DOI: 10.15386/cjmed-675

ENERGY SYSTEMS EFFICIENCY INFLUENCES THE RESULTS OF 2,000 M RACE SIMULATION AMONG ELITE ROWERS

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Abstract

Hypothesis. *Energy efficiency within an elite group of athletes will ensure metabolic adaptation during training.*

Objectives. *To identify energy system efficiency and contribution according to exercise intensity, and performance obtained during a 2,000 m race simulation in an elite group of rowers.*

Method. *An observational cross-sectional study was conducted in February 2016 in Bucharest, Romania, on a group of 16 elite rowers. Measurements were performed through Cosmed Quark CPET equipment, and Concept 2 ergometer, by conducting a VO2max test over a standard rowing distance of 2,000 m. The analyzed parameters during the test were: HR (bpm), Rf (b/min), VE (l/min), VO2 (ml/min), VCO2 (ml/min), VT (l), O2exp (ml), CO2exp (ml), RER, PaCO2 (mmHg), PaO2 (mmHg), Kcal/min, FAT (g), CHO (g), from which we determined the ventilatory thresholds, and the energy resource used during the specific 2,000 m rowing distance (ATP, ATP+CP, muscle glycogen).*

Results. *We performed an association between HR (180.2±4.80 b/min), and carbohydrate consumption during the sustained effort (41.55±3.99 g) towards determining the energy systems involved: ATP (3.49±1.55%), ATP+CP (18.06±2.99%), muscle glycogen (77.9±3.39%). As a result, completion time (366.3±10.25 s) was significantly correlated with both Rf (p=0.0024), and VO2 (p=0.0166) being also pointed out that ≥5 l VO2 value is associated with an effort time of ≤360 s. (p=0.040, RR=3.50, CI95%=1.02 to 11.96). Thus, the average activation time among muscle ATP (12.81±5.70 s), ATP+CP (66.04±10.17 s, and muscle glycogen (295±9.5 s) are interrelated, and significantly correlated with respiratory parameters.*

Conclusions. *Decreased total activity time was associated with accessing primary energy source in less time, during effort, improving the body energy power. Its effectiveness was recorded by early carbohydrates access, as a primary energy source, during specific activity performed up to 366 seconds.*

Keywords: Rowers, ATP, Glycogen, Oxygen, biological processes

Introduction

Activity specificity is one of the most important aspects analyzed in the training period of an elite athlete. Training timing in order to increase the overall capacity of the body represents the main form which will influence the athlete's exercise capacity.

Rowing is a sport whose practice depends on the environment conditions such as the temperature, humidity, rainfall and wind. At the same time, other forms of activities can be developed in a special surrounding that will depend much less on the environment conditions,

Manuscript received: 12.04.2016
Received in revised form: 13.06.2016
Accepted: 22.06.2016
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namely, indoor practice using Concept 2 ergometer type [1]. Such practice is considered an accurate method used in order to determine the athletes' exercise capacity, based on minimizing the influence of external factors such as environment, and techniques factors. In fact, numerous studies have examined through maximal VO_{2max} test the energy systems contribution and lactate response correlated with the effort performed [2-4].

An increased number of papers have studied the energy systems, starting with a research protocol whose activity and/ or intensity have been established before testing. Few papers have studied these elements under specific activity without restricting the parameters mentioned [5-6]. Thereby it should be noted that a high intensity effort will take place over a period of 1-8 minutes [7] being related to adenosine triphosphate (ATP) released both by anaerobic and aerobic path. However, it is suggested that within a period of activity ≤90 s, the anaerobic system will provide the energy needed, while a balance within the energy systems can be observed during an intensity effort that exceeds 90 s [8-9].

Hypothesis

Establishing energy efficiency in an elite group of athletes will ensure metabolic efficiency during training, reported in aerobic and anaerobic effort zone and energy distribution. Energy input during exercise will be directly proportional to the total activity time, particularly in activity groups whose completion time does not exceed 365 seconds.

Method

A cross-sectional study was conducted in February 2016 in Bucharest, Romania, on a group of 16 elite male athletes after receiving verbal acceptance, from the athletes, to participate in the study and written acceptance from the administration offices. A total of 16 elite male athletes, international level, were included in the study. Only male athletes were included in the study due to hormonal influences reported in the case of female rowers associated in different stages of the menstrual cycle. Furthermore, for this research stage we analyzed male rowers only. Measurements were performed through Cosmed Quark CPET equipment (Rome, Italy) and Concept 2 ergometer (Morrisville, United States), applying a maximal effort test (VO_{2max}) over a standard distance of 2,000 m. The following parameters were monitored: heart rate (HR -bpm), respiratory exchange ratio (RER), minute ventilation (VE -l/min), maximum rate of oxygen consumption (VO_2 -ml/min), carbon dioxide elimination rate (VCO2 -ml/min), metabolic equivalent (METS), tidal ventilation (VT -l), the amount of oxygen expired (O_{2exp} -ml), amount of carbon dioxide expired (CO_{2exp} -ml), end-tidal oxygen tension ($PetO_2$ -mmHg), end-tidal carbon dioxide tension ($PetCO_2$ -mmHg), partial pressure of carbon dioxide in the arterial blood ($PaCO_2$ -mmHg), partial pressure of oxygen in the arterial blood (PaO_2 -mmHg), the ratio of physiologic dead space over tidal volume (VD/VT), energy expenditure (Kcal/min), Lipid consumption (Fat –g%), Carbohydrate consumption (CHO –g/%) in order to determine the ventilatory thresholds, and the energy systems contribution during specific 2,000 m rowing distance (ATP, ATP+CP, muscle glycogen).

The VO_{2max} test was performed after a complementary activity conducted in order to adapt the body to exercise over a total time of 20 minutes, involving both basic elements in preparing the body for effort and ergometer specific activity at a predetermined intensity (55-85% HR) in order to simulate technically the effort to be performed. The test was carried out over a distance of 2,000 m without imposing a time limit for completion, or an effort developed in different intensity stages. VO_2 value, along with respiratory and metabolic parameters were determined through Cosmed Quark CPET equipment, while the heart rate value, representing the only cardiovascular parameter analyzed, was determined through Cosmed Bluetooth strip with direct transmission to the main device.

Statistical evaluation was performed using GraphPad Prism 5.0 software. Statistical indicators used were: average value (mean), median value (median), standard deviation (SD), standard error (SE), and coefficient of variation (CV). For data normalization Shapiro-Wilk test (w) was used. At the same time, in order to demonstrate associations type hypothesis the Pearson correlation (r) was applied, whereas in order to determine the differences between the study groups, we applied the student t-test (unpaired). Level of significance, $p<0.05$ was considered statistically significant, while the obtained values illustration was conducted via mean value and standard deviation (mean±SD).

Results

A total number of 16 elite male athletes were included in the study. The average age was 19.69±2.05 years, while the anthropometric data showed an average weight of 94.44±10.15 kg, and 193.1±6.42 cm height. The average 2,000 m completion time, in the study group, was 366.3±10.25 s. Therefore, muscle ATP was the main form of energy, on average, over a period of 12.81±5.70 s. A change in the energy system occurred at an average heart rate of 148.3±15.15 b/min, accounting for 3.49±1.55% of the total energy provided during exercise. ATP+CP was the main form of energy distribution during 66.04±10.17 s, up to a heart rate value of 175.8±6.24 b/min accounting for 18.06±2.99% of the total energy provided. At the same time, the stage of aerobic energy supply is associated with accessing 100% carbohydrate, through the muscle glycogen. This source was the main energy form over an average period of 288.02±10.2 s, while the end of the effort was achieved at a mean heart rate of 190.2±5.71 b/min. Muscle glycogen was equivalent to 77.94±3.39% of the total energy provided during the race (Figure 1). Thereby the total energy consumption monitored during the 2,000 m race has reached 172.6±16.63 kcal, represented through 41.55±3.99 g CHO, and 0.24±0.49 g fat.

Decreased exercise time by improving 2,000 m completion time, was associated with increased energy consumption over a minute (10.47±3.74 kcal), through p=0.0038, r=-0.6797, CI95%=-0.8792 to -0.2774. Similar actions were identified in the case of elevated RER value (≥1.0), which is associated with carbohydrate consumption, being highlighted an increased total energy consumption in association with a total 2,000 m completion time under 365 s, and an increased value of over 25 kcal/min energy consumption (p=0.0105, r=-0.6194, CI95%=-0.8532 to -0.1784). More similar results are highlighted in Table I.

A short activity time was associated with a higher VO2 value (4.97±0.44 l/min). Also, parameters such as VT (3.112±0.4819 l) and O2exp (542.7±88.57 ml/min), by relating low determined values, along with an increase CO2exp value (123.3±21.33 ml/min) were associated with a reduced effort time.

Muscle ATP function (12.81±5.70 s) indicated a direct proportional increase with the final value of carbohydrates consumption during the race (41.55±3.99 g). Muscle ATP was associated with prolonged activity time in association with increased VE (176±15.24 l/min), respectively VCO2 (5559±474 ml/min) values (Figure 2).

Table I. Measurements of statistical significance among the determined parameters.

Correlated parameters								
Parameter 1	Parameter 2	p value	95% Confidence Interval of the Difference		Median	CV%	Shapiro Wilk - W	Passed normality test?
			Lower	Upper				
2,000 m time (365.4 s)	VO_2 (ml)	0.0166	-0.839	0.1300	4981	10.74	0.9261	YES
						8.95	0.9348	YES
	VT (l)	0.0001	-0.9382	-0.5618	3.040	10.74	0.9261	YES
						15.49	0.8314	NO
	CO_{2exp} (ml)	0.0001	-0.9408	-0.5768	119.8	10.74	0.9261	YES
						7.29	0.8488	NO
	O_{2exp} (ml)	0.0001	-0.9388	-0.5649	526.7	10.74	0.9261	YES
						16.32	0.8239	NO
Muscle ATP (12 s)	CHO/race (g)	0.0015	0.3582	0.8981	40.84	44.54	0.8172	NO
						9.62	0.9355	YES
	VE (l/min)	0.0459	0.01264-	-0.8005	176.9	44.54	0.8172	NO
						8.66	0.9739	YES
	VCO_2 (ml/min)	0.0055	0.2429	0.8705	5514	44.54	0.8172	NO
						8.53	0.9552	YES
ATP+CP (17.14 %)	VT (l)	0.0192	0.1144-	0.8344	3.040	16.59	0.8903	YES
						15.49	0.8314	NO
	O_{2exp} (ml)	0.0169	0.1280-	0.8385	526.7	16.59	0.8903	YES
						16.32	0.8239	NO
A T P + C P (22.05 s)	PaO_2 (mmHg)	0.033	0.05173	0.8142	113.3	10.85	0.9146	YES
						1.76	0.9514	YES
	CO_{2exp} (ml)	0.0332	0.05173	0.8142	119.8	10.85	0.9146	YES
						7.29	0.8488	NO
M u s c l e Glycogen (293.4 s)	VT (l)	0.0001	-0.9382	-0.5618	3.040	2.80	0.9463	YES
						15.49	0.8314	NO
	O_{2exp} (ml)	0.0001	-0.9388	0.5649	526.7	2.80	0.9463	YES
						16.32	0.8239	NO
	CO_{2exp} (ml)	0.0001	-0.9408	0.5768	119.8	2.80	0.9463	YES
						7.29	0.8488	NO

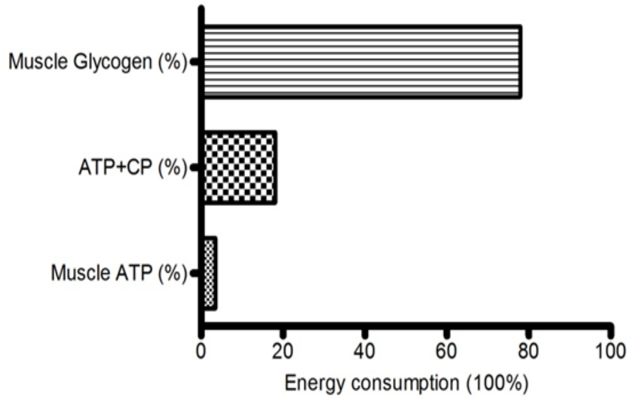

Figure 1. The predominance of the energy systems – 2,000 m.

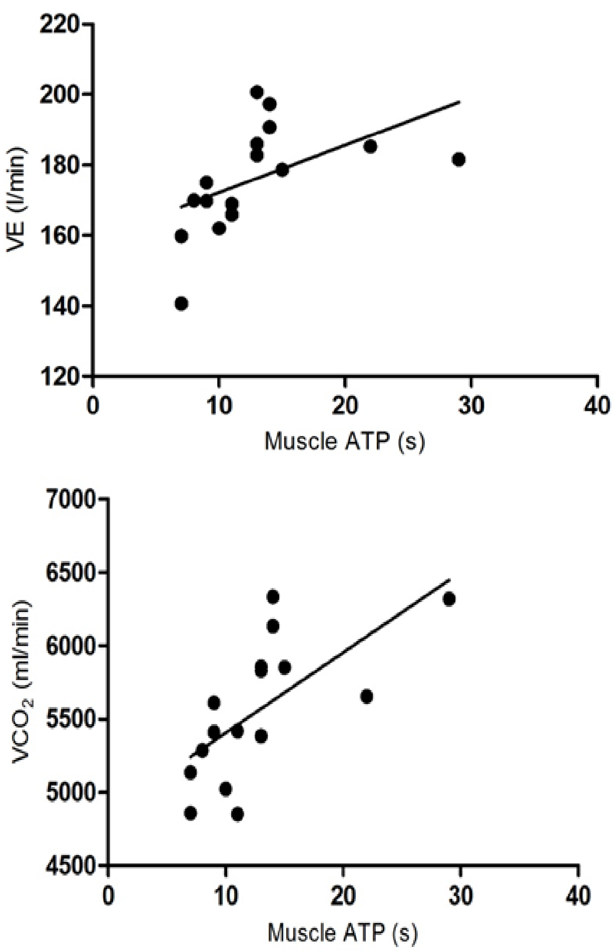

Figure 2. Relating muscle ATP (s), VE, VCO_2

ATP rephosphorylation function (ATP+CP), per time unit, indicates a decrease percentage of muscle glycogen contribution, during exercise, through increased ATP+CP energy system action time (p=0.0022, r=-0.7059, CI95%=-0.8902 to 0.3233). Similar results regarding ATP+CP, and RER where obtained, relating a decreased total activity time within the mentioned energy system associated to RER above 1.10. Thus, the contribution of ATP+CP (66.04±10.17 s) associates a directly proportional increase with parameters such as VT (3.11±0.48 l), and O_{2exp} (542.7±88.57 ml/min). At the same time, increasing energy production through ATP+CP system was associated with low VO_2, VCO_2, CO_{2exp} values, while PaO_2 value (113.1±1.99 mmHg) dropped by increasing the energy provided through ATP+CP (p=0.0333, r=-0.5336, CI95%=-0.8141 to -0.05144). Furthermore, muscle glycogen has been identified as the main aerobic energy function (288.02±10.2 s). Early work efficiency was determined by relating the carbohydrates accessing HR (175.8±6.24 b/min), and decreased total exercise time (366.3±10.25 s) in direct correlation with decreased VT, O_{2exp} and CO_2 values.

A low respiratory rate (Rf) associates an increased VT value (p=0.0002, r=-0.7948, CI95%=-0.9258 to -0.4934). Similar data were identified within O_{2exp} (p=0.0004) and CO_{2exp} (p=0.0001) parameters, while a growth in respiratory frequency was associated to a certain increase in $PaCO_2$ (p=0.0262), and PaO_2 (p=0.0093). Increasing VE values were correlated to an elevated VO_2 (p=0.0012, r=0.7356, CI95%=0.3774 to 0.9023), VCO_2 (p=0.0012, r=0.7327, CI95%=0.3720 to 0.901), VT (p=0.0105, r=0.6192, CI95%=0.1780 to 0.8531) and O_{2exp} value (p=0.0086, r=0.6319, CI95%=0.1982 to 0.8587).

Discussion

During this study we differentiated the energy systems in a study group represented by elite rowers. Therefore the athletes' adaptation, as well as metabolic changes, during 2,000 m completion time were associated with both respiratory and metabolic parameters through the energy systems. Based on our knowledge, this is one of the only papers that recently have studied the energy systems evolution during indoor 2,000 m race simulation [3-4,10-14]. The obtained results indicate an anaerobic energy system contribution, through phosphates, ATP, and phosphocreatine, to a total of 33%, and an aerobic energy system contribution of 77% from the total energy demands during the 2,000 m race simulation, represented by muscle glycogen degradation during exercise, accounting similar results to those identified in the literature [13-14].

The fastest energy source identified in the study group, during exercise was represented by adenosine triphosphate hydrolization (ATP), an action also reported in other papers [15]. However due to low concentration found in the body, different mechanisms are used to maintain muscle contraction [15-16]. The first phase of the energy system is considered to be the phosphates, phosphocreatine and ATP use in order to sustain energy distribution during the beginning of the effort, which is characterized through high intensity activity, and oxygen debt [17], related in our study to a RER above 1.0, and an elevated carbohydrate consumption. The following energy process relies on aerobic degradation of carbohydrates, pyruvic acid or lactic acid via glycolysis [18], characterized in time unit to a total of 288.02±10.2 s of carbohydrate distribution reported to a RER value above 1.0, during the 2,000 m completion time. The third energy distribution process is the anaerobic oxidative metabolism state as involving sources represented by carbohydrates, lipids, and in some cases, proteins, in the presence of oxygen [19], a process which is not reported during a maximal effort, either in literature or in our study. From a practical standpoint, relating to the study, the beginning of the effort is characterized by accessing carbohydrates, due to high RER, and oxygen debt. However, sustenance of the effort, in energy terms, will be conducted through ATP and CP, but the energetic value and its effectiveness appears to be inferior compared to the aerobic pathway, due to total activity time obtained in the study group, with a reported low 2,000 m completion time in association with high ATP muscle energy and muscle glycogen energy contribution [20].

Aerobic production of energy from sources such as carbohydrates and lipids is affected by VO_2 value, representing the amount of oxygen taken up by the body [21], aspect which is reported through the paper due to high amount of oxygen used during the effort. Moreover, the determined amount of CO_2 produced by the body will be directly proportional to the use of macronutrient during exercise [21], as in the study conducted, being possible an association between CO_2, and increasing proportion of carbohydrates. In terms of energy efficiency and the body's reaction, energy release rate will be a basic element towards determining and maintaining a high level of force, expressed through watts (W) [22]. During athletes' maximal effort, the rate of glycolysis may be increased by up to 100 times compared to the rest period [23], the actual period of energetic activity in this system being still low. A reduction in pH will inhibit the activity of glycolytic enzymes, having a precisely effect on reducing the rate of ATP resynthesize [15], which, based on the obtained results, will be associated to ATP resynthesis (66.04±10.17 s). However, VO_2 value, during the beginning of the effort would reflect the transport of oxygen and the body's metabolic evolution [24]. As a result, an elevated contribution of the aerobic system is significant during specific activity that exceeds 90 seconds, being reported a decline in the importance of anaerobic system during increased total effort time [25], as shown in the conducted study with a proportion of 33% of the total energy demands. It is also seen that the anaerobic energy system will support short duration activity, especially in the beginning of the effort and the end of the 2,000 m race, while the aerobic energy system will support the mentioned effort in a much smaller proportion, due to its ability to react in relationship with the requested effort intensity in the beginning and the end of the effort [25]. Thus, parameters such as Rf, O_{2exp}, CO_{2exp}, and VT, parameters that are proportional with the race completion time [26], will be proportional to the effort volume and energy system efficiency during a maximal effort. As a result, increasing muscle ATP activity time (s) is associated with increased VO_2, respectively VCO_2 values, while increased ATP+CP total activation time is correlated with increased VT and O_2 values, therefore, being identified an increasing proportion of fat used during high intensity physical effort [20, 27].

Conclusions

The results of the study groups indicated a decreased total activity time by increasing the proportion of energy from muscle glycogen, through increasing the anaerobic system efficiency, and the importance of aerobic system during an effort with total activity time between 320-380 seconds. Therefore, in this paper, short 2,000 m completion time was associated with increased period of muscle ATP (%/s), as anaerobic energy system, along with high muscle glycogen energy contribution (%/s), representing the aerobic energy system, associated to a reduced amount of fat consumed during maximal effort, due to metabolic adaptation.

Acknowledgements.

The study uses partial results from the first author's paper presented at the International Marisiensis Congress, carried out at the University of Medicine and Pharmacy of Târgu Mureş, Romania, in 2016.

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