Pacing Strategy in Simulated Cycle Time-trials is Based on Perceived Rather than Actual Distance

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This study determined the pacing strategies and performance responses of six well-trained cyclists/triathletes (peak O2 uptake 66.4±3.7 ml•kg^{-1}•min^{-1}, mean±SD) during seven simulated time-trials (TT) conducted on a wind-braked cycle ergometer. All subjects first performed a 40 km familiarisation ride (TT_1). They were then informed they would be riding a further four 40 km TT for the purpose of a reliability study. Instead, the actual distances ridden for the next three TT were a random order of 34 (TT_2), 40 (TT_3) and 46 km (TT_4). The only feedback given to subjects during TT_1-4 was the percentage distance of that ride remaining. During a further 40 km TT (TT_5) subjects were allowed to view their heart rate (HR) responses throughout the ride. Despite the significantly different performance times across the three distances (47:23±4:23 vs 55:57 ±3:24 vs 65:41±3:56 min for the 34, 40 and 46 km respectively, P<0.001), average power output (296±48 vs 294±48 vs 286±40 W) and HR (173±11 vs 174±12 vs 173±12 beats•min^{-1}) were similar. The true nature of the first part of the study was then revealed to subjects who subsequently completed an additional 34 km and 46 km TT (TT_6-7) in which the actual and perceived distance ridden was the same. Power output and HR responses were similar for both unknown (TT_2 and TT_6) and known (TT_4 and TT_7) rides for both distances: 296±48 vs 300±55 W and 173±11 vs 177±11 beats•min^{-1} (34 km) and 286±40 vs 273±42 W and 173±12 vs 174±12 beats•min^{-1} (46 km). In conclusion, well-trained cyclists rode at similar power outputs and HR during time trials they perceived to be the same distance, but which varied in actual distance from 34 to 46 km.

Introduction

Pacing is a strategy used by athletes during competition to self-regulate their effort/work in order to maximize performance. In all but the shortest events lasting <60 s, it has been recommended that an "even-pace" strategy results in the fastest overall race time (Foster et al., 1993). Although the effects of enforcing different pacing strategies during simulated time trials (TT) lasting ∼3 min has been investigated (Foster et al., 1993), only one preliminary report has attempted to examine the performance responses of cyclists to self-selected pacing strategies. In that study, Palmer et al. (1998) investigated the performance responses of endurance cyclists during three self-paced simulated TT which varied in distance from 34 to 46 km. However, subjects were informed that the TT's would all be 40 km in distance. Surprisingly, no differences were found in...
average speed, power output or mean heart rate for either the 34, 40 or 46 km TT.

The aim of the present study was to extend the findings of Palmer et al. (1998) by investigating the performance and physiological responses of well-trained cyclists to self-selected pacing strategies during TT of varying distance. A second aim was to explore the subjective feedback cues that cyclists employed when selecting their pacing strategy during simulated laboratory TTs. To this end, the first part of the investigation examined the self-selected pacing strategies of cyclists during five TT of three different distances (34, 40 and 46 km) that subjects perceived to be of equal distance (40 km). In the second part of the study subjects repeated the shortest (34 km) and longest (46 km) TT knowing the actual distance to be ridden. This allowed the performance and physiological responses arising from the self-selected pacing strategies to be compared between TT of perceived and known distance.

We hypothesised that power output and HR would be similar between TTs of varying actual distance (ie 34-46 km) when subjects perceived the distance to be equal (ie 40 km). Furthermore, we hypothesised that informing subjects of the actual distance to be completed would result in an increased average power output for the shortest (34 km) TT and a decreased average power output for the longest (46 km) TT.

**Methods**

**Subjects**

Six well-trained male cyclists/triathletes (age 22±2 yr, mass 68.8±5.2 kg, peak oxygen uptake [VO2peak] 66.4±3.7 ml•kg•min⁻¹, peak power output [PPO] 5.25±0.41 W•kg⁻¹) with a minimum of 3 yr regular endurance training and competition were recruited to participate in this study, which was approved by the Human Research Ethics Committee of RMIT University. However, due to injury, one subject was not able to complete the final two TT. All subjects provided written informed consent in accordance with the guidelines outlined by the American College of Sports Medicine (2000).

**Preliminary testing, training and nutritional control**

All subjects performed a progressive incremental test to volitional fatigue for the determination of individual lactate threshold (LT, described subsequently) and peak oxygen uptake (VO2peak) on an electronically braked cycle ergometer (Lode, Groningen, The Netherlands) modified with clip-in pedals and low-profile handlebars. All tests were conducted under standard laboratory conditions (19°C, 45-55% relative humidity). During the 24 hr period prior to each test subjects refrained from heavy exercise and consumed a prepared food pack consisting of three meals with a total energy of 50 kcal•kg⁻¹ body mass (BM). Such a diet - exercise regimen has previously been reported to result in standardized muscle glycogen content (Flynn et al., 1987).

On the day of the LT test, subjects reported to the laboratory at 0700-0800 hr after a 12-14 hr overnight fast. After resting quietly for 10 min an indwelling sterile cannula was inserted into a forearm antecubital vein and a stopcock was attached to allow for repeated blood sampling during exercise. Patency of the cannula and stopcock was maintained by flushing with 1-2 ml of a 0.9% saline solution following each blood draw. The LT test commenced at a workload of 100 W. This workload was maintained for 5 min after which subjects stopped cycling.
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but remained seated on the ergometer for 1 min while a blood sample (5 ml) was taken. The workload was then increased by 25 W for an additional 5 min with blood samples being drawn at the end of each work bout. Once a workload of 200 W was attained, subsequent workload increments were reduced to 15 W while maintaining the same work:rest ratio to allow for regular blood sampling. The LT test was terminated when each subject reached a blood lactate concentration of > 2 mM. Individual LT was determined according to the methods of Coyle et al. (1983). In brief, LT for each subject was taken as the workload at which blood lactate concentration rose 1 mM above baseline (taken as the average blood lactate concentration of the first two exercise bouts).

All blood samples were collected in EDTA Vacutainer tubes (Becton Dickinson, NJ, USA) and immediately analysed for blood glucose and blood lactate concentration using a YSI 2000 Blood Glucose and Lactate Analyser (YSI Incorporated, Yellow Springs, Ohio, U.S.A). Throughout each work bout, subjects breathed through a mouthpiece attached to a Quark b2 metabolic cart (Cosmed, Rome, Italy). Expired gas was passed through a flow meter, an O2 analyser and a CO2 analyser that were calibrated prior to the test using a 3 L Hans-Rudolph syringe and gases of known concentrations (4.00% CO2 and 16.00% O2). The flow meter and gas analysers were connected to a computer that calculated minute ventilation (Ve), oxygen consumption (VO2), carbon dioxide production (VCO2) and respiratory exchange ratio (RER) from conventional equations.

Upon completion of the LT test, subjects immediately commenced an incremental maximal test to exhaustion for the determination of VO2peak, peak power output (PPO), and peak heart rate (HRpeak) according to the protocol of Hawley and Noakes (1992). The initial workload (W) was the same as the final stage completed during the LT test with subsequent workload increments of of 25 W•150 s\(^{-1}\). Tests were terminated at the point of volitional fatigue which coincided with the inability of a subject to maintain a cadence of >70 rev•min\(^{-1}\) and/or an RER >1.15. The highest VO2 for any 60 s was taken as the subject’s VO2peak. PPO was calculated by adding the work completed on the final (uncompleted) workload to the last successfully completed workload (W). Heart rate (HR) was monitored throughout all exercise testing using a Polar Sports Tester Heart Rate Monitor (Polar Electro Oy, Kempele, Finland).

**Experimental trials**

During all time trials (TT) subjects rode their own road bicycle mounted on a Kingcycle ergometry system (Kingcycle Ltd, High Wycombe, Buckinghamshire, UK). This system utilises rolling resistance uniformly applied to the rear wheel of the bicycle via a computerised, air-braked flywheel to simulate outdoor conditions. The Kingcycle ergometry system has previously been reported to be reliable and valid, with a test-retest coefficient of 1.0±0.5% for three 40 km TT, and performance times on average, 8% faster than on road performances (Palmer et al., 1996). Prior to the beginning of each trial, the Kingcycle was calibrated as described by Palmer et al. (1996).

Subjects were informed that they would be participating in five 40 km TT to determine the accuracy and reliability of a new ergometry system. All TT were separated by 3-7 d and were preceded by a self-selected 5 min warm up after which subjects were instructed to complete each ride “as quickly as possible”. Subjects completed an initial 40 km familiarisation TT (TT\(_1\)), followed by a random
order of three TT (TT1-3) of varying actual distance (34, 40 and 46 km). The only feedback provided to subjects during TT1-3 was the percentage of total distance remaining. During a fifth ride (TT5) subjects completed a known distance of 40 km and were allowed to view their HR responses for the duration of the trial, but not the elapsed time. On completion of TT5 the true nature of the first part of the study was revealed to all subjects who were then asked if they would volunteer to undertake two further rides (TT6-7). These subsequent TT were over the shortest (34 km) and longest (46 km) distances. However, before these rides subjects were truthfully informed of the actual distance they would complete.

Following all TT, finishing time, average speed and average power output were downloaded from the Kingcycle computer interface and recorded. HR responses were downloaded from the Sports Tester HR monitor using the Polar Advantage Interface System (Polar Electro Oy, Kempele, Finland) and stored on a computer for subsequent analysis. At the completion of each trial, subjects were told to reflect upon their perceived exertion over the entire TT using the Borg scale (2).

**Statistical analyses**

All results are presented as mean±SD. Prior to statistical analysis, power output and HR obtained during each trial were averaged for every 10% interval of total time. Performance and physiological responses for each time interval were tested for statistical significance by one-way analysis of variance (ANOVA) using GraphPad Prism (GraphPad Software, San Diego California USA). Significance was accepted at P<0.05, and where appropriate, Tukey’s post-hoc tests were used to locate differences. Coefficients of variation (CV) were calculated for power output, time to completion and HR for all trials and averaged to obtain an overall CV.

**Results**

The results of the LT and VO2peak test are shown in Table 1. LT was attained at a power output of 261±28 W which corresponded to 73±3% of PPO. VO2 at LT was 3.75±0.27 L·min⁻¹ or 79±5% of VO2peak, while HR at LT was 164±11 beats·min⁻¹ or 85±4% of HRmax. There was no relationship between the workload at LT, the % of VO2peak or % of PPO at LT and TT time for any of the rides. Although there were moderate correlations between PPO and average 40 km TT time (r=−0.77, 95% CI -0.9 - 0.10), this relationship failed to reach statistical significance.

<table>
<thead>
<tr>
<th>Mass (kg)</th>
<th>PPO (W)</th>
<th>VO2max (L·min⁻¹)</th>
<th>PO@LT (W)</th>
<th>% PPO</th>
<th>VO2@LT (L·min⁻¹)</th>
<th>VO2peak (%)</th>
<th>HRpeak (beats·min⁻¹)</th>
<th>HR@LT (beats·min⁻¹)</th>
<th>% HRpeak</th>
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<tbody>
<tr>
<td>S1</td>
<td>71.4</td>
<td>382</td>
<td>4.82</td>
<td>268</td>
<td>70</td>
<td>3.96</td>
<td>83</td>
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<td>176</td>
</tr>
<tr>
<td>S2</td>
<td>66.7</td>
<td>322</td>
<td>4.08</td>
<td>239</td>
<td>74</td>
<td>3.45</td>
<td>84</td>
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<td>156</td>
</tr>
<tr>
<td>S3</td>
<td>73.8</td>
<td>396</td>
<td>4.88</td>
<td>305</td>
<td>77</td>
<td>3.94</td>
<td>76</td>
<td>197</td>
<td>175</td>
</tr>
<tr>
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<td>378</td>
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<td>262</td>
<td>70</td>
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<tr>
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<td>32</td>
<td>0.49</td>
<td>28</td>
<td>3</td>
<td>0.27</td>
<td>5</td>
<td>9</td>
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</tr>
</tbody>
</table>

Table 1: Physiological characteristics of subjects under investigation. VO2peak, peak oxygen uptake; HRpeak, peak heart rate recorded during maximal incremental test; PPO, peak sustained power output measured during maximal incremental test; PO, power output; LT, lactate threshold.
Table 2: Performance responses for the various distance time trials. TT1, familiarisation 40 km; TT2, unknown 34 km; TT3, experimental 40 km; TT4, unknown 46 km; TT5, Feedback 40 km; TT6, known 34 km; TT7, known 46 km. TT1,3,5 significantly greater than TT2; TT4,7 significantly greater than TT2,6. *P < 0.001. Values are mean±SD.

Table 2 displays the performance times and power output of all time trials. There were significant differences in the performance times for the three different distances (47:23±4:23 vs 65:41±3:56 vs 55:57±3:24 min for the 34, 46 and average of the three 40 km trials respectively, P<0.001). Despite the significant differences in TT times (Table 2), power output (296±48 vs 286±40 vs 294±48 W) and HR (173±11 vs 174±12 vs 173±12 beats•min⁻¹ for the 34, 46 and average of the three 40 km time trials, respectively) were not significantly different across the three distances. The co-efficient of variation (CV) for power output and HR for TT1,5 was 2.44% (likely range 283-302 W) and 2.86% (likely range 167-179 beats•min⁻¹) respectively. Further analysis revealed no order effect.

Figure 1 displays the power output and HR responses for each 10% time interval for the three 40 km TTs. Power output was similar between trials (293±45 vs 292±47 vs 296±52 W), with a CV of 2.04% (likely range 279 - 309 W). Similarly, there were no differences in HR between the three trials (176±12 vs 172±9 vs 174±17 beats•min⁻¹) with a CV of 3.28% (likely range 160 - 188 beats•min⁻¹).

Figure 2 shows the HR and power output responses for each 10% time interval.
for the known and unknown 34 and 46 km trials. Performance times for the
known 34 and known 46 km distances were significantly different (47:03±3:56 vs
67:11±4:19 min respectively, P<0.001). However, power output and HR were
similar between the unknown and known 34 km trials (296±48 vs 300 ± 55 W
and 173±11 vs 177±11 beats*min⁻¹ respectively) and the unknown and known 46
km time trials (286±40 vs 273±42 W and 173±12 vs 174±12 beats*min⁻¹
respectively).

**Discussion**

In contrast to our original hypothesis that informing subjects of the actual distance
to be completed would result in an increased average power output for the
shortest (34 km) TT and a decreased average power output for the longest (46 km)
TT, the major finding of the current study was that when well-trained cyclists
perceived time trials which varied in actual distance (from 34 to 46 km) to be the
same (ie 40 km), they rode at similar power outputs and heart rates. Such an
observation is remarkable in that there was a 26% difference between the shortest
(34 km) and longest (46 km) time trial which resulted in a 28% difference in riding
time. Our findings extend those of Palmer et al. (1998) who, in a preliminary
report, observed that moderately-trained subjects rode at similar power outputs
and heart rates during time trials they perceived to be the same distance (ie 40
km) but were actually 34, 40 and 46 km.

The physiological mechanism(s) that might explain such a phenomenon are
difficult to elucidate. However, it is highly unlikely that substrate depletion limited
the performances of our subjects during even the longest (46 km) time trial
(Hawley et al., 1997). Neither is it likely that our trained subjects did not produce
maximal efforts for all time-trials: both heart rate during, and ratings of perceived
exertion after the rides were similar for all trials. During a time trial in the field,
cyclists would typically use external visual feedback cues (such as speed at which
they cover the ground, air resistance, cadence and split times) to modify their
pacing strategy. In our laboratory setting, all of these external cues were
eliminated, which could possibly explain why subjects chose to ride at similar power outputs despite varying time trial distances.

In an effort to determine why subjects self-selected to ride at similar power outputs and heart rates for time trials of vastly different length, cyclists were questioned as to which variable(s) they considered the most important in the selection of their individual pacing strategies. Surprisingly, all subjects rated the distance of that trial remaining followed by leg heaviness as the two most influential variables in determining their riding strategy for each trial. Heart rate was not used as a ‘pacing tool’ by any subject, even when allowed to view their heart rate responses during TT₅, and despite one subject claiming he trained to specific heart rates. The explanation provided by most subjects as to why they did not use heart rate to gauge the intensity/speed of a time trial was that adhering to a pre-determined HR would not allow them to maintain their optimal power output.

The second finding of this study was that power output was slightly higher when subjects were informed of the true distance of the 34 km time trial, and slightly lower when told the true distance of the 46 km time trial (although neither reached statistical significance), compared to when they perceived both rides to be 40 km. Although the difference between the power output during the unknown versus known 46 km rides failed to reach statistical difference, a 13 W difference between rides is likely to be of importance to trained cyclists: at the average speed produced during this trial, a 90 s time difference equates to 1,030 m. Figures 1 and 2 show the typical “U” shaped power output vs time curves from all time trials. The shape of the curves suggest that despite the differences in distance completed, in all trials subjects employed a fast—even—fast strategy. The slightly more conservative strategy observed in the known/formed 46 km time trial resulted in a more pronounced trough of the “U” shaped graph. It appears that subjects completed each time trial according to a pre-determined intensity they perceived would optimise performance at each respective distance. Interestingly, the differences in power output between the known and unknown 46 km time trials were not accompanied by differences in heart rate responses, which remained within a narrow range (173±12 and 174±12 beats•min⁻¹) despite the 13 W average variation in power output. Palmer et al. (1996) reported similar results, observing steady-state heart rate responses throughout 20 and 40 km TT despite large (~ 60 W) variations in power output. Similarly, no differences in heart rate were found by Liedl et al. (1998) when power output was varied by ±5% every 5 min during cycling ergometer trials. The results of these studies are in agreement with other investigations (Gilman, 1996; Jeukendrup & van Diemen, 1998; Palmer et al., 1999) suggesting that under a variety of laboratory and field conditions heart rate may not accurately reflect muscular work.

The randomisation of trials and deceptive nature of the protocol in the present study proved to be very effective: upon the completion of all trials subjects were unaware of any difference in distance between the trials. When subjects were questioned as to which trial they found the most demanding, they nominated TT₃ (40 km) followed by TT₂ (34 km). Surprisingly, the unknown 46 km time trial was not nominated. Performance time was highly reliable across the three 40 km TT with an average CV of 1.12 %. This compares favourably to Palmer et al. (1996) who reported a CV of 1.1 % for a series of 20 and 40 km TT. However, whether these results would be reproducible in the field where environmental conditions and changes in terrain can affect performance warrants further investigation.
The results of this investigation should, however, be interpreted with caution. Indeed, a possible limitation of this study was its small sample size. The lack of significant differences in power output and heart rate recorded during TT of different distances could in part be related to the limited number of subjects. Therefore, the possibility that a larger sample size may have provided more statistical power and ultimately different results should not be discarded.

In conclusion, we determined the self-selected pacing strategies employed by well-trained cyclists during time trials of different distance. The results show that a) well-trained cyclists select a pacing strategy based on the perceived distance of a time trial rather than the actual distance (within the tested range) and b) that such a pacing strategy was not modified even when subjects were provided with a physiological cue of exercise intensity (ie. heart rate). The practical implications of this study are that athletes may often perform at perceived workloads which may be below their physiological capabilities. This presents a challenge to the sports scientist and coach to firstly identify when an athlete is ‘under performing’, and to then provide alternative training/competition strategies to overcome such barriers.

Acknowledgements
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References