Experiment HE-1: Metabolic and Thermal Response to Exercise

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.

Equipment Required

PC or Mac Computer

IXTA, USB cable, IXTA power supply

Doctor's scale

PPG-320 – pulse and temperature probe

Surgical tape

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

Step (23-30 cm in height)

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

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

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 4 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 3 or 4 days. The paper should turn tan as it absorbs iodine.

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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 2 t-shirts, 2 pair of gym shorts, 1 pair of cotton socks, 1 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.

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 pape;
    - 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.

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Pulse Transducer & Temperature Probe Setup

1. Locate the PPG-320 pulse/temperature sensor.
2. Plug the connector into the PT port on the front of the TA.

Figure HE-1-S1: The PPG pulse / temperature sensor connected to the TA data recorder.

Preparation Needed before Exercise Begins

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 of the subject, and wrap the Velcro strap around the end of the finger to attach the unit firmly in place.

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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.
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.

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.

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.

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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.

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.

Approximate Time: 30 minutes

Procedure

1. Record the subject's resting heart rate and skin temperature after the subject has rested for five minutes.
2. Type **Resting** in the Mark box.
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. Click the mark button to mark the recording.
4. Click on the AutoScale All button.
    - If the signal on the Pulse channel is upside down when compared to the trace, 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 sensor to the finger.
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 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 1 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.

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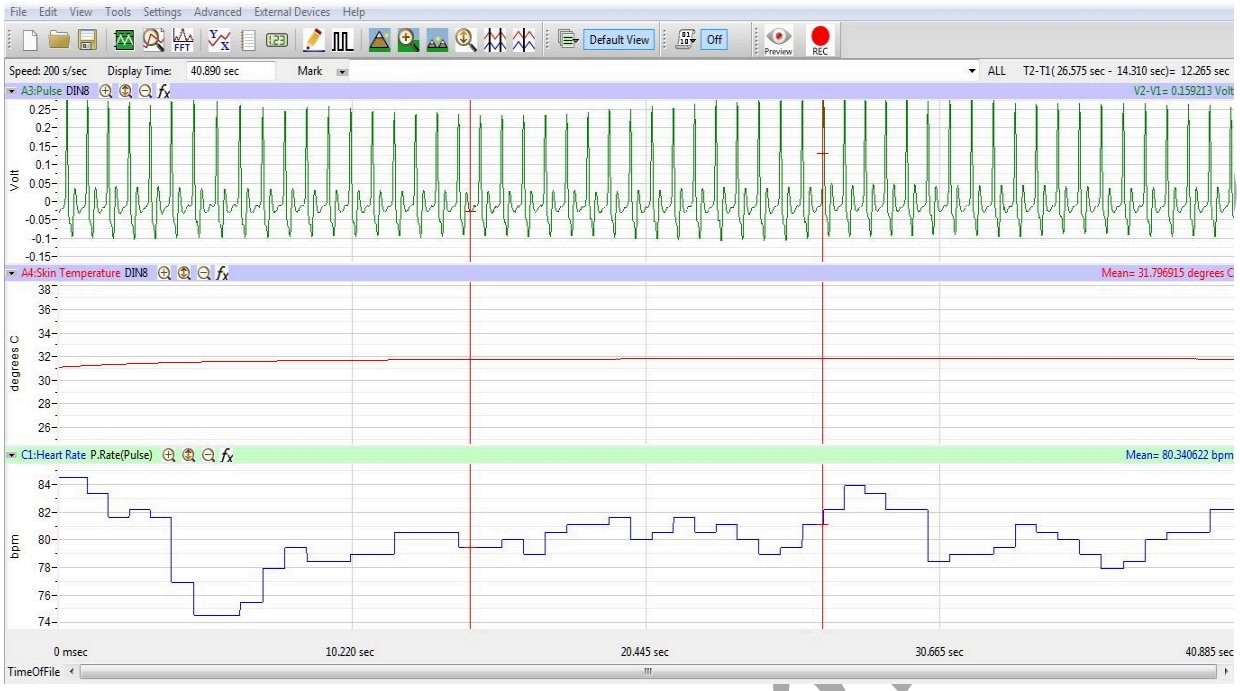

Figure HE-1-L1: Pulse, skin temperature, and heart rate recordings while subject is at rest, displayed in the Main window.

8. Multiply the number of dots in the 5 mm^2 box by 4 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.
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, like your lab group folder. Designate the file type as *.iwxdata. Click on the Save button to save the data file.
11. Remove the pulse sensor 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.

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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.

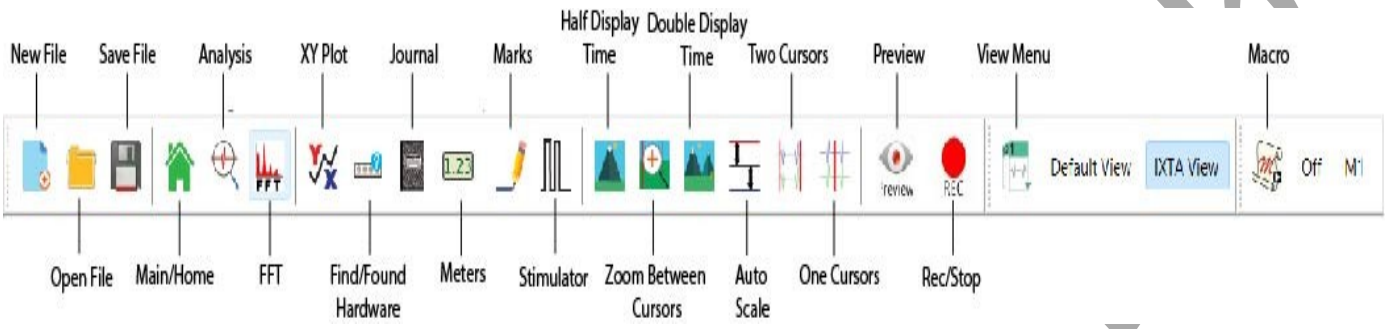

Figure HE-1-L2: The LabScribe toolbar.

3. Data Analysis can be done right in the Main Window.
4. The mathematical function, Mean, will be shown to right of both the Heart Rate and Temperature channels.
5. Place a cursor near the beginning of the data displayed, 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.
7. Record the mean resting heart rate for in Table 1.

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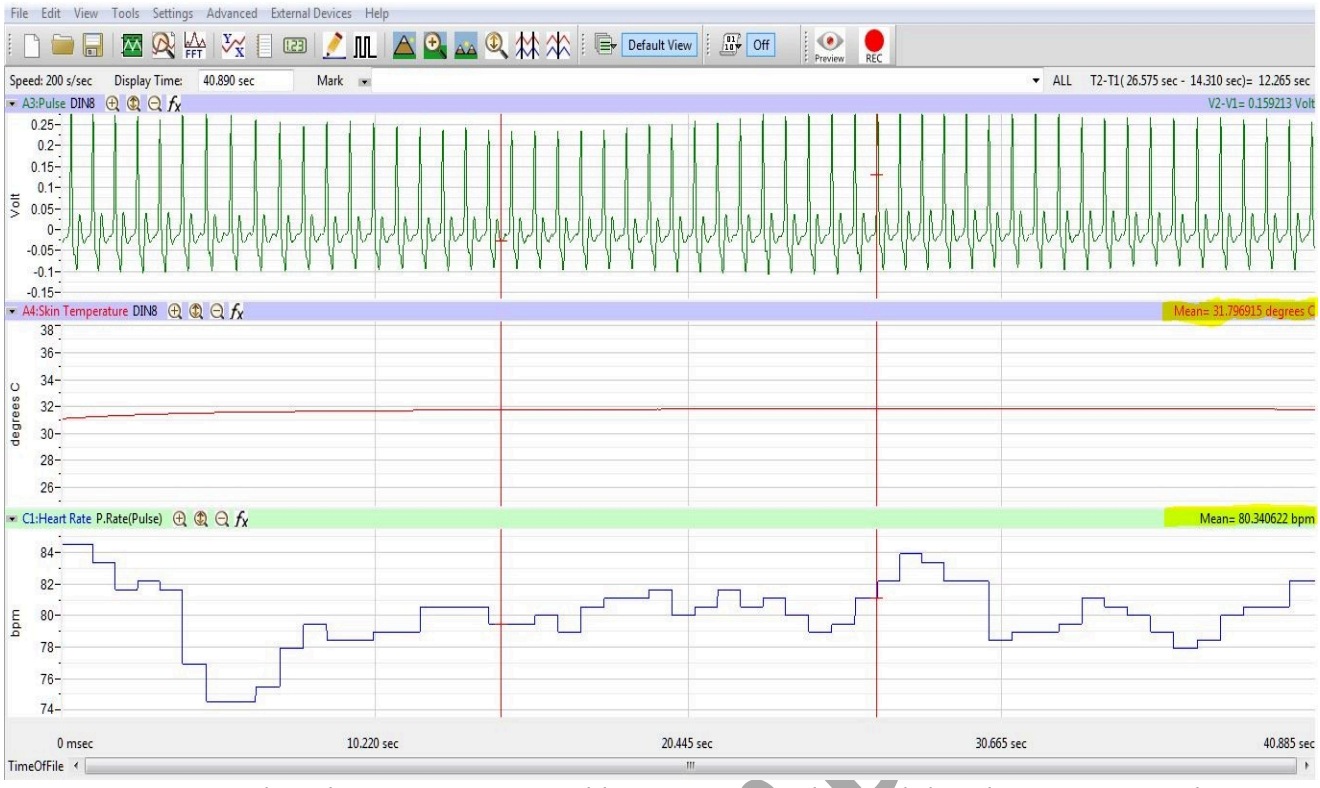

Figure HE-1-L3: Pulse, skin temperature, and heart rate recordings while subject is at rest, showing the Mean values highlighted.

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.

Approximate Time: 30 minutes

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 10-second countdown before calling “Start!”. Once “Start” is called the subject should begin stepping.
4. The subject will step up and down for 3 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.

Wow Sam

6. Type **HR and Skin Temp at End of 12 Steps/min** in the Mark box and click the mark button to mark the recording.
7. At the end of the 3-minute exercise period, the timekeeper should give the subject and assistants a 10-second countdown before calling "Stop!". At the end of the 3-minute stepping exercise, the subject should immediately sit in a chair and attach the pulse sensor to the same finger with the same tension used earlier.
8. As soon as the subject is seated and the pulse sensor is in place, click on the Record button. Click on the AutoScale All button.
9. 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 1 second with iodine paper.
10. 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.
11. Remove the pulse sensor from the subject's finger and disconnect the temperature probe from its extension cable at the 4.5 minute mark of the recovery period.
12. 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.
13. 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.
14. Repeat Steps 1 through 12 of these directions for the remaining exercise and recovery periods.
15. 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 to expand the ten seconds of data to the width of the Main window.
3. Use the same directions as in Exercise 1 to record the temperature and heart rate.
4. Enter these values in Table 1.

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5. Go to the 4 minute mark of the data from the first recovery period and find a section of five adjacent pulse waves that are free of artifacts.
6. 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.
7. 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 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 70 kg person stepping on a 30 cm step, 30 times in a minute, will perform 630 kg-m/min of work:

630 kg-m/min = 70 kg 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, 630 kg-m/min of work equals 1.474 kcal/min of work:

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

3. Energy cost can be measured as the amount of Oxygen Consumed (VO2). Calculate the relative VO2 (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 VO2 (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

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

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

- H = 6.00 = 30 steps/min x 0.2
- V = 21.51 = 0.3 m 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:

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

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

10.85 kcal/min =31.01 ml O_2/kg/min x 70 kg x 5 kcal/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} = 3.5 ml O_2/kg body weight/min x Body Weight (kg) x 5kcal/1000 ml

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

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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/^{o}C x 0.6 x Body Weight (kg) x Change in Core Temp (Δ^{o}C)

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

69.7 kcal = 0.83 kcal/kg/^{o}C x 70 kg x 0.6 x 2.0^{o}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 = 0.58 kcal/g H_2O x Weight Loss (g)

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

87 kcal = 0.58 kcal/g H_2O x 150 g

Questions

<u>Graphs may be helpful in demonstrating any trends that might be present.</u>

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?
6. What is the relationship between the subject's heart rate at the end of each exercise period and the amount of work completed during the period?
7. What is the relationship between the subject's heart rate at the end of each exercise period and the amount of energy consumed during the period?

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Additional Analysis

1. The heart rates of the subject during each exercise and recovery period were recorded and can be used to:
    - Compare heart rate to work performed and energy used.
    - Measure the ability to recover from exercise. The relative cardiac health of the subject can be demonstrated by the time it takes the subject's heart rate to return to normal after exercising.
2. 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).
3. 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.

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Table HE-1-L1: Data Sheet 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								
		ΔS = _____ kcal				E = _____ kcal		

1. Developed by American College of Sports Medicine

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