HE-10: Aerobic Fitness Testing

Background

Fitness Factors

Aerobic fitness is the ability to exercise continuously for extended periods without tiring. Also known as cardiovascular endurance, aerobic fitness is an important component in many endurance sports, like distance running, cycling, and rowing.

Aerobic fitness is dependent on the amount of oxygen that can be transported by the body to the muscles performing work. Factors that influence the amount of oxygen transported include:

- the amount of oxygen brought into the lungs;
- the effective surface area of the alveoli in the lungs;
- the saturation level of the hemoglobin in the red blood cells (RBCs) with oxygen;
- the movement of blood through the circulatory system;
- the dissociation of oxygen from the RBCs; and,
- the association of oxygen with the tissues in the working muscles.

The efficiency of the working muscles to utilize the oxygen transported also affects aerobic fitness. Factors that affect utilization include:

- the intensity of work being performed;
- the sources of energy (carbohydrates and fats) available to the cells in the muscles; and,
- the metabolic pathways used to make the energy required by the muscles.

Energetics

The energy requirements of the body are met with a mixture of energy derived from carbohydrates and fats. The intensity of the activity being performed determines the proportion of carbohydrates and fats being utilized and, ultimately, the amount of oxygen needed to utilize those energy sources. At rest, a body derives about 40% of its energy from carbohydrates and 60% from fats. As the intensity of activity increases, the demand for energy increases, and a greater proportion of this demand is met by the oxidation of carbohydrates. At the most intense exercise level, carbohydrates are supplying 100% of the energy because the catabolism of fat is too slow to supply the amount of energy required.

As the ratio of energy supplied by fats and carbohydrates shifts during changes in activity, the ratio of carbon dioxide produced to oxygen consumed also shifts because the oxidation of fats requires more oxygen than the oxidation of carbohydrates. The oxidation of a molecule of carbohydrate requires 6 molecules of oxygen and produces 6 molecules of carbon dioxide, a ratio of 1.0, as seen in the following equation:

$$6\ O_2 + C_6H_{12}O_6 = 6\ CO_2 + 6\ H_2O + 38\ ATP$$

The oxidation of a molecule of fatty acid requires 23 molecules of oxygen and produces 16 molecules of carbon dioxide, a ratio of 0.7, as seen in the following equation:

$$23\ O_2 + C_{16}H_{32}O_2 = 16\ CO_2 + 16\ H_2O + 129\ ATP$$

In turn, the rates at which oxygen and carbon dioxide are exchanged between the alveoli and the capillaries in the lungs are directly proportional to the amounts of oxygen consumed and carbon dioxide produced during cellular respiration in muscles and other organs.

The amounts of oxygen and carbon dioxide exchanged in the lungs are measured using an oxygen/carbon dioxide gas analyzer connected to a spirometer. The gas analyzer measures the concentration of oxygen and carbon dioxide in inspired and expired air, and the spirometer determines the volumes of air moving into and out of the lungs. When the concentrations and volumes are brought together through a series of equations built into the software of the recording system, the volume of oxygen taken up per minute (VO_2) and the volume of carbon dioxide expelled per minute (VCO_2) are determined.

The ratio of VCO_2/VO_2 is an important parameter known as the Respiratory Exchange Ratio (RER). The RER can be used to determine the proportion of carbohydrates and fats utilized during an activity and the energy expended per liter of oxygen consumed during an activity (Table HE-10-B1).

Table HE-10-B1: Respiratory Exchange Ratio (RER) as a Function of the Proportions of Energy Sources.

RER	Energy kcal/liter O_2	% Energy from CHO	% Energy from Fats
0.70	4.69	0	100
0.75	4.74	15.6	84.4
0.80	4.80	33.4	66.6
0.85	4.86	50.7	49.3
0.90	4.92	67.5	32.5
0.95	4.99	84.0	16.0
1.00	5.05	100	0

Maximal Oxygen Uptake (VO_2 max) Test

The best technique for measuring the aerobic fitness of athletes, especially those involved in endurance sports, is the maximal oxygen uptake (VO_2max) test.

Warning: The VO_2 max test requires the subject to have a reasonable level of fitness. This test is not recommended for recreational athletes or persons with health problems, injuries, or low fitness levels.

In this test, the athlete performs an exercise routine, known as a protocol, using an ergometer on which the workload can be modified. The ergometer should be appropriate for the sport or activity in which the subject participates. The ergometers that are commonly used include treadmills, stationary cycles, rowing machines, and swim benchs. The workloads that are programmed into the ergometer progress from moderate to maximal levels in prescribed increments of time and intensity. A variety of protocols suitable for subjects with different levels of aerobic fitness are available. Some are presented in this manual.

In a VO_2max test, oxygen uptake rate (VO_2) and carbon dioxide production rate (VCO_2) increase as the intensity of exercise being performed by the subject increases. Eventually, the rate of oxygen uptake reaches a plateau. When a plateau in VO_2 values is reached, the VO_2max test and exercise protocol should be terminated and the recovery period should begin. If the subject's heart rate is monitored during the recovery period, the time that it takes the subject's heart rate to return to normal can be used to validate the fitness level of the subject by using one of the tables or normograms that relate the fitness level to heart rate recovery.

During the exercise protocol, the oxygen and carbon dioxide concentrations in the expired air from the subject are measured using gas analyzers. Concurrently, the lung ventilation volumes of the subject are recorded using a spirometer. The subject's heart rates at each intensity of exercise and at completion are also measured using a heart rate monitor. Reaching the subject's maximal heart rate is also an indicator that the VO_2max test should be terminated. And, if the ergometer has an analog output, the workload put on the subject during different phases of the test can also be recorded.

From the concentrations of oxygen and carbon dioxide in the expired air and the corresponding ventilation volumes recorded during the test, the rates of oxygen uptake (VO_2) and carbon dioxide production (VCO_2) during and at the completion of the test can be calculated using computed functions built into the recording software.

When the VCO_2 in an exercise interval is divided by the corresponding VO_2 from that interval, the quotient is the respiratory exchange ratio (RER). RER can be used as a measure of the energy expended and the proportions of the energy sources (carbohydrates and fats) being consumed during the test. RER values can also be used to determine the point at which the VO_2max test should be terminated. The VO_2max test should be terminated when the RER reaches a value of 1.15 or greater.

The VO_2max test should also be terminated when the subject reaches his or her maximal heart rate. The test can also be terminated when the subject quits the test on his or her own volition because exhaustion has been reached.

Whenever the test is terminated, continue to record the subject's lung volumes, VO_2, VCO_2, RER, and heart rate to document the subject's recovery and to validate the fitness level of the subject.

The rates of oxygen uptake (VO_2, VO_2max) and carbon dioxide expelled (VCO_2) are expressed as minute volumes, with units that are liters per minute (L/min) or milliliters per kilogram of body weight per minute (ml/kg/min). The norms for VO_2max for men and women are listed in Table HE-10-B2 and Table HE-10-B3, respectively.

Table HE-10-B2: Maximal Oxygen Uptake Norms for Men - VO_2 max in ml/kg/min

	Age (Years)					
Fitness Level	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-B3: Maximal Oxygen Uptake Norms for Women - VO_2 max in ml/kg/min

	Age (Years)					
Fitness Level	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

HE-10: Aerobic Fitness Testing

Equipment Required

PC or Mac Computer

IXTA data acquisition unit, power supply, and USB cable

Flow head tubing and A-FH-1000 flow head

A-GAK-201 Reusable mask and non-rebreathing valve

6ft Smooth-bore tubing (35mm I.D.)

5 Liter Mixing Chamber

Nafion gas sample tubing

iWire-GA CO_2/O_2 Gas Analyzer with filter

A-CAL-150 Calibration kit

PHRM-220 Heart rate monitor

Stopwatch

Treadmill with adjustable speed and gradient

3 Liter Calibration syringe

Setup the IXTA and iWire-GA

1. Connect the iWire-GA to the iWire1 port on the front of the IXTA, and plug it into the wall using the power supply.
2. Plug the IXTA into the wall and, using the USB cable, to the computer.

NOTE: The iWire-GA must be plugged into the IXTA prior to turning both machines on.

3. Turn on the IXTA and the iWire-GA.
4. Open LabScribe.
5. Click Settings → Human Exercise-iWireGA → AerobicFitness.
6. Once the settings file has been loaded, click the **Experiment** button on the toolbar to open any of the following documents:
    - Appendix
    - Background
    - Labs
    - Setup (opens automatically)

Setup the Metabolic Cart

1. Locate the A-FH-1000 flow head and tubing in the iWorx kit (Figure HE-10-S1).

Figure HE-10-S1: The A-FH-1000 flow head, and airflow tubing.

2. Carefully attach the two airflow tubes onto the two sampling outlets of the A-FH-1000 flow head and the other ends of the two airflow tubes onto Channel A1 on the front of the IXTA (Figure HE-10-S4).

Note: *Make sure to connect the airflow tubing so that the ribbed tube is attached to the red outlet port of the flow head and also to the red inlet port of the spirometer. The smooth side of the tubing attaches to the white ports.*

3. Locate the mixing chamber in the iWorx kit (Figure HE-10-S2).
4. Connect the inlet of the A-FH-1000 flow head to the outlet of the mixing chamber (Figure HE-10-S3).

Note: *Be sure to connect the flow head to the mixing chamber so that the red outlet port is facing towards the mixing chamber.*

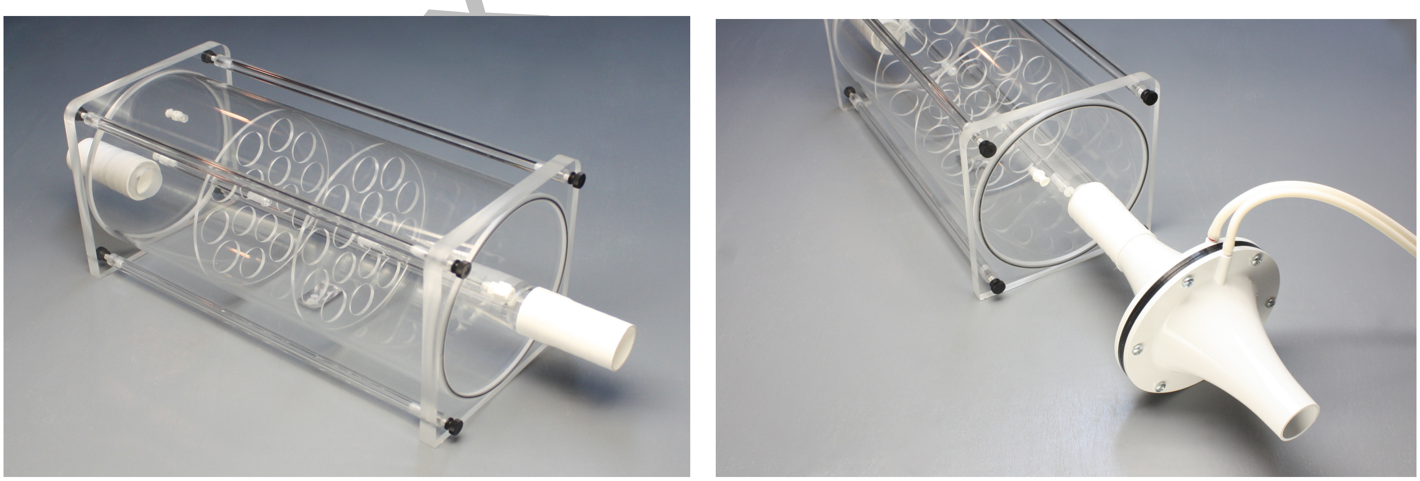

Figure HE-10-S2 and HE-10-S3: The mixing chamber showing the 1000L/min flow head connected to the outlet.

5. Locate the non-rebreathing valve, mask, and smooth interior tubing in the iWorx kit (Figure HE-10-S5).
6. Attach one end of the smooth interior tubing to the inlet of the mixing chamber (Figure HE-10-S6), and the other end to the outlet of the non-rebreathing valve. There are arrows on the valve that indicate the direction of air flow.
7. Attach the mask to the side port of the non-rebreathing valve.

Figure HE-10-S4: The iWire-GA gas analyzer connected to an IXTA. All tubings are connect properly in this image.

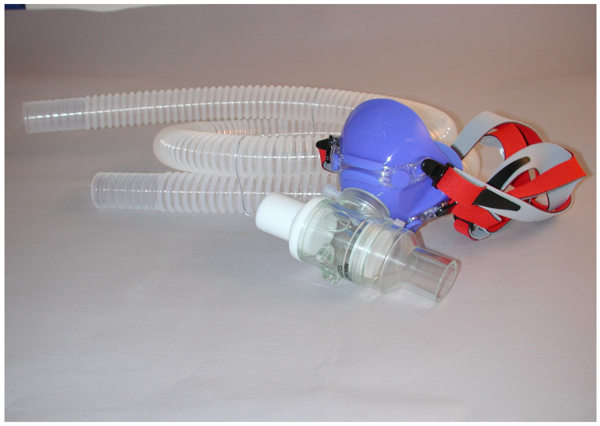

Figure HE-10-S5: Mask, non-rebreathing valve, and smooth interior tubing.

8. On the iWire-GA, place one filter on the “Room Air” port, place a second filter on the “Sample In” port. Attach the braided end of the Nafion sampling tube to the filter on the “Sample In” port.
9. Place the other end of the Nafion sampling tube on the gas sampling port near the outlet of the mixing chamber (Figure HE-10-S6).

Figure HE-10-S6: The assembled devices used during metabolic studies. The assembly includes: the mixing chamber, smooth interior tubing, Nafion sampling tubing, flow head, spirometer, non-rebreathing valve, and mask.

10. Plug the outlet tubing from the iWire-GA to the port on the mixing chamber, opposite the flow head.
11. Locate the PHRM-220 Polar[tm] heart rate monitor transmitter, electrode belt, and receiver in the iWorx kit (Figure HE-10-S8).

12. Plug the connector of the PHRM-220 receiver into the "HR" input on the iWire-GA.

Figure HE-10-S8: The PHRM-220 transmitter, belt, and receiver set.

The non-rebreathing valve can be used with the attached mask or with an optional mouthpiece.

If the subject is using a mask (preferred method):

- Attach the head gear to the mask.
- Attach the non-rebreathing valve to the mask. Depending on the model of the mask, an adapter may be required.
- Instruct the subject to try on the assembly. Adjust the straps so that the mask fits the subject comfortably. Make sure there are no leaks around the mask.

If the subject is using a mouthpiece:

- Attach the headgear to the brackets on the non-rebreathing valve. The pair of straps with the narrowest spacing go over the top of the subject's head.
- Connect the mouthpiece to the side port of the valve so that the valve is oriented horizontally, and the saliva trap of the mouthpiece is pointed downward.
- Instruct the subject to try on the assembly. Adjust the straps so that the mouthpiece fits the subject comfortably. Make sure there are no leaks between the mouthpiece and the valve or around the mouthpiece.

The gas analyzer must warm up for at least 15 minutes.

Note: For increased accuracy, users must complete the flow Head Calibration procedure. Please see Appendix I for directions on how to perform this calibration. The calibration of the 1000L flow head requires a 3L Calibration Syringe.

Load a PreSaved flow Head Calibration (*.iwxfcd) File

Note: *This procedure is used once a calibration curve has been generated using the Spirometer Calibration directions in Appendix I.*

All of the following directions will be prompted by the software. Follow the directions as they pop up on the LabScribe software.

1. Load the lab settings file you wish to perform as stated in the "Start the Software" section (Figure HE-10-S9).
2. Assemble the spirometer, flow head, tubing, mixing chamber and calibration syringe as shown in Appendix I or in the SpirometerCalibration directions.
3. Click the Setup button shown in the left side window. Follow the directions as prompted by the (Figure HE-10-S10). The Online Setup Dialog window will open
    - Enter your subject's information or Load a subject from a previously saved file.
    - Click "Settings" to change any parameters you wish to view (Figure HE-10-S11).

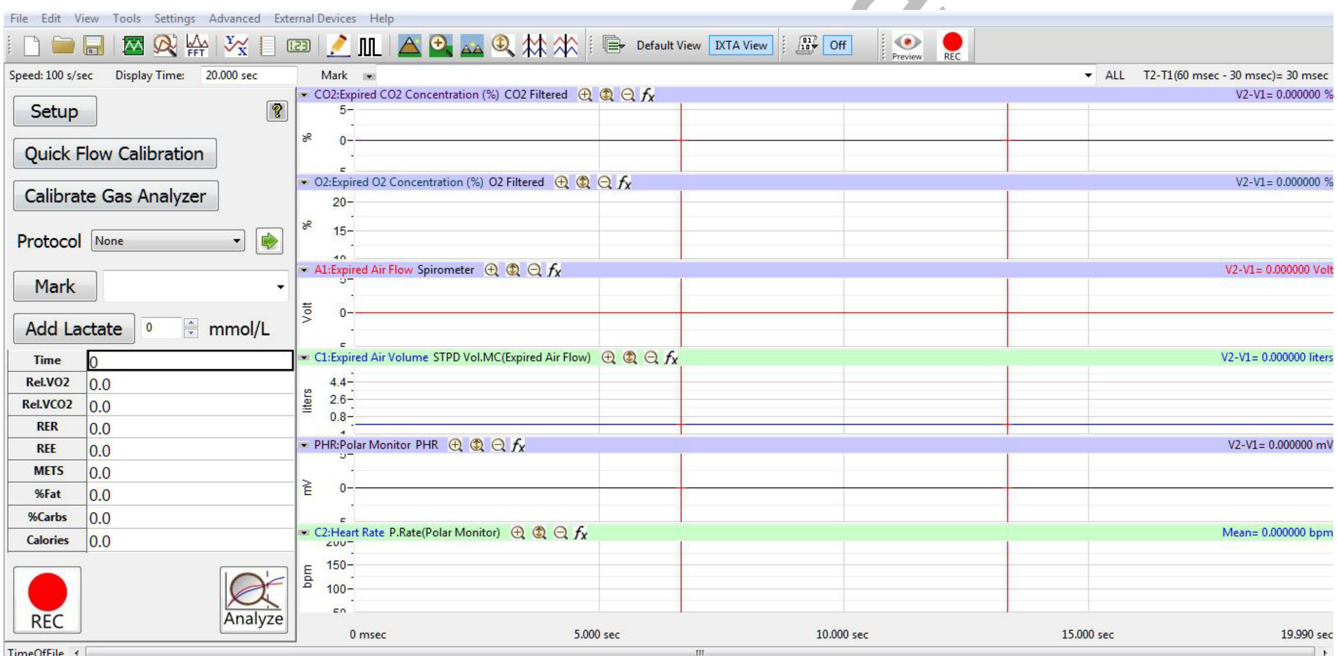

Figure HE-10-S9: Initial screen for starting a Fitness Assessment test. Follow the directions as prompted by the buttons on the left side of the window.

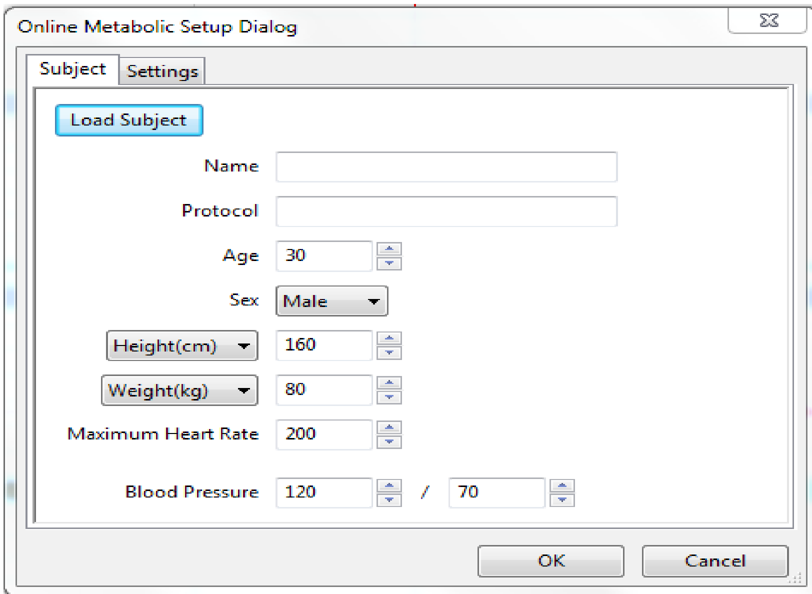

Figure HE-10-S10: Online Metabolic Setup Dialog window.

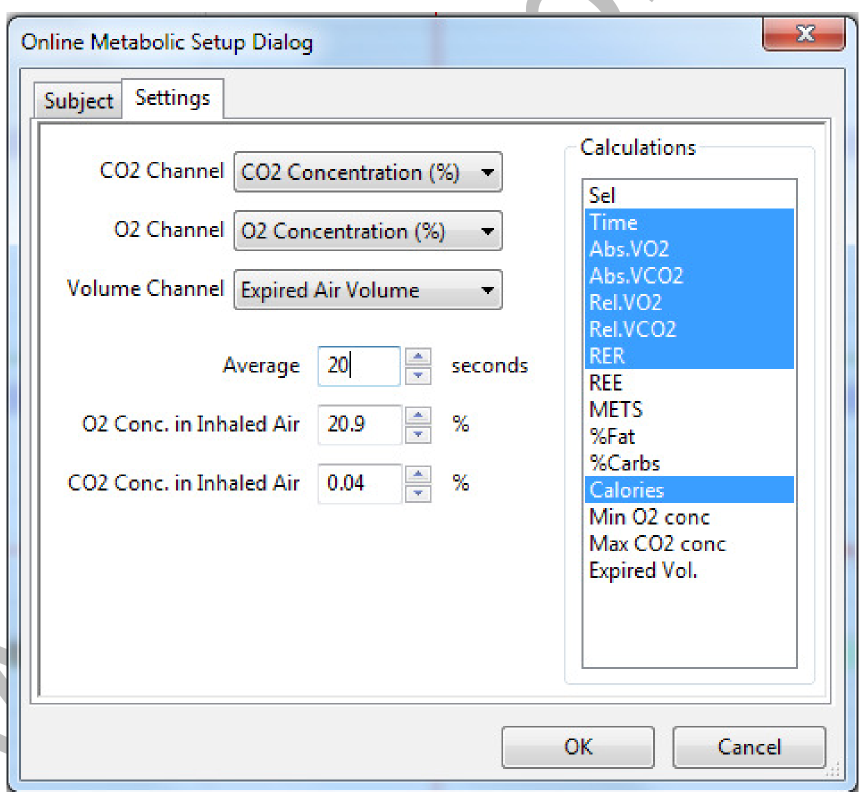

Figure HE-10-S11: Settings dialog of the Online Metabolic Setup window.

4. Perform the Quick Flow Calibration by clicking the button and following the prompted directions (Figure HE-10-S12).
   - When you click “Load”, you will be prompted to load the .iwxfcd file created when you performed the full flow head calibration.

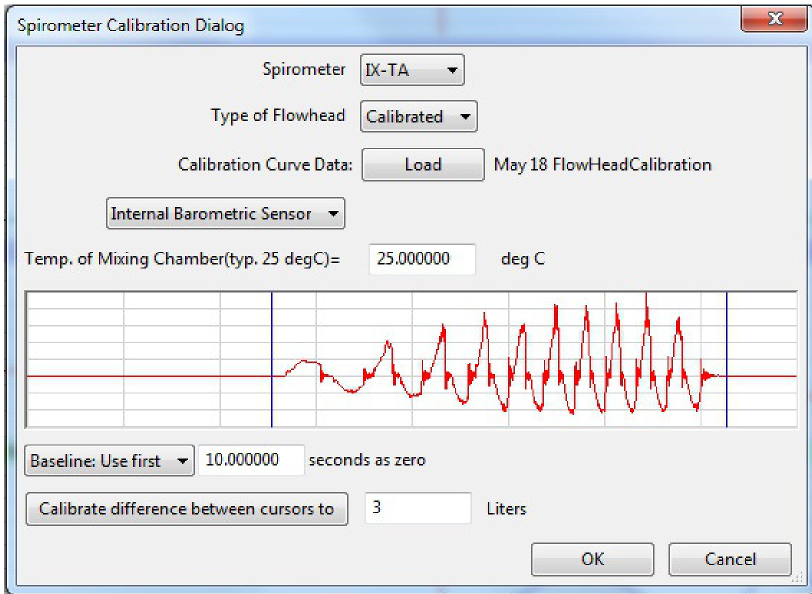

Figure HE-10-S12: Spirometer Calibration dialog window.

5. Select Save As in the File menu, type a name for the file. Click on the Save to save the data file.

Calibrating the iWire-GA Gas Analyzer

Note: *Warm up the gas analyzer for at least 15 minutes prior to use. Make sure the calibration gas tank is located close to the gas analyzer.*

This procedure will calibrate both the O_2 and CO_2 channels.

Connect the gas sample tubing of the A-CAL-150 Calibration Kit (Figure HE-10-S13) to the Luer-Lock connector on the output of the regulator.

Figure HE-10-S13 Calibration Kit (A-CAL-150).

1. Click the Calibrate Gas Analyzer button. Click Perform Quick Software Gas Calibration.
2. Follow the directions as prompted. Room air will be sampled for 10 seconds. Calibration gas will be sampled for 15 seconds.
3. If necessary, move the cursors into correct position (Figure HE-10-S14).

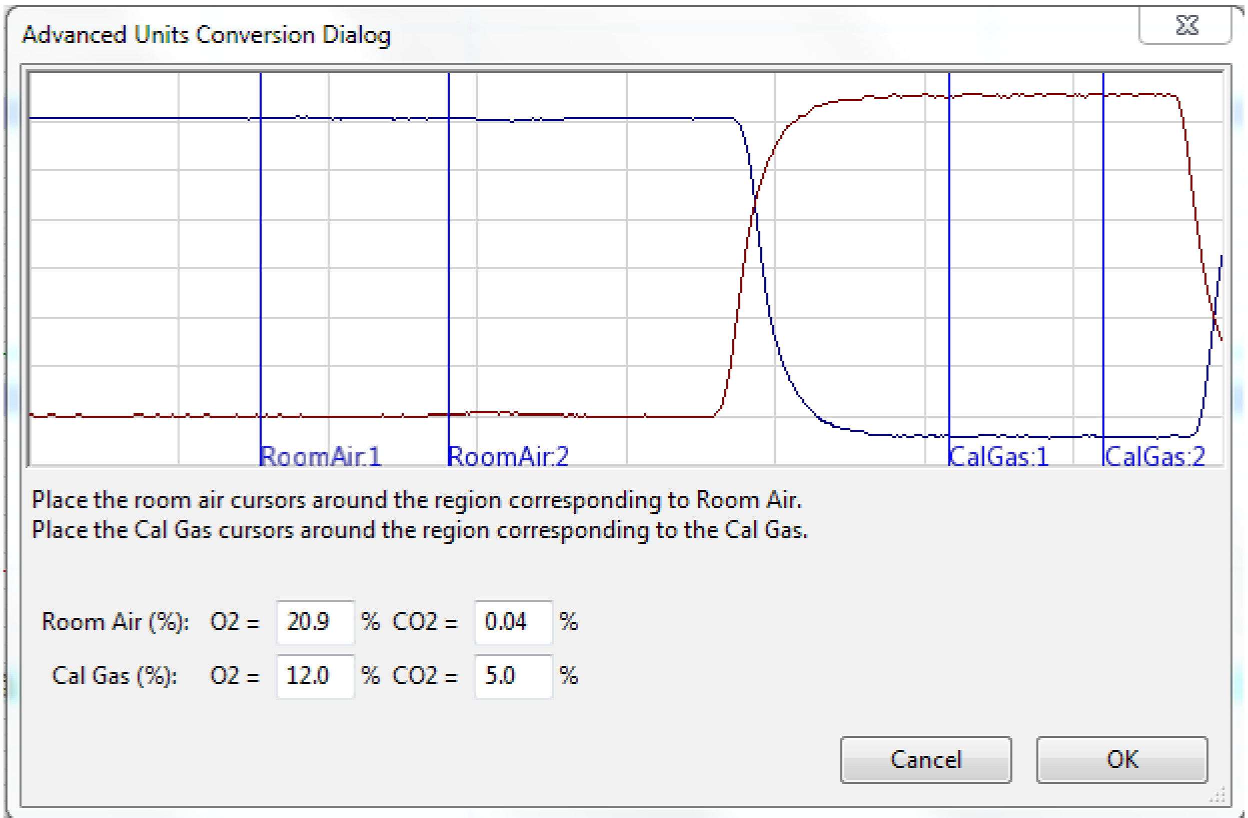

Figure HE-10 -S14: Advanced units conversion dialog for room air and calibration gas.

Appendix I: Initial Spirometer flow head Calibration

For accuracy of measurements, users must include this calibration procedure as part of the Exercise Physiology Lab protocol.

It is suggested that this procedure be followed at the beginning of every term and when using a new flow head-spirometer combination.

Note: *This calibration protocol precedes the actual calibration of the GA-200 or GA-300 gas analyzer. You will not need the gas analyzer at this time.*

Note: *Whenever you will be using a different flow head, you will need to repeat this calibration procedure from the beginning by loading a new Spirometer Calibration settings file.*

1. Open the LabScribe software.
2. Click Settings - Human Exercise-iWireGA. Choose SpirometerCalibration to launch the calibration settings file.
3. Assemble the flow head, tubing, mixing chamber and calibration syringe.
4. Plug the tubing into the internal spirometer channel A1.
    - Connect the flow head to the IXTA using the flow head tubing, making sure that the ribbed side of the tubing connects the red marked port on the flow head to the red marked port on the spirometer (Figure HE-10-S15).
    - Connect the smooth side of the tubing to the other ports.
5. Connect end of the1000L flow head with the red marked onto white flange of the mixing chamber. Make sure the tubing is in an upright direction (Figure HE-10-S16).

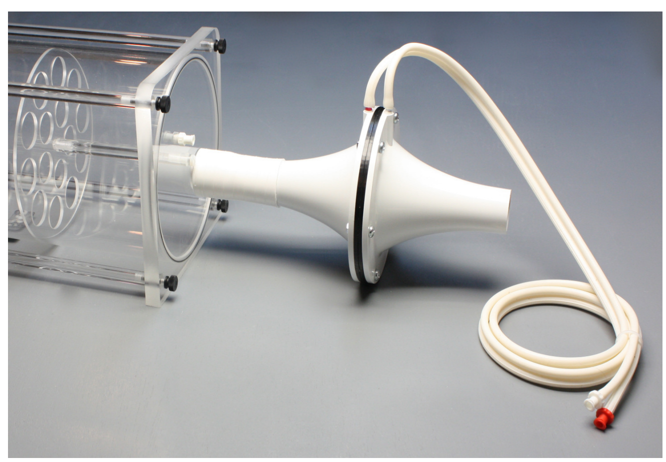

Figure HE-10-S15: The 1000L flow head and Figure HE-10-S16: The 1000L flow head attached to the mixing chamber showing the tubing in an upright position and the red port facing the mixing chamber.

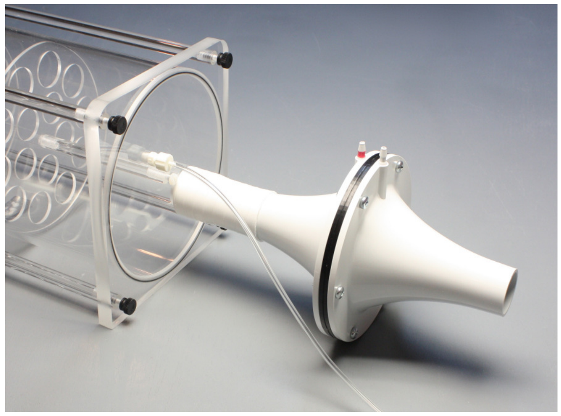

Figure HE-10-S17: 1000L flow head connected to the mixing chamber, showing the Nafion tubing connected to the outlet sampling port near the flow head.

Note: *Make sure the red port on the flow head faces into the mixing chamber.*

6. Connect one end of the smooth bore tubing to the 3L calibration syringe as shown in Figure HE-10-S18).
7. Connect the other end of the smooth bore tubing to the mixing chamber, opposite the flow head (Figure HE-10-S19).

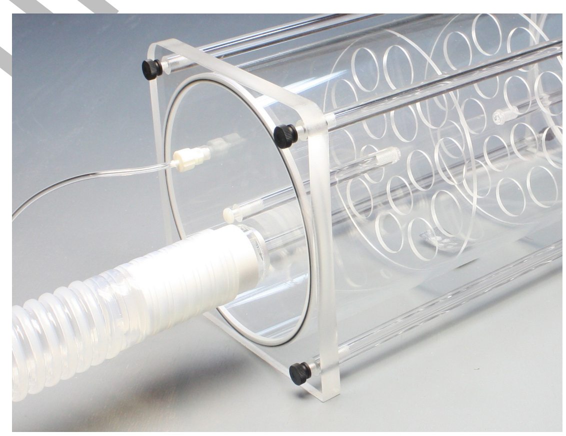

Figure HE-10-S18: 3 liter calibration syringe connected to the smooth bore tubing and Figure HE-10-S19: The smooth bore tubing connected to the mixing chamber.

8. If also setting up the gas analyzer at this time:
   - Connect the braided Nafion tubing to the filter on the gas analyzer and to the flow head side of the mixing chamber. Make sure the braided end is connected to the filter (Figure HE-10-S17).
   - Connect the thin flexible tubing from the outlet of the gas analyzer to the port next to the smooth bore tubing on the opposite side of the mixing chamber.

9. If not using the gas analyzer at this time, connect the flexible tubing from the port on one side of the mixing chamber to the port on the other. This ensures there is no air leaking from the chamber.
10. Pull the plunger on the 3L Calibration Syringe all the way out until it stops.
11. Click the Record button.
12. Wait for at least 10 seconds of recording so that there is no flow of air moving through the syringe.
13. Push the plunger in all the way until it stops. Pull the plunger out all the way until it stops.
14. Repeat the procedure in Step 13, for at least 50 repetitions, varying the speed and force on the plunger. Make sure to pause between strokes.
15. The faster the speed of the stroke, the higher the flow through the calibration syringe.

***Note:** Ideally the flow head calibration recording should span air flow values to include the minimum to maximum flow levels for the particular experiment being conducted.*

16. After at least 50 repetitions have been performed, wait at least 5 seconds after the final repetition and then click Stop.
17. Select Save As in the File menu, type a name for the file.
18. Click on the Save button to save the raw data for generation of a flow head calibration *.iwxfcd file.
19. Click AutoScale on the Air flow channel.
20. Use the Display Time icons to adjust the Display Time of the Main window to show the complete calibration data (Figure HE-10-S20).
21. Click the Double Cursor icon so that two cursors appear on the Main window.

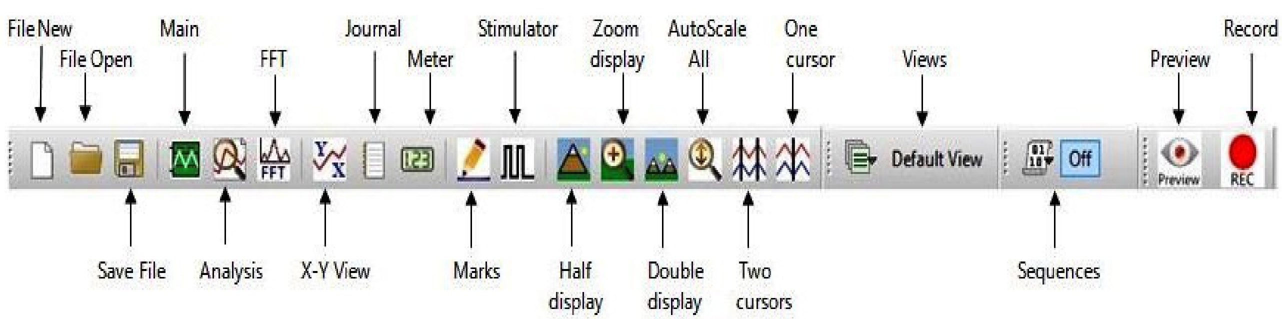

Figure HE-10-S20: The LabScribe toolbar.

22. Click Advanced on the main toolbar. Then click Metabolic, and Calibrate flow head (Figure HE-10-S21).
23. Place the two blue vertical cursors so that:

- The left-hand most cursor is on the flat line prior to the start of the calibration data. Make sure the cursor is at the beginning of the 10 second baseline.
- The right-hand most cursor is on the flat line after the final calibration stroke (Figure HE-10-S22).

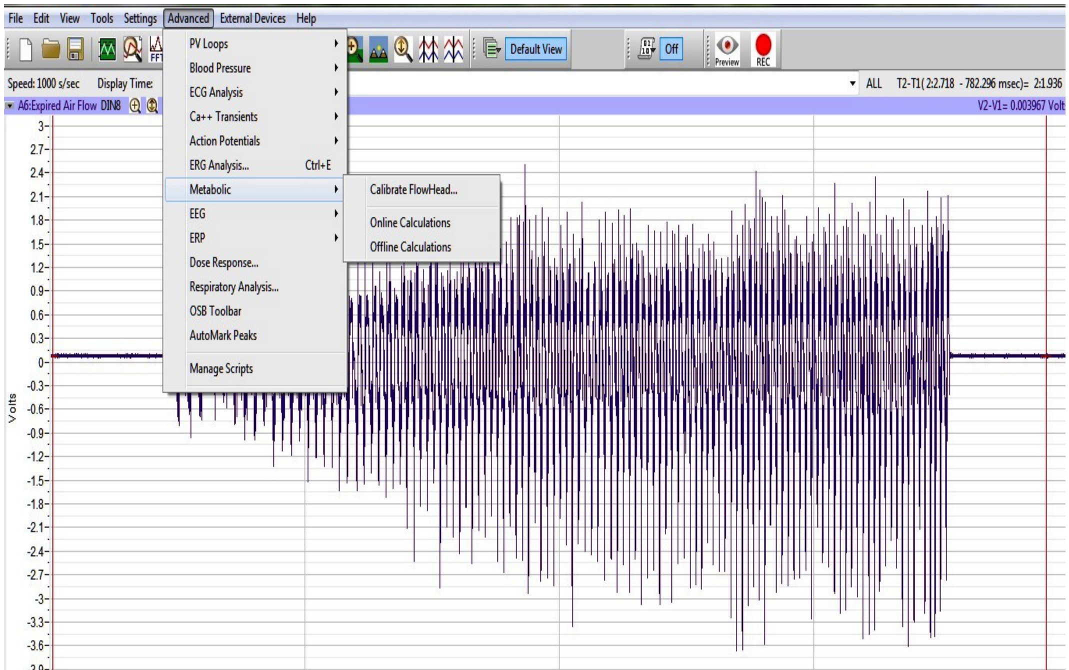

Figure HE-10-S22: Calibrate flow head dialog window.

24. In the new window that opens (Figure HE-10-S24), enter these values:
    - flow channel = Expired Air flow
    - Baseline = Use the first 10 seconds as zero
    - Calibrate difference between cursors to 3 L.
25. Click the Calibrate the difference between cursors to button. This will generate the curve as shown above.
26. A new window will open prompting you to Save your file as an *.iwxfcd flow head calibration file. Name your file and click Save.
27. Click OK.

Note: *At this point, a raw calibration data file (*.iwxdata) and a flow head calibration file (*.iwxfcd) have been generated.*

28. Exit LabScribe or open a Human Exercise lab settings file.

Note: *Once a saved *.iwxfcd file is loaded, a simple 5-10 stroke calibration procedure can be used to update the file for immediate use.*

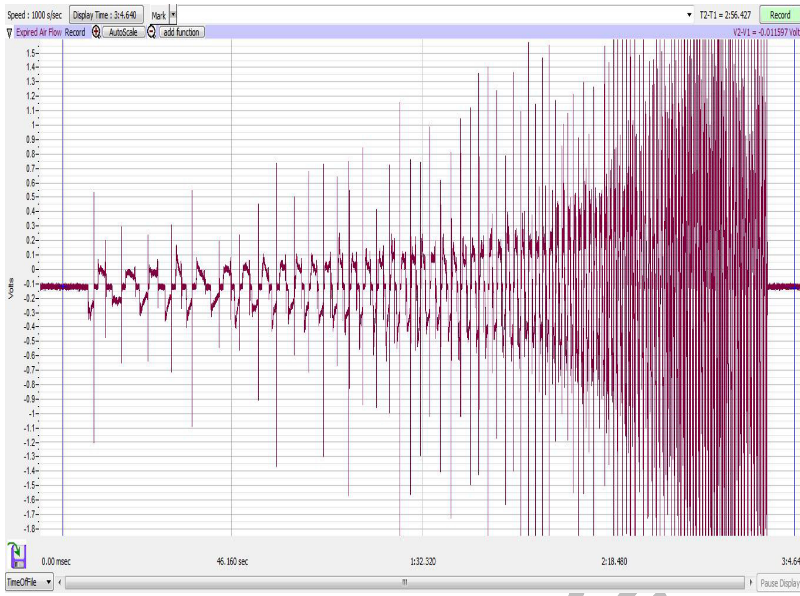

Figure HE-10-S23 The calibration recording showing the vertical cursors in the correct position for generating a calibration curve. Note – the recording you generate should look similar to this.

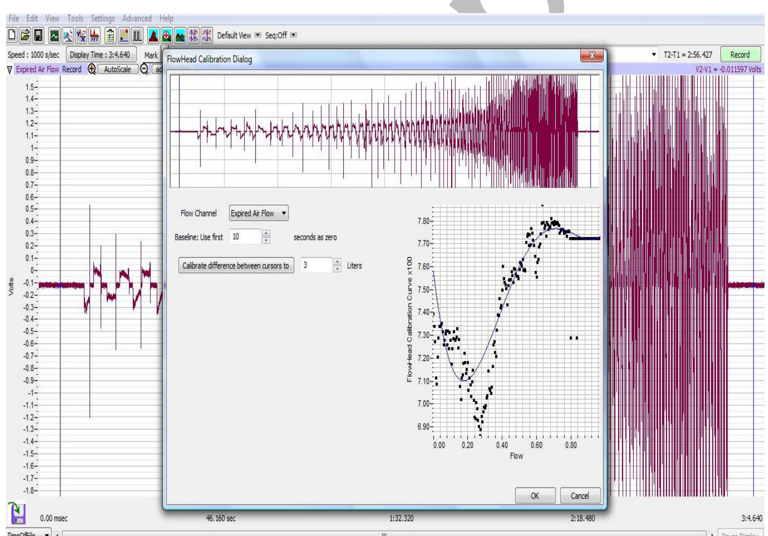

Figure HE-10-S24: Calibration syringe data.

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 gas analyzer to warm up for 15 minutes before recording for the first time.
4. Determine if the airflow tubes between the flow head 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 on 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 flow head 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 flow head from the outlet of the mixing chamber and place the other end of the flow head 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 person 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.
2. After the first stage, the gradient is increased by 2% and the speed is increased to the speed listed for each stage in the table at three minute intervals.

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

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.

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 person with health problems, injuries or low fitness levels, please have medical assistance on hand.

1. 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.
2. In each successive stage, the gradient is increased by 2.5% in two minute intervals while the speed is kept the same.
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.

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 fist 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 requires a reasonable level of fitness. If this test is going to be performed by recreational athletes or person 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 the time until the subject is exhausted.
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.

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

	Exercise Intensity			Elapsed Time	
	Speed		Gradient	Modified Bruce	Cornell
Stage	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

4. After the third stage, the gradient is increased by 2% and the speed is increased to the speed listed for each stage in the table 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 requires a reasonable level of fitness. If this test is going to be performed by recreational athletes or person 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 (Table HE-10-L3). 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.
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	%	Minutes
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_2max Test

1. While preparations are being completed, have the subject become accustomed to wearing the non-rebreathing valve with either a mouthpiece or a mask. 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.
3. Wet the cloth electrode patches on the inside of the Polar heart rate monitor 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 can wear a shirt since it will not interfere with the operation of the heart rate monitor.
4. Once the subject and recording equipment are all prepared, disconnect the smooth-bore tubing from the mixing chamber to ensure that no air is entering the system at this time.

Note: *So that the LabScribe software can zero the Lung Volume channel, no air can be moving through the system during the first ten seconds of the recording.*

5. Type <Subject’s Name> baseline in the Mark box that is to the right of the Mark button.
6. Click on the Record button. After waiting ten seconds for the Lung Volume channel to zero, the smooth bore tubing should be reconnected to the mixing chamber. Make sure that the tubing is firmly attached to the chamber.
7. Press the Enter key on the keyboard to mark the recording as the subject begins breathing through the mask and the flow head.
8. The subject should record a baseline reading for at least 5 to 10 minutes to exchange the air in the mixing chamber. Once the mixing chamber air has been replaced by the subject’s expired air, the test protocol can begin.
    - The trace on the CO_2 Concentration (%) channel increases as the mixing chamber fills with exhaled air. It gradually increases as the fitness test proceeds.
    - The trace on the O_2 Concentration (%) channel decreases as the mixing chamber fills with exhaled air. It gradually decreases as the fitness test proceeds.
9. Type <Subject’s Name> Stage 1 in the Mark box that is to the right of the Mark button.
10. Press the Enter key on the keyboard to mark the recording as the subject begins breathing through the mask and the flow head. Start the stopwatch to keep track of the time in each stage of the exercise protocol.
11. Click the AutoScale buttons on all channels and make sure all channels are being recorded properly (Figure HE-10-L1).
    - 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.

12. 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.

13. 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.

14. Click the Stop button to halt the exercise protocol when the subject reaches volitional exhaustion, or his or her maximum heart rate.

15. 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.

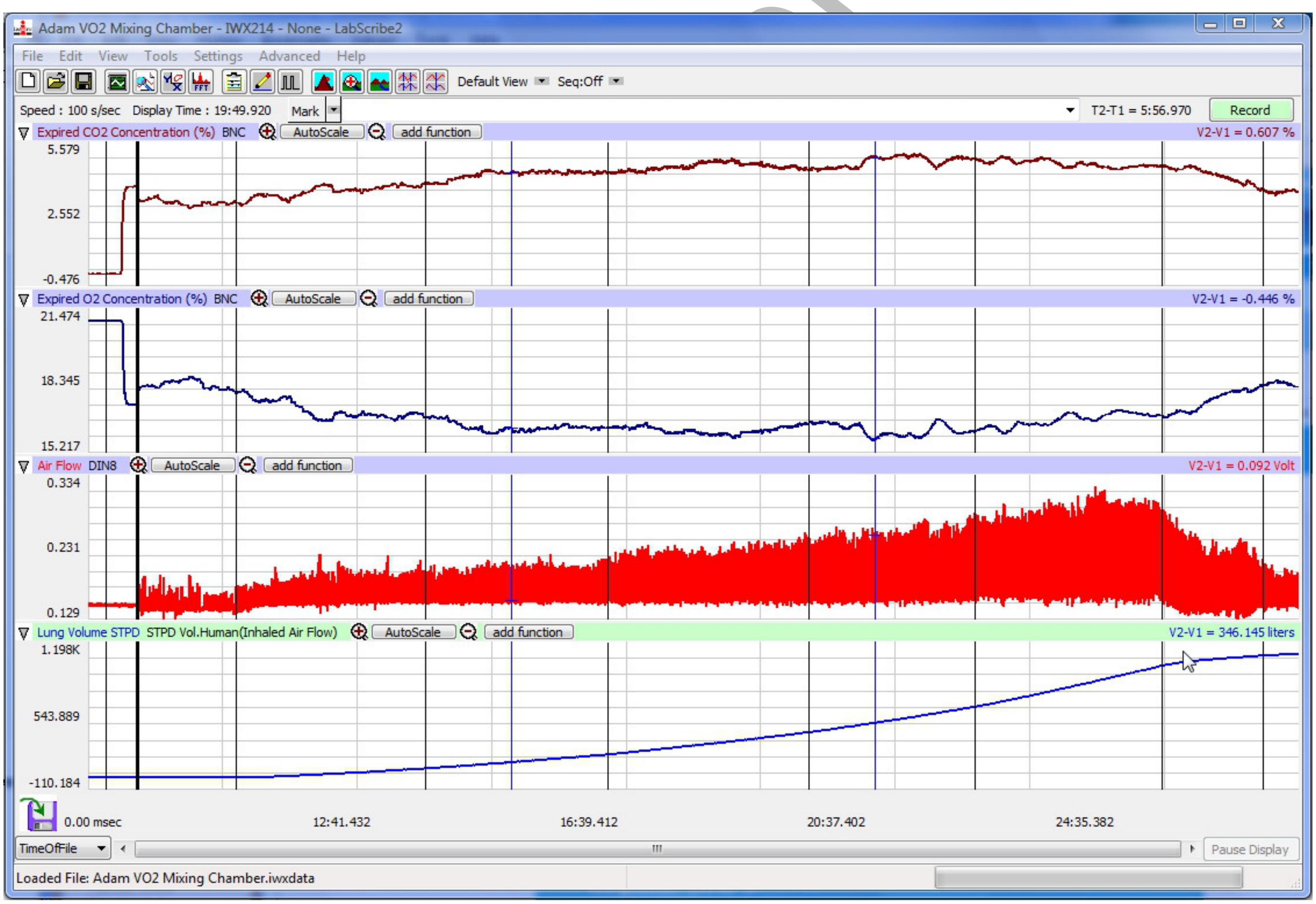

Figure HE-10-L1: The CO_2 Concentration (%), O_2 Concentration (%), Air Flow, and Lung Volume STPD channels shown on the Main window.

Calculate and Plot Metabolic Parameters

Values for VO_2, VCO_2, 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 CO_2 and O_2 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 O_2 and CO_2 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.

Note: *The first time using the Advanced Metabolic Calculations will require the entry of a User Name and Serial Number. These were supplied when you received your equipment.*

Interpret the Data

1. Compare the VO_2 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 VO_2 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?

Table HE-10-L5: List of Parameters Calculated on the Mixing Chamber Offline Metabolic Window

Term	Parameter	Description	Units
Abs.VO_2	Absolute VO_2	Volume of oxygen (O_2) consumed per minute	Liters/minute
Abs.VCO_2	Absolute VCO_2	Volume of carbon dioxide (CO_2) produced per minute	Liters/minute
Rel.VO_2	Relative VO_2	Volume of O_2 consumed per kg body weight per minute	milliliters/kg/minute
Rel.VCO_2	Relative VCO_2	Volume of CO_2 produced per kg body weight per minute	milliliters/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
METS	Metabolic Equivalent of Task	1 MET = 3.5ml O_2/kg/min or 1kcal/kg/hr	MET
O_2 Min.	O2 Minimum - exhalation	Minimum concentration of O_2 recorded during test period	Percentage
CO_2 Max.	CO2 Maximum - exhalation	Maximum concentration of CO_2 recorded during test period	Percentage
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 calculated by dividing (60 sec/min) by the beat period (sec/breath)	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

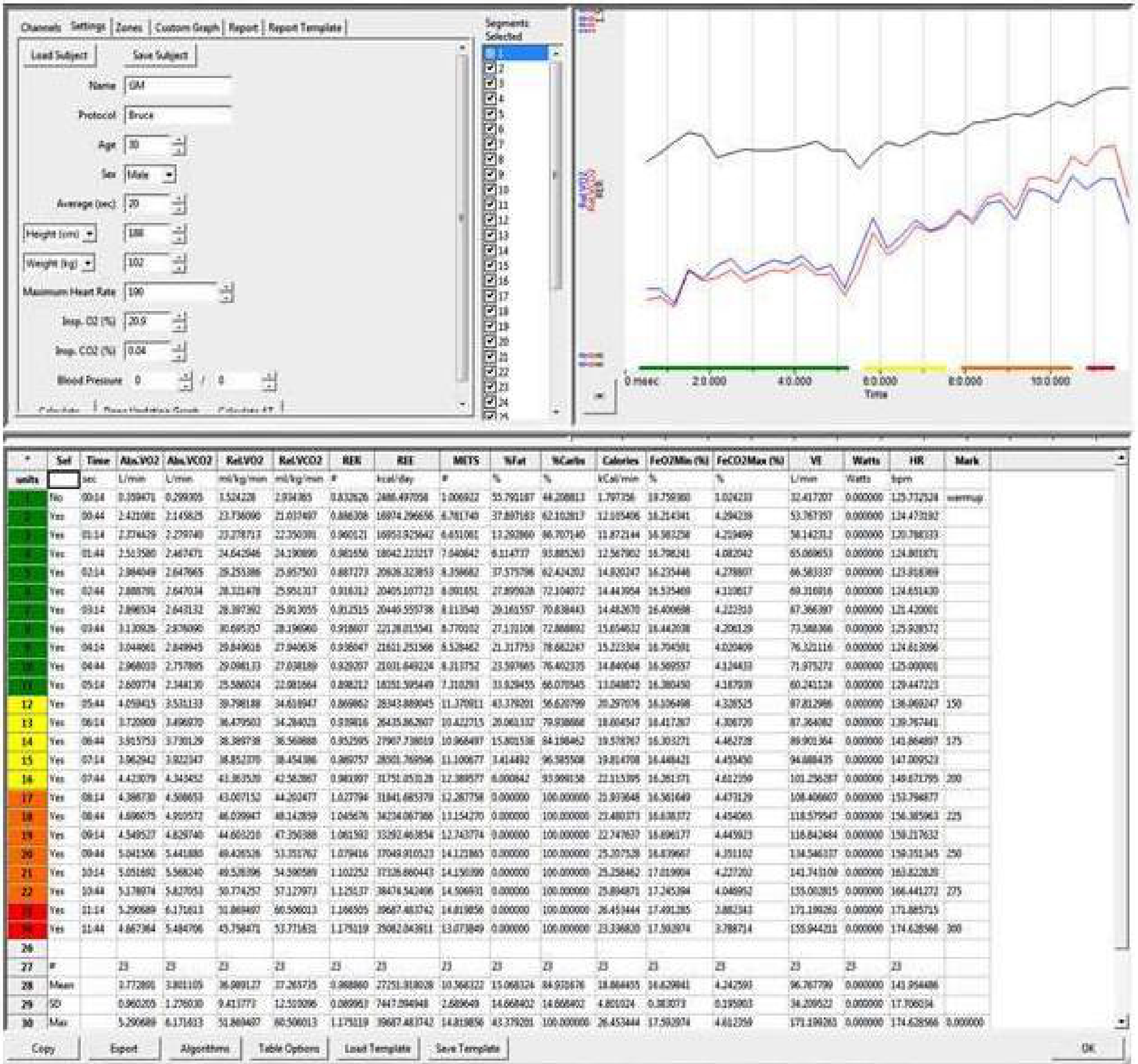

Figure HE-10-L2: The metabolic parameters, and plots of VO_2, VCO_2, and RER vs. Time, displayed in the Metabolic Calculations window used offline to analyze data collected during an aerobic fitness test. Notice that the VO_2 and VCO_2 values increase quickly as the subject performs more strenuous segments of the test.

Table HE-10-L7: Maximal Oxygen Uptake Norms for Men - VO_2 max in ml/kg/min

	Age (Years)					
Fitness Level	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 - VO_2 max in ml/kg/min

	Age (Years)					
Fitness Level	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