Wingate-based sprint interval training elicits aerobic adaptations comparable to those resulting from continuous endurance training of moderate intensity, with training duration ≥ 30 min.4

Notwithstanding, a rather time-efficient interval training programme, in comparison to the Wingate regime, consisting of a further brief SIE protocol (10 × 6-s cycle sprint against 7.5% body mass with 60-s passive recovery) have been shown to improve the aerobic capacity and endurance performance markedly in triathletes.5 Moreover, when the exercise time and work-rest ratio of the Wingate-based and 6-s sprint interval training regimes were matched, the two training regimes produced similar improvements
in self-paced 10-km time trial performance in active individuals. However, whether the 6-s cycle SIE could be a potential alternative to the Wingate protocol in the development of time-efficient aerobic training intervention has not been investigated. It has been shown that in high-intensity interval training the load and duration of the work intervals determine the time spent at high percentages of \( \text{VO}_2\text{max} \), a parameter which is crucial to eliciting aerobic adaptations to the training.\(^{12}\) Although researchers continue to address the methodological variables of interval training that can affect the duration and degree of cardiovascular and metabolic stress that individuals can tolerate in a single session, it is not clear whether the time spent at high rates of \( \text{VO}_2 \) (\( \geq 90\% \text{VO}_2\text{max} \)) during a 6-s SIE protocol is a function of recovery duration per se. A recent study\(^{6}\) reported that total exercise time above \( 80-95\% \text{VO}_2\text{max} \) was comparable regardless of whether 2- or 4-min recovery intervals were used during an aerobic interval exercise (4 x 4-min runs at 90\% of maximal aerobic velocity). However, such findings may not have implications for 6-s SIE protocols where the recovery interval is \( \leq 60 \) s, as the haemodynamic and metabolic challenges, and the dominant sources of energy during the exercise, are apparently different from those in aerobic interval exercise.

The purpose of this study was to compare the time spent at high rates of \( \text{VO}_2 \) (\( \geq 80\% \text{VO}_2\text{max} \)) under three SIE protocols in which the load and duration of the work interval were identical (40 x 6-s all-out sprints) but the duration of the recovery interval duration varied (15-s, 30-s or 60-s passive recovery). The temporal characteristics of the increase in \( \text{VO}_2 \) elicited by the three 6-s SIE protocols were also compared with those for a Wingate-based SIE protocol (8 x 30-s all-out sprints with 4-min passive recovery) in which the total work interval duration was matched to that of the four SIE protocols. It was hypothesised that time spent at high rates of \( \text{VO}_2 \) during a single bout of 6-s SIE would be a function of recovery interval duration, and that the time efficiency of the 6-s SIE protocol for inducing strenuous aerobic demand was higher than that of the work duration-matched Wingate-based SIE protocol.

### Method

#### Research design

In this study, participants performed four single SIE sessions on a Wingate testing cycle ergometer (Monark 894 E, Stockholm, Sweden) on separate days. In three of the SIEs, participants performed 40 x 6-s all-out sprints interspersed with 15-s (SIE\(_{15}\)), 30-s (SIE\(_{30}\)) or 60-s (SIE\(_{60}\)) of passive recovery. The remaining session was a Wingate-based SIE consisting of 8 x 30-s all-out sprints with 4-min passive recovery intervals (SIE\(_{win}\)), performed on the same ergometer. In all SIEs, the ergometer resistance was set at 7.5\% of the participant’s body mass. The order in which the four SIE trials were performed was counterbalanced and the assignment of participants to orders was random. The accumulated time spent at \( \geq 80\%, 85\%, 90\%, 95\% \) and 100\% of \( \text{VO}_2\text{max} \) and \( \text{HR}_{\text{max}} \) were compared across the four trials.

#### Participants

Thirteen male athletes [age: 26.2 ± 6.2 yrs, height: 172.8 ± 7.3 cm, weight: 60.8 ± 3.8 kg, \( \text{VO}_2\text{max}: 61.3 \pm 9.1 \text{ml min}^{-1} \text{kg}^{-1} \), maximum heart rate (HR\(_{\text{max}}\)): 164.9 ± 8.1 beat min\(^{-1}\)] who had been engaged in long-distance running for over five years participated voluntarily. The sample size was computed based on the formula \( n = \sigma^2 \left( \frac{z_0 + z_1}{\Delta} \right)^2 \), where the mean differences (\( \mu_{0-\mu_{1}} \)) and standard deviation (\( \sigma \)) were estimated from pilot testing results. Alpha and power level were set at 0.05 and 0.9, respectively. \( z_0 \) is the critical value for effect size under the null distribution and \( z_1 \) is the critical value associated with the alternative distribution.

The participants had no familial history of cardiovascular disease and were not taking any cardiovascular medication. Moreover, none had prior experience of nutritional or ergogenic supplements. Following an explanation of the purpose and requirements of the study, participants gave written informed consent. Study approval was obtained from the Research Ethics Board, University of Macau.

#### Preliminary and familiarization trials

First, the participants’ physical characteristics were measured. Body mass was measured using a bioelectrical impedance analyser (InBody 720, Biospace, Tokyo, Japan) and used to determine the resistance used in subsequent SIE tests. Next, participants were familiarised with the all-out SIE protocols over two days.

During the experimental period, all participants were asked to maintain their daily activity as well as their training load and volume, and avoid altering their eating habits. Participants were asked to refrain from eating and participation in strenuous physical activity for, respectively, at least 2 h and one day before trials. All experimental trials were performed under identical, controlled laboratory conditions (temp: 22 °C, RH: 75\%). All trials were scheduled to occur at the same time of day and were separated by at least five days.

#### Graded exercise test

The test was carried out on an electronically braked cycle ergometer (Monark 839E, Stockholm, Sweden). Following a 3-min warm-up at 25 W, the test started with an initial work rate of 50 W. Participants were asked to maintain a pedalling cadence of 60 rpm, and the power was increased by 25 W every minute, until volitional exhaustion. Metabolic data were recorded during the test using the Metamax 3B gas analysis system (Cortex, Leipzig, Germany) and HR was monitored using a Polar HR sensor (H3, Finland). Ten-s means were calculated and the highest values were the maximal. Participants were assumed to have achieved their \( \text{VO}_2\text{max} \) when they met any three of the following criteria: 1) apparent exhaustion; 2) plateau in \( \text{VO}_2 \), \( \Delta \text{VO}_2 < 2.1 \text{ml kg}^{-1} \text{min}^{-1} \) regardless of increase in workload; 3) \( \text{HR}_{\text{max}} > 90\% \) of the predicted maximum (220 - age); 4) respiratory exchange ratio \( > 1.15 \).

#### Sprint interval exercise test

All SIE trials consisted of a standardised warm-up exercise consisting of 5-min cycling exercise at 60 W, five 6-s cycle sprints at progressively increasing speed and 5-min of stretching. During the SIE recovery intervals, participants remained seated but stationary on the cycle ergometer. During the last 5 s of each recovery interval participants were given a 5-s countdown and in the last 2 s they were instructed to accelerate to a stationary start with minimum friction applied to the flywheel. At the start of the work interval, the preset load was applied instantaneously with an electromagnetic device. Participants remained seated whilst cycling and their feet were secured to the pedals using toe clips. Verbal encouragement was given throughout each sprint to ensure all-out effort. Power output in each sprint was recorded using Monark Anaerobic Test Software (3.0, Stockholm, Sweden) with a preset sampling rate of 50 Hz. \( \text{VO}_2 \) and HR were recorded throughout the exercise using the Metamax 3B system and Polar HR sensor, respectively. Immediately after exercise, participants used the Borg scale (6–20) to provide ratings of perceived exertion (RPE). Five-s \( \text{VO}_2 \) means were plotted against exercise time. Horizontal lines at 80\%, 85\%, 90\%, 95\%, and 100\% of \( \text{VO}_2\text{max} \) were drawn on the graph. The total time spent at...
each VO₂ level was taken as the number of time points at or above the relevant horizontal line x 5 s. A similar procedure was used to calculate total time spent at each HR level.

**Statistical analyses**

A Shapiro-Wilk test revealed that all variables were normally distributed. Repeated measures ANOVA was used to examine between-level and between-trial differences. Post-hoc analyses were carried out using the Newman-Keuls test. Cohen’s d was calculated to reveal the effect size of selected mean differences. The level of significance in all statistical test was set at p < .05. Data were expressed as mean ± SE.

**Results**

Table 1 shows peak and mean power output, post-SIE RPE and total trial times spent at selected percentages of VO₂max and HRmax for the four SIEs. Peak and mean power output were highest in the SIE60 trials and decreased progressively with recovery interval duration in the SIE30 and SIE15 trials (p < .05, Cohen’s d ≥ 1.18). The lowest power output occurred in the SIEWin trials. However, post-SIE RPE was similar in the SIE30, SIE15, and SIEWin trials (p > .05), whereas it was lower in SIE60 trials (p < .05).

In SIE15 trials more time was spent at all selected high percentages of VO₂max than in other trials (p < .05, Cohen’s d ≥ 0.99). In contrast, less time was spent at all selected high percentages of VO₂max, except >100% VO₂max, in SIE60 trials than in other trials (p < .05, Cohen’s d ≥ 0.87). In SIE30 more time was spent at ≥80% VO₂max and >85% VO₂max than in SIEWin (p < .05, Cohen’s d ≥ 0.69), but the total times spent at all percentages of VO₂max were similar (p > .05).

More time was spent at ≥80% HRmax in the SIE15 and SIE60 trials than in other trials (p < .05, Cohen’s d ≥ 0.94). More time was spent at ≥85% HRmax in SIE30 trials than other trials, and less time in SIE60 trials (p < .05). More time was spent at ≥90% HRmax and ≥95% HRmax in the SIE15 and SIE30 trials than in other trials (p < .05, Cohen’s d ≥ 0.70). Similar results were also found in time spent at ≥100% HRmax (p < .05, Cohen’s d ≥ 0.52) while the difference between SIE30 and other trials was not significant (p > .05).

**Discussion**

To the best of our knowledge, this is the first study to compare the temporal characteristics of the increase in VO₂ across three 6-s SIE protocols with different recovery intervals and a work-duration-matched Wingate-based SIE protocol. The novel findings are: (a) altering the recovery interval (15 s; 30 s; 60 s) used in the 6-s SIE protocol altered the total time spent at high percentages of VO₂ (>90% VO₂max); (b) the brief duration of the work and recovery intervals in the 6-s SIE protocol resulted in longer time spent at high percentages of VO₂max relative to a SIEWin protocol; (c) the temporal characteristics of the increase in HR during the four SIEs do not correspond to those of the increase in VO₂, suggesting that the HR response may not be a precise reflection of the metabolic stress imposed by SIE.

During the three 6-s SIEs in which participants were required to exert all-out effort in each sprint reducing the recovery-interval duration markedly increased VO₂ during both work intervals and recovery intervals, and hence accumulated time at ≥80% VO₂max, this was matched by decreases in peak and mean power output (Table 1). These findings contrast with those reported previously for high-intensity aerobic interval exercise, and indicate that the extent to which participants maximise their use of their functional aerobic capacity during SIEs is partly determined by the length of the recovery interval, whilst the metabolic stress during SIE appears to increase incrementally as recovery interval duration decreases. It was noted that the longer the recovery intervals during SIE, the greater the decrease in VO₂ relative to the preceding work interval. Although the lower VO₂ might have resulted in faster VO₂ kinetics at the beginning of the subsequent exercise bout, the extent of the increase in VO₂ during the exercise bouts of the three SIEs were not conformed. This was reflected in peak VO₂ in work intervals, which was consistently lower during the SIE60 trials than in the SIE30 and SIE15 trials, with peak VO₂ being highest in SIE15 trials (Fig. 1a). However, peak and mean power output were higher in the SIE60 trials than the SIE15 and SIE30 trials (Table 1). In fact, restoration of power output during repeated supramaximal sprint exercise (<10 s) is mainly reliant on the rate of PCr resynthesis; the halftime for PCr turnover following a sprint is 20–30 s and this increases to 56 s as a result of sluggish blood flow in active muscles during passive recovery between sprints. It was therefore reasonable to postulate that the longer recovery interval during SIE60 trials would result in greater PCr availability than in SIE15 and SIE30 trials, enabling participants to work harder during the exercise intervals. As the relatively short recovery duration in SIE15 limits resynthesis of PCr, there is presumably greater reliance on aerobic energy in the repeated sprints. This was supported by our current findings that the VO₂ spectrum in response to work and recovery intervals during the 6-s SIE (Fig. 1a) increased as recovery duration decreased, and this was concomitant with the decrease in the SIE power output (Fig. 2).

It is generally agreed that the optimal interval training stimulus for improving peak aerobic function is one that allows participants to exercise above 90% VO₂max over an accumulated total of several minutes, preferably 5–10 min per session. Of the three SIE protocols, the SIE15 protocol appeared to be most effective in ensuring that participants exercised at intensities corresponding to ≥90% VO₂max for more than 6 min in total; this several times higher than achieved under the SIE30 and SIE60 protocols. It is plausible to suggest that accumulated high-intensity exercise time under the SIE30 and SIE60 protocols could be extended by increasing the repetitions of the sprint in each protocol. However, lengthening an SIE protocol would compromise its time-efficiency as a method of improving aerobic function. It also deviates from a recent report on development of health interventions which recommended that the
Involvement of minimal sprint durations and repetitions should be a top priority for the future development of the sprint interval training for health benefit. Based on the data presented here the best SIE protocol for potentially development of training intervention to improve aerobic capacity, on grounds of time efficiency, is the 14-min SIE15, under which ~45% of exercise time was spent at intensities approaching VO2max.

Four to ten 30-s Wingate sprints interspersed with 4-min recovery intervals was considered as a classic sprint interval training protocol that is associated with various central and peripheral aerobic adaptations. However, less time was spent at ≥90% VO2max (~1.2 min) in SIEWin than in SIE15 trials. Moreover, the peak power output in the first SIEWin work interval (726 ± 147 W) was lower than the corresponding power output in the SIE15 trial (870 ± 180 W), despite the fact that participants were requested to exert all-out effort in all sprints in both trials. This discrepancy in physical exertion is consistent with earlier findings of teleoanticipation in all-out sprint cycle exercise. It has been reported that an all-out pacing strategy is only found in repeated sprint cycles if the duration of a single exercise bout is no more than 15 s; dampening of power output occurs with work intervals of 30 s and 45 s. The lower power output achieved in the first 30-s sprint in the SIEWin trial (Table 1) might reflect participants’ unconscious adoption of a pacing strategy in an attempt to complete the SIEWin protocol within their biomechanical and metabolic limits. Together with the decline in metabolic rate during the prolonged recovery intervals of the SIEWin protocol, this may partly explain the relatively short total time spent at high percentages of VO2, relative to the SIE15 trials. Performance of the SIEWin protocol, including recovery time, took >30 min. The lengthy SIEWin protocol does not, however, appear to be more effective than 6-s SIE15 protocol in imposing metabolic stress on the oxidative system.

The temporal characteristics of the increase in HR during the four SIE trials were not matched by the pattern in increases in VO2 (Table 1). In SIE15 and SIE30 trials, participants’ HR increased to >80% HRmax as soon as they started the first sprint and remained at that level throughout the trial (Fig. 1b). In fact more than 90% and 60% of work time was spent at ≥90% HRmax during the SIE15 and
SIÈ₆₀ trials respectively, which is inconsistent with the amount of work time spent at ≥90% VO₂. Similar discrepancies between the temporal characteristics of the increases in HR and in VO₂ in participants doing aerobic interval exercise have been reported previously.⁹ Such findings suggest that the HR response to high-intensity interval exercise may not precisely reflect the immediate stress on participants’ oxidative systems. Moreover, the strenuous cardiovascular stress elicited from all-out sprints during the 6-s SIÈs, which did not release effectively in brief recovery intervals, potentiates the risk of cardiac distress that sedentary and unfit individuals should participate in it with cautions.

Conclusions

This study found that reducing the recovery interval used in a 6-s SIÈ protocol (SIÈ₆₀; SIÈ₃₀; SIÈ₁₅) increased the total exercise time spent at high percentages of VO₂max (≥90% VO₂max), suggesting that the length of the recovery interval is a crucial parameter when 6-s SIÈ protocols are used to improve aerobic capacity. Moreover, the SIÈ₁₅ protocol, which involves shorter exercise and recovery intervals, resulted in longer time spent at high percentages of VO₂max relative to the SIÈ₆₀ protocol, implying that the SIÈ₁₅ protocol is a potential alternative to 30-s SIÈ₆₀ in the development of time-efficient aerobic training intervention. Nevertheless, it is worth noting that the current findings of the metabolic and cardiovascular responses resulting from the SIÈ protocols were obtained from the trained participants who were accustomed to rigorous workouts and associated intense physical stress. Cautions should be exercised in untrained populations participating in the repeated-sprint protocol, taking into account the individual’s cardio-respiratory fitness.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jesf.2018.01.001.

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