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A comparison of three different work to rest periods during intermittent sprint training on maintaining sprint effort performance

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ABSTRACT

Background/objectives: Team sports are characterised by repeated maximal intensity bursts of activity, requiring significant energy contribution from the phosphagen pathways. The objective of this study was to evaluate the impact of different rest periods on repeated maximal intensity efforts.

Methods: The effect of three different recovery periods (60 s, 90 s and 120 s) during a 10 × six-seconds intermittent sprint training protocol performed on a cycle ergometer was investigated. Thirteen part-time female athletes from two sports, Rugby Sevens and Netball competing for their state participated in the study. Peak Power (PPO), Mean Power (MPO), "total work" in the form of calorie expenditure, performance decrement, repetitions over 95% PPO, blood lactate, and RPE were recorded.

Results: There was a significant effect of condition on MPO and calorie expenditure ($p < 0.050$). MPO was significantly lower for 60 s compared to 90 s (710.4 vs 734.4 W, ES = 0.27–0.42) and 120 s (710.4 vs 743.3 W, ES = 0.36–0.47). Calorie expenditure was significantly lower for 60 s compared to 90 s (4.41 vs 4.56 cal, ES = 0.25–0.46) and 120 s (4.41 vs 4.59 cal, ES = 0.40–0.48). There was a significant effect of time (60 s 11.7, 90 s 11.1.120 s 10.9 mmol/L, $p < 0.010$) but not condition ($p = 0.617$) for blood lactate accumulation, and a significant difference in session RPE between 60 and both 90 s and 120 s (60 s 15.5, 90 s 14.2. $p = 0.034$ 120 s 13.9, $p = 0.039$).

Conclusion: Shorter recovery durations resulted in decreased mean power and calorie expenditure, but higher RPE when compared to longer recovery periods. All three recovery periods may have fallen between the fast and slow phases of PCr resynthesis of approximately 20 and 180 s resulting in partial but not complete recovery. Total training time should be a consideration when determining what protocol to implement.

1. Introduction

Open skill sports have been defined as any sport that requires performing skills in an ever changing environment.[1] Examples of open skill sports include invasion games, court and wall sports, and combat sports. They are characterised by high intensity bursts of activity, interspersed by lower intensity activity and stoppages in play of various lengths.[2] These short duration, all-out efforts have been referred to as maximal neuromuscular activations.[3] Decision making, reactions, and skill performance, in combination with the ability to perform at high intensity and recover adequately between intense bouts will contribute to overall performance.[4] The ability to repeat these maximal intensity actions for the duration of the sport is a crucial quality that coaches need to develop in preparation for competition.[5]

Brief maximal intensity efforts synonymous with open skill team sports will require significant energy contribution from the phosphagen pathways.[6] The phosphagen energy system is the predominant, although not exclusive, source of energy for maximal intensity actions lasting up to approximately six seconds[7] As most important actions in open skill sports are typically less than six seconds in duration,[8] the importance of phosphagen pathways to repeatedly provide energy for elite performance is apparent. The capacity of phosphagen energy system is limited by the rate at which phosphocreatine (PCr) can replenish ATP stores.[9] The duration of the recovery period between maximal intensity efforts will impact the degree to which PCr stores will be replenished with partial recovery occurring during the first ~22 s but full restoration of

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the PCr stores can take as long as 3 min.[9]

Rest periods between maximal intensity efforts, crucial to open skill sports, play an important role in physical development, performance, and training, as the duration of recovery periods will result in different adaptations.[5] Repeated maximal intensity training can be divided into three categories. Repeated Sprint Ability (RSA) is characterised by shorter (3–7 s) efforts with incomplete rest periods of less than 60 s.[10] Sprint Interval Training (SIT) comprises maximum intensity efforts of 20–30 s duration, with 2–4 min recovery and is associated with elevated blood lactate.[11] Finally, Intermittent Sprint Training (IST) is comprised of maximal intensity efforts of less than 10 s with longer rest periods of more than 60 s, allowing greater or near complete recovery.[10] The primary goal of IST is to minimize decreases in performance and focus on specific phosphagen energy system development, whereas RSA training is very likely to require contribution from glycogen and aerobic energy systems.[12] A common feature of open skill sports such as Rugby Sevens and Netball is the need for short duration, maximal intensity efforts to be performed throughout competition and training.[2]

Practitioners trying to develop the capacity of the phosphagen energy system may be interested in focusing on using IST as a training method. Longer rest periods used in IST increase the likelihood of maximum intensity performance being maintained for a greater number of repetitions compared to shorter rest periods.[13] The longer rest periods used in IST may become problematic however, as a rest period that allows complete recovery of PCr stores will also significantly increase total training time. Training in open skill teams sports comprises many different aspects to meet tactical, technical, psychological and physical development.[14] Often those technical and technical training needs take priority over physical development, particularly during the competition season.[15] Efficient, lower volume training sessions may also decrease the risk of soft-tissue injury.[16] As a result of the multiple training needs in team sports, coaches and athletes will target physical training that is not only effective but also time efficient.[17] Therefore, this study investigated the effect of three different recovery periods (60, 90 and 120 s) on power output, calorie expenditure and perceived exertion, as well as the blood lactate response in an IST trial on a cycle ergometer in female national-level team sport athletes.

2. Methods

2.1. Participants

Fifteen female participants volunteered to participate in the study. Two participants were unable to attend all sessions of the study leaving 13 participants with complete data sets (18.1 ± 2.0 y, 175.1 ± 5.8 cm, 77.2 ± 11.0 kg). Seven participants played Rugby Sevens and six played Netball. All participants were academy scholarship holders at a state-level sporting academy with a minimum of two years' experience in the program. Despite playing in a national-level competition, none of the participants were full-time athletes. The participants regardless of the sport played completed a training regimen of three technical and tactical training sessions, three full-body strength sessions, and two speed and conditioning training sessions per week. All physical conditioning was overseen by the same strength and conditioning coach and performed at the same sports institution. The participants also periodically completed interval training on a cycle ergometer. Participants were asked to maintain the same dietary, sleep and physical activity in the 24-h preceding each testing day. Trials were performed with of 48-h rest between trials. All trials were carried out at the same time each day to ensure no variations due to diurnal rhythms. No training was carried out in the 24 h prior to the trials.

The purpose and procedures were explained to the participants verbally by the researchers and written explanations of the procedures were provided. Participants were given the opportunity to ask questions before committing to the study. Written informed consent was obtained according to the Declaration of Helsinki after gaining approval from the University of Waikato Human Research Ethics Committee (HREC (health)#2019#05).

2.2. Research design

This investigation consisted of three performance trials using a cycle ergometer (WattBike, Nottingham UK). Each of the performance trials followed the same number of cycling intervals using a different work to rest ratio. Performance data, blood lactate samples, and a rating of perceived exertion (RPE) were collected in each of the three trials. All participants completed a familiarisation session prior to the first trial. Participants had experience using the WattBike as part of their training.

Each collection started with the participants completing a five-minute warm up pedaling at 70 rev·min^{-1}. Resistance was set according to manufacturer recommendations based on weight and sex. At the third, fourth and fifth minute of the warm-up, the participants completed a two-second sprint at the highest rev·min^{-1} they could achieve. Following three-minutes of passive recovery sitting quietly on the bike, the participants completed an IST trial consisting of 10 repetitions of a six-second sprint previously outlined in the literature.[18] Each trial used the same resistance and protocol. A different work to rest ratio was applied for each of the three sessions. All participants completed trials in a random order. There was one trial with 60 s recovery between sprints (R60), one with 90 s recovery (R90), and one with 120 s recovery (R120). Peak Power Output (PPO), Mean Power Output (MPO), and "total work" was recorded for each sprint effort. The measurement of "total work" is calculated from the distance per revolution multiplied by the force with the result record in calories (Cals).[19] The number of repetitions where PPO stayed above 95% (PPO95+) were recorded. Performance decrement (%Dec) in performance was calculated after the completion of each of the three trials using the following formula as outlined by previously[10]:

$$\%Dec = 1 - (\text{sum of sprints 1 to 10/best sprint} \times 10) \times 100.$$

Blood samples for capillary blood lactate measures were taken two minutes prior to the start, immediately after the first, fourth, seventh and 10th repetition via a finger prick using a handheld portable blood lactate analyser (Lactate Pro2, Arkray Kyoto JAP). A final sample was collected 2 min after the final sprint. A 16-point rating of perceived exertion (RPE) score was taken after each repetition and a total session RPE 15 min after the final session.

2.3. Statistical analysis

Group data is reported in means and standard deviations. A single factor 1 × 3 ANOVA was used to determine differences between the performance variables between the conditions (R60, R90 and R120). A two-factor without replication ANOVA (time × condition) was used to analyse the change in performance across the 10-repetitions for each of the three conditions. Where significance was detected, a post-hoc T-Test (two sample for means) was completed to determine at what repetition differences between treatments occurred. The level of significance was set at $p \leq 0.05$.

3. Results

Mean and standard deviation results for PPO, MPO, Cals, PPO95+, and %Dec are recorded in Table 1. The single factor ANOVA revealed no significant difference between R60, R90 and R120 across the 10 repetitions. Although not significant, an average of 1.4 greater repetitions above 95% PPO was observed for the P120 trial compared to the P60 trial ($p = 0.0571$; ES = 0.66 [−0.02,1.35]). The number of participants to exceed PPO95+ on each repetition is shown in Fig. 1. There were no significant differences in %Dec.

The two-factor ANOVA demonstrated no interaction effect for PPO

Table 1
Peak Power Output, Mean Power Output, Total Work and repetitions over 95% Peak Power Output and percentage decrement in an Intermittent Sprint Training protocol with three different recovery periods.

Mean	60 s (SD)	90 s (SD)	120 s (SD)
Peak Power Output (W)	864.4(±120.9)	880.8(±106.8)	884.3(±106.3)
Mean Power Output (W)	710.4(±103.9)	734.4(±98.3)	743.3(±116.4)
Calorie Expenditure (Cals)	4.4(±0.56)	4.6(±0.55)	4.6(±0.62)
PPO95+	2.9(±1.7)	3.7(±1.6)	4.3(±2.4)
% Decrement	**60 s**	**90 s**	**120 s**
Peak Power Output (W)	8.1(±2.4)	7.4(±3.9)	7.6(±3.9)
Mean Power Output (W)	7.4(±5.3)	6.3(±3.4)	5.3(±2.9)
Calorie Expenditure (Cals)	6.5(±4.3)	5.7(±3.0)	5.1(±3.1)

PPO95+: Repetitions above 95% of highest peak power output.

across the 10 repetitions; however, there was a near significant effect for time (p = 0.093). There was a significant effect of condition on MPO (F = 3.01, p = 0.050) and calories (F = 3.22, p = 0.041). Post-hoc analysis for differences between repetitions for the three conditions are outlined in Fig. 2 for MPO and Fig. 3 for calories. MPO was significantly lower for R60 than R90 on the sixth to ninth repetitions (ES = 0.27–0.42) and on the fifth, eighth, and ninth repetition (ES = 0.36–0.47) compared to 120 s recovery. Calorie expenditure was significantly lower for R60 than R90 on the fifth to ninth repetitions (ES = 0.25–0.46) and on the fifth, eighth and ninth repetition (ES = 0.40–0.48) compared to R120. There was no difference between the three trials for MPO of calorie expenditure on the final repetition. There were no significant differences when comparing R90 and R120. There was a significant effect of time (F = 108.4, p < 0.01) for blood lactate accumulation for but no differences between conditions (F = 0.48, p = 0.617). The progression of blood lactate

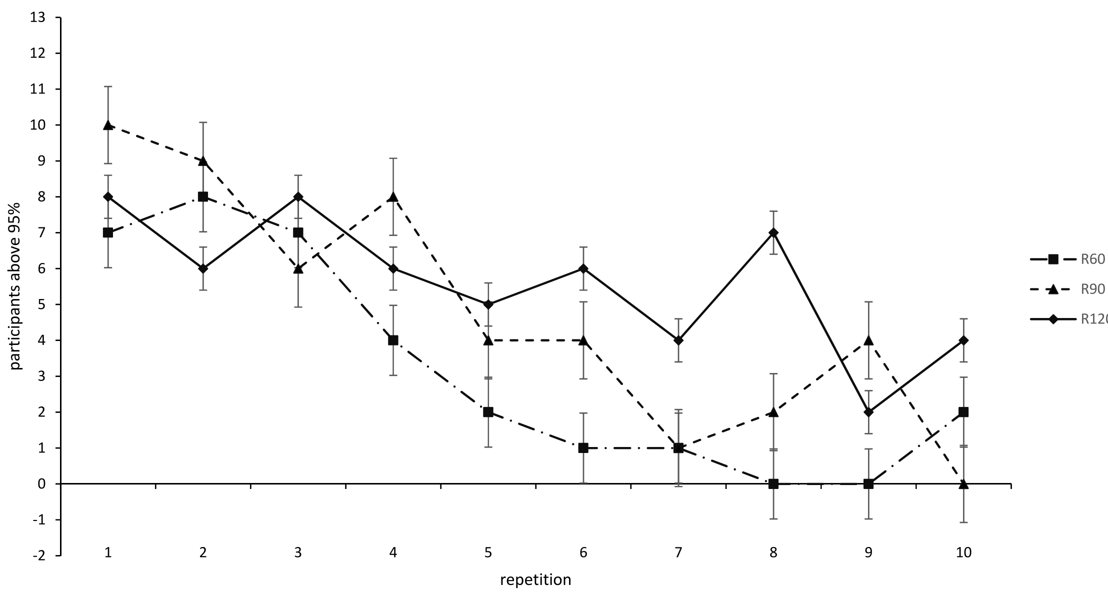

Fig. 1. Number of participants to exceed 95% of peak power output on each repetition. Error bars represent standard deviations. * Significant difference between 60 s and 90 s recovery, † Significant difference between 60 s and 120 s recovery.

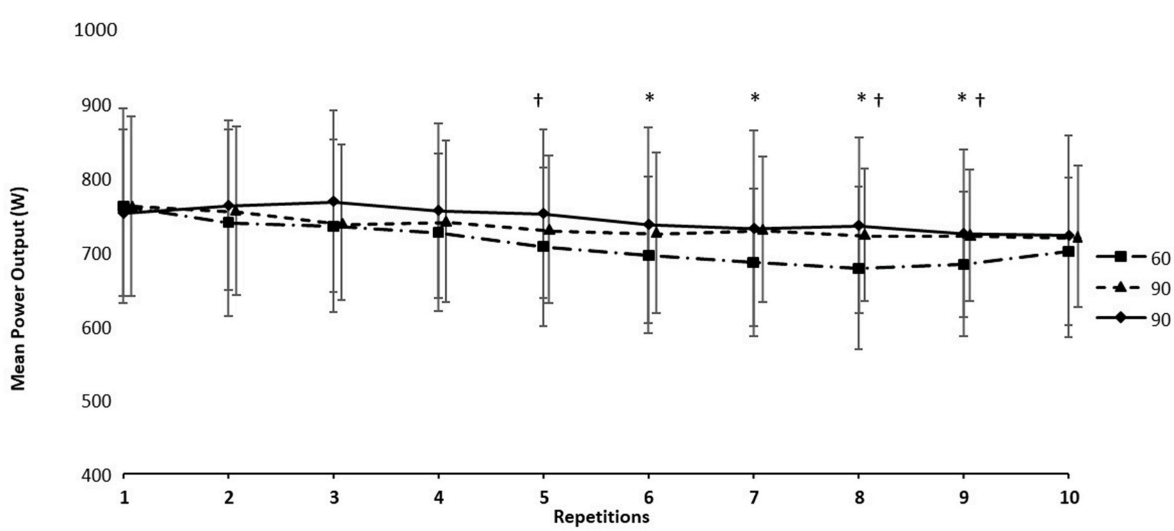

Fig. 2. Mean Power Output differences across 10 × 6 s Intermittent Sprint Training with 60 s, 90 s and 120 s recovery durations. Error bars represent standard deviations. * Significant difference between 60 s and 90 s recovery, † Significant difference between 60 s and 120 s recovery.

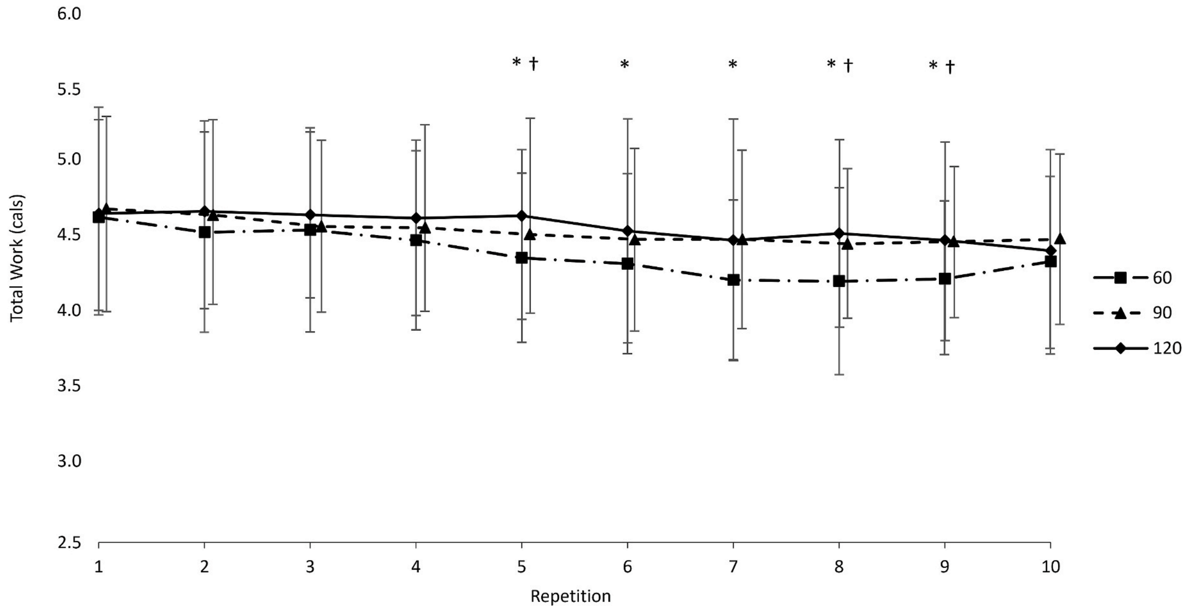

Fig. 3. Calorie Expenditure differences across 10 × 6 s Intermittent Sprint Training with 60 s, 90 s and 120 s recovery durations. Error bars represent standard deviations. * Significant difference between 60 s and 90 s recovery, † Significant difference between 60 s and 120 s recovery.

accumulation is shown in Fig. 4.

There was a significant difference in session RPE (R60: 15.5 ± 1.56, R90: 14.2 ± 1.68, R120: 13.9 ± 1.66, p = 0.034). Post-hoc testing showed a significant difference between R60 and R90 (p = 0.039) and R60 and R120 RPE (p = 0.017) with no difference between R90 and R120 RPE (p = 0.727).

4. Discussion

The main finding from this study that investigated the effect of three different recovery periods during an IST protocol was that there was no difference in peak power and blood lactate response between the three protocols, although there were significant differences between protocols for MPO, caloric expenditure, and perceived exertion. Specifically, MPO and calorie expenditure were lower on several later repetitions of the protocol and RPE was significantly higher in the R60 than the R90 and R120 protocols.

Similar to our findings for peak power, no difference in final running speed was reported in previous research for 30, 60, and 90 s recovery between 40-m sprint running efforts (approximately six-seconds), and for accelerations for 60 and 90 s recovery.[20] Similar research found 4 min recovery between 10 s high intensity efforts was no more beneficial than 2 min recovery on peak and mean power during cycling sprints,[21] whilst no differences were found in peak power when comparing two and four minute rest periods when performing upper body 10 s sprint efforts.[22] Thus this study adds to the literature on IST showing that PPO can be maintained across a variety of different recovery durations. The lack of difference between the three protocols could possibly be explained by the rate of PCr resynthesis. Research into the resynthesis of PCr found that resynthesis was biphasic, with a fast and slow component, with the fast component lasting 21–22 s and the slow component lasting 170 s.[9] However, this represents a very large time frame,

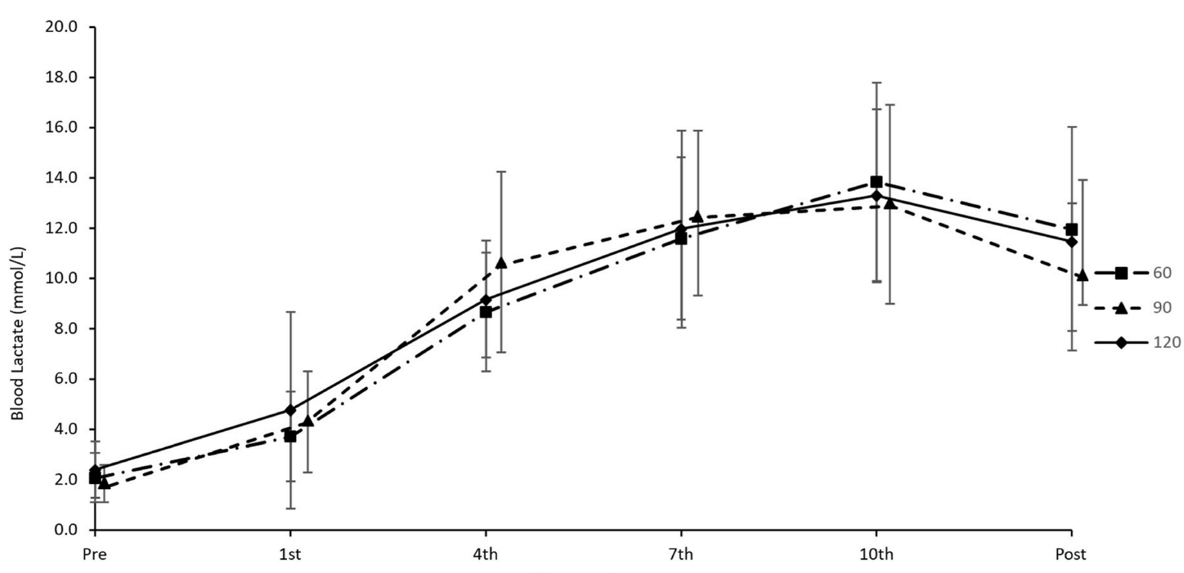

Fig. 4. Blood Lactate accumulation across 10 × 6 s Intermittent Sprint Training with 60 s, 90 s and 120 s recovery durations. Error bars represent standard deviations.

requiring greater clarity to fully understand the effect on maximal intensity efforts and to make more accurate decisions about training prescription. The shorter rest periods would fall into RSA style training whilst longer would fall into IST style training. Significant differences have been found in peak power when comparing 20 s with 170 s recovery between 10 s sprint cycle efforts.[23] The 20 s recovery, much closer to the length of the fast component of resynthesis reported previously,[9] was insufficient to allow complete PCr resynthesis, whereas the 170 s allowed sufficient resynthesis. The rest periods used in this study may offer greater clarity to coaches when determining recovery for IST methods.

The rest periods in our study fell between the two reported earlier,[23] which may account for the lack of difference between the three protocols in PPO. Rest periods in the current investigation may have allowed at least partial PCr resynthesis, allowing the participants to achieve similar PPO but insufficient to allow complete recovery resynthesis.[22] Whilst this investigation did not focus on muscular function, previous research into repeated maximal sprint efforts found compromised muscle fibre recruitment, as a result of decreased neural activation to be a possible reason for a drop off in performance.[24] It is possible slow twitch muscle fibres with higher endurance capacity may be required to contribute to performance across the duration of the sprint when fast twitch muscle fibres become fatigued.[25]

Rest periods shorter than those used in a typical IST protocol may be adequate to allow PPO for a low number of repetitions, however this is not sustainable for an extended protocol as performance will decrease.[26] Even with as little as 10 s rest it was possible to maintain PPO for three repetitions before a decrease in performance, in maximal cycle efforts of 5 s duration.[27] This finding would seem to be supported by the minimal difference in the number of participants that exceeded 95% of PPO in the first three repetitions in this investigation. Although there was a non-significant difference between the three treatments for repetitions above 95% of peak power (60 s 2.85, 90 s 3.69, 120 s 4.31), the results represent 0.84 extra repetitions for the R90 and 1.46 extra repetitions for the R120 protocol when compared to R60. The cumulative effect of completing a greater number of repetitions where intensity is maintained across an extended training block may be of value to coaches and athletes and warrant further investigation. A more individualized approach has been proposed to minimize decrement and better match individual needs, due to the large variation in fatigue during repeat six-second efforts.[28] Coaches may consider the longer recovery protocols if the goal is to maintain the highest PPO for the highest number of repetitions and might consider using multiple sets of fewer repetitions if peak power development is the goal.

The PPO results found with the three protocols in this study were aligned with the changes in blood lactate. Rest periods of 3 min, longer than the recovery ranges used in this study, have been shown to be adequate to prevent blood lactate accumulation and allow sufficient PCr resynthesis.[22] There was an increase in lactate response across all three IST protocols; however similar to PPO, there were no differences between the three trials at any time point. A previous training study also found no difference in lactate response when performing 30 s efforts with 30, 60 and 120 s recovery between efforts.[12] The observed increase in blood lactate indicates that the glycolytic energy system plays a significant role in energy production even in a sprint as short as six-seconds. Our findings aligned with previous work that found a six-fold increase in blood lactate after a single six-second sprint.[7] Similar increases in blood lactate have also been reported after a 40 m and 60 m sprint[29] and a 30 m shuttle run,[30] tasks of similar duration. These findings reinforce earlier research that even for short maximal intensity efforts, glycolytic energy system contributes substantially to overall energy production. The recovery periods in the study were potentially inadequate to allow complete PCr resynthesis and therefore energy from glycolytic pathways was required on subsequent efforts to assist with total energy production. The similar increases in blood lactate between the three trials would suggest a similar level of glycolytic energy production from these pathways. We acknowledge that blood lactate onset and clearance will differ on an individual level, such that collecting at a standardized time frame post exercise may not reflect the maximum level.

Unlike PPO, there was a significant decrease in performance for MPO and Cals. Peak power is achieved in the first 1–2 s of the sprint[31]; but may not indicate the capacity of the phosphagen energy pathways which is the dominant energy for efforts of under 6 s.[32] Therefore PPO and MPO in a 6 s cycle test represent distinct physical capacities. The highest possible result for MPO and "total work" in the form of calories require the participant to pedal maximally for the entire duration of each sprint. In addition, a reliability study on the Wattbike 6 s cycle sprint found that "total work", in Cals, was the most reliable measure.[19]

Not being able to measure PCr decrement directly may have been a limitation of the study. The shorter rest period in the R60 trial may not have allowed sufficient replenishment of PCr stores, which may have restricted the ability for a maximal performance for the entire duration of subsequent sprint efforts resulting in decreased MPO and "total work". Conversely, the R120 trial may have allowed greater replenishment of PCr than either of the shorter rest periods. Further research could include direct measures of PCr to better understand and apply the broad range of recovery time put forward previously.[9] It has been suggested that 80 s recovery between maximal intensity efforts is ideal for improving maximal power and capacity.[12] A recovery period of 80–90 s, very similar to our protocol, may be a more time efficient approach for coaches to implement when training maximal intensity efforts, without compromising performance. Lower MPO and calories in the shorter recovery trials in this study may indicate a greater reliance on energy from aerobic sources, likely due to lower PCr resynthesis and therefore lower PCr energy contribution, when compared to the longer recovery periods. These findings are in line with previous research that has shown greater aerobic contribution from shorter recovery between maximal sprint efforts.[12] Interestingly, there was no difference between any of the trails on the final repetition. This may have been due to the participants putting one final extra effort knowing this was the final repetition.[28]

Our results showed that the R60 recovery period had a significantly higher perception of effort compared to the R90 and R120 protocols but there was no difference between the two longer recovery trials. Higher ratings of perceived exertion have been found previously when shorter recovery periods are employed between maximal intensity efforts[27,33]; however, this finding has not been universal.[5,34] Perception of effort is an important consideration when designing training programs as motivation to train plays an important role alongside physiological change.[34] Although there was no difference in PPO across the three protocols, coaches should consider RPE as it may help indicate if fatigue is preventing maximum efforts on every sprint which could be problematic if a pacing strategy is then adopted due to the perception of fatigue.

Rest period selection will ultimately depend on the training goals. Longer rest periods may be required to develop PPO, whilst shorter rest periods will build anaerobic capacity.[35] Similar results in PPO with the different work to rest ratios may allow for shorter recovery periods if time efficiency is an issue, whilst longer rest periods may allow a higher number of repetitions performed above 95% of peak power. Total training duration is an important consideration for coaches when developing maximal intensity, as protocols must be both effective and time efficient.[21] The total training time for the R60, R90 and R120 recovery trials in this study were 11, 16, and 21 min respectively. Shorter, more time efficient, interval sessions such as the R60 recovery protocol may have some appeal to coaches who must balance multiple training activities, as well as for non-professional athletic populations who have less time to devote to training. However, rest periods of less than 60 s may lead to greater fatigue therefore longer rest periods would be required if PPO is the goal. Additionally, perception of training intensity and enjoyment must be taken into account when considering compliance of less fit individuals.[36]

5. Conclusion

Shorter recovery durations resulted in decreased MPO and caloric expenditure and higher perceived exertion when compared to longer recovery periods when performing 10 × six-second IST protocol. This decrement would indicate a lower total performance for the duration of the effort. However, there was no difference in PPO and blood lactate between the three protocols. A 120 s recovery protocol resulted in higher number of repetitions where PPO was maintained above 95%, whilst perceived exertion was significantly higher for the 60 s recovery protocol when compared to the other two protocols. All three recovery periods may have fallen between the fast and slow phases of PCr resynthesis of approximately 22 and 180 s resulting in partial but not complete recovery between efforts. Coaches need to consider the goals and time-effectiveness of training sessions before choosing a recovery duration. The R90 protocol may provide a balance between maintaining maximal intensity performance and time efficiency.

Author contributions

Conception of study and methodology development: T.J. Rogers, N. Gill, C.M. Beaven, acquisition of data: T.J. Rogers, analysis of data: T.J. Rogers, C.M Beaven, drafting of manuscript: T.J. Rogers, N. Gill, C.M. Beaven, Revising the manuscript critically for important intellectual content: T.J. Rogers, N. Gill, C.M. Beaven.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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