The Physics of Human Performance: An IDEAL Lab

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ABSTRACT

Physics lab goes to the gymnasium, where students calculate the mechanical power required to walk on an inclined treadmill in watts and convert to units power used to measure human performance: $\dot{V}O_2$, and METs. Students learn how to use two linear regression models: the ACSM "walking equation" to estimate the actual power expenditure of walking and the Rockport 1 mile test to estimate their own $(\dot{V}O_2)_{max}$. Students use models to prescribe exercise parameters for themselves and for two cases. The IDEAL lab collaboration is developing labs that are open, applied to life, and rigorously quantitative.

CARDIOVASCULAR TRAINING UNITS

- Forget about **work**: pay attention to **power!**
- Heart rate (HR) linearly related to power.

Field	Energy/Work	Power
Physics	Joule, calorie	$1\ watt = 1\ J/s$
Nutrition	1 Calorie=1 kcal	Kcal/time
Physiology	ATP or VO_2 (mL O_2)	$\dot{V}O_2$ (mL O_2/min)
Clinical practice		1 MET=3.5 mL O_2/min/kg

$\dot{V}O_2$ IS A MEASUREMENT OF POWER

- Aerobic metabolism of glucose:
  - *Oxygen + glucose → carbon dioxide + water + "energy"*
    - $6O_2 + C_6H_{12}O_6 \rightarrow 6CO_2 + 6H_2O + ATP$
- Directly measure aerobic energy production from consumed O_2
- Work measured by volume of oxygen consumed VO_2 (mL)
- Power measured by **rate** $\dot{V}O_2$ (mL/min) or $\dot{V}O_2\left(\frac{mL}{min}/kg\right)$

MAYBE I WILL USE THIS AGAIN!

Quantitative athletic training leads to measurable benefits

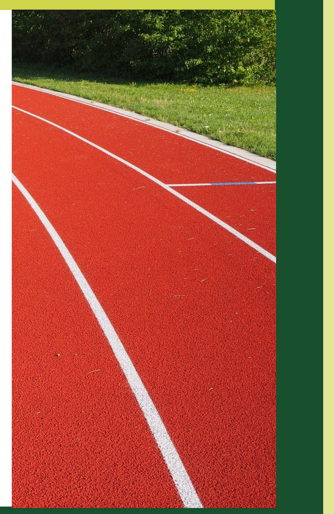
- Calculate target HR for optimal aerobic training
- Measure and monitor maximum aerobic power $(\dot{V}O_2)_{max}$

LEARNING ACTIVITIES

1. CALCULATE PERSONAL $(\dot{V}O_2)_{max}$

Quantify your current cardiovascular performance

1. Walk 1 mile. Record time and final HR.
2. Estimate personal peak power $(\dot{V}O_2)_{max}$ from linear regression (time, HR, age, sex, weight)
3. Compare $(\dot{V}O_2)_{max}$ to tabulated data to determine cardiovascular fitness



2. OPTIMIZE YOUR CARDIO WORKOUTS

How do you know you're getting the most cardiovascular benefit?

1. Determine training intensity percentage from above table
2. Calculate target heart rate (THR) using Karvonen formula

$$THR = (HR_{max} - HR_{rest}) \times Intensity$$

3. RELATE HR TO UNITS OF POWER

1. Walk on a treadmill with at least 10% grade and record HR
2. Calculate (sub-maximal) power expense
   1. Use "walking equation" to estimate $\dot{V}O_2$
   2. Use HR to estimate $\dot{V}O_2$ from linear response (Eq. 1)
   3. Use speed and grade to calculate $\dot{V}O_2$ from "walking equation" (Eq. 2)
3. Relate personal HR to $\dot{V}O_2$, METS, and watts

V (mph)	Grade	HR (bpm)	%HRR	$\dot{V}O_2\ \left(\frac{mL}{min \cdot kg}\right)$	METS	Effort (W/kg)	Efficiency
4.7	0%	130	58%	16	4.6	5.6	0%
2.3	12%	112	44%	22	6.4	7.8	15%
3.3	12%	144	69%	31	8.7	11	15%

4. MODEL-BASED PRESCRIPTIONS

1. Shajesh wants to train at of $\dot{V}O_2 = 38\,mL/min/kg$ but can't run due to upper-body injury. Prescribe reasonable treadmill parameters for him to walk on an incline.

2. Su-Yun exercises by walking (in a flat city with 20 blocks/mile). You want her to exercise at 2.5 METs. Give her a simple instruction with practical units so that she can know that she's walking at the right speed.

[Practical units: 1 min 36 sec per block, 16 blocks every 10 min. Impractical units: 50 m/min, 0.63 blocks/min]

BACKGROUND: LINEAR RESPONSE

- HR reserve:

$$HRR = (HR)_{max} - (HR)_{rest}$$

- $\dot{V}O_2$ reserve:

$$VO2R = (\dot{V}O_2)_{max} - (\dot{V}O_2)_{rest}$$

$$\%HRR = \frac{HR - (HR)_{rest}}{HRR} = \frac{\dot{V}O_2 - (\dot{V}O_2)_{rest}}{VO2R} = \%VO2R \quad \text{(Eq 1)}$$

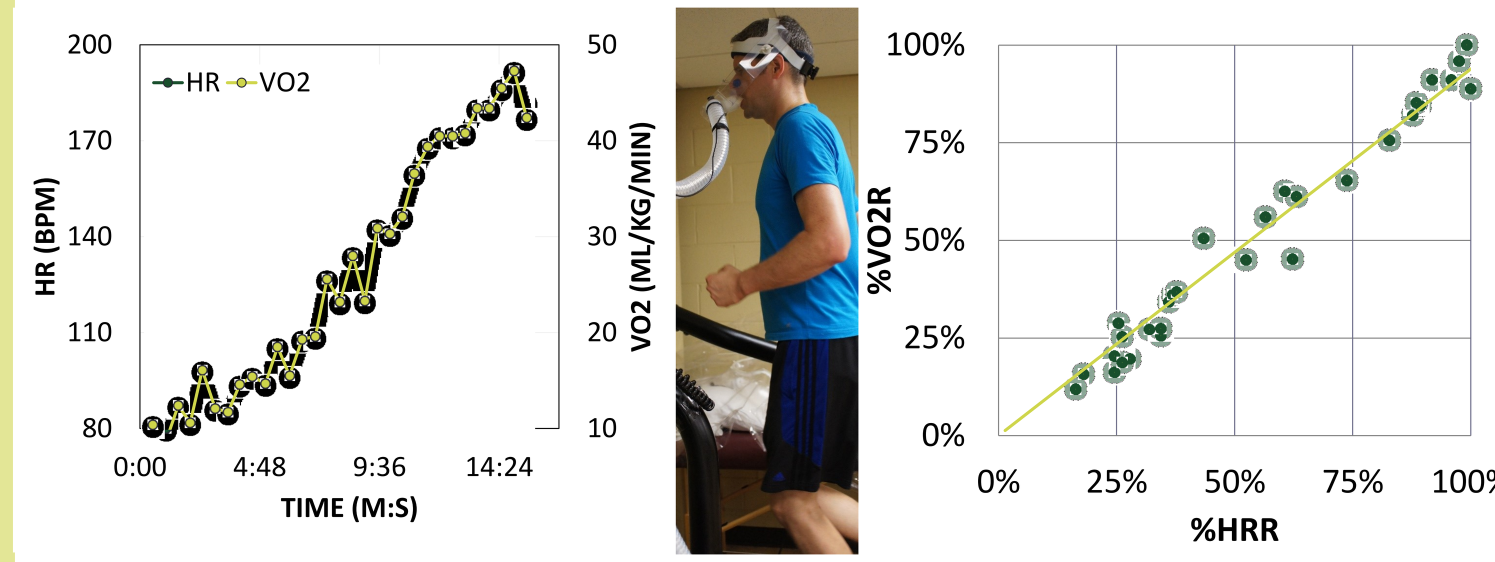


Fig 1 Measurement of HR and $\dot{V}O_2$ by the authors. The linear correlation between %VO2R %HRR is highly significant ($r = 0.987$, P<0.05%). The empirical relationship is consistent with $\%HRR$=%VO2R.

$y = (0.99 \pm 0.06)x + (-0.03 \pm 0.04)$ (95% CL)

Therefore HR measurements can be used to estimate $\dot{V}O_2$

NO NEED FOR $\dot{V}O_2$ EQUIPMENT!

Purchase heart rate monitors (fingertip pulse-oximeter ≈ $20)

Use ¼ mile track and treadmills at the school gym

ACSM "WALKING EQUATION"

- From the American College of Sports Medicine (ACSM) Metabolic Calculations Handbook

$$\dot{V}O_2 = c_h\, v \cos\theta + c_v\, v\, \sin\theta + c_r \quad \text{(Eq 2)}$$
$$\approx v(c_h + c_v \tan\theta) + c_r$$

$c_h = 0.1\frac{mL}{m \cdot kg}$	Work cost per horizontal meter
$c_v = 1.8\frac{mL}{m \cdot kg}$	Work cost per vertical meter
$c_r = 3.5\frac{mL}{min \cdot kg}$	Power cost of resting (1 MET)

IDEAL LAB PROJECT

I Didn't **E**xpect **A**pplications to **L**ife! (IDEAL)

- Life-science and personal health applications
- Use of simple statistics to form quantitative conclusions
- www.southern.edu/physicslab