

HE-10: Aerobic Fitness Testing

Before Starting

1. Read the procedures for the experiment completely before beginning the experiment. Have a good understanding of how to perform the experiment before making recordings.
2. It is important that the subject is healthy and has no history of respiratory or cardiovascular problems.
3. Allow the SP-304 to warm up for 15 minutes before recording for the first time.
4. Determine if the airflow tubes between the flowhead to the spirometer amplifier are attached to the proper inlets on each device.
 - Since this test does not need to be recorded, click on the Save to Disk button in the lower left corner of the Main window. If LabScribe is in Preview mode, there will be a red X across the Save to Disk button.
 - Click on the Preview button.

Note: If the user clicks the Preview button and an error window appears the Main window indicating the iWorx hardware cannot be found, make sure the iWorx unit is turned on and connected to the USB port of the computer. Then, click on the OK button in the error window. Pull down the LabScribe Tools menu, select the Find Hardware function, and follow the directions on the Find Hardware dialogue window

- Have the subject inhale and exhale through the mask 2 or 3 times while the complete spirometry circuit is assembled.
 - Click on the AutoScale button at the upper margin of the Expired Air Flow and Lung Volume channels.
 - If the proper end of the flowhead is attached to the outlet of the mixing chamber, the traces on the Air Flow and Lung Volume channels will go up when the subject exhales.
 - If the traces on these channels go down during exhalation, remove the flowhead from the outlet of the mixing chamber and place the other end of the flowhead on the outlet of the mixing chamber.
 - Click on the Stop button.
5. Click on the Save to Disk button, in the lower left corner of the Main window, to change LabScribe from Preview mode to Record mode. If LabScribe is in Record mode, there will be a green arrow on the Save to Disk button.

Select the Exercise Protocol

Some of the common exercise protocols used to test aerobic fitness are described over the next few pages.

Bruce Treadmill Exercise Protocol

This protocol was developed in the 1950's by Dr. Robert A. Bruce as a clinical test to evaluate the cardiovascular fitness of patients with suspected coronary heart disease. Currently, it is the most commonly used exercise stress test conducted on a treadmill.

Warning: This test is a maximal test, which requires a reasonable level of fitness. If this test is going to be performed by a recreational athlete or persons with health problems, injuries or low fitness levels, please have medical assistance on hand.

1 The test begins with the subject walking on a treadmill at a speed of 2.74 km/hr (1.7 mph) and a gradient of 10% for three minutes ([Table HE-10-L1](#)). The stopwatch is started at the beginning of the test to measure the time until the subject is exhausted.

Table HE-10-L1: Speeds and Gradients Used in Each Stage of the Bruce Protocol.

Stage	Speed		Gradient	Elapsed Time
	km/hr	mph	%	Minutes
1	2.74	1.7	10	3
2	4.02	2.5	12	6
3	5.47	3.4	14	9
4	6.76	4.2	16	12
5	8.05	5.0	18	15
6	8.85	5.5	20	18
7	9.65	6.0	22	21
8	10.46	6.5	24	24
9	11.26	7.0	26	27
10	12.07	7.5	28	30

2. After the first stage, the gradient is increased by 2% and the speed is increased to the speed listed for each stage in at three minute intervals.
3. The test proceeds until the subject reaches volitional exhaustion, maximum heart rate, a VO_2 plateau, or an RER of 1.15 or greater.
4. The stopwatch is stopped when the subject can no longer continue.

- Since heart rate is monitored during this test, the determination of the maximum heart rate can be used to set the intensity of exercise in the subject's training program.

Astrand Treadmill Protocol

This protocol is another test that is suitable for athletes involved in endurance sports.

Warning: This test is a maximal test, which requires a reasonable level of fitness. If this test is going to be performed by a recreational athlete or persons with health problems, injuries or low fitness levels, please have medical assistance on hand.

- The test begins with the subject jogging on a treadmill at a speed of 8.05 km/hr (5.0 mph) and a gradient of 0% for three minutes (Table HE-10-L2). The stopwatch is started at the beginning of the test to measure the time until the subject is exhausted.
- In each successive stage, the gradient is increased by 2.5% in each two minute interval while the speed is kept the same.
- The test proceeds until the subject reaches volitional exhaustion, maximum heart rate, a VO_2 plateau, or an RER of 1.15 or greater. The stopwatch is stopped when the subject can no longer continue.
- Since heart rate is monitored during this test, the determination of the maximum heart rate can be used to set the intensity of exercise in the subject's training program.

Table HE-10-L2: Speeds and Gradients Used in Each Stage of the Astrand Treadmill Protocol.

Stage	Speed		Gradient	Elapsed Time
	km/hr	mph	%	Minutes
1	8.05	5.0	0	3
2	8.05	5.0	2.5	5
3	8.05	5.0	5.0	7
4	8.05	5.0	7.5	9
5	8.05	5.0	10.0	11
6	8.05	5.0	12.5	13
7	8.05	5.0	15.0	15
8	8.05	5.0	17.5	17
9	8.05	5.0	20.0	19
10	8.05	5.0	22.5	21

Modified Bruce Treadmill Exercise Protocol

The Modified Bruce Protocol is used when testing the cardiovascular fitness of elderly or sedentary patients. The modified test starts at a lower workload than the standard test. The first two stages of the Modified Bruce Protocol are performed at 1.7 mph and 0% grade and 1.7 mph and 5% grade. The third stage of the modified protocol corresponds to the first stage of the standard Bruce Protocol.

Warning: This test is a maximal test, which requires a reasonable level of fitness. If this test is going to be performed by recreational athletes or persons with health problems, injuries or low fitness levels, please have medical assistance on hand.

1. The test begins with the subject walking on a treadmill at a speed of 2.74 km/hr (1.7 mph) and a gradient of 0% for three minutes (Table HE-10-L3). The stopwatch is started at the beginning of the test to measure time until the subject is exhausted.

Table HE-10-L3: Speeds, Gradients, and Times used in each stage of the Modified Bruce and Cornell Treadmill Protocols.

Stage	Exercise Intensity			Elapsed Time	
	Speed		Gradient	Modified Bruce	Cornell
	km/hr	mph		mins	mins
P1	2.74	1.7	0	3	2
P2	2.74	1.7	5	6	4
1	2.74	1.7	10	9	6
1.5	3.38	2.1	11		8
2	4.02	2.5	12	12	10
2.5	4.82	3.0	13		12
3	5.47	3.4	14	15	14
3.5	6.11	3.8	15		16
4	6.76	4.2	16	18	18
4.5	7.40	4.6	17		20
5	8.05	5.0	18	21	22

2. In the second stage of the protocol, the gradient is increased to 5% while the speed is maintained at 2.74 km/hr (1.7 mph) for three minutes.

3. In the third stage of the protocol, the gradient is increased to 10% while the speed is maintained at 2.74 km/hr (1.7 mph) for three minutes.
4. After the third stage, the gradient is increased by 2% and the speed is increased to the speed listed for each stage in at three minute intervals.
5. The test proceeds until the subject reaches volitional exhaustion, maximum heart rate, a VO_2 plateau, or an RER of 1.15 or greater. The stopwatch is stopped when the subject can no longer continue.
6. Since heart rate is also monitored during this test, the determination of the maximum heart rate can be used to set the intensity of exercise in the subject's training program.

Cornell Protocol

The Cornell Protocol has workloads that are gently graded from stage to stage making this test suitable for subjects that might experience heart failure. This protocol contains stages that are whole and half increments of the Bruce Protocol. The stages in the Cornell Protocol are completed in two minute increments, not three minute increments. For a comparison of the Cornell Protocol to the Modified Bruce Protocol, go to [Table HE-10-L3](#).

Warning: This test is a maximal test, which requires a reasonable level of fitness. If this test is going to be performed by recreational athletes or persons with health problems, injuries or low fitness levels, please have medical assistance on hand.

1. The test begins with the subject walking on a treadmill at a speed of 2.74 km/hr (1.7 mph) and a gradient of 0% for two minutes. The stopwatch is started when the test is started to measure the total amount of time that passes until the subject is exhausted.
2. In the next increment of the protocol, the gradient is increased to 5% while the speed is maintained at 2.74 km/hr (1.7 mph) for two minutes.
3. In the successive increments of the protocol, the gradient is increased by 10% while the speed is maintained at 2.74 km/hr (1.7 mph) for two minutes.
4. After the third increment, the gradient is increased by 2% per increment and the speed is increased to the speed listed for each increment ([Table HE-10-L3](#)).
5. The test proceeds until the subject reaches volitional exhaustion, maximum heart rate, a VO_2 plateau, or an RER of 1.15 or greater. The stopwatch is stopped when the subject can no longer continue.
6. Since heart rate is also monitored during this test, the determination of the maximum heart rate can be used to set the intensity of exercise in the subject's training program.

Naughton Protocol

The Naughton Protocol is a low intensity exercise protocol that has incremental increases in workload that are more gradual than the Bruce Protocol. Because of these gradual increases, the cardiovascular

response of a subject to the workload has a greater linearity than other protocols. The protocol is frequently used on subjects that are debilitated by heart failure.

1. The test begins with the subject walking on a treadmill at a speed of 1.93 km/hr (1.2 mph) and a gradient of 0% for two minutes (Table HE-10-L4). The stopwatch is started when the test is started to measure the total amount of time that passes until the subject is exhausted.
2. In the second stage, the speed is increased to 2.41 km/hr (1.5 mph) while the gradient is maintained at 0%.
3. In each of the next three stages, the speed is maintained at 2.41 km/hr (1.5 mph) while the gradient is increased by 3% every two minutes.
4. In the sixth stage, the speed is increased to 3.21 km/hr (2.0 mph) while the gradient is increased to 12%.
5. The test proceeds until the subject reaches volitional exhaustion, maximum heart rate, a VO_2 plateau, or an RER of 1.15 or greater. The stopwatch is stopped when the subject can no longer continue.
6. Since heart rate is monitored during this test, the determination of the maximum heart rate can be used to set the intensity of exercise in the subject's training program.

Table HE-10-L4: Speeds, Gradients, and Times used in each stage of the Naughton Protocol.

Stage	Speed		Gradient	Elapsed Time
	km/hr	mph		
1	1.93	1.2	0	2
2	2.41	1.5	0	4
3	2.41	1.5	3	6
4	2.41	1.5	6	8
5	2.41	1.5	9	10
6	3.21	2.0	12	12

Balke Treadmill Protocol

The Balke Treadmill Protocol is another assessment of aerobic fitness that is recommended for cardiac patients since the increase in workload is moderate. The protocol is considered safe for patients with severe left ventricular dysfunction.

1. The test begins with the subject walking on a treadmill at a constant walking and a gradient of 0%. A stopwatch is started at this time to measure the total amount of time that passes until the subject is exhausted.

2. Depending on the gender of the subject, the gradient is increased every one minute, two, or three minutes.
3. The test proceeds until the subject reaches volitional exhaustion, maximum heart rate, a VO_2 plateau, or an RER of 1.15 or greater. The stopwatch is stopped when the subject can no longer continue.
4. Since heart rate is monitored during this test, the determination of the maximum heart rate can be used to set the intensity of exercise in the subject's training program.
5. There are several variations of the Balke Treadmill Protocol. Here are some examples of these variations that have been used.
 - For active and sedentary men, the treadmill speed is set at 5.28 km/hr (3.3 mph) with a gradient of 0%. After 1 minute, the gradient is raised to 2%. At each successive one minute interval, the gradient is increased by 1%.
 - For active and sedentary women, the treadmill speed is set at 4.81 km/hr (3.0 mph) with a gradient of 0%. After three minutes, the gradient is increased by 2.5% at each three minute interval.
 - For all subjects, the treadmill speed is set at a constant speed of 3.00 km/hr (1.88 mph) as the gradient is increased by 2.5% at each two minute interval.

Conduct the VO_2 max Test

1. While preparations are completed, have the subject become accustomed to wearing the non-rebreathing valve with the mask or optional mouthpiece. The subject must be able to breathe normally before any recordings can be made.
2. Remind the subject and all the persons assisting in the test about the specifications of the exercise protocol being used in the test.
3. Wet the cloth electrode patches on the inside of the PHRM-100 belt with water. Position the belt around the chest of the subject with the electrodes making contact with the skin that is over the heart. Snap the heart rate transmitter to the electrode belt so that the label is right side up. The subject may wear a shirt since it will not interfere with the operation of the PHRM-100.
4. Once the subject and recording equipment is all prepared, have the subject remove the mask from his or her face and hold the non-rebreathing valve and mask in a position so that the subject's breath is not moving through the valve.

Note: The LabScribe software will automatically zero the Lung Volume STPD channel. No air can be moving through the non-rebreathing valve during the first ten seconds of the recording.

5. Type <Subject's Name> Stage 1 in the Mark box that is to the right of the Mark button.
6. Click on the Record button. After waiting three seconds for the Lung Volume STPD channel to zero, the subject should put the mask in his or her mouth and adjust the position of the mask and flow head to create a seal. The assembly should be firmly, but comfortably, attached to head of the subject.
7. Press the Enter key on the keyboard to mark the recording as the subject begins breathing

through the mask and the flowhead. Start the stopwatch to keep track of the time in each stage of the exercise protocol.

8. Click the AutoScale buttons on all channels and make sure all channels are being recorded properly (Figure HE-10-L1).
 - The trace on the CO₂ Concentration (%) channel increases as the mixing chamber fills with exhaled air. It gradually increases as the fitness test proceeds.
 - The trace on the O₂ Concentration (%) channel decreases as the mixing chamber fills with exhaled air. It gradually decreases as the fitness test proceeds.
 - The trace on the Heart Rate Monitor channel registers a spike for each heart beat.
 - The trace on the Air Flow channel records an individual peak for each breath exhaled by the subject.
 - The trace on the Lung Volume STPD channel increases steadily as the cumulative volume of air exhaled by the subject is recorded.
 - The trace on the Heart Rate channel should appear as a histogram that traces the heart rate between beats.

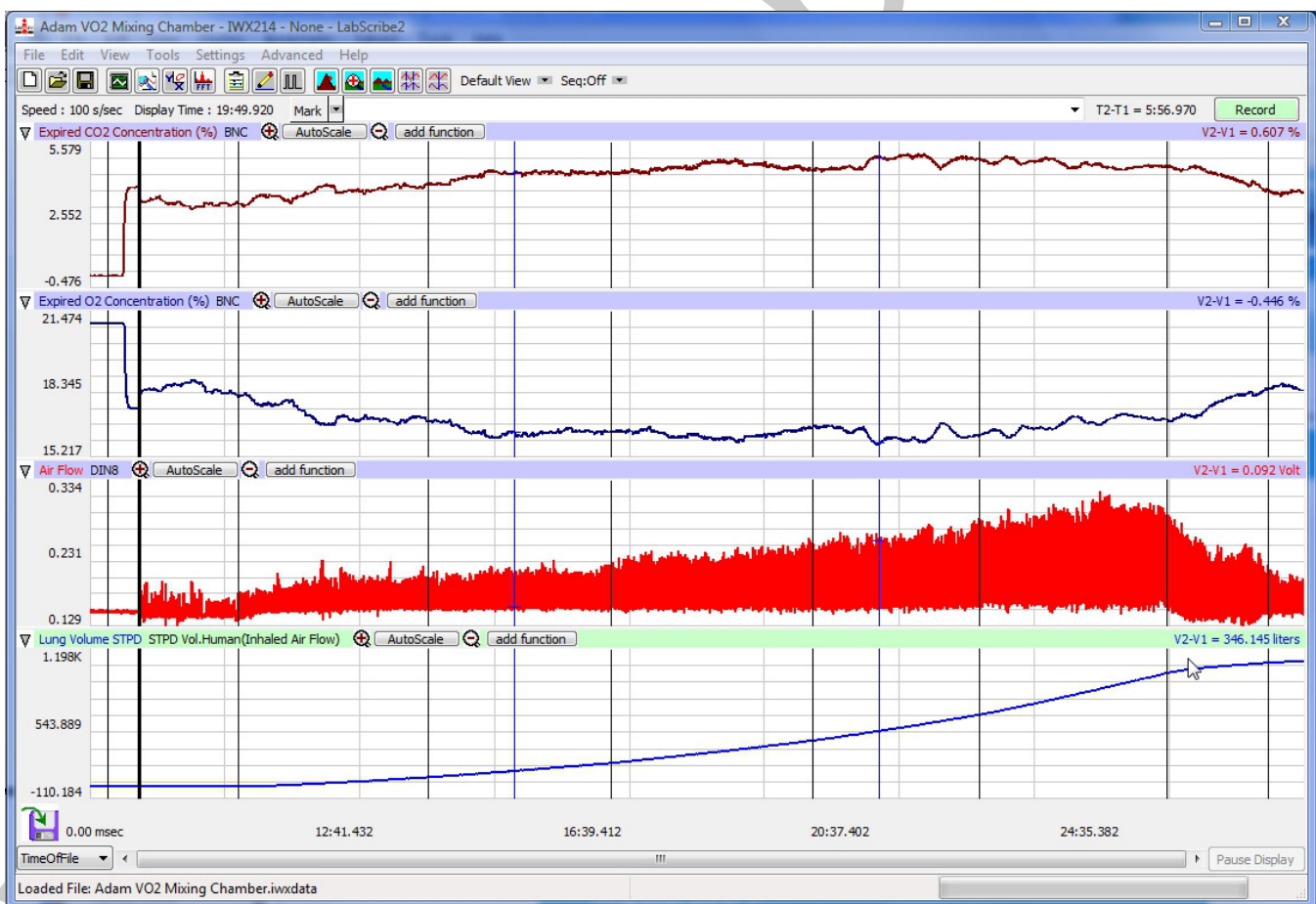


Figure HE-10-L1: The CO₂ Concentration (%), O₂ Concentration (%), Air Flow, and Lung Volume STPD channels shown on the Main window.

9. Follow the exercise protocol selected and change the speed and/or elevation of the treadmill at the times listed in the protocol. Enter the name of each stage in the Mark box and press the Enter key to mark the recording at the beginning of each stage of the protocol.
10. Continue to record as the subject exercises. Observe the changes in the O₂ and CO₂ concentrations, the air flow per breath and the total volume of air exhaled from the lungs as the protocol continues.
11. Click the Stop button to halt the exercise protocol when the subject reaches volitional exhaustion, or his or her maximum heart rate.
12. Select Save As in the File menu, type a name for the file. Choose a destination on the computer in which to save the file, like your lab group folder). Designate the file type as *.iwxdata. Click on the Save button to save the data file.

Calculate and Plot Metabolic Parameters

Values for VO₂, VCO₂, RER, TV, and other parameters ([Table HE-10-L5](#)) from the segments of the test can be calculated automatically by using the Metabolic Calculations window.

1. To use the Metabolic Calculations window, pull down the Advanced menu and select Metabolic. Select Mixing Chamber: Offline Calculations from the submenu to open the Metabolic Calculations Dialog window.
2. On the left side of the Metabolic Calculations window:
 - Pull down the CO₂, O₂, Volume, Heart Rate, and Energy Channel menus to select the channels on which the CO₂ and O₂ concentrations, lung volumes, heart rates, and workload were recorded.
 - When analyzed, the data file will be divided into time segments. The average of each parameter in each segment will be reported in the data table on the Metabolic Calculations window. Enter the time (in secs) in the Average box to select the time length of each segment.
 - In the O₂ and CO₂ Concentrations in Inhaled Air boxes, enter the concentrations of oxygen and carbon dioxide in the inhaled air, which is room air in most tests.
3. Click on the Calculate button on the left side of the Metabolic Calculations Dialog window to calculate the average value of each parameter listed in the table for each time segment of the recorded data, and to plot the selected parameters against each other in the plot panel ([Figure HE-10-L2](#)).
4. In the lower left corner of the plot panel, click on the arrow to open the pull-down menu listing the types of plots ([Table HE-10-L6](#)) that can be made with the metabolic parameters calculated by this analytical tool. Select the plot to be displayed in the plot panel when the calculations are performed

Table HE-10-L5: List of Parameters Calculated on the Breath By Breath Offline Metabolic Window

Term	Parameter	Description	Units
Abs.VO ₂	Absolute VO ₂	Volume of oxygen (O ₂) consumed per min.	Liters/minute
Abs.VCO ₂	Absolute VCO ₂	Volume of carbon dioxide (CO ₂) produced per min.	Liters/minute
Rel.VO ₂	Relative VO ₂	Volume of O ₂ consumed per kg body weight per minute	ml/kg/minute
Rel.VCO ₂	Relative VCO ₂	Volume of CO ₂ produced per kg body weight per minute	ml/kg/minute
RER	Respiratory Exchange Ratio	Ratio of VCO ₂ /VO ₂	None
REE	Resting Energy Expenditure	5.46 (Absolute VO ₂) + 1.75 (Absolute VCO ₂)	kcal/day
TV	Tidal Volume	Volume of air displaced during a normal breath cycle - inhalation and exhalation	Liters/breath
RR	Respiratory Rate	Number of breaths per minute: (60 sec/min) divided by the breath period	Breaths / minute
METS	Metabolic Equivalent of Task	1 MET = 3.5ml O ₂ /kg/min or 1kcal/kg/hr	MET
O ₂ Min.	O ₂ Minimum - exhalation	Minimum concentration of O ₂ recorded during test period	Percentage
CO ₂ Max.	CO ₂ Maximum - exhalation	Maximum concentration of CO ₂ recorded during test period	Percentage
VI	Inspired Tidal Volume	Volume of air displaced during normal inhalation	Liters/breath
VE	Expired Tidal Volume	Volume of air displaced during normal exhalation	Liters/breath
P	Power	Workload during the stages of the test	Watts
HR	Heart Rate	Number of beats in a minute: (60 sec/min) divided by the beat period	Beats per Minute

Table HE-10-L6: Plots Available on the Offline Metabolic Window.

		Available Plots									
Y-Axis Parameter 1	VO ₂	VCO ₂	V _e	V _e	HR	V _t	V _e	HR	VO ₂	V _e /VO ₂	RER
Y-Axis Parameter 2	VCO ₂				VCO ₂			VO ₂ /HR	VCO ₂	V _e /VCO ₂	
Y-Axis Parameter 3	RER										
X-Axis Parameter	Time	VO ₂	VO ₂	VCO ₂	VO ₂	V _e	Watts	Watts	Watts	Watts	Watts

Interpret the Data

1. Compare the VO₂ value from the last minute of the last exercise segment completed by the subject to the values for the subject's age group in [Table HE-10-L7](#) or [Table HE-10-L8](#).
2. Determine the fitness level of the subject based on the subject's VO₂ level.
3. What is the subject's RER in the last minute of the last exercise segment completed?
4. In which minute of which segment does the slope of VE/VO₂ change significantly? This dramatic increase in slope indicates the anaerobic threshold.
5. If the work performed is also being recorded, at which workload is the ratio of VO₂/HR the greatest?

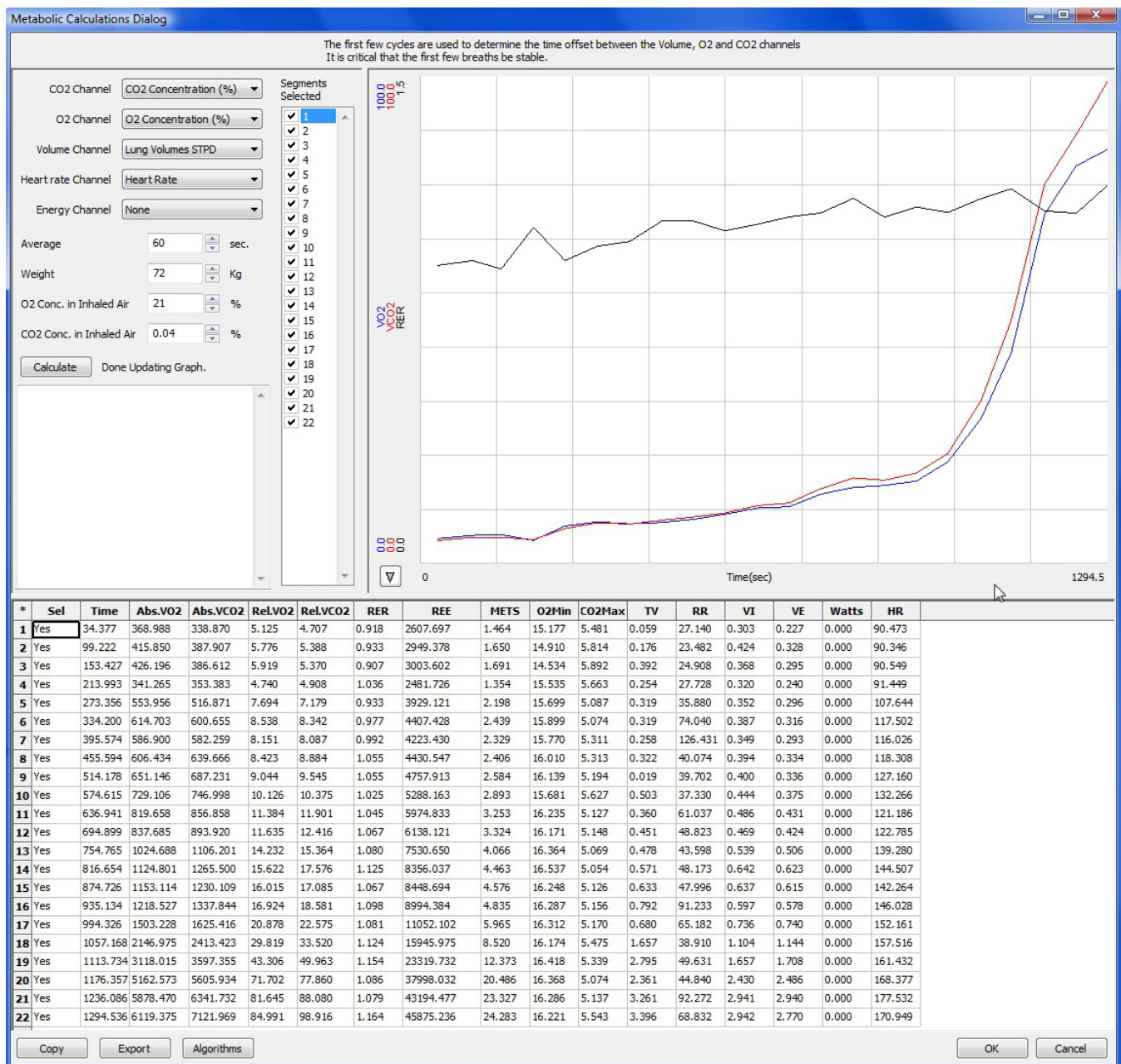


Figure HE-10-16: The metabolic parameters, and plots of VO_2 , VCO_2 , and RER vs. Time, displayed in the Metabolic Calculations window used offline to analyze data collected during an aerobic fitness test. Notice that the VO_2 and VCO_2 values increase quickly as the subject performs more strenuous segments of the test.

Table HE-10-L7: Maximal Oxygen Uptake Norms for Men - VO₂ max in ml/kg/min

Fitness Level	Age (Years)					
	18-25	26-35	36-45	46-55	56-65	>65
Excellent	>60	>56	>51	>45	>41	>37
Good	52-60	49-56	43-51	39-45	36-41	33-37
Above Average	47-51	43-48	39-42	35-38	32-35	29-32
Average	42-46	40-42	35-38	32-35	30-31	26-28
Below Average	37-41	35-39	31-34	29-31	26-29	22-25
Poor	30-36	30-34	26-30	25-28	22-25	20-21
Very Poor	<30	<30	<26	<25	<22	<20

Table HE-10-L8: Maximal Oxygen Uptake Norms for Women - VO₂ max in ml/kg/min

Fitness Level	Age (Years)					
	18-25	26-35	36-45	46-55	56-65	>65
Excellent	>56	>52	>45	>40	>37	>32
Good	47-56	45-52	38-45	34-40	32-37	28-32
Above Average	42-46	39-44	34-37	31-33	28-31	25-27
Average	38-41	35-38	31-33	28-30	25-27	22-24
Below Average	33-37	31-34	27-30	25-27	22-24	19-22
Poor	28-32	26-30	22-26	20-24	18-21	17-18
Very Poor	<28	<26	<22	<20	<18	<17