Video Article

Determining the Contribution of the Energy Systems During Exercise

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Abstract

One of the most important aspects of the metabolic demand is the relative contribution of the energy systems to the total energy required for a given physical activity. Although some sports are relatively easy to be reproduced in a laboratory (e.g., running and cycling), a number of sports are much more difficult to be reproduced and studied in controlled situations. This method presents how to assess the differential contribution of the energy systems in sports that are difficult to mimic in controlled laboratory conditions. The concepts shown here can be adapted to virtually any sport.

The following physiologic variables will be needed: rest oxygen consumption, exercise oxygen consumption, post-exercise oxygen consumption, rest plasma lactate concentration and post-exercise plasma peak lactate. To calculate the contribution of the aerobic metabolism, you will need the oxygen consumption at rest and during the exercise. By using the trapezoidal method, calculate the area under the curve of oxygen consumption during exercise, subtracting the area corresponding to the rest oxygen consumption. To calculate the contribution of the alactic anaerobic metabolism, the post-exercise oxygen consumption curve has to be adjusted to a mono or a bi-exponential model (chosen by the one that best fits). Then, use the terms of the fitted equation to calculate anaerobic alactic metabolism, as follows: ATP-CP metabolism = A_1 (mL . s^{-1}) x t_1 (s). Finally, to calculate the contribution of the lactic anaerobic system, multiply peak plasma lactate by 3 and by the athlete's body mass (the result in mL is then converted to L and into kJ).

The method can be used for both continuous and intermittent exercise. This is a very interesting approach as it can be adapted to exercises and sports that are difficult to be mimicked in controlled environments. Also, this is the only available method capable of distinguishing the contribution of three different energy systems. Thus, the method allows the study of sports with great similarity to real situations, providing desirable ecological validity to the study.

Video Link

The video component of this article can be found at http://www.jove.com/video/3413/

Protocol

Introduction

The energy necessary for sustaining a physical effort comes from two metabolic sources: aerobic and anaerobic metabolism. While the aerobic metabolism is more efficient than the anaerobic metabolism (i.e., it produces a higher amount of ATP per mol of substrate), producing energy through anaerobic metabolism can provide a high amount of energy in a very short time period. This may be decisive for any situation that requires extremely fast movements.

Each sport has specific characteristics in terms of motor skills that confer unique physiologic and metabolic demands for that particular sport. The most important aspect of the metabolic demand is the relative contribution of the energy systems to the total energy required for the activity. To determine the specific demand of each sport is crucial for developing optimized training models, nutritional strategies and ergogenic aids that may maximize athletic performance.

Some sports are relatively easy to be reproduced in a laboratory setting, thus it is possible to create a controlled environment in which athletes can be evaluated. This is the case of running and cycling, for example. Predictable movements compose these sports and, therefore, they are easy to be studied. Using some simple equipment, it is possible to mimic quite exactly the same movements that athletes perform in real

situations, such as training and competitions. Indeed, these sports have been more extensively studied by exercise scientists and benefited with a more complete and reliable scientific literature.

On the other hand, a number of sports are much more difficult to be reproduced in laboratory. These sports are unpredictable and dependent on the actions of the partner(s) and opponent(s). This leads to an inability to accurately reproduce the competitive conditions in the lab and an inability to assess these athletes in field during either training or competition. Maybe because of these problems, they have received much less attention from the scientists. This is the case of the majority of team sports and many individual sports[1].

Considering these aspects, we aimed to describe how to assess the differential contribution of the energy systems in sports that are difficult to reproduce in controlled laboratory conditions. Because judo is a very complex and unpredictable sport, we will use judo as an example. However, the concepts shown here can be adapted to a number of different sports.

1. Physiological Measurements at Rest

1. Measure the athlete's body mass before he/she initiates exercising.
2. Before initiating the exercise, collect a small resting blood sample from earlobe or fingertip and keep it on ice until the whole experimental procedure is finished.
3. Following, place the calibrated portable gas analyser at the most convenient position, which depends on the movements that the athlete will perform, and record resting or baseline oxygen consumption for five minutes. During the baseline measurement, the athlete has to stay quiet standing on his/her feet (if the exercise will be performed in a standing position) or sat in the equipment that will be used (if the exercise will be performed in a cycloergometer or in any similar equipment).

2. Physiological Measurements during Exercise

1. After collecting resting blood sample and resting oxygen consumption, you may ask the athlete to start the specific exercise that you are studying. The portable gas analyser has to be placed in a position that will no interfere with exercise and that exercise will not damage the equipment. Continue measuring oxygen consumption throughout the exercise period.

3. Physiological Measurements after Exercise

1. After collecting exercise oxygen consumption data, keep recording oxygen consumption for ten minutes before shutting the equipment down. Always recalibrate the gas analyser if more than one athlete is being evaluated in the same day.
2. In order to identify the peak plasma lactate after exercise, collect small blood samples immediately after exercise, three, five and seven minutes after exercise. Keep them on ice until analysis.

4. Blood Samples Processing and Peak Plasma Lactate Determination

1. All blood samples must be placed in microtubes containing a similar volume of a 2% NaF solution (i.e., if you are collecting 25 μL of blood, place it in 25 μL of 2% NaF).
2. When data collection is finished, separate plasma from erythrocytes by spinning the samples for 5 minutes at 2000 g at 4°C.
3. Plasma lactate can be determined through a variety of methods2,3. In our lab, we use the electrochemical method with the aid of an automatized lactate analyser (Yellow Springs 1500 Sport, Ohio).

5. Calculations

1. Calculate the net energy generated by the aerobic metabolism by subtracting rest oxygen consumption from exercise oxygen consumption. Oxygen consumption at rest is obtained by multiplying the average of the last 30 seconds of baseline oxygen consumption by the total exercise duration time. Then, calculate the area under the curve of exercise oxygen consumption by using the trapezoidal method. Finally, subtract the resting oxygen consumption from exercise oxygen consumption.
2. The contribution of the anaerobic alactic metabolism (i.e., the ATP-CP pathway) can be considered as the fast component of excess post-exercise oxygen consumption[4-6], as illustrated in **Figure 1.** Calculate the energy produced by the alactic system by fitting the kinetics of post-exercise oxygen consumption to a bi- or a monoexponential curve. This can be done with the aid of mathematics' software (e.g. Microcal Origin version 7.0). Choose by the mono- or bi-exponential curve based on the model that best fits to your data set (i.e., the lowest residue). Then, use the terms provided by the fitted equation (**Equation 1**) to calculate alactic contribution according to **Equation 2**.
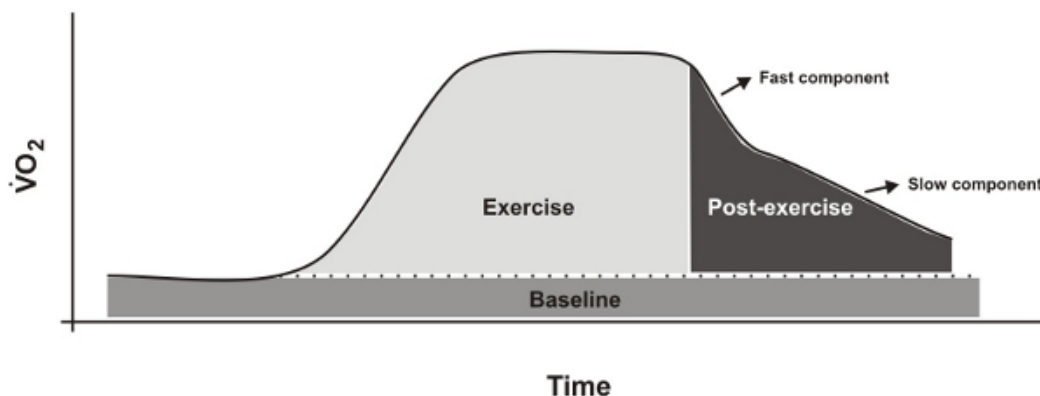
Figure 1. Schematic illustration of a typical oxygen consumption curve obtained at rest, during, and after exercise.
Equation 1:

$$\mathring{V}O_{2(t)} = \mathring{V}O_{2baseline} + A_1[e^{-(t-\delta)/\tau_1}] + A_2[e^{-(t-\delta)/\tau_2}]$$

Equation 2:

$$\text{Alactic contribution} = A_1 \cdot \tau_1$$

where $V_{O2(t)}$ is oxygen uptake at time t, $V_{O2baseline}$ is oxygen uptake at baseline, A is the amplitude, δ is the time delay, τ is a time constant, and $_1$ and $_2$ denote the fast and slow components, respectively.

3. To calculate the contribution of the lactic anaerobic system, it is assumed that 1 mM of lactate above the resting values corresponds to 3 mL of oxygen consumed per kilogram of body mass[7]. Thus, calculate delta peak plasma lactate (i.e., peak plasma lactate minus resting plasma lactate) and multiply it by 3 and by the athlete's body mass. The obtained value of oxygen in mL is then converted to L and to energy (kJ), assuming that each 1 L of O_2 is equal to 20.92 kJ.
4. Finally, the result obtained by each energy system is summed so you have the total energy expenditure during the activity and the relative contribution of each of system can be calculated.

6. Representative Results

Figure 2 depicts a representative curve of oxygen consumption at rest, during exercise and after exercise. In the example used here, athletes performed three different judo techniques (*o-uchi-gari, harai-goshi* and *seoi-nage*) for five minutes (one throw every 15 s)[8]. This is a typical response to intermittent exercise. After the calculations, we obtained the final results on the contribution of the energy systems during judo exercises (**Table 1**).

Additional representative results are displayed in **Table 2**. In this example, indoor rock climbers of different competitive levels (i.e., recreational vs. elite) were assessed during a low-difficulty climb route. Individual results for one elite athlete and one recreational athlete are shown (**Table 2**).

	Seoi-nague		*Harai-goshi*		*O-uchi-gari*	
	kJ	*%*	*kJ*	*%*	*kJ*	*%*
Anaerobic alactic	46 ± 20	16.3 ± 2.8	43 ± 21	16.1 ± 2.7	36 ± 22	14.6 ± 2.8
Aerobic	223 ± 66	82.2 ± 2.9	211 ± 66	82.3 ± 3.8	196 ± 74	84.0 ± 3.8
Anaerobic lactic	4 ± 2	1.5 ± 0.7	5 ± 5	1.6 ± 1.4	4 ± 4	1.5 ± 1.1
Total	**273 ± 86**	-	**259 ± 91**	-	**237 ± 99**	-
Total (kJ/min)	**51.9 ± 8.7**	-	**49.4 ± 8.9**	-	**45.3 ± 19.6**	-

Table 1. Representative results of total energy expenditure and the contribution of the energy systems during three different judo exercises.

Competitive Level	Aerobic (%)	Anaerobic Lactic (%)	Anaerobic Alactic (%)	Total (kJ)	Total (kJ/s)
Elite	40	8	52	70.4	1.00
Recreational	40	15	45	96.1	1.15

Table 2. Representative individual data of total energy expenditure and the contribution of the energy systems during a low-difficulty climb route.
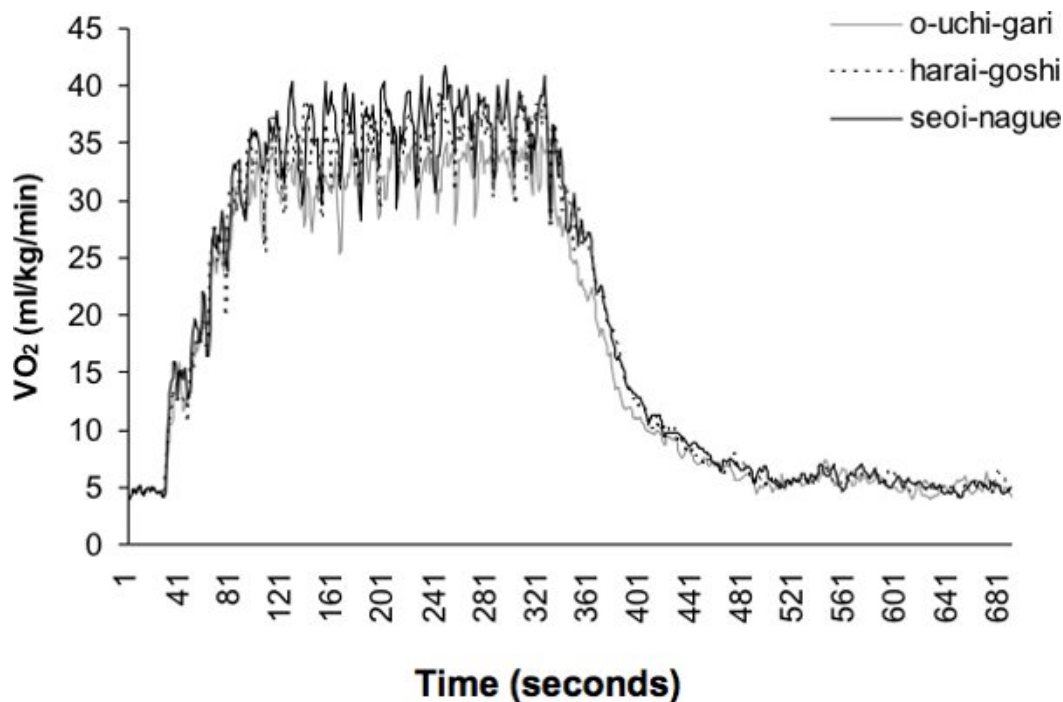
Figure 2. Representative results obtained during a 5-minute judo exercise.

Discussion

The method we have shown hare can be used for both continuous and intermittent exercise. The great advantage of the method is that it can be adapted to exercises and sports that are difficult to be mimicked in controlled laboratory settings. Furthermore, this is the only available method capable of distinguishing the contribution of three different energy systems. Thus, the method allows the study of sports with great similarity to real situations, providing desirable ecological validity to the study[9]. For example, a recent study by Mello et al.[10] showed that the glycolytic contribution in a 2000 m on water rowing race is of only 7%, which means that rowing performance is mainly dependent on the aerobic metabolism. Similarly, a study by Beneke et al.[4] confirmed that the main source of energy during one of the most used anaerobic tests, the Wingate Anaerobic Test, is the anaerobic metabolism (20% aerobic; 30% alactic and 50% glycolytic). Recent studies by our group have also characterized the energy contributions of indoor climbing[6] and judo[8], as reported in this example. Indeed, the knowledge on the energetic contribution is critical for the development of ergogenic strategies, training organization or even for validating a test.

This method has some limitations. First, the cost of the equipment is somewhat high, and specialized trained personnel are required. Second, although most sports can be mimicked with this technique, it is not any type of exercise that can be studied using the portable gas analyzer. Finally, as plasma lactate does not exactly represent the total lactate produced by skeletal muscle during activity, the results obtained by this procedure can be considered as an estimative of the metabolic demand during exercise, rather than a precise quantification of the energetic contribution. Nonetheless, this is the only validated method available[11] capable of distinguishing the contribution of the three different energy systems.

Disclosures

The authors declare they have no conflict of interest regarding this study.

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