Chapter 6: Measurement of Work, Power, and Energy Expenditure

Objectives

• Define the terms work, power, energy, and net efficiency
• Give a brief explanation of the procedure used to calculate work performed during: cycle ergometer exercise & treadmill exercise
• Describe the concept behind the measurement of energy expenditure using: direct and indirect calorimetry

Objectives

• Discuss the procedure used to estimate energy expenditure during horizontal treadmill walking and running
• Define the following terms. Kilogram-meter, relative VO₂, MET and open-circuit spirometry
Units of Measure

- English system used in United States
- Metric system is the standard system of measurement for scientists
  - Used to express mass, length, and volume
- System International units or SI units
  - Standardized terms for measurement of:
    - Energy
    - Force
    - Work
    - Power

Work

Work is the product of force and distance

\[ \text{Work} = \text{force} \times \text{distance} \]

- Lifting a 5 kg weight up a distance of 2 m
  \[ \text{Work} = \text{force} \times \text{distance} \]
  \[ \text{Work} = 5 \text{ kp} \times 2 \text{ m} \]
  \[ \text{Work} = 10 \text{ kpm} \]

Kg – measure of mass, not force
Kp = force acting on a mass of 1 kg at normal gravity

Power

Power is how much work is done per unit of time

\[ \text{Power} = \frac{\text{work}}{\text{time}} \]

- Performing 2,000 kgm of work in 60 seconds
  \[ \text{Power} = \frac{\text{work}}{\text{time}} \]
  \[ \text{Power} = 2,000 \text{ kgm/60s} \]
  \[ \text{Power} = 33.3 \text{ kgm\cdot s}^{-1} \]

SI Units: 1 Watt (W) = 0.102 kpm\cdot s^{-1}

\[ \text{Power} = 326.8 \text{ W} \]
Measurement of Work and Power

Bench Step

Work = body weight (kg) x distance/step x steps/min x min

Work = body weight (kg) x distance (m)

= 70 kp x 150 m

= 10,500 kpm or ~ 103 kilojoules

Power = work ÷ minutes

= 10,500 kpm / 10 min

= 1,050 kpm/min or 171.6 W

Measurement of Work and Power

Cycle Ergometer

Work = resistance (kg) x (distance/revolution X revolutions)

Work = force (kg) x distance (m)

= 1.5 kp x (6m/rev x 600 rev)

= 5,400 kpm or 52.97 kilojoules

• Power = work ÷ minutes

= 5,400 kpm / 10 min

= 540 kpm/min or 88.2 W

Measurement of Work and Power

Treadmill

• Calculation of work performed while a subject runs or walks on a treadmill is not generally possible when the treadmill is horizontal.

• Although running horizontal on a treadmill requires energy

• Work performed during horizontal walking or running is complicated

• Quantifiable work is being performed when walking or running up a slope
**Determination of Percent Grade on a Treadmill**

Incline of the treadmill is expressed in percent grade. Percent grade is the amount of vertical rise per 100 units of belt travel.

Vertical displacement = % grade x Distance

Treadmill speed = 200m/min

Percent Grade = 7.5% or 0.075

Exercise time = 10 mins

Total vertical distance traveled

\[ \text{Total vertical distance} = 200 \text{m/min} \times 0.075 \times 10 \text{ mins} = 150 \text{ m} \]

**Measurement of Work and Power Treadmill**

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- **Percent grade** is the amount of vertical rise per 100 units of belt travel

Vertical displacement = % grade x Distance

Treadmill speed = 200m/min

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Exercise time = 10 mins

Total vertical distance traveled

\[ \text{Total vertical distance} = 200 \text{m/min} \times 0.075 \times 10 \text{ mins} = 150 \text{ m} \]

Work = body weight (kg) x total vertical distance traveled

\[ \text{Work} = 70 \text{ kp} \times 150 \text{ m} = 10,500 \text{ kpm or } \sim 103 \text{ kilojoules} \]

Power = work ÷ minutes

\[ \text{Power} = 10,500 \text{ kpm} / 10 \text{ mins} = 1050 \text{ kpm/min or Watts} \]
Measurement of Energy Expenditure

- Direct calorimetry
  - Measurement of heat production as an indication of metabolic rate
  
  \[
  \text{Foodstuff} + \text{O}_2 \rightarrow \text{ATP} + \text{Heat} \quad \text{Cell work} \quad \text{Heat}
  \]

- Indirect calorimetry
  - Measurement of oxygen consumption as an estimate of resting metabolic rate
  
  \[
  \text{Foodstuff} + \text{O}_2 \rightarrow \text{Heat} + \text{CO}_2 + \text{H}_2\text{O}
  \]

Open-Circuit Spirometry

Estimation of Energy Expenditure

- Energy cost of horizontal treadmill walking or running
  - \(O_2\) requirement increases as a linear function of speed

- Expression of energy cost in METs
  - 1 MET = energy cost at rest
  - 1 MET = 3.5 ml\(\text{kg}^{-1}\text{min}^{-1}\)
Linear Relationship Between VO\textsubscript{2} and Walking or Running Speed

![Graph showing VO\textsubscript{2} consumption for walking and running at different speeds.]

Calculation of Exercise Efficiency

- Net efficiency

\[
\% \text{ net efficiency} = \frac{\text{Work output}}{\text{Energy expended above rest}} \times 100
\]

- Net efficiency of cycle ergometry
  - 15-27%

Factors That Influence Exercise Efficiency

- Exercise work rate
  - Efficiency decreases as work rate increases
- Speed of movement
  - There is an optimum speed of movement and any deviation reduces efficiency
- Fiber composition of muscles
  - Higher efficiency in muscles with greater percentage of slow fibers
Net Efficiency During Arm Crank Ergometry

Fig 6.8

Relationship Between Energy Expenditure and Work Rate

Fig 6.9

Effect of Speed of Movement of Net Efficiency

Fig 6.10
Running Economy

- Not possible to calculate net efficiency of horizontal running
- Running Economy
  - Oxygen cost of running at given speed
  - Lower VO₂ (ml•kg⁻¹•min⁻¹) indicates better running economy
- Gender difference in running economy
  - No difference at slow speeds
  - At “race pace” speeds, males may be more economical than females

Comparison of Running Economy Between Males and Females

![Comparison of Running Economy Between Males and Females](image)