Section 05: Assessment of Cardiovascular/Aerobic Fitness from Submaximal Exercise Tests

ACSM Guidelines: Chapter 4 – Health-Related Physical Fitness Testing and Interpretation (pp. 72-94)

ACSM Manual: Chapters 7 – Cardiorespiratory Fitness: Estimation from Field and Submaximal Exercise Tests

HPHE 4450
Dr. Cheatham

Outline

• Introduction and general testing guidelines
• Type of test to assess CR fitness
• Laboratory Submaximal Tests
  – YMCA Cycle Ergometer Test
  – Astrand Cycle Ergometer Test
  – Bruce Submaximal Treadmill Test
• Maximal Exercise Testing
• Interpretation of results
CR Fitness Defined

• Cardiorespiratory Fitness
  – Ability to perform large-muscle, dynamic, moderate-to high-intensity exercise for prolonged periods
  – Primarily Assessed Variable: Maximal Oxygen Consumption \( (VO_{2\text{max}}) \)
  – Major Physiological Systems:
    • Respiratory/Pulmonary (Oxygenate Blood)
    • Cardiovascular (Deliver \( O_2 \) rich blood)
    • Skeletal Muscle (Utilize \( O_2 \))

How is \( VO_{2\text{max}} \) Expressed?

• Absolute \( VO_2 \)
  – The actual amount of oxygen your body utilizes
  – Usually in \( L O_2/\text{min} \) or \( mL O_2/\text{min} \)

• Relative \( VO_2 \)
  – The amount of oxygen your body used per kilogram of bodyweight
  – \( mL O_2/\text{kg/min} \)
  – Allows comparison between people of different sizes.
**How is VO_{2\text{max}} Expressed?**

Body Mass = 230 lbs (104.5 kg)

- VO_{2\text{max}} = 5 L O_2/min
- VO_{2\text{max}} = 47.8 mL O_2/kg/min

Body Mass = 150 lbs (68.2 kg)

- VO_{2\text{max}} = 4 L O_2/min
- VO_{2\text{max}} = 58.7 mL O_2/kg/min
How is VO$_{2\text{max}}$ Expressed?

How to convert from Absolute to Relative VO$_{2\text{max}}$ (and Vice-Versa)

- **Absolute to Relative** (LO$_2$/min or mLO$_2$/min $\rightarrow$ mLO$_2$/kg/min)
  - If absolute is in LO$_2$/min
    - Multiply LO$_2$/min by 1000 to get mLO$_2$/min
    - Divide mLO$_2$/min by bodyweight in kg
  - If absolute is in mLO$_2$/min
    - Divide mLO$_2$/min by bodyweight in kg

- **Relative to Absolute** (mLO$_2$/kg/min $\rightarrow$ LO$_2$/min or mLO$_2$/min)
  - Multiply mLO$_2$/kg/min by bodyweight in kg to get mLO$_2$/min
  - If you want absolute as LO$_2$/min:
    - Divide mLO$_2$/min value by 1000

---

How is VO$_{2\text{max}}$ Expressed?

How to convert from Absolute to Relative VO$_{2\text{max}}$ (and Vice-Versa) - Example

- **Grace,** who weighs 55 kg, has an absolute VO$_{2\text{max}}$ of 2.5 LO$_2$/min. What is her relative VO$_{2\text{max}}$?
  - 2.5 LO$_2$/min $\times$ 1000 = 2500 mLO$_2$/min
  - 2500 mLO$_2$/min $\div$ 55 kg = 45.5 mLO$_2$/kg/min

- **Lucy,** who weighs 60 kg, has a relative VO$_{2\text{max}}$ of 47.0 mLO$_2$/kg/min. What is her absolute VO$_{2\text{max}}$ in mLO$_2$/min and LO$_2$/min?
  - 47.0 mLO$_2$/kg/min $\times$ 60 kg = 2820 mLO$_2$/min
  - 2820 mLO$_2$/min $\div$ 1000 = 2.820 LO$_2$/min
**Why Measure CR Fitness?**

- Health Implications
  - Exercise prescription and programming
  - Progress and motivation for the individual
  - Prediction of medical conditions
    - A low level of CRF has been established as an independent risk factor for all-cause mortality and cardiovascular mortality.
- Functional Implications
  - Occupational, recreational activities

---

**General Test Guidelines**

- Use risk stratification before initiating the test
- The person being tested should abstain from:
  - Eating within 4 hours of the test
  - Strenuous exercise within 24 hours of the test
  - Caffeine products within 12 to 24 hours of the test
  - Nicotine products within 3 hours of the test
  - Alcohol within 24 hours of the test
- Consider medications that may affect the resting or exercise HR
Types of Tests to Assess CR Fitness

- Field Tests
  - Usually done in a non-laboratory setting
  - Safety concerns for sedentary individuals with risk of complications
  - Relatively easy and inexpensive to administer
  - Ideal for large groups of subjects
  - Not as accurate as laboratory tests
  - Examples:
    - 1.5 Mile Run Test
    - 12 minute Walk/Run Test
    - Rockport 1 Mile Walk Test
    - Queens College Step Test

- Laboratory Submaximal Tests
  - Examples:
    - YMCA Cycle Ergometer Test
    - Astrand Cycle Ergometer Test
    - Bruce Submaximal Treadmill Test

---

**BOX 8-1 Advantages and Disadvantages of Laboratory Submaximal Exercise Testing**

**Advantages**
- Relatively inexpensive and require less equipment, personnel, and medical supervision than do maximal exercise tests
- Allows for more mass exercise testing
- Generally shorter test duration time
- If multistage test can assess multiple HR and BP responses to standardized work outputs

**Disadvantages**
- Maximal measurements (HR, BP VO_{2}) are not taken, but often predicted
- VO_{2peak} prediction error can range around 10-20%
- Limited diagnostic utility for certain diseases such as coronary heart disease
- Limited for exercise prescription purposes with no measured HR_{max}
Types of Tests to Assess CR Fitness

- Laboratory Submaximal Tests (cont’d)
  - Submaximal exercise tests are able to estimate VO$_{2\text{max}}$ due to the following assumptions:
    1. A linear relationship exists between HR, VO$_2$, and exercise intensity
    2. That the maximum HR at a given age is uniform (220-age)
    3. That the mechanical efficiency (VO$_2$ at a given workload) is the same for everybody

Types of Tests to Assess CR Fitness

- Laboratory Submaximal Tests (cont’d)
  - VO$_2$ or Exercise Intensity vs. HR (BPM)
Types of Tests to Assess CR Fitness

• Laboratory Submaximal Tests (cont’d)
  – Additional Assumptions
    • Linear response between VO$_2$ and HR between HR of 110 – 150 bpm
    • HR$_{SS}$ can be achieved in 3 to 4 minutes at a constant submaximal work output
    • A cadence of 50 rpm is comfortable and mechanically efficient (specific to cycle ergometer tests)
    • Submaximal work outputs can predict maximal work output, thus maximal CRF
    • HR at two separate work outputs can be plotted as HR – VO$_2$ relationship and extrapolated to HR$_{max}$

Types of Tests to Assess CR Fitness

• Maximal Exercise Tests
  – Advantages
    • Accuracy
  – Disadvantages
    • Increased risk to participant
    • Generally more time consuming
    • May require expensive equipment
    • More knowledge needed by technician
Submaximal Cycle Ergometer Tests

• Advantages
  – Non-weight-bearing mode of exercise
  – Accurate workloads
  – Relative ease of obtaining heart rate (HR) and blood pressure (BP)
  – Relatively inexpensive

• Disadvantages
  – Generally an unfamiliar work mode in the United States
  – Must maintain a cadence to maintain workload
  – The Monark cycle has few “bells and whistles”
  – Treadmills are believed to yield a truer physiologic maximum than cycles

Submaximal Cycle Ergometer Tests

• Work Output
  – Also termed work rate or workload
  – Total amount of work
    • Work = Force \times Distance
    • Work = Resistance (kp) \times Revolutions/min (rpm) \times Flywheel travel distance (m\cdot rev^{-1})
    • On a cycle, expressed as:
      – kp\cdot m\cdot min^{-1} (~ kgm\cdot min^{-1})
      – Watts
      – Newtons
      – Joules
Submaximal Cycle Ergometer Tests

- **Work Output (cont’d)**
  - **Resistance**
    - Applied by tightening friction belt attached to the pendulum weight on the flywheel
    - Measured in kiloponds (kp) or kilograms (kg)
    - Force the pendulum weight applies to the friction belt
  - **Cadence**
    - Pedal revolutions per minutes (RPM)
    - Protocols dictate a constant cadence of 50 rpm (comfortable and efficient)
  - **Flywheel Distance**
    - Distance the circumference of the flywheel travels per complete pedal revolution
    - Specific to the brand of cycle ergometer used
      - Monark (most popular) = 6 m·rev⁻¹ ratio
      - Tunturi and Bodyguard = 3 m·rev⁻¹ ratio

Submaximal Cycle Ergometer Tests

- **Work Output (cont’d)**
  - Conversion from kgm·min⁻¹ to Watts
    - 6 kgm·min⁻¹ = 1 Watt
  - **Examples:**
    - 1 kp · 50 rpm · 6 m·rev⁻¹ = 300 kp·m·min⁻¹
      - 300 kp·m·min⁻¹/6 = 50 watts
    - 2 kp · 50 rpm · 6 m·rev⁻¹ = 600 kp·m·min⁻¹
      - 600 kp·m·min⁻¹/6 = 100 watts
    - 2 kp · 60 rpm · 6 m·rev⁻¹ = 720 kp·m·min⁻¹
      - 720 kp·m·min⁻¹/6 = 120 watts
    - 2 kp · 50 rpm · 3 m·rev⁻¹ = 300 kp·m·min⁻¹
      - 300 kp·m·min⁻¹/6 = 50 watts
**Submaximal Cycle Ergometer Tests**

• Sources of error in predicting maximal CR fitness from submaximal CE tests
  – Prediction of HR\text{max} (220 bpm – age)
  – Efficiency of client on ergometer
  – Calibration of cycle
    • See procedure (AM: P. 119)
  – Accurate measurement of HR at each stage
  – Assume HR\text{SS} at each stage

**Box 7.5**

<table>
<thead>
<tr>
<th>General Procedures for Submaximal Testing of Cardiorespiratory Fitness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Obtain resting HR and BP immediately prior to exercise in the exercise posture.</td>
</tr>
<tr>
<td>2. The client should be familiarized with the ergometer. If using a cycle ergometer, properly position the client on the ergometer (i.e., upright posture, ~25-degree bend in the knee at maximal leg extension, and hands in proper position on handlebars) (14–16).</td>
</tr>
<tr>
<td>3. The exercise test should begin with a 2–3 min warm-up to acquaint the client with the cycle ergometer and prepare him or her for the exercise intensity in the first stage of the test.</td>
</tr>
<tr>
<td>4. A specific protocol should consist of 2- or 3-min stages with appropriate increments in work rate.</td>
</tr>
<tr>
<td>5. HR should be monitored at least two times during each stage, near the end of the second and third minutes of each stage. If HR is &gt;110 beats · min\textsuperscript{−1}, steady state HR (i.e., two HRs within 5 beats · min\textsuperscript{−1}) should be reached before the workload is increased.</td>
</tr>
</tbody>
</table>
Submaximal Cycle Ergometer Tests

6. BP should be monitored in the last minute of each stage and repeated (verified) in the event of a hypotensive or hypertensive response.

7. RPE using either the Borg category or category-ratio scale (see Table 4.7 from GETPA) and additional rating scales should be monitored near the end of the last minute of each stage.

8. Client's appearance and symptoms should be monitored and recorded regularly.

9. The test should be terminated when the subject reaches 70% heart rate reserve (65% of age-predicted HRmax), fails to conform to the exercise test protocol, experiences adverse signs or symptoms, requests to stop, or experiences an emergency situation.

10. An appropriate cool-down/recovery period should be initiated consisting of either
   a. continued exercise at a work rate equivalent to that of the first stage of the exercise test protocol or lower or
   b. a passive cool-down if the subject experiences signs of discomfort or an emergency situation occurs.

11. All physiologic observations (e.g., HR, BP signs and symptoms) should be continued for at least 5 min of recovery unless abnormal responses occur, which would warrant a longer posttest surveillance period. Continue low-level exercise until HR and BP stabilize, but not necessarily until they reach preexercise levels.

BP: blood pressure; HR: heart rate; HRmax: maximal heart rate; RPE: rating of perceived exertion.

Submaximal Cycle Ergometer Tests

| TABLE 4.7. CATEGORY AND CATEGORY-RATIO SCALES FOR RATINGS OF PERCEIVED EXERTION |
|-----------------------------------------------|-----------------------------------------------|
| CATEGORY SCALE | CATEGORY-RATIO SCALE |
| 6 No exertion at all | 0 Nothing at all |
| 7 Extremely light | 0.3 |
| 8 | 0.5 Extremely weak |
| 9 Very light | 0.7 |
| 10 | 1 Very weak |
| 11 Light | 1.5 |
| 12 | 2 Weak |
| 13 Somewhat hard | 2.5 |
| 14 | 3 Moderate |
| 15 Hard (heavy) | 4 |
| 16 | 5 Strong |
| 17 Very hard | 6 |
| 18 | 7 Very strong |
| 19 Extremely hard | 8 |
| 20 Maximal exertion | 9 |
| 10 Extremely strong | “Maximal” |
| 11 | 11 |
| 12 | Absolute maximum |

Copyright © 2010 American College of Sports Medicine
**Submaximal Cycle Ergometer Tests**

**Box 7.3 General Indications for Stopping an Exercise Test**

- Onset of angina or angina-like symptoms
- Drop in SBP of ≥ 10 mm Hg with an increase in work rate or if SBP decreases below the value obtained in the same position prior to testing
- Excessive rise in BP: systolic pressure > 260 mm Hg and/or diastolic pressure > 115 mm Hg
- Shortness of breath, wheezing, leg cramps, or claudication
- Signs of poor perfusion: light-headedness, confusion, ataxia, pallor, cyanosis, nausea, or cold and clammy skin
- Failure of HR to increase with increased exercise intensity
- Noticeable change in heart rhythm by palpation or auscultation
- Subject requests to stop
- Physical or verbal manifestations of severe fatigue
- Failure of the testing equipment

*Assumes that testing is non-diagnostic and is being performed without direct physician involvement or ECG monitoring. For clinical testing, Box 7.3 provides more definitive and specific termination criteria.

BP: blood pressure; ECG: electrocardiogram; HR: heart rate; SBP: systolic blood pressure.

---

**YMCA Cycle Ergometer Test**

- **What is the purpose of this test?**
  - To estimate maximal oxygen consumption (VO$_{2\text{max}}$)

- **How does this test estimate VO$_{2\text{max}}$?**
  - Based on the subject’s heart rate response to several submaximal workloads, we can predict what workload would they have gotten to if we would have let them reach his or her HR$_{\text{max}}$.
  - By knowing the predicted maximal workload, we can calculate what the subject’s VO$_2$ (i.e. VO$_{2\text{max}}$) would have been if we would have let them exercise to his or her maximum.
YMCA Cycle Ergometer Test

• Preliminary Testing Procedures:
  – Explain the test to the client
  – Perform adequate screening/risk stratification
  – Obtain informed consent
  – Outfit the subject with equipment and explain the RPE scale
  – Record basic patient information (i.e. age, height, body weight, gender)
  – Obtain resting HR and BP measurement
  – Adjust the seat height, have all data forms ready

YMCA Cycle Ergometer Test

• Exercise Procedures
  – Allow the subject to warm-up on the cycle ergometer for 2 to 3 minutes with a resistance of 0 kg and an RPM of 50
  – Start the 1st workload (3 min @ 150 kgm/min, 0.5 kg, 50 RPM)
    • Record HR at 2:00 min
    • Measure BP from 2:00 to 3:00 min
    • Record RPE at 2:45 min
    • Record HR at 3:00 min
    • If the 2:00 and 3:00 HR’s are not within 5 bpm, add a 4th minute to this stage and record HR at 4:00 min
    • Based on the HR at 3:00 min (or 4:00 min if you had to extend the stage), adjust the workload appropriately and follow these same instructions for the next stages
YMCA Cycle Ergometer Test

• Exercise Procedures (cont’d)

- What is the goal of the test (or in other words when is it finished?)
  - You want the client to achieve two consecutive workloads where the HR is between 110 bpm and 85% of age-predicted $HR_{max}$
  - So, the minimum time for the test is 6 min (two stages), the maximum time for the test is 12 min (4 stages)

- After the test is finished:
  - 3 min active recovery (0.5-1 kg, 50 RPM)
    - Record HR and BP and end of the three minutes
  - 2 to 3 min passive recovery (seated)
    - Record HR and BP at end of passive recovery
YMCA Cycle Ergometer Test

• How do you calculate the results (i.e. calculate the estimated VO$_{2\text{max}}$)?
  – Plotting or Graphing Technique
  – Numerical Calculation

YMCA Cycle Ergometer Test

• Plotting or Graphing Technique
  – Make a graph
    • X axis = Workload (kgm/min)
    • Y axis = Heart Rate (bpm)
    • Plot the two stages with HR between 110 bpm and 85% of age-predicted maximum
    • Draw a horizontal line at the age-predicted maximal HR (220-age)
  – Extrapolate
    • Connect the two point for your stages and extend this line until it crosses the age-predicted maximal HR line.
    • Drop a perpendicular line down from where the two lines cross to the X-axis and record what the workload would have been if you let the person go to his or her maximum HR.
**YMCA Cycle Ergometer Test**

- **Plotting or Graphing Technique**

<table>
<thead>
<tr>
<th>Name</th>
<th>Pedo</th>
<th>Age</th>
<th>Height</th>
<th>Weight</th>
<th>Predicted Max HR</th>
<th>Predicted Max Workrate</th>
<th>VO2max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test #1</td>
<td>Date</td>
<td>1st Workload HR</td>
<td>2nd Workload HR</td>
<td>(Est) Max Workload</td>
<td>(Est) Max HR</td>
<td>(Est) Max VO2</td>
<td>(Est) Max VO2 (kgm/min)</td>
</tr>
<tr>
<td>Test #2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test #3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Directions:**
1. Plot the HR of the two workloads versus the work (kg m/min).
2. Determine the subject's max HR line by subtracting subject's age from 220. Draw a line straight down from the point where the two lines cross and read the predicted max work rate.
3. Draw a line through both HR points extending up to the max HR line and connect the lines.
4. Drop a line straight down from the point where the two lines cross and read the predicted max work rate.

**YMCA Cycle Ergometer Test (cont’d)**

- **Calculate estimated VO2max**
  - You need to convert the predicted maximum workrate (kgm/min) to VO2 (mL/kg/min)
  - VO2 (mL/kg/min) = ((1.8 x workrate)/BW) + 7
    - Workrate is in kgm/min
    - Bodyweight (BW) is in kilograms
YMCA Cycle Ergometer Test

**Numerical Calculation**

- $VO_{2\text{max}} \, (\text{mL/kg/min}) = m \, (HR_{\text{max}} - HR2) + VO2_2$
  
  - Where:
    - $m = (VO2_2 - VO2_1)/(HR2 - HR1)$
    - $VO2_1 = \text{Submaximal VO}_2 \, (\text{mL/kg/min}) \text{ from Stage 1}$
      - $VO2 \, (\text{mL/kg/min}) = ((1.8 \times \text{workrate})/\text{BW}) + 7$
        - Put in the workrate (kgm/min) for the first stage with the HR in the desired range
    - $VO2_2 = \text{Submaximal VO}_2 \, (\text{mL/kg/min}) \text{ from Stage 2}$
      - $VO2 \, (\text{mL/kg/min}) = ((1.8 \times \text{workrate})/\text{BW}) + 7$
        - Put in the workload (kgm/min) for the second stage with the HR in the desired range
  
  - $HR1 = HR_{ss} \, (\text{bpm}) \text{ from Stage 1}$
  - $HR2 = HR_{ss} \, (\text{bpm}) \text{ from Stage 2}$
  - $HR_{\text{max}} = 220 - \text{age}$

**Numerical Calculation (Example)**

- Subject:
  - 30 year old male, Bodyweight = 75 kg

- Test Data:
  - Stage 1: 150 kgm/min, HRss = 98 (Don’t include)
  - Stage 2: 450 kgm/min, HRss = 116 (Include)
  - Stage 3: 600 kgm/min, HRss = 130 (Include)

- Calculations:
  - $VO2_1: \quad VO2 = ((1.8 \times 450)/75) + 7 = 17.8$
  - $VO2_2: \quad VO2 = ((1.8 \times 600)/75) + 7 = 21.4$
  - $m = (21.4 - 17.8)/(130 - 116) = 0.257$
YMCA Cycle Ergometer Test

• Numerical Calculation (Example) (cont’d)
  — Calculations (cont’d)
    • \( VO_{2\text{max}} \) (mL/kg/min) = \( m(HR_{\text{max}} - HR^2) + VO_2^2 \)
      – \( VO_{2\text{max}} \) (mL/kg/min) = \( [0.257((220-30) - 130)] + 21.4 \)
      – \( VO_{2\text{max}} \) (mL/kg/min) = 36.8

Astrand Cycle Ergometer Test

• What is the purpose of this test?
  – Same as YMCA Cycle Ergometer Test

• How does this test estimate \( VO_{2\text{max}} \)?
  – Same as YMCA Cycle Ergometer Test

• Preliminary Testing Procedures
  – Same as YMCA Cycle Ergometer Test
Astrand Cycle Ergometer Test

- **Exercise Procedures**
  - Allow the subject to warm-up on the cycle ergometer for 2 to 3 minutes with a resistance of 0 kg and an RPM of 50
  - Start the subject at the 1st workload (Stage 1)

<table>
<thead>
<tr>
<th>Individual</th>
<th>Work Output (kg \cdot m \cdot min⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Men</td>
<td></td>
</tr>
<tr>
<td>Unconditioned</td>
<td>300–600</td>
</tr>
<tr>
<td>Conditioned</td>
<td>600–900</td>
</tr>
<tr>
<td>Women</td>
<td></td>
</tr>
<tr>
<td>Unconditioned</td>
<td>300–450</td>
</tr>
<tr>
<td>Conditioned</td>
<td>450–600</td>
</tr>
<tr>
<td>Poorly conditioned or older</td>
<td>300</td>
</tr>
</tbody>
</table>

This protocol table is designed as a guide. The protocol is designed to elicit an HR of between 125 and 170 bpm by 8 min. You can adjust the workload as necessary during the test usually after the first 6 min to achieve an HR in or near this range in your subject.

Astrand Cycle Ergometer Test

- **Exercise Procedures (cont’d)**
  - Stage 1 (0:00 – 6:00)
    - Record HR every minute starting at 2:00
    - Measure BP from 2:00 to 3:00 min
    - Record RPE at 2:45 min
    - Measure BP from 5:00–6:00 min
    - Record RPE at 5:45 min
    - If the 5:00 and 6:00 min are not within 5 beats/min continue for one extra minute
      - If the average of the 5:00 and 6:00 min (or 6 and 7) HR is not between 125 and 170 bpm, adjust the workload according to chart on next page and continue for a second 6-min stage.
      - If the average of the 5:00 and 6:00 min (or 6 and 7) HR is between 125 and 170, the test is finished.
Astrand Cycle Ergometer Test

• Exercise Procedures (cont’d)

Table 3 Possible Power Adjustments After the Third Minute (2:30–3:00) of the Astrand Cycle Test

<table>
<thead>
<tr>
<th>A. Raise Power Level by:</th>
<th>Heart Rate</th>
<th>Force</th>
</tr>
</thead>
<tbody>
<tr>
<td>150–200 W</td>
<td>50–75 bpm</td>
<td>1.5–2.5 kg</td>
</tr>
<tr>
<td>20–40 kg</td>
<td></td>
<td>5–10</td>
</tr>
<tr>
<td>&gt;50 kg</td>
<td></td>
<td>&gt;10</td>
</tr>
<tr>
<td>B. Lower Power Level by:</td>
<td>150–200 W</td>
<td>50–75 bpm</td>
</tr>
<tr>
<td>20–40 kg</td>
<td></td>
<td>1.5–2.5 kg</td>
</tr>
<tr>
<td>&gt;50 kg</td>
<td></td>
<td>&gt;10</td>
</tr>
</tbody>
</table>

Note: Subtract 5 (a) or add 5 (b) one-half watt per minute for each year above or below 30 years of age, respectively.

Figure 6Schematic of power adjustments after the third minute (2:30–3:00) of the Astrand Cycle Test. Also adjust for age by subtracting or adding one-half b·min⁻¹ for each year above or below 30 years of age, respectively.

Astrand Cycle Ergometer Test

• How do you calculate the results (i.e. calculate the estimated VO₂max)?
  – Nomogram Technique
  – Numerical Calculation
Astrand Cycle Ergometer Test

• Nomogram Technique
  – Plot the average of the 5:00 and 6:00 minute (or 6:00 and 7:00 minute if you had to extend the last stage) HR and the corresponding workload that elicited this HR
  • Make sure you use the correct sides of the scales based on gender
  – Connect the points
  – Record the estimated VO$_{2\text{max}}$ (L/min)
  – Correct this for age based on the age correction chart
  – Convert the age corrected VO$_{2\text{max}}$ (L/min) to relative VO$_{2\text{max}}$ (mL/kg/min)
Astrand Cycle Ergometer Test

### TABLE 7.2. Age Correction Factor for Astrand Cycle Ergometer Test Results

<table>
<thead>
<tr>
<th>Age</th>
<th>Correction Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>1.10</td>
</tr>
<tr>
<td>25</td>
<td>1.00</td>
</tr>
<tr>
<td>35</td>
<td>0.87</td>
</tr>
<tr>
<td>40</td>
<td>0.83</td>
</tr>
<tr>
<td>45</td>
<td>0.78</td>
</tr>
<tr>
<td>50</td>
<td>0.75</td>
</tr>
<tr>
<td>55</td>
<td>0.71</td>
</tr>
<tr>
<td>60</td>
<td>0.68</td>
</tr>
<tr>
<td>65</td>
<td>0.65</td>
</tr>
</tbody>
</table>


---

Astrand Cycle Ergometer Test

- **Nomogram Technique (Example)**
  - **Subject:**
    - Female, Age = 27 years, Body weight = 50 kg
  - **Test Data:**
    - Stage 1 (450 kgm/min)
      - HR @ 2:00 min = 127
      - HR @ 3:00 min = 129
      - HR @ 4:00 min = 130
      - HR @ 5:00 min = 132
      - HR @ 6:00 min = 136
**Astrand Cycle Ergometer Test**

- Nomogram Technique (Example)
  - $\text{VO}_{2\text{max}}$ (L/min) = 3.0
  - Age Correction:
    - 25 years = 1.00
    - 35 years = 0.87
    - Between these ages, each year is equal to 0.013
    - She is closer to 25. She is two beyond 25.
    - So, 0.013 x 2 = 0.026
    - 1.00 - 0.026 = 0.974
    - 3.0 x 0.974 = 2.92 L/min

- Nomogram Technique (Example)
  - Need to convert the absolute age-corrected $\text{VO}_{2\text{max}}$ (L/min) to relative $\text{VO}_{2\text{max}}$ (mL/kg/min)
    - 2.92 x 1000 = 2920 mL/min
    - 2760/50 kg = 58.4 mL/kg/min
**Astrand Cycle Ergometer Test**

- Numerical Calculation

\[
VO_{2\text{max}}(\text{mL/kg/min}) = \frac{VO_21(220-\text{age}-73-\text{SEX} \times 10)}{HR - 73 - \text{SEX} \times 10}
\]

- Where:
  - \(VO_21\) = Submaximal \(VO_2\) (mL/kg/min) from final stage
    - \(VO_2\) (mL/kg/min) = \((1.8 \times \text{workrate})/\text{BW}\) + 7
  - \(\text{SEX} = 0\) for women and 1 for men
  - \(HR\) = Steady state HR from final stage
    - Average of 5th and 6th minute (or 6th and 7th minute if you had to extend the stage)

---

**Astrand Cycle Ergometer Test**

- Numerical Calculation (Example)

- **Subject:**
  - Female, Age = 27 years, Body weight = 50 kg

- **Test Data:**
  - Stage 1 (450 kgm/min)
    - HR @ 2:00 min = 127
    - HR @ 3:00 min = 129
    - HR @ 4:00 min = 130
    - HR @ 5:00 min = 132
    - HR @ 6:00 min = 136
**Astrand Cycle Ergometer Test**

- Numerical Calculation (Example) (cont’d)

\[
VO_{2\text{max}} (\text{mL/kg/min}) = 23.2 \frac{(220 - 27 - 73 - (0 \times 10))}{134 - 73 - (0 \times 10)}
\]

- \( VO_2 \): \( VO_2 = \frac{(1.8 \times 450)}{50} + 7 = 23.2 \)

- \( VO_{2\text{max}} (\text{mL/kg/min}) = 45.7 \)

---

**Bruce Submaximal Treadmill Test**

- What is the purpose of this test?
  - Same as YMCA Cycle Ergometer Test

- How does this test estimate \( VO_{2\text{max}} \)?
  - Same as YMCA Cycle Ergometer Test

- Preliminary Testing Procedures
  - Same as YMCA Cycle Ergometer Test (except for seat height)
**Bruce Submaximal Treadmill Test**

- **Exercise Procedures**
  - Subject performs the first two or three stages of the Bruce protocol

**TABLE 8-2**

<table>
<thead>
<tr>
<th>Stage</th>
<th>Time (min)</th>
<th>Speed (mph)</th>
<th>Grade (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>0-3</td>
<td>1.7</td>
<td>10</td>
</tr>
<tr>
<td>II</td>
<td>3-6</td>
<td>2.5</td>
<td>12</td>
</tr>
<tr>
<td>III</td>
<td>6-9</td>
<td>3.4</td>
<td>14</td>
</tr>
</tbody>
</table>

**Bruce Submaximal Treadmill Test**

- **Exercise Procedures (cont’d)**
  - For each three minute stage
    - Record HR each minute
    - Measure BP from 2:00-3:00 min
    - Record RPE at 2:45 min
    - If HR’s at 2:00 and 3:00 are not within 5 bpm, extend the stage one extra minute and record HR at 4:00
  - **Goal:**
    - Two stages with HR’s between 110 and 150

---

*Copyright © 2008 Wolters Kluwer Health / Lippincott Williams & Wilkins*
**Bruce Submaximal Treadmill Test**

- **Calculations**
  - \( VO_{2\text{max}} \text{ (mL/kg/min)} = m \times (HR_{\text{max}} - HR_{2}) + VO_{2\text{2}} \)
    - Where:
      - \( m = (VO_{2\text{2}} - VO_{2\text{1}})/(HR_{2} - HR_{1}) \)
      - \( VO_{2\text{1}} = \text{Submaximal VO}_{2} \text{ (mL/kg/min) from Stage 1} \)
        - \( VO_{2} \text{ (mL/kg/min)} = [(0.1 \times \text{speed}) + (1.8 \times \text{speed} \times \text{%grade})] + 3.5 \)
      - \( VO_{2\text{2}} = \text{Submaximal VO}_{2} \text{ (mL/kg/min) from Stage 2} \)
        - \( VO_{2} \text{ (mL/kg/min)} = [(0.1 \times \text{speed}) + (1.8 \times \text{speed} \times \text{%grade})] + 3.5 \)
      - \( HR_{1} = HR_{\text{ss}} \text{ (bpm) from 1st stage that counts (Use the 3 or 4 min HR)} \)
      - \( HR_{2} = HR_{\text{ss}} \text{ (bpm) from 2nd stage that counts (Use the 3 or 4 min HR)} \)
      - \( HR_{\text{max}} = 220 - \text{age} \)

*Note: To convert speed from mph to m/min, multiply the mph x 26.82*

---

**Bruce Submaximal Treadmill Test**

- **Example:**
  - **Subject**
    - 27 year old, male
  - **Exercise Data**
    - Stage 1 (1.7 mph, 10%), HRss = 94
    - Stage 2 (2.5 mph, 12%), HRss = 122
    - Stage 3 (3.4 mph, 14%), HRss = 144
Bruce Submaximal Treadmill Test

• Example (cont’d)
  – Calculations
    • $\text{VO}_2^1$: $\text{VO}_2 = [(0.1 \times 67.1) + (1.8 \times 67.1 \times 0.12)] + 3.5$
      – $\text{VO}_2 = 24.7 \text{ mL/kg/min}$
    • $\text{VO}_2^2$: $\text{VO}_2 = [(0.1 \times 91.2) + (1.8 \times 91.2 \times 0.14)] + 3.5$
      – $\text{VO}_2 = 35.6 \text{ mL/kg/min}$
    • $m = \frac{(35.6-24.7)}{(144-122)} = 0.50$
    • $\text{VO}_{2\text{max}} \text{ (mL/kg/min)} = [0.50(220-27) - 144)] + 35.6$
      – $\text{VO}_{2\text{max}} \text{ (mL/kg/min)} = 60.1$

Maximal Exercise Testing

• We will cover this in “Clinical Exercise Testing” section
TABLE 4.8. Fitness Categories for Maximal Aerobic Power for Men and Women by Age

<table>
<thead>
<tr>
<th></th>
<th>Age 20–29</th>
<th>Age 30–39</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td>Rate (l/min)</td>
</tr>
<tr>
<td>99</td>
<td>Superior</td>
<td>31.30</td>
</tr>
<tr>
<td>95</td>
<td>Excellent</td>
<td>28.05</td>
</tr>
<tr>
<td>90</td>
<td>Good</td>
<td>27.00</td>
</tr>
<tr>
<td>85</td>
<td></td>
<td>26.30</td>
</tr>
<tr>
<td>80</td>
<td></td>
<td>25.00</td>
</tr>
<tr>
<td>75</td>
<td></td>
<td>23.13</td>
</tr>
<tr>
<td>70</td>
<td></td>
<td>22.30</td>
</tr>
<tr>
<td>65</td>
<td></td>
<td>22.00</td>
</tr>
<tr>
<td>60</td>
<td></td>
<td>21.12</td>
</tr>
<tr>
<td>55</td>
<td></td>
<td>21.40</td>
</tr>
<tr>
<td>50</td>
<td></td>
<td>20.00</td>
</tr>
<tr>
<td>45</td>
<td></td>
<td>19.08</td>
</tr>
<tr>
<td>40</td>
<td></td>
<td>18.20</td>
</tr>
<tr>
<td>35</td>
<td></td>
<td>18.00</td>
</tr>
<tr>
<td>30</td>
<td></td>
<td>17.17</td>
</tr>
<tr>
<td>25</td>
<td></td>
<td>16.36</td>
</tr>
<tr>
<td>20</td>
<td></td>
<td>15.56</td>
</tr>
<tr>
<td>15</td>
<td></td>
<td>15.00</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>13.37</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>11.38</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>8.00</td>
</tr>
</tbody>
</table>

Total n = 15,058
Interpretation

<table>
<thead>
<tr>
<th>Age 40-49</th>
<th>MEN</th>
<th>Age 50-59</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Superior</td>
<td>26.00</td>
<td>95.1</td>
</tr>
<tr>
<td>Excellent</td>
<td>29.00</td>
<td>95.6</td>
</tr>
<tr>
<td>Good</td>
<td>32.00</td>
<td>96.4</td>
</tr>
<tr>
<td>Fair</td>
<td>33.00</td>
<td>96.4</td>
</tr>
<tr>
<td>Poor</td>
<td>34.00</td>
<td>96.4</td>
</tr>
<tr>
<td>Very poor</td>
<td>35.00</td>
<td>96.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total n = 28,731

Practice Problem - YMCA

YMCA CYCLE TEST

Data Recording Sheet

Subject Information:
Name: Male #1
Age: 29 yrs Date: 10/16/2009
Height: 70 in 77.0 cm
Weight: 175 lbs __________ kg
Age Predicted HRmax: _____ b/min
85% Age Predicted HRmax: _____ b/min
Resting HR: 80 b/min
Resting BP: 110/60 mmHg
Test Date:

Stage 1: Workload: 100 kg min/min
HR 1: 1:30-2:30 min: 82 b/min
HR 2: 2:30-3:30 min: 80 b/min
HR 3: 3:30-4:30 min: 78 b/min
BP 1: 2:00-3:00 min: 120/70 mmHg
BP 2: 2:30-3:30 min: 120/70 mmHg
RPE: 5

Stage 2: Workload: 200 kg min/min
HR 1: 1:30-2:30 min: 106 b/min
HR 2: 2:30-3:30 min: 104 b/min
HR 3: 3:30-4:30 min: 102 b/min
BP 1: 2:00-3:00 min: 126/70 mmHg
BP 2: 2:30-3:30 min: 126/70 mmHg
RPE: 12

Stage 3: Workload: 700 kg min/min
HR 1: 1:30-2:30 min: 123 b/min
HR 2: 2:30-3:30 min: 121 b/min
HR 3: 3:30-4:30 min: 119 b/min
BP 1: 2:00-3:00 min: 130/75 mmHg
BP 2: 2:30-3:30 min: 130/75 mmHg
RPE: 14

Stage 4: Workload: 900 kg min/min
HR 1: 1:30-2:30 min: 157 b/min
HR 2: 2:30-3:30 min: 155 b/min
HR 3: 3:30-4:30 min: 153 b/min
BP 1: 2:00-3:00 min: 170/76 mmHg
BP 2: 2:30-3:30 min: 170/76 mmHg

* If necessary
## Practice Problem - Astrand

### Astrand-Rhyming Cycle Test

**Data Recording Sheet**

<table>
<thead>
<tr>
<th>Subject Information:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Name: Female #1</td>
<td>Age: 37 yrs</td>
</tr>
<tr>
<td>Height: 62 in 157.5 cm</td>
<td>Weight: 145.5 lbs</td>
</tr>
<tr>
<td>Age Predicted HR&lt;sub&gt;max&lt;/sub&gt;: _______ b/min</td>
<td>85% Age Predicted HR&lt;sub&gt;max&lt;/sub&gt;: _______ b/min</td>
</tr>
<tr>
<td>Resting HR: 77 b/min</td>
<td>Resting BP: 110/76 mmHg</td>
</tr>
</tbody>
</table>

**Test Data:**

<table>
<thead>
<tr>
<th>Stage 1: Workload: 300 kg·m/min</th>
<th>Stage 2*: Workload: 600 kg·m/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR 1.45-2.00 min: 105 b/min</td>
<td>HR 1.45-2.00 min: 132 b/min</td>
</tr>
<tr>
<td>BP 2.00-3.00 min: 130/74 mmHg</td>
<td>BP 2.00-3.00 min: 150/72 mmHg</td>
</tr>
<tr>
<td>RPE 2.40-3.00 min: 10</td>
<td>RPE 2.40-3.00 min: 13</td>
</tr>
<tr>
<td>HR 3.45-4.00 min: 110 b/min</td>
<td>HR 3.45-4.00 min: 125 b/min</td>
</tr>
<tr>
<td>HR 4.45-5.00 min: 112 b/min</td>
<td>HR 4.45-5.00 min: 142 b/min</td>
</tr>
<tr>
<td>BP 5.00-6.00 min: 132/74 mmHg</td>
<td>BP 5.00-6.00 min: 140/72 mmHg</td>
</tr>
<tr>
<td>RPE 5.40-6.00 min: 11</td>
<td>RPE 5.40-6.00 min: 14</td>
</tr>
<tr>
<td>HR 5.45-6.00 min: 115 b/min</td>
<td>HR 5.45-6.00 min: 151 b/min</td>
</tr>
<tr>
<td>HR* 6.45-7.00 min: _______ b/min</td>
<td>HR* 6.45-7.00 min: _______ b/min</td>
</tr>
<tr>
<td>HR AVERAGE (Last two min): _______ b/min</td>
<td>HR AVERAGE (Last two min): _______ b/min</td>
</tr>
</tbody>
</table>

*If necessary

---

## Practice Problem - Astrand

![Image of a graph showing VO2 max and workload relationship](image)
## Practice Problem - Bruce

### BRUCE SUBMAXIMAL TREADMILL TEST

**Data Recording Sheet**

**Subject Information:**

- **Name:** Male #2
- **Age:** 45 yrs
- **Date:** 10/19/2009
- **Height:** 73 in 185.4 cm
- **Weight:** 195 lbs 88 kg
- **Resting HR:** 64 b/min
- **Resting BP:** 120/86 mmHg

### Test Data:

#### Stage I (1.7 mph, 10% Grade):

<table>
<thead>
<tr>
<th>Time</th>
<th>HR (b/min)</th>
<th>BP (mmHg)</th>
<th>RPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0:45</td>
<td>105</td>
<td>120/84</td>
<td>12</td>
</tr>
<tr>
<td>1:45</td>
<td>107</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2:45</td>
<td>106</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3:45</td>
<td>105</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Stage II (2.5 mph, 12% Grade):

<table>
<thead>
<tr>
<th>Time</th>
<th>HR (b/min)</th>
<th>BP (mmHg)</th>
<th>RPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0:45</td>
<td>140</td>
<td>130/90</td>
<td>14</td>
</tr>
<tr>
<td>1:45</td>
<td>142</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2:45</td>
<td>143</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3:45</td>
<td>143</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Stage III (3.4 mph, 14% Grade)*

<table>
<thead>
<tr>
<th>Time</th>
<th>HR (b/min)</th>
<th>BP (mmHg)</th>
<th>RPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0:45</td>
<td>147</td>
<td>130/92</td>
<td>16</td>
</tr>
<tr>
<td>1:45</td>
<td>155</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2:45</td>
<td>163</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3:45</td>
<td>161</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* If necessary