Estimating VO_2 To Predict Metabolic Intensity and VO_2 Demand

Even though you may have the equipment and expertise to measure VO_2 using indirect calorimetry, it is also important to be able to **estimate** or **predict** the **VO_2 demand** of a specific exercise condition. Such knowledge helps the exercise physiologist to devise protocols that are more conducive to attaining valid results for the purpose of the exercise test. In addition, comparing expected to measured VO_2 responses provides the exercise physiologist with added data from which to interpret the associated test exercise physiology.

The methods for estimating the **VO_2 cost** of exercise will be presented by **exercise mode**. I present steady state VO_2 estimation based on a simplified expression of the equations from the American College of Sports Medicine, with the only exception being the added presentation of VO_2 estimations for a more accurate research-validated equation for cycle ergometry.

All equations are presented in Table 1, with specific equations presented again in each sub-topic to follow.

Table 1. Prediction equations for steady state VO_2.

VO2 units	System	Equation
		(horizontal + vertical + resting)
Treadmill Walking		
mL/kg/min	**metric**	(km/hr x 1.6667) + ((%grade/100) x km/hr x 30) + 3.5
mL/kg/min	**imperial**	(mi/hr x 2.6834) + ((%grade/100) x mi/hr x 48.3) + 3.5
Treadmill Running		
mL/kg/min	**metric**	(km/hr x 3.3333) + ((%grade/100) x km/hr x 15) + 3.5
mL/kg/min	**imperial**	(mi/hr x 5.3668) + ((%grade/100) x mi/hr x 24.15) + 3.5
Cycle Ergometry		
mL/min (ACSM)	**Watts**	0 + (Watts x 12.236) + (3.5 x kg body mass)
mL/min (ACSM)	**kgm/min**	0 + (kgm/min x 2) + (3.5 x kg body mass)
mL/min (Latin)	**Males**	0 + ((Watts x 11.624) + 260) + (3.5 x kg body mass)
mL/min (Latin)	**Females**	0 + ((Watts x 9.7892) + 205) + (3.5 x kg body mass)
Arm Ergometry		
mL/min	**Watts**	0 + (kgm/min x 18.354) + (3.5 x kg body mass)
mL/min	**metric**	0 + (kgm/min x 3) + (3.5 x kg body mass)
Bench Stepping		
mL/kg/min	**metric**	(steps/min x 0.35) + (step ht cms x steps/min x 0.02394) + 0
mL/kg/min	imperial	(steps/min x 0.35) + (step ht inches x steps/min x 0.06081) + 0

ACSM equations from ACSM. Guidelines for exercise testing and prescription. 4th Edition, Lea & Febiger, Philadelphia, 1991; Latin equations from Latin RW, Berg KE, Smith P, Tolle R, Woodby-Brown S. Validation of a cycle ergometry equation for predicting steady-rate VO_2. ***Med Sci Sports Exerc*** 1993;25(8):970-4.

Walking

The steady state energetics of walking has been studied by numerous researchers, and the range of walking speeds is critical for the accuracy of the estimation because the energy cost of walking is only linear across an individually specific range of speeds. Above a certain speed, the **economy** of walking decreases (Figure 1), which means the VO_2 change for a given increase in walking speed becomes higher and higher the faster one walks. Usually at the speed of this deviation from linearity in the VO_2 response, or the increase in the VO_2 cost of a speed increment, we subconsciously transition from walking to jogging, because jogging is more economical at these higher speeds. Due to this, there is a major limitation to the use of VO_2 estimation equations for walking. To make this estimate valid, you have to make sure the subject is walking at a comfortable pace.

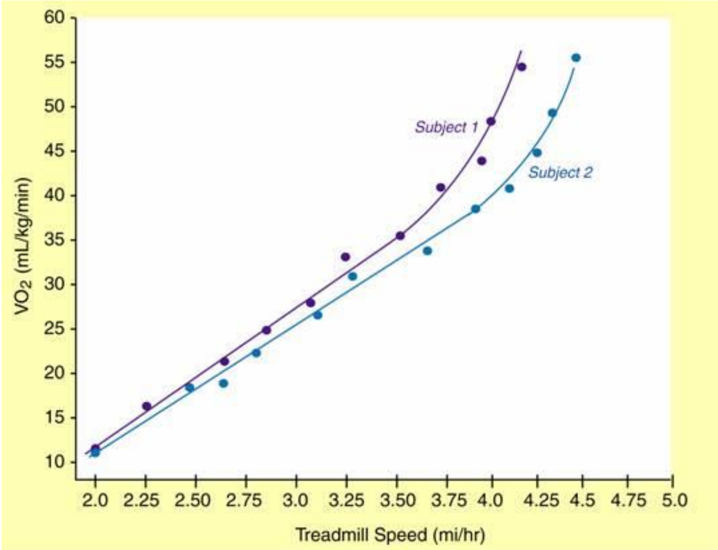

Figure 1. The change in the VO_2 response to walking as speed increases for two sample subjects. Above an individually specific speed, the VO_2 demand for a given speed increment increases dramatically.

The ACSM equation for estimating steady state VO_2 while walking is presented in Equations 1 and 2 for metric and imperial measurements of speed, respectively. Figure 2 presents the VO_2 response for walking at select speeds as %grade increases, using the ACSM equation.

$$Walking\ VO_2(mL/kg/\min) = (km/hr \times 1.6667) + \left(\frac{\%grade}{100} \times km/hr \times 30\right) + 3.5 \qquad \text{Equation 1}$$

$$Walking\ VO_2(mL/kg/\min) = (mi/hr \times 2.6834) + \left(\frac{\%grade}{100} \times mi/hr \times 48.3\right) + 3.5 \qquad \text{Equation 2}$$

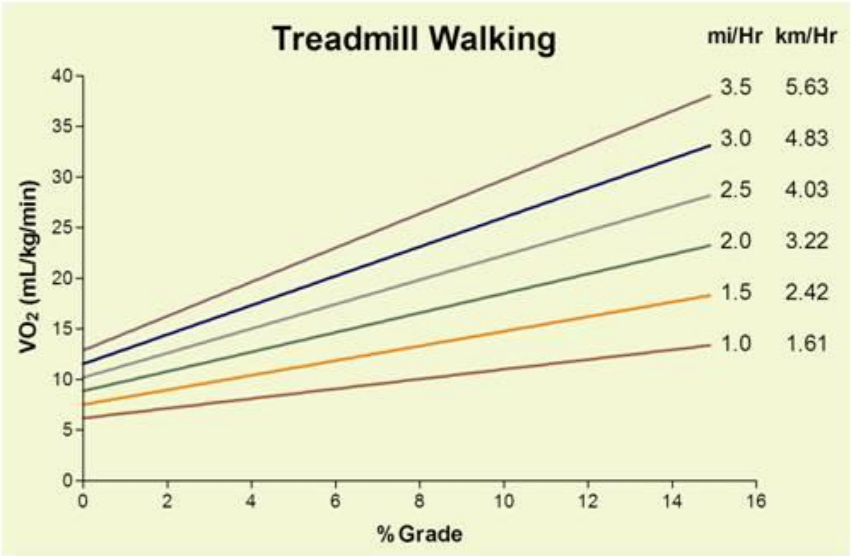

Figure 2. The VO_2 response for walking at select speeds as %grade increases, using the ACSM equation.

Estimating VO_2 To Predict Metabolic Intensity and VO_2 Demand

Running

Treadmill running has been shown to induce an identical VO_2 response to over-ground running during conditions with no head or tail-wind. However, estimation or prediction equations for steady state VO_2 have considerable error due to individual differences in **running economy**, which research has proven to be a trainable facet of the exercise physiology of running. The more experienced, well-trained and mechanically correct the runner, the lower the steady state VO_2 for a given running speed. The ACSM equation for treadmill running is presented in Equations 3 and 4 for metric and imperial measurements of speed, respectively.

$$Running\ VO_2(mL/kg/\min) = (km/hr \times 3.3333) + \left(\frac{\%grade}{100} \times km/hr \times 15\right) + 3.5 \qquad \text{Equation 3}$$

$$Running\ VO_2(mL/kg/\min) = (mi/hr \times 5.3668) + \left(\frac{\%grade}{100} \times mi/hr \times 24.15\right) + 3.5 \qquad \text{Equation 4}$$

Figure 3 presents the VO_2 response for running at select speeds as %grade increases, using the ACSM equation.

Figure 3. The VO_2 response for running at select speeds as %grade increases, using the ACSM equation.

Note the increased slope of the horizontal component of VO_2 prediction for running vs. walking, and the lower slope for the vertical component for running vs. walking. Also, I will discuss in great detail in the Topic on "Incremental Exercise Protocol Development" that the VO_2 increment for each %grade increment for treadmill walking and running is speed dependent. In other words, as speed increases, the VO_2 increment for a given %grade increment increases. If you think about it, this is logical, as the faster you walk or run up a hull, the greater your vertical displacement per unit time, even though the %grade remains constant. Thus, you are doing more work, or generating more power, at faster speeds. You see this response in the data of Figures 2 and 3, as the increasing slope (angle of the line) of the VO_2-%grade lines increases as speed increases. For example, an increase in %grade from 1 to 3% is a smaller increase in VO_2 demand when running at 5 mi/hr compared to running at 10 mi/hr. Understand this now and you will have an easier time with protocol development later in this text.

To be honest, I am surprised that research has not upgraded the steady state VO_2 estimation equations for running like it has for the cycle ergometer equations (see next). There really should be gender and fitness specific prediction equations for steady state VO_2, or equations that have variables in them for gender, fitness and/or training miles/week. This would be a great topic for a faculty-mentored student research project.

Cycle Ergometry

Clear research evidence exists to show gender specific responses in steady state VO_2 to cycle ergometry. As such, I recommend to always use the gender specific equations of Latin (see Table 1) when estimating steady state VO_2 for cycle ergometry. The ACSM equations are presented in Equations 5 and 6, and the equations from Latin are presented in Equations 7 and 8 for males and females, respectively.

$$ACSM\ Cycling\ VO_2(mL/\min) = (Watts \times 12.36) + (3.5 \times kg) \qquad \text{Equation 5}$$

$$ACSM\ Cycling\ VO_2(mL/\min) = (kgm/\min \times 2) + (3.5 \times kg) \qquad \text{Equation 6}$$

$$Cycling\ VO_2(mL/\min) = (Watts \times 11.624) + 260 + (3.5 \times kg) \quad males \qquad \text{Equation 7}$$

$$Cycling\ VO_2(mL/\min) = (Watts \times 9.7892) + 205 + (3.5 \times kg) \quad females \qquad \text{Equation 8}$$

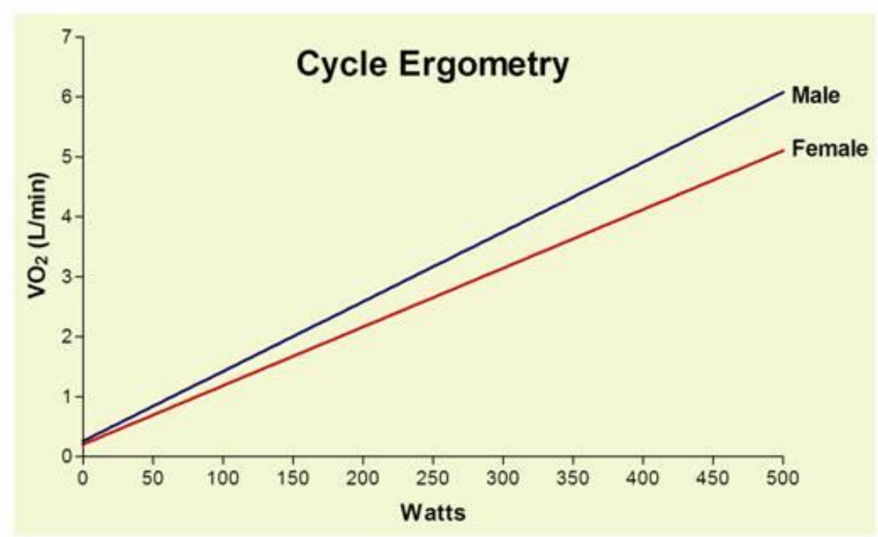

Figure 4. The VO_2 response for cycle ergometry for men and women as Watts increases, using the gender specific equations of Latin.

Estimating VO_2 To Predict Metabolic Intensity and VO_2 Demand

Figure 4 presents the VO_2 response for cycle ergometry for men and women as Watts increases, using the gender specific equations of Latin.

Arm Ergometry

For individuals with leg injury, or spinal cord injury, **arm ergometry** is another good exercise mode from which to assess their exercise physiology. Equations 9 and 10 present the ACSM equations for arm ergometry steady state VO_2 estimation from Watts and kgm/min, respectively.

$$ACSM\ \ Arm\ ergometry\ VO_2(mL/\min) = (Watts \times 18.354) + (3.5 \times kg) \qquad \text{Equation 9}$$

$$ACSM\ \ Arm\ ergometry\ VO_2(mL/\min) = (kgm/\min \times 3) + (3.5 \times kg) \qquad \text{Equation 10}$$

Step Testing

Bench step exercise testing was one of the earliest exercise modes used to study human exercise physiology to incremental exercise. This was obviously due to the ability to perform such exercise without mechanization or added sophisticated equipment. Equations 11 and 12 present the ACSM equations for bench or step testing steady state VO_2 estimation for metric and imperial measurements of step height, respectively.

$$Bench\ \ step\ VO_2(mL/kg/\min) = (steps/\min \times 0.35) + (step\ ht\ cm \times steps/\min \times 0.02394) \qquad \text{Equation 11}$$

$$Bench\ \ step\ VO_2(mL/kg/\min) = (steps/\min \times 0.35) + (step\ ht\ inches \times steps/\min \times 0.06081) \qquad \text{Equation 12}$$

Glossary Words

estimate is a type of educated guess. Also used synonymously with “predict”.

predict refers to the ability to calculate a value from measurements of other variables.

VO_2 demand is the VO_2 cost of a given exercise/metabolic condition.

VO_2 cost is the VO_2 required to perform a specific exercise condition.

exercise mode is the specific type of exercise, such as cycling, walking, running, roller blading, etc.

steady state VO_2 is the VO_2 cost of a specific exercise when at steady state, and is synonymous with running economy.

running economy refers to the VO_2 cost of running at a specific speed.

arm ergometry involves the use of upper body muscles to turn cranks that allow computation of work and power, similar to cycle ergometry.

bench step exercise involves the raising of the body's center of gravity by stepping up a known height, then down, repeatedly at a given rate.