Pacing, the Missing Piece of the Puzzle to High-intensity Interval Training

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Abstract

This study examined physiological and perceptual responses to matched work high-intensity interval training using all-out and 2 even-paced methodologies. 15 trained male cyclists performed 3 interval sessions of three 3-min efforts with 3 min of active recovery between efforts. The initial interval session was completed using all-out pacing, with the following 2 sessions being completed with computer- and athlete-controlled pacing in a randomised and semi-counterbalanced manner. Computer- and athlete-controlled intervals were completed at the mean power from the corresponding interval during the all-out trial. Oxygen consumption and ratings of perceived exertion were recorded during each effort. 20 min following each session, participants completed a 4-km time trial and provided sessional rating of perceived exertion. Oxygen consumption was greater during all-out (54.1 ± 6.6 ml.kg^{-1}.min^{-1}; $p < 0.01$) and athlete-controlled (53.0 ± 5.8 ml.kg^{-1}.min^{-1}; $p < 0.01$) compared with computer-controlled (51.5 ± 5.7 ml.kg^{-1}.min^{-1}). Total time $\geq 85\%$ maximal oxygen consumption was greater during all-out compared to both even-paced efforts. Sessional ratings of perceived exertion were greater after all-out compared to both even-paced sessions. Mean 4-km power output was lower after all-out compared with both even paced intervals. Distribution of pace throughout high-intensity interval training can influence perceptual and metabolic stress along with subsequent performance and should be considered during the prescription of such training.

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Introduction

High-intensity interval training has been shown to provide superior improvements in cardiovascular dynamics [6], maintenance of acid-base balance [16] and metabolic adaptations compared to traditional prolonged continuous training [12]. Buchheit and Laursen [7,8] recently published a comprehensive literature review detailing several key areas (i.e., work-to-rest ratios, periodization) which can influence the effectiveness of interval training. Not mentioned in this review [7,8], the distribution of work throughout an interval training session (i.e., pacing) may influence the maximal power output achievable, energy systems utilised and, consequently, training adaptations. For instance, faster oxygen uptake [4], greater utilisation of aerobic metabolism and greater average power output [1] have been observed during a single 5 min cycling performance trial using an all-out (e.g. maximal acceleration followed by maintenance of effort) approach compared to a slower start or even-paced strategy [1]. Furthermore, the extreme high-intensity at commencement of all-out efforts can induce significant vascular shear and metabolic stress [13] as well as result in substantial anaerobic energy demand [10].

In contrast to maximal all-out high-intensity efforts, many studies have set the work intensity during repeated high-intensity intervals [12,23]. During such efforts, participants maintain a constant exercise intensity throughout the work bout, possibly lowering energy contribution from anaerobic metabolism [9], reducing fatigue development [15] and thereby allowing participants to maintain relatively high average power outputs during repeated intervals [13]. Depending on the ergometer and exercise protocol, intensity during constant or even-paced efforts is usually controlled automatically by the ergometer/computer [21] or by the participant, presumably using visual feedback of exercise intensity (e.g. power output or speed) [22]. When compared to computer controlled efforts, the requirement to consciously maintain a given intensity can increase cognitive load associated with the task, which could alter exercise performance and perceived exertion. To date, however, the influence of pacing on physiological and perceptual responses during an interval training session has yet to be examined.

The purpose of this study was to examine the influence of an all-out vs. 2 work-matched even-paced (computer- and athlete-controlled) interval sessions on cardiorespiratory physiology, perceptual responses and latent fatigue. We hypothesised that intervals completed using an all-out pacing strategy would result in increased oxygen consumption during the interval session and a higher level of fatigue when compared with both even-paced strategies. Furthermore, we hypothesised that perceived exertion during athlete-controlled intervals would be greater when compared to the computer-controlled efforts.

Methods

15 years trained male cyclists (age: 39 ± 8 years, height: 181.1 ± 4.9 cm, body mass: 79.4 ± 8.2 kg, maximal oxygen consumption: 59.8 ± 6.5 ml.kg^{-1}.min^{-1}, peak power: 436 ± 27 W) with previous experience with high-intensity interval training volunteered to participate in the study. Participants were provided with a written description of the risks and benefits associated with this study and provided their written informed consent prior to data collection. All exercise sessions were conducted at a similar time of day, and participants were instructed to avoid strenuous physical activity 24 h prior to each session. Ethical approval for this study was granted by the Murdoch University Human Ethics Committee. Furthermore, this study was conducted in accordance with the ethical standards of International Journal of Sports Medicine [14].

Preliminary testing and familiarisation

Participants were required to complete 5 laboratory sessions no less than 5 and no greater than 10 days apart. During the initial session, participants completed a graded exercise test on an electronically braked cycle ergometer (Velotron, Racermate, USA) starting at 70 W and increasing by 35 W.min^{-1} until volitional fatigue. Expired ventilation was collected throughout the graded exercise test, using a metabolic cart (Parvo TrueOne; Parvomedics, USA) at a frequency of 1 Hz and expressed at 30 s mean values.

During the second visit participants completed a familiarisation session consisting of three 3-min efforts with 3 min of active recovery (cycling at a power output consistent with 50 % of aerobic threshold) between each effort (total of 18 min of cycling). Each of the 3 interval efforts was completed using a different pacing strategy: all-out, athlete- and computer-controlled. Prior to the efforts, participants completed a 15 min warm-up (5 min at 30 %, 40 % and 50 % of peak power measured during the graded exercise test) after which they cycled for 5 additional min at a power output equal to 50 % of their aerobic threshold. During the initial effort of the familiarisation session (all-out), participants were instructed to "go as hard as they could" and were provided with feedback of instantaneous power output. The second effort was completed in an athlete-controlled manner with participants attempting to maintain 90 % of the mean power calculated from the all-out effort through manipulation of gearing and cadence. During the third effort (computer-controlled), participants were instructed to pedal at 85 % of the mean power output that was recorded during the all-out effort. Resistance during the computer-controlled effort was controlled by the Velotron software ensuring a constant power output, irrespective of simulated gear ratio or cadence. Participants were then provided with 20 min of passive recovery after which a 4 km cycling time trial (flat course profile) was completed. During this time trial, only feedback on distance covered was provided.

Experimental session

During the third session, participants completed the all-out interval protocol. This session commenced with the standardised warm-up and 5 min submaximal lead-in, after which participants completed three 3-min all-out efforts with 3 min of active recovery (power output at 50 % aerobic threshold) between efforts. Participants were instructed to provide maximal effort and to "go as hard as they could" from the beginning and throughout the interval entirety. During each effort, heart rate (Polar 810i; Polar; Finland), power output and expired gases were recorded at a frequency of 1 Hz. Immediately following each interval, participants were asked to rate quadriceps pain (0 = no pain, 10 = maximal pain; [11]) and perceived exertion (Borg scale [5]: 6 = no exertion, 20 = maximal exertion). After 20 min of passive recovery, participants completed a 4 km cycling time trial. During the time trial, participants were provided with feedback only relating to distance covered. Sessional ratings of perceived exertion were collected 20 min following the completion of the time trial.

The remaining exercise sessions (computer- and athlete-controlled) were completed in a randomised and semi-counterbalanced order. These sessions followed a similar methodology as the all-out session with the only difference being the pacing strategy used during these efforts. Interval intensity was matched to the mean power output achieved during the corresponding interval in the all-out condition. During the athlete-controlled session, participants were required to match the mean power as closely as possible (e. g. ± 3 W) for each effort. A 6 s ramping protocol was incorporated prior to the onset of each interval to ensure participants were at the required power output at the beginning of each effort. During the computer-controlled session, participants' mean power outputs were controlled automatically, ensuring that the entire 3-min work bout was spent at the required intensity.

Statistical analysis

Differences in performance (mean power, 30 s power and peak power output (W)), physiological (oxygen consumption, heart rate) and perceptual (RPE, pain) measures during each interval as well as differences in mean 0.5 km power output measured during the 4 km cycling time trials were analysed using a two-way analysis of variance (2-way ANOVA; condition × interval) with repeated measures. Main effects or interactions were analysed using a Tukey's Post Hoc HSD test. Effect size estimates (Cohen's d; ES) were calculated for differences between conditions for oxygen consumption, time at or above 85 % maximal oxygen consumption and mean power output during the 4 km time trial [20]. Differences in sessional RPE between conditions were analysed using a one-way ANOVA. All statistical analyses were conducted using Statistica statistical analysis software version 7.0 (Statistica; USA) with a $p \leq 0.05$ level of significance. All data are presented as mean ± standard deviation unless otherwise noted.

Results

Data on mean power, 30 s power and peak power output are highlighted in ▶ **Table 1**. By design, no differences in mean power output were observed between the all-out, computer- or athlete-controlled conditions during any interval. However, an interaction was observed for power output measured during the initial 30 s of each interval, with greater power output observed during intervals 1 through 3 in all-out compared to the computer- and athlete-controlled conditions (▶ **Table 1**). Peak power output was greater in all efforts of the all-out condition compared to the computer and athlete-controlled conditions.

A main condition effect was observed for oxygen consumption during the interval session with greater oxygen consumption during the all-out (54.1 ± 6.6 $ml.kg^{-1}.min^{-1}$; $p < 0.01$) and athlete-controlled (53.0 ± 5.8 $ml.kg^{-1}.min^{-1}$; $p < 0.01$) conditions when compared to the computer-controlled condition (51.5 ± 5.7 $ml.kg^{-1}.min^{-1}$; ES: 0.4 and 0.2; respectively) (▶ **Fig. 1a**). A main condition effect was observed for the time spent at or greater than 85 % of maximal oxygen consumption with longer durations observed in the all-out (150.7 ± 11.0 s) compared to the computer- (124.1 ± 18.5 s; $p < 0.01$; ES: 1.8) and athlete-controlled (136.2 ± 14.2 s, $p < 0.01$; ES: 1.2) conditions (▶ **Fig. 1b**). Additionally, greater time at or above 85 % maximal oxygen consumption was observed in the athlete- compared to computer-controlled condition ($p < 0.01$; ES: 0.7). Immediately prior to each interval (last 30 s epoch prior to the start of the effort), a trend ($p = 0.07$) was observed for higher oxygen consumption in the all-out (28.7 ± 4.8 $ml.kg^{-1}.min^{-1}$) and athlete-controlled (28.6 ± 3.8 $ml.kg^{-1}.min^{-1}$) conditions when compared to the computer-controlled (25.9 ± 2.8 $ml.kg^{-1}.min^{-1}$) condition.

A main effect for condition was observed for heart rate during the interval session, with greater heart rate during the all-out compared to the computer- ($p < 0.01$) and athlete-controlled ($p < 0.01$) conditions (▶ **Table 2**). An interaction was observed for RPE with greater perceived exertion reported immediately after all 3 intervals in the all-out compared with computer- and athlete-controlled conditions. Furthermore, sessional RPE was greater after the all-out (18.4 ± 1.1 units) compared to the computer- (16.1 ± 2.2 units, $p < 0.01$) and athlete-controlled (16.4 ± 1.2 units, $p < 0.01$) conditions. Self-reported quadriceps pain displayed a main effect for condition with greater ($p = 0.03$) overall pain observed in the all-out (7.4 ± 1.3 units) compared to the computer-controlled condition (6.2 ± 3.0 units) only.

Table 1 Mean (± SD) peak power, 30 s power and mean power output (W) measured during intervals 1 through 3 in the all-out (AO), computer- (CC) and athlete-controlled (AC) trials.

	Interval 1	Interval 2	Interval 3
Peak power			
AO	882.2 (330.6) [a]	644.0 (163.2) [a]	641.6 (146.9) [a]
CC	409.9 (45.2)	345.5 (32.5)	337.9 (31.3)
AC	449.9 (67.2)	372.4 (44.7)	360.9 (35.6)
Initial 30 s			
AO	648.7 (153.0) [a]	483.3 (72.8) [a]	468.7 (60.0) [a]
CC	409.0 (45.1)	344.5 (32.3)	337.5 (31.4)
AC	393.7 (40.1)	334.6 (36.9)	320.8 (35.8)
Mean power			
AO	410.0 (45.1)	345.5 (32.4)	337.9 (31.5)
CC	410.0 (45.1)	345.5 (32.4)	337.9 (31.5)
AC	406.1 (45.0)	344.0 (32.4)	336.3 (29.9)

a: AO greater than CC and AC; $p \leq 0.05$

A main effect for condition was observed in power output during the 4 km time trial (▶ **Fig. 2**), with lower power output measured following the all-out (333.0 ± 33.2 W) compared to the

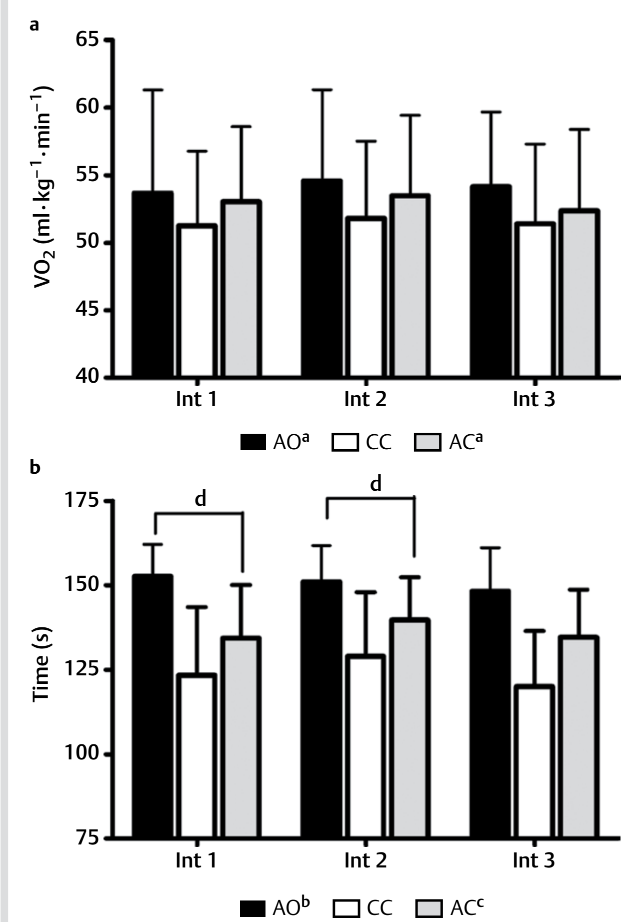

Fig. 1 Mean (± SD) relative oxygen consumption (VO_2; **a**) and time spent ≥ 85 % of maximal oxygen consumption (VO_{2max}; **b**) measured during intervals 1 through 3 (Int 1–Int 3) in the all-out (AO), computer- (CC) and athlete-controlled (AC) interval sessions. a: AO and AC greater than CC; $p \leq 0.05$. b: AO greater than AC and CC; $p \leq 0.05$. c: AC greater than CC; $p \leq 0.05$. d: intervals 1 and 2 greater than interval 3; $p \leq 0.05$.

Table 2 Mean (± SD) heart rate (bpm), ratings of perceived exertion (RPE) and quadriceps pain measured during each interval in the all-out (AO), computer-controlled (CC) and athlete-controlled (AC) conditions.

	Interval 1	Interval 2	Interval 3
Heart rate			
AO [b]	165 (8)	164 (10)	166 (9)
CC	161 (11)	155 (12)	158 (10)
AC	160 (12)	157 (12)	160 (11)
RPE			
AO	18.6 (1.3) [a]	19.2 (0.6) [a]	19.2 (1.0) [a]
CC	16.7 (2.3)	16.0 (2.8)	16.3 (3.0)
AC	17.1 (1.9)	16.6 (2.3)	16.0 (2.3)
Quadriceps pain			
AO [b]	6.9 (1.4)	7.5 (1.2)	7.7 (1.3)
CC	6.2 (3.1)	6.1 (3.0)	6.1 (2.9)
AC	6.3 (2.4)	6.3 (2.4)	6.3 (2.4)

a: AO greater than both CC and AC; $p \leq 0.05$. b: Main effect for condition; AO greater than CC and AC; $p \leq 0.05$. Note, RPE measured on a scale of 6 to 20 (6 = no exertion, 20 = maximal exertion) and quadriceps pain measured on a scale of 0 to 10 (0 = no pain, 10 = maximal pain)

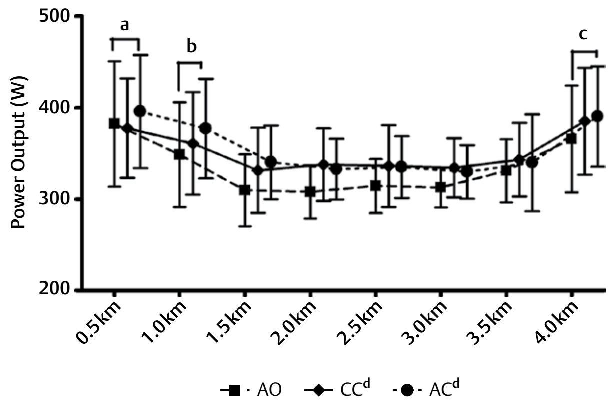

Fig. 2 Mean (± SD) power output measured during the 4 km time trial following the all-out (AO; ■), computer-controlled (CC; ♦) and athlete-controlled (AC; ●) interval sessions. a: 0.5 km greater than 1.5–3.0 km; $p \leq 0.05$. b: 1.0 km greater than 1.5–3.5 km; $p \leq 0.05$. c: 4 km greater than 1.5–3.5 km; $p \leq 0.05$. d: AC and CC greater than AO; $p \leq 0.05$.

computer- (350.2 ± 41.7 W; $p < 0.01$; ES: 0.5) and athlete-controlled (354.2 ± 38.6 W; $p < 0.01$; ES: 0.6) conditions. No differences were observed in heart rate throughout the 4 km time trials in the all-out (164 ± 12 bpm), computer- (161 ± 13 bpm) and athlete-controlled (163 ± 11 bpm) conditions.

Discussion

The purpose of the current study was to examine the influence of the selection of pace (all-out compared with even-pacing) during high-intensity interval training on physiological, perceptual and subsequent fatigue responses in trained cyclists. The main findings from the study were that under matched work conditions: 1) oxygen consumption was greater during the all-out and athlete-controlled conditions compared to the computer-controlled condition, 2) time spent at or above 85 % of maximal oxygen consumption was greater in the all-out compared to the athlete- and computer-controlled conditions, 3) subsequent 4 km time trial mean power output was lower following the all-out compared to the computer- and athlete-controlled conditions and 4) participants' overall ratings of perceived exertion were greater in the all-out compared to both athlete- and computer-controlled conditions.

Despite the athletes completing a similar amount of work, overall oxygen consumption during the all-out and athlete-controlled intervals were greater than during the computer-controlled condition (▶ **Fig. 1a**). Higher oxygen consumption during the all-out condition may be due to the initial supramaximal sprint effort (e.g. first 30 s) during each interval, resulting in a large oxygen deficit [17] and a compensatory increase in oxygen consumption during the efforts [2]. Furthermore, compared to a slower start, high-intensity sprint efforts are associated with a faster rise in oxygen consumption [6]. Indeed, during the all-out efforts, our participants reached 85 % of maximal oxygen consumption (measured during a graded exercise test) faster than during the athlete- or computer-controlled conditions. In contrast, we believe differences observed between the athlete- and computer-controlled conditions are not due to physiological phenomena, but rather methodological issues. During the athlete-controlled efforts, participants were instructed to increase power output approximately 6 s from the start of each effort. While this strategy resulted in the desired power output throughout the effort, it also increased oxygen consumption (~10 %) immediately prior to each effort.

To maximise aerobic adaptations induced by high-intensity interval training (e.g. increased aerobic capacity and endurance performance), athletes should maximise the time spent at or above 85 % of maximal oxygen consumption [23]. Within the present study, we observed greater time at or above 85 % of maximal oxygen consumption when using an all-out pacing strategy compared to both the athlete- or computer-controlled conditions (▶ **Fig. 1b**). These results indicate that an all-out approach to interval training may provide the best stimuli for aerobic and performance adaptations. Nevertheless, in the current study all-out pacing resulted in greater cardiac stress [18] (▶ **Table 2**) and higher levels of latent fatigue (▶ **Fig. 2**). Furthermore, regardless of work completed, participants reported higher ratings of sessional perceived exertion following the all-out compared to both even-paced sessions. These findings have implications for training prescription. For instance, if an all-out approach is implemented within a training program, these data indicate greater attention is needed to ensure recovery between interval bouts and subsequent training sessions [19].

The lower perceived exertion and pain observed within the athlete- and computer-controlled sessions (▶ **Table 2**) are likely to be important in the prescription of high-intensity intervals, especially within non-athletic populations. Indeed, maximising physical activity adherence rates can be achieved using exercise which individuals perceive as more enjoyable [3]. Contradictory to our hypothesis, we did not observe any difference in perceived exertion or pain between the computer- and athlete-controlled sessions. It is therefore plausible that the prescription of all-out high-intensity interval sessions may have lower adherence rates than both even-paced interval models used within the present study. Furthermore, the extremely high initial effort required during the all-out paced intervals may further limit their use in non-athletic populations as this method could result in the rapid development of fatigue ultimately leading to the cessation of effort and session termination. Further longitudinal studies are clearly required to test these hypotheses.

Conclusion

Compared to work-matched even-paced strategies, the use of an all-out pacing strategy during high-intensity interval training provides the greatest physiological stress, possibly leading to greater adaptation. Regardless, high levels of fatigue associated with this strategy does warrant concern as the increased level of stress could compromise recovery and in-competition performance. For these reasons, athletes and coaches should consider pacing strategies when undertaking or prescribing high-intensity interval training in order to achieve the greatest outcomes possible.

Conflict of interest: The authors have no conflict of interest to declare.

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