Energy Expenditure and Fatigue

1. **Define direct calorimetry and indirect calorimetry and describe how they are used to measure energy expenditure.**
   - **Direct Calorimetry**
     - A way to gauge the body’s rate and quantity of energy production is through heat production ("measuring heat") – since the basic unit of heat is a calorie
     - Substrate metabolism efficiency
       - 40% of substrate energy $\rightarrow$ ATP
       - 60% of substrate energy $\rightarrow$ heat
     - Heat production increases with energy production
     - An example of this is a treadmill in an airtight chamber
       - Pros: accurate, good for resting metabolic measurements
       - Cons: expensive, slow, exercising equipment adds extra heat, sweat creates errors in measurements
   - **Indirect Calorimetry**
     - Estimates total body energy expenditure based on O2 used and CO2 produced
       - Measures respiratory gas concentrations
     - Cons: only accurate for steady-state oxidative metabolism, expensive, slow
     - Remember
       - Inspired air volume = expired air volume only when the $\text{VO}_2 = \text{VCO}_2$
       - $\text{VO}_2 > \text{VCO}_2$ $\rightarrow$ volume of air inspired is greater than the volume expired
       - $\text{VCO}_2 > \text{VO}_2$ $\rightarrow$ volume of air exhaled is greater than the volume of air inhaled

2. **What is the respiratory exchange ratio (RER)? Explain how it is used to determine the oxidation of carbohydrate and fat.**
   - **RER:** ratio btwn rates of CO2 production and O2 usage; $\text{RER} = (\text{VCO}_2) / (\text{VO}_2)$
     - $\text{VO}_2$: volume of O2 consumed per minute; volume of inspired O2 minus volume of expired O2
     - $\text{VCO}_2$: volume of CO2 produced per minute; volume of expired CO2 minus volume of inspired CO2
   - **RER predicts substrate use**
     - The higher the RER ratio, the more glucose/carbs the body burns
     - The lower the RER, the more fat burned

<table>
<thead>
<tr>
<th>Carbohydrates</th>
<th>Fats</th>
<th>RER</th>
<th>Energy (kcal/ L O2)</th>
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</table>
- The amount of oxygen used during metabolism depends on the type of fuel being oxidized
  - Fats have more carbons, which require more \( \text{O}_2 \) to metabolize, and so they have a lower RER
- Limitations of RER
  - Inaccurate for protein oxidation
  - Energy derived from fat and amino acids \( \rightarrow \) glucose may cause an underestimation of the carbohydrate contribution to exercise energy demands
  - During high-intensity exercise, exhaled \( \text{CO}_2 \) may reflect buffering of lactate and non-metabolic (oxidation of food) production of \( \text{CO}_2 \)
- Higher intensity \( \rightarrow \) higher RER; lower intensity and longer duration \( \rightarrow \) lower RER

3. **What are the basal metabolic rate and resting metabolic rate, and how do they differ?**
- Metabolic Rate: rate of energy use by the body
- Basal Metabolic Rate (BMR): rate of energy expenditure at rest (minimum energy requirement for living)
  - Affected by age, stress, body surface area, hormones, body temperature
  - Related to fat-free mass
- Resting Metabolic Rate (RMR): similar to BMR, except it can be calculate under less stringent conditions and includes not only the number of calories burned in a day to maintain basic bodily functions, but also includes the number of calories burned eating and conducting small amounts of activity; RMR is 5-10% above BMR
- Both BMR and RMR are measured by gas analysis through either direct or indirect calorimetry
4. What is maximal oxygen uptake? How is it measured? What is its relationship to sports performance?
- \( \text{VO}_{2\text{max}} \): oxygen utilization during maximum exertion
  - Point at which \( O_2 \) consumption doesn’t increase with further increase in intensity; remain in steady state
  - Considered the best indicator of an athlete’s cardiovascular fitness and aerobic endurance
  - Plateaus after 8-12 weeks of training, though performance continues to improve as more training allows athlete to compete at a higher percentage of their \( \text{VO}_{2\text{max}} \)
  - The more oxygen you can use during high-level exercise, the more ATP (energy) you can produce; \( O_2 \) is required to breakdown substrates for energy
- \( \text{VO}_{2\text{max}} \) affected by age, gender, altitude
- \( \text{VO}_{2\text{max}} \) is measured through graded exercise, where the athlete starts exercising at a low intensity which increases incrementally as \( \text{VO}_2 \) reaches steady state for that particular intensity
- \( \text{VO}_2 \) Drift: slow increase in \( \text{VO}_2 \) during prolonged, submaximal, constant power output exercise, most likely due to increased ventilation and increased circulating catecholamines

**Oxygen Consumption Relative to Exercise Intensity**

![Graph of Oxygen Consumption Relative to Exercise Intensity](Hungary)
5. **Describe two markers of anaerobic capacity.**

- **Blood Lactate Threshold:** point at which blood lactate begins to substantially accumulate above resting concentrations during exercise of increasing intensity
  - Higher blood lactate threshold indicates being able to exercise for longer periods before fatiguing
  - Lactate accumulation contributes to fatigue during exercise
- **EPOC (Excess post exercise oxygen consumption):** increased oxygen consumption occurring in body after exercise stops to
  - Replenish ATP and PCr stores
  - Removes accumulated lactic acid from tissues and converts it to glycogen
  - Clear CO₂ accumulated in tissues
  - Restoration of oxygen in hemoglobin and myoglobin of the blood
  - Physiological mechanism(s) responsible for the EPOC include
    - Elevated cardiorespiratory function post-exercise
    - Elevated body temperature
    - Elevated epinephrine and norepinephrine
6. **What is the lactate threshold? How is it measured? What is the relationship to sport performance?**
   - Lactate Threshold: point at which blood lactate accumulation increases markedly
     - Lactate production rate > lactate clearance rate
     - Indicator of potential for endurance exercise
     - Expressed as percentage of VO$_{2\text{max}}$
     - Measured by taking blood samples at various points of exercise
   - Ability to exercise at high intensities without accumulating lactate is beneficial to athletes because lactate accumulation contributes to fatigue
     - Higher lactate threshold = higher sustained exercise intensity = better endurance performance
     - For two athletes with the same VO$_{2\text{max}}$, higher LT predicts better performance

![Graph showing blood lactate concentration vs. running speed](image)

7. **What is economy of effort? How is it measured? What is its relationship to sport performance?**
   - As athletes become more skilled, they use less energy for a given pace
   - Independent of VO$_{2\text{max}}$
   - High economy of effort means using less energy during activity and therefore being able to exercise for longer periods of time
   - Economy of effort can be measured by having 2 individuals complete identical exercises, and the individual that burns more calories and exercises at a higher percentage of his/her VO$_{2\text{max}}$ has a low economy of effort
8. **What is the relationship between oxygen consumption and energy production?**
   - Oxygen consumption (VO$_2$) is the amount of oxygen taken up and utilized by the body per minute.
   - Used for the production of ATP in the mitochondria of our cells (O$_2$ is the final electron acceptor in the ETC).
   - Greater O$_2$ consumption contributes to more energy available.

9. **Why do athletes with high VO$_{2\text{max}}$ values perform better in endurance events than those with lower values?**
   - Successful endurance athletes:
     - High VO$_2$
     - Perform at a high percentage of VO$_{2\text{max}}$ before they hit lactate threshold
     - High economy of effort
     - High lactate threshold
     - High percentage of Type I muscle fibers (which have a high oxidative capacity)
   - A high VO$_{2\text{max}}$ enables the individual to better utilize oxygen for energy production.

10. **Why is oxygen consumption often expressed as milliliters of oxygen per kilogram of body weight per minute (ml. kg$^{-1}$.min$^{-1}$)?**
    - VO$_2$ can be reported in absolute terms (L/min) or relative to body mass (ml/kg*.min).
    - VO$_{2\text{max}}$ is usually expressed in relative (uptake relative to body weight) terms as milliliters of oxygen consumed per kilogram of body weight per minute (ml O$_2$/kg/min or ml/kg/min).

11. **Describe the possible causes of fatigue during exercise bouts lasting 15 to 30 seconds and 2 to 4 hours.**
    - Fatigue: inability to maintain required power output to continue muscular work at a given intensity; decrements in muscular performance with continued effort accompanied by a sensation of tiredness. Fatigue is reversible by rest.
    - Failure of energy systems to adequately supply the body:
      - PCr depletion, as PCr is used for short-term, high intensity effort and it depletes more quickly than total ATP.
      - ATP decreasing as phosphate accumulates from the breakage of PCr → P + Cr
      - Muscle glycogen depletion
        - Depletes more quickly during first few minutes of exercise versus later stages
        - Depletes more quickly with high intensity
        - Depletion related to total glycogen depletion, NOT rate of glycogen depletion
        - Muscle glycogen insufficient for prolonged exercise.
- Lactic acid accumulation --> failure of muscle fiber's contractile mechanism
  o Fibers recruited first or most frequently deplete the fastest
    ▪ Type I recruited 1st for light-moderate intensity
    ▪ Type 2a recruited next for moderate-high intensity
    ▪ Type 2x recruited last for maximal intensity
  o Depletion in different muscle groups – activity specific muscle deplete fastest
- Muscle Acidosis as a result of increased H+ from Lactic acid accumulation decreases muscle pH
  o pH < 6.4 → inhibition of glycolysis and the making of ATP
  o pH = 6.4 → prevents further glycogen breakdown
  o Takes about 35 minutes to recover pH as the lactic acid is broken down
- Nervous System
  o Failure at neuromuscular junction, preventing muscle activation, caused by:
    ▪ Decrease in Ach synthesis and release
    ▪ Altered Ach breakdown in synapse
    ▪ Increase in muscle fiber stimulus threshold
    ▪ Altered muscle resting membrane potential
  o Fatigue may inhibit Ca^{2+} release from sarcoplasmic reticulum, and Ca^{2+} exposes the actin-myosin binding site → contraction
  o The CNS plays a role in motivation and pain tolerance

12. Discuss three mechanisms though which lactate can be used as an energy source
- Lactate can be directly oxidized by Type I fibers in the Mitochondria

- Lactate can be shuttled from Type II to Type I fibers for oxidation

- Lactate can be converted to glucose via gluconeogenesis in liver

Sources
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