KINE 648 Lab #1

Estimation of Work, Power, & Metabolism

Equipment needed:

Quinton 3040 and 4500 treadmill & ECG machines
Step boxes (red wooden boxes located in the lab)
Monarch 818 E ergometers
Metronomes
Stop watches
Handouts
Web page notes

Estimation of Work, Power, & Metabolism

- **Terms and Definitions**:
  - **WORK** = Force X Distance (or force moved through a distance)
    - Measured in Kilogram-Meters (kgm) , Joules (J)
      - 1 kgm = 9.8J = 1.8 ml O_2 (consumed to perform 1 kgm of work)
    - On a braked ergometer (Monarch bike), a resistance force in kilograms is applied to a flywheel using a tension belt and the distance the flywheel travels is measured

Work (kgm) = kg of resistance X meters traveled

- On a treadmill, body weight is the resistance (force) to be moved alternately up and down with each step. With horizontal movement, estimation of how far the body is moved up with each step is difficult to quantify. Alternately, if we walk or run up an incline with angle **q**, work can be estimated as follows:

Work (kgm) = distance belt travels X body weight X sine **q**

Estimation of Work, Power, & Metabolism

- **Terms and Definitions**:

  - **POWER** = WORK / Time   or   (Force X Distance) / Time
    - measured in Kilogram-Meters / Minute (kgm/min or kgm•min^{-1})
    - also measured in Watts: 1 Watt = 6.1 kgm/min
    - on a Monarch, power is the product of the belt resistance, the distance the flywheel travels with every pedal revolution (6), and the number of pedal revolutions per minute:

      Power = kg X (meters/revolution) X (revolutions/min)

    - on a treadmill, power is the product of velocity of travel on the belt, the sine of the angle of incline and the body weight.

      Power = velocity X sine **q** X body weight

Note: training for POWER is the emphasis in many major college strength training programs

Energy Metabolism Estimation

Resting Metabolic Rate (RMR) = 1 MET = 3.5 ml O_2 / kg body wt / min = 1 kcal / kg / hr
1 Liter O_2 = 5 Kcal = 2153 kgm = 15, 575 ft-lbs.
1 lb adipose tissue (fat) = 3500 Kcal
1 kg = 2.2 lbs.
1 mph = 26.8 meters / min = 60 minutes per mile
1 kgm = 9.807 joules
1 watt = 6.1 kgm/min
Speed in mph = 60 / speed in minutes per mile

Example:

1. Estimate the daily energy requirements of a 176 lbs. Man (RMR)

2. How much weight would the man lose in one week if he reduced his caloric intake by 250 kcal / day and burned an extra 250 kcal / day by running on a treadmill (assume all metabolic hormone influences are negligible and that he does indeed have fat to lose)?

$$\frac{\frac{3.5\ \text{ml}}{\text{kg}}}{\text{min}} \cdot \frac{1\ \text{kg}}{2.2\ \text{lbs}} \cdot \frac{176\ \text{lbs}}{1} \cdot \frac{1\ \text{liter}}{1000\ \text{ml}} \cdot \frac{60\ \text{min}}{1\ \text{hr}} \cdot \frac{24\ \text{hr}}{1\ \text{day}} \cdot \frac{5\ \text{kcal}}{1\ \text{liter}} = \frac{2016\ \text{kcal}}{1\ \text{day}}$$

$$\frac{500\ \text{kcal}}{\text{day}} \cdot \frac{7\ \text{days}}{1\ \text{week}} \cdot \frac{1\ \text{lbs. fat}}{3500\ \text{kcal}} = \frac{1\ \text{lb. fat}}{\text{week}}$$

Estimation Equations for Exercise Metabolism

Walking - speeds 50 to 100 m/min : 1.9 to 3.7 mph

Horizontal Component: VO_2 mlO2/kg/min = SPEED m/min x .1 mlO2/kg/min/m/min

Vertical Component: VO_2 mlO2/kg/min = SPEED m/min x % GRADE x 1.8 mlO2/kg/min/m/min

Resting Component: VO_2 mlO2/kg/min = 3.5 mlO2/kg/min

Total VO2 mlO2/kg/min = sum of the resting, horizontal and vertical components

Running - speeds > 134 m/min : > 5 mph

(this equation can also be used for slower speeds (3 - 5 mph) if subject is truly running)

Horizontal Component: VO_2 = SPEED m/min x .2 mlO2/kg/min/m/min

Vertical Component: VO_2 mlO2/kg/min = SPEED m/min x % GRADE x .9 mlO2/kg/min/m/min

Resting Component: VO_2 mlO2/kg/min = 3.5 mlO2/kg/min

Total VO_2 mlO2/kg/min = sum of the resting, horizontal and vertical components

Cycle Ergometry

VO_2 mlO2/min = (WORK RATE kgm/min x 2 mlO2/kgm) + (3.5 mlO2/kg/min x body weight kg)

WORK RATE = Resistance kg x Pedal Revolution Circumference m/rev x RPM rev/min

Pedal Revolution Circumference: Monarch - 6 m/rev Tunturi - 3 m/rev

Estimation Equations for Exercise Metabolism

Cycle Ergometry (Watts)

VO_2 mlO2/kg/min = [(10.8 X Watts) / body weight kg] + 7

(Results may differ from other equation)

Arm Ergometry

VO_2 mlO2/min = (WORK RATE kgm/min x 3 mlO2/kgm) + (3.5 mlO2/kg/min x body weight kg)

WORK RATE = Resistance kg x Pedal Revolution Circumference m/rev x RPM rev/min

Note: Monarch Arm ergometer: Pedal Revolution Circumference = 2.4 meters

Step Ergometry

Horizontal Component:

VO_2 mlO2/kg/min = (STEPPING RATE steps/min x .2 mlO2/step/kg)

Vertical Component:

VO_2 mlO2/kg/min = (STEPPING RATE steps/min x STEP HEIGHT m/step x 2.4 mlO2/kg/m)

Resting Component:

VO_2 mlO2/kg/min = 3.5 mlO2/kg/min

Metabolic Calculation Example

You have bee assigned to supervise exercise for a new post-CABG cardiac patient who weighs 210 lbs. And has a peak VO_2 of 6 METS. At what speed would you set the treadmill at a 5% grade for a workout at 50% of his peak VO_2?

METS to VO_2 conversion

$$\frac{6\ \text{METs}}{1} \cdot \frac{3.5\ \frac{\text{ml}}{\text{kg}}/\text{min}}{1\ \text{MET}} = 21\ \frac{\text{ml}}{\text{kg}}/\text{min}\ (\times .5) = 10.5\ \frac{\text{ml}}{\text{kg}}/\text{min}$$

$$10.5\ \frac{\text{ml}}{\text{kg}}/\text{min} = (\text{speed} \times .1) + (\text{speed} \times .05 \times 1.8) + (3.5)$$

$$10.5 = (.19 \times \text{speed}) + (3.5)$$

speed = 36.8 meters / min

= 1.4 mph

Substitution into and then solving the equation

Metabolic Calculation Example

You have been directed to change the patient's workout in the previous question from a treadmill to a monarch cycle ergometer. His peak VO_2 was 6 METS and he weighed 210 lbs. At what resistance would you set a Monarch bike at 50 rpm for a workout at 50% of his peak VO_2? How many calories would the patient burn in a 30 minute workout at this workload?

Body Weight Conversion

$$\frac{210 \text{ lbs}}{1} \quad \frac{1 \text{ kg}}{2.2 \text{ lbs}} = 95.5 \text{ kg}$$

Relative to Absolute VO_2 Conversion

$$10.5 \frac{\text{ml}}{\text{kg} \cdot \text{min}} \quad 95.5 \text{ kg} = 1002.75 \frac{\text{ml}}{\text{min}}$$

Substitution into and then solving the equation for kg of resistance

$$1002.75 \frac{\text{ml}}{\text{min}} = \left(\frac{\text{kg}}{1} \times \frac{50 \text{ rev}}{\text{min}} \times \frac{6 \text{ meters}}{\text{rev}} \times 2 \right) + (3.5 \times 95.5 \text{ kg})$$

resistance (kg) = 1.1

Caloric expenditure calculation

$$1002.75 \frac{\text{ml}}{\text{min}} = \frac{1 \text{ liter } O_2}{\text{min}} \times \frac{5 \text{ kcal}}{\text{liter } O_2} \times 30 \text{ min} = 150 \text{ kcal}$$

Derivations of the Fick Equation

$$VO_2 \ \frac{\text{ml } O_2}{\text{min}} = Q \ \frac{\text{L blood}}{\text{min}} \times AVO_2D \ \frac{\text{ml } O_2}{\text{L blood}}$$

$$VO_2 \ \frac{\text{ml } O_2}{\text{min}} = HR \ \frac{\text{beats}}{\text{min}} \times SV \ \frac{\text{L blood}}{\text{beat}} \times AVO_2D \ \frac{\text{ml } O_2}{\text{L blood}}$$

$$AVO_2D \ \frac{\text{ml } O_2}{\text{L blood}}$$

$$\left(CaO_2 \ \frac{\text{ml } O_2}{\text{L blood}} - CvO_2 \ \frac{\text{ml } O_2}{\text{L blood}} \right)$$

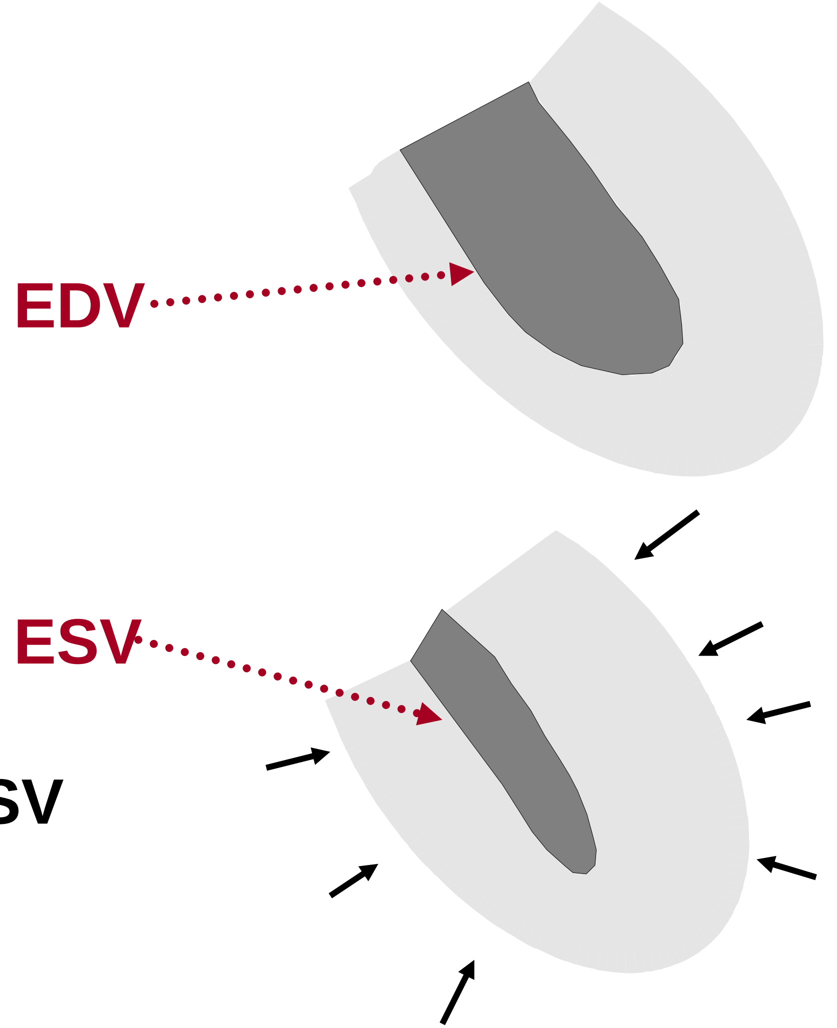
$$\left(1.34 \ \frac{\text{ml } O_2}{\text{g Hb}} \times [Hb] \ \frac{\text{g Hb}}{\text{100 ml blood}} \times SaO_2 \ \%O_2 \text{ sat} \times 10 \right) - \left(1.34 \ \frac{\text{ml } O_2}{\text{g Hb}} \times [Hb] \ \frac{\text{g Hb}}{\text{100 ml blood}} \times SvO_2 \ \%O_2 \text{ sat} \times 10 \right)$$

the unit on the "10" in the above equation is : $\frac{\textbf{ml } \mathbf{O_2}\textbf{/liter of blood}}{\textbf{ml } \mathbf{O_2}\textbf{/100 ml of blood}}$

Left Ventricular Volumes

End Diastolic Volume (EDV)

Volume at the end of diastole
(end of ventricular filling)



End Systolic Volume (ESV)

Volume at the end of systole
(end of ventricular contraction)

Stroke Volume (SV) = EDV - ESV

Ejection Fraction (EF) = $$\frac{SV}{EDV}$$

One of the best indicator of heart performance and disease prognosis
Left Ventricular Norm: about 62%

A 158.4 pound cardiac patient has been assigned to rehab in your lab. The physician's instructions say that he is to work at a cardiac output (Q) 20.6 liters per minute which translates into a VO2 of 40 ml / kg / min. 1. Find his AVO2diff 2. What is his venous saturation if his arterial saturation is 92% and his hemoglobin concentration is 16 gHb/100ml blood.

$$VO_2 \ \frac{\text{ml } O_2}{\text{min}} = Q \ \frac{\text{L blood}}{\text{min}} \times AVO_2D \ \frac{\text{ml } O_2}{\text{L blood}}$$

$$40 \ \frac{\frac{\text{ml } O_2}{\text{kg}}}{\text{min}} \ X \ (158.4 / 2.2) = 20.6 \times AVO_2D$$

Solving for AVO_2D: $139.8 \ \frac{\text{ml } O_2}{\text{L blood}}$

$$AVO_2D = \left(1.34 \ \frac{\text{ml } O_2}{\text{g Hb}} \times [Hb] \ \frac{\text{g Hb}}{\text{100 ml blood}} \times SaO_2 \ \%O_2 \text{ sat} \times 10 \right) - \left(1.34 \ \frac{\text{ml } O_2}{\text{g Hb}} \times [Hb] \ \frac{\text{g Hb}}{\text{100 ml blood}} \times SvO_2 \ \%O_2 \text{ sat} \times 10 \right)$$

$$139.8 \ \frac{\text{ml O2}}{\text{L blood}} = \left(1.34 \times 16 \times .92 \times 10 \right) - \left(1.34 \times 16 \times SvO_2 \times 10 \right)$$

Solving for SvO2: 26.8%

Other Relevant Terms and Calculations

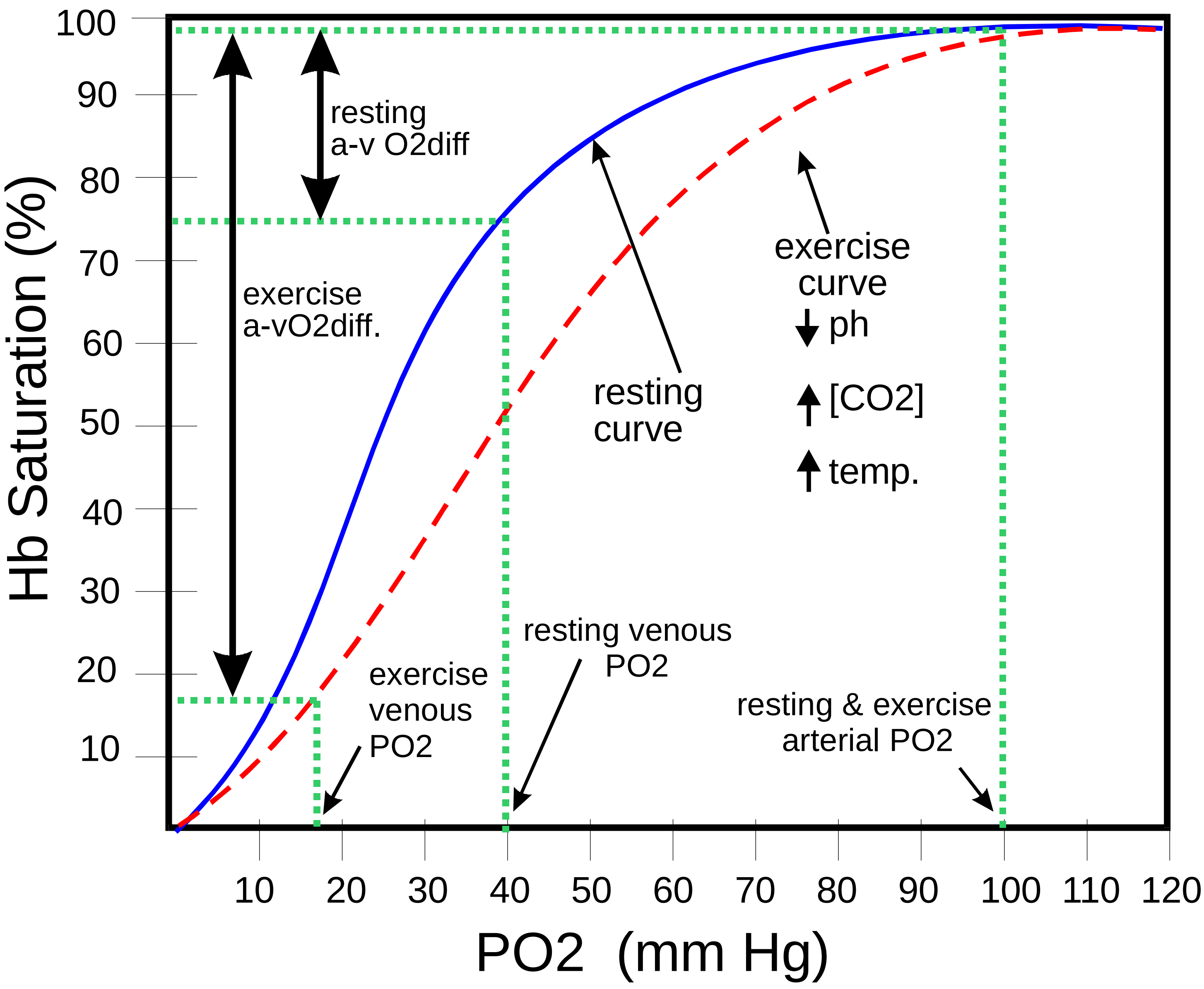
Oxygen Pulse:

- oxygen consumed by the body with each heart beat
- VO_2 / HR
- usually 4 –5 ml O_2 per beat

Rate Pressure Product (Double Product):

- HR X SBP
- Highly reflective of myocardial oxygen consumption (workload on the heart)

Oxygen - Hemoglobin (De)saturation Curve



Lab Assignment for Data Collection #1

Directions: Students should work in groups of 2 with each student serving as both a subject and a data collector. Each student will complete the assignment using his partner's data. Record all requested information and perform all calculations. **Construct a typewritten data sheet in which you show your data and your calculations and turn this data sheet in with you lab report.**

1. Weigh the subject to the nearest .5 kilograms and take his resting pulse. Using a metronome and one of the red wooden steps found in the lab, conduct an 8 min exercise bout of stepping at a rate of 24 steps / min (96 cadence on the metronome with a foot touch at each beep). Be sure to measure the exact height of the step for your calculations. Time the subject with a stop watch to ensure accuracy of bout length. At the end of each minute, record the subject's pulse using a *POLAR* heart monitor. Calculate total work performed during the bout (stepping up only), the power (stepping up only), and, using the estimation equations, the rate of O2 consumption.

2. Weigh the subject to the nearest .5 kilograms and take his resting pulse. Using one of the treadmills, conduct 3 consecutive stages of exercise for 4 minutes each: 2.5 mph @ 10%, 3.4 mph @ 11%, 4 mph @12%. Record the subject's pulse at the end of each minute of each stage of the bout using a *POLAR* heart monitor. Using the estimation equations, calculate the VO2. Calculate the caloric expenditure for the entire bout. Assume the cardiac output for the 1st stage is 10 L/min the SaO2 = 99% and the SvO2=57%. Calculate the O2 carrying capacity of the blood

3. Weigh the subject to the nearest .5 kilograms and take his resting pulse. Correctly position the subject on the Monarch bike. Adjust the bike seat so that at pedal extension, the knee is at a 160^{o} angle (almost straight) and have your subject sit on the bike. Have the subject pedal at 125 watts power for 3 minutes, then 3kg of resistance at 60 RPM for 3 minutes. Use the metronome to ensure proper RPM (120 ticks/min for 60 RPM). Record the subject's pulse at the end of each stage of the bout using a *POLAR* heart monitor. Using the estimation equations, calculate the rate of O2 consumption for each stage and the caloric expenditure for the entire bout.

Note: if the step, treadmill, and cycle workloads are too strenuous for the subject, they may be adjusted downward, if they are too light, they may be adjusted upward. Just be sure to note the changes for your calculations.

Lab Write-up for Assignment #1

1. For lab assignment part 1: using a graphing program (PowerPoint, Excel, etc), plot the heart rate (y-axis) against each 1 minute interval of the exercise bout (beginning with rest and the resting pulse). What is the shape of the relationship? Explain what physiological mechanisms are responsible for the change (or lack thereof) in heart rate as the time of the bout increases. Be sure to construct and reference your answers as outlined in the syllabus.

2. For lab assignment part 2: using a graphing program (PowerPoint, Excel, etc), plot the heart rate (y-axis #1) and rate of oxygen consumption in mlO2/kg/min (y-axes #2) against each minute of the bout (x axis label). Also, explain the shape of the relationship between the amount of time performing at each workload in the bout and the corresponding change in heart rate. Provide physiological rationale / evidence as to why this relationship (or lack thereof) occurs. Be sure to construct and reference your answers as outlined in the syllabus.

3. For lab assignment part 3: Using the estimation equations and oxygen / fat / calorie relationships, calculate how long it would take your subject to loose 10 pounds if they performed this two stage bout of exercise every day. Assume that the individuals caloric intake and resting metabolic rate remains exactly constant and other metabolic factors such as "set point" are negligible (big assumption!). Also assume that the individual "has the fat to loose". (SHOW YOUR CALCULATIONS IN DETAIL)