J Sci Cycling. Vol. 1(2), 35-41

RESEARCH ARTICLE **Open Access**

The effect of power alternation frequency during cycling on metabolic load and subsequent running performance

Colin F Hill ✉[1] and Alan St Clair Gibson[2]

Abstract

The purpose of this study was to determine whether the frequency of power output alternation during cycling affects subsequent running performance. Eleven male triathletes completed a graded cycle test to determine peak oxygen uptake and the corresponding power at 35% delta. Two performance tests were then conducted, each comprising of a thirty minute cycling protocol followed by a 5 km free pace run. Mean cycling power was equal for both trials (35% delta), however the frequency of power alternations differed. In one trial cycling power output alternated every five minutes, whereas in the other trial cycling power output alternated every one minute. Power was set to alternate 15% above and below the 35% delta value. No significant difference was found between trials for the subsequent 5 km running performance time (P = .63). A significant difference was observed for overall mean heart rate between cycle trials (P = .045), however no significant difference was observed for overall mean oxygen uptake, minute ventilation, respiratory exchange ratio, blood lactate, rating of perceived exertion or pedal cadence (P > 0.05). When data was divided into 5 minute epoch stages rating of perceived exertion was significantly different between cycle trials at epochs three (minutes 10-15; P = .046) and five (minutes 20-25; P < 0.001). We conclude that when power is alternated equally during cycling, the frequency of power change (maximum of five minutes, minimum of one minute) does not affect subsequent running performance.

Keywords: triathletes, power-regulation, oxygen-uptake, triathlon, pacing.

✉ **Contact email:** *c.hill@worc.ac.uk* (CF. Hill)

[1] Institute of Sport and Exercise Science, University of Worcester, United Kingdom.

[2] School of Psychology and Sport Sciences, Northumbria University, United Kingdom

Received: 13 September 2012. Accepted: 6 December 2012.

Introduction

Varying power output during cycling has previously been investigated in order to determine whether significant metabolic differences are observed when compared to a constant load that achieves the same mean power output (Bernard et al., 2007; Brickley et al., 2007; Liedl et al., 1999; Palmer et al., 1997 & 1999; Suriano et al., 2007). The observation of metabolic differences between constant versus variable power cycling is particularly pertinent to activities that require a subsequent bout of exercise that directly proceeds the cycle, namely duathlon and triathlon. Despite mean workloads being equal between cycle protocols, using either constant or variable power during cycling may result in a significant increase or decrease in subsequent running performance (Bernard et al., 2007; Suriano et al., 2007).

Suriano et al. (2007) observed that alternations of power during cycling can significantly improve subsequent running performance when compared to constant power cycling despite both trials achieving the same mean workload. The authors compared five minute bouts of power that alternated ±20% of constant power during a thirty minute cycle protocol. Subsequent running time to exhaustion was significantly increased following the alternate power cycle protocol. Mean metabolic stress was not significantly different between trials, however the reduced load during the final five minutes of the cycle protocol, performed at a power corresponding to -20% of constant power, appears to have provided a greater degree of recovery prior to running.

Bernard et al. (2007) also observed no significant metabolic differences between 20 km cycle trials when comparing variable power versus constant power protocols. Variable power changed within the range of ±15%, ±5% and ±10% of the mean constant power. Despite similar metabolic responses during the cycle protocols, subsequent 5 km running time was significantly reduced following constant power cycling, suggesting neuromuscular rather than metabolic indices may have been responsible for the difference in running performance.

Despite no significant differences in overall metabolic load for constant versus alternate / variable power trials (Bernard et al., 2007; Liedl et al., 1999; Suriano et al., 2007), it is important to note the occurrence of within test (epoch to epoch) significant differences for VO_2 in the studies of Liedl et al. (1999) and Suriano et al. (2007). This is in contrast to the study of Bernard et al. (2007) who recorded no significant epoch differences between trials. This contrast in epoch to epoch metabolic responses between studies may be associated with the frequency in which the power changed. For instance Suriano et al. (2007) utilised five minute power bouts, a duration that is consistent with a previous cycle only protocol (Liedl et al., 1999), whereas Bernard et al. (2007) utilised variable bouts of power change in order to reflect stochastic variation. Although details of power durations were not reported their results reflect earlier work by Brickley et al (2007). In this study alternate power consisted of 120 s at 73% critical power and 30 s at 158% critical power for 30 minutes.

The utilisation of different protocols between studies and the differences in metabolic responses that have been reported following alternate power cycling may therefore be associated with the frequency and duration of power shifts rather than simply the magnitude of power change from the mean. This may be an important consideration given that the $\dot{V}O_2$ kinetic and slow component time phases (Whipp & Wassermann, 1986; Wilkerson & Jones, 2007) may differ between trials due to differences in the frequency of power change or the duration of the power interval despite achieving the same mean workload. Ultimately this may result in a significant difference in the overall metabolic load despite an equal overall workload. Furthermore, any metabolic differences between cycle trials may affect subsequent running performance. As such, it is beneficial to understand whether the frequency of power alternation is responsible for the different metabolic responses reported during variable and alternate power cycle protocols. In addition, it is also of great interest to understand whether the frequency of power alternation during cycling affects subsequent exercise performance. The aim of this study was: 1) to investigate the effect of power frequency change on metabolic responses during cycling and 2) to investigate the effect of power alternation frequency during cycling on subsequent running performance.

Materials and methods

Participants

Eleven male triathletes volunteered to take part in this study. Mean ($\pm$ SD) age, stature and mass was 34 $\pm$ 10 years, 179 $\pm$ 5 cm and 78 $\pm$ 4 kg respectively. Participants were experienced at undertaking combined cycle-run exercise and trained 5 $\pm$ 1 times per week. Prior to testing, all participants were required to provide written informed consent. The study had approval from an Institutional Ethics Committee and complied with the ethical standards of Journal of Science and Cycling (Harriss and Atkinson 2009).

Designs and procedure

A repeated-measures experimental design was employed. Participants visited the laboratory on three occasions separated by 7 + 4 days. Testing was undertaken at a similar time of day for all three tests in order to limit the effects of diurnal variation. Participants were asked to abstain from training 24 hours prior to all testing. On their first visit to the laboratory, participants undertook a graded cycle test (GCT). On their next two visits to the laboratory participants undertook the following two protocols using a counterbalanced design; 1) a sub-maximal cycle protocol with power alternations every five minutes followed by a 5km run (CR5MIN); 2) a sub-maximal cycle protocol with power alternations every one minute followed by a 5km run (CR1MIN).

Graded Cycle Test

The GCT was conducted on an electromagnetically braked ergometer (Excalibur Sport, Lode, Gronigen, The Netherlands). The ergometer was fitted with clipless pedals, a racing saddle and a racing handlebar. The saddle and handlebar could be adjusted both vertically and horizontally. All reference values were recorded from the ergometer control unit in order to maintain consistency of the cycle setup for the following two laboratory tests. The cycle ergometer regulated power output (PO) independent of changes in pedal cadence. PO, pedal cadence and time completed were available to view on a computer screen that was interfaced with the ergometer throughout the exercise. Participants warmed up at 100 Watts (W) for 5 minutes. Thereafter the PO was increased by $0.58W.s^{-1}$ until subjects could no longer maintain a cadence above 70rpm. $\dot{V}O_2$peak was determined as the highest value attained over a 15s period. The V-slope method (Beaver et al., 1986) was employed to determine anaerobic threshold (AT) following the cycle test. Breath-by-breath $\dot{V}CO_2$ and $\dot{V}O_2$ values (averaged every 15 s) were plotted and the point of excess CO_2 output subsequently calculated. Values collected during the initial 5 minute warm-up period and values indicating a plateau in the final part of the test were excluded from the calculation. Power at 35% of delta (WΔ35%), representing the difference between AT and $\dot{V}O_2$peak, was then calculated to provide mean PO for the subsequent cycle tests. Maximum and minimum PO for the two cycle strategies were then set at $\pm$ 15% of WΔ35% respectively. The regulation of power at $\pm$ 15% of the mean was selected as this reflects the typical power oscillation that is experienced by cyclists who switch between drafting and non-drafting conditions (Kyle, 1979). Prior to data collection pilot tests were performed in order to establish realistic cycle racing intensity. Participant feedback and physiological analysis suggested that when using a mean power of WΔ35% the workload was demanding yet sustainable and realistic of their exercise intensity during sprint triathlon events. The study therefore considered the realistic workload that athletes may experience when selecting the intensity and magnitude of power oscillation during a triathlon.

Cycle-Run Test

Both cycle-run (CR) tests required the participant to undertake an alternating cycle workload of $\pm$15% of WΔ35% for 30 minutes. The duration of the cycle protocol replicates previous triathlon studies and represents a typical duration for the sprint distance event (Hausswirth et al., 1999 & 2001). During one CR test the workload alternated every 5 minutes (CR5MIN) whereas for the other CR test the workload alternated every one minute (CR1MIN). These durations were selected since previous research has used similar long (Surinao et al., 2007) and short (Hausswirth et al., 2001) power change durations but only compared against a constant workload.

For both CR tests the exercise commenced at a power output of -15% WΔ35% directly after a 5 minute warm up at 100W. Expired air, heart rate (HR), and pedal cadence were recorded throughout the exercise and later averaged per five minute epoch. Blood lactate [La¯] and rating of perceived exertion (RPE) (Borg, 1970) were collected at the end of each epoch. After completing the cycle protocol a 90 s 'transition' was allocated for participants to dismount the cycle ergometer and change from cycling shoes to running shoes. Within this time participants exited the laboratory, ran along a flat asphalt surface and entered a flat synthetic running field (lap perimeter measuring 250m) located 60 metres from the laboratory. At the end of the 90 s transition period participants commenced a 5km self-regulated running time trial. Participants were informed to complete the 5km distance in the fastest possible time. 1km split times were recorded using infra-red photocells (Tag Heuer, La Chaux-de-Fonds, Switzerland). HR was recorded throughout the run and later averaged per 1km epoch (4 laps). A final [La¯] sample was collected 120 s after completing the 5 km run. This allowed time for athletes to return to the laboratory for blood collection followed by an active recovery on the cycle ergometer in order to enhance blood lactate removal (Taoutaou et al., 1996). Temperature / humidity was 18.4 ± 3.2°C / 57.6 ± 16.8% and 21.7 ± 1.3°C/ 46.2 ± 5.3% for external and internal conditions respectively. Barometric pressure averaged 760.2 ± 3.8mmHg.

Gas analysis

$\dot{V}O_2$, $\dot{V}_E$ and RER were collected throughout all cycling performances using an automated gas analysis system (Oxycon Pro, Jaeger, Germany) as validated by Rietjens et al. (2001). Prior to all tests, the system was calibrated using a 3L syringe (Hans Rudolph, Kansas, USA) and a known gas concentration. Participants were required to wear a face mask for the duration of the exercise. Data was averaged over a 15s period.

Heart Rate

HR was recorded for all tests via telemetry using a Polar interface (RS800, Polar Electro, Kempele, Finland). Data was recorded every 15s and later averaged for each epoch.

Blood lactate

Capillary blood samples were taken from the earlobe (~30uL) and analysed immediately for [La¯] concentration. An Analox lactate analyser (GM7, London, UK) was used for all blood analysis. The

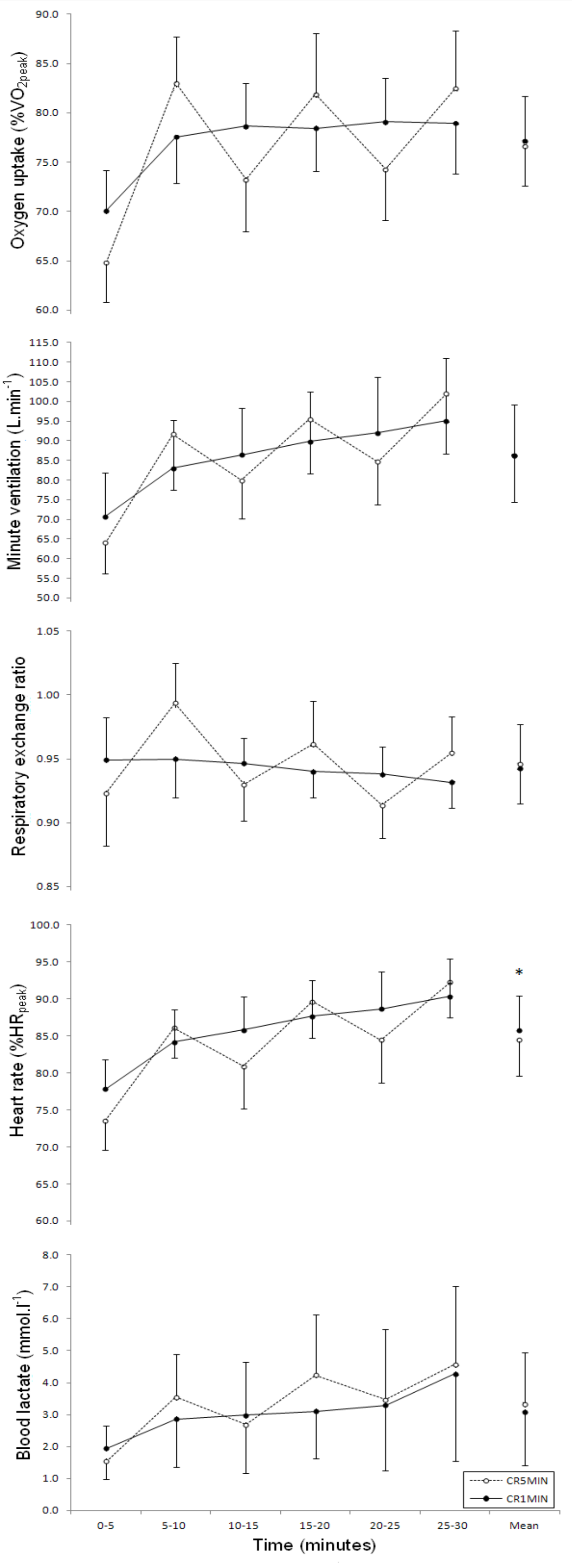

Figure 1 Epoch and mean values for cardiorespiratory variables (oxygen uptake, ventilation, respiratory exchange ratio, heart rate) and blood lactate for the CR5MIN and CR1MIN cycle protocols. Values are mean ± SD.

*Significantly different from corresponding protocol (P = .045).

system was calibrated with a known assay concentration prior to use as per manufacturer's instructions.

Rating of Perceived Exertion

Borg's category scale (6-20) (Borg, 1970) was placed next to the computer monitor allowing participants to select the appropriate value at the end of each cycle epoch. Prior to the test, participants were provided with a clear explanation of how to interpret the scale. Participants were asked to relate the highest figure on the scale to a previous experience where they had performed the highest maximal exertion activity possible.

Statistical analyses

A paired sample *t*-test was used to determine if a significant difference in mean $\dot{V}O_2$, $\dot{V}_E$, RER, HR, [La⁻], pedalling rate and run performance time occurred between trials. A Wilcoxon matched pairs test was performed for the analysis of mean RPE. A two way analysis of variance (ANOVA, 2x6) with repeated measures was performed to analyse the effect of cycle strategy and time during the cycling trials using $\dot{V}O_2$, $\dot{V}_E$, RER, HR, [La⁻], RPE, and pedalling rate as the dependent variables. A 2x5 ANOVA with repeated measures was performed to analyse any effect of cycle strategy and distance during the 5 km run using HR and 1 km split times as the dependent variables. A Bonferroni post hoc test was used to determine where any significant differences occurred between trials. Alpha was set at $P < 0.05$ for all analysis. GraphPad Prism 5 version 5.03 (La Jolla, California, USA) was used for statistical analysis.

Results

Graded Cycle Test

The mean ± SD data for $\dot{V}O_2$peak, W $\dot{V}O_2$peak and HRpeak attained during the GCT were 52.6 ± 8.0 mL.kg^{-1}.min^{-1}, 364 ± 41 W and 176 ± 11 beats.min^{-1} respectively. The AT corresponded to 69.7 ± 6.0 % of $\dot{V}O_2$peak and was attained at a PO of 150 ± 31 W. The mean PO at WΔ35% for the following CR tests was calculated at 225 ± 24 W.

Cycling Protocol

Mean HR was significantly higher for CR1MIN vs. CR5MIN (85.7 ± 4.6 vs. 84.5 ± 4.9 %HR_{peak} respectively, P = .045). No significant difference was found between protocols for mean $\dot{V}O_2$ (76.7 ± 4.6 vs. 77.1 ± 4.3 % $\dot{V}O_2$peak), $\dot{V}_E$ (86.5 ± 11.2 vs. 84.9 ± 11.4 L.min^{-1}), RER (0.95 ± 0.3 vs. 0.94 ± .02), [La⁻] (3.3 ± 1.1 vs. 3.1 ± 0.8 mmol.l^{-1}), pedalling rate (82 ± 8 vs. 82 ± 9 rev.min^{-1}) and RPE (15 ± 1 vs. 16 ± 1) for CR5MIN vs. CR1MIN respectively. The statistical analysis indicated a significant (P < .001) effect of time

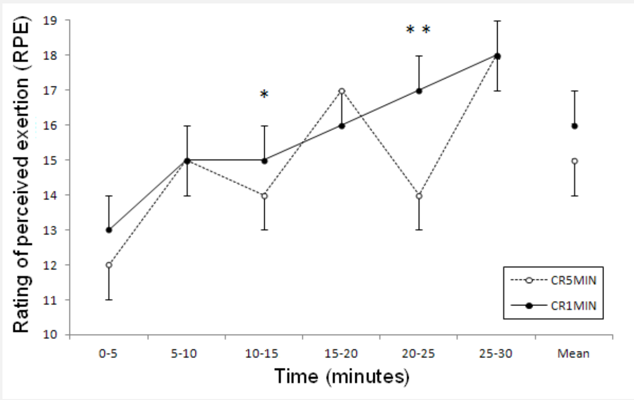

Figure 2 Epoch and mean values for rating of perceived exertion for the CR5MIN and CR1MIN cycle protocols. Values are mean ± SD.

* Significantly different from corresponding protocol (P < .05).
** Significantly different from corresponding protocol (P < .001).

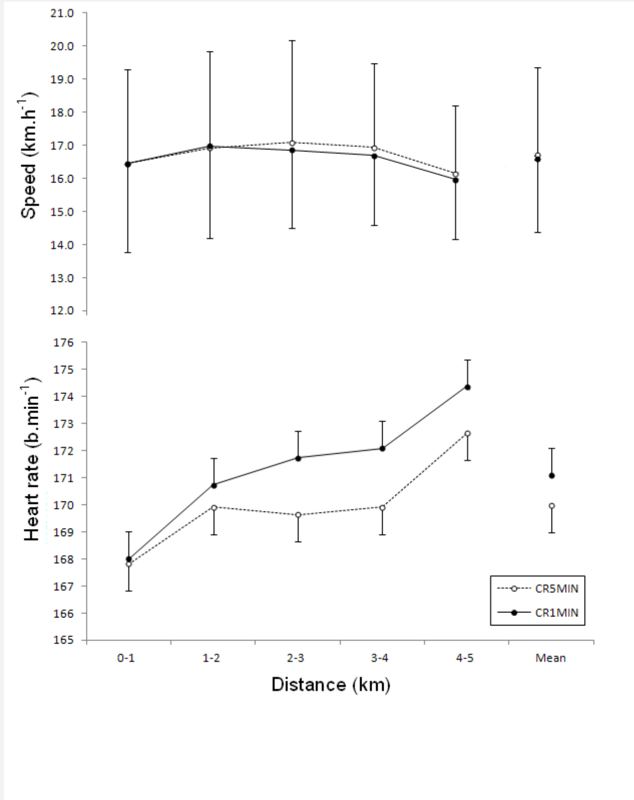

Figure 3 1 km epoch and mean values for running speed and heart rate following the CR5MIN and CR1MIN cycle protocols. Values are mean ± SD.

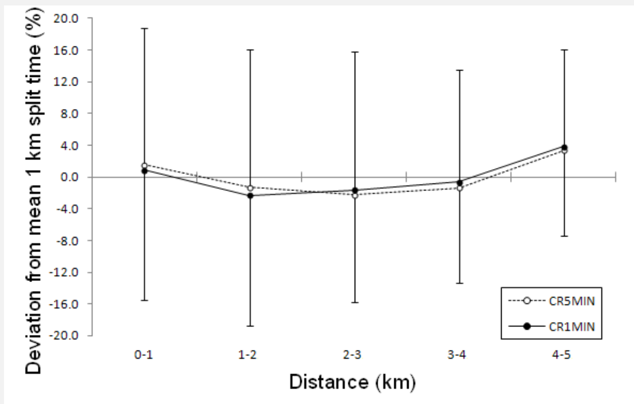

Figure 4 Deviation from mean 1 km split times following the CR5MIN and CR1MIN cycle protocols. Values are mean ± SD.

for $\dot{V}O_2$, $\dot{V}_E$, RER, HR, [La⁻] and RPE (Figures 1 & 2 respectively). When divided into 5 minute epoch stages the statistical analysis indicated that RPE was significantly higher for CR1MIN compared to CR5MIN at epochs 3 and 5 ($P = .046$ & $P < .001$ respectively, Figure 2).

5 km Running Performance

No significant difference was observed between trials for overall time (CR5MIN vs. CR1MIN was 1393 $\pm$ 221 vs. 1382 $\pm$ 184 s respectively, $P = .63$), or mean HR during the run (168 $\pm$ 10 vs. 171 $\pm$ 9 for CR5MIN vs. CR1MIN respectively, P = .38,). At each 1 km epoch, running speed and the deviation from mean 1 km split times were not significantly different between trials ($P > .05$, Figures 3 & 4). Six athletes performed the CR1MIN run faster than the CR5MIN trial and five athletes performed the CR5MIN run faster than the CR1MIN trial. The mean coefficient of variation between the trials was 1.1%. Statistical analysis indicated a significant effect of distance on running speed ($P = .02$), deviation from mean 1 km split time ($P < .001$) and HR ($P < .001$, Figures 3 & 4 respectively). There was no significant difference in post-run [La⁻] values between trials (CR5MIN vs. CR1MIN was 4.0 $\pm$ 1.4 vs. 4.6 $\pm$ 1.6 $mmol.l^{-1}$ respectively, $P = 0.20$).

Discussion

The main finding from this study is that the frequency of power alternation during cycling does not significantly affect overall metabolic load. In turn, subsequent running performance is not affected by the power alternation frequency employed during cycling. Despite the CR1MIN run performance averaging 11 s faster than the corresponding CR5MIN trial, it is likely that this value falls within the intra-individual variability of 5 km running time for this group of athletes. The 1.1% mean coefficient of variation between trials in this study falls within the expected typical error for a 5 km performance test (Laursen et al., 2007). The results of this study agree with Brickley et al. (2007) who suggest that when the average PO between two protocols is similar, variations in exercise intensity do not significantly affect muscle metabolism. This is demonstrated by the similar overall values attained for $\dot{V}O_2$ and [La⁻] for both cycle protocols (Figures 1). Although the higher frequency of power change reduced the $\dot{V}O_2$ differential between epochs during CR1MIN, this reduction appears insufficient to significantly lower physiological demand in comparison to 5 minute power changes. Consideration should therefore be given to the potential to reduce the $\dot{V}O_2$ difference between epochs even further by increasing power alternation frequency. This may lead to reduced $\dot{V}O_2$ oscillation, resulting in greater $\dot{V}O_2$ stability and ultimately significant epoch differences when compared to $\pm$15% CR5MIN workloads.

Although all other physiological variables ($\dot{V}O_2$, $\dot{V}_E$, RER, [La⁻]) showed no mean significant difference between cycle trials (Figure 1), it is interesting that HR was significantly higher overall for CR1MIN compared to CR5MIN (Figure 1). This may be a phenomenon associated with differences in heat stress between trials. An increase in HR, despite a steady $\dot{V}O_2$, may be a mechanistic response to heat regulation (Rowell, 1974). It is possible that the CR1MIN protocol, incorporating more frequent power alternations than CR5MIN, created additional internal heat stress during the workload which is reflected by the significantly higher overall HR value. Given that RPE was significantly higher at epochs 3 and 5 for CR1MIN (Figure 2), this may be associated with a difference in thermoregulatory demand between trials. Since mean $\dot{V}O_2$ and $\dot{V}_E$ remained comparable between trials the significantly higher mean HR for CR1MIN may have, alternatively, compensated for a lower stroke volume, enabling cardiac output and therefore $\dot{V}O_2$ to remain comparable between cycle protocols. Hausswirth et al. (2001) previously associated a difference in HR between their cycle trials due to a difference in pedalling frequency, however, the similar cadence that was recorded between trials in this study negates this theory. Given that Hausswirth et al. (2001) observed a significantly faster running performance following a lower HR during the cycle it is interesting that no significant difference in running performance was observed in this current study.

Suriano et al. (2007) observed significant differences for $\dot{V}O_2$, HR, [La⁻] and cadence during their cycle protocol at different time points when they compared constant versus alternate power. The lack of significant difference between trials at each epoch (with the exception of RPE) during the present cycle protocol (Figure 1) is probably reflected by the smaller variation in PO. In the present study power was regulated $\pm$ 15% of 35%Δ, whereas Suriano et al. (2007) regulated power by $\pm$ 20% of 90% lactate threshold. Oscillating power above and below lactate threshold has therefore already been shown to affect metabolic load due the aero-anaerobic mono-exponential fluctuations inflicted during the exercise. A novel aspect of this study was to utilise a mean exercise intensity of 35%Δ. This ensured exercise intensity remained above AT. Any differences that may have occurred between cycle trials would be due to the effect of power frequency rather than the intensity of exercise oscillating above and below AT. Furthermore W35%Δ produced almost identical relative $\dot{V}O_2$ values to a previous triathlon study (Hausswirth et al., 1999) suggesting the intensity of this study reflects that of a sprint triathlon.

Unlike Suriano et al. (2007), in this study no significant difference in overall running performance was found, however running performance was determined by a self-paced 5 km run, designed to replicate the running demands of a triathlon. This is in contrast to Suriano et al. (2007) who utilised a time to exhaustion treadmill run. The termination of the protocol at +15% WΔ35% was performed in accordance with Bernard et al. (2007) who prescribed a high intensity at the end of their cycle protocol, simulating a race situation where triathletes increase the intensity in order to try and enter the transition area in the best position. Similar to Bernard et al. (2007) this study observed a time effect for HR (Figure 3) during the run whilst also recording no significant difference in mean HR or post-run [La⁻] between trials. Unlike Bernard et al. (2007) this study did not find a significant difference in run performance time (Figure 3). Interestingly the pace profile of the 5 km run is similar to that described by Bernard et al. (2007), in that the pace reduced after the initial 1 km (producing a transition from a positive to a negative split time) followed by an 'endspurt' producing another positive split time (Figure 4). This resulted in a significant effect of distance on running speed.

Interestingly, the pacing strategy during the run may be an important component in the tests conducted. Hausswirth et al. (2010) suggest a triathlon run performance is optimised when the first 1 km of the 10 km distance is performed at an intensity 5% below mean control run pace (control run being a free pace 10 km running time trial). With consideration to this, it is important to question whether the triathletes in this study paced themselves optimally, or whether a slower (negative) pace during the first 1km would have enhanced or differentiated running performance between trials following the cycle intervention. The initial 1 km split pace for this study (Figure 4) did not differ significantly between trials, however the small positive deviation from the mean pace during the first 1 km does not follow the recommendation by Hausswirth et al. (2010). Regardless of whether or not a sub-optimal strategy was employed, the comparable pacing between trials suggests the regulation of total workload during the run was consistent for both the CR1MIN and CR5MIN performances, as evidenced by the lack of significant difference for HR values between trials (Figure 3). It is also important to consider whether the triathletes in this study automatically resorted to a pacing strategy that has been 'learnt' over time (Mauger et al., 2009; Micklewright et al., 2010), particularly as the triathletes in this study were experienced at running 5 km as part of a triathlon. Such a 'hardwired' pacing template may have been pre-determined before exercise (Albertus et al., 2005) therefore failing to expose the potential ability to increase running performance following one of the preceding and possibly advantageous cycling interventions. This is particularly worthy of mention given that this study recorded a significantly higher mean HR for the CR1MIN cycle intervention, yet this had no significant affect between trials on the subsequent running performance and associated HR and [La⁻] values. Further research is required in order to establish the distance and time effect of a longer race.

Conclusion

Long or short power alternations (maximum of 5 minutes and minimum of 1 minute) during cycling produce similar physiological stress. As such no significant difference is observed for the subsequent 5 km running performance. The physiological effects of longer and shorter power alternations during cycling should be explored, as well as the pacing strategy of the run following power oscillations during the cycle.

Practical applications

In a draft / non-draft scenario triathletes who have 'paired up' can rotate positions equally within a range of every one and five minutes without inducing additional fatigue prior to running. This provides triathletes with the flexibility to regularly adjust draft / non-draft durations during a race so long as rotation and therefore power oscillation is equal.

Acknowledgment

The authors would like to acknowledge the access to facilities for testing provided by the Motion Performance Centre (MPC) at the University of Worcester.

Conflict of interest

None

References

1. Albertus Y, Tucker R, St Clair Gibson A, Lambert EV, Hampson DB, Noakes TD (2005) Effect of distance feedback on pacing strategy and perceived exertion during cycling. Medicine and Science in Sports and Exercise 37 (3): 461-468
2. Beaver WL, Wasserman K, Whipp BJ (1986) A new method for detecting anaerobic threshold by gas exchange. Journal of Applied Physiology 60 (6): 2020-2027
3. Bernard T, Vercruyssen F, Mazure C, Gorce P, Hausswirth C, Brisswalter J (2007) Constant versus variable-intensity during cycling: effects on subsequent running performance. European. Journal of Applied Physiology 99(2): 103-111
4. Borg G (1985) An introduction to Borg's RPE-Scales. New York: Mouvement
5. Brickley G, Green S, Jenkins DG, McEinery M, Wishart C, Doust JD, Williams CA (2007) Muscle metabolism during constant and alternating-intensity exercise around critical power. International Journal of Sports Medicine 28 (4): 300-305
6. Harriss DJ, Atkinson G (2011) Update – Ethical Standards in Sport and Exercise Science Research. International Journal of Sports Medicine 32: 819-821
7. Hausswirth C, Lehenaff D, Dreano P, Savonen K (1999) Effects of cycling alone or in a sheltered position on subsequent running performance in triathletes. Medicine and Science in Sports and Exercise 31 (4): 599-604
8. Hausswirth C, Vallier J-M, Lehenaff D, Brisswalter J, Smith D, Millet G, Dreano P (2001) Effect of two drafting modalities in cycling on running performance. Medicine and Science in Sports and Exercise 33 (3): 485-492
9. Hausswirth C, Le Meur Y, Bieuzen F, Brisswalter J, Bernard T (2010) Pacing strategy during the initial phase of the run in triathlon: influence on overall

performance. European Journal of Applied Physiology 108 (6):1115 – 1123.

10. Kyle CR (1979) Reduction of wind resistance and power output of racing cyclists and runners travelling in groups. Ergonomics. 22 (4): 387-397
11. Laursen PB, Francis GT, Abbiss CR, Newton MJ, Nosaka K (2007) Reliability of time-to-exhaustion versus time-trial running tests in runners. Medicine and Science in Sports and Exercise 39 (8): 1374-1379
12. Liedl M, Swain DP, Branch JD (1999) Physiological effects of constant versus variable power during endurance cycling. Medicine and Science in Sports and Exercise 31 (10): 1472 - 1477
13. Mauger AR, Jones AM, Williams CA (2009) Influence of feedback and prior experience on pacing during a 4-km cycle time trial. Medicine and Science in Sports and Exercise 41 (2): 451-458
14. Micklewright D, Papadopoulou E, Swart J, Noakes T (2010) Previous experience influences pacing during 20-km time trial cycling. British Journal of Sports Medicine 44(13): 952-960
15. Palmer GS, Noakes TD, Hawley JA (1997). Effects of steady-state versus stochastic exercise on subsequent cycling performance. Medicine and Science in Sports and Exercise 29(5): 684 - 687
16. Palmer GS, Borghouts LB, Noakes TD, Hawley JA. (1999). Metabolic and performance responses to constant-load vs. Variable intensity exercise in trained cyclists. Journal of Applied Physiology 87 (3): 1186 - 1196
17. Rietjens GJ, Kuipers H, Kester AD, Keizer HA (2001) Validation of a computerized metabolic measurement system (Oxycon-Pro) during low and high intensity exercise. International Journal of Sports Medicine 22 (4): 291-294
18. Rowell LB (1974) Human cardiovascular adjustments to exercise and thermal stress. Physiology Review. 54 (1): 75 – 159
19. Suriano R, Vercruyssen F, Bishop D, Brisswalter J (2007) Variable power output during cycling improves subsequent treadmill run time to exhaustion. Journal of Science and Medicine in Sport 10 (4): 244-251
20. Taoutaou Z, Granier P, Mercier B, Mercier J, Ahmaidi S, Prefaut C (1996) Lactate kinetics during passive and partially active recovery in endurance and sprint athletes. European Journal of Applied Physiology 73 (5): 465-470
21. Whipp BJ, Wasserman K (1986) Effect of anaerobiosis on the kinetics of O2 uptake during exercise. Federation Proceedings 45 (13): 2942-2947
22. Wilkerson DP, Jones AM (2007) Effects of baseline metabolic rate on pulmonary O2 uptake on-kinetics during heavy intensity exercise in humans. Respiratory Physiology and Neurobiology 156 (2): 203-211