Physiological Response of 5/1 Intermittent Aerobic Exercise and its Relationship to 5 km Endurance Performance

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A great number of specialists and coaches believe that conventional laboratory measurements lack specificity and that more practical testing should be instituted. The majority of studies have addressed this issue by looking at the relationship between physiological variables and time trials (TT). However, few have examined the pertinence of standardized aerobic interval training (AIT) programs to a simulated race performance or time trial. We studied 23 athletes (runners and multi-sport) to determine if their performance on the track during regular strenuous intermittent workouts would be associated with the 5000 m TT. The 3 interval track workouts each totalling 4800 m with a work to rest ratio of about 5 to 1, consisted of either 12 x 400 m (15 s rest), 6 x 800 m (30 s rest) or 3 x 1600 m (60 s rest) and performed at maximal cruising speed (maxCS). Correlation coefficients between the 400, 800, 1600 m workouts and 5000 m TT were not significantly higher (0.90, 0.95, 0.93) than those for VO₂max (0.84) or maximal aerobic speed (0.85). When considering only the work interval, the mean %HRmax for the AIT and TT were accomplished respectively at 97.5 and 97.3 for the runners and 95.9 and 95.7 for the multi-sport athletes. In conclusion, our results indicate that the AIT programs performed with brief rest periods during normal training periods are as capable of predicting 5000 m race performance as are laboratory measurements. Also, within the limit of this study, the 6 x 800 m (30 s rest) AIT workout seems to be a very efficient and specific manner to simulate a competitive endurance performance.

Key words: Simulated race, time trial, cruising speed, maximal aerobic speed

Introduction

The search to delineate endurance performance from its physiological correlates has been the subject of investigations for many years. While maximal oxygen consumption (VO₂max) tests dominated all parameters for almost half a century, the maximal aerobic speed (MAS) and the anaerobic threshold have been explored more recently. Whereas some studies have shown that these variables seem to explain much of the variability in endurance performance (11,23,27), others have obtained less convincing results when using MAS (16) or the anaerobic threshold (29). Furthermore, in the case of laboratory measurements, tests are usually costly, time-consuming and, as such, inaccessible to the vast majority of endurance athletes.

On the other hand, time trials (TT) are the accepted and preferred endurance performance test in many recent publications. Indeed, this parameter has been utilized to obtain indices of overtraining (24), to examine the effects of tapering (17,18,21,26), to verify the day-to-day variation in cycling performance (19), to better define pacing strategy (12) and to investigate the physiological response during simulated competition (8,13,14,31). Furthermore, it requires maximal effort, is relatively simple to administer in field settings and represents the best predictor of running performance (30). However, since this type of effort resembles actual racing conditions, is continuous in nature, and is mentally taxing, TT of this sort are sparingly used in training circles (25). Endurance athletes therefore have few testing tools available to monitor their training progress.

It it also known that aerobic intermittent exercise using very brief periods of recovery is similar to continuous exercise, particularly in the case of long work intervals (6,15,32). Although some studies have systematically looked at exercise to pause ratios (E/P) of 1:4 to 1:10 (3,4) and 2:1, 1:1, 1:2 (2) which respectively tend to be anaerobic and of a mixed energy contribution, no studies, to our knowledge, have investigated ratios of a more aerobic nature of 4:1 to 6:1 and compared them to distance running performance. Furthermore, with athletes using intermittent training on a regular basis, the use of this type of exercise as a testing procedure should not result in the same deleterious effect observed with time trial evaluations.

Thus, the main purpose of this study was to examine the relationship between three aerobic interval training (AIT) protocols and actual competitive conditions, in this case, a 5000 m TT. Secondly, since the E/P ratio was held constant at 5:1, we also wanted to examine whether or not a particular interval training distance would better predict performance. We believe that performance, or the mean cruising speed of regular
but standard aerobic interval workouts conducted in normal training state, will closely match the race performance in the tapered state and hence provide valuable information to endurance athletes and coaches. This novel approach could certainly help alleviate the great need for practical and useful monitoring field tests (20), while at the same time, following the recommendations regarding the use of "free-range exercise" when evaluating endurance athletes (13, 19).

Methods

Subjects

The subjects in this study were 23 well-trained male athletes who had been training and competing for several years. In order to test the pertinence of the procedure, they were divided into two groups. As such, these were composed of 13 distance runners and 10 multi-sport athletes which included triathletes, cross-country skiers and one mountain bike cyclist, all being accustomed with running training. All provided written informed consent for participation, and procedures were approved by our university Human Rights Ethics Committee. Selected anthropometric characteristics, laboratory data and training information are listed in Table 1.

This project was realized with the collaboration of two university laboratories (A and B). As such, the multi-sport athletes and a few runners from Lab A did all their track workouts on an outdoor 400 m facility. A few weeks later, albeit in colder climate, the second group from Lab B, mostly runners, performed their AIT and TT on an indoor 200 m track.

Table 1 Anthropometric, physiological characteristics and training values of subjects.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Runners (n = 13)</th>
<th>Multi-Sport (n = 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Anthropometric</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (yr)</td>
<td>29.6</td>
<td>8.3</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>66.8</td>
<td>6.6</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>13.5</td>
<td>4.8</td>
</tr>
<tr>
<td>Laboratory</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VO2,max (l/min)</td>
<td>4.45</td>
<td>0.52</td>
</tr>
<tr>
<td>(ml/kg .min)</td>
<td>66.4</td>
<td>5.1</td>
</tr>
<tr>
<td>HRmax (b/min)</td>
<td>182.2</td>
<td>9.4</td>
</tr>
<tr>
<td>VE,max (l/min)</td>
<td>155.2</td>
<td>19.5</td>
</tr>
<tr>
<td>TTE (mins)</td>
<td>16:43</td>
<td>2:34</td>
</tr>
<tr>
<td>Speed max (m/s)</td>
<td>5.00</td>
<td>0.36</td>
</tr>
<tr>
<td>MAS (m/s)</td>
<td>4.91</td>
<td>0.37</td>
</tr>
<tr>
<td>Performance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5000 m (min:s)</td>
<td>16:23*</td>
<td>0:42</td>
</tr>
<tr>
<td>in-season (km/wk)</td>
<td>75*</td>
<td>23.2</td>
</tr>
<tr>
<td>Off-season (km/wk)</td>
<td>50*</td>
<td>14.9</td>
</tr>
<tr>
<td>Interval training experience (yr)</td>
<td>5.9</td>
<td>2.6</td>
</tr>
</tbody>
</table>

Body fat (%): Durnin & Womersley, 1974; TTE: time to exhaustion; MAS: maximal aerobic speed
*Significant difference between two groups, p < 0.05, unpaired t-test

Design

The testing period occurred during the months of November and December which represent the off-season or transition period for triathletes. In the case of cross-country skiers and runners, it was the preparation for a new season. Consequently, most of the subjects were examined in a recuperative state and therefore were well rested.

The intermittent work sessions and the 5000 m TT were administered during a 3-week period. The standard interval track workouts were randomly scheduled once per week. During the last week and after at least 72 hours of recuperation (easy or no training depending on the subject's habits), the criterion 5000 m was performed. Laboratory investigations were carried out either the week prior to or following the field evaluations. Athletes followed their regular training schedule except for the third week. After the last AIT program, they were asked to prepare for the criterion run and proceed with their own individual taper. However, tabulation of the weekly training distances showed that the runners and multi-sport groups decreased their volume respectively by 25% and 5% for the taper week. This represents a mini taper that athletes would follow during normal training but not the taper preceding a major competition (18).

Maximal testing

After the athletes were acquainted with the treadmill, a VO2,max test was performed. With the grade held constant at 3%, the initial speed was set at 12 km/h. After the first five minutes, the speed was increased stepwise by 1 km/h every two minutes until volitional exhaustion occurred. Expired gas was collected and analyzed every 30 s using computer-based systems while heart rates were obtained either via electronic heart monitors (Polar Vantage – Lab A) or monitored by ECG (Lab B). The VO2,max was the highest value obtained while the maximal heart rate (HRmax) was recorded during the final minute of the laboratory VO2,max. The maximal aerobic speed (MAS) was defined as the speed attained at the last completed stage on the treadmill while speed max was the velocity obtained from the last 30 s of the test, whether or not the stage was completed.

Aerobic interval training protocols

Aerobic intermittent training was performed at maximal cruising speed (maxCS) which was the highest average speed that could be maintained over all work intervals of a single training session. Although the instructions given prior to the beginning of the experiment indicated that the subjects should find the optimal maximal training pace they believed they could maintain for the duration of the workout, the intensity was not intended to recreate the all-out performance that is typically exhibited during a major competitive effort. Repetitions, distances and rest interval durations of the three AIT protocols were:

Protocol 1: 12 x 400 m with 15 s rest
Protocol 2: 6 x 800 m with 30 s rest
Protocol 3: 3 x 1600 m with 60 s rest
Table 2 Mean exercise data of aerobic interval training, 5 km TT and maximal laboratory test.

<table>
<thead>
<tr>
<th>Protocols</th>
<th>Cruising speed (m/s)</th>
<th>Heart rate (b/min)</th>
<th>Lactate (mmol/l)</th>
<th>RPE (#)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 x 400 m</td>
<td>Runners Multi</td>
<td>Runners Multi</td>
<td>Runners Multi</td>
<td>Runners Multi</td>
</tr>
<tr>
<td>5.05# 0.30</td>
<td>4.78# 0.17</td>
<td>177.2 7.8</td>
<td>16.7 4.0</td>
<td>15.5 1.8</td>
</tr>
<tr>
<td>4.99# 0.30</td>
<td>4.67# 0.20</td>
<td>177.7 9.1</td>
<td>15.1 4.6</td>
<td>15.0 2.2</td>
</tr>
<tr>
<td>3 x 1600 m</td>
<td>4.89 0.28</td>
<td>176.9 7.9</td>
<td>15.9 4.8</td>
<td>15.2 1.0</td>
</tr>
<tr>
<td>5000 m TT</td>
<td>4.87 0.27</td>
<td>177.1 8.4</td>
<td>17.8 4.8</td>
<td>16.4 1.4</td>
</tr>
<tr>
<td>Max lab test</td>
<td>4.91 0.37</td>
<td>182.2 9.4</td>
<td>17.3 2.1</td>
<td>-</td>
</tr>
</tbody>
</table>

Values are mean and standard deviation; *p < 0.05, #p < 0.01: different from 5000 m TT, Anova-repeated measures

Table 3 Correlation coefficients, standard errors of the estimate and % error between field and lab variables and the 5000 m TT (m/s).

<table>
<thead>
<tr>
<th>Field</th>
<th>12 x 400 (m/s)</th>
<th>6 x 800 (m/s)</th>
<th>3 x 1600 (m/s)</th>
<th>MAS (m/s)</th>
<th>Laboratory VO2max (ml/kg.min)</th>
<th>TTE (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>r</td>
<td>0.90</td>
<td>0.95</td>
<td>0.93</td>
<td>0.85</td>
<td>0.84</td>
<td>0.83</td>
</tr>
<tr>
<td>See</td>
<td>0.13</td>
<td>0.10</td>
<td>0.11</td>
<td>0.16</td>
<td>0.17</td>
<td>0.17</td>
</tr>
<tr>
<td>% error</td>
<td>2.8</td>
<td>2.1</td>
<td>2.3</td>
<td>3.4</td>
<td>3.8</td>
<td>3.6</td>
</tr>
</tbody>
</table>

All correlations significant (p < 0.001), both groups combined (n = 23)

In all cases, E/P ratios were 5:1 and total running distance was 4800 m excluding brief recuperative runs between repetitions. After thoroughly warming-up, the athletes proceeded with their workouts on an individual basis. For every repetition completed, the elapsed time and heart rate were collected. Subsequently, the average maximal cruising speed was calculated from all completed work intervals.

Five kilometre time trial

The subjects competed against each other on the last Saturday of each three-week period. They were instructed to run this distance in the fastest possible time. Group A faced windy, rainy and cool conditions while Group B raced in ideal indoor temperatures. This probably affected the overall performance of Group A. Elapsed time was given and heart rates were verbally transmitted at every kilometre to an assistant positioned on the track. Five subjects were unable to participate with the groups and subsequently raced in groups of two and three. Verbal encouragements were given to all athletes.

Blood lactate

Blood samples were collected during the second minute of recuperation following the termination of each AIT protocol, 5000 m TT and VO2max test. These consisted of 40 microliters of fingertip whole blood added to 80 ml of 6% perchloric acid in heparinized pipettes, centrifuged and frozen at -20°C until analyzed with an automated lactate analyzer (YSI).

Additional measurements

Percent body fat was estimated by skinfold measurement (9). For the field conditions, the subjective rating of perceived effort was also obtained via Borg's scale (7).

Statistical analysis

For data analysis, the mean cruising speed and heart rate were calculated from all repetitions for each specific interval protocol and at each kilometer for the 5 km time trial. An unpaired T-test was used to compare differences between groups while a repeated one-way analysis of variance (ANOVA) was administered to verify whether or not differences existed in the physiological variables between AIT workouts and the criterion run (10). When a significant F-ratio was observed, a post-hoc Scheffé F-test was performed to determine the location of the significant differences. Correlation coefficients and regression analysis were used where applicable to verify the degree of relationship between variables. Furthermore, in order to verify if there was a significant difference between laboratory and field variables, a direct statistical comparison of correlation coefficients was performed (33).

Results

The group of runners had a faster 5000 m performance time and a higher training volume than did the multi-sport group (Table 1). The VO2max, MAS and time to exhaustion also tended to be better for the runners but these did not reach the 0.05
As indicated, the runners trained at greater distances during the season as well as the off-season.

**Cruising speed**

For the runners, the mean cruising speed of the $3 \times 1600$ m interval program and the MAS were similar to the 5000 m CS (Table 2). However, there was a significant difference with the criterion run and the $12 \times 400$ m and $6 \times 800$ m workout mean CS for this group. In the case of the multi-sport group, all AIT programs mean CS and MAS were different from the 5000 m CS. In both groups, the $6 \times 800$ m and $3 \times 1600$ m workouts were similar to the treadmill MAS. Average maxCS of the $12 \times 400$ m, $6 \times 800$ m, $3 \times 1600$ m and 5000 m TT were respectively 102.8, 100.9, 100.4 and 98.4% of MAS. As shown in Fig. 1, the individual speeds for each interval program and each repetition varied somewhat. The running group was better able to maintain initial speed and showed a lesser drop-off. During the 5000 m, the CS of the runners was much more stable than that of the multi-sport group. In both instances, there was a marked decrease in speed between kilometers 2 and 4.

In spite of significant differences between the mean maxCS (m/s) of the AIT programs and the 5000 m TT, these measures were significantly correlated ($r = 0.90$ to .95), (Table 3). Corresponding correlation values between 5 km performance and multistage indices varied between 0.83 and 0.85. As for MAS, speed max was similarly correlated with 5 km performance ($r = 0.75$). When a direct comparison of correlation coefficients between lab and field variables was performed, no significant difference was found. Furthermore, standard errors of estimate for the AIT workouts were between 0.10 and 0.13 m/s with a mean percentage error of 2.4% compared to 3.6% for the laboratory measurements. Also, as the data of runners and multi-sport athletes were in line with each other in the scatterplot, with similar dispersion around the regression line and with the slope and intercept not being significantly different, they were grouped together. The regression equations used to predict the 5000 m TT from the best AIT workout ($6 \times 800$ m) and from MAS are compared in Fig. 2.

**Heart rates and lactate**

The mean heart rates for each AIT program and 5000 m TT for both groups were very similar (Table 2) but significantly different from the treadmill HRmax. Although the multi-sport subjects appeared to be working at a higher percentage of their maximal treadmill heart rate (Table 2 and Fig. 3), these differences were small and not significant. On the other hand, it can be seen that heart rate increased from the first to last running interval and from the beginning to the end of the 5000 m TT. In fact, at the end of AIT or TT, heart rate was very close to HRmax (Fig. 3). As for heart rate, most of the lactate values in the AIT programs were not significantly different from the 5000 m TT or VO$_2$max (Table 2).
Physiological Response of 5:1 Intermittent Aerobic Exercise


Questionnaire

The ratings of perceived exertion (RPE) showed some significant differences but were not consistent (Table 2). Generally, they exhibited values of 15 to 16 on the Borg's scale which corresponds to a perceived exertion between "hard" and "very hard". This means that, in most conditions, the subjects felt they were working at a slightly lower intensity during their AIT workouts as compared to the 5000 m TT for which RPE values rose slightly over 16.

Discussion

The present study was undertaken to examine the relationship between aerobic interval workouts and endurance performance. To this end, heart rate and lactate response during this type of intermittent training and 5000 m TT criterion were similar. Our results are in accordance with previous investigations that have shown that the maximal aerobic speed has a close relationship with performances from the 1500 m to the 5000 m range (23,27,29). Also, both AIT and multistage indices explained a similar percentage of the variance of the predicted 5 km performance. This type of control interval training thus appears to be a good simulator and indicator of endurance performance. Furthermore, it is not excluded that other forms of interval training might be better than the ones tested in this study. Nevertheless, intermittent exercise is a regular feature of an athlete's training program, causes less disruption and is better tolerated than an all-out effort such as a TT. Consequently, AIT could represent a viable alternative solution for periodic field evaluations.

From this study, we also sought to investigate the applicability of a rarely used E/P ratio of 5:1. As most prevailing training programs for endurance sports use a 1:1 or 2:1 ratio, our purpose was to determine if the 5:1 ratio, coupled with a total running distance close to TT, could be used more extensively. To this end, the AIT program successfully reproduced the physiological responses observed during the criterion run. Specifically, this type of workout makes the training more intense, meaning that total training time is reduced when compared to the traditional intermittent training ratio of 1:1. Subsequently, a greater contribution from the anaerobic metabolism is elicited. This is supported by Ballor & Volovsek (1992) who have observed a higher glycolytic implication when the E/P ratio was set at 2:1 instead of 1:1 or 1:2 at a supramaximal intensity of 110% VO2max. The logic behind the traditional E/P ratio was to permit sufficient recuperation to take place and allow the athletes to pursue a level of effort close to 100% VO2max (1). However, Olsen et al. (1988) have shown that intermittent training at an intensity of 92% VO2max is as valuable as 100% VO2max and that the physiological changes are similar. Thus, when combining an E/P ratio of 5:1 with a 95% VO2max intensity, the product favors the simulation of a 15 to 20 minute endurance performance. Consequently, athletes would benefit...
from utilizing a lower level of intensity and a reduced recuperation time.

The physiological responses of the 5000 m criterion run were very similar to those found in other studies. Ramsbottom et al. (1992) have shown that a treadmill 5 km TT was conducted at intensities between 82 – 94% VO2max and 95 – 98% HRmax from the first to fifth kilometer. Recent studies have corroborated these results. Hence, Foster et al. (1993) using a 5 km cycle TT, therefore a shorter exercise period, observed an exercise level of 90 – 96% VO2max and 95 – 98% HRmax while Gillman & Wells (1993) reported 94% to 96% HRmax for women athletes completing an 8 km outdoor run. Finally, Hou-mard et al. (1994) found that at the completion of a 5 km time trial, the SHRmax was 99% and 100% at a pre and post-taper period respectively. Concomitantly, the AIT protocol was performed at almost identical values (Fig. 3). In fact, the 12 x 400 m, 6 x 800 m and 3 x 1600 m intervals were respectively executed between 90 – 98%, 92 – 98% and 95 – 98% HRmax. We can conclude that in terms of intensity, both groups of athletes worked as hard during the AIT programs as they did during the 5000 m TT. Therefore, since the bulk of high intensity interval work of competitive endurance athletes ranges between 90 – 98 %HRmax, we suggest that regular aerobic intervals with a fixed E/P ratio can be used as a substitute for other laboratory or field tests.

Lactate values observed in this study were high (Table 2) but similar to the ones reported for other TT events (13, 31). While most would consider the 5000 m and the AIT protocol to be aerobic events, we must acknowledge the significant contribution of the anaerobic metabolism (22). Hence, these aerobic intermittent workouts could be renamed “mixed aerobic-anaerobic” interval training. As for the MAS test, a high anaerobic component is present at the completion of the test. Since the intensity of effort was estimated to be over 90% VO2max with a gradual accumulation of lactate, the glycolytic pathway would seem to be a major energy supplier. This was confirmed by the estimated RER of 1.06 obtained via the HR-VO2 laboratory relationship for both the aerobic intervals and 5000 m TT.

As the specificity principle, in this case meaning average cruising speed, remains a critical factor to consider in the design of training programs, it was interesting to compare maxCS to MAS and race performance. For both the runner and multi-sport groups, the cruising speed of the AIT program was very similar to the MAS (Fig. 1, Table 2). Moreover, the MAS for the multi-sport athletes was higher than the 5000 m CS while for the runners, these speeds were similar. However, as shown in Table 3 and Fig. 2, the 6 x 800 m session produced a standard error of 0.10 m/s, 0.35 km/h or 23 seconds for the 5 km race therefore a percentage error that compares well to values for MAS. Since MAS remains a variable much studied, we must recognize that different MAS protocols and definitions exist and potentially can furnish varying results or final speeds. In the present study we chose a protocol with a 1 km/h speed increment per 2 min stage and a 3% slope, while others have used a 1 km/h per 60 s stage with 0% slope eliciting a higher final MAS speed (29). In this latter protocol, the attainment of greater velocity probably solicits the anaerobic metabolism to a higher degree, but at the same time, permits the better discernment of homogenous subjects. Even though the former and traditional concept of MAS, being that stages should represent the lowest speed eliciting VO2max, is respected, these longer workloads tend to force a cluster of data as illustrated in Fig. 2. In order to clarify this issue and make MAS comparison with performance justifiable, these considerations should be addressed in future studies.

Therefore, these data would seem to support the utilization of an AIT program in the determination of maximal endurance performance. As noted elsewhere (17, 21, 26), many laboratory measurements, besides being inaccessible to fitness enthusiasts, lack sensitivity to varying training status. In monitoring elite athletes, Barbeau et al. (1993) have shown that submaximal data executed at an intensity close to 90% VO2max are more reliable than maximal laboratory data and may represent the preferred intensity for evaluation purposes. An AIT program, besides being freely accessible to endurance athletes, is of the free-range nature that Foster and Hickey have referred to and seem to recommend. Additionally, we feel we answer Ingen-Schenau’s plea to exercise scientists to provide measurements which would be relevant to performance, could reflect seasonal progression and be readily translated into training.

Be that as it may, all our subjects enjoyed this type of workout as they found it was at a correct intensity for 5000 m performance, was not time-consuming and gave immediate feedback. The results of this study clearly demonstrate the effectiveness of aerobic intermittent exercise in predicting and simulating endurance performance. If a recommendation could be formulated, it would state that an aerobic interval training format using an E/P ratio of 5:1 can be administered in a normal training state at an intensity of 90 – 96% HRmax, a RPE of 15 to 16 (hard to very hard) and at the intended cruising speed of a 15 – 20 minute endurance performance. Also, this investigative workout should be conducted in a non-tapered training state. The resultant maintained velocity should provide the athlete and coach with very pertinent information concerning future performances. Thus we suggest that aerobic intermittent training can be easily applied to regular workouts and be used as an additional physiological monitor.

References
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