Influence of Starting Strategy on Cycling Time Trial Performance in the Heat

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Abstract

The purpose of this study was to determine the influence of starting strategy on time trial performance in the heat. Eleven endurance trained male cyclists (30\textpm5 years, 79.5\textpm4.6 kg, $\dot{V}O_{2max}$ 58.5\textpm5.0 ml.kg$^{-1}$ min$^{-1}$) performed four 20-km time trials in the heat (32.7\textpm0.7 $^\circ$C and 55\% relative humidity). The first time trial was completed at a self-selected pace (SPTT). During the following time trials, subjects performed the initial 2.5-km at power outputs 10\% above (10\% ATT), 10\% below (10\% BTT) or equal (ETT) to that of the average power during the initial 2.5-km of the self-selected trial; the remaining 17.5-km was self-paced. Throughout each time trial, power output, rectal temperature, skin temperature, heat storage, pain intensity and thermal sensation were taken. Despite significantly (P<0.05) greater power outputs for 10\% BTT (273\textpm45W) compared with the ETT (267\textpm48W) and 10\% ATT (265\textpm41W) during the final 17.5-km, overall 20-km performance time was not significantly different amongst trials. There were no differences in any of the other measured variables between trials. These data show that varying starting power by \textpm10\% did not affect 20km time trial performance in the heat.

Introduction

Optimising performance requires athletes to appropriately regulate the distribution of work throughout an exercise task [16–18], in an attempt to maintain physiological homeostasis and prevent premature fatigue [28]. This distribution of work has been termed ‘pacing’ or ‘pacing strategy’ [1, 8, 14]. While research has begun to investigate factors that may influence this regulation of pace [25, 30, 33], few studies have manipulated exercise intensity in an attempt to uncover an optimal employable pacing strategy [6, 10, 18, 31], especially during prolonged exercise [7, 21]. To date, only one study has examined the influence of starting strategy on overall performance during a prolonged cycling time trial [21]. In this study the authors found that a slower start during the first 4 min of a 20 km time trial performed in standard laboratory conditions (~21–22 $^\circ$C) improved performance relative to a faster start, but neither strategy was statistically better than a self-selected starting strategy. As of yet, no study has examined the influence of starting strategy on prolonged time trial performance during exercise in the heat. This is despite the fact that the self-selected adoption of a relatively fast starting strategy may be exacerbated during exercise in the heat [4]. Indeed, it has previously been found that well-trained cyclists tend to significantly reduce power output during the later stages of self-paced cycling time trials in hot (32 $^\circ$C) compared with temperate (23 $^\circ$C) conditions [4, 30]. These results indicate that trained cyclists may commence self-paced cycling trials in the heat at aggressive power outputs that cannot be maintained for the duration of the entire time trial. Therefore, the purpose of the present study was to examine the influence of starting strategy on prolonged time trial performance during exercise in the heat.

Methods

Subjects

Eleven endurance-trained male cyclists (mean\textpmSD; age 30\textpm5 years, height 1.87\textpm0.06 m, mass 79.5\textpm4.6 kg, $\dot{V}O_{2max}$ 58.5\textpm5.0 ml.kg$^{-1}$ min$^{-1}$, maximal aerobic power 422\textpm52 W) volunteered to participate in this study. Subjects had at least one year of cycling experience and at the time of

the study were cycling between 250 and 400 km·wk$^{-1}$ (303 ± 43 km·wk$^{-1}$). Prior to the study, eight of the eleven subjects had previous experience performing prolonged cycling time trials in the heat using the same equipment mentioned in this study. All subjects completed a medical history questionnaire and gave written informed consent prior to study commencement. The experimental design and procedures were approved by the institutional human research ethics committee. Subjects were requested to maintain regular training commitments throughout the duration of the study and refrain from heavy exercise in the 24 h period preceding each test. Analysis of the training records showed no anomalies. Subjects were also asked to consume a similar diet in the 24 h period before each trial.

Experimental trials

On separate days, spaced at least seven days apart, subjects performed four 20-km time trials in the heat (32.7 ± 0.7 °C and 55% relative humidity). The environmental conditions used in this study were selected as they have previously been shown to influence pacing strategy in athletes of a similar calibre to those in this study [4]. All cycling tests were conducted in an automated climatic chamber (2.9 × 6.8 × 2.7 m) which has been used in previous studies [4]. Trials were conducted on an electromagnetically-braked cycle ergometer (Velotron; RacerMate; Seattle, WA, USA), which was adjusted to replicate the subject's own bicycle and fitted with aerobars. The first of these time trials was self-paced (SPTT), acted as a familiarisation trial and conducted in order to obtain the starting power output during subsequent trials. Subjects were instructed to complete the entire 20-km distance in as short a time as possible. Following this, the average power output during the initial 2.5-km was calculated. The power output for the first 2.5-km of the three subsequent 20-km time trials was manipulated to be equal to (ETT), 10% above (10% ATT), or 10% below (10% BTT) that of the self-selected trial. Trials were conducted in a randomised crossover order and were counterbalanced so that all six possible combinations were completed twice. However, one subject withdrew from the study and therefore the following order was only completed once; 10% ATT, 10% BTT and ETT. A variation in starting power output of 10% was chosen, pilot data and previous research [4] indicated that cyclists of the calibre used in this study tend to begin prolonged cycling trials in the heat approximately 10% above their mean trial power output. The starting distance was chosen because pilot data indicated that our subject cohort was unable to ride for greater than 2.5-km at power outputs in excess of 10% above their self-selected pace in the heat. Further, with the use of discrete Fourier transformation, previous research has documented that the dominant power frequency during a 20-km cycling time trial is 2.5-km [32]. A trial distance of 20-km was chosen as it is a distance typical of previous research and competitive time trial racing [19,27,32,36]. The reproducibility of output during a 20-km cycling time trial performed by well-trained cyclists using the Velotron cycle ergometer has previously been reported (coefficient of variation < 4%) [27,36]. Throughout all trials, subjects were only given feedback as to how much distance they had covered. Power output, cycling speed and performance times were recorded every second (1 Hz) via the Velotron software. In order to mimic real world cycling environmental conditions, a fan providing a wind speed of ~32 km·h$^{-1}$ was placed directly in front (~1 m) of the subject during all trials [26]. A maximum wind speed of 32 km·h$^{-1}$ was chosen, as markers of thermoregulatory stress are not influenced by higher wind speeds (i.e. 50 km·h$^{-1}$) when cycling in similar environmental conditions [26].

Power output during the initial 2.5-km of each trial was blinded to the subject, held constant irrespective of cycling cadence and controlled using the Velotron Coaching Software (Version 1.5). During the remaining 17.5-km, subjects were free to alter their gear ratio and pedalling cadence as desired. Subjects were instructed to complete the self-paced 17.5-km section as fast as possible. The Velotron cycle ergometer determines cycling power output based upon the velocity of the rear flywheel and the electromagnetic resistance applied to the wheel. Thus in this study, the time taken for each cyclist to complete the first 2.5-km of each time trial was calculated by back-calculating cycling velocity based upon the relationship between power and speed that is built into the Velotron software. The time taken to complete the 2.5-km was then calculated based upon the average velocity performed during the 2.5-km. The power output recorded by the Velotron cycle ergometer has previously been reported to be highly accurate and valid (< 1% error) when compared to a dynamic calibration rig [5] and an SRM power monitor [5,22]. Throughout the trials, skin temperature ($T_{sk}$) was measured using four flat-top copper skin thermistors (YTS Temperature, 400 Series; Dayton, OH) attached to the chest, arm, thigh and calf [20,29,34] and mean skin temperature was determined by Ramanathan's formula:

$$T_{sk} = (0.3 \times T_{ch} + 0.3 \times T_{bicep} + 0.2 \times T_{thigh} + 0.2 \times T_{cal})$$

Rectal temperature ($T_{rect}$) was determined using a disposable rectal thermistor (Monatherm Thermistor, 400 Series; Mallinckrodt Medical, St. Louis, MO, USA) which was self-inserted to a depth of 12 cm from the sphincter. Mean body temperature ($T_{body}$) was determined by Burton's formula:

$$T_{body} = (0.65 \times T_{re}) + (0.35 \times T_{sk})$$

The heat content ($Q_{content}$) was calculated every 2.5-km during the time trial and determined by the following equation:

$$Q_{content} = T_{body} \times b \times mass \times 3.47 \times kJ \cdot \degree C \cdot kg^{-1}$$

Heat storage ($Q_{storage}$) was determined by comparing the heat content calculated during 2.5-km (i.e. D2) to that of the preceding 2.5-km (i.e. D1) and determined by the following equation:

$$Q_{storage} = Q_{content \ (D2)} - Q_{content \ (D1)}$$

Skin, rectal and environmental temperatures were recorded every second (SquirrelView, Grant 2020; Cambridge, UK) and averaged over each 2.5-km. Heart rate was measured beat-by-beat (Polar Electro Oy; 810i; Kempele, Finland) and averaged over each 2.5-km of the time trials. Ratings of perceived exertion (6–20 point scale) [11], thermal sensation (0–8 point scale) [35] and pain intensity in the quadriceps (0–10 point scale) [12] were recorded at 2.5, 10 and 20-km during the time trial. Thermal sensation was also recorded immediately prior to the time trial.

Statistical analysis

Average power output and overall performance times over the self-paced 17.5-km and entire 20-km of each time trial were analysed for significant effects using a one-way repeated measures ANOVA. For each dependent variable (i.e. power output, temperatures, heart rate and perceived scales), a two-way repeated measures ANOVA was used to delineate significant differences between trials (i.e. 10% BTT, ETT and 10% ATT) and distance during the 20-km time trial. Where a significant effect was found, the main effect was analysed using the “least significant difference” test for pairwise comparisons. All statistical tests
were conducted using SPSS version 10.0 (Chicago, IL, USA), and data are presented as means and standard deviations. For analysis, significance was accepted at P < 0.05.

Results

The time (min:s) taken to complete the initial 2.5-km was 3:46 ± 0:15, 3:53 ± 0:15 and 4:02 ± 0:17 during the 10% ATT, ETT and 10% BTT, respectively. Average power output and overall performance times for the entire 20-km time trials are shown in Table 1. Average power output and overall performance time during the 20-km time trials were not significantly different between any of the four trials. Average power output during the initial 2.5-km was significantly different between all three trials (Fig. 1). Average power output during the self-paced 17.5-km portion was significantly greater during the 10% BTT (273 ± 45W) compared with the SPTT (262 ± 36W), ETT (267 ± 48W) and 10% ATT (265 ± 41W; P < 0.05) trials. Average heart rate was not significantly different between any of the trials (Fig. 1B). Mean skin, mean body and rectal temperatures were not significantly different between 10% BTT, ETT and 10% ATT (Fig. 2). Compared with the first 2.5-km, heat storage significantly increased from 5 to 7.5-km in all trials (Fig. 3). However, heat storage was not significantly different between 10% BTT, ETT and 10% ATT (Fig. 3). Rating of perceived exertion was significantly greater during the first 2.5-km of 10% ATT compared with the 10% BTT (Fig. 4; P < 0.05). However, pain intensity in the quadriceps and thermal sensation were not significantly different between trials (Fig. 4).

Discussion

The main finding of the present study was that overall performance time of endurance-trained male cyclists performing a 20-km cycling time trial in the heat was not significantly influenced by the manipulation of starting power output either 10% above or 10% below that of a self-paced trial. Furthermore, the adoption of relatively fast (10% ATT) and slow (10% BTT) starting strategies did not significantly influence core body temperature, rate of heat development, perceived pain, thermal sensation or average heart rate.

In the present study, it was hypothesised that an initially low power output would attenuate the rise in core body temperature, prevent a subsequent decline in power output and improve overall performance times. Despite this however, overall performance time and average power output were not significantly different between any of the three performance trials. This occurred despite the significantly greater power outputs observed during the 17.5-km self-paced portion of the 10% BTT. Thus, it appears that the prolonged time (i.e., 4:02) spent at low speed during the start of the 10% BTT resulted in overall performance times being similar to that of the control trial (ETT). The similarities in overall performance times found between the 10% BTT, ETT and 10% ATT in the present study somewhat contradict previous findings [18, 21]. Mattern et al. [21] found that a controlled slow starting strategy resulted in a greater improvement in 20-km cycling time trial performance in thermoneutral conditions (~21–22°C), when compared with the relative improvements in performance achieved by adopting a faster starting strategy. It is possible that the disparities between findings of the present study and that of Mattern et al. [21] are due to methodological differences between these two studies. Firstly, the influence of environmental temperature on self-selected and optimal pacing strategies has yet to be established. It is possible that starting strategy may be more influential on performance in thermoneutral compared to hot environmental conditions. In addition, Mattern et al. [21] compared the performance during various time trials as a percentage of change of the initial self-

Table 1  Average power output and overall performance time during the self-paced 20-km time trial (SPTT), as well as during trials where starting strategy was altered to 10% below (10% BTT), even (ETT) and 10% above (10% ATT) that of the self-paced 20-km time trial. No differences in these variables were shown amongst trials.

<table>
<thead>
<tr>
<th></th>
<th>SPTT</th>
<th>10% BTT</th>
<th>ETT</th>
<th>10% ATT</th>
</tr>
</thead>
<tbody>
<tr>
<td>time</td>
<td>32:39 ± 1:39</td>
<td>32:19 ± 1:46</td>
<td>32:26 ± 1:05</td>
<td>32:20 ± 1:40</td>
</tr>
<tr>
<td>power</td>
<td>266 ± 36</td>
<td>273 ± 44</td>
<td>272 ± 46</td>
<td>276 ± 41</td>
</tr>
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</table>

Values are expressed as means ± SD.
Training & Testing


It is worth noting that the participants of the present study were ‘sub-elite’ and thus the application of findings from this study should be interpreted with caution. Indeed, the performance times of all trials in this study appeared relatively slow (Table 1), when compared with the speed of elite/professional cyclists [24,30]. It is also possible that the relatively slow performance times observed in this study may have been exacerbated by an inability of the Velotron cycle ergometer to accurately calculate realistic cycling speeds. While the accuracy and reliability of the Velotron to determine cycling power output has previously been determined [5,36], no study to date has attempted to examine the accuracy and validity of cycling speed calculated by the Velotron software. Indeed, by comparing the present study to that of previous research [9,15] it appears that the Velotron cycle ergometer underestimates velocity at a given cycling power output. It is possible that such underestimations in cycling velocity are due the fact that the Velotron cycle ergometer does not account for an individual’s body mass and calculates cycling velocity based upon an upright as apposed to an aerodynamical position. Future studies should verify this hypothesis and should demonstrate the validity of the Velotron cycle ergometer to estimate actual cycling speed.

While power output at the beginning of the 10% ATT was 20% (~60 watts) greater than the 10% BTT, markers of thermoregulatory stress used in this study were not significantly different between trials. These results provide evidence to suggest that either the variables used to measure thermal stress in this study were insensitive to physiological differences or, moderate variations in power output upon commencement of the time trial had limited influence on the development of thermoregulatory fatigue. It is also possible that the use of the large fan in the present study, used to replicate realistic cycling wind speeds (~32 km.h⁻¹), permitted adequate dissipation of excess heat through enhanced evaporative cooling, thereby limiting the development of hyperthermia and its influence on time trial performance [26]. In support of this, both rectal and body temperature significantly increased over the duration of the trial, whereas mean skin temperature did not (Fig. 2). Further, rectal temperatures upon completion of the time trials in the present study (<38.9 °C) were below those previously reported critical values thought to induce thermoregulatory fatigue (39.5–41 °C) [2,23]. Indeed, upon completion of a 20-km cycling time trial in similar environmental conditions (35 °C, 60% relative humidity), Tucker et al. [34] observed final rectal temperatures of 39.2 °C, when wind speed was only 10 km.h⁻¹.

Interestingly, this study also found that power output and muscle activation of vastus lateralis were similar between hot (35 °C) and temperate (15 °C) trials until rectal temperature reached...
-38.5°C [34]. Consequently, the high wind speeds used in the present study likely prevented the development of hyperthermia and thus limited the influence of environmental heat on overall performance. Clearly, further research is needed to examine the influence of wind speed on temperature regulation, the distribution of pace and overall performance during prolonged cycling in the heat.

In conclusion, the results of the present study provide evidence to suggest that when endurance-trained male cyclists perform a 20-km cycling time trial in the heat, overall performance time is not significantly influenced by the manipulation of starting power output either 10% above or 10% below that of a self-paced trial. In addition, the adoption of relatively fast and slow starting strategies did not significantly influence markers of thermoregulatory stress measured in this study. Further research is needed in order to better understand the mechanisms responsible for fatigue and the regulation of pace during prolonged cycling in the heat in order to gain a greater understanding of the optimal pacing strategies that should be applied in such conditions. In addition, future research should examine the influence of varying starting strategy on performance of elite/professional athletes during field-based exercise in the heat in order to confirm the applicability of the present study.

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References

33 Tucker R, Marle T, Lambert EV, Noakes TD. The rate of heat storage mediates the anticipatory reduction in exercise workload during cycling in the heat at a fixed rating of perceived exertion. J Physiol 2006; 574: 905–915
34 Tucker R, Rauch I, Harley YXR, Noakes TD. Impaired exercise performance in the heat is associated with an anticipatory reduction in skeletal muscle recruitment. Pflugers Arch 2004; 448: 422–430