

## Chapter 18

# Use of the Impedance Pneumograph in Exercise Physiology

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## Introduction

### Objectives

1. To record the changes in heart rate, blood pressure, ventilation rate/depth, and heat generation/loss that occur with exercise.
2. To understand the mechanisms controlling the above responses.
3. To investigate the recovery time of pulse, blood pressure, ventilation and body temperature after exercise.

### Level of difficulty

This experiment is designed for non-science majors taking Human Anatomy and Physiology during their sophomore and junior years. Most students are enrolled from the schools of Agriculture, Consumer and Family Sciences, Engineering, Health Sciences, Liberal Arts, Education, Nursing, Science, and Technology.

The time required to prepare/set up this exercise is 1 hour for a class of 30. The time required by students is 2 hours in class for discussion and data collection and 1 hour outside of class for the lab report.

## Materials

Quantities for one station (3-4 students per station)

- 1 MacLab/computer/impedance pneumograph pre-amp
- ECG lead cable and 2 lead wires
- finger pulse transducer
- exercise devise (if applicable)
- 2 alcohol swabs
- 2 ECG pads
- 1 sphygmomanometer

1 stethoscope  
1 fever strip  
tape  
towels

### Notes to the Instructor

#### Student Teachers' (TAs) training:

- TAs require training in the MacLab format. The minimum training needed is on trouble shooting techniques. I instruct the TAs in managing the input amplifier to adjust the range, changing the recording speed, and print manager troubleshooting.
- TAs must recognize poor records that require adjustments in the ECG pad placement versus ones that may require a new subject. If the ECG pads are not in the correct body position or not sticking to the skin well the record will be very noisy. If the subject has a very deep breathing pattern we have found that data is difficult to record as it tends to drift away from the baseline frequently.

#### Altering the lab format to different levels:

- The course design listed is intended for second and third year non-biology majors (mostly from the Schools of Nursing, Health Sciences, and Technology).
- To increase the difficulty of this study or to adjust it to have an investigative format, record the ECG rather than the pulse. While recording the ECG analyze the record prior to and after exercise, looking for any change or irregularity. One could also ask for a more detailed analysis of the data. (One could have the students make more comparisons and graphs so that more information is available for discussion.)
- Students could be asked to design their own exercise physiology laboratory by taking this type of data. Some example questions include:
  - Do males or females recover faster from exercise?
  - What is the relationship between the length of exercise and the time of recovery?
  - Is recovery shortened or lengthened with repeated exercise?

#### Difficulties with the lab:

- Choosing a subject that doesn't have too deep a breathing pattern.
- Placement of the ECG pads on the subject.
- Adjustment in the baseline record.
- Adjustment of the length of exercise to tire each subject. (This lab was originally written with a standard stepping protocol, but we found that it rarely tired our students.)

## Use of the Impedance Pneumograph in Exercise Physiology

### Objectives:

1. To record the changes in heart rate, blood pressure, ventilation rate/depth, and heat generation/loss that occur with exercise.
2. To understand the mechanisms controlling these responses.
3. To investigate the recovery time of pulse, blood pressure, ventilation and body temperature after exercise.

### I. Metabolic changes during exercise

#### A. Source of ATP for muscle contraction

The energy (ATP) used during strenuous exercise is derived from:

1. ATP already in the cell.
2. Creatine phosphate already in the cell.
3. Anaerobic energy (ATP) derived from glycolysis - glucose is derived from glycogen stored in the muscle cells.
4. Aerobic energy (ATP) derived from oxidative phosphorylation.

During glycolysis, each glucose molecule is split into two pyruvate molecules, and the energy is released to form two ATP molecules.

Ordinarily, when there is plenty of oxygen present, pyruvate then enters the mitochondria of the muscle cells, is converted to acetyl CoA, and passes through the Krebs (citric acid) cycle, generating carbon dioxide and water and the electron-storing substances NADH and FADH<sub>2</sub>. Fatty acids also enter the Krebs cycle via acetyl CoA. NADH and FADH<sub>2</sub> then pass their electrons to oxygen, generating ATP by the process of oxidative phosphorylation. A total of 36 molecules of ATP is generated by the Krebs cycle and oxidative phosphorylation. This is the **aerobic** part of the system.

However, when there is insufficient oxygen for pyruvate to be fully utilized in the aerobic system, it is not converted to acetate and acetyl CoA, but to **lactic acid**. This lactic acid diffuses out of the muscle cell into the blood. In the absence of adequate oxygen, a large amount of pyruvic acid is converted into lactic acid.

Thus, the only ATP generated under anaerobic conditions is when pyruvate is formed from glucose by the process of glycolysis. However, the formation of lactate from pyruvate needs electrons (i.e. it is an oxidative process). These electrons are provided by NADH, which had been generated by the formation of pyruvate from glucose. Therefore, the conversion of pyruvate to lactate uses electrons provided by NADH, and therefore regenerates NAD<sup>+</sup>. This NAD<sup>+</sup> is then recycled during glycolysis, when more pyruvate and ATP are formed.

#### B. Oxygen debt

The anaerobic system (glycogen-glucose-pyruvate-lactic acid) can provide 1.3 to 1.6 minutes of maximal muscle activity in addition to the 8-10 seconds provided by the phosphagen system.

|                   |  |
|-------------------|--|
| Phosphagen system | 8 - 10 seconds                             |
| Anaerobic system  | 1.3 - 1.6 minutes                          |
| Aerobic system    | unlimited time (as long as nutrients last) |

As lactic acid from the anaerobic system accumulates in the body a person develops an **oxygen debt** that must be repaid at a later time. The amount of oxygen debt built up is equal to the amount of oxygen needed to:

1. Convert the accumulated lactate back to glucose in the liver.
2. Replenish the muscle ATP and creatine phosphate stores.
3. Replenish the oxygen content of the muscle myoglobin.

This is why, after strenuous exercise, you continue to breathe hard and consume excessive amounts of oxygen for at least a few minutes and sometimes for up to an hour.

### C. Muscle fatigue

Muscle fatigue occurs after long periods of repeated contraction and relaxation of the muscle. The force the muscle exerts during each contraction progressively diminishes and there is accompanying discomfort. The causes of this effect are not well understood. One factor may be depletion of muscle glycogen. Eating carbohydrates before a marathon race ("carbohydrate loading") may increase muscle glycogen and delay the onset of fatigue. Drinking a solution of glucose during the race may also be beneficial. Other important factors seem to be the accumulation of lactic acid and elevation of muscle temperature.

### D. Heat production by contracting muscles

When muscles are active, large amounts of heat are produced. During endurance athletics, even under normal environmental conditions, the body temperature may rise from its normal level of 98.6°F (37°C) to 102° or 103°F (~ 39°C).

With very hot and humid conditions or excess clothing, the body temperature can easily rise to as high as 106° to 108°F (41-42°C). This can be destructive to cells, particularly brain cells. Symptoms of **heat stroke** include extreme weakness, exhaustion, headache, dizziness, nausea, profuse sweating, confusion, staggering gait, collapse and unconsciousness.

Untreated, heat stroke can lead to death. Even if exercise is stopped, the body temperature does not easily decrease by itself. There is a breakdown in homeostasis because the temperature regulating mechanisms often fail. Therefore, clothing must be removed, the body sprayed with cold water or even immersed in water containing crushed ice if available.

## II. Respiration

### A. Oxygen demand and carbon dioxide production

Oxygen consumption at rest is about 300 ml/min, but this can rise to 3 liters/min in a moderately fit subject, and can reach 6 liters/min in an elite athlete.

Carbon dioxide production at rest is about 240 ml/min, and this can increase to 3 liters/min in a moderately fit subject.

To accommodate the increased demand for oxygen and the increased production of carbon dioxide, ventilation increases promptly during strenuous exertion and may reach very high levels. A fit young man who attains a maximum O<sub>2</sub> consumption of 4 liters/min may have a total ventilation of 120 liters/min, that is, about 15 times his resting level. This increase in ventilation closely matches the increase in O<sub>2</sub> uptake and CO<sub>2</sub> output. It is remarkable that the cause of the increased ventilation during exercise remains largely unknown.

## B. Measurements

Suppose the volume exhaled with each breath is 500 ml and there are 15 breaths/min. Then the total volume leaving the lung each minute is  $500 \times 15 = 7500$  ml/min. This is known as the total ventilation. The volume of air entering the lung is very slightly greater because more oxygen is taken in than carbon dioxide is given out.

However, not all the air that passes the lips reaches the alveolar gas compartment where gas exchange occurs. Of each 500 ml inhaled 150 ml remain behind in the anatomic dead space. Thus, the volume of fresh gas entering the respiratory zone each minute is  $(500 - 150) \times 15$  or 5250 ml/min. This is called the alveolar ventilation and is of key importance because it represents the amount of fresh inspired air available for gas exchange. (Strictly, the alveolar ventilation is also measured on expiration, but the volume is almost the same.)

We will be measuring **ventilation units**. This value is proportional to ml/min. You will measure the amplitude of a peak multiplied by the number of breaths per minute.

$$\text{Amplitude} \times \text{breaths/min} = \text{ventilation units}$$

## III. Cardiovascular System

### A. Anticipation

Even the **anticipation** of physical activity causes activation of the sympathetic nervous system by the cerebral cortex, and inhibits parasympathetic vagus nerve discharge to the heart. The result is that the heart rate and force of contraction increase and there is increased vasoconstriction. This increased vasoconstriction affects mainly the blood vessels of the *skin* and *abdominal viscera*: the effect is quite mild in the muscles. The result is that a higher proportion of the cardiac output is available to flow through the muscles.

### B. Changes in muscle blood flow

The function of the cardiovascular system in exercise is to deliver oxygen and nutrients (glucose, fatty acids) to active muscles, and to remove wastes (lactic acid, carbon dioxide). The blood flow through muscles during exercise can increase enormously.

| Condition                          | ml blood/100 gm muscle/min |
|------------------------------------|----------------------------|
| Resting blood flow                 | 3.6                        |
| Blood flow during maximal exercise | 90                         |

Circulatory changes during exercise affect the heart (cardiac output) and the blood flow through the skin, muscles and viscera.

### C. Neural and local factors

There are two important types of factors operating on the cardiovascular system during a bout of exercise:

1. *Neural* factors - mainly sympathetic nervous system.
2. *Local* factors - release of vasodilator substances (CO<sub>2</sub>, lactic acid) in active muscles.

### D. Summary of cardiovascular changes

Once exercise has begun, the increased sympathetic drive and reduced parasympathetic inhibition of the S-A node continue, and may even be augmented.

1. Stimulation of the sympathetic nervous system leads to the following:
  - (a) *Heart rate, force of contraction, stroke volume and cardiac output* increase. The heart rate can increase to as much as 180 beats per minute. In the average individual, there is a modest increase in stroke volume - between 10 and 35% - caused by increased venous return because the veins have constricted and reduced their volume. At elevated heart rates, the stroke volume may actually decrease, because the heart is beating so fast that efficient filling of the ventricles does not have a chance to occur. Overall, however, there is a steady increase in cardiac output as the work performed during exercise is increased. This increase in cardiac output is achieved mainly by an increase in heart rate. The situation may be different in well-trained long distance runners, where the stroke volume during exercise can double (see the section below on cardiac output and athletic conditioning).
  - (b) *Arterioles are constricted* mainly in the *skin and abdominal viscera*, reducing blood flow through these organs. This action is due to the binding of norepinephrine to alpha adrenergic receptors in the arterioles of these organs.
  - (c) *Venous return* is increased by constriction of the veins and venules in the skin and abdominal viscera.
2. *Venous return* is increased not only by the action of the sympathetic nervous system, but also by the *pumping action* of active muscles (venous pump) and by increased respiratory rate and depth.
3. Blood flow through the *brain* does NOT change significantly.

4. Blood flow through *coronary circulation* increases markedly in response to increased demand for oxygen by the myocardium.
5. There is the release of vasodilator substances (e.g. carbon dioxide, lactic acid) in the active muscles. This leads to the following:
  - (a) Muscle arterioles and precapillary sphincters open up, allowing blood to flow into all the capillary beds.
  - (b) The blood flow through active muscles can increase by as much as 15-20 times, effectively having been diverted from the circulation in the skin and abdominal viscera.
  - (c) The vasodilation in the active muscles is so strong that it actually *reduces* the peripheral resistance, even though the vessels in the skin and abdominal viscera remain constricted. In exercise that involves a large percentage of the body's musculature (running and swimming), the reduction of peripheral resistance may be quite large. The reduction of total peripheral resistance is important, because it minimizes the large rise in blood pressure that could be a consequence of a vastly increased cardiac output.

Blood pressure = cardiac output **X** total peripheral resistance  
 Cardiac output = stroke volume **X** heart rate

6. If the body temperature rises during strenuous exercise, the heat-regulation center in the hypothalamus is activated, and the skin vessels dilate to enhance heat loss from the skin. If this occurs, there is a further drop in the peripheral resistance.
7. More oxygen is extracted from the blood perfusing active muscles. This is facilitated by an increase in muscle temperature and a reduction of pH, both of which cause hemoglobin to release more oxygen.

**E. Athletic conditioning**

Aside from promoting muscle development, training has an important effect on the cardiovascular system. The maximum cardiac output during exercise is much higher in the trained athlete than in an untrained individual. This is obvious from the table below.

|  | <b>Cardiac output</b>   |
|--|-------------------------|
| Average young man at rest (trained or untrained)     | 5.5 liters per minute   |
| Max. output by young untrained man during exercise   | 20-22 liters per minute |
| Maximum output during exercise by trained marathoner | 30-40 liters per minute |

Therefore, the untrained person can increase cardiac output by about four times, whereas the trained marathoner can increase cardiac output by more than seven times. These results are accounted for by the fact that the heart chambers of the marathoner are about 40% larger and the myocardial mass is also greater than in the untrained individual. This means that the stroke volume of the marathoner is much greater than in the untrained person. However, because the marathoner's heart rate is much *slower*, the cardiac output *at rest* is about the same as for an untrained individual. You can understand this by studying the table below.

Remember that cardiac output (ml/min.) is calculated by multiplying the stroke volume (ml/min.) by the heart rate (beats/min.). To get the cardiac output in liters per minute, you must divide the answer by 1000.

|                | Stroke vol.<br>(ml/min.) | Heart rate<br>(beats/min.) | Cardiac output<br>(liters/min) |
|----------------|--------------------------|----------------------------|--------------------------------|
| <b>Resting</b> |                          |                            |                                |
| Non-athlete    | 75                       | 73                         | 5.5                            |
| Marathoner     | 105                      | 52                         | 5.5                            |
| <b>Maximum</b> |                          |                            |                                |
| Non-athlete    | 110                      | 195                        | 21.5                           |
| Marathoner     | 162                      | 185                        | 30.0                           |

**It is important to understand, however, that heart enlargement and increased pumping capacity occurs in endurance types of training, NOT in sprint types.**

#### IV. Laboratory Study Of Exercise

Exercise can be studied using a stepping device, treadmill, stationary bicycle, or jogging in place. In addition to measuring the cardiovascular and respiratory system *before* exercise, you will also measure the rate at which these responses *recover* during a post-exercise period.

You will need to maintain an exercising pace for a period of 8-10 minutes. Your teaching assistant will demonstrate a pace for you. If you can maintain a faster pace please do so. The intensity of exercise should be strenuous although certainly not maximal. Labored breathing and sweating should occur, along with an elevation of heart rate to about 150-180 beats/min. The subject should be able to maintain the same pace for the entire 8 minute submaximal exercise period.

**The exercise candidate must not be obese, must not have a blood pressure greater than 140/90, must not have a recent history of cardiovascular disease, must not have a resting pulse rate greater than 90, and must not have a joint disease of the lower extremities. All candidates using a step should be between 5' - 5'10" tall for a 15-17 inch step.**

#### Use of the Impedance Pneumograph in Exercise Physiology

##### A. Connecting the subject

1. On the blue pre-amp box, set **LEAD** to **STBY** (it will remain there throughout our study). Select **PNEUMOGRAPH** from the next switch.
2. Remove jewelry, watches etc.
3. Clean the skin on the rib cage at nipple height by first rubbing with a Kimwipe, then with an alcohol prep pad. Let the alcohol dry.

4. Strip the backing off 2 electrodes pads and fasten one to either side of the rib cage above nipple height. Hair will interfere with attachment!
5. Attach the electrode clips to either side.
6. Secure the pulse transducer so that the white area contacts the fleshy pad of the index finger. Contact should be firm, not tight and not loose.
7. Put the blood pressure cuff on the arm opposite to the pulse transducer.
8. Tape the "plug-in" to the subject's hip to avoid accidental disconnections.

### B. Collecting Data

1. Sit the subject in an easy, relaxed position. Select the icon at the top left of the screen or **File** followed by **New** to open a new screen.
2. Using the mouse, click on **PULSE** and select **INPUT AMPLIFIER**. You will see your pulse record displayed in red. If it is too big for the window, select a higher voltage range. If too small, select a lower voltage range. Click on **OK** when you are satisfied. (A value near 500 mV is the norm.)
3. Using the mouse, click on **PNEUMO** (lower, green tracing) and select **INPUT AMPLIFIER**. Adjustment of this variable requires using the **Pneumograph baseline** selector on the blue box before continuing. *Very slowly* adjust the tracing, bringing it into view. If a gray line appears at the bottom of the chart adjust the knob **CLOCKWISE**. If you do not see this gray line adjust the knob **COUNTER CLOCKWISE**. Adjust the tracing to approximately the zero mark. **Do not add/remove any check marks in the boxes at the right!!!**
4. With the pneumograph tracing still in view adjust the **RANGE** to a value that gives visible peaks. If it is too big for the window, select a higher voltage range. If too small, select a lower voltage range. Click on **OK** when you are satisfied. (A value near 500 mV is the norm.)
5. Click **START**. If the pneumograph tracing is not visible or there is a flat line across the bottom adjust the baseline as in #3. Click **STOP** when you have collected an accurate record for about 30-45 seconds.
6. Write a comment; identifying this as the **INITIAL RECORDING** followed by the *subject's name* or *initials*. Follow instructions for **Adding a Comment**. *Ask your instructor to review this recording before you go on.*
7. Your subject will begin exercising in a moment. Record an initial systolic blood pressure and temperature.
8. Your instructor will demonstrate the exercise pattern according to the sound of a metronome on tape. The subject will begin to exercise *with arms swinging* for a full **8 minutes** when the



instructor indicates. If they become overly fatigued, light headed, nauseous, or have difficulty breathing they **MUST** stop before the full 8 minutes.

9. Start **RECORDING** when 1 min. of stepping remains. *The recording will stay on from this point to the end of the 12 minutes recovery.* Adjust the baseline of the pneumograph. It may be necessary to decrease the voltage range given the increased amplitude of the breath. Be prepared to **ADD COMMENTS WHILE RECORDING** throughout the recovery period.  
\***WARNING\***: Data acquisition at 0 and 1 minute after exercise is hectic! Be prepared!!!
10. At the end of the exercise period ask the subject to **be seated**. **The subject MUST** remain **still** and **not talk** to record accurate data. Record pulse and ventilation immediately following exercise. Adjust the baseline for the pneumograph again as necessary. You will **add a comment** indicating **0 min. recovery** and the **subjects initials**. Record blood pressure and temperature also.
11. Record *pulse* and *ventilation* continuously, **ADD A COMMENT** at **1, 3, 6, and 12 minutes** past the end of exercise. The tracing for the pneumograph may require adjustment each time. Record *temperature* at the same times. Record the systolic *blood pressure* only at **3, 6, and 12 minutes** past the end of exercise.

### C. Printing Data after collection of all data:

1. *Printing from the record (tracing)*: Print a copy of the **initial recording** and one at the time **Zero (0) minutes recovery**.
  - High-light a portion of the pulse data using the mouse.
  - Press and hold the shift key down. Now select the same region from the pneumograph tracing.
  - Select the **Print button** from the **Tool bar**. Once printed, title each of these correctly with the subjects name and the time of the recording. Each member of the group will need a copy.

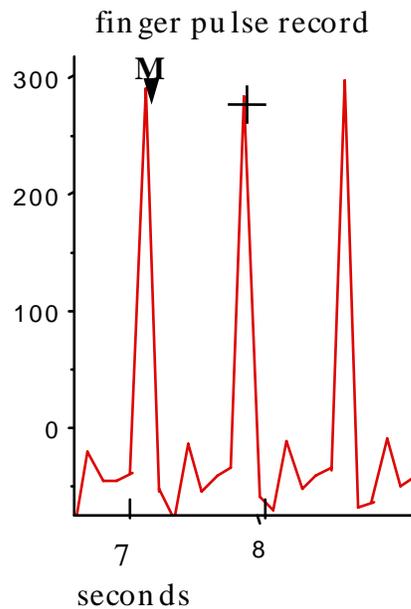
### D. Analysis Of Data

#### *Pulse and pneumograph recordings using zoom*

#### 1. Calculating heart rate:

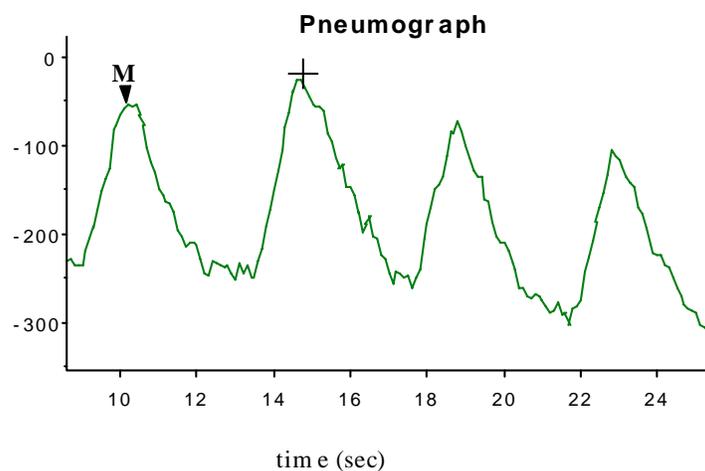
**Zoom** on *two* full finger pulse records for each of the 6 recording times. Now measure the seconds between two peaks of your finger pulse. Place the "**M**" marker at the peak of one wave, and move your "+" cursor to the peak of the next wave. Note the time in seconds = **S**. You will repeat this **heart rate** calculation for all of the recording times (6 times). Put these calculated values in the data table.

$$\text{Heart rate} = \frac{60}{S} \text{ beats/minute}$$

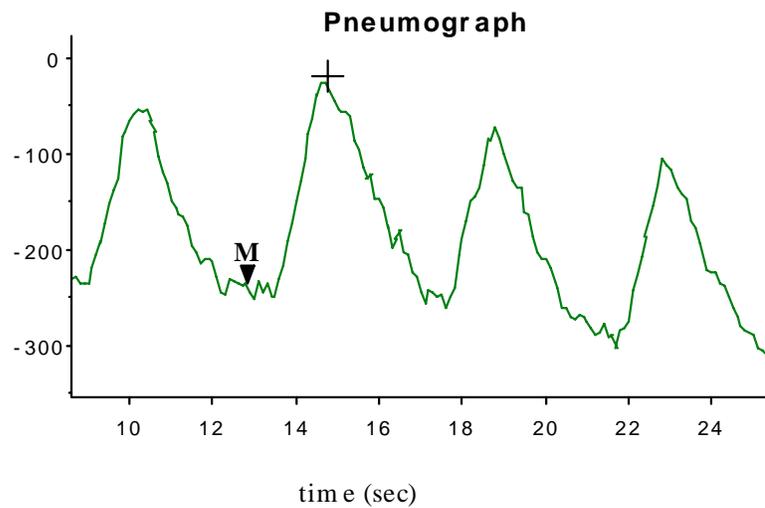


2. **Calculating ventilation rate and depth:** (Note: complete data collection for **a** and **b** of one time point before going on to the next time point.)

- a. **Rate:** **Zoom** on 4 breath recordings for each of the 6 recording times. Now measure the seconds between the 4 peaks of your breath. Place the "M" marker at the peak of one wave, and move your "+" cursor to the peak of the next wave. Note the time in seconds = **S**. Convert this to minutes. Repeat this for the other three breaths in the zoom and calculate an average. (Put these calculated averages in the data table.)



- b. **Depth:** Depth is measured using amplitude. **Now measure the amplitude** of each of these waves. Place the "M" marker at the valley of one wave, and move your "+" cursor to the peak of the wave. Note the **amplitude** in millivolts = **mV**. Repeat this for the other three breaths in the zoom and calculate an average. (Put these calculated averages in the data table.)



c. Repeat a and b for each time point in the experiment (initial, 0, 1, 3, 6, & 12).

d. **Ventilation Units:** this value is *proportional* to ml/min. You will *multiply* the number of breaths per minute by the mean amplitude.

$$\text{RATE (breaths/min)} \times \text{DEPTH (amplitude)} = \text{VENTILATION UNITS}$$

**Make this calculation and list it in the data table.**

**Laboratory Report: Exercise Physiology**

Name \_\_\_\_\_

Div. \_\_\_\_\_

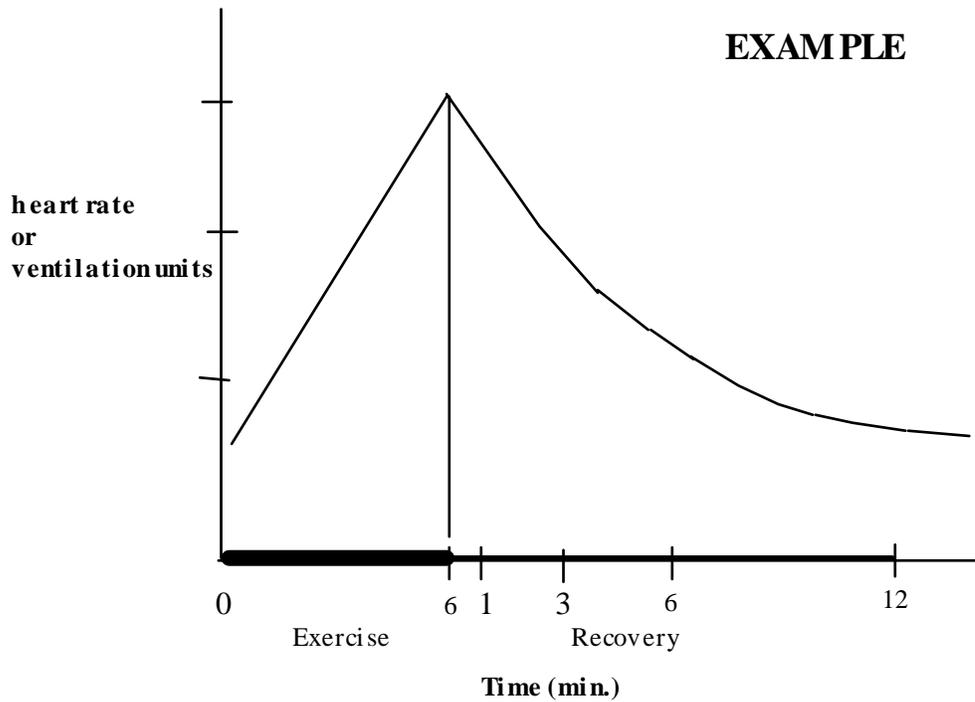
SUBJECT'S NAME \_\_\_\_\_

Current physical activity \_\_\_\_\_ (1 = inactive; 4 = regularly active)

| Time                  | Heart rate<br>(beats/min) | Systolic<br>BP(mmHg) | Mean Rate<br>Ventilation<br>(breaths/min)<br>Units | Ventilation<br>X Mean<br>Amplitude | = | Skin<br>Temp°F |
|-----------------------|---------------------------|----------------------|--|------------------------------------|---|----------------|
| initial               |                           |                      |  |                                    |   |                |
| 0 minutes<br>recovery |                           |                      |  |                                    |   |                |
| 1 minute<br>recovery  |                           |                      |  |                                    |   |                |
| 3 minutes<br>recovery |                           |                      |  |                                    |   |                |
| 6 minutes<br>recovery |                           |                      |  |                                    |   |                |
| 12 min<br>recovery    |                           |                      |  |                                    |   |                |

Note: to calculate **ventilation units** multiply **mean amplitude by rate**.

- Give reasons for any change in heart rate as a result of exercise.
- What 3 important variables cause a change in blood pressure during exercise?
- Using the graph paper, plot the recovery time for **ventilation units**.
- Using the graph paper, plot the recovery time for **heart rate**.



How long does it take for each of the four variables studied to recover?

**Heart rate**

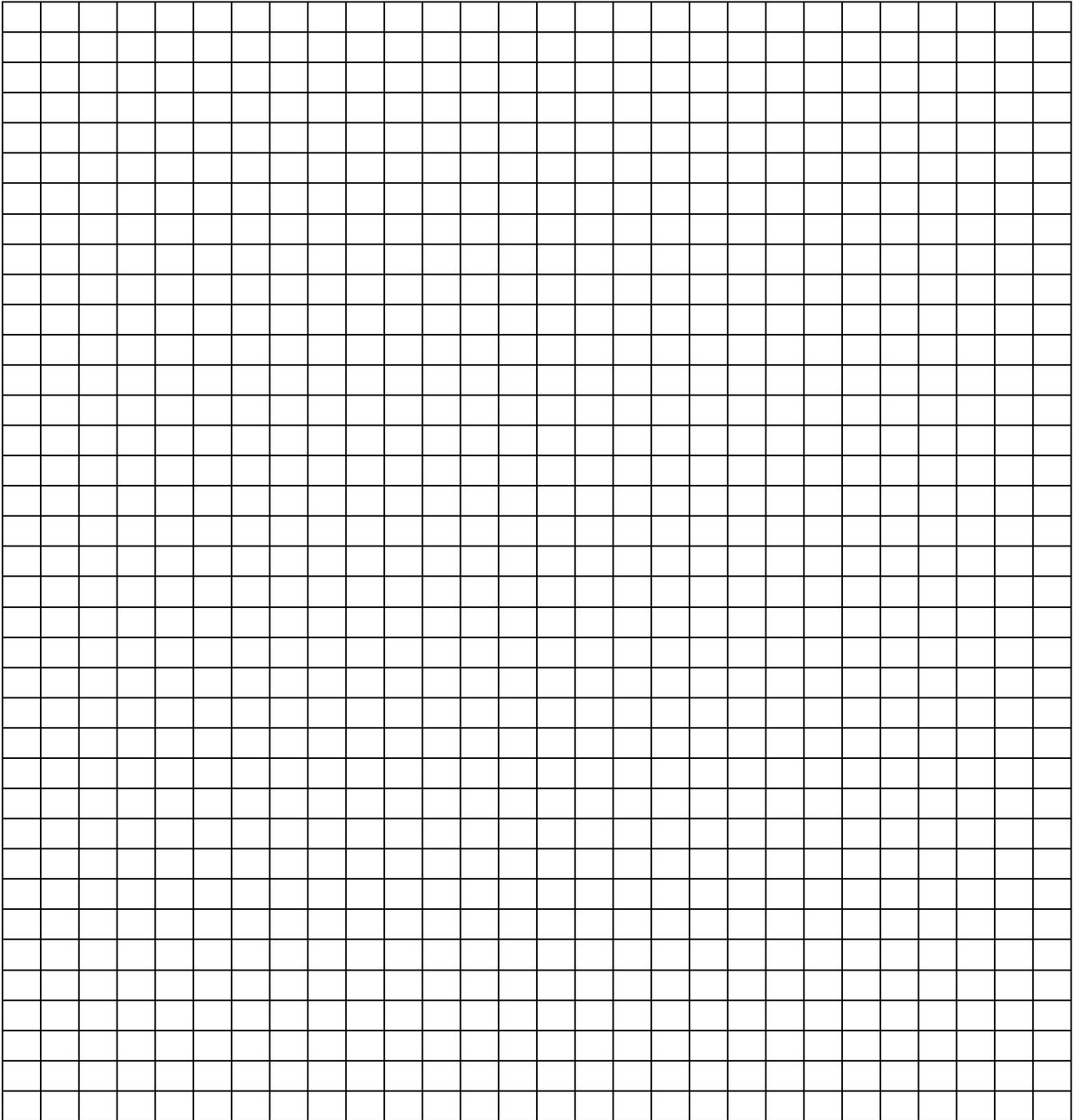
**Systolic blood pressure**

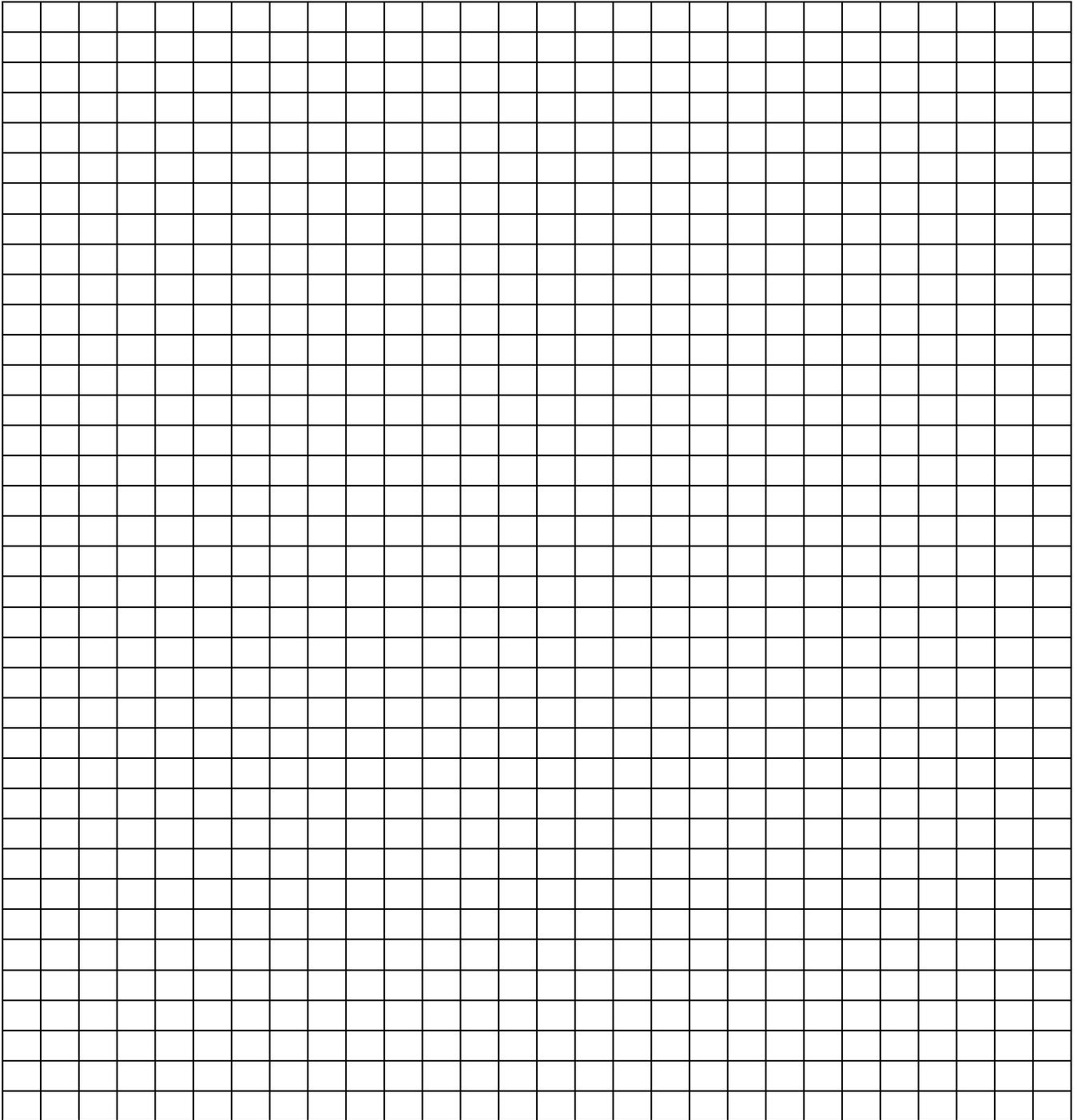
**Ventilation**

**Skin temperature**

Are the recovery times the same for all four variables?

Turn in a copy of the pulse and pneumograph recordings. One from the initial recording and the other from the recording immediately following exercise. Label the recordings correctly with the subject's name and time of the recording.





### Acknowledgments

Dr. C. David Bridges, Course Instructor for Biol 203/204: Human Anatomy and Physiology, Purdue University.

### References

1. Geddes, L.A., Hoff, H.E., Hickman, D.M., and A.G. Moore. The Impedance Pneumograph. *Aerospace Medicine*. 33(62): 28-33. January, 1962.
2. Bridges, C.D. and Brewer, C. Biol 204 Manual for Human Anatomy and Physiology. January, 1997.

### Appendix A *Vendors*

Owens & Miner  
1-800-382-1707  
9727 Bauer Drive  
Indianapolis, IN 46280-1999

- ECG pads - Catalog #0144-AV-330 (300/box) at \$58.35/box
- Standard ECG 5 lead cable (40" lead Pinch Set) - Catalog #4654-03-5970 @ \$27.71

Baxter Healthcare/Scientific Products  
1430 Waukegan Road  
McGaw Park, IL 60085-6787

- Standard alcohol swab - Catalog #40000-090 (case) @ \$49.40/case

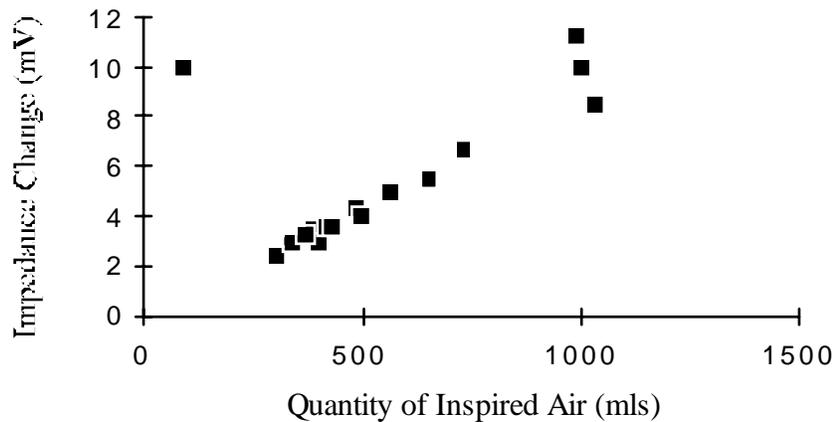
Lafayette Instruments  
3700 Sagamore Pkwy N  
Lafayette, IN 47906  
1-800-428-7545

- NDM Leadwire set - Catalog #03-5970 (set of 5) @ \$30.00
- ECG/Pneumograph used in this exercise was developed in the Department of Biological Sciences at Purdue University. For more information, contact Mary Gray.

### Appendix B

#### *Calibration of the Impedance Pneumograph in the Human Subject*

This experiment has been designed to look at the relative change in ventilation that occurs during recovery from exercise. There may be occasions when the instructor desires to quantify the respiration of the subject. This is possible, but requires the use of a spirometer. Testing at Purdue has indicated that the impedance system must be calibrated for each subject as individual variation is wide. To calibrate, spirometric measurements are taken simultaneously with pneumograph readings. We have gotten the most consistent results by having the subject exhale fully and then inhale specific quantities of air as measured by the spirometer. These measured volumes are then plotted against the pneumograph readings. For most subjects, this is a linear relationship.



**Figure 18.1** Calibration of the Impedance Pneumograph.

### Appendix C

#### *Use of Impedance Pneumography in Non-Human Subjects*

Impedance pneumography may be utilized in virtually any vertebrate with primary lung ventilation and an expandable rib cage. We have used this method to record respiration in anesthetized rats in our advanced physiology labs. An electrode is placed on either side of the chest, just posterior to the forelimbs.

Calibration of the pneumograph may be done after the rat has been humanely euthanized. Sever and cannulate the trachea. The cannula can be made with tubing and a 3-way valve at one end. Attach a 6 ml syringe filled with air to the 3-way valve. Manually "exhale" the rat by compressing the rib cage. This gives the baseline reading for maximal exhalation. Then add air at 1 ml increments via the attached syringe. You will see a series of step-like readings on the pneumograph. Volume of air added may be plotted against the impedance value. Taking several series of readings will improve accuracy.



**Appendix D**  
*Schematic of Data Acquisition System and Preamplifier*

