Original Article

Energy cost during running and cycling in climbers and mountain bike riders

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Abstract:

The purpose of this study was to compare energy cost between climbers and mountain bike riders, during running and cycling.

Seventeen climbers (29,1±7,4 yrs) and seventeen mountain bike riders (32,3±7,4 yrs) participated in the study. All participants performed exercise tests on a treadmill and on a cycle ergometer. Energy cost, maximal oxygen uptake (VO₂max) and other cardiorespiratory parameters were determined by an open circuit system, during maximal performance and three submaximal loads (8, 10, 12 km/h for running and 100, 150, 200 Watt for cycling).

The results revealed differences in VO₂max for both groups. Comparing running with cycling showed that VO₂max values were higher for climbers during running and for mountain bike riders during cycling ($p < 0.05$). Energy cost showed no differences for climbers compared to MTB riders during running (for 8, 10 & 12 km/h respectively). On the other hand a significantly lower energy cost was observed in MTB riders, compared to climbers, during cycling test ($p < 0.05$ for 100 & 150 Watt respectively).

The conclusion was that mountain bike riders presented lower energy cost than climbers during the first two submaximal loads in cycling test (100, 150 watt). Contrarily, no differences in energy cost occurred between the groups during running. It was hypothesized that those differences were due to the different exercise models between the groups and that climbers are not specifically cycle trained.

Key words: energy cost, running economy, maximal oxygen uptake, climbers, mountain bike riders

Introduction

Running economy (RE) is defined as the energy cost (EC) for a given velocity of submaximal running and it is determined by measuring the steady condition consumption of oxygen (VO₂) and the respiratory exchange ratio (RER) (Saunders et al., 2004). Runners who have a better EC, use less energy and less oxygen, at the same speed, than runners with poor running economy. There is a strong association between EC and distance running performance, with EC being a better predictor of performance than maximal oxygen uptake (VO₂max) in elite runners, who have a similar VO₂max (Saunders et al., 2004). A number of physiological and biomechanical factors seem to influence RE and EC, including temperature, heart rate, ventilation, VO₂max, age, gender, body mass, muscle fiber type distribution and other biomechanical variables (Morgan et al., 1989; Daniels & Daniels, 1992; Morgan & Craib, 1992; Pate et al., 1989; Saunders et al., 2004). Lower running economy is a result of neuromuscular fitting shortage and the disability of elastic energy utilization. Contrarily, higher running economy is due to better neuromuscular coordination and coordinated movement and it leads to a greater performance. Metabolic adaptations in muscles, with increased density of muscle mitochondria, oxidative enzymes and better ability to store and utilize elastic energy by the muscles lead to a lower EC of running (Saunders et al., 2004).

None of the athletes seems to consume 22% more oxygen than high level runners at the same steady condition speed (Costiel, 1986). Comparing high level runners with moderately trained runners, the results show better EC for the first group (Morgan et al., 1992). Long distance runners also present better economy, than semi-distance and sprint runners. It leads to a greater EC, at a 150 to 300 Kcal, in a marathon race for elite runners, compared to moderately trained runners (Conley et al., 1980; Daniels et al., 1992). EC is also correlated with muscle tissue apportion. Cyclists with better energy cost have a greater amount of type I fibers in leg muscles. It is calculated that performance factor of fibers type I is 27 %, and type II is 13% (Coyle et al., 1992, 1999).

It has been suggested that a higher percentage of slow-twitch muscle fibres is associated with better running economy. (Bosco et al., 1987; Williams et al., 1987). The relationship between EC and performance is well established for running (Cavanagh & Kram, 1989), walking (Minetti et al., 1995) and cycling (Hagberg et al., 1981). A Treadmill running and cycle ergometry comparison showed similar parameters of the VO₂ responses, except for the VO₂ slow component, which was significantly greater for cycling than for running (Carter et al., 2000). Oxygen uptake seems to be lower and blood lactate higher for a brief period of intense non-steady state cycling as compared to uphill running. On the contrary, anaerobic energy cost is higher for cycling, although in terms of work efficiency those two can be similar (Scott et al., 2006). Also metabolic cost of submaximal cycling in different pedalling rates rises in a linear regression with speed and pedal rate (McDaniel et al., 2002). The majority of studies indicate that runners achieve a higher VO₂max on treadmill, whereas cyclists can achieve a VO₂max value in cycle ergometry similar to that in treadmill running (Millet et al., 2009). An increase of energy cost along with exercise duration had already been observed for prolonged exercises such as running (Davies et al., 1986) and cycling (Leppers et al., 2000). All mountain bike riders (MTB) seem to have similar physical characteristics with climbers (Impellizzeri & Marcora, 2007).

Although in bibliography there are reports about studies, that examined energy cost and economy of cycling and running, there is no report concerning the comparison in the energy cost of climbers and MTB riders. The aim of the present study was to evaluate and compare the cardiorespiratory performance and energy cost in trained climbers and MTB athletes.

Method

Participants

Seventeen male mountain climbers (aged 29.1±7.4 yrs, training experience 8.9±5.0 yrs) and seventeen male MTB athletes (aged 32.3±7.4 yrs, training experience 6.0±3.9 yrs) were examined in our study. The physical characteristics of the athletes are summarized in Table 1. Training logbook was assessed by each athlete, containing the percentage of training methods (cycling & cross running). The protocol of this study was in accordance with the guidelines of the Ethical Committee of Aristotle University of Thessaloniki and the revised Declaration of Helsinki. All participants gave their written consent of participating in the study.

Procedures

Anthropometric measurements

All data were collected during the last phase of the pre-season training of the participants. Participants' height and body weight were measured using a digital stadiometer (Seca 707, Germany) and their body surface area (BSA, m²) was calculated.

Participants were instructed to arrive at the laboratory in fully hydrated condition and quite rested, at least 3 hours postprandial, and to avoid strenuous exercise for the 48 h preceding a test session. For each athlete tests took place at the same time of day (± 2h), in order to minimize the effects of diurnal biological variations of the results.

Submaximal and Maximal Exercise Test

The athletes completed two submaximal and maximal exercise tests till exhaustion on separate days, in order to determine submaximal and maximal oxygen uptake during treadmill and cycle ergometry on a random order. Tests took place in the laboratory for two days, separated by 48 h, under the same environmental conditions.

Both, running and cycling tests were performed following a maximal incremental continuous protocol, starting with three 4-min. submaximal steps. Maximal running test was performed on a motorized treadmill (Pulsar 3p, h/p/Cosmos, Nussdorf-Traustein, Germany) till exhaustion. The protocol began at 8 km/h with an additional 2 km/h added every 4-minutes until the time of 12 minutes; at this point the increase was 2km/h every 1-minute. Uphill grade was maintained at 1,5% all over the test. Maximal cycling test was completed also to volitional exhaustion conducted on a mechanical braked ergometer (Monark, 818e, Sweden) with seat and handlebar height kept constant over the sessions for each athlete. Pedal frequency was maintained at 60 rpm. The cycle max test started at 100 Watts with an additional 50 Watts added every 4-minutes until the time of 12 minutes; from this point the increase was 25 Watts every 1-minute.

During exercise tests, the gas exchange was determined with the method of breath by breath. Subjects breathed through a high-resistance mouthpiece and turbine assembly. Gases were continuously drawn from the mouthpiece through a small bore and analyzed for O₂, CO₂ concentrations by a spirometer (Oxycon-Pro, Jaeger Wurzburg, Germany) that was calibrated before each test, using gases of known concentration. Respiratory variables (VO₂, VCO₂, RER and minute ventilation) were calculated and displayed for every breath. Heart rate was continuously recorded telemetrically through the exercise test using a telemetry system (Polar, Kempele, Finland). The room temperature was 20-22° C and the relative humidity was approximately 50%.

Blood samples were taken from fingertips five minutes after the completion of the two tests in order to determine blood lactate concentration, using an enzymatic lactate analyzer (Accusport, Boehringer Mannheim, Germany).

Statistical Analysis

Data are expressed as means $\pm$ standard deviation (mean $\pm$ SD). A two way analysis of variance (ANOVA) was applied to investigate differences ($\text{VO}_{2\max}$, VE, HR, RER, LA) between climbers and MTB riders. Independent T-tests were used to determine the significance of differences between climbers and MTB riders for maximum speed and maximum watt during treadmill and cycling tests. All statistical analyses were performed using the 15.0 version of SPSS for Windows (SPSS Inc. Chicago, IL, USA). Statistical significance was accepted at $p < 0.05$.

Results

The anthropometric characteristics of the subjects are demonstrated in table 1 (Mean $\pm$ SD). No significant differences appeared comparing age, training age, height, weight, systolic and diastolic blood pressure, heart rate during rest and Body Surface Area between the two groups.

Training logbooks revealed different training methods for each group, 72% mountain biking and 28% cross running for MTB riders and 25% mountain biking and 75% cross running for climbers.

Table 1. Physical and anthropometric characteristics of the subjects (mean $\pm$ SD).

	Climbers (n=17)	MTB riders (n=17)
Age (years)	29.1 $\pm$ 7.4	32.3 $\pm$ 7.4
Training Age (years)	8.9 $\pm$ 5.0	6.0 $\pm$ 3.9
Height (cm)	172.8 $\pm$ 7.9	177.3 $\pm$ 5.6
Weight (kg)	74.9 $\pm$ 11.4	76.1 $\pm$ 6.5
HR rest (b $\cdot$ min)	68.71 $\pm$ 10.88	61.71 $\pm$ 11.02
BPsystolic (mmHg)	127.35 $\pm$ 12.60	124.59 $\pm$ 7.08
BPdiastolic (mmHg)	66.35 $\pm$ 6.37	62.82 $\pm$ 10.08
BSA (m ²)	1.87 $\pm$ 0.16	1.93 $\pm$ 0.10

Significant differences in $\text{VO}_{2\max}$ in relative values ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) were detected between running and cycling tests for both groups (table 2). Climbers had higher $\text{VO}_{2\max}$ during running (56.1 $\pm$ 9.3) versus cycling (53.3 $\pm$ 9.3). On the contrary, MTB riders had higher $\text{VO}_{2\max}$ during cycling (54.7 $\pm$ 7.3) as compared to running (51.8 $\pm$ 8.1). $\text{VO}_{2\max}$ in absolute values ($\text{l}\cdot\text{min}^{-1}$) revealed significant differences between tests only for MTB riders, who reached higher values during cycling (4.15 $\pm$ 0.56 vs. 3.82 $\pm$ 0.61) (table 2).

Table 2. $\text{VO}_{2\max}$ during running and cycling (mean $\pm$ SD).

	$\text{VO}_{2\max}$	running	cycling
	($\text{l}\cdot\text{min}^{-1}$)	4.16 $\pm$ 0.73	3.96 $\pm$ 0.65
Climbers (n=17)	($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)	56.1 $\pm$ 9.4	53.3 $\pm$ 9.3*
	($\text{l}\cdot\text{min}^{-1}$)	3.82 $\pm$ 0.61	4.15 $\pm$ 0.56*
MTB riders (n=17)	($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)	51.8 $\pm$ 8.1	54.7 $\pm$ 7.3*

* $p < .05$, Running vs. Cycling

$\text{HR}_{\max}$ reached higher values ($p < .05$) for climbers during running and for MTB riders during cycling. The time till exhaustion was longer during cycling, compared to running for both groups and longer for MTB riders compared to climbers in cycling test ($p < .05$). Maximal Ventilation ($\text{VE}_{\max}$) data seemed to be significantly increased during cycling compared to running for both climbers and MTB riders ($p < .01$ and $p < .05$ respectively), but no significant differences were observed between the two groups. Respiratory Exchange Ratio (RER) was significantly higher during cycling, compared to running only for climbers ($p < .001$, $p < .01$, $p < .05$) and no differences were observed between the groups (Table 3). No significant differences were detected for maximal lactate concentrations between running and cycling, or climbers and MTB riders (table 3).

Table 3. Time to Exhaustion (T.E.), Maximum heart rate (HR_{max}), ventilation maximum (VE_{max}), respiratory exchange ratio (RER) and Blood Lactate (BLa) during running and cycling (mean ±SD)

	VO _{2max}	running	cycling
T.E (min)	Climbers (n=17)	13.7±1.7	15.7±2.3***
	MTB riders (n=17)	13.2±1.9	17.2±1.6*** [#]
HR _{max} (b·min)	Climbers (n=17)	196.06±8.1	187.3±9.5*
	MTB riders (n=17)	182.9±12.8	191.1±11.2*
VE _{max} (l·min ⁻¹)	Climbers (n=17)	146.5±22.7	161.8±26.5**
	MTB riders (n=17)	136.2±19.7	147.5 ±29.3*
RER	Climbers (n=17)	1.15±0.08	1.20±0.08*
	MTB riders (n=17)	1.17±0.08	1.20±0.07
BLa (mmol·l ⁻¹)	Climbers (n=17)	9.6±2.7	9.7±1.9
	MTB riders (n=17)	9.3±2.4	11.2±2.2

*p< .05, Running vs. Cycling

**p< .01, Running vs. Cycling

***p< .001, Running vs. Cycling

[#]p< .05, Climbers vs. MTB riders

Results showed no significant differences at the maximum speed during treadmill test between the two groups (table 4). Contrarily, maximum load during cycling test was higher (p<.05) for MTB riders compared to climbers (table 4).

Table 4. Maximum Speed (Km·h⁻¹) during running & Maximum Work Load (Watt) during cycling (mean ±SD)

	Running Maximum Speed (km·h ⁻¹)	Cycling Maximum Work Load max (Watt)
Climbers (n=17)	13.1±1.9	289.7±53.0
MTB riders (n=17)	13.0±1.9	325.0±38.5 [#]

[#]p< .05, Climbers vs. MTB riders

Energy cost was calculated by plotting VO₂ against running velocity. VO₂ values at submaximal speeds of 8, 10 and 12 km/h showed no significant differences among climbers and MTB riders during the treadmill test (fig. 1).

Fig. 1

Lower VO₂ values (ml·min⁻¹) and consequently lower energy cost resulted for MTB riders compared to climbers (p<.05) at the 100 watt and 150 watt load during the cycling test (fig. 2).

Fig. 2

Although no statistical significances were observed, oxygen uptake values, expressed as percentages (%) of running VO_{2max} , showed a tendency for MTB riders to run at higher percentages of their running VO_{2max} compared to climbers, during all three submaximal running loads (fig. 3).

Fig. 3

Contrarily, MTB riders performed at lower percentages of their cycling VO_{2max} compared to climbers during cycling, at all three submaximal loads (fig. 4).

Fig. 4

Additionally, cycling VO_{2max} values expressed as a percentage of the running VO_{2max} , showed that MTB riders could reach higher values during cycling tests, compared to running tests exceeding the 100%, in contrast with climbers, whose VO_{2max} has been underestimated during cycling compared to running (-5%) (table 5).

Table 5. Cycling $\text{VO}_{2\text{max}}$ expressed as percentage (%) of running $\text{VO}_{2\text{max}}$ (mean $\pm$ SD)

		cycling $\text{VO}_{2\text{max}}$ (%)
Climbers (n=17)	($\text{l}\cdot\text{min}^{-1}$)	94.9
	($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)	95.1
MTB riders (n=17)	($\text{l}\cdot\text{min}^{-1}$)	108.6
	($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)	105.4

Discussion

The present study compared energy cost between two different groups (climbers & MTB riders) during running and cycling. Energy cost was assessed at three submaximal running speeds and cycling loads.

There was an extensive research concerning the running economy in runners (Morgan et al., 1989; Daniels et al., 1992; Morgan et al., 1992; Saunders et al., 1992; Fletcher et al., 2009) and energy cost during cycling (Niemela et al., 1980; Lucia et al., 2000; McDaniel et al., 2002; Impellizzero et al., 2007; Tokui et al., 2008; Leirdal et al. 2011). As far we know there is no previous research that investigated the comparison of submaximal energy cost and maximal oxygen uptake between the above group of athletes during both running and cycling.

With similar physical and anthropometric characteristics, both groups had no significant differences in their $\text{VO}_{2\text{max}}$ values expressed in absolute (l/min) or body mass related values ($\text{ml}/\text{kg}/\text{min}$), neither during running nor during cycling. On the other hand significant differences in $\text{VO}_{2\text{max}}$ revealed when compared running with cycling for each group separately. MTB athletes presented significant higher $\text{VO}_{2\text{max}}$, both in absolute and related to body mass values, during cycling as compared with running ($p<.05$). This was not apparent for climbers who presented higher $\text{VO}_{2\text{max}}$ values during running as compared with cycling, although this was monitored only in relation to body mass values ($p<.05$).

It is well known that, during maximal performance, cycling produces a lower O_2 uptake at least compared with running (Åstrand & Rodalh, 1986; Carter et al., 2000; Kravitz et al., 1997; Zeni et al., 1996). However, Hermansen & Saltin (1969) reported no differences in $\text{VO}_{2\text{max}}$ between trained and untrained subjects when comparing cycling and running, but in their study the untrained subjects were familiar in cycling. In persons who have no familiarization with cycling before, a maximal test on the cycle ergometer may be undesirable as a method to assess maximal oxygen uptake. For ordinary subjects reported values of $\text{VO}_{2\text{max}}$ with running tests are on the average 4 to 8 percent higher than with cycling (Åstrand & Rodalh, 1986). This phenomenon could be caused by the activation of a larger muscle mass during running compared with exercise using the legs only. Motivation and stimulation is an additional important issue during maximal tests. When a person runs on the treadmill is easier to reach exhaustion, as he is forced to follow the speed of the belt or jump off, instead of cycling where revolution per minute should be kept by the subjects themselves. In our study all subjects were well motivated both during running and cycling.

Participants' cycling $\text{VO}_{2\text{max}}$ expressed as percentages (%) of their running $\text{VO}_{2\text{max}}$ values revealed that MTB riders exceeded the 100% of their running $\text{VO}_{2\text{max}}$, in absolute and related to body mass values (108.6 & 105.4 respectively). Instead, during cycling climbers reached only 94.9% and 95.1% (in absolute and related to body mass values, respectively) of their running $\text{VO}_{2\text{max}}$. From our findings we could assume that, although climbers use cycling for cross-training, the lack of specialization in cycling results in underestimated $\text{VO}_{2\text{max}}$ during cycling test. On the other hand, it seems that specifically trained athletes in cycling as MTB riders can reach or even exceed the $\text{VO}_{2\text{max}}$ values assessed during running.

Energy cost during running was assessed at three submaximal loads on the treadmill (8, 10 and 12 km/h). Although a tendency of higher VO_2 values were noticed for MTB riders, statistical analysis revealed no significant differences between the two groups. The absence of significant differences may be due to the fact that MTB riders utilize running as a part of their training program and although in a smaller percentage than climbers do, is well enough to present similar results between the two groups.

On the contrary, cycling at three submaximal loads (100, 150 & 200 Watts) revealed significant differences in energy cost. MTB riders had significantly lower oxygen consumption ($p<.05$) and eventually lower energy cost during the first two submaximal loads (100 & 150 Watt). The above findings could be attributed by the fact that MTB riders' specialization in cycling is more important than specialization in running, which is a natural activity of human movement.

Significant differences were observed also in heart rate max (HR_{max}) for both groups ($p<.05$). During maximal running both groups had higher HR values compared with cycling. On the contrary, maximal ventilation was higher during cycling compared with running for both groups ($p<.01$, $p<.05$). These findings could be explained by the fact that during cycling anaerobic glycolysis is much more activated than in running (Nagle et al., 1971). RER was also higher during cycling compared to running, but only climbers' group showed significantly higher values ($p<.05$).

A comparison between running and cycling or within groups showed no significant differences for lactic acid, although cycling differs from running by having a bigger participation of the anaerobic mechanisms. Previous investigations showed that during cycling anaerobic glycolysis is much more activated than in running (Nagle et al., 1971), and therefore higher blood lactate concentrations were expected. This was apparent for MTB riders, but statistical analysis revealed no significant differences.

Eventually maximal exercise performance, expressed as the total exercise time for each participant, was higher ($p < .001$) for cycling than running for both groups. The comparison between climbers and MTB riders, revealed that during cycling, MTB riders managed to cycle more time until exhaustion than climbers (1,5 minute plus approximately). These findings are in accordance with maximal workload results, that showed MTB riders were able to complete the cycling test at significant greater load ($p < .05$, +35.3 watts) than climbers. These results could be attributed to the fact that although both groups utilize similar exercise models (running & cycling) in their training program, specialization only in cycling of MTB riders was crucially important to reveal significant differences.

Conclusions

Our study showed that MTB riders presented lower energy cost as compared to mountain climbers during submaximal cycling. However, no significant differences appeared in energy cost between the two groups during running. These findings reveal that, although running and cycling are exercise patterns for both MTB athletes and climbers, specialization of MTB riders in cycling gives a significant advantage of lower energy cost during cycling.

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