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Metabolic Responses to Prolonged Open Water Rowing: A Case Study

Dan A. Gordon, Anglia Polytechnic University

The present study examined the metabolic and physiological responses to a period of prolonged open water rowing during a 4950 Km rowing race across the Atlantic Ocean. A single male participant underwent laboratory-based assessments of maximal oxygen uptake (VO_2max) and lactate turnpoint on a slide mounted Concept II rowing ergometer. During this trial heart rate (HR) and Rating of Perceived Exertion (RPE) were recorded. Testing was undertaken 2 weeks prior to commencing the race. During the race, HR telemetry data was collected along with RPE. Results indicated that VO_2max was $5.36\text{ l}\cdot\text{min}^{-1}$ and lactate turnpoint (LaT) occurred at 84% VO_2max . Mean, standard deviation (SD) exercising HR during the race was 109.2 (14.7). Using linear regression equations between exercise, HR, and laboratory data the metabolic responses were determined. Power output during the race was 164.5 (48.2) Watts (W), corresponding to a sub-maximal VO_2 of $2.3\text{ l}\cdot\text{min}^{-1}$ (0.6). Respiratory Exchange Ratio (RER) was 0.87 (0.03). Calorific cost of exercise and rest were estimated to be 46.8 (3.4) and 13.0 (1.69) Kilojoules ($\text{kJ}\cdot\text{min}^{-1}$) respectively. Findings show there was an energy deficit of $\sim 18,133\text{ kJ}\cdot\text{day}^{-1}$, with the major fuel source based on RER data being fats. Overall the data provides an initial insight into the metabolic responses to this extreme endurance exercise.

The metabolic responses to exercise in excess of 2 hr, but less than 4 hr have been well documented (Davies & Thompson, 1979; Lucia, Hoyos, Carvajal, & Cicharro, 1998; Sjodin & Svedenhag, 1985). During such continuous aerobic exercise, energy expenditure has been estimated to be between 25,116 and 37,674 kJ respectively, corresponding to an exercise intensity of between 67 and 82% of maximal oxygen uptake (VO_2max) (Sjodin & Svedenhag). VO_2max is the measure of the maximal amount of oxygen that can be taken up and utilized for aerobic energy supply. Previous studies have ascertained that there is a significant and positive correlation between VO_2max and endurance performance (Noakes, 1991). Furthermore, this form of exercise has been shown to reduce whole body glycogen stores in a semilogarithmic fashion (Brooks & Mercier, 1994). The research examining the physiological effects of exercise in excess of 4 hr are, however, less clear. The energy cost of 14 days of running has been estimated to range between 25,513 and 27,418 $\text{kJ}\cdot\text{day}^{-1}$ (Hill & Davies, 2001), whereas the cost of cross-country ski training is 30,214 $\text{kJ}\cdot\text{day}^{-1}$ (Sjodin, Anderson, Hogberg, & Westerterp, 1994). The assessment of energy expenditure has massive implications for ultra-endurance sport. During such sports the metabolic demands imposed on the body are far greater than experienced during any other physical activity (Hill & Davies). Indeed during such events the energy expended is likely to be at the extremes of human tolerance for extended periods of time, resulting in an increased concern with regards to matching energy intake to energy expenditure. It is well established that inadequate nutrition and energy intake can be detrimental to both sports performance and general health and well being. Methods have therefore been established to determine the metabolic cost of sporting activities so as to be able to match dietary energy intake with energy expended during the exercise. To date though there has been no research conducted to examine the metabolic and physiological responses to extreme prolonged open water rowing. Therefore the purpose of this study was to examine the metabolic cost of prolonged open water rowing, in terms of energy supply and demand.

Using linear regression equations between exercise, HR, and laboratory data the metabolic responses were determined.

Method

Participant

One male athlete (age 29, body mass 109 kg, height 175 cm), participated in this study. Written informed consent was given prior to commencement of testing, in accordance with the institutional human subjects' guidelines (Anglia Polytechnic University).

Laboratory Protocols

Two weeks prior to the commencement of the Trans Atlantic rowing race the participant reported to the laboratory for assessment of lactate turn-point (LaT) and VO₂max. LaT is a point during incremental exercise where there is a systemic increase in the blood lactate concentration. This point, identified by a breakpoint in the work rate/lactate relationship, represents the metabolic point in the cell where the production of lactate exceeds its rate of removal. As a result the concentration, measured from the blood rises and metabolic peripheral fatigue can ensue. Research has demonstrated significant correlations between LaT and sustained aerobic performance (Jones & Carter, 2000). Prior to the testing session the participant was familiarised with the equipment and testing procedures used in this study. Additionally he was instructed to refrain from intense training during the day prior to testing.

The participant undertook a graded-based exercise test to exhaustion on a slide mounted rowing ergometer (Concept II model 'B' Nottingham, UK). The power output was increased by 25 W from an initial starting level of 175 W. The power output increased every 3 min until the participant reached LaT and then every min thereafter. The participant maintained a constant stroke rate of ~30 strokes per min throughout the test. Exercise tests were terminated when the participant either reached volitional exhaustion or a power output of >10 W of the designated workload could not be maintained.

Three weeks after completing the race the participant reported back to the laboratory to undergo the same series of tests. The tests were conducted under environmentally controlled laboratory conditions (20°C and 55% relative humidity).

Analysis of expired air and determination of VO₂max. Gas exchange data (Douglas bag, open circuit spirometry), heart rate bpm⁻¹ (Sports tester, Polar Electro, Kempele, Finland) and Rating of Perceived Exertion (RPE) were recorded during the final 30 s of each workload. The participant breathed through a Hans Rudolph valve (Kansas City, USA) and was connected to a series of 100 L Douglas bags via short light-weight tubing. The criteria for an attainment of VO₂max included any of the following; an increase in VO₂ with successive workloads of <2 ml.min⁻¹, a Respiratory Exchange Ratio (RER) >1.10 or a maximum heart rate of

220-age + 10 bpm⁻¹ (Basset & Howley, 2000). Fractions of carbon dioxide and oxygen were determined using a paramagnetic oxygen and infrared carbon dioxide analyser (exhaled breath analyser, Patterson Instruments, UK), which had been calibrated against gases of known concentration (British Oxygen Company, Wembley UK). The volume of each sample was determined using a Harvard dry gas meter (Harvard Apparatus Ltd, Kent, UK). The meter had previously been calibrated with volumes from 12–99 L.

Analysis of blood lactate and determination of lactate turn-point. Earlobe blood samples were taken at rest and at the end of each 3 min workload. Blood lactate concentration was analysed immediately during the test using an Accusport Lactate analyzer (Boehringer Mannheim, Mannheim, Germany). The lactate turn-point was determined by visually inspecting the lactate concentration (mM) power output (W) relationship and determining the point of systemic rise in blood lactate.

Field-Based Protocols

Throughout the duration of the race the two teammates undertook bouts of 90 min individual rowing followed by 90 min of rest. Throughout the exercise bouts the participant wore a heart rate (HR) monitor (Sports tester, Polar Electro, Kempele, Finland). Approximately 45 min into each exercise bout he recorded his HR. He also recorded HR at the end of his rest period as well as estimating his RPE.

Determination of Energy Cost

Linear regression interpolation was applied to the HR race data because all of the HR data from the race occurred below LaT and hence there was no development of the slow component of oxygen uptake. The linear regression was used to interpolate the following variables from the pre-race laboratory data: Power output (W), VO₂ l.min⁻¹, RER, calorific expenditure. VO₂ l.min⁻¹ refers to the volume of oxygen consumed at any intensity below the maximal level (VO₂max l.min⁻¹). Energy expenditure both at rest and during exercise was calculated using equation 1 (Weir, 1949), below:

$$\text{Kcal} \cdot \text{min}^{-1} = [(1.1 \times \text{RER}) \times 3.9] \times \text{VO}_2 \text{ l} \cdot \text{min}^{-1}$$

Energy intake per day was around 25116 kJ⁻¹, from this value and data from the energy expenditure calculations, energy balance values could be estimated.

Results

The participant's pre-race VO₂max was 5.36L/min⁻¹ (49.6 ml.Kg⁻¹.min⁻¹). This value decreased by 13.2% to 4.71 L.min⁻¹ (43.6ml.Kg⁻¹.min⁻¹), when re-tested three weeks after completion of the race.

The total distance rowed was 4,950 Km and was completed in 63 days, 3 hr and 36 min. Mean distance covered

per day was 78.5 ± 8.9 Km². The metabolic data obtained during the race are presented in Table 1.

Heart rates ranged from 96 to 144 and 60 to 90 bpm⁻¹ exercise and resting data respectively. Pre-race laboratory data showed that lactate turn-point occurred at a concentration of 3.3 mM; HR 153 bpm⁻¹ and power output of 300 W. The exercise HR's measured occurred below lactate turn-point, therefore linear regression analysis were applied between recorded HR's and the pre race laboratory data in order to generate data detailing the metabolic cost of rowing.

Regression analysis revealed that the power output range was 101.6 to 278.0 W. The VO₂ during exercise and rest ranged from 1.69 to 3.89 and 0.84 to 0.97 L.min⁻¹ respectively. During the race the subject consumed ~25,116 kJ.day⁻¹, of which 65% was fat; 35% carbohydrate and 10% protein. The participant rowed for a total of 12 hr per day, usually for periods of between 90 and 120 min. Therefore the mean energy cost for the 12 hr exercise period was estimated to be $33,751 \pm 10,285$ kJ⁻¹. The remaining 12 hr period was assumed to be rest as the participant was not rowing, mean energy cost for the total 12 hr rest period was $9,372 \pm 5,106$ kJ⁻¹. The mean daily energy expenditure was $43,249 \pm 15,391$ kJ.day⁻¹. There was an energy deficit of 18,133 kJ.day⁻¹.

	HR	VO ₂	KJ	RER	RPE	PO
Exercise	109.2	2.3	46.8	0.87	17.5	164.5
SD +/-	14.7	0.6	14.2	0.03	1.8	48.2
Rest	73.1	0.87	13.0	0.78		
SD +/-	7.6	0.03	7.07	0.02		

Table 1: Participant Metabolic Data Obtained During Race

Note. All values represent mean data; HR bpm⁻¹; VO₂ l.min⁻¹; KJ.min⁻¹; PO= Power output (W)

SD = one Standard deviation

Discussion

The data show that there was a deficit of around 18,133 kJ.day⁻¹ (4,332 Kcal/day) in total energy input compared to energy expenditure. The energy expenditure data is somewhat higher than that reported during 14 day ultra-marathon running (Hill & Davies, 2001). It was determined that energy expenditure for this continuous activity was in the region of 26,459 kJ.day⁻¹. A possible explanation for the high level of energy expenditure in the current study is the nature of the activity, which was intermittent. The ultra marathon runner was exercising continuously for approximately 9 hr per day, whereas the participant in the current study was rowing for 90–120 min interspersed by the same duration of rest. The total energy cost of intermittent exercise has been shown to be higher than that of duration and intensity-matched continuous exercise (Astrand & Rohdal, 1986). The high-energy expenditure deficit could be slightly skewed in that for the

final 10 days of the exercise the participant was consuming half rations, less than 12,558 kJ.day⁻¹, as food supplies were running out. Furthermore, despite rowing being a weight-supported activity, the resistance to forward motion has been estimated to be proportional to two-thirds of the power of the weight of the vessel and crew (Secher, 1998). This, in conjunction with extreme environmental conditions, could have increased the energy expenditure. Indeed the values of daily energy expenditure in this study ($43,249 \pm 15,391$ Kcal.day⁻¹) are in excess of those reported (35,865 kJ.day⁻¹) for Tour de France cyclists (Westerterp, Saris, van Es, & Hoor 1986). Furthermore, the mean exercise heart rate reported for that event has been shown to be 142 ± 4 bpm (Lucia et al., 1998), this value is somewhat higher than that reported in this study (109.2 ± 14.77). Yet when expressed as a percentage of HR_{max} both Lucia et al. (1998) and the current study show similarity, with values of 74.3 and 75.6%, respectively.

The RER data show that the majority of energy was derived from fats. This finding is in agreement with previous research, which has studied the metabolic response to prolonged periods of aerobic exercise (McConnell, Snow, Proietto, & Hargreaves, 1999). The data therefore suggest that the relative contribution of each macro-nutrient was correct but the daily kJ intake was too low.

The results also indicate that despite 63 days of intermittent rowing, there was a large decrease in the participant's VO₂max (13.2%), when comparing pre and post-race values. The overriding reason for this decrease was that the post-race analysis was completed 3 weeks post-race, during which time the participant ceased training. This decrease is in accordance with previous research, which demonstrated a drop of between 4–14% following 4 weeks of detraining (Moore et al., 1987).

The large range and variance in the exercise HR data is primarily due to environmental factors; (high winds, swells, extreme changes in temperature) and having to drop anchor during adverse conditions. Some caution does need to be applied to the analysis of the HR data, which has been used to generate the metabolic data.

The use of HR telemetry to assess exercise intensity and energy expenditure during exercise has recently been questioned (Swain, Abernathy, Smith, Lee, & Bunn, 1994). These limitations such as cardiac drift, environmental temperature and the non-linearity between HR and VO₂, have been shown to overestimate the energetic cost of exercise by as much as 20 bpm⁻¹ (Gilman, 1996). In terms of the current study this would equate to a 16% over-estimation of all of the interpolated data.

Despite these limitations, the use of HR to estimate energy expenditure and intensity has its benefits and provides some data as to the metabolic cost of prolonged

open water rowing. Indeed, in this case study, it helped to demonstrate the level of nutritional sustenance that is required to complete such a task. This study has provided the first metabolic analysis of this form of exercise. The evidence presented can be translated to other extreme sports and conditions. Indeed the method presented can be used to assess and estimate the metabolic and physiological response to any form of environmental or physical situation, thereby allowing calculations to be made as to the metabolic cost. This has potential benefits in helping prepare individuals to work in extreme environments.

Future research should make use of the doubly labeled water technique (DLWT) and more participants. The DLWT involves the ingestion by the participant of the stable isotopes ^2H and ^{18}O as water and the resultant measurement of their enrichment via isotope mass spectrometry (Hill & Davies, 2001). The measurement can be obtained from most bodily fluids such as plasma, urine and saliva. Energy expenditure is calculated by measuring the difference between the elimination rates of the two isotopes and determining the carbon dioxide production rate. DLWT provides a much more exact means of estimating energy cost at the metabolic level, furthermore the elimination of ^2H is considered to be representative of water turnover rate, and so fluid requirements can also be determined.

This study has provided an initial insight into the metabolic cost of prolonged open water rowing. The data show that there was a significant energy deficit throughout the race, and that the major metabolic fuel was derived from fats, therefore suggesting that in order to complete this form of exercise the individual should be consuming a relatively high fat diet, which is in excess of ~43,000 KJ.d⁻¹.

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