Experiment EP-2: The Effect of Exercise on Metabolism and Body Temperature

NOTE: Preparations for this experiment need to be reviewed with the students in the week prior to performing the experiment. Also, some materials used in the experiment need to be prepared four days before the experiment is performed.

Background

In this experiment, human subjects will be monitored for their metabolic and thermal responses to a progressively dynamic exercise routine. In this type of routine, periods of exercise with increasing intensity are followed by periods of recovery. Changes in the heart rate, core temperature, skin temperature, and active sweat gland density of the subjects will be recorded and used to determine how the expenditure of energy, mechanical efficiency, heat storage, and evaporative heat loss by each subject changes with increased exercise. Since some subjects will be doing the experiment while wearing heavier clothing than others, a reduction in heat loss through radiation, convection, conduction, and evaporative cooling should cause the heat storage of these subjects to be greater than the lightly dressed subjects.

Energy

The energy cost of doing dynamic exercise increases in proportion to the work performed until a maximum level of oxygen consumption is reached. Maximum oxygen consumption (VO_2 max) is a plateau which is defined by the limits of the oxygen transport system, which include: pulmonary ventilation, the circulatory system, tissue/blood gas exchange, and cellular respiration. The principal factors that determine VO_2 max are genetically inherited or developed through endurance training. Humans can exercise above the VO_2 max workload, for short durations, because humans have a limited anaerobic capacity for energy production.

In this experiment, it will be seen that a minor portion of the energy produced during dynamic exercise is transformed into work. The maximum efficiency of utilizing energy for doing work is between 20% and 25%. The amount of work that each subject does in each exercise period and the amount of energy consumed in the same periods will calculated and compared. Students will use equations developed by the American College of Sports Medicine to accurately determine the energy cost of doing these exercises.

Contracting muscles utilize energy to create motion, but the majority of the energy consumed during dynamic exercise is transformed to heat. Heat production is proportional to metabolic rate and work; but, the additional heat load generated by exercise produces thermal stress on the oxygen transport mechanisms. Also, thermoregulation in the body is affected by the balance of heat exchange between the body and the environment as seen in the following equation:

$$S = M \pm R \pm C \pm K - E$$

where: S = Heat Stored in a body   M = Metabolic Rate   R = the gain or loss of heat by Radiation

C = the gain or loss of heat by Convection   K = the gain or loss of heat by Conduction

E = the loss of heat by Evaporation

Evaporative cooling is the primary means of dissipating heat during exercise. Sustainable levels of sweat production of 1 L/hr can occur during heavy work. Higher rates exceeding 3 L/hr can occur for shorter periods.

Equipment Required

PC or Macintosh computer

IX-ELVIS

USB cable

Power supply

Doctor's scale

PTN-104 Pulse plethysmograph

TMN-100 Temperature sensor with extension cable

Surgical tape

Auditory canal temperature probe or an electronic oral thermometer with disposable sheaths

Step (23-30 cm in height)

Iodine paper (2.5cm x 7.5cm) in a 1 liter glass jar

Small wood blocks (2.5cm x 2.5cm x 2.5cm)

Metronome (electronic or mechanical)

Stopwatch

Preparations Needed Four Days before Lab Day

Making Iodine Paper for Measuring SGD

Paper strips, for measuring the active sweat gland density (SGD) on the subjects, should be prepared at least four days before they are needed.

1. Cut plain white printer paper into strips that are approximately 1" wide by 3" long. About 15 strips should be cut and prepared for each subject doing this experiment.

2. Place all the strips for the whole lab section in a one liter glass jar that has a layer of iodine crystals on the bottom. The layer of iodine crystals on the bottom of the jar should be about 1/8" thick. Tightly cover the glass jar with its lid.

3. Let the paper sit in the glass jar for about three or four days. The paper should turn tan as it absorbs iodine.

Selecting Subjects and Bringing Clothing for Lab.

1. The number of subjects that can participate in this experiment will depend on the number of stations that are available, the length of the laboratory period, and the number of students in the lab section. It will take about one hour for each subject to complete the experiment.

2. Each subject should be paired up with another subject of the same gender, same body size, and the same relative degree of fitness.

3. Each subject should bring two t-shirts, two pairs of gym shorts, one pair of cotton socks, one pair of athletic shoes, and a towel to lab on the day of this experiment.

4. In addition to the equipment listed in Step 3, one member of each pair should bring a heavy sweat shirt, a pair of heavy sweat pants, and a knit cap.

IX-ELVIS Setup

1. Place the IX-ELVIS unit on the bench, close to the computer.

2. Connect the IX-ELVIS to the computer with the supplied USB cable.

3. Insert the power plug into the rear of the IX-ELVIS and plug the transformer into the electrical outlet. Turn on the power switches on the rear and on the upper right side of the top of the unit and confirm that the LEDs are illuminated.

Start the Software

1. Click on the LabScribe shortcut on the computer's desktop to open the program. If a shortcut is not available, click on the Windows Start menu, move the cursor to All Programs and then to the listing for iWorx. Select LabScribe from the iWorx submenu. The LabScribe Main window will appear as the program opens.

2. On the Main window, pull down the Settings menu and select Load Group.

3. Locate the folder that contains the settings group, ELVISNI.iwxgrp. Select this group and click Open.

4. Pull down the Settings menu again. Select the Exercise-Metabolism-Temp-LS2 settings file.

5. After a short time, LabScribe will appear on the computer screen as configured by the Exercise-Metabolism-Temp-LS2 settings.

6. The settings used to configure the LabScribe software and the IX-ELVIS for this experiment are programmed on the Preferences Dialog window which can be viewed by selecting Preferences from the Edit menu on the LabScribe Main window.

Pulse Transducer & Temperature Probe Setup

1. Locate the PTN-104 pulse transduvcer (Figure EP-2-S1) and the TMN-100 (Figure EP-2-S2).
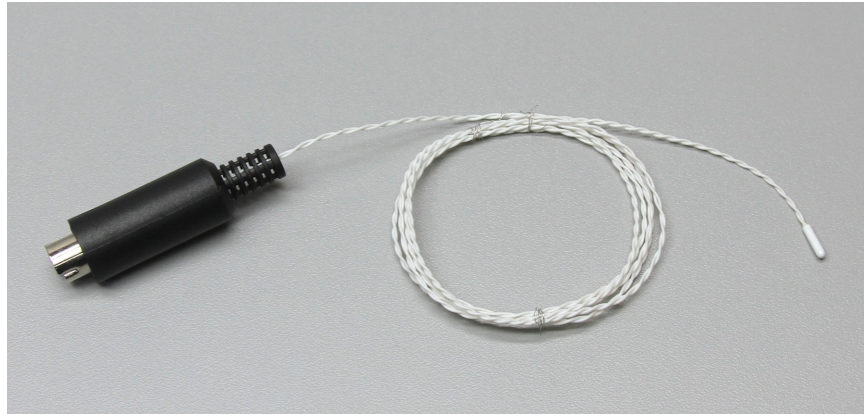

Figure EP-2-S1: The PTN-104 pulse plethysmograph.

Figure EP-2-S2: The TMN-100 temperature probe.

2. Plug the mini-DIN connector to the PT-104 into the Channel 3 input of the IX-ELVIS (Figure EP-2-S3).

3. Plug the mini-DIN connector on the end of the temperature probe into Channel 4 of the IX-ELVIS (Figure EP-2-S3).

4. Place the plethysmograph on the volar surface (where the fingerprints are located) of the distal segment of the subject's middle finger or thumb, and wrap the Velcro strap around the end of the finger to attach the unit firmly in place.
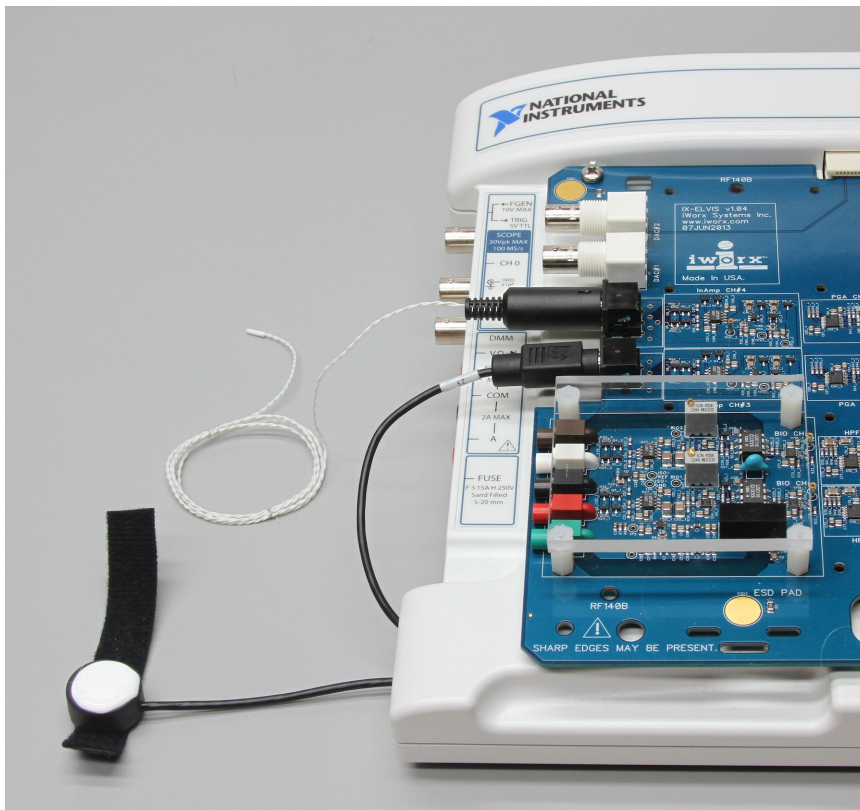

Figure EP-2-S3: The PTN-104 pulse transducer and the TMN-100 temperature probe connected to the IX-ELVIS.

Assistants and Their Duties.

1. At least two other students, who are not subjects, should join each pair of subjects to form a lab group. While one of the subjects is performing the exercises, the other subject and the other students in the group will perform the various duties needed to run the experiment successfully.

2. One member of the group should:

   - Time the rest, exercise, and recovery periods;

   - Tell the subject when to get ready for rest, exercise, or recovery periods;

   - Tell the subject when to start and stop exercising;

   - Tell the other assistants when to record the subjects' vital numbers.

3. Another member of the group should:

   - Measure the core temperature of the subject with the thermometer;

   - Determine the active sweat gland density with iodine paper;

   - Set the metronome for the required step rhythm.

4. The third member of the group should:

   - Operate the computer system that records heart rate and skin temperature;

   - Record the values for the core temperature and the sweat gland density of the subject in the Journal or on a separate data table.

Preparation Needed before Exercise Begins

Calibration of Temperature Probe

1. Place the tip of the temperature probe in cold water of a known temperature (~10°C). Type "Calibration <Cold Water Temperature>" in the Mark box to the right of the Mark button on the LabScribe Main window.

2. Click on the Record button and press the Enter key on the keyboard. Record data until the voltage on the temperature channel reaches a plateau; this usually takes about 20 seconds. While recording at this temperature, type "Calibration <Warm Water Temperature>" in the Mark box.

3. Without stopping the recording, move the tip of the probe from cold to warm water of a known temperature (~40°C).

4. Press the Enter key on the keyboard. Record the change in voltage on the Temperature channel until a plateau is reached (Figure EP-2-L1). Click on the Stop button to halt the recording.
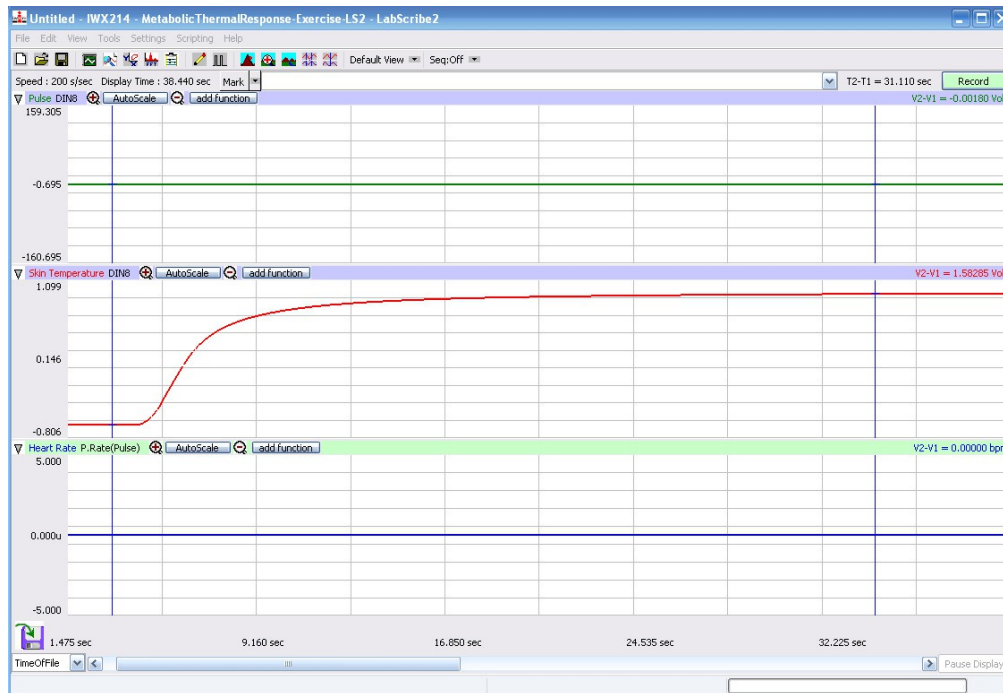
Figure EP-2-L1: The output of the TMN-100 temperature probe recorded at two different temperatures. Data is used to calibrate the TMN-100.

5. 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. Designate the file type as *.iwxdata. Click on the Save button to save the data file.

6. Use the Display Time icons (Figure EP-2-L2) to adjust the Display Time of the Main window to show the recording at both temperatures in the same window.

7. Click the 2-Cursor icon (Figure EP-2-L2) so that two vertical cursors appear on the Main window. Place a cursor on the plateau of the temperature recording taken from cold water and the other cursor on the plateau of the temperature recording from the warm water.
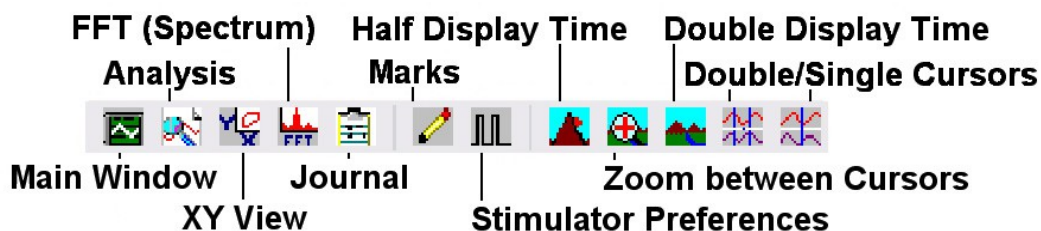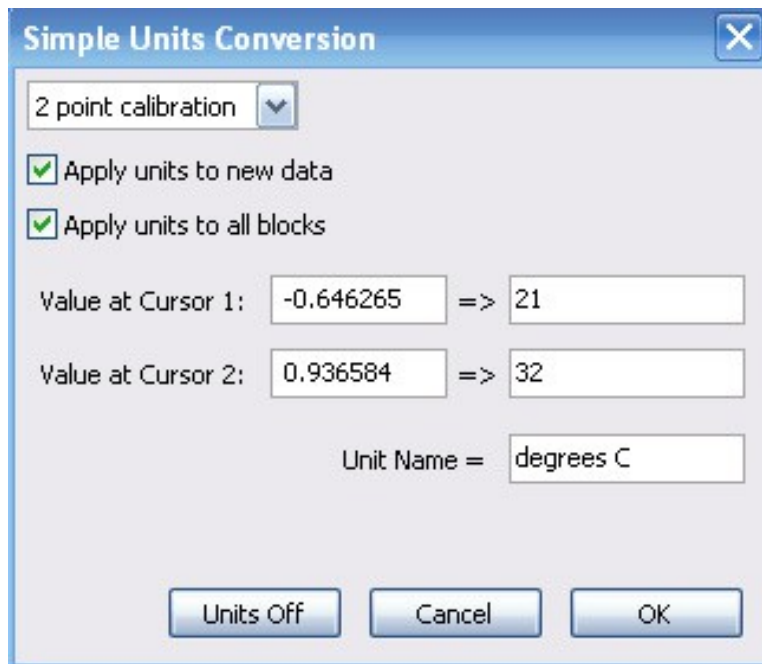

Figure EP-2-2: The LabScribe toolbar.

8. To convert the voltages at the positions of the cursors to temperatures, use the Simple Units Conversion dialogue window (Figure EP-2-L3). To access this dialogue window, click on the arrow to the left of the channel title, Skin Temp, to open the channel menu. Select Units from the channel menu, and select Simple from the Units submenu.

9. On the Simple Units Conversion window, make sure 2 point calibration is selected in the pull-down menu in the upper-left corner of the window.

- Put a check mark in the box next to Apply units to all blocks.
- Notice that the voltages from the positions of the cursors are automatically entered into the value equations.
- Enter the two temperatures used in the calibration recording in the corresponding boxes on the right side of the conversion equations.
- Enter the name of the units, ^{o}C, in box below the pressures.
- Click the OK button to activate the units conversion.

Figure EP-2-L3: The Simple Units Conversion dialogue window with the voltages at the cursors set to equal the temperatures of the water used to calibrate the temperature probe.

Weighing the Subjects before Exercise

1. Each subject should change into a t-shirt and shorts (no socks or shoes), and weigh-in before the initial rest period. Record the initial weight of each subject.
2. Use surgical tape to attach the temperature probe to the skin on the right thigh of the subject. The tip of the probe should be over the large muscle (quadriceps) on the front of the thigh, in the center of the thigh midway between the knee and the hip.
3. The subject should put on his or her socks and shoes in preparation to exercise.
4. Place the plethysmograph on the volar surface (where the fingerprints are located) of the distal segment of the left middle finger or thumb of the subject, and wrap the Velcro strap around the end of the finger to attach the unit firmly in place.
5. The subject should sit in a chair and rest for at least 5 minutes before recording data from the time right before the beginning of the first exercise period.

6. It is the job of the timekeeper to keep the experiment on pace so it can be completed in a timely manner.

7. The subject assigned to wear sweat clothes while exercising should not dress in those items or put the knit cap until he or she is ready to begin the first exercise period.

Rest and Exercise Periods Used in the Experiment

1. Each subject will perform four 3-minute periods of stepping exercises. In addition to the 5-minute rest period before the first 3-minute exercise period, there are 5-minute recovery periods between the exercise periods and a 5-minute recovery period after the last exercise period.

    Warning: The Step Test should not be attempted by individuals with a very poor level of physical fitness, or individuals taking a beta blocker medication or any medication affecting heart rate.

2. The amount of work completed in each exercise period will increase progressively as do the step rates (steps/min). The step rates are 12, 18, 24, and 30 steps per minute.

3. Each step is a four-beat cadence, so the metronome will be set to 48, 72, 96, and 120 beats per minute, respectively.

4. The movements for each of the four beats in a step are:

    •   1st beat: Left foot up on step.

    •   2nd beat: Use the left leg to lift body, and place right foot on step.

    •   3rd beat: Lower the left foot to the ground.

    •   4th beat: Lower the right foot to the ground.

5. The subject can begin stepping with his or her right foot if he or she is more comfortable with that arrangement.

6. It is important to secure the step against the side of a lab bench or up against a wall to prevent it from slipping from under the feet of the subject.

Exercise 1: Resting Heart Rate, Temperatures, and Sweat Gland Density (SGD)

Aim: To measure the heart rate, skin and core temperatures, and active sweat gland density of resting subject.

Procedure

1. Record the subject's resting heart rate and skin temperature after the subject has rested for five minutes.

2. Type "<Subject's Name> Resting HR and Skin Temp" in the Mark box that is to the right of the Mark button.

3. At the end of the rest period, click on the Record button, located on the upper right side of the LabScribe Main window. The signal should begin scrolling across the screen. Press the Enter key on the keyboard to mark the recording.

4. Click on the AutoScale buttons at the upper margins of the Pulse, Skin Temp, and Heart Rate

channels. The pulse, skin temperature, and heart rate recordings should expand to fill the channel windows (Figure EP-2-L4).

- If the signal on the Pulse channel is upside down when compared to trace in Figure EP-2-L4, click on the downward arrow to the left of the channel title and select the Invert function. The trace should now look similar to the one in the figure.

- If the pulse signal is small or noisy, adjust the tension on the strap holding the pulse plethysmograph to the finger.

Note: If the user clicks the Record button and there is no communication between the IX-ELVIS and computer, an error window will appear in the center of the Main window. Make sure the IX-ELVIS is turned on and connected to the USB port of the computer. Click OK and select the Find Hardware function from the LabScribe Tools menu.
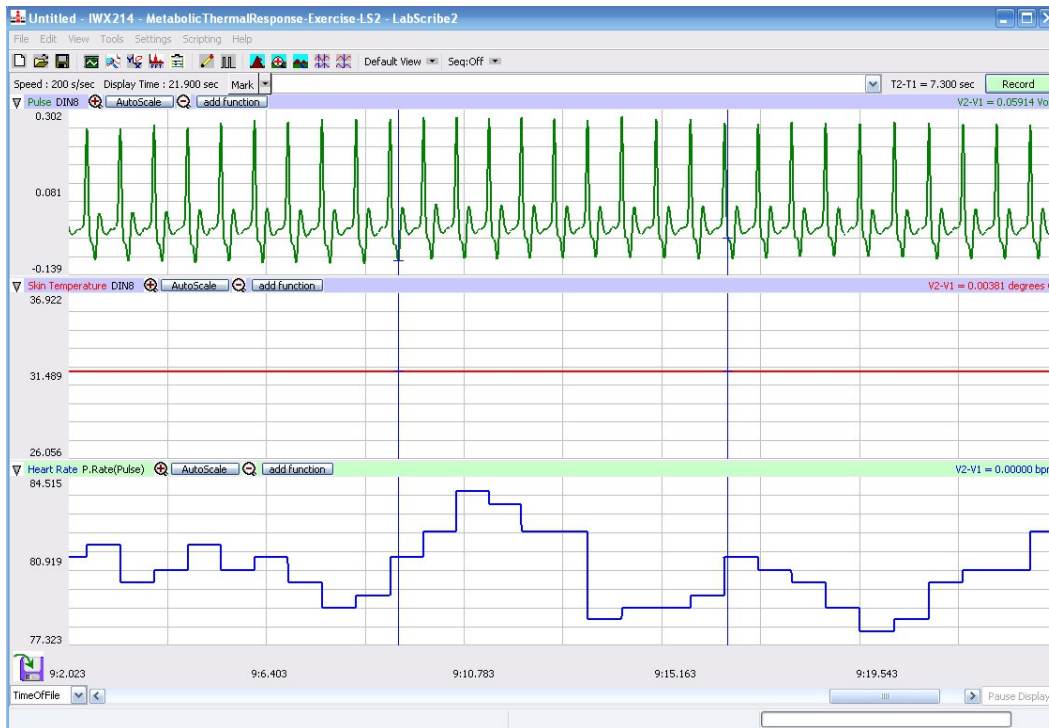

Figure EP-2-L4: Pulse, skin temperature, and heart rate recordings while subject is at rest, displayed in the Main window.

5. Record the subject's resting heart rate and skin temperature for one minute. Then, click Stop to halt the recording.

6. Determine the subject's core temperature by using the thermometer provided. Please follow the directions for using the thermometer in order to take accurate measurements and to avoid injury to the subject

7. Determine the subject's active sweat gland density (SGD):

- Wipe an area of the forehead dry with a lab wipe.

- Wrap a piece of the iodine paper around the small wood block, so a 2.5cm x 2.5cm surface is available for use as a blotter.

- Gently press the iodine paper blotter on the skin of the forehead for one second.

- Place a 5 mm x 5 mm grid over the iodine paper blotter. Count the number of blue dots in the 5 mm^2 grid. Each blue dot indicates an active sweat gland. The carbohydrates in sweat combine with iodine to create the blue dye in the dot.

8. Multiply the number of dots in the 5 mm^2 box by four to determine the number of active sweat glands in 1 cm^2.

9. Record the subject's core temperature and sweat gland density (SGD) in the on-line notebook of LabScribe by typing the name and value of the parameter directly into the Journal, or on a separate data table. You can open and close the Journal by clicking on its icon on the LabScribe toolbar (Figure EP-2-L5).

10. 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. Designate the file type as *.iwxdata. Click on the Save button to save the data file.

11. Remove the pulse plethysmograph from the subject's finger. If the subject is able to keep the connector of the temperature probe in the belt of their shorts or sweat pants (after the probe has been disconnected from its extension cable), let them do so. If the connector of the temperature probe cannot be secured on the subject, the probe must be removed from the subject's skin before the exercise period and reattached at the beginning of the recovery period.

Data Analysis

1. Scroll to the beginning of the recording of the subject's heart rate while at rest. Display a ten second section of data that is free of artifacts in the Main window.

2. Use the Display Time icons to adjust the Display Time of the Main window to show ten seconds of data on the Main window. The ten second section of data can also be selected by:

- Placing the cursors on either side of the ten seconds of data; and

- Clicking the Zoom between Cursors button on the LabScribe toolbar (Figure EP-2-L5) to expand the ten seconds of data to the width of the Main window.
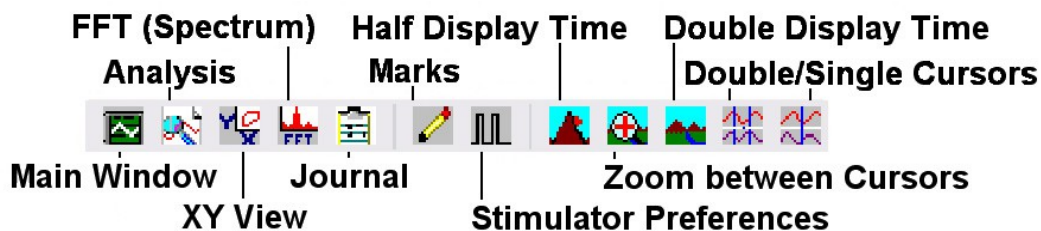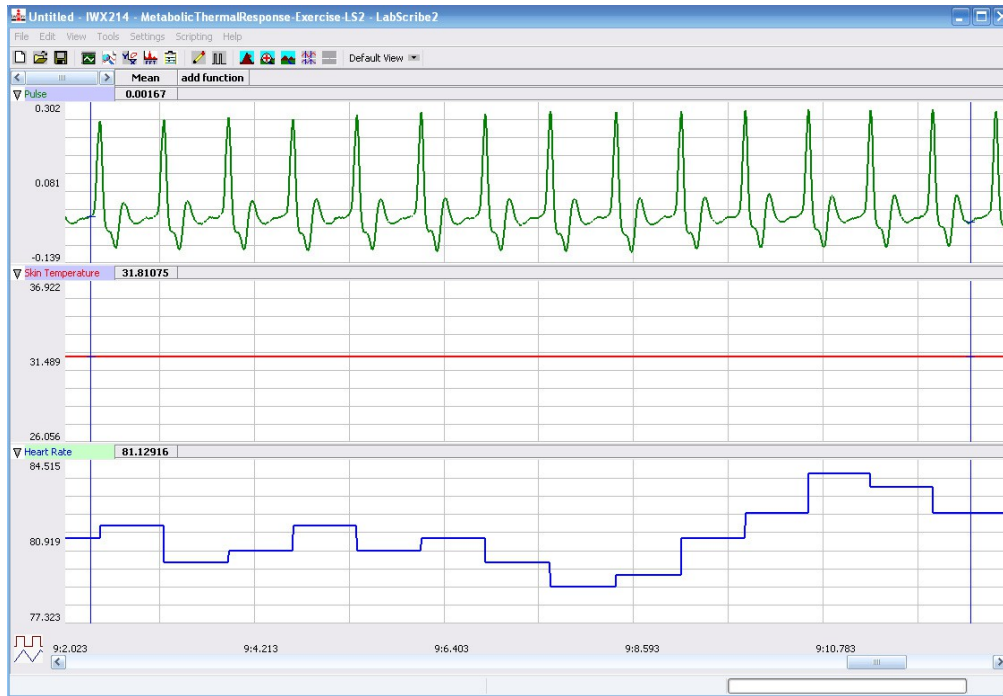

Figure EP-2-L5: The LabScribe toolbar.

3. Click on the Analysis window icon in the toolbar (Figure EP-2-L5) or select Analysis from the Windows menu to transfer the data displayed in the Main window to the Analysis window (Figure EP-2-L6).

4. Look at the Function Table that is above the uppermost channel displayed in the Analysis window. The mathematical function, Mean, should appear in this table. The value for the mean heart rate should appear across the top margin of the Heart Rate channel.

5. Place a cursor near the beginning of the data displayed on the Analysis window, and place the other cursor near the end of the data displayed on the window. The cursors are in the correct positions for determining the mean resting heart rate of the subject from the ten seconds of data on the window.

6. Record the mean resting heart rate of the subject in the on-line notebook of LabScribe by typing the name and value of the parameter directly into the Journal. You can open and close the Journal by clicking on its icon on the LabScribe toolbar (Figure EP-2-L5).

Figure EP-2-L6: Pulse, skin temperature, and heart rate recordings while subject is at rest, displayed in the Analysis window.

7. The functions in the channel pull-down menus of the Analysis window can also be used to enter the names and values of parameters from the recording to the Journal. To use these functions:

   • Transfer the names of the mathematical functions used to determine the volumes and rates to the Journal using the Add Title to Journal function in the Heart Rate Channel pull-down menu.

   • Transfer the values for the volumes and rates to the Journal using the Add All Data to Journal function in the Heart Rate pull-down menu.

8. Record the mean resting heart rate in Table EP-1-L2.

Exercise 2: Changes during Exercise and Recovery Periods

Aim: To measure the changes in the heart rate, skin temperature, core temperature, and active sweat gland density of a subject exercising and recovering from exercise.

Procedure

1. When the measurements from the rest period have been completed, the timekeeper should inform the subject and the assistants when the first exercise period will begin.

2. The metronome should be ticking at the proper cadence, 48 beats/minute, for about 30 seconds before the exercise period begins. The subject should be standing in front of the step at that time. Any subject dressed in sweat clothes should put on his or her knit cap.

3. The timekeeper should give the subject a ten second countdown before calling "Start!". Once "Start" is called the subject should begin stepping.

4. The subject will step up and down for three minutes at the pace designated for the exercise period. While the subject is stepping, the assistants can measure and enter pertinent data into the Journal, or on a separate data table.

5. Thirty seconds before the end of the exercise period, the timekeeper should alert the assistants to be ready to take measurements of heart rate, skin temperature, core temperature, and sweat gland density. Type "HR and Skin Temp at End of 12 Steps/min" in the Mark box that is to the right of the Mark button.

6. At the end of the three minute exercise period, the timekeeper should give the subject and assistants a 10-second countdown before calling "Stop!". At the end of the three minute stepping exercise, the subject should immediately sit in a chair and attach the pulse plethysmograph to the same finger with the same tension used earlier.

7. As soon as the subject is seated and the pulse plethysmograph is in place, click on the Record button. Click on the AutoScale buttons on all channels.

8. The assistants should record the subject's core temperature with the thermometer, and active sweat gland density with iodine paper. Remember to wipe off a section of the subject's forehead before blotting the skin for one second with iodine paper.

9. Continue to record the subject's heart rate and skin temperature until the 4-minute mark of the recovery period. Click on the Stop button. Select Save in the File menu.

10. Remove the pulse plethysmograph from the subject's finger and disconnect the temperature probe from its extension cable at the 4.5 minute mark of the recovery period.

11. Measure and record the subject's core temperature and active sweat gland density between the 4 and 4.5 minute marks of the recovery period.

12. The timekeeper should set the metronome to the beat cadence for the next exercise period and have the device ready to begin ticking 30 seconds before the start of the next exercise period:

    • Exercise Period 2: 72 beats/minute = 18 steps/minute.

    • Exercise Period 3: 96 beats/minute = 24 steps/minute.

    • Exercise period 4: 120 beats/minute = 30 steps/minute.

13. Repeat Steps 1 through 12 of these directions for the remaining exercise and recovery periods.

14. When the subject has finished his or her last recovery period, the subject should quickly move to the restrooms, dry off, and change into a dry t-shirt and shorts. The subject should return to the lab, take off his or her shoes and socks, weigh-in, and record his or her post-exercise weight.

Data Analysis

1. Scroll to the beginning of the recording of the subject's heart rate during the first recovery period. Display a ten second section of data that is free of artifacts in the Main window.

2. Use the Display Time icons to adjust the Display Time of the Main window to show ten seconds of data on the Main window. The ten second section of data can also be selected by:

   • Placing the cursors on either side of the ten seconds of data; and

   • Clicking the Zoom between Cursors button on the LabScribe toolbar (Figure EP-2-L5) to expand the ten seconds of data to the width of the Main window.

3. Click on the Analysis window icon in the toolbar (Figure EP-2-L5) or select Analysis from the Windows menu to transfer the data displayed in the Main window to the Analysis window.

4. Position a cursor on either side of the five pulses on the Pulse channel. The value for Mean in the table across the upper margin of the Heart Rate channel is the subject's mean heart rate at the start of the first recovery period. The value for Mean in the table across the upper margin of the Skin Temp channel is the subject's mean skin temperature at the start of the first recovery period.

5. Record these values in the Journal using one of the two techniques described in Exercise 1. Enter these values in Table EP-2-L1.

6. Go to the four minute mark of the data from the first recovery period and find a section of five adjacent pulse waves that are free of artifacts.

7. Measure and record the mean heart rate and mean skin temperature from this section of the recovery period using the same techniques used in Steps 1 through 5.

8. Scroll to the beginning and 4-minute marks of the three other recovery periods, and measure and record the mean heart rate and mean skin temperature for each section of the remaining recovery phases using the same techniques used earlier.

Calculations

Fill in a data table (Table EP-2-L1) for each subject using the data recorded and the following calculations:

1. Determine the amount of Work completed in a minute by each subject during each exercise period using the following equation:

Work (kg-m/min) = Body Weight of Subject (kg) x Step Height (m/step) x Step Rate (steps/min)

For example, a 70kg person stepping on a 30cm step, 30 times in a minute, will perform 630kg-m/min of work:

630kg-m/min = 70kg x 0.3m/step x 30 steps/min

2. Use the following equation to convert Work from units of mass and distance to units of energy:

Work (kcal/min) = Work (kg-m/min) x (0.00234kcal/kg-m)

In our example, 630kg-m/min of work equals 1.474 kcal/min of work:

1.474 kcal/min = 630kg-m/min x 0.00234kcal/kg-m.

3. Energy cost can be measured as the amount of Oxygen Consumed (VO_2). Calculate the relative VO_2 (ml O_2/kg body weight/min), a parameter which takes into account the body weight of the subject, for each subject during each exercise period using the following equations[1]:

Relative VO_2 (ml O_2/kg body weight/min) = H + V + R

H = Step Rate (steps/min) x 0.2

V = Step Height (m) x Step Rate (step/min) x 2.39

R = 3.5

In our example, a subject stepping on a 30cm step, 30 times in a minute, will consume 31.01ml O_2/kg body weight/min:

31.01ml O_2/kg body weight/min = 6 + 21.51 + 3.5

H = 6.00 = 30 steps/min x 0.2

V = 21.51 = 0.3m x 30 steps/min x 2.39

R = 3.5

4. Energy cost can also be expressed as the amount of Energy Consumed. Convert each subject's relative VO2 for each exercise period to Energy Consumed (E) per minute in the same period by the following equation:

E (kcal/min) = VO_2 (ml O_2/kg body weight/min) x Body Weight (kg) x 5 kcal/1000ml O_2

In our example, the 70 kg subject consuming 31.01ml O_2/kg body weight/min will consume energy at the rate of 10.85 kcal/min:

10.85 kcal/min = 31.01ml O_2/kg/min x 70kg x 5kcal/1L O_2

5. Determine the Net Mechanical Efficiency (ME_{net}) for each exercise period. Mechanical Efficiency (ME) is a ratio of the amount of Work performed to the amount of Energy Consumed. If the energy consumed during rest is subtracted from the total energy consumed, ME_{net} can be determined. Use the following equation to determine ME_{net} for each subject in each exercise period:

ME_{net}(%) = (Work (kcal/min) x 100) / ($E_{exercise}$ - E_{rest} (kcal/min))

E_{rest} = 3.5ml O_2/kg body weight/min x Body Weight (kg)

In our example, the 70 kg subject consuming Energy at the rate of 10.85 kcal/min and doing Work at the rate of 1.474 kcal/min, has a Net Mechanical Efficiency of 15.32%.

15.32% = (1.474 kcal/min x 100) / (10.85 - 1.225 kcal/min)

6. Heat Storage (S) in a body normally increases during exercise, unless heat loss is high. Use the core temperatures recorded in the initial rest period and in the last exercise period, and the following equation to calculate the Change in Heat Storage (ΔS) of the subject:

ΔS (kcal) = 0.83 kcal/kg body weight/°C x 0.6 x Body Wt. (kg) x Change in Core Temperature (Δ°C)

In our example, if the 70 kg subject had a core temperature of 37°C at rest and 39°C after the last exercise period, the ΔS is 69.7 kcal.

$$69.7 \text{kcal} = 0.83 \text{kcal/kg/°C} \times 70 \text{kg} \times 0.6 \times 2.0°C$$

7. Determine the amount of Evaporative Heat Loss (E) for each subject from the amount of weight loss that each subject experiences during the experiment. Evaporative cooling removes 0.58 kcal/gram H_2O evaporated. So,

E = 0.58kcal/g H_2O x Weight Loss (g)

In our example, the 70kg subject, who loses 150g of weight while exercising, loses 87 kcal of heat through evaporative heat loss.

$$87 \text{ kcal} = 0.58 \text{kcal/g } H_2O \times 150 \text{g}$$

Questions

Use graphs to demonstrate any trends in the data.

1. Does the mechanical efficiency of a lightly clothed subject improve or decline with the increase in exercise?

2. Does the mechanical efficiency of a heavily clothed subject improve or decline with the increase in exercise?

3. How does the net mechanical efficiency of a subject in heavy clothing compare to that of a subject in lighter clothing?

4. How does the change in stored heat of a heavily clothed subject compare to that of a lightly clothed subject?

5. How does the evaporative heat loss of a lightly clothed subject compare to that of a heavily clothed subject?

Additional Equations

1. The equation that is usually used to determine the maximum heart rate is:

   Maximum heart rate (BPM) = 220 - age (years)

   The standard deviation for this parameter is 10 to 12 beats per minute (BPM).

2. The upper and lower limits of a subject's heart rate during exercise is determined by the following equations:

   Lower-limit exercise HR (BPM) = Max. heart rate x 0.6

   Upper-limit exercise HR (BPM) = Max. heart rate x 0.9

Table EP-2-L1: Data Table for Recording Subject's Metabolic and Thermal Responses to Exercise

Clothing = Heavy or Light			Body Wt = Pre_____kg Post_____kg			Age =		
	Work	E Used	ME_{net}	Core T	Skin T	SGD	HR	HR/Max
Period/Units	kcal/min	kcal/min	%	ºC	ºC	$\#/cm^2$	BPM	%
Rest								
End of Exercise 1								
End of Recovery 1								
End of Exercise 2								
End of Recovery 2								
End of Exercise 3								
End of Recovery 3								
End of Exercise 4								
End of Recovery 4								
		$\Delta S =$ _____ kcal				E = _____ kcal		

1. Developed by American College of Sports Medicine