Effect of work: rest ratio on cycling performance following Sprint Interval Training: a randomised control trial

Authors:

Molly Lloyd Jones

Martyn G. Morris

John R. Jakeman

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Abstract

Sprint interval training (SIT) has been shown to improve performance measures in a range of individuals, and it is understood that different responses can be elicited from different training protocols. However, consideration of changes in work: rest ratios could offer important insight into optimising training programmes. The purpose of this study was to investigate the effect of three different work: rest ratios on exercise performance.

Thirty-six male and female participants were randomly allocated to one of three training groups, or a non-training control group. Training consisted of 10x6 second 'all-out' sprints on a cycle ergometer, with a 1:8, 1:10 or 1:12 work: rest ratio. Performance data, including peak power output, performance decrement, and 10km time trial performance data were collected before and after 2-weeks of SIT.

There were significant ($p \leq 0.05$) improvements in all parameters for the training groups, but no changes in the control condition. Peak power increased by 57.2W, 50.7W and 53.7W in the 1:8, 1:10 and 1:12 groups respectively, with no significant differences in response between conditions. Time trial performance improved significantly in all three training conditions (29.4s, 8.7s, and 25.1s in the 1:8, 1:10 and 1:12 groups), while worsening in the control group.

All training conditions resulted in significant improvements in performance, but there were no significant differences in improvement for any of the groups. Any of the three stated work: rest ratios would be appropriate for use with athletes and allow some level of personal preference for those interested in using the protocol.

INTRODUCTION

It is now well established that both High Intensity Interval Training (HIIT; defined here as repeated brief high intensity exercise bouts performed above the anaerobic threshold) and Sprint Interval Training (SIT; defined here as any repeated sprint training performed at 'all-out' effort for ≤ 30 sec) can be effective methods of improving exercise performance and cardiorespiratory fitness in relatively short periods of time (1,5,20). The mechanisms by which adaptations occur to this type of training approach continue to be explored, and are increasingly well understood. Both HIIT and SIT elicit changes in oxidative metabolism commonly associated with prolonged, low-intensity exercise training, such as increases in oxidative enzyme activity, as well as increases in peak power generating capacity, likely resulting from increased muscle glycogen content (5,19). In addition, changes in recovery ability as a result of HIIT/SIT have been reported, with increases in monocarboxylate transporters for example potentially providing a key role (23).

While one of the most common approaches to SIT involves 4x30sec repeated supramaximal sprints, often with a four-minute recovery period (9), a number of studies have considered whether shorter sprint durations can elicit similar effects (11), and repeated bouts as short as 6 seconds have been shown to significantly benefit exercise performance (12). Studies which have compared shorter to longer sprint exercise bouts, have demonstrated that the bout duration can be shortened and still elicit similar physiological adaptations. However, the matching of work or rest duration is not necessarily consistent, and this may be an important determinant in adaptations to training interventions (18). Studies are now more frequently matching work duration in an effort to standardise elements of protocol, which may allow a better comparison between approaches (14,18). In these studies, the importance of work: rest ratio is becoming apparent, as this may influence exercise training prescription. Longer rest periods which allow a more complete replenishment of ATP/PCr may be more beneficial to the development of peak power over the course of a training intervention, while shorter rest periods are more challenging to the aerobic energy system, and may have a bigger impact on changes in parameters such as VO_{2max}, but this remains to be determined. Kavaliauskas et al. (13) for example observed that 6 x10sec sprints with a recovery of 120sec led to significantly greater improvements in peak power production than the same sprint protocol used with rest periods of either 30sec or 80sec. Further, these two, shorter rest periods resulted in significant improvements in time to exhaustion (TTE), while this was not the case in the longer rest period group.

While changes in absolute performance, such as peak power, are important for athletes and coaches to achieve, the ability to maintain power output, and exhibit less performance decrement during efforts is also important. Mean power production therefore is also of interest, and these power markers can be used to reflect in changes in the fatiguing profile of individuals. While there are debates over their usefulness as performance indicators (21), fatigue index and performance decrement quantification can provide insight into the ability of an individual to maintain power output, over an exercise bout. The consideration of fatigue should factor in both peak power, and power decrement over a number of sprints, as this is important to get a true indicator of performance change in repeated sprint exercise. As the rest period may play a key role in the adaptation effect, determining the effect of work: rest ratio is an important aspect of the research into HIIT and SIT, as this may allow for the selection of optimal modalities for desired adaptations. The purpose of this study was to build on previous work by Lloyd Jones et al. (18) and Jakeman et al. (12) to determine whether repeated 6-sec sprint bouts with differing work: rest ratios resulted in different training adaptations. In addition, this study aimed to support and develop the findings of Kavaliauskas et al. (13), by using similar work: rest ratios, but using still shorter sprint durations (10 x 6 sec in the current study, vs. 6 x 10 sec in Kavaliauskas et al. (13)).

METHODS

Experimental Approach to the Problem

To determine the effectiveness of different work: rest ratios of SIT bouts, four independent groups were recruited, with participants allocated in a stratified random fashion to one of three training groups, or a non-training control group. All participants were assessed for time trial performance before and after a two-week period, where six SIT sessions were completed for those in the training groups. Data on key performance outcomes of peak power, mean power and performance decrement were also collected during training for those in the training groups.

Subjects

Thirty-six male and female volunteers (table 1) were informed of potential risks and benefits of the investigation, and provided written, informed consent to participate in the study, which was granted ethical approval by the local University ethics board. Inclusion criteria for the study were that participants had aged between 18 and 35 years, to be physically active (minimum 5x45min moderate to vigorous activity per week), free from musculoskeletal injury or illness, and have no personal history of diabetes, heart, or pulmonary disease.

INSERT TABLE 1 HERE

Procedures

Prior to the training protocol, participants completed an incremental maximal aerobic test to volitional exhaustion (VO_{2max}) on a cycle ergometer (Lode Excalibur Sport). Following a standardised, 5-minute cycling warm up at 50W, resistance was increased by 25W every 3-minutes, until volitional exhaustion. Cadence was self-selected, but the test was stopped when a participant could not maintain 60rpm. Heart rate and VO_2 were measured continuously throughout the test (Cortex Metalyzer), with the maximal VO_2 and power being determined as the mean value achieved in the final 30sec of the test to allow the determination of the ergometer resistance for the pre and post time trials.

At least 24h after the VO_{2max} test, participants completed a self-paced, 10km time trial on the cycle ergometer. The resistance to pedaling during the time trial effort was set so that the subjects would attain a power output of 70% of the maximum power recorded during the VO_{2max} test on reaching their preferred cadence, using the linear factor of the Lode ergometer (linear factor = power/cadence^2). This factor was used for both the pre and post trials, allowing participants to self-regulate their efforts throughout the trials to improve ecological validity. Participants were aware of the distance completed, but not time, to reduce the possibility of pacing strategies being used.

Training

A stratified sample to ensure equal sex split was used to allocate participants to one of four groups. All training groups completed, 10x6sec sprints against a load comparable to 7.5% body mass on a Lode Excalibur cycle ergometer, with either 48sec (1:8 work: rest ratio (1:8)), a 60sec (1:10 work: rest ratio (1:10)) or a 72sec (1:12 work: rest ratio (1:12)) recovery. All training groups completed a total of 1min sprint work, and one group was retained as a non-training control (Con). Three sessions were completed each week for two weeks, and each training session was separated by at least 24hr. Power output was monitored continuously throughout training, via online software. Participants were asked to refrain from exhaustive exercise for the duration of the testing, and from caffeine and alcohol for 12hr before exercise.

Statistical Analyses

Performance decrement was calculated using the following formula (10)

$$S_{dec}\,(\%) = \left\{1 - \frac{(S1 + S2 + S3 \ldots S10)}{Sbest \times number\ of\ sprints}\right\} \times 100$$

Where the peak power (PP) of each sprint is represented (S1 is PP for sprint 1, S2 is PP for sprint 2 etc.)

Data were checked for assumptions of normality using the Shapiro-Wilk test. Repeated measures ANOVA was used to analyse peak power, mean power and energy expenditure data from each training session, and time trial data. The Maulchley Sphericity test was used to test assumptions of sphericity, and where this was violated, the Greenhouse Geisser value was used. Where appropriate, the Scheffe post hoc test was applied. Confidence intervals and effect sizes within groups were also analysed, with effect sizes of ≤0.35, 0.35-0.8, 0.8-1.5 and ≥1.5 being considered as trivial, small, moderate and large respectively (24). Additionally, smallest worthwhile change values were calculated. Significance was set a *$p \leq 0.05$ a priori*.

RESULTS

Sprint performance

Main effects for time were observed for both absolute mean power ($F_{3.2, 79.1} = 21.5$, $p < 0.05$) and absolute peak power ($F_{3.1, 71.6} = 18.6$, $p < 0.05$), although there were no significant differences between groups, and no interaction effects for either mean or peak power. Peak power increased by 5.5%, 4.6% and 5.1% for the 1:8, 1:10 and 1:12 groups respectively, and mean power by 4.3%, 4.2% and 2.8% for the 1:8, 1:10 and 1:12 groups respectively. The same pattern of responses was observed for mean ($F_{3.6, 80.6} = 21.5$, $p < 0.05$) and peak power ($F_{3.5, 83.9} = 18.4$, $p < 0.05$) relative to body mass (Table 2).

Time trial performance

Data analysis revealed that following SIT, there was no overall main effect for time ($F_{1, 32} = 0.6$, $p > 0.05$), but there was an interaction effect ($F_{1, 32} = 9.2$, $p < 0.05$), where time trial performance significantly improved by in the 1:8 (+3.8%), 1:10 (+1.4%) and 1:12 (+3.9%) groups in comparison with the control group (-6.3%). There were no significant differences in improvement between treatment groups ($F_{3, 32} = 1.5$, $p > 0.05$). A repeated measures

ANOVA revealed that there was no significant difference in pacing strategy between groups as indicated by km distance completion times, or from pre- to post-testing ($p > 0.05$) during the time trial, and there was no significant difference between groups on heart rate response following training ($p > 0.05$).

INSERT TABLE 2 HERE

Performance decrement

A significant time main effect ($F_{5,\ 120} = 3.5$, $p < 0.05$) was observed on performance decrement, with the performance decrement decreasing from 7.1% (±2.2) to 5.1% (±2.5), 5.3% (±2.3) to 3.7% (±0.8) and 5.7% (±2.1) to 4.5% (±2.0) in for the 1:8, 1:10 and 1:12 groups respectively, from pre to post training. There was no group, or group by time interaction effect. In addition, there was a significant time main effect for the range (difference between highest and lowest) of both peak power ($F_{5,120} = 5.5$, $p < 0.05$) and mean power ($F_{5,120} = 4.1$, $p < 0.05$) outputs within sessions, with mean and peak power output becoming more consistent over the training period. The range of peak power output decreased between session 1 and session 6 by 35.1%, 35.6% and 31.7% for the 1:8 (Fig. 1A), 1:10 (Fig. 1B) and 1:12 (Fig. 1C) groups respectively, with decreases in the range of mean power output of 14.1%, 39.1% and 25.2% noted for the 1:8, 1:10 and 1:12 groups respectively between sessions 1 and 6.

INSERT FIGURE 1 HERE WITH PANELS A-C ADJACENT TO EACH OTHER HORIZONTALLY

DISCUSSION

The purpose of this study was to examine responses to SIT, when using different work: rest ratios, but where training was matched for sprint duration. Other SIT studies (Koral et al. (15) for example) have shown, that peak power output and mean power output both increased significantly following two-weeks of training, as was the case in the current study, however, there was no significant difference between conditions, indicating that adaptations were similar regardless of whether participants completed the training with a 1:8, 1:10 or 1:12 work: rest ratio.

Adaptations to power output following SIT are well characterised, and the improvements observed in the present study are similar to those observed in previous research (18). A number of studies have reported changes to factors influencing power generating capacity, including increased glycogen availability, and increases in enzymes associated with anaerobic metabolism following this type of training (17,25). However, the consideration of work: rest ratio is important in repeated sprint training studies, because of the changes in relative contributions of energy from aerobic and anaerobic sources during repeated sprints and recoveries of different durations (4,8). Kavaliauskas et al. (13), and Shi et al. (26) for example have reported that following 'all-out' sprinting of short duration ($\leq$ 10s), a shorter recovery time improves typically aerobic exercise performance (time trial performance and $VO_{2\ max/peak}$), likely due to an increased aerobic challenge, and a longer recovery period improves peak power and mean power output, likely because of the increased ATP/PCr resynthesis period. It is worth noting that this is not well reflected in the current study, with power output adaptations being similar between training conditions, and therefore differing from the findings of Kavaliauskas et al. (13) for example. While similar work: rest ratios were used, the rest duration of 80sec and 120sec used by Kavaliauskas and colleagues for their 1:8 and 1:12 ratio conditions may have provided the additional time for recovery needed to develop more adaptations in power generation capacity, in comparison with the 48sec and 72sec rest durations used in the current study, despite replicating the 1:8 and 1:12 ratios. A more pronounced difference in work: rest ratio may therefore be required to elicit optimal adaptations.

Sprint exercise performance is metabolically complex, and in maximal sprint exercise, relative changes in metabolic energy contribution depend on sprint duration. Sprints lasting from 1-6sec are predominantly fuelled by ATP/PCr, which is rapidly resynthesized from anaerobic pathways (8). Sprints lasting 6-10sec are predominantly fuelled by anaerobic glycolysis, and longer lasting sprint exercise is increasingly fuelled by oxidative components. It is likely that incomplete recovery of ATP/PCr associated with repeated sprints, results in an increase in oxidative contribution, which underpins the adaptations observed more usually related to prolonged distance training. Given that shorter sprints can also elicit similar adaptive responses, it seems logical that the work: rest ratio may be an important component. If relatively short rest periods are employed, which preclude sufficient recovery of ATP/PCr, it could be expected that an increased aerobic contribution would be necessary to fuel repeated work (18). Longer rest periods may not result in such a high aerobic demand, and therefore adaptations may be observed which are less aerobically characterised, and more focused on developments in peak power because of the ability to reach and maintain a higher power output through repeated bouts of sprinting.

Associated to the positive changes in power generating capacity as indicated in the current study, both HIIT and SIT have been shown to positively affect repeated sprint ability, by improving the recovery ability of individuals between bouts of exercise (3). Repeated sprint ability itself is conditional on both the ability to execute a high-intensity sprint, producing high power, and the ability to recover effectively from that sprint, and it has been indicated, that those with a higher aerobic capacity can recover more quickly during repeated sprint exercise (2). The improvement in fatigue profile, as indicated by changes in performance decrement observed in the current study, suggest that in conjunction with improved between sprint recovery, SIT with all work: rest ratios considered here allows for improved maintenance of power generating capacity. This is also reflected in the changes in peak and mean power ranges during sessions, across time. In the current study, there was a significant time effect for the range (difference between highest and lowest) of both peak and mean power outputs within sessions, with these measures becoming more consistent over the training period (Peak power changes represented in Fig. 1). The range of peak power output decreased between session 1 and session 6 by 35.1%, 35.6% and 31.7% for the 1:8 (Fig. 1A), 1:10 (Fig. 1B) and 1:12 (Fig. 1C) groups respectively, with decreases in the range of mean power output of 14.1%, 39.1% and 25.2% noted for the 1:8, 1:10 and 1:12 groups respectively between sessions 1 and 6, such that power generation became more consistent over time. This is a consideration not made in studies such as that of Kavaliauskas et al. (13), and it would be of interest for future studies to consider this aspect.

As with other power output data, there was no significant difference between conditions, which again, may be a result of the need for a longer sprint duration or recovery phase to demonstrate differences between the work: rest ratios. It has been noted in a number of studies that changes to mechanisms regulating intracellular pH, such as monocarboxylate transporters for example, occur following HIIT, and these may be responsible for an enhanced recovery ability over the training period, meaning participants could better achieve higher mean and peak power outputs (6,7,27), in this case to similar degrees in the training conditions.

The data also indicated that there was a significant improvement in time trial performance in the training conditions in comparison with a control group. The magnitude of this improvement was relatively small, but was consistent with other similar studies. Lloyd Jones et al. (18) examined the effect of 6-second sprints with a 1:8 work: rest ratio when matched for total session sprint duration in comparison with a 30-second sprint protocol, and observed that 20x6-second sprints elicited an improvement of 5% in time trial performance. Similarly, Jakeman et al. (12) reported significant improvements in time trial performance using 10x6-second sprints with a 1:10 work: rest ratio. These studies, and others (16,17), concluded that short duration sprints (<10seconds) are effective in eliciting both health benefits, and performance improvements. However, although some of these data indicate that there were statistically significant responses to this training intervention, it should be noted that the effect sizes for all parameters were small, likely as a result of the large standard deviations observed throughout. Consideration of effect sizes with power data normalised for body mass showed larger effect sizes, and while the current data overall do show improvements in performance of greater than 2%, which has been considered previously to be of practical importance in some circumstances (22), they should be considered as useful, though not necessarily conclusive.

PRACTICAL APPLICATIONS

This study indicates that SIT with short, 6-sec exercise bouts, is an effective form of training to improve peak and mean power production in moderately trained individuals. Additionally, work: rest ratios of 1:8, 1:10 and 1:12 all produced similar results. From a practical perspective therefore, as similar physiological adaptations can be elicited, the personal preference of the athlete could be considered in programming the most effective training approach. Further study is required to more comprehensively outline mechanisms involved in adaptation, and to explore other work: rest ratio combinations, factoring in different work durations, depending on desired outcome goals.

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Table 1:

Table 1
Subject characteristics.*

	Age (y) mean (± *SD*)	Height (m) mean (± *SD*)	Mass (kg) mean (± *SD*)	$\dot{V}O_2max$ (ml·kg·min^{-1}) mean (± *SD*)
1:8 overall (*n* = 9)	23 (3)	1.77 (0.12)	74 (17)	51 (9)
Male (*n* = 6)	22.7 (3.6)	1.83 (0.09)	82.9 (12)	54.8 (8.5)
Female (*n* = 3)	24.3 (3.5)	1.66 (0.09)	57.3 (10.7)	44.3 (2.3)
1:10 overall (*n* = 9)	25 (5)	1.81 (0.08)	78 (13)	54 (8)
Male (*n* = 6)	26.5 (11.5)	1.85 (0.08)	81.4 (10.2)	55.7 (8.1)
Female (*n* = 3)	23.3 (2.1)	1.74 (0.06)	70.3 (18.5)	50.3 (7.8)
1:12 overall (*n* = 9)	24 (4)	1.77 (0.09)	75 (11)	53 (6)
Male (*n* = 6)	25.0 (4.1)	1.81 (0.05)	79.3 (9.3)	55.0 (6.6)
Female (*n* = 3)	22.0 (1.7)	1.68 (0.01)	65.2 (8.1)	48.7 (1.5)
Control overall (*n* = 9)	24 (4)	1.75 (0.09)	73 (11)	54 (11)
Male (*n* = 6)	24.3 (4.5)	1.79 (0.05)	78.6 (7.1)	56.5 (11.8)
Female (*n* = 3)	22.0 (1.7)	1.69 (0.07)	61.3 (5.8)	48.7 (5.7)

*Data presented as mean (± *SD*).

Table 2:

Table 2
Primary outcome measures.*†

Variable	Condition		Pre mean ± *SD*	Post mean ± *SD*	*d*	*SWC*
Peak power output (W)	1:8	Mean ± *SD*	1,038.0 (330.1)	1,095.2 (357.4)‡	−0.2	66.0
		95% CI	391.1–1,684.9	394.8–1795.7		
	1:10	Mean ± *SD*	1,107.0 (267.9)	1,157.7 (268.7)‡	−0.1	53.6
		95% CI	582.0–1,632	631.1–1,684.3		
	1:12	Mean ± *SD*	1,042.9 (200.9)	1,096.6 (226.3)‡	−0.3	40.2
		95% CI	649.1–1,436.7	653.1–1,540.0		
Peak power output (W·kg)	1:8	Mean ± *SD*	13.7 (1.7)	14.4 (1.8)‡	−0.4	0.33
		95% CI	10.4–17.0	10.9–17.9		
	1:10	Mean ± *SD*	14.1 (1.3)	14.8 (1.0)‡	−0.5	0.25
		95% CI	11.6–16.6	12.7–16.9		
	1:12	Mean ± *SD*	13.9 (1.1)	14.6 (1.2)‡	−0.6	0.22
		95% CI	11.7–16.1	12.3–16.8		
Mean power output (W)	1:8	Mean ± *SD*	887.4 (271.6)	927.0 (282.6)‡	−0.1	54.3
		95% CI	355.0–1,419.8	373.1–1,480.9		
	1:10	Mean ± *SD*	960.4 (216.7)	1,002.9 (216.5)‡	−0.2	43.3
		95% CI	535.7–1,385.0	578.6–1,427.2		
	1:12	Mean ± *SD*	924.0 (182.2)	950.9 (192.5)‡	−0.1	36.4
		95% CI	566.9–1,281.1	573.7–1,328.1		
Mean power output (W·kg)	1:8	Mean ± *SD*	11.8 (1.4)	12.3 (1.5)‡	−0.4	0.27
		95% CI	9.0–14.4	9.3–15.2		
	1:10	Mean ± *SD*	12.3 (1.0)	12.8 (0.8)‡	−0.5	0.19
		95% CI	10.4–14.1	11.2–14.5		
	1:12	Mean ± *SD*	12.3 (1.1)	12.7 (1.0)‡	−0.4	0.22
		95% CI	10.2–14.5	10.7–14.7		
Mean session work (kJ)	1:8	Mean ± *SD*	53.2 (16.3)	55.6 (17.0)‡	−0.1	3.3
		95% CI	21.3–85.2	22.4–88.9		
	1:10	Mean ± *SD*	57.6 (13.0)	60.2 (13.0)‡	−0.2	2.6
		95% CI	32.1–83.1	34.7–85.7		
	1:12	Mean ± *SD*	55.4 (10.9)	57.1 (11.5)‡	−0.2	2.2
		95% CI	34.0–76.9	34.4–79.7		
Time trial (s)	1:8	Mean ± *SD*	780.4 (257.9)	751.0 (270.4)‡	0.1	51.6
		95% CI	274.9–1,285.9	221.0–1,281.0		
	1:10	Mean ± *SD*	583.4 (133.7)	574.7 (129.1)‡	0.1	26.7
		95% CI	321.3–845.5	321.7–827.7		
	1:12	Mean ± *SD*	640.9 (100.6)	615.8 (93.6)‡	0.2	20.1
		95% CI	444.0–837.6	432.3–799.3		
	Con	Mean ± *SD*	716.3 (207.2)	761.4 (228.8)	−0.2	41.4
		95% CI	310.2–1,122.4	313.0–1,209.9		

*CI = confidence intervals.
†Data presented as mean (± *SD*).
‡Significantly different to baseline.

Figure Legend:

Figure 1: Peak power for all sprints during the training period. The 1:8, 1:10 and 1:12 groups are represented in figures 1A, B, and C respectively.