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

E. K. Zadow1, N. Gordon1, C. R. Abbiss2, J. J. Peiffer1

1 School of Psychology and Exercise Science, Murdoch University, Murdoch, Australia
2 School of Exercise, Biomedical and Health Sciences, Edith Cowan University, Perth, Australia

Key words
- pacing
- training
- cyclist
- endurance performance

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 ≥ 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.

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 com-
pared to computer controlled efforts, the requirement to con-
sciously 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 ses-
sion and a higher level of fatigue when compared with both
even-paced strategies. Furthermore, we hypothesised that per-
ceived 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 con-
sumption: 59.8±6.5 mL·kg⁻¹·min⁻¹, peak power: 436±27 W)
with previous experience with high-intensity interval training vol-
teed to participate in the study. Participants were pro-
vided with a written description of the risks and benefits associ-
ated with this study and provided their written informed
consent prior to data collection. All exercise sessions were con-
ducted 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 Uni-
versity Human Ethics Committee. Furthermore, this study was
conducted in accordance with the ethical standards of Interna-
tional 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 voli-
tional fatigue. Expired ventilation was collected throughout the
graded exercise test, using a metabolic cart (Parvo TrueOne; Par-
vomedics, 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 aero-
bic 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 partici-
pants 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), partici-
pants 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 sim-
gulated 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 standard-
ised warm-up and 5 min submaximal lead-in, after which par-
ticipants completed three 3-min all-out efforts with 3 min of
active recovery (power output at 50% aerobic threshold) be-
tween 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 pro-
vided 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-con-
trolled) were completed in a randomised and semi-counterbal-
anced 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 corre-
sponding 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 out-
put at the beginning of each effort. During the computer-con-
trolled 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 ana-
lysed using a Tukey’s Post Hoc HSD test. Effect size estimates
(Cohen’s d; ES) were calculated for differences between condi-
tions 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≤0.05 level of significance. All
data are presented as mean ± standard deviation unless other-
wise 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.

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

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
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. 2). 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] and higher levels of latent fatigue (Table 2) and improved aerobic adaptations. Nevertheless, in the current study all-out pacing resulted in greater cardiac stress [18] and higher levels of latent fatigue (Table 2) and improved aerobic adaptations.

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.

**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.
References


