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UWTSD Sport and Exercise Science Physiological Testing Protocols

**Astrand-Rhyming Submaximal Cycle
Ergometer estimation of VO₂max**

Taken From:

Lab 8

**Housh, T.J., Cramer, J.T., Weir, J.P., Beck, T.W. and
Johnson, G.O. (2016). Laboratory manual for
Exercise Physiology, Exercise Testing and Physical
Activity. London: Routledge.**

BACKGROUND

Endurance capabilities are reflected in one's ability to take in and utilise oxygen. Oxygen is a crucial factor in the operation of the electron transport system, where the production of large quantities of adenosine triphosphate (ATP) occurs as a result of oxidative metabolism. The ability to sustain moderate to high-intensity exercise for appreciable lengths of time is based on the rate at which ATP can be produced by oxidative means. Consequently, this rate will be reflected by the rate at which oxygen is consumed (taken in and utilised): oxygen consumption rate or VO_2 . One means of describing the cardiorespiratory endurance fitness level of an individual is by determining maximal oxygen consumption rate ($\text{VO}_{2\text{max}}$).

As one performs heavier power outputs on a cycle ergometer, both oxygen consumption rate and heart rate (HR) increase. Oxygen consumption rate increases because the demands of the work require increased production of energy and increased HR to transport oxygen and fuels to the active muscle tissues and remove their metabolic waste products more rapidly. The relationship of power output to oxygen consumption rate remains fairly constant between individuals, as well as for the same individual at various times. Therefore, when we know the power output, the corresponding oxygen consumption rate can be predicted with reasonable accuracy ($\pm$ about 10%). However, the proportion to which HR increases in comparison to either power output or oxygen consumption rate will vary between individuals or for a certain individual based on level of fitness (endurance capability).

The ability to predict VO_2 max is based on the fact that the heart pumps more efficiently and oxygen is more readily utilised for metabolism in individuals with higher maximal oxygen consumption capabilities. We can refer to this as increased cardiovascular efficiency, since the heart doesn't have to work as hard (HR is lower) to meet the metabolic demands of a task. Therefore, if two individuals are performing at the same power output (requiring the same rate of oxygen consumption), the individual with the higher VO_2 max will tend to have a lower HR. The basis of the Astrand–Rhyming Test (named for the distinguished scientists who developed the test, the husband-and-wife team P. O. Astrand and I. Rhyming) is to make use of this relationship.²

In essence, we would expect that if two individuals were to work such that similar HRs result (say 150 bpm), the individual with a higher VO_2 max will actually be performing more physical work (again, this reflects cardiovascular efficiency). Therefore, the basic procedure of the test is to have an individual work at moderate intensity (HR = 120–170 bpm) and record both the HR and the power output. Using these two pieces of data, we can estimate VO_2 max ($\pm$ 10 to 15% error) from previously determined relationships available in tables 8.1 and 8.2. This laboratory experience will help you become familiar with the procedures and supportive principles of this basic mode of fitness testing. In addition, you should be able to interpret the results of such testing in terms of fitness levels.

KNOW THESE TERMS & ABBREVIATIONS

- $\text{kgm} \cdot \text{min}^{-1}$ = kilogram meters per minute
- HR = heart rate
- O_2 = oxygen consumption rate; an indirect measure of aerobic ATP production
- $\text{O}_2 \text{ max}$ = maximal oxygen consumption rate

PROCEDURES

1. Set the seat height on the Wattbike to hip height. Raise or lower your saddle height using the lever on the rear of the saddle stem. **Photo 1.0**
2. Put on a heart rate (HR) monitor, turn on AtomX or if using the Atom login to the Wattbike App. Select 'Just Ride', connect the Ipad to the Atom, connect the heart rate monitor to the Ipad/screen set the Wattbike into Ergo mode- In Ergo mode the Wattbike will hold the desired target wattage regardless of cadence. **Photo 2**
3. The test is a single stage test lasting 6 minutes with the goal of obtaining HR values between 125 and 170bpm
4. Select the desired work rate [very little resistance] for a 3-5 minute warm up.
5. The suggested work rate for the 6-minute test is based on sex and an individual's fitness status as follows:
 - Men, unconditioned: 300 or 600 $\text{kgm} \cdot \text{min}^{-1}$ [50 or 100W]
 - Men, conditioned: 600 or 900 $\text{kgm} \cdot \text{min}^{-1}$ [100 or 150W]
 - Women, unconditioned: 300 or 450 $\text{kgm} \cdot \text{min}^{-1}$ [50 or 75W]
 - Women, conditioned: 450 or 600 $\text{kgm} \cdot \text{min}^{-1}$ [75 or 100W]
6. After the warmup start the 6-minute test.
7. Measure and record the 30-second HR for the last 30 seconds of minutes 2 through 6. Record data on worksheet 8.1.
8. At the end of the third minute, adjust the power output (up or down) if it is not likely that the subject will be in the target HR zone (120–170 bpm) at the end of the 6-minute test.
9. If the subject has not reached a steady state HR by the end of the 6 minutes, extend the test until the difference between consecutive minutes is less than 10 bpm. The last two HR values should be averaged for use in calculations.
10. Allow the subject to cool down
11. Convert the raw data (power and HR) into a VO_2max prediction using the calculation methods described below, or using the online calculator which can be found at <https://www.health-calc.com/fitness-tests/aastrand-test>



PHOTO 1.0 Wattbike Atom/AtomX

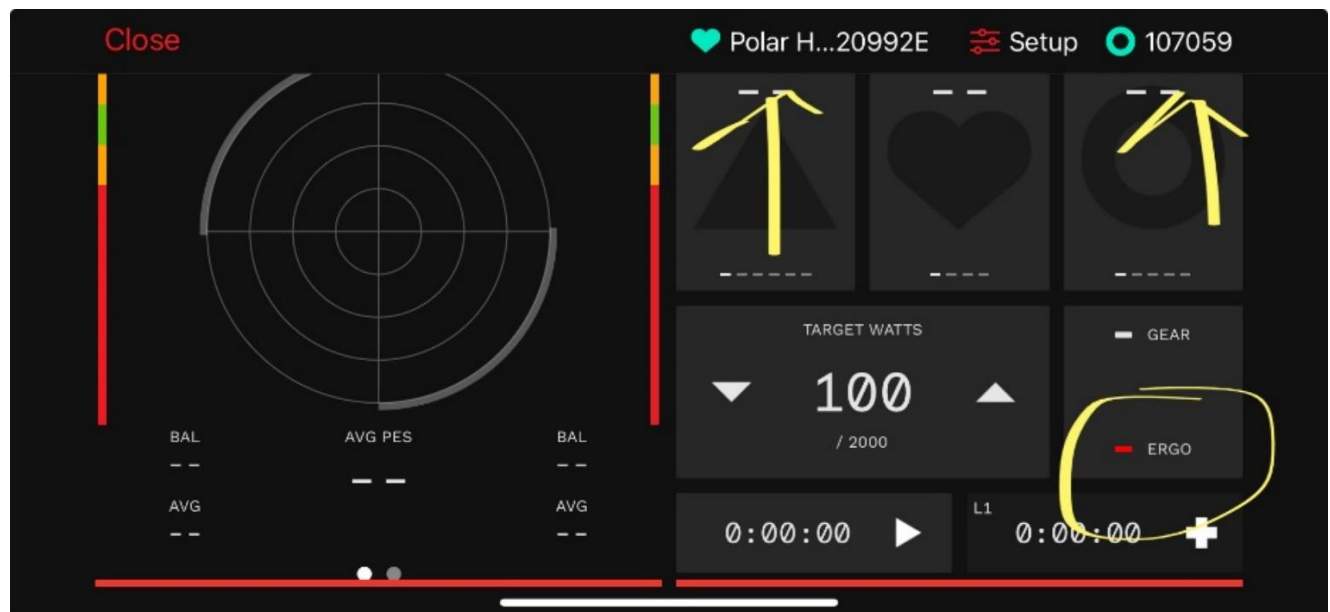


PHOTO 2.0 Select 'Just Ride', connect the Wattbike, heart rate monitor, select Ergo mode and select desired Wattage.

Worksheet 8.1

ASTRAND-RHYMING TEST FORM

Name _____

Date _____

Body weight _____

Gender _____

MINUTE	HEART RATE FOR LAST 30 SECONDS OF THE TIME INTERVAL	POWER OUTPUT
1		
2		
3		
4		
5		
6		
Use if needed		
7		
8		

Initial power output _____

Adjusted power output (if applicable) _____

Average HR for last 2 minutes of test _____

- Preliminary $\dot{V}O_2$ max value from table 8.1 or 8.2 _____ $L \cdot \min^{-1}$
- Multiply preliminary $\dot{V}O_2$ max value by age correction factor (table 8.3) _____ $L \cdot \min^{-1}$
- Multiply $\dot{V}O_2$ max in $L \cdot \min^{-1} \times 1000 =$ _____ $mL \cdot \min^{-1}$
- Divide the age-corrected $\dot{V}O_2$ max ($mL \cdot \min^{-1}$) value by body weight in kg = _____ $mL \cdot kg^{-1} \cdot \min^{-1}$
- Fitness category (table 8.4) _____

Males' maximal oxygen consumption rate ($L \cdot \min^{-1}$) predicted from cycle ergometer test.¹

TABLE

8.1

HR	Power Output ($\text{kgm} \cdot \min^{-1}$)									
	150	300	450	600	750	900	1050	1200	1350	1500
120	1.6	2.2	2.8	3.5	4.1	4.8	5.6			
121	1.6	2.2	2.8	3.4	4.0	4.7	5.5			
122	1.6	2.2	2.8	3.4	4.0	4.6	5.4			
123		2.1	2.7	3.4	3.9	4.6	5.3			
124		2.1	2.7	3.3	3.9	4.5	5.2	6.0		
125		2.0	2.6	3.2	3.8	4.4	5.1	5.9		
126		2.0	2.6	3.2	3.8	4.4	5.1	5.8		
127		2.0	2.5	3.1	3.7	4.3	5.0	5.7		
128		2.0	2.5	3.1	3.6	4.2	4.9	5.6		
129		1.9	2.4	3.0	3.6	4.2	4.8	5.6		
130		1.9	2.4	3.0	3.5	4.1	4.8	5.5		
131		1.9	2.4	2.9	3.5	4.0	4.7	5.4		
132		1.8	2.3	2.9	3.4	4.0	4.6	5.3	6.0	
133		1.8	2.3	2.8	3.4	3.9	4.6	5.3	5.9	
134		1.8	2.3	2.8	3.3	3.9	4.5	5.2	5.8	
135		1.7	2.3	2.8	3.3	3.8	4.4	5.1	5.7	
136		1.7	2.2	2.7	3.2	3.8	4.4	5.0	5.6	
137		1.7	2.2	2.7	3.2	3.7	4.3	5.0	5.6	
138		1.6	2.2	2.7	3.2	3.7	4.3	4.9	5.5	
139		1.6	2.1	2.6	3.1	3.6	4.2	4.8	5.4	
140		1.6	2.1	2.6	3.1	3.6	4.2	4.8	5.4	6.0
141			2.1	2.6	3.0	3.5	4.1	4.7	5.3	5.9
142			2.1	2.5	3.0	3.5	4.1	4.6	5.2	5.8
143			2.0	2.5	2.9	3.4	4.0	4.6	5.2	5.7
144			2.0	2.5	2.9	3.4	4.0	4.5	5.1	5.7
145			2.0	2.4	2.9	3.4	3.9	4.5	5.0	5.6
146			2.0	2.4	2.8	3.3	3.9	4.4	5.0	5.6
147			2.0	2.4	2.8	3.3	3.8	4.4	4.9	5.5
148			1.9	2.4	2.8	3.2	3.8	4.3	4.9	5.4
149			1.9	2.3	2.7	3.2	3.7	4.3	4.8	5.4
150			1.9	2.3	2.7	3.2	3.7	4.2	4.8	5.3
151			1.9	2.3	2.7	3.1	3.7	4.2	4.7	5.2
152				2.3	2.7	3.1	3.6	4.1	4.6	5.2
153				2.2	2.6	3.0	3.6	4.1	4.6	5.1
154				2.2	2.6	3.0	3.5	4.0	4.5	5.1
155				2.2	2.6	3.0	3.5	4.0	4.5	5.0
156				2.2	2.5	2.9	3.4	4.0	4.4	5.0
157				2.1	2.5	2.9	3.4	3.9	4.4	4.9
158				2.1	2.5	2.9	3.4	3.9	4.3	4.9
159				2.1	2.4	2.8	3.3	3.8	4.3	4.8
160				2.1	2.4	2.8	3.3	3.8	4.3	4.8
161				2.0	2.4	2.8	3.2	3.7	4.2	4.7
162				2.0	2.4	2.8	3.2	3.7	4.2	4.6
163				2.0	2.4	2.8	3.2	3.7	4.2	4.6
164				2.0	2.3	2.7	3.1	3.6	4.1	4.5
165				2.0	2.3	2.7	3.1	3.6	4.1	4.5
166				1.9	2.3	2.7	3.1	3.6	4.1	4.5
167				1.9	2.2	2.6	3.0	3.5	4.0	4.4
168				1.9	2.2	2.6	3.0	3.5	4.0	4.4
169				1.9	2.2	2.6	3.0	3.5	3.9	4.3
170				1.8	2.2	2.6	3.0	3.4	3.9	4.3

Note: To convert $\text{kgm} \cdot \min^{-1}$ to watts, divide by 6.12.From P. O. Astrand and K. Rodahl, *Textbook of Work Physiology*. Copyright © 1977 McGraw-Hill Book Company. Used with permission of the author.

TABLE

8.2

Females' maximal oxygen consumption rate ($L \cdot \min^{-1}$) predicted from cycle ergometer test.¹

HR	Power Output ($kgm \cdot \min^{-1}$)					
	150	300	450	600	750	900
120	1.8	2.6	3.4	4.1	4.8	
121	1.7	2.5	3.3	4.0	4.8	
122	1.7	2.5	3.2	3.9	4.7	
123	1.7	2.4	3.1	3.9	4.6	
124	1.7	2.4	3.1	3.8	4.5	
125	1.6	2.3	3.0	3.7	4.4	
126	1.6	2.3	3.0	3.6	4.3	
127	1.6	2.2	2.9	3.5	4.2	
128	1.6	2.2	2.8	3.5	4.2	4.8
129	1.6	2.2	2.8	3.4	4.1	4.8
130		2.1	2.7	3.4	4.0	4.7
131		2.1	2.7	3.4	4.0	4.6
132		2.0	2.7	3.3	3.9	4.5
133		2.0	2.6	3.2	3.8	4.4
134		2.0	2.6	3.2	3.8	4.4
135		2.0	2.6	3.1	3.7	4.3
136		1.9	2.5	3.1	3.6	4.2
137		1.9	2.5	3.0	3.6	4.2
138		1.8	2.4	3.0	3.5	4.1
139		1.8	2.4	2.9	3.5	4.0
140		1.8	2.4	2.8	3.4	4.0
141		1.8	2.3	2.8	3.4	3.9
142		1.7	2.3	2.8	3.3	3.9
143		1.7	2.2	2.7	3.3	3.8
144		1.7	2.2	2.7	3.2	3.8
145		1.6	2.2	2.7	3.2	3.7
146		1.6	2.2	2.6	3.2	3.7
147		1.6	2.1	2.6	3.1	3.6
148		1.6	2.1	2.6	3.1	3.6
149			2.1	2.6	3.0	3.5
150			2.0	2.5	3.0	3.5
151			2.0	2.5	3.0	3.4
152			2.0	2.5	2.9	3.4
153			2.0	2.4	2.9	3.3
154			2.0	2.4	2.8	3.3
155			1.9	2.4	2.8	3.2
156			1.9	2.3	2.8	3.2
157			1.9	2.3	2.7	3.2
158			1.8	2.3	2.7	3.1
159			1.8	2.2	2.7	3.1
160			1.8	2.2	2.6	3.0
161			1.8	2.2	2.6	3.0
162			1.8	2.2	2.6	3.0
163			1.7	2.2	2.6	2.9
164			1.7	2.1	2.5	2.9
165			1.7	2.1	2.5	2.9
166			1.7	2.1	2.5	2.8
167			1.6	2.1	2.4	2.8
168			1.6	2.0	2.4	2.8
169			1.6	2.0	2.4	2.8
170			1.6	2.0	2.4	2.7

Note: To convert $kgm \cdot \min^{-1}$ to watts, divide by 6.12.

From P.O. Astrand and K. Rodahl, *Textbook of Work Physiology*. Copyright © 1977 McGraw-Hill Book Company. Used with permission of the author.

Age correction factors for predicting maximal oxygen consumption rate.¹

TABLE

8.3

Age (yrs)	Correction Factor
20	1.07
25	1.00
35	0.87
45	0.78
55	0.71
65	0.65

From P. O. Astrand and K. Rodahl, *Textbook of Work Physiology*. Copyright © 1977 McGraw-Hill Book Company. Used with permission.

Men's and women's aerobic fitness classifications.

TABLE

8.4

Men		Age (years)					
CATEGORY	MEASURE	13–19	20–29	30–39	40–49	50–59	60+
I. Very Poor	$\dot{V}O_2$ max (mL • kg ⁻¹ • min ⁻¹)	<35.0	<33.0	<31.5	<30.2	<26.1	<20.5
II. Poor	$\dot{V}O_2$ max (mL • kg ⁻¹ • min ⁻¹)	35.0–38.3	33.0–36.4	31.5–35.4	30.2–33.5	26.1–30.9	20.5–26.0
III. Fair	$\dot{V}O_2$ max (mL • kg ⁻¹ • min ⁻¹)	38.4–45.1	36.5–42.4	35.5–40.9	33.6–38.9	31.0–35.7	26.1–32.2
IV. Good	$\dot{V}O_2$ max (mL • kg ⁻¹ • min ⁻¹)	45.2–50.9	42.5–46.4	41.0–44.9	39.0–43.7	35.8–40.9	32.3–36.4
V. Excellent	$\dot{V}O_2$ max (mL • kg ⁻¹ • min ⁻¹)	51.0–55.9	46.5–52.4	45.0–49.4	43.8–48.0	41.0–45.3	36.5–44.2
VI. Superior	$\dot{V}O_2$ max (mL • kg ⁻¹ • min ⁻¹)	>56.0	>52.5	>49.5	>48.1	>45.4	>44.3

Women		Age (years)					
CATEGORY	MEASURE	13–19	20–29	30–39	40–49	50–59	60+
I. Very Poor	$\dot{V}O_2$ max (mL • kg ⁻¹ • min ⁻¹)	<25.0	<23.6	<22.8	<21.0	<20.2	<17.5
II. Poor	$\dot{V}O_2$ max (mL • kg ⁻¹ • min ⁻¹)	25.0–30.9	23.6–28.9	22.8–26.9	21.0–24.4	20.2–22.7	17.5–20.1
III. Fair	$\dot{V}O_2$ max (mL • kg ⁻¹ • min ⁻¹)	31.0–34.9	29.0–32.9	27.0–31.4	24.5–28.9	22.8–26.9	20.2–24.4
IV. Good	$\dot{V}O_2$ max (mL • kg ⁻¹ • min ⁻¹)	35.0–38.9	33.0–36.9	31.5–35.6	29.0–32.8	27.0–31.4	24.5–30.2
V. Excellent	$\dot{V}O_2$ max (mL • kg ⁻¹ • min ⁻¹)	39.0–41.9	37.0–40.9	35.7–40.0	32.9–36.9	31.5–35.7	30.3–31.4
VI. Superior	$\dot{V}O_2$ max (mL • kg ⁻¹ • min ⁻¹)	>42.0	>41.0	>40.1	>37.0	>35.8	>31.5

Source: Cooper, Kenneth H. *The Aerobics Way*. Toronto: Bantam Books, 1977, pp. 280–281. Printed with permission of Kenneth H. Cooper, MD, MPH, www.cooperaerobics.com, and J.B. Lipponcott via Copyright Clearance Center.

1. Astrand, P. O., and Rodahl, K. *Textbook of Work Physiology*. New York: McGraw-Hill, 1977, pp. 350–352.
2. Astrand, P. O., and Rhyning, I. A nomogram for calculation of aerobic capacity (physical fitness) from pulse rate during submaximal work. *J. Appl. Physiol.* 7: 218–221, 1954.
3. Cooper, K. H. *The Aerobics Way*. Toronto: Bantam Books, 1977, pp. 280–281.