

HSE201 EXERCISE PHYSIOLOGY

LABORATORY #3 MANUAL: METABOLISM

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INTRODUCTION

The Metabolism practical will be conducted over two sessions (one per week for on-campus students):

In **session one** you will learn how to measure internal (i.e., metabolic) work by calculating energy expenditure. You will conduct an experiment examining the metabolic response to constant load submaximal exercise. In conducting the experiment you will learn how the metabolic (i.e., energy) demands of submaximal exercise are met. Such that, after a few minutes of exercise at a given power output, a steady-state $\dot{V}O_2$ is attained where pulmonary $\dot{V}O_2$ essentially reflects the oxygen utilisation of the tissues. In this experiment, you will also explore the concepts of O_2 deficit and the excess post-exercise oxygen consumption, (EPOC).

In **session two** you will learn about how to use metabolic measurements collected during exercise to estimate the rates of carbohydrate and fat utilisation at different workloads. Specifically you will examine the impact of exercise intensity on fuel selection.

SESSION 1:

OBJECTIVES

The aims of session one are to:

- Examine changes in oxygen consumption in response to submaximal exercise, and learn about the significance of the oxygen deficit and EPOC.
- Calculate energy expenditure (EE) during submaximal exercise
- Calculate cycling efficiency during submaximal cycling exercise.

RELEVANT MODULE CONTENT

Metabolism Topics:

- 2.1 Energy Systems and ATP resynthesis

Powers and Howley. Exercise Physiology. Theory and Application to Fitness and Performance.

Chapter 4. Pages 69-74.

EXPERIMENT: ASSESSMENT OF OXYGEN CONSUMPTION DURING SUBMAXIMAL CYCLING

Procedures

1. Record environmental conditions and subject anthropometric measures
2. Screen your subject using the APSS
3. Calibrate the metabolic cart as shown previously and assemble mouthpiece
4. Set up the subject on the Monark cycle ergometer

Experimental protocol

1. Collect resting data for 3 minutes. Record the last 30 s value in the table
2. Commence exercise and collect data for 5 minutes. Record the values for each 30 s period.
 - a. Men: 120W (2kp * 60 rpm)
 - b. Women: 90W (1.5kp * 60 rpm)
3. Stop exercising and collect data for 5 minutes of recovery (subject remains seated on the ergometer)

DATA RECORDING AND ANALYSIS

TASK 1: RECORD THE RELEVANT DATA IN THE TABLE

Record the values for each variable in the AT1 report #3 submission template.

Environmental Conditions and Participant Characteristics

Barometric pressure (mmHg)	768
Room temperature (°C)	19.2
Relative humidity (%)	56.8
Sex	Male
Subject age (yrs)	22
Subject height (cm)	176.3
Subject body mass (kg)	73.5
Subject BMI (kg/m ²)	
BMI Classification	

Energy Expenditure During Rest, Exercise and Recovery

PERIOD	TIME (min)	$\dot{V}O_2$ (l.min ⁻¹)	RER	$\dot{V}_E$ (l.min ⁻¹)
Rest	-----	0.27	0.947	5.79
Exercise	0.5	0.44	0.937	14.12
	1.0	0.93	0.779	19.62
	1.5	1.30	0.747	23.20
	2.0	1.40	0.799	26.27
	2.5	1.43	0.867	29.07
	3.0	1.41	0.942	31.13
	3.5	1.55	0.924	33.40
	4.0	1.26	0.960	29.35
	4.5	1.41	0.890	29.61
	5.0	1.49	0.933	33.34
Average Steady state				
Recovery	0.5	1.38	0.902	29.51
	1.0	1.27	0.87	26.10
	1.5	0.77	0.96	18.91
	2.0	0.52	1.02	14.14
	2.5	0.43	1.05	12.86
	3.0	0.40	1.02	11.98
	3.5	0.20	1.04	6.73
	4.0	0.26	0.97	8.77
	4.5	0.33	0.85	9.54
	5.0	0.26	0.84	7.07

TIP: Steady state refers to the final 2 minutes of exercise

ENERGY EXPENDITURE

Energy is never lost, but it can change form. During exercise, chemical energy (contained within the chemical bonds of carbohydrates/fats) is converted into mechanical energy (the force produced by muscle), which in turn gets converted into kinetic energy (human movement). **Energy expenditure** refers to the chemical energy released via metabolism of carbohydrates and fats. The unit of energy is the same as for work; Joules.

There is a fixed relationship between oxygen consumption and energy expenditure, which depends on whether oxygen is used to metabolise carbohydrate or fat. The respiratory exchange ratio ($RER = \dot{V}CO_2 / \dot{V}O_2$) can be used to calculate the ratio of fat to carbohydrate used by the body, which can then help us determine the amount of energy used per litre of oxygen (i.e., "calorific equivalent", see table below). We can then use the oxygen consumption recorded to determine total energy expenditure in Joules, or the rate of energy expenditure in $J \cdot s^{-1}$ or in $kJ \cdot min^{-1}$.

* Note: 1kcal = 4.182 kJ

TABLE 1. Table of Nonprotein Respiratory Quotient (RQ) - Source: McArdle, Katch, and Katch (2010)

TABLE 8.1 ■ THERMAL EQUIVALENTS OF OXYGEN FOR THE NONPROTEIN RQ, INCLUDING PERCENTAGE KILOCALORIES AND GRAMS DERIVED FROM CARBOHYDRATE AND FAT					
NONPROTEIN RQ	KCAL PER LO_2	PERCENTAGE KCAL DERIVED FROM		GRAMS PER LO_2	
		CARBOHYDRATE	FAT	CARBOHYDRATE	FAT
0.707	4.686	0.0	100.0	0.000	0.496
0.71	4.690	1.1	98.9	0.012	0.491
0.72	4.702	4.8	95.2	0.051	0.476
0.73	4.714	8.4	91.6	0.090	0.460
0.74	4.727	12.0	88.0	0.130	0.444
0.75	4.739	15.6	84.4	0.170	0.428
0.76	4.750	19.2	80.8	0.211	0.412
0.77	4.764	22.8	77.2	0.250	0.396
0.78	4.776	26.3	73.7	0.290	0.380
0.79	4.788	29.9	70.1	0.330	0.363
0.80	4.801	33.4	66.6	0.371	0.347
0.81	4.813	36.9	63.1	0.413	0.330
0.82	4.825	40.3	59.7	0.454	0.313
0.83	4.838	43.8	56.2	0.496	0.297
0.84	4.850	47.2	52.8	0.537	0.280
0.85	4.862	50.7	49.3	0.579	0.263
0.86	4.875	54.1	45.9	0.621	0.247
0.87	4.887	57.5	42.5	0.663	0.230
0.88	4.899	60.8	39.2	0.705	0.213
0.89	4.911	64.2	35.8	0.749	0.195
0.90	4.924	67.5	32.5	0.791	0.178
0.91	4.936	70.8	29.2	0.834	0.160
0.92	4.948	74.1	25.9	0.877	0.143
0.93	4.961	77.4	22.6	0.921	0.125
0.94	4.973	80.7	19.3	0.964	0.108
0.95	4.985	84.0	16.0	1.008	0.090
0.96	4.998	87.2	12.8	1.052	0.072
0.97	5.010	90.4	9.6	1.097	0.054
0.98	5.022	93.6	6.4	1.142	0.036
0.99	5.035	96.8	3.2	1.186	0.018
1.00	5.047	100.0	0	1.231	0.000

From Zuntz N. Ueber die Bedeutung der verschiedenen Nährstoffe als Erzeuger der Muskelkraft. Arch Gesamte Physiol, Bonn, Germany: 1901; LXXXIII:557-571; Pflügers Arch Physiol, 1901; 83:557.

TASK 2: CALCULATE ENERGY EXPENDITURE (EE)

Locate the average RER for your subject for the exercise steady state period in the table and determine the calorific equivalent (i.e. kCal expended for each litre of oxygen consumed (i.e. $\dot{V}O_2$) **.

Note: 1kcal = 4.182 kJ

** For the purpose of the calculations going forward in this report, Respiratory Quotient (RQ) is equivalent to the Respiratory Exchange Ratio (RER). RQ reflects the gas exchange at the tissue but RER is measured at the lungs. During steady state exercise, RER and RQ are largely equivalent.

$$\text{Energy Expenditure (kJ} \cdot \text{min}^{-1}) = \dot{V}O_2 (\text{l} \cdot \text{min}^{-1}) \times \text{calorific equivalent (kJ} \cdot \text{l}^{-1})$$

$\dot{V}O_2$	_____	$\text{l} \cdot \text{min}^{-1}$
Calorific equivalent	_____	$\text{kCal} \cdot \text{l}^{-1}$
Calorific equivalent	_____	$\text{kJ} \cdot \text{l}^{-1}$
Energy expenditure	_____	$\text{kJ} \cdot \text{min}^{-1}$

Record the calculated values for each variable in the AT1 report #3 submission template.

EXERCISE EFFICIENCY

Efficiency can be thought of as the amount of mechanical energy transferred to the bike from the breakdown of chemical energy. It is expressed as a percentage of the energy expenditure (ie: chemical energy released). Not all of the energy expended from the breakdown of fats and carbohydrates gets transferred into the mechanical energy required to pedal the cycle ergometer. Most of this chemical energy is lost as heat! However, the amount of energy that IS transferred to the cycle ergometer is different between people, and this can affect performance, which is why it is useful to measure. The higher the % the greater the efficiency. Efficiency is commonly expressed in two ways:

1. **Gross efficiency** is simply the percentage of total energy expenditure (measured as metabolic cost of exercise, in $\text{kJ} \cdot \text{min}^{-1}$) that is converted to the mechanical energy (i.e. cycling wattage expressed as in $\text{kJ} \cdot \text{min}^{-1}$) of the exercise

$$\text{Gross Efficiency (\%)} = 100 \times \frac{P_{\text{mech}}}{EE}$$

2. **Net efficiency** is the ratio of the mechanical power output (P_{mech}) of the exercise (i.e. the cycling wattage expressed in $\text{kJ} \cdot \text{min}^{-1}$) to the extra energy expenditure (metabolic power) required during the exercise that is greater than the resting energy expenditure.

$$\text{Net Efficiency (\%)} = 100 \times \frac{P_{\text{mech}}}{\text{Exercising EE} - \text{Resting EE}}$$

TASK 3: CALCULATE GROSS AND NET EFFICIENCY

$$P_{\text{mech}} = \underline{\hspace{2cm}} \text{ W} \xrightarrow{\text{converts to}} \underline{\hspace{2cm}} \text{ J.s}^{-1} = \underline{\hspace{2cm}} \text{ kJ.min}^{-1}$$
$$\text{Exercising EE} = \underline{\hspace{2cm}} \text{ kJ.min}^{-1}$$
$$\text{Resting EE} = \underline{\hspace{2cm}} \text{ kJ.min}^{-1}$$
$$\text{Gross efficiency} = \underline{\hspace{2cm}} \%$$
$$\text{Net efficiency} = \underline{\hspace{2cm}} \%$$

* see the appendix for a worked example of this calculation

Record the calculated values for each variable in the AT1 report #3 submission template.

DATA REPORTING

TASK 4: GRAPH OXYGEN CONSUMPTION VERSUS TIME

Using the data from the table (Task 1), plot a graph of $\dot{V}O_2$ versus time. Be sure to label this graph accurately, and identify the i) rest, ii) exercise, iii) recovery, and iv) what you would consider the steady state period of exercise.

Include this figure in the AT1 report #3 submission template.

DATA INTERPRETATION

TASK 5: PRINCIPLES OF $\dot{V}O_2$ KINETICS DURING EXERCISE

Examine the graph you have drawn for Task 4. You will notice that at the start of exercise there is a gradual increase in $\dot{V}O_2$ from resting levels until it reaches a steady state period where $\dot{V}O_2$ is reflective of the energy requirement of the exercise. At the onset of exercise, the energy requirement cannot be met by aerobic metabolism and is described by the term **oxygen deficit**.

- Explain why there is a delay between the starting the exercise and reaching the new $\dot{V}O_2$ steady state.
- Explain which energy systems are contributing to ATP production at rest, at the start, and end of exercise.
- Identify one factor that will influence the size of the oxygen deficit and explain why?

Record your responses to these questions in the AT1 report #3 submission template.

SESSION 2.

OBJECTIVES

The aims of this session are to:

- Quantify the contributions of different fuel sources to energy expenditure during submaximal exercise of different intensities.

RELEVANT MODULE CONTENT

Metabolism Topic Lectures:

- 2.3. Hormonal responses to exercise
- 2.4. Fuel use during exercise: intensity and duration

Powers and Howley. Exercise Physiology. Theory and Application to Fitness and Performance.

Chapter 4. Pages 80-86.

SUBSTRATE OXIDATION

Fat and carbohydrate are important fuels for exercise. The oxidation rates of fat and carbohydrate will change depending on the intracellular and extracellular metabolic environment. Two key factors that affect oxidation rates include; the availability of substrate, and exercise intensity. Substrate availability is dependent on diet, such that increases in a particular macronutrient in the diet tends to increase its availability, and therefore oxidation, during exercise. Exercise intensity affects oxidation rates because the substrate being oxidised needs to be able to meet the energetic demands of the working muscle. At high exercise intensities, energy is needed much more rapidly, and so carbohydrate (both muscle glycogen and plasma glucose), which can be metabolized into ATP more quickly than fat, is preferentially oxidized. However, at rest or light exercise intensities, fat is preferentially oxidised as it is a more rich source of energy (i.e., oxidation of fat typically yields more ATP than oxidation of carbohydrate). We can use steady state RER to determine the relative contributions of fat and carbohydrate to overall energy expenditure. Then, since we know that oxidation of **1 g of CHO yields 17.5 kJ and 1 g of FAT yields 39.6 kJ**, we can calculate the oxidation rates in grams per minute ($\text{g} \cdot \text{min}^{-1}$) of each substrate

EXPERIMENT: OXYGEN CONSUMPTION DURING SUBMAXIMAL CYCLING

Procedures

1. Record environmental conditions and subject anthropometric measures
2. Screen your subject using the APSS
3. Calibrate the metabolic cart as shown previously and assemble mouthpiece
4. Set up the subject on the Monark cycle ergometer

Experimental protocol

4. Collect resting data for 3 minutes
5. Commence 10 min of *low intensity* exercise and collect data in the final 5 minutes
 - a. Men: 60W (1kp * 60 rpm)
 - b. Women: 60W (1kp * 60 rpm)
6. Rest for 5 min (subject remains seated on the ergometer, mouthpiece can be removed)
7. Commence 10 min of *higher intensity* exercise and collect data in the final 5 minutes
 - a. Men: 150W (2kp * 60 rpm)
 - b. Women: 120W (1.5kp * 60 rpm)
8. Stop exercising

DATA RECORDING AND ANALYSIS

TASK 1: RECORD THE RELEVANT DATA IN THE TABLE

Record the values for each variable in the AT1 report #3 submission template.

Environmental Conditions and Participant Characteristics

Barometric pressure (mmHg)	724
Room temperature (°C)	18.6
Relative humidity (%)	62.1
Sex	Female
Subject age (yrs)	19
Subject height (cm)	162.0
Subject body mass (kg)	65.8
Subject BMI (kg/m ²)	

Energy Expenditure and RER Exercise of Low and Higher Intensity

PERIOD	TIME (min)	$\dot{V}O_2$ (l.min ⁻¹)	RER	$\dot{V}_E$ (l.min ⁻¹)
Low intensity exercise	5.5	1.35	0.854	35.65
	6.0	1.30	0.823	32.52
	6.5	1.32	0.834	33.82
	7.0	1.37	0.842	32.18
	7.5	1.34	0.832	34.76
	8.0	1.32	0.817	34.12
	8.5	1.35	0.839	32.46
	9.0	1.30	0.845	33.21
	9.5	1.36	0.830	34.56
	10	1.33	0.856	32.67
Average of final 2 minutes				
Higher intensity exercise	5.5	2.13	0.932	50.21
	6.0	2.02	0.976	52.38
	6.5	2.23	0.945	53.22
	7.0	2.20	0.923	50.61
	7.5	2.38	0.967	53.77
	8.0	2.21	0.978	51.83
	8.5	2.23	0.976	52.30
	9.0	2.18	0.973	52.81
	9.5	2.09	0.954	53.76
	10	2.17	0.962	54.0
Average of final 2 minutes				

TASK 2: CALCULATE SUBSTRATE OXIDATION RATES

Using the average data calculated for the final two minutes of exercise and the table of calorific equivalents (see [TABLE 1](#)), calculate the energy expenditure, substrate contribution and rates of carbohydrate and fat oxidation for each exercise bout.

Note: 1 g of CHO yields 17.5 kJ and 1 g of FAT yields 39.6 kJ,

Low Intensity Exercise

kCal equivalent = _____ kCal.l⁻¹ $\xrightarrow{\text{converts to}}$ _____ kJ.l⁻¹
Energy Expenditure = _____ KJ.min⁻¹
Energy from CHO = _____ %
Energy from FAT = _____ %

CHO oxidation rate = _____ g.min⁻¹ Total CHO oxⁿ for 10 min of Ex = _____ g
FAT oxidation rate = _____ g.min⁻¹ Total FAT oxⁿ for 10 min of Ex = _____ g

Higher Intensity Exercise

kCal equivalent = _____ kCal.l⁻¹ $\xrightarrow{\text{converts to}}$ _____ kJ.l⁻¹
Energy Expenditure = _____ KJ.min⁻¹
Energy from CHO = _____ %
Energy from FAT = _____ %

CHO oxidation rate = _____ g.min⁻¹ Total CHO oxⁿ for 10 min of Ex = _____ g
FAT oxidation rate = _____ g.min⁻¹ Total FAT oxⁿ for 10 min of Ex = _____ g

* see the appendix for a worked example of this calculation

Record the relevant data in the AT1 report #3 submission template.

DATA REPORTING

TASK 3: SUBSTRATE OXIDATION RATES

Draw a bar graph to show the contribution of carbohydrate and fat (as a % of total energy expenditure) during the low and higher intensity exercise bouts.

Include this figure in the AT1 report #3 submission template.

DATA INTERPRETATION

TASK 4: THE IMPACT OF EXERCISE INTENSITY ON SUBSTRATE UTILISATION

Examine the data in Task 2 and the figure in Task 3 and using the knowledge you have gained about the energy systems in this module:

1. Describe the observed change in fat and carbohydrate utilization between the lower and higher intensity of exercise and explain whether this change is expected.
2. Discuss the likely fuel sources (i.e. muscle and blood-derived fuels) contributing to fat and carbohydrate utilization during exercise and how the contributions of these fuel stores likely differ between the low and higher intensity exercise bout.

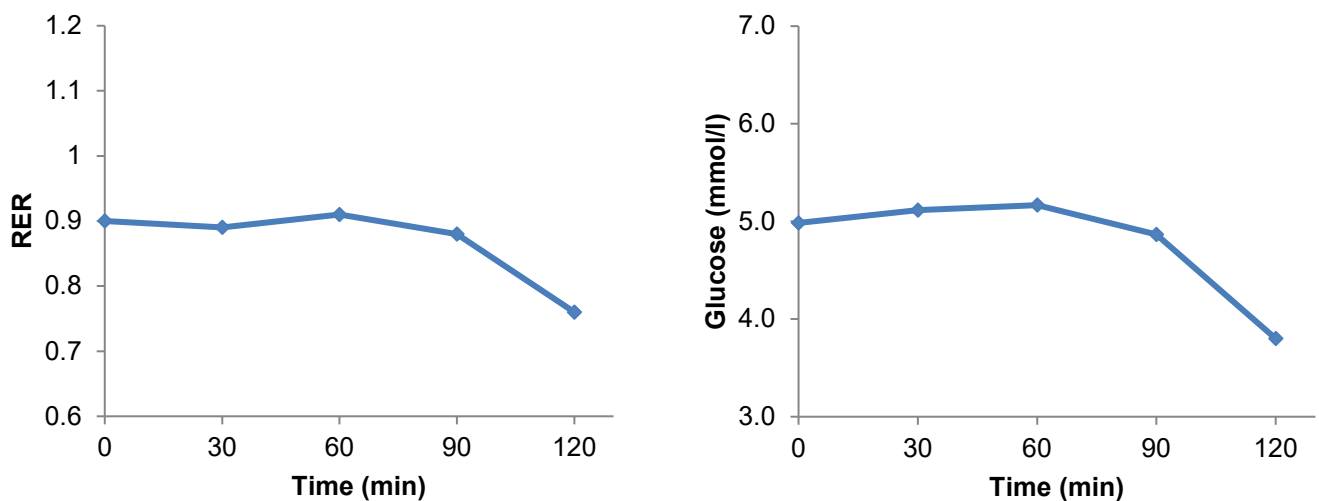
Record your responses to these questions in the AT1 report #3 submission template.

CASE STUDY

TASK 5: METABOLIC DETERMINANTS OF EXERCISE PERFORMANCE

An endurance runner comes to you for help. She explains that after competing in half-marathons for a few years, she has recently decided to step-up to the full marathon. She describes that she has increased the distance of her long runs (2-3 hours) but has been fatiguing towards the end, cannot maintain her pace and is struggling to finish. She has come to you as an exercise physiologist looking for an explanation.

You invite her into the lab and she completes a 2 h run on the treadmill and you measure substrate utilization using indirect calorimetry and take blood samples and measure blood glucose at regular intervals during the run. The results are displayed below.



When meeting this athlete to discuss your findings, how would you answer the following questions?

1. Making reference to the data you have collected, describe the likely shifts in fuel use that occur during the exercise bout and why these metabolic changes contribute to fatigue that she is experiencing towards the end of her prolonged training runs?
2. In relation to the data provided, how may carbohydrate feeding during exercise help to delay the onset of fatigue in this situation?

When answering these questions consider:

- What are the dominant fuels and how do they change during this duration of exercise?
- What does RER represent and why does it decline towards the end of the run?
- How do these metabolic changes result in a decline in blood glucose?
- How do these metabolic changes impact performance?

Record your responses to these questions in the AT1 report #3 submission template.

RECOMMENDED READING

[Coyle EF, Coggan AR, Hemmert MK, Ivy JL. Muscle glycogen utilization during prolonged strenuous exercise when fed carbohydrate. J Appl Physiol 61, 165-172, 1986.](#)

[Hagberg, JM, Mullin, JP & Nagle, FJ 1978, 'Oxygen consumption during constant-load exercise', *Journal of Applied Physiology*, 45, pp. 381-4.](#)

Powers, SK & Howley, ET 2009, *Exercise physiology: theory and application to fitness and performance*, 7th edn, McGraw-Hill, Chapter 4.

[Jones, AM, Grassi, B, Christensen, PM, Krustrup, P, Bangsbo, J & Poole, DC 2011, 'Slow component of VO₂ kinetics: mechanistic bases and practical applications', *Med Sci Sports Exerc*, vol. 43, no. 11, pp. 2046-62.](#)

REFERENCES

McArdle, WD, Katch, FI & Katch, VL 2010, *Exercise physiology: energy, nutrition and human performance*, 7th edn, LWW.

APPENDICES

EXERCISE EFFICIENCY: AN EXAMPLE

Nb: (calorific equivalent is assumed to be 21kJ.L^{-1} in this example)

Resting $\dot{V}O_2$	= 0.25 l.min^{-1}	<u>converts to</u>	EE = $0.25\text{ l.min}^{-1} \times 21\text{ kJ.l}^{-1}$	= 5.25 kJ.min^{-1}
PowerOutput #1	= 100 W	<u>converts to</u>	100 J.s^{-1}	= 6.0 kJ.min^{-1}
Exercise $\dot{V}O_2$ #1	= 1.5 l.min^{-1}	<u>converts to</u>	EE = 31.5 kJ.min^{-1}	
PowerOutput #2	= 150 W	<u>converts to</u>	150 J.s^{-1}	= 9.0 kJ.min^{-1}
Exercise $\dot{V}O_2$ #2	= 2.1 l.min^{-1}	<u>converts to</u>	EE = 44.1 kJ.min^{-1}	

Therefore, at 100 W :

$$\begin{aligned}\text{net efficiency at } 100\text{ W} &= 100 \times \frac{6}{31.5 - 5.25} = 22.9\% \\ \text{gross efficiency at } 100\text{ W} &= 100 \times \frac{6}{31.5} = 19.0\%\end{aligned}$$

Therefore, at 150 W :

$$\begin{aligned}\text{net efficiency at } 150\text{ W} &= 150 \times \frac{6}{44.1 - 5.25} = 23.2\% \\ \text{gross efficiency at } 150\text{ W} &= 150 \times \frac{6}{44.1} = 20.3\%\end{aligned}$$

SUBSTRATE OXIDATION: AN EXAMPLE

A subject exercised for 10 min. Average $\dot{V}O_2 = 2 \text{ l} \cdot \text{min}^{-1}$; Average RER = 0.87.

Using information from the Table of kCal equivalents above:

An RER of 0.87 provides a kCal equivalent $= 4.887 \text{ kCal} \cdot \text{l}^{-1}$.

Convert Kcal into kJ $= 4.887 \text{ kCal} \cdot \text{l}^{-1} \times 4.182 = 20.437 \text{ kJ} \cdot \text{l}^{-1}$

Therefore, $EE = 2 \text{ l} \cdot \text{min}^{-1} \times 20.437 \text{ kJ} \cdot \text{l}^{-1} = 40.9 \text{ kJ} \cdot \text{min}^{-1}$.

Also from the Table of kCal equivalents above, with an RER of 0.87:

the energy derived from CHO $= 57.5\%$, and

the energy derived from FAT $= 42.5\%$

Therefore, the energy derived from:

CHO: $40.9 \times \frac{57.5}{100} = 23.5 \text{ kJ} \cdot \text{min}^{-1}$, and

FAT: $40.9 \times \frac{42.5}{100} = 17.4 \text{ kJ} \cdot \text{min}^{-1}$.

Since oxidation of 1 g of CHO yields 17.5 kJ and 1 g of FAT yields 39.6 kJ:

CHO oxidation rate $= \frac{23.5 \text{ kJ} \cdot \text{min}^{-1}}{17.5 \text{ kJ} \cdot \text{g}^{-1}} = 1.34 \text{ g} \cdot \text{min}^{-1}$, and

FAT oxidation rate $= \frac{17.4 \text{ kJ} \cdot \text{min}^{-1}}{39.6 \text{ kJ} \cdot \text{g}^{-1}} = 0.44 \text{ g} \cdot \text{min}^{-1}$.