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Research article

TREADMILL AND CYCLE ERGOMETER TESTS ARE INTERCHANGEABLE TO MONITOR TRIATHLETES ANNUAL TRAINING

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ABSTRACT

The purpose of this study was to verify the use of a single test to obtain annual training guidelines applicable to multiple modes of training. Eight triathletes (4 females, 4 males) were tested 3 times during their training year (Phase I; Phase II; Phase III) on a treadmill and cycle ergometer. Cardio-respiratory variables were calculated at standardized percentages of maximal oxygen uptake (VO_{2max}; 50-100%). VO_{2max} differences between tests reached 6% in every testing session ($p \le 0.01$). VO_{2max} was stable for both tests throughout the season. The ANOVA (3 phases x 2 tests x 6 intensities) demonstrated that there was a significant difference for heart rate (HRs; $p \le 0.05$) between tests in Phase I only. However, the nonparametric sign test did not show any significant differences in any phase. These results demonstrated that triathletes could use the relationship between HR and % VO_{2max} collected during a treadmill or a cycle ergometer test to obtain interchangeable reference HRs for monitoring their running and cycling training bouts in high volume and/or high intensity phases of their training year.

KEY WORDS: Performance test, triathlete, VO_{2max}, monitoring of training, heart rate.

INTRODUCTION

Sport training exercises induce physiological adaptations that enhance athletic performance (Mujika and Padilla, 2000a; Mujika and Padilla, 2000b). To provoke adequate physiological adaptations, specific task have to be done under specific conditions, where the task is characterized as a set of particular physical and psychological stressors (*i.e*., the principal of specificity) (Viru and Viru, 1993). Triathletes are in a particular position when considering training specificity because they evidently have to devote a portion of their training to swimming, biking and running while other athletes have generally a single mode of training. Triathletes face additional difficulties because specific physiological adaptations, particularly peripheral adaptations, induced by different modes of training require that specific tests should be used in order to monitor training effects. Therefore, precise monitoring of training adaptations in triathletes should theoretically involve testing in the three modes of training. On the other hand, it has been reported in a previous study (Basset and Boulay, 2000) that the heart rate (HR) differences between a cycle ergometer and a running test, in triathletes, cyclists and runners were smaller than the habitual intra-individual variations observed while carrying out prolonged training activities. This latter results confirmed an acute HR adaptation to different modes of testing. What about long-term HR adaptation?

Triathletes and their coaches have been interested in establishing the optimal work intensity with accurate indicators to determine the overall density of training (composite of volume and intensity of training (Boulay, 1995)) programs. Even though VO_{2max} is related to endurance performance, some day-to-day variations convey restriction on the use of this variable alone (Arts and Kuipers, 1994). Thus, to prescribe exercise intensities coaches need a criterion that reflects the specific physiological responses of their athletes (Basset and Boulay, 2000).

Heart rate and VO_2 have been shown to be linearly related in cycling as well as in running (Coast and Welch, 1985; Ricci and Leger, 1983; Swain and Leutholtz, 1997; Swain et al., 1998; Van Handel et al., 1988). Thus, HR has been frequently taken as the variable of choice to monitor work intensity in athletes using running and/or cycling in their training (Pichot et al., 2000). Therefore, HR has been proposed for prescribing exercises for training bouts of short duration (15-30 min) (Weltman et al., 1990). Heart rate has been shown to be a more stable variable during prolonged exercise (90 min) than other physiological variables, such as pulmonary ventilation (VE), work rate (W), blood lactate and expired carbon dioxide (VCO_2) and thus has been proposed for the same purpose in longer training activities (Boulay et al., 1997). Establishing training intensities with HR gathered during common laboratory exercise tests thus seem to be an efficient approach for monitoring exercise intensity and density of training (Boulay, 1995).

Based on our previous study (Basset and Boulay, 2000), demonstrating a strong HR relationship between cycle ergometer and treadmill tests, we hypothesize that this latter result would also be found all through triathletes annual training (*i.e.*, long-term adaptation). Therefore, the aim of the present study was to verify the feasibility of using a single laboratory test to obtain training guidelines applicable to multiple modes of training.

METHODS

Subjects

Eight triathletes (4 females and 4 males; age 22 ± 2 years; body mass 60.7±10.0; height 1.70 ± 0.08 m), gave their written informed consent (in compliance with Université Laval's Ethics Committee regulations) to participate in this study. All subjects were active athletes and had been competing at the provincial and national levels for periods ranging from 2 to 12 (5 ± 4) years. Tests were performed in three different training phases. First in fall during the general preparatory training phase (Phase I), then in winter during the specific preparatory training phase (Phase II) and finally in summer at the beginning of the competitive phase (Phase III).

Maximal oxygen uptake test (VO_{2max})

Subjects underwent continuous, incremental tests to volitional exhaustion on a treadmill and cycle ergometer. Tests were terminated when subjects could no longer keep pace with treadmill or could no longer keep rpm ≥ 60. These two maximal tests were carried out in random order with a minimal interval of two days and a maximal interval of seven days between tests. Test protocols were designed to yield approximate similar test duration. The running test was conducted on a motor-driven treadmill (Quinton Instruments, Seattle WA). After a 5 min warm-up at a speed of 3.5 $km.h^{-1}$, the starting speed was set at 5.5 $km.h^{-1}$ and 5% grade, and was increased every two min by 1.1 $km.h^{-1}$ until 13.2 $km.h^{-1}$ after which the grade was raised by 3% every two min until exhaustion. The ergocycle test was performed on an electromagnetically braked cycle ergometer (Warren E. Collins, Braintree, MA). Subjects were asked to choose a familiar and comfortable pedalling rate greater than 60 rpm and to maintain it through the test. It should be noted that the mean value of pedalling rate was about 90 rpm for the entire group. The test was initiated at an initial power output of 100 W after a 4 min warm-up period at 100 W. Increments of 25 W were made every min until 200 W was reached then afterwards at every 2 min until exhaustion.

Physiological measurements

During the tests, VO_2, VE and respiratory exchange ratio (RER) were continuously recorded (average of 30 s) with an automated open circuit gas analysis system using O_2 and CO_2 analyzers (Model S-3A and Anarad AR-400, Ametek, Pittsburgh, PA), and a turbine driven digital spirometer (Model S-430, Vacumetrics/Vacumed Ldt., Ventura, CA) with a 5.3L mixing chamber. Heart rate was recorded by electrocardiography in the CM6 position (Model M200, Burdick Corp., Milton, WI). Criteria for reaching VO_{2max} were plateauing in spite of an increase in speed or work rate and a respiratory exchange ratio value greater than 1.1. All subjects at least showed one of the above mentioned criteria. Heart rate at exhaustion was taken as maximal heart rate (HR_{max}).

Training program

Subjects maintained their habitual training and competition regimen through the year. During Phase I, corresponding to general preparatory training (13 weeks), training sessions focused on light aerobic workouts performed by swimming, running and cycling plus two weight training sessions per week. In Phase II, corresponding to specific preparatory training (13 weeks), while weight training sessions were maintained, emphasis was centered on

Table 1. Training volume per week in running cycling and swimming. Data are mean ± (SD).

	Training volume							
	Phase I		Phase II		Phase III		All year	
	Volume (km)	Duration (h)	Volume (km)	Duration (h)	Volume (km)	Duration (h)	Volume (km)	Duration (h)
Running	42.4	3.31	55.9	4.39	53.9	4.29	50.8	4.13
	(7.2)	(0.36)	(5.6)	(0.27)	(6.9)	(0.34)	(8.8)	(0.43)
Cycling	107.3	3.34	237.7	7.55	438.5	14.36	265.5	8.51
	(20.3)	(0.40)	(303.8)	(10.07)	(132.3)	(4.24)	(231.7)	(7.43)
Swimming	16.2	4.37	17.4	4.57	18.6	5.18	17.4	4.58
	(5.4)	(1.33)	(9.2)	(2.38)	(4.2)	(1.13)	(6.5)	(1.51)

swimming and running workout sessions whereas cycling volume increased two fold mainly due to a training camp. In Phase III, corresponding to pre-competition season (14 weeks), the cycling volume increased again while swimming and running volumes were maintained. Mean overall volumes ($km \cdot wk^{-1}$ and $h \cdot wk^{-1}$) for each training mode and each phase are presented in Table 1.

Statistical analysis

Firstly, a two-way (3 phases x 2 tests) analysis of variance was performed to look at phase and mode of testing effects on test duration, HR_{max}, maximal pulmonary ventilation (VE_{max}), and VO_{2max} relative to body mass. Secondly, physiological variables during the incremental tests were interpolated, using a resampling function (MatLab 6.1 Software, MatWorks, Boston, MA), for six relative intensities (from 50% to 100% of VO_{2max}) to compensate for different absolute values between individuals and between tests. The cardio-respiratory data were analyzed using a three-way (3 phases x 2 tests x 6 intensities) analysis of variance with repeated measures on three factors. Based on a previous study of triathletes (Basset and Boulay, 2000), *a priori* contrast statements were designed to test: (a) the effects of training phases and (b) the effects of mode of testing. In addition, to assess intra-individual HR differences between tests the non-parametric Sign test was computed. This test was used because the differences were treated as a single sample, and the random assignment of treatments to units within each pair justifies the assumption of a random sample of observations. Significant *F*-ratios were followed by *post-hoc* comparison using Tukey HSD test procedure. For all statistical tests, a $p \leq 0.05$ was considered significant. All values are expressed as means ± (SD).

RESULTS

Table 2 presents maximal physiological responses to cycle ergometer and treadmill tests during the training year. Values of HR_{max} were significantly higher on treadmill than cycle ergometer ($p \leq 0.01$) for each testing session. HR differences between tests varied from 3 $beats \cdot min^{-1}$ during Phase I to 4 $beats \cdot min^{-1}$ during Phase III. Test durations were not significantly different between phases but tended to last longer in Phase III.

The subjects had significantly higher relative VO_{2max} on treadmill (~6%) than cycle ergometer ($p \leq 0.01$) for each testing session.

Figure 1 shows mean HR plotted against fixed percentages of VO_{2max} (50-100%). Significant differences ($p \leq 0.05$) were found between tests on mean submaximal HR. *A priori* contrast analysis indicated that differences were restricted to HRs observed from 70% of VO_{2max} to VO_{2max} in Phase I only. No HR differences were found between phases on each mode of testing.

The nonparametric sign test on HR did not show differences between cycle ergometer and treadmill at any percentage of VO_{2max} through the season.

Table 2. Maximal physiological responses to cycle ergometer and treadmill tests during a triathlon season.

	Cycle ergometer				Treadmill			
Period	Duration (min)	HR_{max}	VE_{max}	VO_{2max}	Duration (min)	HR_{max}	VE_{max}	VO_{2max}
Phase I	15.0 (5.2)	193 (8)*	140.5 (34.0)	60.9 (6.7)*	17.8 (2.1)	196 (7.3)	136.6 (24.7)	64.8 (5.8)
Phase II	15.7 (5.6)	192 (8)*	144.2 (36.6)	61.9 (6.4)*	18.6 (1.9)	195 (8.1)	136.5 (25.4)	66.1 (6.9)
Phase III	16.0 (5.7)	191 (8)*	146.9 (25.8)	62.8 (7.2)*	19.0 (1.8)	195 (8.4)	143.2 (25.4)	67.1 (5.9)

Abbreviations: HR_{max}= Maximal heart rate ($beat \cdot min^{-1}$), VE_{max}= Maximal pulmonary ventilation ($l \cdot min^{-1}$), VO_{2max}= Maximal oxygen uptake ($ml \cdot min^{-1} \cdot kg^{-1}$).Data are mean ± (SD). * Mode effect ($p \leq 0.05$).

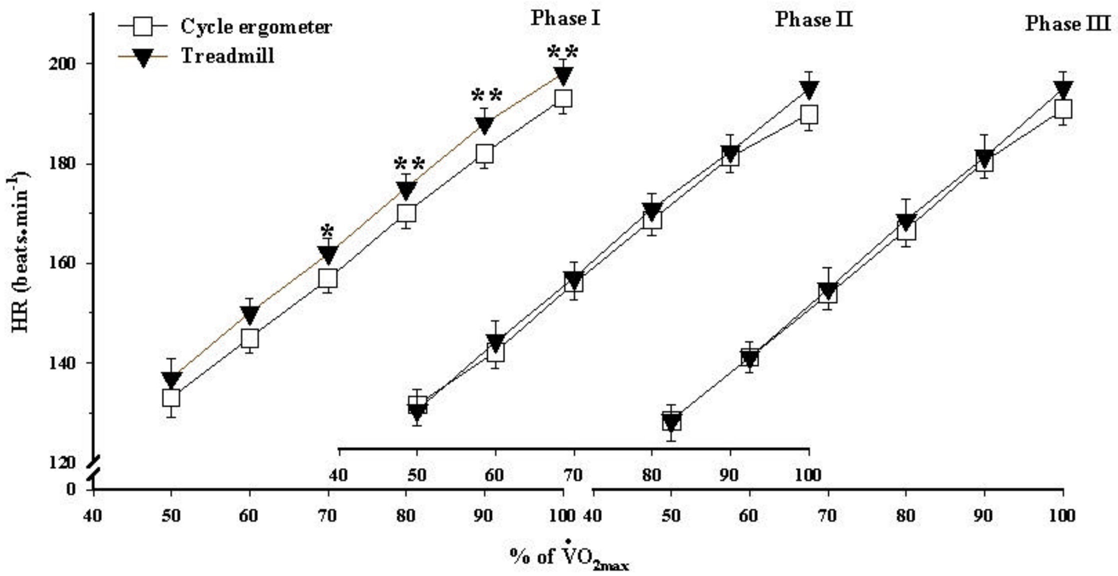

Figure 1. Mean heart rate plotted against fixed percentages of VO_{2max} for the cycle ergometer (□) and treadmill (▼) tests performed in Phase I (left), Phase II (middle) and Phase III (right). * $p \leq 0.05$, ** $p \leq 0.01$.

DISCUSSION

The purposes of the present study were firstly, to look at the triathlete long-term HR adaptation on ergometer and treadmill tests; secondly, to verify the use of a single test to obtain yearly training guidelines applicable to multiple modes of training in triathletes. The main finding of the study demonstrates that HR at different relative intensities did not show major differences between running and cycle ergometer tests during most parts of the training year. Our investigation brings new information with regard to the monitoring of multiple modes of exercise in triathlon. Thus, the results indicate that triathletes could use a single mode of testing to obtain their training HR in running and cycling throughout the year.

At maximal work rate, significant differences were observed in HR_{max} between tests with higher values on the treadmill. These results are in agreement with some previous reports (Basset and Boulay, 2000; Martinez et al., 1993; McArdle and Magel, 1970; Medelli et al., 1993; Schneider and Pollack, 1991; Zhou et al., 1997) but different from others which reported no significant differences (Hermansen and Saltin, 1969; Moreira-Da- Costa et al., 1989; Schneider et al., 1990). Fernhall and Kohrt (1990) showed that responses in local muscles produced an effect on central circulation by having smaller muscle mass involvement and leg blood flow during cycle ergometry compared with treadmill running. Moreover, Verstappen et al. (1982) postulated that a submaximal stimulus of neurogenic origin, due to the smaller muscle mass used during cycle ergometer produced lower HR_{max}. The maximal HR differences between tests reached about 4beats· min^{-1} and were in the range of the variations habitually observed during training sessions.

Over the training year, the subjects running VO_{2max} values were significantly higher than their cycling VO_{2max}. Running and cycling VO_{2max} increased by about 3% during the season. Mean cycling VO_{2max} represented about 94% of running VO_{2max} for each testing session. These proportions are similar to those seen in runners or untrained subjects (~90%) but higher than those observed in highly trained cyclists (~100%) (McArdle and Magel, 1970; Pechar et al., 1974). Individuals differences between tests varied from 0 % to 17 %. Kohrt et al. (1989) found similar pattern in a longitudinal study of trained triathletes and suggested that greater differences between running and cycling of well-trained triathletes arose from muscle mass adaptations of the leg extensors. Thus, triathletes must find the best combination of these two somewhat opposing modes of training to optimize performance in both events. It is interesting to note that running and cycling VO_{2max} did not change over the seasons probably because of insufficient increases in training volume and/or intensity to induce cardio-respiratory adaptations or because subjects had reached their potential in this component. Similar results over yearly phases of training have been reported by others (Barbeau et al., 1993; Bunc and Heller, 1989; Perez, 1981). It has been suggested that the maintenance training program performed by athletes during the regenerative phase is sufficient to maintain their VO_{2max} in spite of a fairly reduced volume (Barbeau et al., 1993). This tends to indicate that, in well-trained subjects, maximal trainability appears to be maintained with a relatively small volume of training provided that training intensity is adequate (Hickson et al., 1985; Koutedakis, 1995).

Due to the restricted number of subjects, analysis was computed with gender factor blocked. Nevertheless, descriptive statistics showed that men VO_{2max} had reached higher values than women on both tests through the season. Men values ranged from 68.5±1.4 to 71.6±2.1 $ml\cdot min^{-1}\cdot kg^{-1}$ and from 65.7±1.9 to 68.3±2.1, while women values ranged from 61.2±2.9 to 62.7±1.6 $ml\cdot min^{-1}\cdot kg^{-1}$ and from 56.1±2.7 to 57.3±2.5 for treadmill and cycle ergometer, respectively. Even though the subjects displayed some physiological differences owing to a gender effect, they represented a good cluster of competitive athletes.

A priori contrast statements revealed that when expressed against percentages of VO_{2max}, HRs during Phase I were significantly different between tests from 70% of VO_{2max} up to maximal oxygen uptake while no difference was observed in Phase II and Phase III. These results confirm that the training period plays a major role in cardio-respiratory fitness. Thus, when athletes were tested in their competitive phase no HR differences were observed between cycle ergometer and treadmill tests when work intensities were expressed in percentage of VO_{2max} (Martinez et al., 1993; McArdle and Magel, 1970). On the other hand, Hermansen and Saltin (1969) reported a different pattern as their subjects achieved higher HRs on cycle ergometer than treadmill at the same metabolic rates expressed as % of maximal power. They assumed that a position effect was present with a reduced venous return and a lower stroke volume in the sitting position. However, the trend for higher HRs on cycle ergometer was reduced with training as trained subjects demonstrated smaller differences (4 $beats\cdot min^{-1}$) than untrained subjects (11 $beats\cdot min^{-1}$). In the present study, the decrease HRs at submaximal work load appeared in the running test only. This probably reflects the fact that the training program showed a greater emphasis on running than cycling in the first two phases of the training year and that cycling volume was then not optimal.

In many experimental studies, particularly in exercise sciences, it is almost impossible to obtain a random sample in the true sense of the definition. Most studies deal with a systematic sample, not a probability sample. In addition, random factors are frequently introduced into experiments that justify parametric statistical inferences. In fact, those statistical procedures are too sensitive facing biological variations and produce statistical significant differences which in practice are often of little importance. To eliminate the probability of a type II error, the proper statistical procedure to use is the Sign test. With this test, no statistical difference was observed on the paired comparisons between cycle ergometer and treadmill tests throughout the season. This means that HR adaptation during the training year followed similar patterns in both modes of testing. This conclusion ensured athletes and coaches that the use of HR at relative percentage of VO_{2max} to monitor training sessions is valid. This confirmed the results of a previous study (Basset and Boulay, 2000) which demonstrated that the HR generated on cycle ergometer or treadmill could be used interchangeably to monitor intensities with either mode of exercise in samples of runners, cyclists and triathletes.

Mean training volume (Table 2) for cycling and running were similar to those reported in previous studies (Hickson et al., 1985; Kohrt et al., 1989; Schneider et al., 1990). Mean weekly volume of cycle training increased the most during the training year (+ 76% from Phase I to Phase III) whereas mean weekly volume of running increased the least throughout the year (+ 24%). Mean swimming volume was slightly higher in this study than those reported by others (Kohrt et al., 1987; Kohrt et al., 1989; Schneider et al., 1990), reaching 18.6 $km\cdot wk^{-1}$ during Phase III and was the most stable training variable through the season with a small 13% increase from Phase I to Phase III. When expressed as duration, the difference between modes of training was the lowest during Phase I. Mean weekly duration of training between cycle and run was almost the same. While, weekly volume of running training progressed smoothly through the season to reach a maximum during Phase II, swimming and cycling training volumes demonstrated larger variations due to training camps during Phase II.

The tests used in the present study were designed to generate comparable VO_2 at each stage and to give comparable VO_2 increments between stages as reported in the previous study from our laboratory (Basset and Boulay, 2000). Moreover, to ensure that test results would be comparable, results were reported against fixed percentages of VO_{2max}. The expression of work intensity in a relative form (% of VO_{2max}) has definitive merits because it allows groups with very different characteristics to be directly compared. This procedure ensured that the results of both cycling and running were not only comparable but also applicable to field situations in mimicking what athletes do in the field because habitually they do not adhere to the same standardized work protocols in different exercise modes (Basset and Boulay, 2000).

CONCLUSION

In conclusion, the results of the present study indicated that athletes and coaches could use a single mode of testing to obtain their training guidelines in running and cycling. The relationship between HR and oxygen consumption expressed as percentages of VO_{2max}, gathered throughout the season during cycle ergometer and treadmill tests, could be interchangeably used, in these athletes, to monitor the intensity of training sessions either in running or in cycling activities. However, it remains to be determined if the same conclusion could be stated with swimming training.

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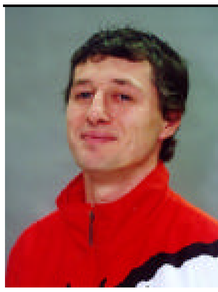

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