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Biopac Student Lab® Lesson 1

ELECTROMYOGRAPHY (EMG) I
Introduction

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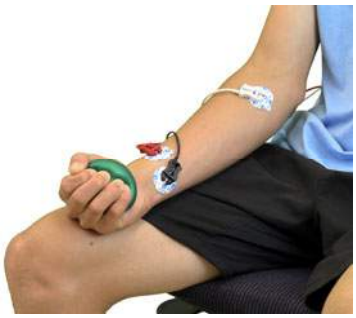

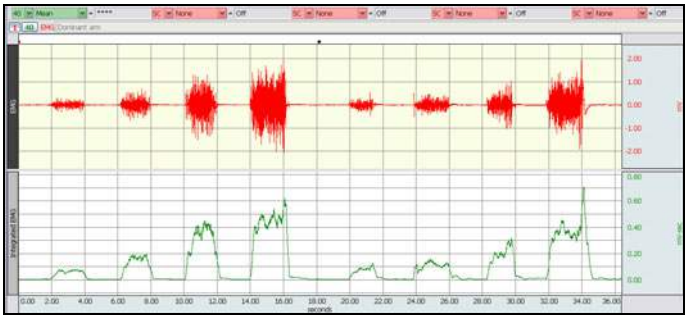

I. INTRODUCTION

In this lesson, you will investigate some properties of skeletal muscle. Physiological phenomena associated with other kinds of muscle, such as electrophysiology of the heart, will be studied in subsequent lessons.

The human body contains three kinds of muscle tissue and each performs specific tasks to maintain homeostasis: **Cardiac muscle**, **Smooth muscle**, and **Skeletal muscle**.

- **Cardiac muscle** is found only in the heart. When it contracts, blood circulates, delivering nutrients to cells and removing cell waste.
- **Smooth muscle** is located in the walls of hollow organs, such as the intestines, blood vessels or lungs. Contraction of smooth muscle changes the internal diameter of hollow organs, and is thereby used to regulate the passage of material through the digestive tract, control blood pressure and flow, or regulate airflow during the respiratory cycle.
- **Skeletal muscle** derives its name from the fact that it is usually attached to the skeleton. Contraction of skeletal muscle moves one part of the body with respect to another part, as in flexing the forearm. Contraction of several skeletal muscles in a coordinated manner moves the entire body in its environment, as in walking or swimming.

The primary function of muscle, regardless of the kind, is to *convert chemical energy to mechanical work*, and in so doing, the muscle shortens or contracts.

Human skeletal muscle consists of hundreds of individual cylindrically shaped cells (called **fibers**) bound together by connective tissue. In the body, skeletal muscles are stimulated to contract by somatic motor nerves that carry signals in the form of nerve impulses from the brain or spinal cord to the skeletal muscles (Fig. 1.1). **Axons** (or nerve fibers) are long cylindrical extensions of the neurons. Axons leave the spinal cord via spinal nerves and the brain via cranial nerves, and are distributed to appropriate skeletal muscles in the form of a peripheral nerve, which is a cable-like collection of individual nerve fibers. Upon reaching the muscle, each nerve fiber branches and innervates several individual muscle fibers.

Although a single motor neuron can innervate several muscle fibers, each muscle fiber is innervated by only one motor neuron. The combination of a single motor neuron and all of the muscle fibers it controls is called a **motor unit** (Fig. 1.1).

When a somatic motor neuron is activated, all of the muscle fibers it innervates respond to the neuron's impulses by generating their own electrical signals that lead to contraction of the activated muscle fibers.

Physiologically, the degree of skeletal muscle contraction is controlled by:

1. Activating a desired number of motor units within the muscle, and
2. Controlling the frequency of motor neuron impulses in each motor unit.

When an increase in the strength of a muscle's contraction is necessary to perform a task, the brain increases the number of simultaneously active motor units within the muscle. This process is known as **motor unit recruitment**.

Resting skeletal muscles *in vivo* exhibit a phenomenon known as **tonus,** a constant state of slight tension that serves to maintain the muscle in a state of readiness. Tonus is due to alternate periodic activation of a small number of motor units within the muscle by motor centers in the brain and spinal cord. Smooth controlled movements of the body (such as walking, swimming or jogging) are produced by graded contractions of skeletal muscle. **Grading** means changing the strength of muscle contraction or the extent of shortening in proportion to the load placed on the muscle.

Skeletal muscles are thus able to react to different loads accordingly. For example, the effort of muscles used in walking on level ground is less than the effort those same muscles expend in climbing stairs.

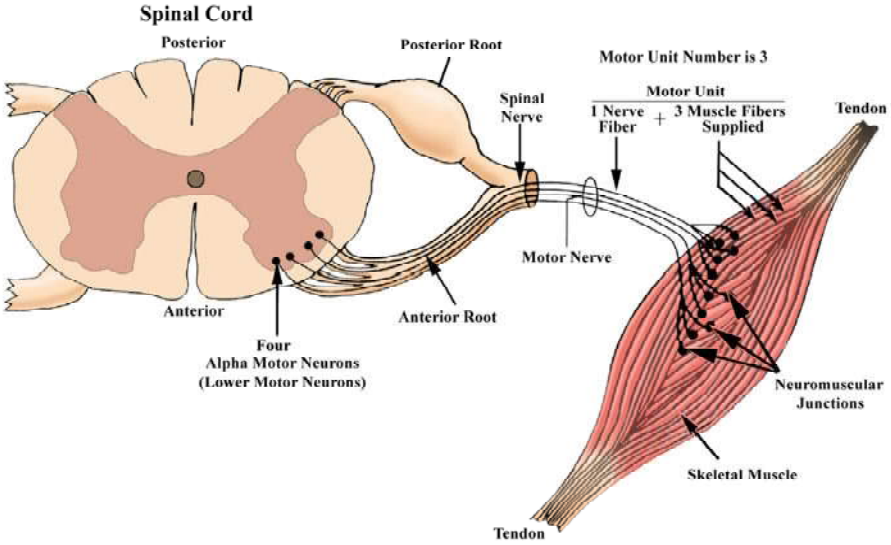

Fig. 1.1 Example of Motor Units

When a motor unit is activated, the component muscle fibers generate and conduct their own electrical impulses that ultimately result in contraction of the fibers. Although the electrical impulse generated and conducted by each fiber is very weak (less than 100 microvolts,) many fibers conducting simultaneously induce voltage differences in the overlying skin that are large enough to be detected by a pair of surface electrodes. The detection, amplification, and recording of changes in skin voltage produced by underlying skeletal muscle contraction is called **electromyography**. The recording thus obtained is called an **electromyogram (EMG).**

The **EMG signal** is the recorded consequence of two principal bioelectric activities: 1) propagation of motor nerve impulses and their transmission at the neuromuscular junctions of a motor unit, and 2) propagation of muscle impulses by the sarcolemma and the T-tubular systems resulting in excitation-contraction coupling. The magnitudes of the action potentials of active motor units are not all the same nor are they in phase with one another. Furthermore, the timing sequence of motor unit activation is variable. The net result of these and other factors is a complex EMG signal. Remember we are recording all of this activity as it is detected by surface electrodes, and propagation of muscle and nerve impulses involves both depolarization and repolarization phenomena. The "spikes" therefore, will have a negative and a positive component and the amplitudes will be influenced by the location of the recording electrodes with respect to the number of active underlying skeletal muscle and motor nerve fibers.

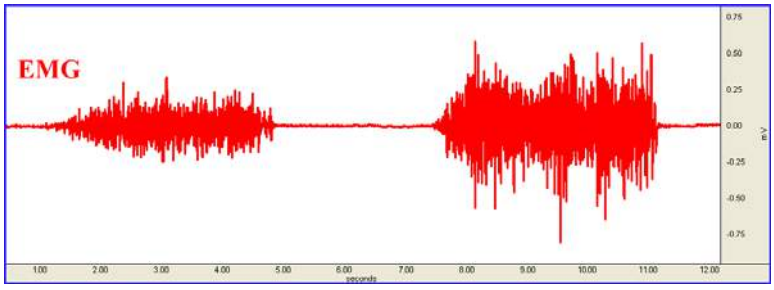

Fig. 1.2 EMG

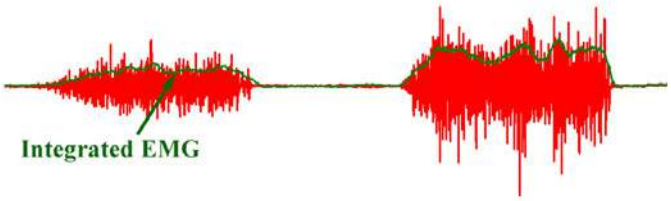

Fig. 1.3 Integrated EMG

Integrated EMG is an alternative view of the EMG signal that clearly shows the pattern of muscle activity. Integrated EMG "averages out" noise spikes in the raw EMG data to provide a more accurate indication of the EMG output level. Integrated EMG calculates a moving average (mean) of the EMG data by first rectifying each point in the sample range (inverting all negative values) and then computing the mean. In this lesson, each data point of Integrated EMG is calculated using 100 samples of data from the EMG source, so the first 100 sample points should be ignored since they reflect the number of zero values being averaged in with the first few samples of data.

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II. EXPERIMENTAL OBJECTIVES

1) To observe and record skeletal muscle tonus as reflected by a basal level of electrical activity associated with the muscle in a resting state.
2) To record maximum clench strength for right and left hands.
3) To observe, record, and correlate motor unit recruitment with increased power of skeletal muscle contraction.
4) To listen to EMG "sounds" and correlate sound intensity with motor unit recruitment.

III. MATERIALS

- BIOPAC Electrode Lead Set (SS2L)
- BIOPAC Disposable Electrodes (EL503,) 6 electrodes per Subject
- BIOPAC Electrode Gel (GEL1) and Abrasive Pad (ELPAD) *or* Skin cleanser or alcohol prep
- *Optional*: BIOPAC Headphones (OUT1/OUT1A for MP3X or 40HP for MP45)
- Biopac Student Lab System: BSL 4 software, MP36, MP35 or MP45 hardware
- Computer system (Windows or Mac)

IV. EXPERIMENTAL METHODS

A. SETUP

FAST TRACK Setup

1. Turn the computer **ON**.
   - If using an MP36/35 unit, turn it **OFF**.
   - If using an MP45, make sure USB cable is connected and "Ready" light is **ON**.
2. **Plug the equipment in** as follows:
   Electrode Lead Set (SS2L) — CH 1
   Headphones (OUT1 or OUT1A*) — back of unit
   **OUT1A is compatible with MP36 only.*
3. Turn **ON** the MP36/35 unit.

Setup continues…

Detailed Explanation of Setup Steps

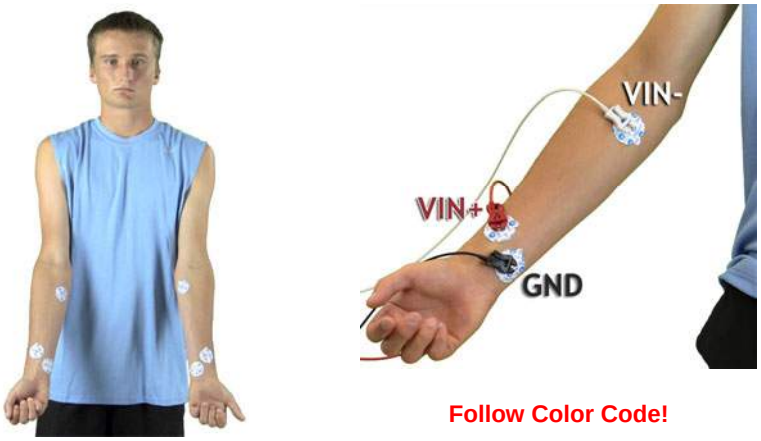
Fig. 1.4 MP3X (top) and MP45 (bottom) equipment connections

- Windows: If using MP45, the Sound Playback device must be set to MP45 via Start > Control Panel.

4. Clean and abrade skin.
5. Attach three electrodes to each forearm (Fig. 1.5).
6. Clip the Electrode Lead Set (SS2L) to **Subject's** dominant arm, following the color code (Fig. 1.5).

If the skin is oily, clean electrode sites with soap and water or alcohol before abrading.

If electrode is dry, apply a drop of gel.



Follow Color Code!

Fig. 1.5 Electrode placement and lead attachment

- If **Subject** is right-handed, the right forearm is generally dominant; if **Subject** is left-handed, the left forearm is generally dominant.
- For optimal electrode adhesion, place electrodes on the skin at least 5 minutes before the start of Calibration.
- The pinch connectors work like a small clothespin and will only latch onto the nipple of the electrode from one side of the connector.

7. **Subject** gets in a seated position, facing the monitor.

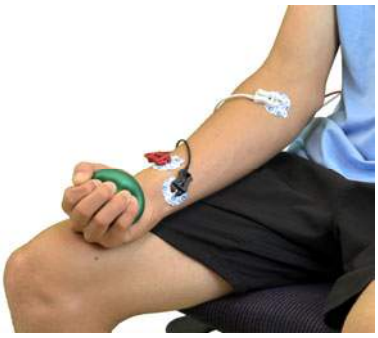


Fig. 1.6 Proper Seating Position

- The dominant arm should rest on thigh to relax the muscles in the shoulder and upper arm.
- Optional: Subject may hold a small object, such as a rubber ball, while performing this procedure

Fig. 1.7 Positioning

Setup continues…

8. **Start** the Biopac Student Lab Program.
9. Choose lesson "**L01 – Electromyography (EMG) I"** and click **OK**.
10. Type in a unique **filename** and click **OK**.

Start Biopac Student Lab by double-clicking the Desktop shortcut.

No two people can share the same filename, so use a unique identifier, such as **Subject's** nickname or student ID#.

A folder will be created using the filename. This same filename can be used in other lessons to place the **Subject's** data in a common folder.

To change the preference, see next step.

11. ***Optional***: Set Preferences.
    - Choose File > **Lesson Preferences**.
    - Select an option.
    - Select the desired setting and click **OK**.

This lesson has optional Preferences for data and display while recording. Per your Lab Instructor's guidelines, you may set:

Grids: Show or hide gridlines

Lesson Recordings: Specific recordings may be omitted based on instructor preferences.

END OF SETUP

B. CALIBRATION

Calibration establishes the hardware's internal parameters (such as gain, offset, and scaling) and is critical for optimal performance. **Pay close attention to Calibration.** *For a video example of proper Calibration procedure*, click the **Calibration** tab in the Lesson Set Up Journal.

FAST TRACK Calibration

1. Click **Calibrate**.
2. Two seconds after Calibration begins**, clench** fist as hard as possible for two to three seconds, then **release**.

Detailed Explanation of Calibration Steps

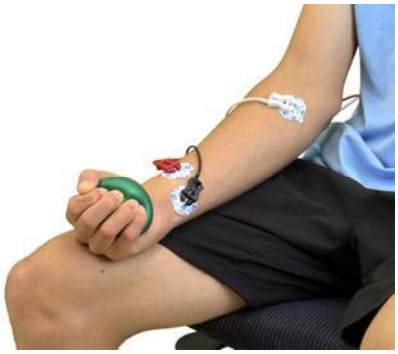


Fig. 1.8 Clench Fist for Calibration

The program needs a reading of the maximum clench to perform an auto-calibration.

3. **Wait** for Calibration to stop.

Calibration lasts eight seconds.

4. Verify recording resembles the example data
    - If similar, click **Continue** and proceed to Data Recording.
    - If necessary, click **Redo Calibration**.

Data should show a zero baseline and a clear burst when **Subject** clenched.

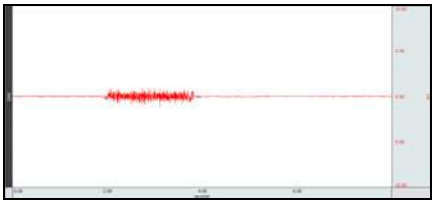


Fig. 1.9 Example Calibration data

<u>If recording does not resemble the Example Data</u>

- If the data is noisy or flatline, check all connections to the MP unit.
- Verify electrodes are making good contact and that leads are clipped to the correct color position with minimal cable strain.

END OF CALIBRATION

C. DATA RECORDING

FAST TRACK Recording

1. Prepare for the **Dominant arm** recording.
   - Electrodes must be attached to **Subject's** dominant arm.
   - **Subject's** hand must be relaxed.
   - **Review** recording steps.

Detailed Explanation of Recording Steps

Two data recordings* will be acquired in this lesson:

a. Recording 1 records **Dominant arm**.

b. Recording 2 records **Nondominant arm.**

To work efficiently, read this entire section before recording, or review onscreen **Tasks** to preview recording steps in advance.

***IMPORTANT**

This procedure assumes that all lesson recordings are enabled in Lesson Preferences, which may not be the case for your lab. Always match the recording title to the recording reference in the journal and disregard any references to excluded recordings.

Dominant arm

2. Click **Record**.
3. Perform a series of four Clench -Release-Wait cycles.
   - Hold clench for two seconds, release for two seconds.
   - Begin with a weak clench, then increase grip so the fourth clench is at maximum.
4. Click **Suspend**.
5. Verify recording resembles the example data.
   - If similar, click **Continue** and proceed to next recording.
   - If necessary, click **Redo**.
   - If all required recordings have been completed, click **Stop** and proceed to Step 11.

- Completely relax the grip between clenches.
- Allow at least two seconds between clenches.
- Two channels will be presented during the recording, CH 1 = Raw EMG, and CH 2 = Integrated EMG (a moving average of the raw signal).

Data should show four EMG "bursts" of increasing amplitude.

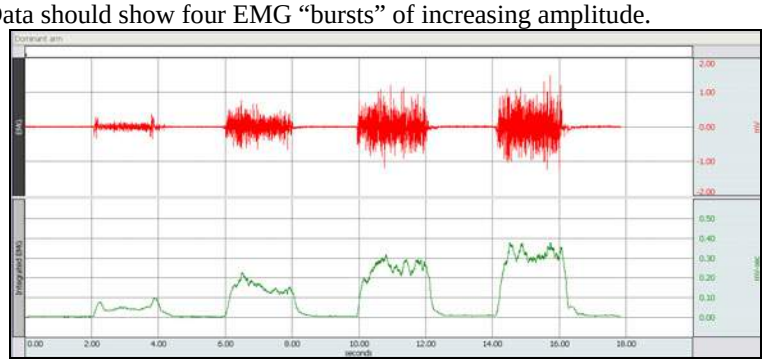


Fig. 1.10 Example data – Dominant arm

If recording does not resemble the Example Data

- If there is not enough variation between the clenches, repeat recording and start with a weaker clench.
- If the data is noisy or flatline, check all connections to the MP unit.
- Verify electrodes are making good contact and that leads are clipped to the correct color position with minimal cable strain.

Click **Redo** and repeat Steps 2 – 5 if necessary. Note that once **Redo** is clicked, the most recent recording will be erased.

Nondominant arm

6. Prepare for the **Nondominant arm** recording.
   - Clip electrode leads to **Subject's** nondominant arm.
   - **Subject's** hand must be relaxed.
   - **Review** recording steps.
7. Click **Record**.

Recording continues…

Disconnect the lead set (SS2L) from the electrodes on the "dominant" forearm and connect to electrodes on "nondominant" forearm. Refer to Fig. 1.5 for proper electrode lead attachment.

8. Perform a series of four Clench-Release-Wait cycles.
   - Hold clench for two seconds, release for two seconds.
   - Begin with a weak clench, and then increase grip so the fourth clench is at maximum.
9. Click **Suspend**.
10. Verify recording resembles the example data.
    - If similar, click **Continue** to proceed to the optional recording section, or click **Stop** to end the recording.
    - If necessary, click **Redo**.

Recording continues…

Perform four cycles of Clench-Release-Wait, holding for two seconds and waiting for two seconds after releasing before beginning the next cycle. Try to increase the strength in equal increments so that the fourth clench is at maximum force.

- Completely relax the grip between clenches.
- Allow at least two seconds between clenches.

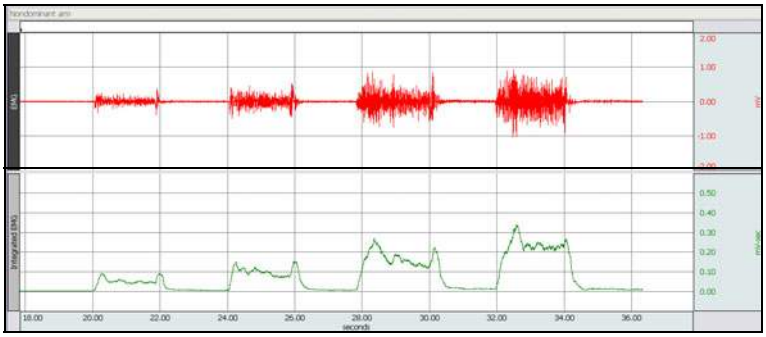


Fig. 1.11 Example data– Nondominant arm

The data description is the same as outlined in Step 4.

Click **Redo** and repeat Steps 7 – 10 if necessary. Note that once **Redo** is clicked, the most recent recording will be erased.

OPTIONAL ACTIVE LEARNING PORTION

With this lesson you may record additional data by clicking **Continue** following the last recording. Design an experiment to test or verify a scientific principle(s) related to topics covered in this lesson. Although you are limited to this lesson's channel assignments, the electrodes may be moved to different locations on the **Subject**.

Design Your Experiment

Use a separate sheet to detail your experiment design, and be sure to address these main points:

A. ***Hypothesis***

Describe the scientific principle to be tested or verified.

B. ***Materials***

List the materials you will use to complete your investigation.

C. ***Method***

Describe the experimental procedure—be sure to number each step to make it easy to follow during recording.

Run Your Experiment

D. ***Set Up***

Set up the equipment and prepare the subject for your experiment.

E. ***Record***

Use the **Continue**, **Record**, and **Suspend** buttons to record as much data as necessary for your experiment.

Click **Stop** when you have completed all of the recordings required for your experiment.

Analyze Your Experiment

F. Set measurements relevant to your experiment and record the results in a Data Report.

- To listen to the EMG signal, proceed to Step 11.
- To skip listening to the EMG signal and end the recording, proceed to Step 14.

Listening to the EMG is optional.

Listening to the EMG is optional and can be a valuable tool in detecting muscle abnormalities, and is performed here for general interest. Data on screen is not saved.

11. Click **Listen** to record EMG data and hear it through the headphones.

The EMG signal will be audible through the headphones as it is being displayed on the screen. The screen will display two channels:

CH 1 EMG and CH 40 Integrated EMG

12. Increase grip force and notice how the volume increases.

The signal will run until **Stop** is clicked. If others in lab group would like to listen to the EMG signal, pass the headphones around before clicking **Stop** or click **Redo** and then **Stop** when done.

13. Click **Stop** when finished.
    - Click **Redo** to hear EMG again.

This will end listening to the EMG.

14. Click **Done** to end the lesson.
15. Choose an option and click **OK**.

If choosing the **Record from another Subject** option:

- Repeat Setup Steps 4 – 7 and then proceed to Calibration.

16. Remove the electrodes.

Remove the electrode cable pinch connectors, and peel off all electrodes. Discard the electrodes (BIOPAC electrodes are not reusable). Wash the electrode gel residue from the skin, using soap and water. The electrodes may leave a slight ring on the skin for a few hours, which is quite normal.

END OF RECORDING

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V. DATA ANALYSIS

FAST TRACK Data Analysis

1. Enter the **Review Saved Data** mode.
   - Note Channel Number (CH) designations:

Channel	*Displays*
CH 1	**EMG**
CH 40	**Integrated EMG**

   - Note measurement box settings:

Channel	*Measurement*
CH 40	**Mean**

2. Set up your display window for optimal viewing of "**Dominant arm**" recording.

Data Analysis continues…

Detailed Explanation of Data Analysis Steps

If entering **Review Saved Data** mode from the Startup dialog or Lessons menu, make sure to choose the correct file.

The data window should resemble Fig. 1.12.

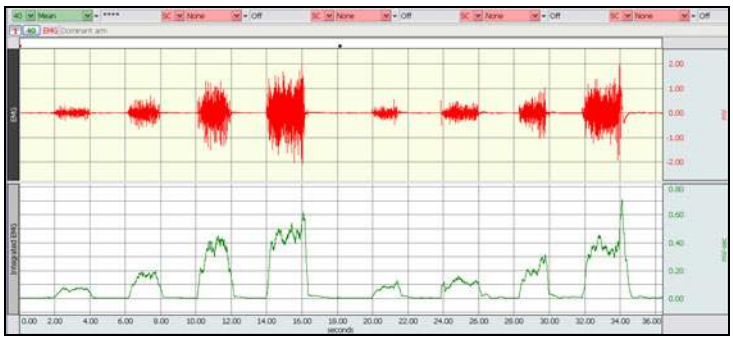

Fig. 1.12 Example data

The measurement boxes are above the marker region in the data window. Each measurement has three sections: channel number, measurement type, and result. The first two sections are pull-down menus that are activated when you click them.

Brief definition of measurements:

Mean: Displays the average value in the selected area.

The "selected area" is the area selected by the **I-beam** tool (including endpoints).

Record measurement data individually by hand or choose **Edit > Journal > Paste measurements** to paste the data to your journal for future reference.

Note:

The append event markers mark the beginning of each recording. Click on (activate) the event marker to display its label.

Useful tools for changing view:

Display menu: Autoscale Horizontal, Autoscale Waveforms, Zoom Back, Zoom Forward

Scroll Bars: Time (Horizontal); Amplitude (Vertical)

Cursor Tools: Zoom Tool

Buttons: Overlap, Split, Show Grid, Hide Grid, -, +

Hide/Show Channel: "Alt + click" (Windows) or "Option + click" (Mac) the channel number box to toggle channel display.

3. Use the I-Beam cursor to select an area on the plateau of the first EMG clench data (Fig. 1.13).

   A

4. Repeat Step 3 on each successive EMG cluster.

   A

Fig. 1.13 below shows an EMG data selection in the first recording.

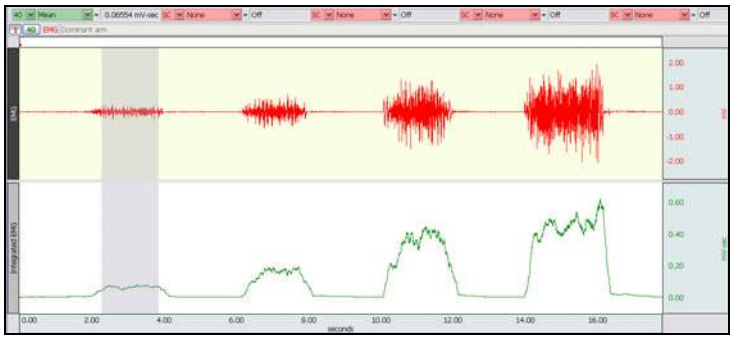

Fig. 1.13 EMG data selection

5. Scroll to the second recording.
6. Repeat Steps 3 and 4 for "**Nondominant arm**" data.

The second recording begins at the append event marker labeled "**Nondominant arm**" and includes four clenches from **Subject's** nondominant arm.

7. Scroll to the first recording.
8. Use the I-Beam cursor to select the area between the first and second clenches (Fig. 1.14).

   C

9. Repeat Step 7 between each successive clench.
10. Scroll to the second recording.
11. Repeat Steps 7 – 8 for "**Nondominant arm**" data.

    C

Tonus is the resting state, and is represented by the area between clenches (clusters). Fig. 1.14 below shows the selected area between clenches.

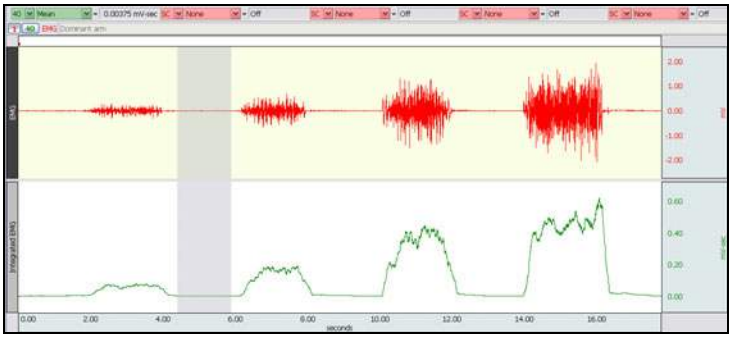

Fig. 1.14 Selection between clenches to measure tonus

12. Answer the questions at the end of the Data Report.
13. **Save** or **Print** the Data Report.
14. **Quit** the program.

An electronically editable **Data Report** can be found in the journal (following the lesson summary,) or immediately following this Data Analysis section. Your instructor will recommend the preferred format for your lab.

END OF DATA ANALYSIS

END OF LESSON 1

Complete the Lesson 1 Data Report that follows.

ELECTROMYOGRAPHY I

- *Standard and Integrated EMG*

DATA REPORT

Student's Name: _____

Lab Section: _____

Date: _____

I. Data and Calculations

Subject Profile

Name:_____ Height:_____ Gender: Male / Female

Age:_____ Weight:_____ Dominant arm: Right / Left

A. EMG Measurements

Table 1.1

Clench #	*Dominant arm* 40 Mean	*Nondominant arm* 40 Mean
1		
2		
3		
4		

B. **Use the mean measurement from the table above to compute the percentage increase** in EMG activity recorded between the weakest clench and the strongest clench of Dominant arm.

Calculation:_____ Answer: _____%

C. Tonus Measurements

Table 1.2

Between Clenches #	*Dominant arm* 40 Mean	*Nondominant arm* 40 Mean
1-2		
2-3		
3-4		

II. Questions

D. Compare the mean measurement for the right and left maximum clench EMG data.

Are they the same or different? _____ Same _____ Different

Which one suggests the greater clench strength? _____ Right _____ Left _____ Neither

Explain.

_____

_____

_____

_____

_____

E. What factors in addition to sex contribute to observed differences in clench strength?

F. Does there appear to be any difference in tonus between the two forearm clench muscles? _____ Yes _____ No

Would you expect to see a difference? Does Subject's gender influence your expectations? Explain.

G. Explain the source of signals detected by the EMG electrodes.

H. What does the term "motor unit recruitment" mean?

I. Define skeletal muscle tonus.

J. Define electromyography.

III. OPTIONAL Active Learning Portion

A. ***Hypothesis***

B. ***Materials***

C. ***Method***

D. ***Set Up***

E. ***Experimental Results***

End of Lesson 1 Data Report

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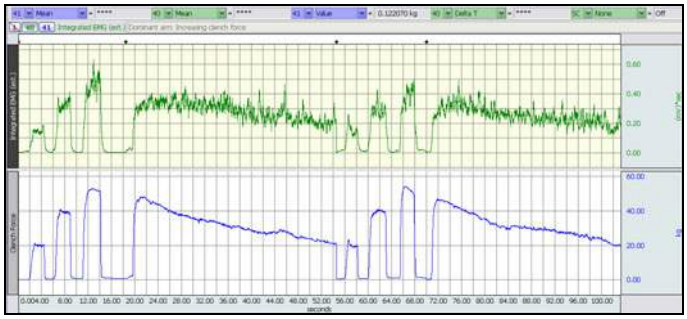

I. INTRODUCTION

Fig. 2.1

Mechanical **work**, in the physical sense, refers to the application of a force resulting in the movement of an object. Skeletal muscle performs mechanical work when the muscle contracts and an object is moved, as in lifting a weight. To lift a weight, your muscles must exert a force great enough to overcome the weight. If you exert less force, then the weight does not move (Fig. 2.1).

Physiologically, skeletal muscle is stimulated to contract when the brain or spinal cord activates **motor units** of the muscle.

Motor units are defined as a motoneuron and all of the muscle fibers that the motoneuron innervates. An action potential (AP) in a human motoneuron always causes an action potential in all of the muscle fibers of the motor unit. As a matter of fact, humans generally do not send just one AP at a time down a motoneuron. Instead, a train of APs is sent — enough to induce tetany (the sustained fusion of individual muscle twitches) in the muscle fibers of the motor unit.
(A discussion of motor units and their control was presented in Lesson 1.)

Most human skeletal muscles are composed of hundreds of motor units (Fig. 2.2). When a skeletal muscle is called on to perform mechanical work, the number of motor units in the muscle activated by the brain is proportional to the amount of work to be done by the muscle; the greater the amount of work to be done, the greater the number of motor units activated. Thus, more motor units are simultaneously active when a skeletal muscle lifts 20 kilograms than when the same muscle lifts 5 kilograms.

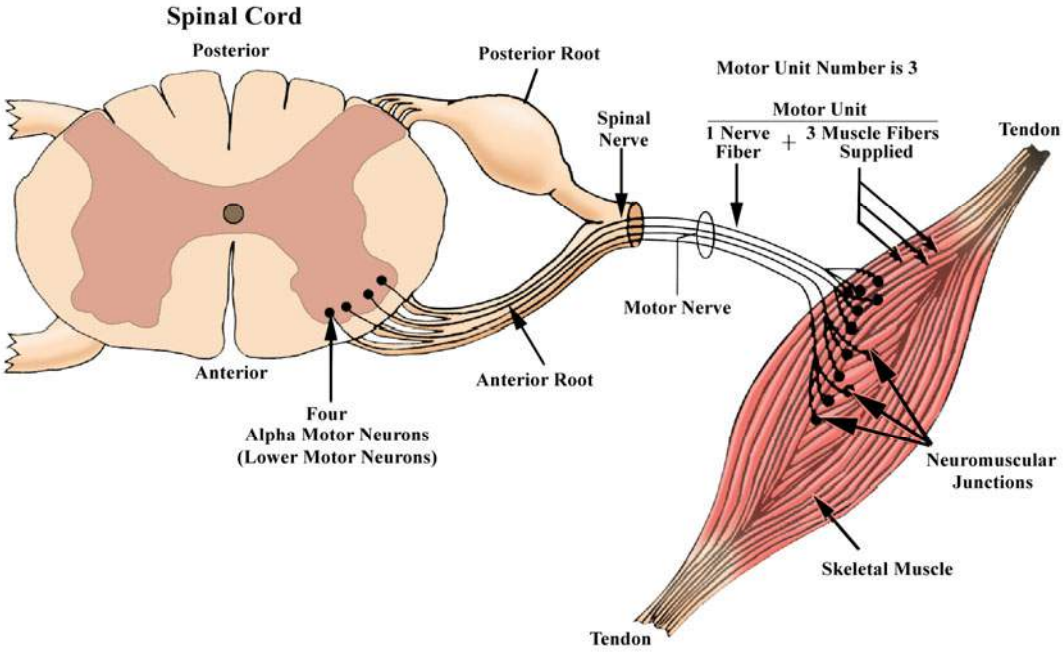

Fig. 2.2 Example of Motor Units

The brain determines the number of active motor units required for a muscle to perform a given task by utilizing sensory information from stretch receptors in the muscle and associated tendons and joint capsules. For example, when lifting a bucket of water from the ground, the brain first activates several motor units in the requisite skeletal muscles. If sensory information returning from the muscles indicates the muscles are contracting but not developing adequate power to lift the bucket, the brain activates additional motor units until the sensory information indicates the bucket is being lifted. The sequential activation of motor units to perform a designated task is called **motor unit recruitment**.

Once you have lifted a light object, the brain recruits approximately the same *number* of motor units to keep the object up, but cycles between *different* motor units. The muscle fibers consume stored energy available in the muscle, and generate a force by contracting. As the muscle fibers deplete this fuel source, more energy must be created in order to continue contracting. By recruiting different motor units, motor units can relax and replenish their fuel sources.

Skeletal muscles performing acute maximum work or chronic submaximum work of a repetitive nature will eventually **fatigue**. Fatigue is defined as a decrease in the muscle's ability to generate force. Fatigue is caused by a reversible depletion of the muscle's fuel supply. If the muscle uses its energy sources faster than they can be generated by cellular metabolism, fatigue occurs. During contraction, skeletal muscle cells convert chemical energy into thermal and mechanical energy, and, in the process, produce chemical waste products.

Normally the waste products are removed from the muscle by the circulatory system as the blood brings nutrients to the muscle for energy transformation. If certain waste products (metabolites) are not removed at an adequate rate, they will accumulate and chemically interfere with the contractile process, thereby hastening the onset of fatigue. Some accumulated waste products also stimulate pain receptors in surrounding connective tissue and induce cramping of skeletal muscle, a general sign of inadequate blood flow to the muscle.

In this lesson, you will examine motor unit recruitment and skeletal muscle fatigue by combining **electromyography** with **dynamometry**.

When a motor unit is activated, the component muscle fibers generate and conduct their own electrical impulses, which cause the fibers to contract. Although the electrical impulse generated and conducted by each fiber is very weak (less than 100 μvolts,) many fibers conducting simultaneously induce voltage differences in the overlying skin which are large enough to be detected by a pair of surface electrodes.

The detection, amplification, and recording of changes in skin voltage produced by underlying skeletal muscle contraction is called electromyography, and the recording thus obtained is called an **electromyogram (EMG**).

The EMG signal is the recorded consequence of two principal bioelectric activities: 1) propagation of motor nerve impulses and their transmission at the neuromuscular junctions of a motor unit, and 2) propagation of muscle impulses by the sarcolemma and the T-tubular systems resulting in excitation-contraction coupling. The magnitudes of the action potentials of active motor units are not all the same nor are they in phase with one another. Furthermore, the timing sequence of motor unit activation is variable. The net result of these and other factors is a **complex EMG signal**. Remember we are recording all of this activity as it is detected by surface electrodes, and propagation of muscle and nerve impulses involves both depolarization and repolarization phenomena. The "spikes" therefore, will have a negative and a positive component and the amplitudes will be influenced by the location of the recording electrodes with respect to the number of active underlying skeletal muscle and motor nerve fibers.

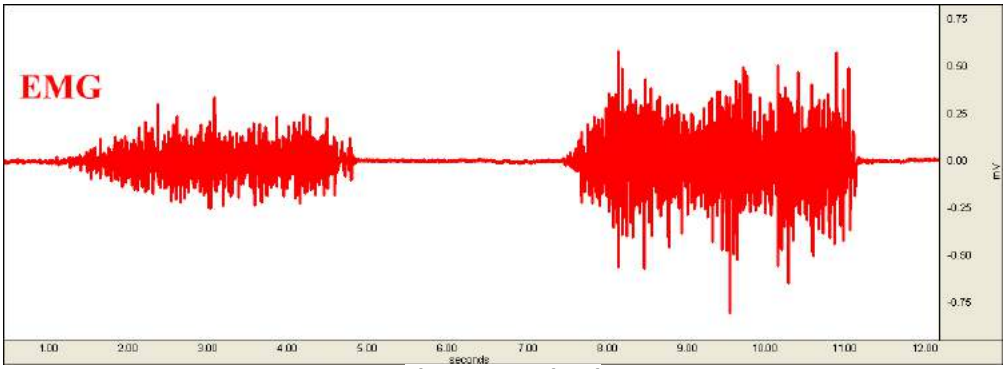

Fig. 2.3 EMG signal

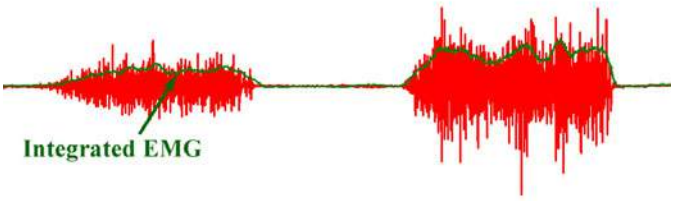

Fig. 2.4

Integrated EMG is an alternative view of the EMG signal that clearly shows the pattern of muscle activity. Integrated EMG "averages out" noise spikes in the raw EMG data to provide a more accurate indication of the EMG output level. Integrated EMG calculates a moving average (mean) of the EMG data by first rectifying each point in the sample range (inverting all negative values) and then computing the mean. In this lesson, each data point of Integrated EMG is calculated using 100 samples of data from the EMG source, so the first 100 sample points should be ignored since they reflect the number of zero values being averaged in with the first few samples of data.

Power is defined as the amount of work done per unit of time. **Dynamometry** means the measurement of power (*dyno* = power, *meter* = measure,) and the graphic record derived from the use of a dynamometer is called a **dynagram**.

In this lesson, the power of contraction of clench muscles will be determined by a **hand dynamometer** equipped with an electronic transducer. Model SS25LA/L measures force in "kg" units; model SS56L measures proportionality of bulb pressure to clench force in "kgf/m^2" units (a pressure unit). Both measures are accurate for the relative measures recorded in this lesson.

The BIOPAC system will simultaneously record three bands of information:

1) The force you exert on the transducer,
2) The electrical signal produced by the muscle during contraction, and
3) The integrated waveform, which is an indication of the activity levels of the muscle.

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II. EXPERIMENTAL OBJECTIVES

1) To determine the maximum clench strength for right and left hands and compare differences between male and female.
2) To observe, record, and correlate motor unit recruitment with increased power of skeletal muscle contraction.
3) To record the force produced by clench muscles, EMG, and integrated EMG when inducing fatigue.

III. MATERIALS

- BIOPAC Hand Dynamometer (SS25LA, SS25LB* or SS25L)
  **SS25LB is compatible with software versions BSL 4.1 and higher only.*
  - *Optional* BIOPAC Hand Clench Force Pump Bulb (SS56L) may be used—pressure in bulb is proportional to clench force. For SS56L units, set the Clench Force Transducer Preference BEFORE starting calibration.
- BIOPAC Electrode Lead Set (SS2L)
- BIOPAC Disposable Electrodes (EL503,) 6 electrodes per Subject
- BIOPAC Electrode Gel (GEL1) and Abrasive Pad (ELPAD) *or* Skin cleanser or alcohol prep
- *Optional*: BIOPAC Headphones (OUT1/OUT1A for MP3X or 40HP for MP45)
- Biopac Student Lab System: BSL 4 software, MP36, MP35 or MP45 hardware
- Computer system (Windows or Mac)

IV. EXPERIMENTAL METHODS

A. SETUP

FAST TRACK Setup

1. Turn your computer **ON**.
   - If using an MP36/35 unit, turn it OFF.
   - If using an MP45, make sure USB cable is connected and "Ready" light is **ON**.
2. **Plug the equipment in** as follows:
   Electrode Lead Set (SS2L) — CH 1
   Hand Dynamometer (SS25LA/LB or SS25L)
   or Clench Force Pump Bulb (SS56L) — CH 2
   Headphones (OUT1 or OUT1A*) — back of unit
   **OUT1A is compatible with MP36 only.*
3. Turn **ON** the MP36/35 unit.

Setup continues...

Detailed Explanation of Setup Steps

Fig. 2.5 MP3X (top) and MP45 (bottom) equipment connections

4. Clean and abrade skin.
5. **Attach three electrodes** to each forearm (Fig. 2.6).
6. **Clip** the Electrode Lead Set (SS2L) to the **Subject's** dominant forearm, following the color code (Fig. 2.6).
7. Hold hand dynamometer with dominant hand.

If the skin is oily, clean electrode sites with soap and water or alcohol before abrading.

If the electrode is dry, apply a drop of gel.
For optimal electrode contact, place electrodes on the skin at least five minutes before the start of Calibration.

Clip the Lead Set (SS2L) to the **Subject's** dominant forearm (Fig. 2.6) for recordings 1 and 2.

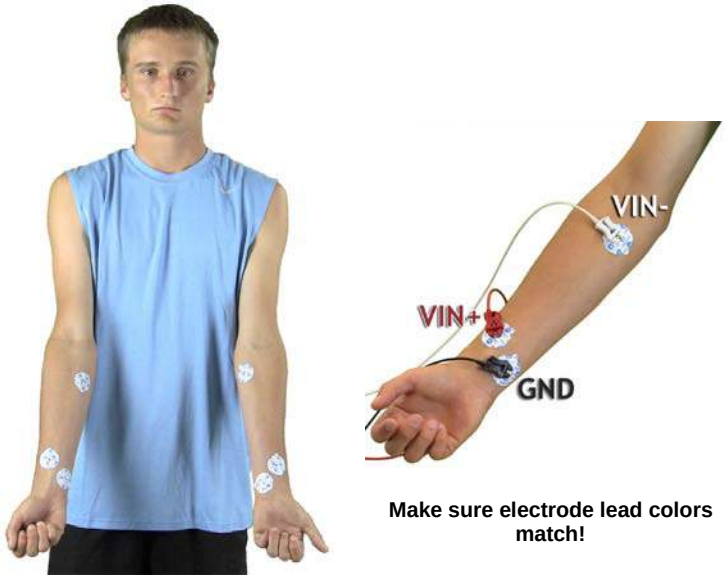

Fig. 2.6 Electrode Placement & Lead Attachment

- If **Subject** is right-handed, the right forearm is generally dominant; if the subject is left-handed, the left forearm is generally dominant.
- The pinch connectors work like a small clothespin and will only latch onto the nipple of the electrode from one side of the connector.

- **Subject** gets in a seated position, facing the monitor.

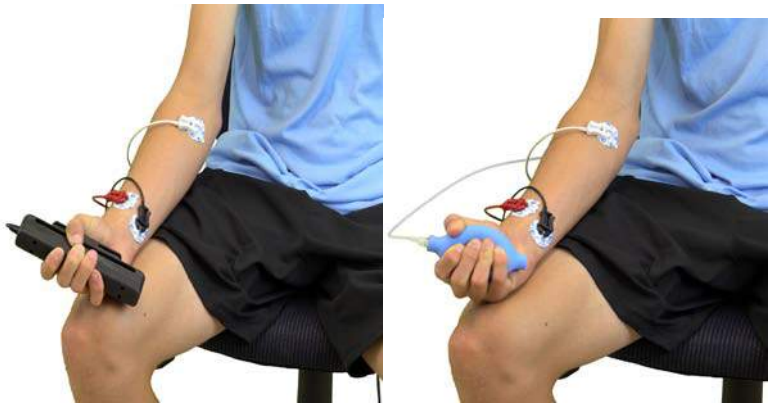

Fig. 2.7 Proper Seating Position

- Arm holding the hand dynamometer should rest on thigh to relax the muscles in the shoulder and upper arm.

Setup continues...

Fig. 2.8 Positioning

8. **Start** the BIOPAC Student Lab Program.

Start Biopac Student Lab by double-clicking the Desktop shortcut.

9. Choose lesson "**L02 – Electromyography (EMG) II**" and click **OK**.

No two people can share the same filename, so use a unique identifier, such as the subject's nickname or student ID#.

10. Type in a unique **filename** and click **OK**.

A folder will be created using the filename. This same filename can be used in other lessons to place the **Subject's** data in a common folder.

11. Make sure the picture in the journal (Hardware tab) matches your setup. If it does not, you may need to change preference settings.

The SS25LA picture represents both the SS25LA/LB and SS25L.

To change the preference, see next step.

This ends the Set Up procedure.

12. ***Optional***: Set Preferences.
    - Choose File > **Lesson Preferences**.
    - Select an option.
    - Select the desired setting and click **OK**.

This lesson has optional Preferences for data and display while recording. Per your Lab Instructor's guidelines, you may set:

Clench Force Transducer: Choose model SS25LA/LB/L or SS56L (Bulb)

Lesson Recordings: Specific recordings may be omitted based on instructor preferences.

END OF SETUP

B. CALIBRATION

The Calibration procedure establishes the hardware's internal parameters (such as gain, offset, and scaling) and is critical for optimal performance. **Pay close attention to Calibration.** For a video example of proper Calibration procedure, click the Calibration tab in the Lesson > Set Up Journal.

FAST TRACK Calibration

1. Click **Calibrate**.
2. Set the hand dynamometer down and click **OK**.
3. Hold the BIOPAC hand dynamometer with dominant hand when prompted and click **OK**.

   SS25LA/B: Place the short grip bar against the palm, toward the thumb, and wrap your fingers to center the force.

   SS25L: Grasp as close to the dynagrip crossbar as possible *without actually touching the crossbar*.

   SS56L: WRAP your hand around the bulb with relaxed fingers—do NOT curl fingers into bulb.

   IMPORTANT
   Hold the dynamometer in the same position for all measurements from each arm. Note your hand position for the first recording and try to repeat it for the subsequent recordings.

4. When Calibration recording begins, **clench** the hand dynamometer as hard as possible for 2 sec. and then **release**.
5. **Wait** for Calibration to stop.
6. Verify recording resembles the example data.
   - If similar, click **Continue** and proceed to Data Recording.
   - If necessary, click **Redo Calibration**.

END OF CALIBRATION

Detailed Explanation of Calibration Steps

You will be prompted to remove any grip force from the hand dynamometer.

This will remove any clench force which is important for establishing a zero force baseline.

Clench with the hand of your dominant forearm.

SS25LA/B grip position

SS25L grip position

SS56L grip position

Fig. 2.9

The program needs a reading of your maximum clench to establish proper force increments (grid settings) used during the recordings.

Calibration lasts eight seconds.

Both channels should begin with a zero baseline and then there should be a clear EMG "burst" and simultaneous increase in Clench Force when the Subject clenched.

- If using SS25L/LA/B, units are kg; If using SS56L, units are kgf/m^2.

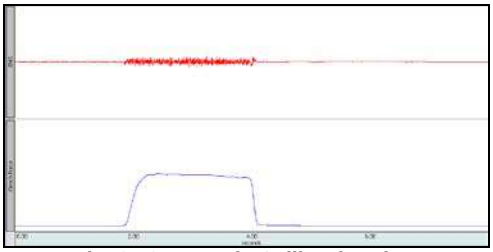

Fig. 2.10 Example Calibration data

If recording does not resemble the Example Data

- If the data is noisy or flatline, check all connections to the MP unit.
- If the hand dynamometer signal is not zero when relaxed, make sure all grip force is removed until prompted.
- Verify electrodes are making good contact and that leads are clipped to the correct color position with minimal cable strain.

C. DATA RECORDING

FAST TRACK Recording

1. Prepare for the **Dominant arm** recording.
   - Electrodes must be attached to **Subject's** dominant arm.
   - **Subject's** hand must be relaxed.
   - Grip the hand dynamometer with dominant hand.
   - **Review** recording steps.

Dominant arm: Increasing clench force

- **Calibrated grip force**

2. Click **Record**.
3. Perform a series of Clench-Release-Wait cycles until maximum grip force is reached.
   - Hold clench for two seconds, release for two seconds.
   - Use sufficient grip force on each cycle to increase the force by one grid line per clench.

Recording continues…

Detailed Explanation of Recording Steps

Four data recordings* will be acquired, two on each arm:

a. Recordings 1 and 3 record Motor unit recruitment.

b. Recordings 2 and 4 record Fatigue

In order to work efficiently, read this entire section, or review onscreen **Tasks** to preview recording steps in advance.

***IMPORTANT**

This procedure assumes that all lesson recordings are enabled in Lesson Preferences, which may not be the case for your lab. Always match the recording title to the recording reference in the journal and disregard any references to excluded recordings.

When **Continue** is clicked following Calibration, the display will change to show only the Clench Force channel, with grids displayed.

Based on maximum grip force during calibration, the software sets the grid as follows:

SS25L/LA/LB Force Calibration (kg)	Assigned Increment (kg)
0 – 25	5
25 – 50	10
50 – 75	15
>75	20

SS56L Max Clench (kgf/m^2)	Assigned Increment (kgf/m^2)
0 – 5,000	1,000
5,000 – 7,500	1,500
7,500 – 10,000	2,000
10,000 – 12.500	2,500
>12,500	3,000

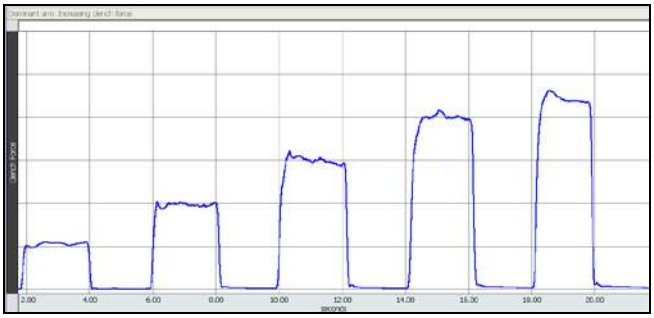

Fig. 2.11 Example Increasing Clench Force data

- Completely relax grip force between clenches.
- It is important to reach the first gridline on the first clench. Increase grip on subsequent clenches to advance the force signal one gridline per clench until maximum grip force is reached.
- A total of five clenches are used in the Example Data, but certain **Subjects** may require a lesser or greater number of clenches to attain maximum grip force.

4. After maximum grip force is reached, click **Suspend**.
5. Verify recording resembles the example data above.
   - If similar, click **Continue** and proceed to Step 6.
   - If necessary, click **Redo**.
   - If all required recordings have been completed, click **Stop**.

- The data must show multiple peaks of increasing clench force.
- The data shown above (Fig. 2.11) is from a **Subject** who was able to maintain an even force throughout the clench. Your data may be correct even if your peaks are not "flat."

If recording does not resemble the Example Data

- If the data is noisy or flatline, check all connections to the MP unit.

Click **Redo** and repeat Steps 2 – 5 if necessary. Note that once **Redo** is clicked, the most recent recording will be erased.

Dominant arm: Continued clench at maximum force

- **Review** recording steps.

6. Click **Record**.
7. Clench the hand dynamometer as hard as possible and try to maintain maximum force.
8. Continue clenching until force has decreased by 50%.

Note the maximum clench force so you can determine when the force has decreased by 50%. (The maximum force may scroll out of view.) Try to maintain the maximum clench force. (The forearm will fatigue and the force will decrease.)

The time to fatigue to 50% of maximal clench force will vary greatly among individuals.

9. Click **Suspend**.
10. Verify recording resembles the example data.
    - If similar to Fig. 2.12, click **Continue** and proceed to the next recording.
    - If necessary, click **Redo**.
    - If all required recordings have been completed, click **Stop**.

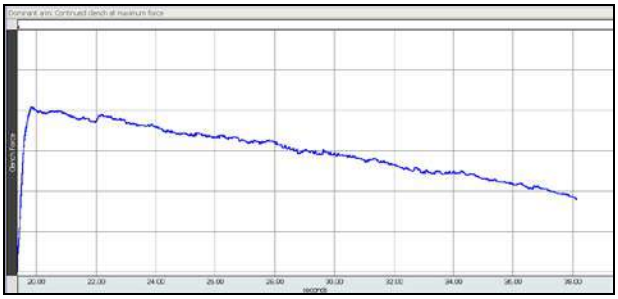

Fig. 2.12 Example Fatigue data

Note that the peak found immediately following the start of the recording represents the maximal clench force. This example shows the point of fatigue to 50% maximal clench force captured on the same screen, but maximum force may scroll out of view. Use the horizontal (time) scroll bar to see the beginning of the recording.

If recording does not resemble the Example Data

- If the data is noisy of flatline, check all connections to the MP unit..

Click **Redo** and have the **Subject** rest arm for a few minutes. When ready, repeat Steps 6 – 10. Note that once **Redo** is clicked, the most recent recording will be erased.

Recording continues…

Nondominant arm: Increasing clench force

11. Prepare for the **Nondominant arm** recording.
    - Clip electrode leads to **Subject's** nondominant arm.
    - **Subject's** hand must be relaxed.
    - Grip hand dynamometer with nondominant hand.
    - **Review** recording steps.

These recordings apply to the **nondominant forearm**, following the same procedure used for the dominant forearm.

Disconnect the lead set (SS2L) from the electrodes on the "dominant" forearm and connect to electrodes on "nondominant" forearm per Fig. 2.13.

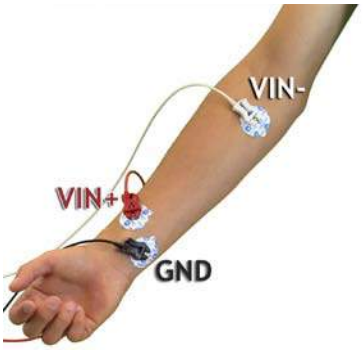

Fig. 2.13 Electrode lead attachment

Follow Color Code!

12. Click **Record**.
13. Perform a series of Clench-Release-Wait cycles.

Repeat a cycle of Clench-Release-Wait, holding for two seconds and waiting for two seconds after releasing before beginning the next cycle. Begin with your Assigned Increment of force (first grid) and increase by the Assigned Increment for each cycle until maximum clench force is obtained.

14. After maximum grip force is reached, click **Suspend**.
15. Verify recording resembles the example data.
    - If similar, click **Continue** and proceed to the next recording.
    - If necessary, click **Redo**.
    - If all required recordings have been completed, click **Stop**.

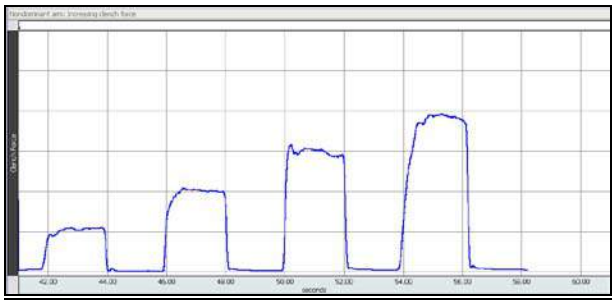

Fig. 2.14 Example Increasing Clench Force data

If recording does not resemble the Example Data

- If the data is noisy or flatline, check all connections to the MP unit.

Click **Redo** and repeat Steps 12 – 15 if necessary. Note that once **Redo** is clicked, the most recent recording will be erased.

Nondominant arm: Continued clench at maximum force

- **Review** recording steps.

16. Click **Record**.
17. Clench the hand dynamometer as hard as possible and try to maintain maximum force.

Note the maximum clench force so you can determine when the force has decreased by 50%. (The maximum force may scroll out of view.) Try to maintain the maximum clench force. (The forearm will fatigue and the force will decrease.)

18. Continue clenching until force has decreased by more than 50%.

The time to fatigue to 50% of maximal clench force will vary greatly among individuals.

19. Click **Suspend**.

Recording continues…

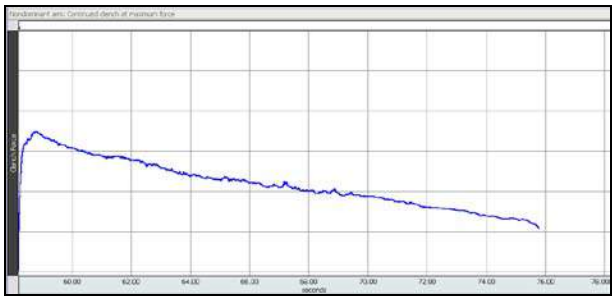

Fig. 2.15 Example Fatigue data

20. Verify recording resembles the example data.
    - If similar to Fig. 2.15, click **Continue** to proceed to the optional recording section, or click **Stop** to end the recording.
    - If necessary, click **Redo**.

If recording does not resemble the Example Data

- If the data is noisy or flatline, check all connections to the MP unit.

Click **Redo** and have the **Subject** rest arm for a few minutes. When ready, repeat Steps 16 – 20. Note that once **Redo** is clicked, the most recent recording will be erased.

OPTIONAL ACTIVE LEARNING PORTION

With this lesson you may record additional data by clicking **Continue** following the last recording. Design an experiment to test or verify a scientific principle(s) related to topics covered in this lesson. Although you are limited to this lesson's channel assignments, the electrodes may be moved to different locations on the **Subject**.

Design Your Experiment

Use a separate sheet to detail your experiment design, and be sure to address these main points:

A. ***Hypothesis***

Describe the scientific principle to be tested or verified.

B. ***Materials***

List the materials you will use to complete your investigation.

C. ***Method***

Describe the experimental procedure—be sure to number each step to make it easy to follow during recording.

Run Your Experiment

D. ***Set Up***

Set up the equipment and prepare the subject for your experiment.

E. ***Record***

Use the **Continue**, **Record** and **Suspend** buttons to record as much data as necessary for your experiment.

Click **Stop** when you have completed all of the recordings required for your experiment.

Analyze Your Experiment

F. Set measurements relevant to your experiment and record the results in a Data Report.

- To listen to the EMG signal, proceed to Step 21.
- To skip listening to the EMG signal and end the recording, proceed to Step 24.

Recording continues…

Listening to the EMG is optional.

Listening to the EMG can be a valuable tool in detecting muscle abnormalities, and is performed here for general interest. Data on screen is not saved.

21. Click **Listen** to record EMG data and hear it through the headphones.
22. Increase clench force and notice how the volume increases.

The EMG signal will be audible through the headphones as it is being displayed on the screen. The screen will display two channels:

CH 1 EMG and CH 41 Clench Force

The signal will run until **Stop** is clicked. If others in your lab group would like to hear the EMG signal, pass the headphones around before clicking **Stop** or click **Redo** and then **Stop** when done.

23. Click **Stop** when finished.
    - Click **Redo** to hear EMG again.

This will end listening to the EMG.

24. Click **Done** to end the lesson.
25. Choose an option and click **OK**.

If choosing the **Record from another Subject** option:

- Repeat Setup Steps 4 – 7 and proceed to Calibration.

26. Remove the electrodes.

Remove the electrode cable pinch connectors, and peel off all electrodes. Discard the electrodes (BIOPAC electrodes are not reusable). Wash the electrode gel residue from the skin, using soap and water. The electrodes may leave a slight ring on the skin for a few hours, which is quite normal.

END OF RECORDING

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V. DATA ANALYSIS

FAST TRACK Data Analysis

1. Enter the **Review Saved Data** mode
   - Note Channel Number (CH) designations:

Channel	*Displays*
CH 1	**EMG** (hidden*)
CH 40	**Integrated EMG**
CH 41	**Clench Force**

   - Note measurement settings:

Channel	*Measurement*
CH 41	**Mean**
CH 40	**Mean**
CH 41	**Value**
CH 40	**Delta T**

Analysis of Increasing Clench Force

2. Setup your display for optimal viewing of **"Dominant arm: Increasing clench force"** data.

3. Read the journal and note your force increment in the Data Report.

   A

Data Analysis continues….

Detailed Explanation of Data Analysis Steps

If entering Review Saved Data mode from the Startup dialog or Lessons menu, make sure to choose the correct file.

The data window should resemble Fig. 2.16.

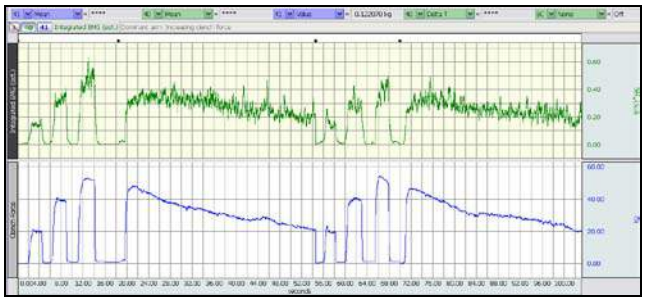

Fig. 2.16 Example data

The measurement boxes are above the event marker region in the data window. Each measurement has three sections: channel number, measurement type, and result. The first two sections are pull-down menus that are activated when clicked.

Brief definition of measurements:

Mean: Displays the average value in the selected area.

Value: Displays the amplitude value at the point selected by the I-beam cursor. If an area is selected, displays the value of the endpoint based on the direction the cursor was dragged.

Delta T: Measures the difference in time between the end and beginning of the selected area.

The "selected area" is the area selected by the I-Beam tool (including endpoints)

Note: The append event markers mark the beginning of each recording. Click (activate) the event marker to display its label.

Useful tools for changing view:

Display menu: Autoscale Horizontal, Autoscale Waveforms, Zoom Back, Zoom Forward

Scroll Bars: Time (Horizontal); Amplitude (Vertical)

Cursor Tools: Zoom Tool

Buttons: Overlap, Split, Show Grid, Hide Grid, -, +

Hide/Show Channel: "Alt + click" (Windows) or "Option + click" (Mac) the channel number box to toggle channel display.

The Journal summary shows the force increment used in your recordings. The grid divisions should use the same increment. Note this increment in Table 2.1 in the second column, **Force (kg) Increments** for Peak #1. For subsequent peaks, add the increment (i.e., 5, 10, 15 kg or 10, 20, 30 kg).

4. Use the **I-Beam** cursor to select an area on the plateau phase of the first clench (Fig. 2.17).

   A

5. **Repeat** Step 4 on the plateau of each successive clench.

   A

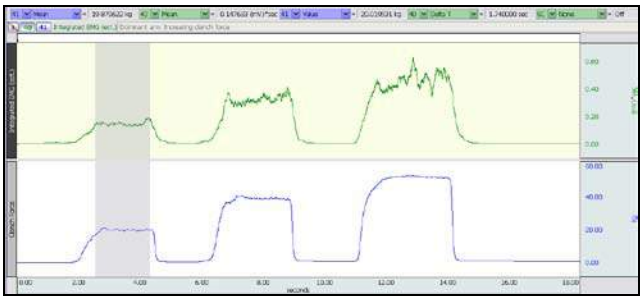

Fig. 2.17 Plateau of first clench selected

6. Scroll to marker labeled **"Nondominant arm: Increasing clench force"** and set up your display for optimal viewing.
7. **Repeat** Steps 3 – 4 for this recording.

Analysis of Continued Clench

8. Scroll to **"Dominant arm: Continued clench at maximum force"** and set up your display for optimal viewing.

This recording begins at the append event marker labeled "**Dominant arm: Continued clench at maximum force**."

9. Use the **I-Beam** cursor to select a point of maximal clench force immediately following the start of the recording (Fig. 2.18).

   B

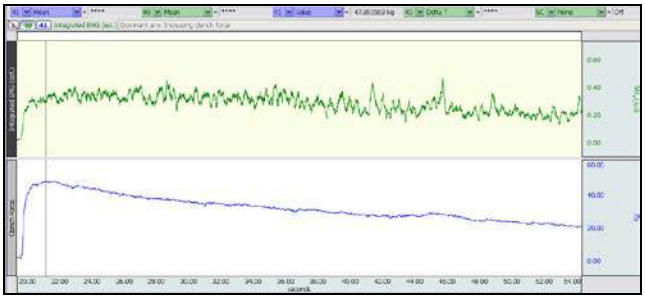

Fig. 2.18

The point selected should represent the maximal clench force at the <u>start</u> of continuous maximal clench recording, as shown in Fig. 2.18.

10. Calculate 50% of the maximum clench force from Step 9.

    B

This number is necessary in order to complete Step 11.

11. Find the point of 50% maximum clench force by using the I-beam cursor and leave the cursor at this point.

Make an eyeball approximation of the point that is 50% down from the maximal clench point. Then, use the I-beam cursor to click points near this region, noting the value displayed in the measurement box, until you are on a point within 5% of the maximal clench force. Leave the cursor at this point.

Data Analysis continues….

12. Select the area from the point of 50% clench force back to the point of maximal clench force by using the I-beam cursor and dragging (Fig. 2.19). Note the time to fatigue measurement (CH 40 Delta T).

    B

    Scroll to marker labeled **"Non dominant arm: Continued clench at maximum force"** and set up your display for optimal viewing.

13. **Repeat** Steps 8 – 12 for this recording.

One way to select the area is as follows: The cursor should be flashing on the point of 50% maximal clench force. Hold down the mouse button and drag to the left of this point until you reach the point of maximal clench force, then release the mouse button.

Note: You do not need to indicate the Delta T polarity as it only reflects the direction the "I-beam" cursor was dragged to select the data. Data selected left to right will have a positive ("+") polarity, while data selected right to left will have a negative ("-") polarity.

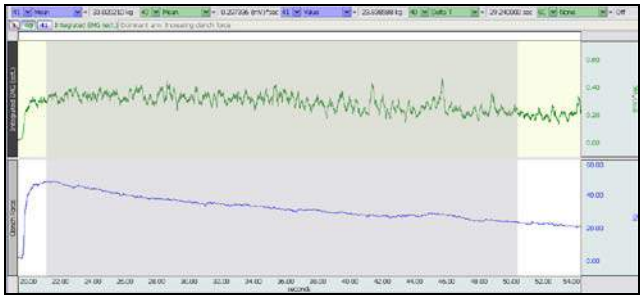

Fig. 2.19 showing area max-50%

14. Answer the questions at the end of the Data Report.
15. **Save** or **Print** the data file.
16. **Quit** the program.

END OF DATA ANALYSIS

An electronically editable **Data Report** is located in the journal (following the lesson summary,) or immediately following this Data Analysis section. Your instructor will recommend the preferred format for your lab.

END OF LESSON 2

Complete the Lesson 2 Data Report that follows.

ELECTROMYOGRAPHY II

- *Motor unit recruitment and Fatigue*

DATA REPORT

Student's Name: _____

Lab Section: _____

Date: _____

Subject Profile

Name:_____ Height:_____ Gender: Male / Female

Age:_____ Weight:_____ Dominant arm: Right / Left

I. Data and Calculations

Motor Unit Recruitment

A. **Complete Table 2.1 using *Dominant arm* and *Nondominant arm* data**. In the "Force (kg) Increments" column, note the force increment assigned for your recording under Peak #1; the increment was pasted to the Journal and should be noted below from Data Analysis—Step 2. For subsequent peaks, add the increment (i.e., 500, 1000, 1500). You may not need eight peaks to reach max.

Table 2.1 Increasing Clench Force Data

Peak #	Assigned Force Increment SS25L/LA = Kg SS56L = kgf/m^2	*(Dominant arm)*		*(Nondominant arm)*	
		Force at Peak	Integrated EMG (mV)	Force at Peak	Integrated EMG (mV)
		41 Mean	40 Mean	41 Mean	40 Mean
1					
2					
3					
4					
5					
6					
7					
8					

Fatigue

B. **Complete Table 2.2 using *Dominant arm* and *Nondominant arm* data.**

Table 2.2 Maximum Clench Force Data

(Dominant arm)			*(Nondominant arm)*		
Maximum Clench Force	50% of Max Clench Force	Time to Fatigue	Maximum Clench Force	50% of Max Clench force	Time to fatigue
41 Value	*calculate*	40 Delta T	41 Value	*calculate*	40 Delta T

II. Questions

C. Is the strength of your right arm different than your left arm? _____Yes _____No

D. Is there a difference in the absolute values of force generated by males and females in your class? ____Yes____No

What might explain any difference?

E. When holding an object, does the number of motor units remain the same? Are the same motor units used for the duration of holding the object?

F. As you fatigue, the force exerted by your muscles decreases. What physiological processes explain the decline in strength?

G. Define **Motor unit**

H. Define **Motor unit recruitment**

I. Define **Fatigue**

J. Define **EMG**

K. Define **Dynamometry**

III. OPTIONAL Active Learning Portion

A. ***Hypothesis***

B. ***Materials***

C. ***Method***

D. ***Set Up***

E. ***Experimental Results***

End of Lesson 2 Data Report

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Biopac Student Lab® Lesson 3

ELECTROENCEPHALOGRAPHY (EEG) I
Introduction

Rev. 08142013

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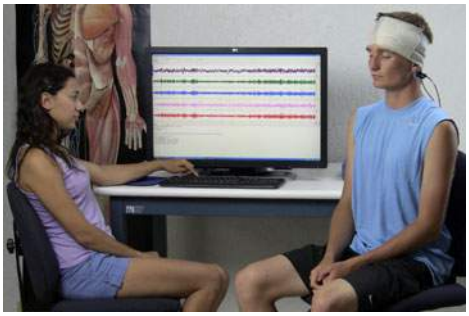

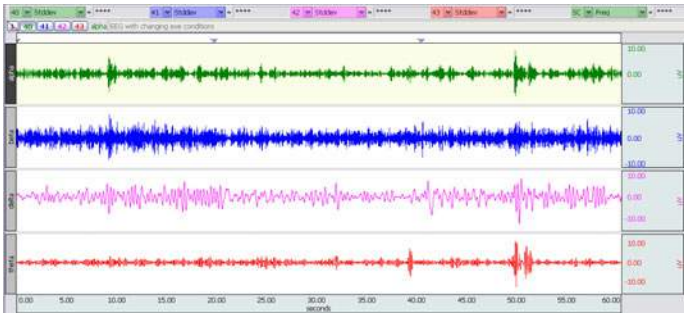

I. INTRODUCTION

The **brain** is encased by the **cranium**, bones of the skull which immediately cover and protect brain surfaces. A thin cover of skin, called the **scalp**, covers most of the cranium. The largest part of the brain immediately beneath the bones of the cranium is the **cerebral cortex**. The cerebral cortex is composed of nerve cells (neurons,) many of which are functionally connected to each other, and connected to other parts of the brain. Electrical activity in the form of nerve impulses being sent and received to and from cortical neurons is always present, even during sleep. In a biological sense (as well as a medical or legal sense,) absence of electrical activity in the human cerebral cortex signifies death.

Functions of the cerebral cortex include abstract thought, reasoning, voluntary and involuntary control of skeletal muscle, and the recognition and differentiation of somatic, visceral, and special sensory stimuli. Specific regions of the cerebral cortex process or generate various kinds of information. For example, the **occipital lobe** processes visual information while the **parietal lobe** processes somatosensory information such as cutaneous pain or temperature (Fig. 3.1).

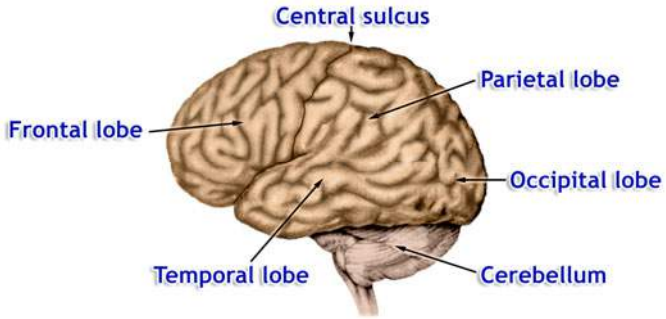

Fig. 3.1 Regions of the brain

The sensory information is relayed from the periphery through lower centers in the brain, and then the information is sent to various regions of the cerebral cortex. Since the cerebral cortex is just under the cranium, **electrodes** placed on the scalp above the various regions of the brain can detect the electrical activity associated with functioning neurons. The recording of the brain's activity obtained by using electrodes is called **electroencephalogram** or **EEG** (*electro* = electrical, *encephelo* = brain, *gram* = record).

An EEG electrode will mainly detect the activity in the brain region just under it. Nevertheless, the electrodes receive the activity from thousands of neurons. In fact, one square millimeter of cortex has more than 100,000 neurons. Since each region of the cerebral cortex of an alert person is busy receiving, integrating, and sending many impulses, this activity is detected in the EEG. (For more information about waveforms, see "Waveform Concepts" in the BSL Tutorial.)

It is only when the input to a region is **synchronized** with electrical activity occurring at the same time that you begin to distinguish simple, periodic waveforms in an EEG.

In 1929, an Austrian physician named Hans Berger discovered that electrodes placed on the scalp could detect various patterns of electrical activity. After verifying that the recordings were indeed recording from the brain, and were not artifacts of muscle or scalp, scientists began to study these "brain waves." Today, the EEG is still a medically useful recording for brain function. In medical and basic research, the correlation of particular brain waves with sleep phases, emotional states, psychological profiles, and types of mental activities is ongoing.

Four simple periodic rhythms recorded in the EEG are **alpha**, **beta**, **delta**, and **theta**. These rhythms are identified by **frequency** (**Hz** or **cycles/sec**) (Table 3.1). The amplitudes recorded by scalp electrodes are in the range of microvolts (μV or 1/1,000,000 of a volt).

Table 3.1 Typical Frequencies of Synchronized Brainwaves

Rhythm	Typical Frequencies (Hz)
alpha	8-13
beta	13-30
delta	1-5
theta	4-8

Alpha

The four basic rhythms have been associated with various states. In general, the alpha rhythm is the prominent EEG wave pattern of an adult who is awake but relaxed with eyes closed. Each region of the brain has a characteristic alpha rhythm but alpha waves of the greatest amplitude are recorded from the occipital and parietal regions of the cerebral cortex. Results from various studies indicate that:

- females tend to have higher mean frequencies of alpha waves than males
- alpha wave amplitudes are likely to be higher in "outgoing" subjects
- alpha wave amplitudes vary with a subject's attention to mental tasks performed with the eyes closed

In general, amplitudes of alpha waves diminish when subjects open their eyes and are attentive to external stimuli although some subjects trained in relaxation techniques can maintain high alpha amplitudes even with their eyes open.

Beta

Beta rhythms occur in individuals who are alert and attentive to external stimuli or exert specific mental effort, or paradoxically, beta rhythms also occur during deep sleep, REM (Rapid Eye Movement) sleep when the eyes switch back and forth. Notice that the amplitude of beta rhythms tends to be lower than for alpha rhythms. This does not mean that there is less electrical activity, rather which the "positive" and "negative" activities are starting to counterbalance so that the sum of the electrical activity is less. Thus, instead of getting the wave-like synchronized pattern of alpha waves, **desynchronization** or **alpha block** occurs. So, the beta wave represents arousal of the cortex to a higher state of alertness or tension. It may also be associated with "remembering" or retrieving memories.

Delta and Theta

Delta and theta rhythms are low-frequency EEG patterns that increase during sleep in the normal adult. As people move from lighter to deeper stages of sleep (prior to REM sleep,) the occurrence of alpha waves diminishes and is gradually replaced by the lower frequency theta and then delta rhythms.

Although delta and theta rhythms are generally most prominent during sleep, there are cases when delta and theta rhythms are recorded from individuals who are awake. For example, theta waves will occur for brief intervals during emotional responses to frustrating events or situations. Delta waves may increase during difficult mental activities requiring concentration. In general, the occurrence and amplitudes of delta and theta rhythms are highly variable within and between individuals.

Electrode positions

Electrode positions have been named according to the brain region below that area of the scalp: **frontal**, **central** (sulcus,) **parietal**, **temporal**, and **occipital**. In the **bipolar method**, the EEG is measured from a pair of scalp electrodes. The pair of electrodes measures the difference in electrical potential (voltage) between their two positions above the brain. A third electrode is attached behind the ear as a point of reference, 'ground', of the body's baseline voltage due to other electrical activities within the body.

In today's lesson, you will record an EEG using the bipolar method.

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Associate Professor Emeritus
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Purdue University School of Science

William McMullen
Vice President, BIOPAC Systems, Inc.

II. EXPERIMENTAL OBJECTIVES

1) To record an EEG from an awake, resting subject with eyes open and eyes closed.
2) To identify and examine alpha, beta, delta, and theta components of the EEG complex.

III. MATERIALS

- BIOPAC electrode lead set (SS2L)
- BIOPAC Disposable Electrodes (EL503,) 3 electrodes per subject
- BIOPAC Electrode Gel (GEL1) and Abrasive Pad (ELPAD) *or* Skin cleanser or alcohol prep
- Lycra® swim cap (such as Speedo® brand) *or* supportive wrap (such as 3M Coban™ Self-adhering Support Wrap) to press electrodes against head for improved contact
- Biopac Student Lab System: BSL 4 software, MP36, MP35 or MP45 hardware
- Computer system (Windows or Mac)

IV. EXPERIMENTAL METHODS

A. SETUP

FAST TRACK Setup

1. Turn the computer **ON**.
   - If using an MP36/35 unit, turn it **OFF**.
   - If using an MP45, make sure USB cable is connected and "Ready" light is **ON**.
2. **Plug the equipment in** as follows:
   - Electrode Lead Set (SS2L)—Electrode Check (MP3x only. For MP45, plug into CH 1.)
3. Turn **ON** the BIOPAC MP36/35 unit.

Setup continues…

Detailed Explanation of Setup Steps

Fig. 3.2 MP3X (top) and MP45 (bottom) hardware connections

4. Position electrodes on the scalp.
   Fig. 3.3 shows a sample configuration.

IMPORTANT
Good electrode contact with scalp is crucial for obtaining a meaningful EEG recording.

Fig. 3.3

Guidelines for electrode placement:

- The placement of the scalp electrodes can vary (within limits) depending on your instructor's or **Subject's** preference.
- Keep the electrodes on one side (right or left) of the head.
- The third electrode is the ground electrode and is placed over the Mastoid region (behind the ear).

Hints for obtaining optimal data:

- As much as possible, move (part) the hair away from the electrode area to ensure the electrode makes contact with the scalp.
- Gently abrade skin at the electrode sites.
- Apply some gel to the electrode. *(A fair amount of gel must be used to obtain a good electrode to scalp connection.)*
- Apply pressure to the electrodes for about 1 minute after the initial placement.
- **Subject** must remain still. Blinking and other movement will affect the recording of all four rhythms.
- Despite your best efforts, electrode adhesion may not be strong enough to record data; try another **Subject** or different electrode placement.

5. Clip the Electrode Lead Set following the color code in Fig. 3.3.

The pinch connectors work like a small clothespin, but only latch onto the nipple of the electrode from one side of the connector.

Drape the electrode cables over the head so that they are not pulling on the electrodes.

6. Place cap/wrap on **Subject's** head to press electrodes into scalp (Fig. 3.4).

The cap or wrap should be snug but not uncomfortably tight.

Place a Lycra® swim cap or supportive wrap on **Subject's** head to press the VIN+ and VIN- electrodes against the scalp with a constant pressure. **Subject** should <u>not</u> press electrodes against scalp.

Setup continues…

Fig. 3.4

7. Get **Subject** in proper seating position (Fig. 3.5).
8. Wait five minutes to allow **Subject** to relax, and for electrodes to establish proper contact.

Subject should be seated and relaxed. Ideally, the room should be *reasonably quiet* to help **Subject** mentally relax.

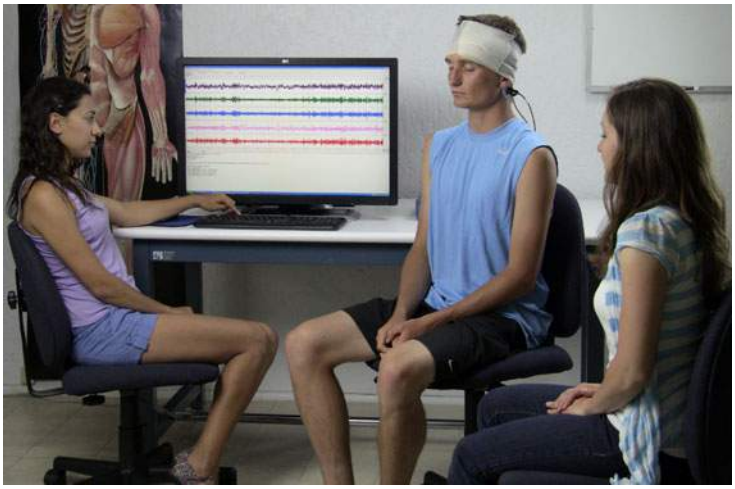


Fig. 3.5 Positioning

9. **Start** the Biopac Student Lab Program.
10. Choose "**L03 – Electroencephalography (EEG) I"** and click **OK**.
11. Type in a unique **filename** and click **OK**.

Start Biopac Student Lab by double-clicking the Desktop shortcut.

No two people can have the same filename, so use a unique identifier, such as **Subject's** nickname or student ID#.

A folder will be created using the filename. This same filename can be used in other lessons to place the **Subject's** data in a common folder.

12. ***Optional***: Set Preferences.
    - Choose File > **Lesson Preferences**.
    - Select an option.
    - Select the desired setting and click **OK**.

This lesson has optional Preferences for data and display while recording. Per your Lab Instructor's guidelines, you may set:

Grids: Show or hide gridlines

Lesson Recordings: Specific recordings may be omitted based on instructor preferences.

END OF SETUP

B. CALIBRATION

The Calibration procedure establishes the hardware's internal parameters (such as gain, offset, and scaling) and is critical for optimal performance. **Pay close attention to Calibration.**

FAST TRACK Calibration

1. **Subject** remains relaxed with eyes closed during Calibration.
2. Check Electrode Impedance. (Optional*)

***Only functional if your MP** hardware is compatible with the Electrode Check feature. If your MP hardware is not compatible, this feature will not be available. Please contact BIOPAC Technical Support for more information on how to enable Electrode Check functionality.

IMPORTANT
Certain subjects may not fall below the 10 K ohm reading. This reading is subject to individual variations in skin conductivity and electrode placement.

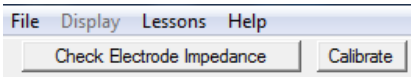
3. Click **Calibrate**.
4. During Calibration **Subject** must:
   - Remain seated, relaxed and still, with eyes closed.
   - Wait for Calibration to stop.
5. Verify recording resembles the example data.
   - If similar, click **Continue** and proceed to Data Recording.
   - If necessary, click **Redo Calibration**.

END OF CALIBRATION

Detailed Explanation of Calibration Steps

This step is optional and not applicable to MP45 hardware.

Use **Check Electrode Impedance** to check the **Subject's** skin conductivity. This opens the Electrode Checker panel and displays skin resistance in k ohm.



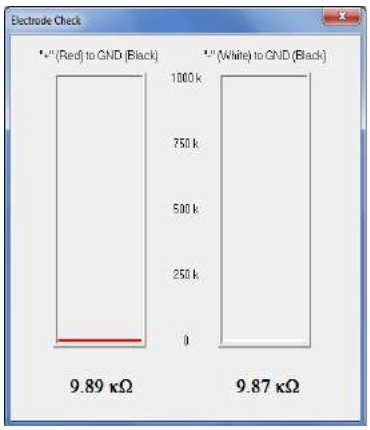


Fig. 3.6

To use:

- Make sure the SS2L is plugged into the MP unit's Electrode Check input.
- Click Check Electrode Impedance button.
- Ideally, both readings should be similar and below 10 k ohm. (See Fig. 3.6.)
- When finished, be sure to remove the SS2L from the Electrode Check input and plug into the CH 1 input before continuing (right).

Calibration lasts eight seconds.

The baseline should be relatively stable around 0 uV.

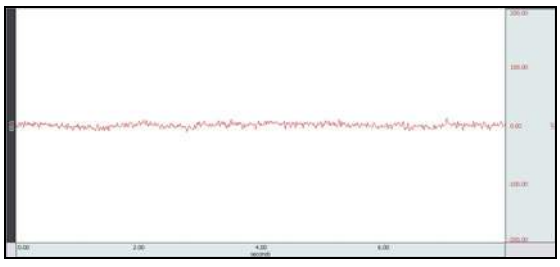


Fig. 3.7 Example Calibration data

If the data shows excessive baseline drift or large spikes, make sure the electrodes are making good contact with the scalp and that the cables are not pulling on the electrodes.

Click **Redo Calibration** and repeat Steps 3 – 5 if necessary.

C. DATA RECORDING

FAST TRACK Recording

1. Prepare for the recording.
   - **Subject** remains seated, relaxed and still, with eyes closed.
   - **Review** recording steps.

2. Click **Record**.
   - **Subject** remains seated, relaxed and still, with eyes closed.
   - Record for 20 seconds.
   - **Director** presses F4 and cues **Subject** to open eyes.
   - Record for an additional 20 seconds.
   - **Director** presses F5 and cues **Subject** to close eyes.
   - Record for an additional 20 seconds.

3. Click **Suspend**.
4. Verify recording resembles the example data.
   - If similar, click **Continue** and proceed to the optional recording section, or click **Done** to finish.
   - If necessary, click **Redo**.

Recording continues…

Detailed Explanation of Recording Steps

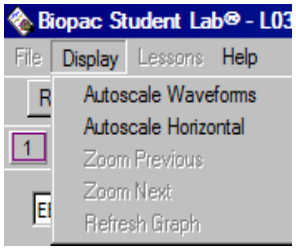
This lesson will record the "raw" (full bandwidth) EEG while the **Subject** is relaxed with eyes closed, eyes opened, and eyes closed again. The alpha, beta, delta and theta channels are simultaneously recorded, but are hidden by default. Hidden channels may be displayed during the recording by holding down the "Alt" (PC) or "Option" (Mac) key when clicking on the channel button.

To work efficiently, read this entire section before recording, or review onscreen **Tasks** to preview recording steps in advance.

Hints for obtaining optimal data:

- **Subject** should be seated and relaxed to keep muscles still, especially facial muscles. (Do not talk.)
- **Subject** must try not to blink during "Eyes Open" portion of recording.
- **Subject** should try to relax mentally; i.e. think of a relaxing place.

Note: **Display > Autoscale Waveforms** and **Autoscale Horizontal** are available DURING recordings to allow scale changes if necessary.



The **Director** instructs **Subject** to change the eye condition for 20-second intervals, and inserts an event marker at each change.

First 20 seconds (secs. 0 – 20)

Subject is relaxed, with eyes closed for the first 20 seconds.

Next 20 seconds (secs. 21 – 40)

Director presses **F4** to insert a marker labeled "Eyes Open" and cues **Subject** to open eyes and try not to blink for the next 20 seconds.

After another 20 seconds (secs. 41 – 60)

Director presses **F5** to insert a marker labeled "Eyes Closed" and cues **Subject** to close eyes for the next 20 seconds.

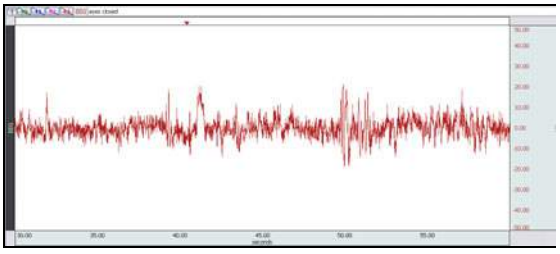


Fig. 3.8 Example data

Verify recording shows variation between the "Eyes Open" and "Eyes Closed" recordings.

Note: To check the data, it may be necessary to show one or more of the hidden frequency bands. To activate, hold down the Alt (PC) or Option (Mac) key when clicking on the channel button.

If recording does not resemble the Example Data

- If the data is noisy or flatline, check all connections to the MP unit.
- If there is excessive baseline drift or large spikes:
- Check that electrodes are making good contact with the scalp, cap or wrap is snug and that the cables are not pulling on the electrodes.
- Subject must remain as still as possible.
- Try relaxation techniques, such as slow breathing or relaxing muscles.

Click **Redo** and repeat Steps 2 – 4 if necessary. Note that once **Redo** is clicked, the most recent recording will be erased.

OPTIONAL ACTIVE LEARNING PORTION

With this lesson you may record additional data by clicking **Continue** following the last recording. Design an experiment to test or verify a scientific principle(s) related to topics covered in this lesson. Although you are limited to this lesson's channel assignments, the electrodes may be moved to different locations on the **Subject**.

Design Your Experiment

Use a separate sheet to detail your experiment design, and be sure to address these main points:

A. ***Hypothesis***

Describe the scientific principle to be tested or verified.

B. ***Materials***

List the materials you will use to complete your investigation.

C. ***Method***

Describe the experimental procedure—be sure to number each step to make it easy to follow during recording.

Run Your Experiment

D. ***Set Up***

Set up the equipment and prepare the subject for your experiment.

E. ***Record***

Use the **Continue**, **Record** and **Suspend** buttons to acquire as many recordings as necessary for your experiment.

Click **Done** when you have completed all of the recordings required for your experiment.

Analyze Your Experiment

F. Set measurements relevant to your experiment and record the results in a Data Report.

5. After clicking **Done**, choose an option and click **OK**.

If choosing the **Record from another Subject** option:

- Continue the entire lesson from Setup Step 4.

6. Remove electrodes.

Remove cap or wrap, the electrode cable pinch connectors, and peel off all electrodes. Discard the electrodes. (BIOPAC electrodes are not reusable.) Wash the electrode gel residue from the skin, using soap and water. The area around the electrode sites may remain red for a few hours, which is quite normal.

END OF RECORDING

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V. DATA ANALYSIS

FAST TRACK Data Analysis

1. Enter the **Review Saved Data** mode.

   - Note Channel Number (CH) designations.

Channel	*Displays*
CH 1	**EEG** (hidden*)
CH 40	**alpha**
CH 41	**beta**
CH 42	**delta**
CH 43	**theta**

   - Note measurement box settings:

Channel	*Measurement*
CH 40	**Stddev**
CH 41	**Stddev**
CH 42	**Stddev**
CH 43	**Stddev**
SC	**Freq**

2. Set up your display window for optimal viewing of the channels 40 – 43.

3. Use the I-Beam cursor to select the first "**Eyes closed**" data.

   A

Data Analysis continues…

Detailed Explanation of Data Analysis Steps

If entering **Review Saved Data** mode from the Startup dialog or lessons menu, make sure to choose the correct file.

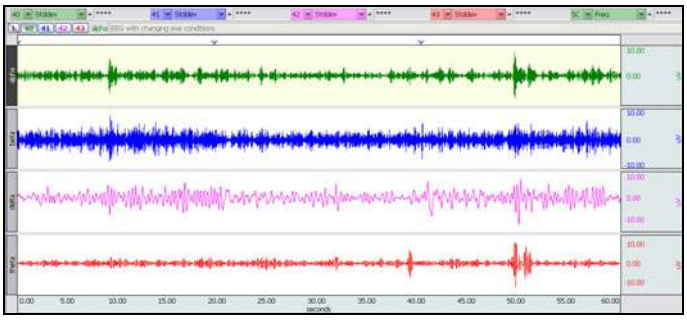

Fig. 3.9 Example data

The EEG channel is hidden but can be easily brought into view. (See Step 2.)

The measurement boxes are above the marker region in the data window. Each measurement has three sections: channel number, measurement type, and result. The first two sections are pull-down menus that are activated when you click them.

Brief definition of measurements:

Stddev: Standard deviation is a measure of the variability of data points. The advantage of the Stddev measurement is that extreme values or artifacts do not unduly influence the measurement.

Freq: Converts the time segment of the selected area to frequency in cycles/sec.

The "selected area" is the area selected by the I-beam tool (including endpoints).

Useful tools for changing view:

Display menu: Autoscale Horizontal, Autoscale Waveforms, Zoom Back, Zoom Forward

Scroll Bars: Time (Horizontal); Amplitude (Vertical)

Cursor Tools: Zoom Tool

Buttons: Overlap, Split, Show Grid, Hide Grid, +, -

Hide/Show Channel: "Alt + click" (Windows) or "Option + click" (Mac) the channel number box to toggle channel display.

This is the data from the time 0 to the first event marker.

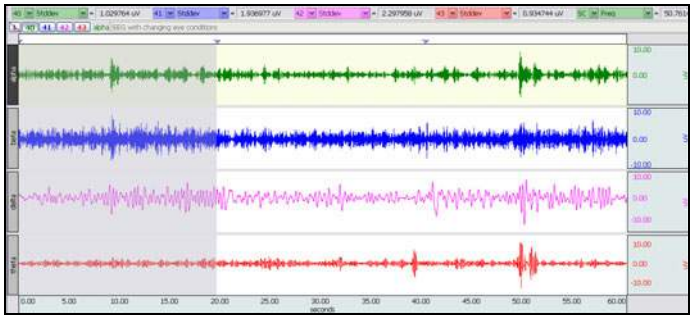

Fig. 3.10 First Eyes Closed data

4. Repeat Step 3 using "**Eyes open**" data.

   A

   This is the data between the first and second event markers.

5. Repeat Step 3 using the second "**Eyes closed**" data.

   A

   This is the data between the second event marker and the end of the file.

6. **Zoom** in on a 3 – 4 second section of the first "**Eyes closed**" data.

7. Use the **I-beam** cursor to select an area that represents one cycle in the **alpha** wave (Fig. 3.11).

   B

   Accurate Frequency calculation requires a selected area of only one cycle.

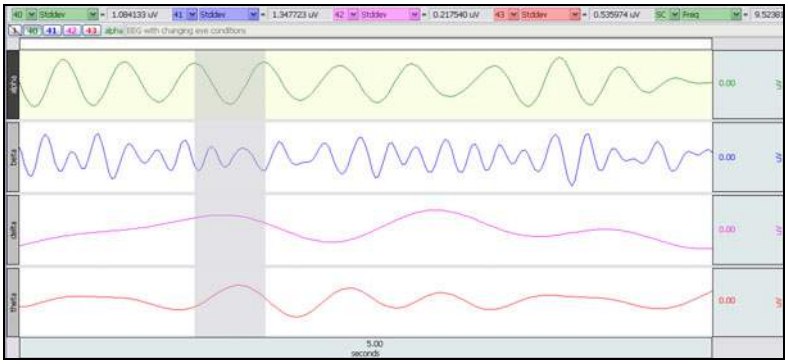

Fig. 3.11 Selected area shows one cycle of the alpha wave.

8. Repeat Step 7 for two other **alpha** wave cycles.

   B

   Make sure you stay in the first "**Eyes Closed**" data region.

9. Repeat Steps 7 – 8 using the **beta** wave data.

   B

   Click the cursor/pointer into the **beta** wave region to select this channel for "SC" measurements. (Channel label will darken.)

10. Repeat Steps 7 – 8 using the **delta** wave data.

    B

    Click the cursor/pointer into the **delta** wave to select this channel for "SC" measurements.

11. Repeat Steps 7 – 8 using the **theta** wave data.

    B

    Click the cursor/pointer into the **theta** wave to select this channel for "SC" measurements.

12. Answer the questions at the end of the Data Report.
13. **Save** or **Print** the Data Report.
14. **Quit** the program.

    An electronically editable **Data Report** is located in the journal (following the lesson summary,) or immediately following this Data Analysis section. Your instructor will recommend the preferred format for your lab.

END OF DATA ANALYSIS

END OF LESSON 3

Complete the Lesson 3 Data Report that follows.

ELECTROENCEPHALOGRAPHY I

- *EEG I*

DATA REPORT

Student's Name: _____

Lab Section: _____

Date: _____

I. Data and Calculations

Subject Profile

Name:_____ Height:_____

Age:_____ Gender: Male / Female Weight:_____

A. EEG Amplitude Measurements from Standard Deviation measurements

Table 3.2 Standard Deviation [Stddev]

Rhythm	CH Measurement	Eyes Closed	Eyes Open	Eyes Re-closed
Alpha	40 Stddev			
Beta	41 Stddev			
Delta	42 Stddev			
Theta	43 Stddev			

B. EEG Frequency Measurements from first 'Eyes closed' data

Table 3.3 Frequency (Hz)

Rhythm	CH Measurement	Cycle 1	Cycle 2	Cycle 3	Mean
Alpha	SC Freq				
Beta	SC Freq				
Delta	SC Freq				
Theta	SC Freq				

II. Questions

C. List and define two characteristics of regular, periodic waveforms.

_____

_____

_____

_____

D. Compare and contrast synchrony and alpha block.

_____

_____

_____

_____

E. Examine the alpha and beta waveforms for change between the "eyes closed" state and the "eyes open" state.

i. Does **desynchronization** of the alpha rhythm occur when the eyes are open?

ii. Does the beta rhythm become more pronounced in the "eyes open" state?

F. The amplitude measurements (Stddev) are indicative of how much alpha activity is occurring in Subject. But, the amplitude values for beta do not truly reflect the amount of mental activity occurring with the eyes open. Explain.

G. Examine the delta and theta rhythm. Is there an increase in delta and theta activity when the eyes are open? Explain your observation.

H. Define the following terms:

i. Alpha rhythm

ii. Beta rhythm

iii. Delta rhythm

iv. Theta rhythm

III. OPTIONAL Active Learning Portion

A. ***Hypothesis***

B. ***Materials***

C. ***Method***

D. ***Set Up***

E. ***Experimental Results***

End of Lesson 3 Data Report

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Biopac Student Lab® Lesson 4

ELECTROENCEPHALOGRAPHY (EEG) II
Introduction

Rev. 03312015

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Indiana University School of Medicine
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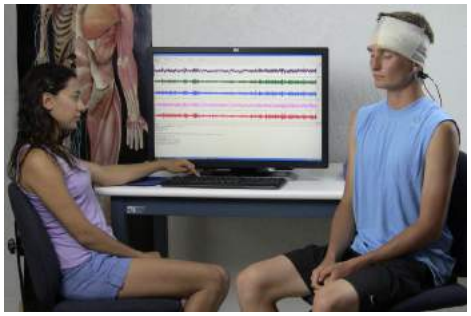

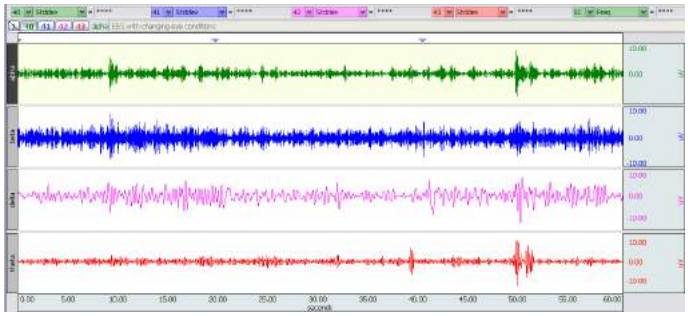

I. INTRODUCTION

The brain constantly receives sensory input and integrates the information. The sensory information is relayed from the periphery through lower centers in the brain, and then the information is sent to specific regions of the **cerebral cortex** where it is processed. For example, the **occipital lobe** processes visual information while the **parietal lobe** processes non-visual, sensory information such as cutaneous pain (Fig. 4.1). If you choose to, you can direct your attention to particular bits of sensory information; you can access memories associated with the sensory information; or you can selectively ignore this sensory input.

The **blood/brain barrier** separates cerebral spinal fluid from the blood. Oxygen, glucose, and carbon dioxide can cross the blood/brain barrier, but unbound protons (H^+) cannot. The brain requires oxygen and glucose for energy. Without a relatively constant source of oxygen and glucose, the brain ceases to function. Levels of carbon dioxide in the spinal fluid can change the pH of the spinal fluid, which can in turn change the body's respiration rate.

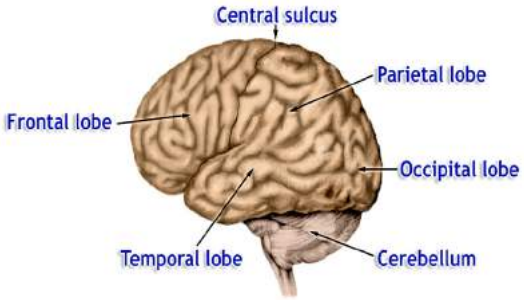

Fig. 4.1 Brain anatomy

Because brain activity is related to ions and charge movement, this activity can be detected by **electrodes**. The record of the brain's activity is called an **electroencephalogram** (**EEG**) from the root words of *electro* (electrical,) *encephalo* (brain,) and *gram* (record).

The EEG records the electrical activity on the surface of the cerebral cortex. The EEG is complex and variable between adults, although under certain conditions, the EEG exhibits simpler, rhythmic activity. Simpler patterns in the EEG occur when many cells **synchronize** their input to the surface of the cerebral cortex. The more synchronized the charge movement, the more rhythmic the EEG.

Your EEG changes as you grow. The development of EEG is rapid with newborns. As neural development proceeds, the EEG recorded from the posterior regions of the brain of an infant of 3-4 months begins to resemble EEGs recorded from the posterior region of adults. The difference is that the 3-4 month old infants have EEGs in the frequency range of 3-4 Hz, whereas adults tend to have average frequencies of 10 Hz. By the time the infant is one year old, the posterior region EEG is approximately 6 Hz, by three years, 8 Hz, and by 13-14 years (puberty,) the average frequency is 10 Hz (similar to adults).

One of the simpler patterns is the **alpha rhythm**. The alpha rhythm is characterized by a frequency of 8-13 Hz and amplitudes of 20-200 μV. Each region of the brain has a characteristic frequency of alpha rhythm. Alpha waves of the greatest amplitude tend to be recorded from the occipital and parietal regions of the cerebral cortex.

Just as the EEG is variable depending upon the mental state of an individual, the frequency and amplitude of alpha rhythms within an individual change as well. In general, the alpha rhythm is the prominent EEG wave pattern of an adult in a relaxed, inattentive state with eyes closed.

More specific conditions of alpha rhythms are listed below:

- **Hyperventilation** (breathing abnormally quickly and deeply) causes the gas composition of the blood to change. During hyperventilation, the carbon dioxide levels of the blood fall, pH levels increase, and blood pressure decreases. These effects of hyperventilation are associated with changes in brainwave activity. With hyperventilation, the overall electrical activity of the brain increases, with the amplitude of the alpha rhythms often increasing as well.
- Females tend to have higher mean frequencies of alpha waves than males, although the differences are small.

- Frequency may affect the speed of "remembering" during memory tests and may be approximately 1 Hz higher for high-scoring subjects than subjects who scored lower.
- Amplitudes tend to be higher in subjects who are more "outgoing" and extroverted.
- Amplitudes vary with the difficulty of mental tasks performed with the eyes closed.
- Amplitudes of alpha waves diminish when subjects open their eyes and are attentive to external stimuli. Thus, instead of getting the wave-like synchronized pattern of alpha waves, **desynchronization** occurs.
- Amplitudes increase when subjects are less alert and tend to be higher from 1:30-4:30 pm.

In this lesson, you will record the EEG and alpha rhythm under several conditions. At the same time, the root-mean-squared of the alpha rhythm (**alpha-RMS**) and an "alpha thermometer" will be displayed. Alpha-RMS and the "alpha thermometer" are indices of the activity levels of the alpha rhythm. Alpha RMS is the root mean square value of the signal within a window length of 0.25 seconds. This parameter provides a good characterization for the actual quantity of the alpha waves.

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Associate Professor Emeritus
Indiana University School of Medicine
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William McMullen
Vice President, BIOPAC Systems, Inc.

II. EXPERIMENTAL OBJECTIVES

1) To record an EEG from an awake, resting subject under the following conditions:
   a) Relaxed with eyes closed;
   b) Performing mental arithmetic with eyes closed;
   c) Hyperventilating (breathing quickly and deeply) with eyes closed;
   d) Relaxed with eyes open.
2) To examine differences in the level of alpha rhythm activity during mental arithmetic and hyperventilation compared to the control condition of eyes closed and relaxed.

III. MATERIALS

- BIOPAC Electrode Lead Set (SS2L)
- BIOPAC Disposable Electrodes (EL503,) 3 electrodes per subject
- BIOPAC Electrode Gel (GEL1) and Abrasive Pad (ELPAD) *or* Skin cleanser or alcohol prep
- Lycra® swim cap (such as Speedo® brand) *or* supportive wrap (such as 3M Coban™ Self-adhering Support Wrap) to press electrodes against head for improved contact
- Biopac Student Lab System: BSL 4 software, MP36, MP35 or MP45 hardware
- Computer system (Windows or Mac)

IV. EXPERIMENTAL METHODS

A. SETUP

FAST TRACK Setup

1. Turn the computer **ON**.
   - If using an MP36/35 unit, turn it **OFF**.
   - If using an MP45, make sure USB cable is connected and "Ready" light is **ON**.
2. **Plug the equipment in** as follows:
   Electrode Lead Set (SS2L)—CH 1
3. Turn ON the BIOPAC MP3X unit.

Setup continues…

Detailed Explanation of Setup Steps

Fig. 4.2 MP3X (top) and MP45 (bottom) hardware connections

4. Position electrodes on the scalp.
   Fig. 4.3 shows a sample configuration.

IMPORTANT
Good electrode contact with the scalp is crucial for obtaining a meaningful EEG recording.

Fig. 4.3

Guidelines for electrode placement:

- The placement of the scalp electrodes can vary (within limits) depending on your instructor's or **Subject's** preference.
- Keep the electrodes on one side (right or left) of the head.
- Apply some gel to the electrode. *(A fair amount of gel must be used to obtain a good electrode to scalp connection.)*
- The third electrode is the *ground* electrode and is placed over the Mastoid region (behind the ear).

Hints for obtaining optimal data:

- As much as possible, move (part) the hair away from the electrode adhesion area to ensure the electrode makes contact with the scalp.
- Gently abrade skin at the electrode sites.
- Apply a drop of gel to the electrode.
- Apply pressure to the electrodes for about one minute after the initial placement.
- **Subject** must remain still. Blinking and other movement will affect the recordings of all four rhythms.
- Despite your best efforts, electrode adhesion may not be strong enough to record data; try another **Subject** or different electrode placement.

5. **Clip** the Electrode Lead Set following the color code in Fig. 4.3.

The pinch connectors work like a small clothespin, but only latch onto the nipple of the electrode from one side of the connector.

6. Place cap/wrap on **Subject's** head to press electrodes into scalp (Fig. 4.4).

Drape the electrode cables over the head so that they are not pulling on the electrodes.

The cap or wrap should be snug but not uncomfortably tight.

Setup continues…

7. Get **Subject** in proper seating position (Fig. 4.5).
8. Wait five minutes to allow **Subject** to relax, and for electrodes to establish proper contact.

Fig. 4.4

Place a Lycra® swim cap or supportive wrap on **Subject's** head to press electrodes against the scalp with a constant pressure. **Subject** should not press electrodes against scalp.

Subject should be seated and relaxed. Ideally, the room should be *reasonably quiet* to help **Subject** mentally relax.

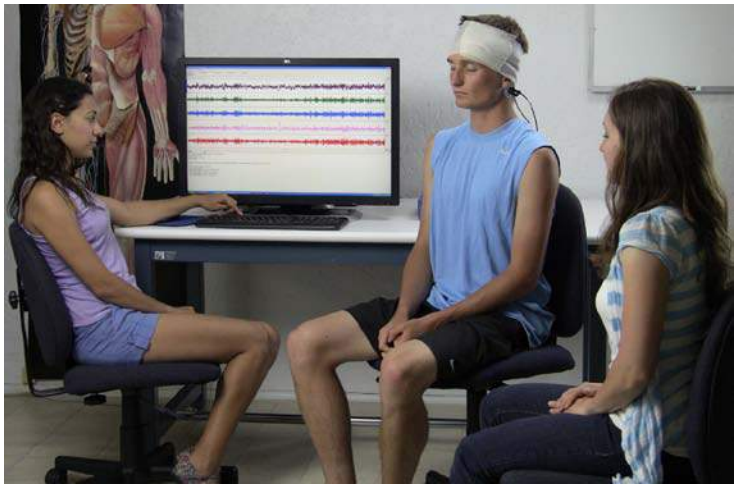


Fig. 4.5 Positioning

9. **Start** the Biopac Student Lab Program.
10. Choose lesson **"L04 – Electroencephalography (EEG) II"** and click **OK**.

Start Biopac Student Lab by double-clicking the Desktop shortcut.

11. Type in a unique **filename** and click **OK**.

No two people can have the same filename, so use a unique identifier, such as **Subject's** nickname or student ID#.

A folder will be created using the filename. This same filename can be used in other lessons to place the **Subject's** data in a common folder.

12. ***Optional***: Set Preferences.
    - Choose File > **Lesson Preferences**.
    - Select an option.
    - Select the desired setting and click **OK**.

This lesson has optional Preferences for data and display while recording. Per your Lab Instructor's guidelines, you may set:

Grids: Show or hide gridlines.

Lesson Recordings: Specific data recordings may be omitted based on instructor preferences.

END OF SETUP

B. CALIBRATION

The Calibration procedure establishes the hardware's internal parameters (such as gain, offset, and scaling) and is critical for optimum performance. **Pay close attention to Calibration.**

FAST TRACK Calibration

1. **Subject** remains relaxed with eyes closed during Calibration.
2. Check Electrode Impedance. (Optional*)

***Only functional if your MP** hardware is compatible with the Electrode Check feature. If your MP hardware is not compatible, this feature will not be available. Please contact BIOPAC Technical Support for more information on how to enable Electrode Check functionality.

IMPORTANT
Certain subjects may not fall below the 10 K ohm reading. This reading is subject to individual variations in skin conductivity and electrode placement.

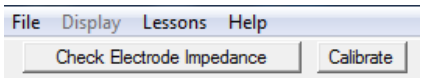
3. Click **Calibrate**.
4. During Calibration **Subject** must:
   - Remain seated, relaxed and still, with eyes closed.
   - Wait for Calibration to stop.
5. Verify recording resembles the example data.
   - If similar, click **Continue** and proceed to Data Recording.
   - If necessary, click **Redo Calibration**.

END OF CALIBRATION

Detailed Explanation of Calibration Steps

This step is optional and not applicable to MP45 hardware.

Use **Check Electrode Impedance** to check the **Subject's** skin conductivity. This opens the Electrode Checker panel and displays skin resistance in K ohms.



To use:

- Remove the Lead Set (SS2L) from CH1 and plug into the 'Electrode Check' input.
- Click 'Check Electrode Impedance' button.
- Ideally, both readings should be similar and below 10 k ohm. (See Fig. 4.6).
- When finished, be sure to remove the SS2L from the 'Electrode Check' input and plug into the CH 1 input before continuing.

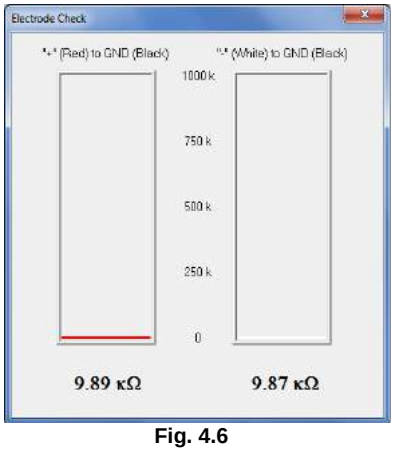


Fig. 4.6

Calibration lasts eight seconds.

The baseline should be relatively stable around 0 uV.

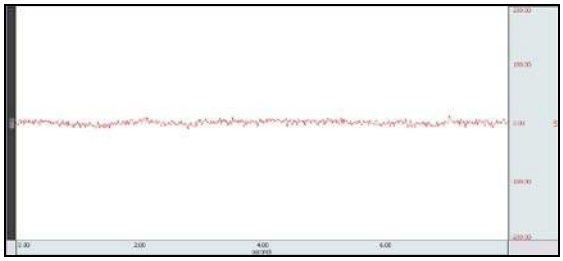


Fig. 4.7 Example Calibration data

If the data shows excessive baseline drift or large spikes, make sure the electrodes are making good contact with the scalp and that the cables are not pulling on the electrodes.

Click **Redo Calibration** and repeat Steps 3 – 5 if necessary.

C. DATA RECORDING

FAST TRACK Recording

1. Prepare for the recording.
   - **Subject** remains seated, relaxed, and still, with eyes closed.
   - **Review** recording steps.

Relaxed with eyes closed (Control)

2. Click **Record**.
   - **Subject** remains seated, relaxed and still, with eyes closed.

3. Record for 10 seconds.
4. Click **Suspend**.

Recording continues…

Detailed Explanation of Recording Steps

Subject will perform four tasks*; **Subject** will perform tasks in the intervals between recordings.

Recording 1: Relaxed with eyes closed

Recording 2: Performing mental math with eyes closed

Recording 3: Recovering from hyperventilation with eyes closed

Recording 4: Relaxed with eyes open

To work efficiently, read this entire section before recording, or review onscreen **Tasks** to preview recording steps in advance.

***IMPORTANT**

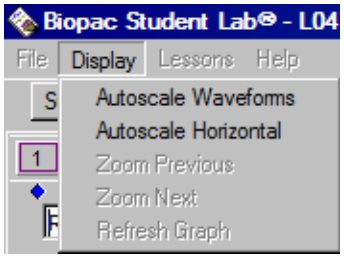
This procedure assumes that all lesson recordings are enabled in Lesson Preferences, which may not be the case for your lab. Always match the recording title to the recording reference in the journal and disregard any references to excluded recordings.

Hints for obtaining optimal data:

- **Subject** must try not to blink during "Eyes Open" portion of recording.
- **Subject** should not talk during any of the recordings, and should not verbalize answers to the mental arithmetic.
- The alpha signal will be increased during the relaxation recording if **Subject** relaxes mentally; i.e. thinks of a relaxing place.

Subject should try to relax mentally; i.e. think of a relaxing place.

Note: **Display** > **Autoscale Waveforms** and **Autoscale Horizontal** are available DURING recordings to allow scale changes if necessary.



Note The graph window will reduce to fit the **Input values** window on the right side of the display. The **Input values** window shows the alpha-RMS value in a thermometer-like bar display, and can be used as a visual aid to determine fluctuations in alpha-RMS activity. It is only updated during the recording.

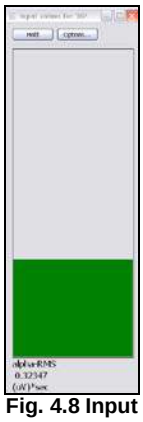


Fig. 4.8 Input Values

5. Verify recording resembles the example data.
   - If similar, click **Continue** and proceed to the next recording.
   - If necessary, click **Redo**.
   - If all required recordings have been completed, click **Done**.

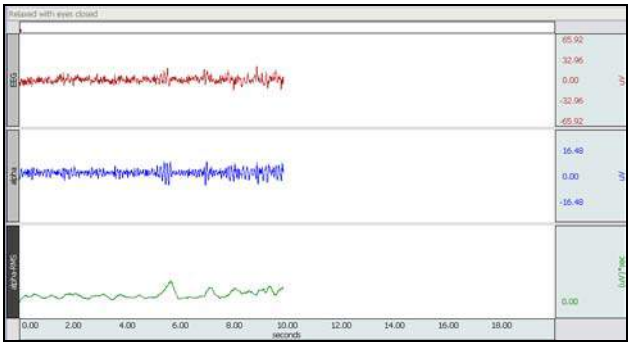


Fig. 4.9 Example Relaxed, Eyes Closed data

If recording does not resemble the Example Data

- If the data is noisy or flatline, check all connections to the MP unit.
- If there is excessive baseline drift or large spikes:
  - Check that electrodes are making good contact with the scalp, cap or wrap is snug and that the cables are not pulling on the electrodes.
  - **Subject** must remain as still as possible.
  - Try relaxation techniques, such as slow breathing or relaxing muscles.

Click **Redo** and repeat Steps 2 – 5 if necessary. Note that once **Redo** is clicked, the most recent recording will be erased.

Mental Arithmetic

6. **Director** prepares a math problem.
   - **Subject** remains seated and relaxed, with eyes closed.
   - **Review** recording steps.

Subject remains relaxed with eyes closed. **Director** prepares a math problem. The problem should be challenging but not too difficult—the point is to make **Subject** really work for the answer, not to stump **Subject**. For example:

2 minus 4…times 3…plus 9…double that…double again…divide by 4...

7. Click **Record**.
8. **Director** verbalizes math problem to **Subject**.
   - **Subject** solves the problem silently with eyes closed.
   - Record for 20 seconds.

Director provides arithmetic problem at a rate that the **Subject** can solve silently.

9. Click **Suspend**.
10. If the **Subject** indicates the math problem was given too quickly, **Redo** the recording.
11. Verify recording resembles the example data.
    - If similar, click **Continue** and proceed to the next recording.
    - If necessary, click **Redo**.
    - If all required recordings have been completed, click **Done**.

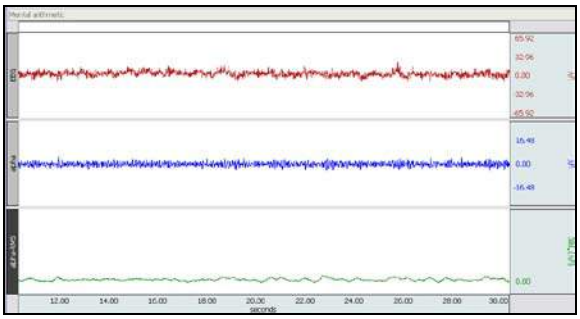


Fig. 4.10 Mental Arithmetic, Eyes Closed

The data may be different for the reasons outlined in Step 5.

Click **Redo** and repeat Steps 7 – 11 if necessary. Note that once **Redo** is clicked, the most recent recording will be erased.

Recording continues…

After Hyperventilation

12. **Subject** is seated.
    - **Review** recording steps.
    - **Subject** hyperventilates for two minutes with eyes closed.

WARNING
Hyperventilation can make **Subject** dizzy and light headed. **Subject** should be seated with **Director** watching. Stop the procedure if **Subject** starts to feel sick or dizzy.

13. As soon as **Subject** stops hyperventilating and is sitting still, Click **Record** immediately.
14. Record for 10 seconds.
15. Click **Suspend**.
16. Verify recording resembles the example data.
    - If similar, click **Continue** and proceed to the next recording.
    - If necessary, click **Redo**.
    - If all required recordings have been completed, click **Done**.

Eyes Open recording

17. **Subject** remains seated and relaxed.
    - **Review** recording steps.
    - **Subject** opens eyes and avoids blinking during recording.
18. Click **Record**.
19. Record for 10 seconds.
20. Click **Suspend**.

Recording continues…

Subject hyperventilates (by breathing rapidly and deeply through mouth) for two minutes with eyes closed.

It is important that recording be resumed as quickly as possible after **Subject** has hyperventilated. However, to avoid EMG artifact, make sure **Subject** has stopped hyperventilating prior to clicking **Record**.

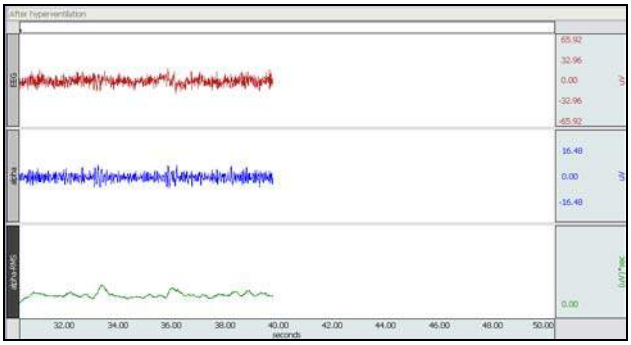


Fig. 4.11 Example after Hyperventilation, Eyes Closed data

The data may be different for the reasons outlined in Step 5, with the following exception:

- It is normal to have some baseline drift after hyperventilation.

Click **Redo** and repeat Steps 12 – 16 if necessary. Note that once **Redo** is clicked, the most recent recording will be erased.

Director instructs **Subject** to open eyes.

21. Verify recording resembles the example data.
    - If similar, click **Continue** and proceed to optional recording section, or click **Done** to finish.
    - If necessary, click **Redo**.

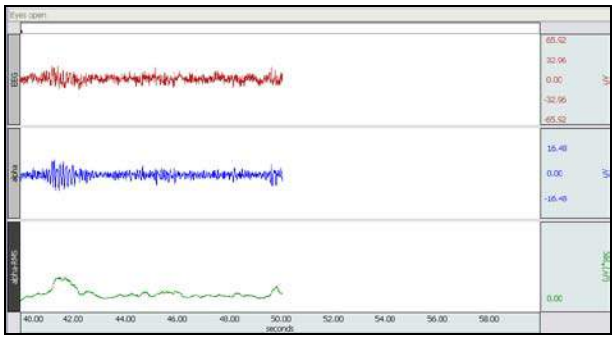


Fig. 4.12 Example Relaxed, Eyes Open data

The data may be different for the reasons outlined in Step 5, with the following exception:

- If the **Subject** blinked, it may have created a large spike in the data. If excessive, consider redoing the recording.

Click **Redo** and repeat Steps 17 – 21 if necessary. Note that once **Redo** is clicked, the most recent recording will be erased.

OPTIONAL ACTIVE LEARNING PORTION

With this lesson you may record additional data by clicking **Continue** following the last recording. Design an experiment to test or verify a scientific principle(s) related to topics covered in this lesson. Although you are limited to this lesson's channel assignments, the electrodes may be moved to different locations on the **Subject**.

Design Your Experiment

Use a separate sheet to detail your experiment design, and be sure to address these main points:

A. ***Hypothesis***

Describe the scientific principle to be tested or verified.

B. ***Materials***

List the materials you will use to complete your investigation.

C. ***Method***

Describe the experimental procedure—be sure to number each step to make it easy to follow during recording.

Run Your Experiment

D. ***Set Up***

Set up the equipment and prepare the subject for your experiment.

E. ***Record***

Use the **Continue**, **Record** and **Suspend** buttons to record as much data as necessary for your experiment.

Click **Done** when you have completed all of the recordings required for your experiment.

Analyze Your Experiment

F. Set measurements relevant to your experiment and record the results in a Data Report.

22. After clicking **Done**, choose an option and click **OK**.

After clicking **Done**, dialog with options will be generated. Make a selection, and continue as directed.

If choosing the **Record from another Subject** option:

- Repeat Setup Steps 5 – 9, and then proceed to Calibration.

23. Remove electrodes.

Remove cap or wrap, the electrode cable pinch connectors, and peel off all electrodes. Discard the electrodes. (BIOPAC electrodes are not reusable.) Wash the electrode gel residue from the skin, using soap and water. The area around the electrode sites may remain red for a few hours, which is quite normal.

END OF RECORDING

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V. DATA ANALYSIS

FAST TRACK Data Analysis

1. Enter the **Review Saved Data** mode.

   - Note Channel Number (CH) designations:

Channel	*Displays*
CH 1	**EEG**
CH 40	**alpha**
CH 41	**alpha RMS**

   - Note measurement box settings:

Channel	*Measurement*
CH 1	**Stddev**
CH 40	**Stddev**
CH 41	**Mean**
CH 40	**Freq**

2. Set up your display window for optimal viewing of the entire recording.

Data Analysis continues…

Detailed Explanation of Data Analysis Steps

If entering **Review Saved Data** mode from the Startup dialog or lessons menu, make sure to choose the correct file.

The data should resemble Fig. 4.13.

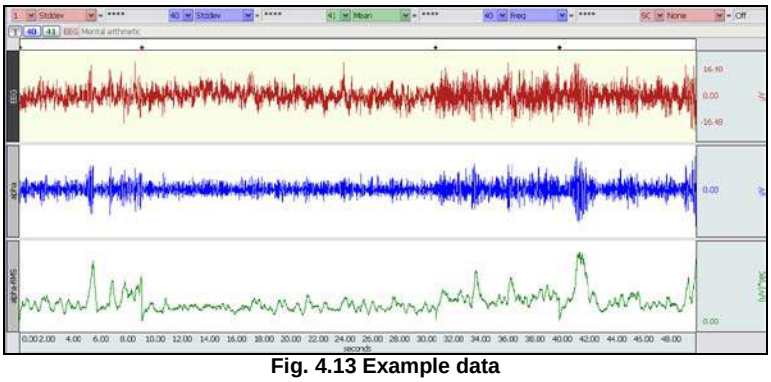

Fig. 4.13 Example data

The measurement boxes are above the marker region in the data window. Each measurement has three sections: channel number, measurement type, and result. The first two sections are pull-down menus that are activated when you click them.

Brief definition of measurements:

Stddev: Standard deviation is a measure of the variability of data points. The advantage of the Stddev measurement is that extreme values or artifacts do not unduly influence the measurement.

Mean: Displays the average value in the selected area.

Freq: Converts the time segment of the selected area to frequency in cycles per second

The "selected area" is the area selected by the **I-beam** tool (including endpoints).

Note: The append event markers mark the beginning of each recording. Click on (activate) the event marker to display its label.

Useful tools for changing view:

Display menu: Autoscale Horizontal, Autoscale Waveforms, Zoom Back, Zoom Forward

Scroll Bars: Time (Horizontal); Amplitude (Vertical)

Cursor Tools: Zoom Tool

Buttons: Overlap, Split, Show Grid, Hide Grid, -, +

Hide/Show Channel: "Alt + click" (Windows) or "Option + click" (Mac) the channel number box to toggle channel display.

3. Use the I-Beam cursor to select the first data recording.

   A

4. Repeat the measurements for each of the data recordings.

   A

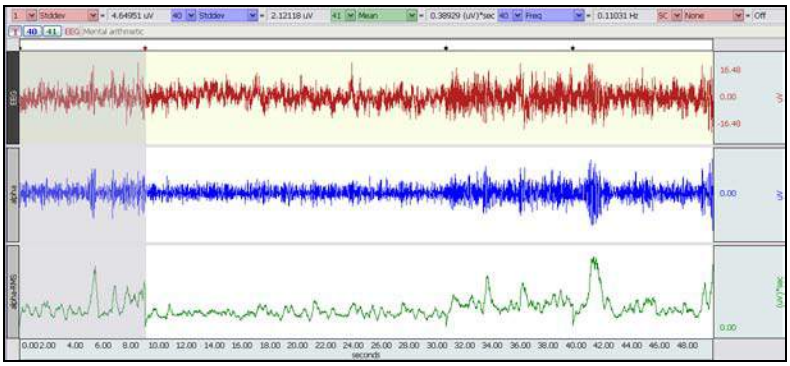

Fig. 4.14 First data recording selected

5. Zoom in on a small section of the Recording 1 data.

Be sure to zoom in far enough so that you can easily measure the frequency of the **alpha** wave.

6. Use the I-Beam cursor to select an area from one peak to the next in the **alpha** band (CH 40).

   B

Fig. 4.15 shows a sample setup for measuring the frequency in the **alpha** band (CH 40).

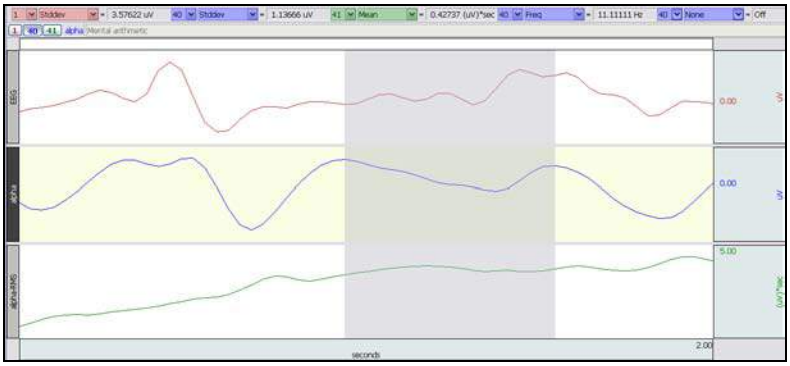

Fig. 4.15 Alpha wave frequency measurement

7. Answer the questions at the end of the Data Report.
8. **Save** or **Print** the Data Report.
9. **Quit** the program.

An electronically editable **Data Report** is located in the journal (following the lesson summary,) or immediately following this Data Analysis section. Your instructor will recommend the preferred format for your lab.

END OF DATA ANALYSIS

END OF LESSON 4

Complete the Lesson 4 Data Report that follows.

ELECTROENCEPHALOGRAPHY II

- *EEG II*

DATA REPORT

Student's Name: _____

Lab Section: _____

Date: _____

I. Data and Calculations

Subject Profile

Name:_____ Height:_____

Age:_____ Gender: Male / Female Weight:_____

Amplitudes

A. **Complete Table 4.1 with the amplitudes of the recorded data** in the control and experimental conditions. Calculate the difference for the Alpha-RMS Mean between the Experimental Conditions and the Control, and then summarize whether the Experimental Mean was larger (+,) smaller (–,) or the same (=) as the Control Mean.

For example: To calculate Alpha-RMS Difference for the "Mental Arithmetic" recording, subtract the "Eyes Closed (Control)" Alpha-RMS value from the measured "Mental Arithmetic" Alpha-RMS value.

Table 4.1

Condition	EEG 1 Stddev	Alpha 40 Stddev	Alpha-RMS 41 Mean	Alpha-RMS Difference (Exp. - Control)	Alpha-RMS Summary (+, –, =)
Eyes closed (**Control**)					
Mental arithmetic					
Recovering from hyperventilation					
Eyes open					

Frequency

B. **What is the frequency of an alpha rhythm from "Eyes closed" data?** 40 Freq =_____Hz

Does this agree with the expected values? Yes No

II. Questions

C. Refer to Table 4.1: When was the general amplitude of the EEG highest?

_____

_____

_____

D. Refer to Table 4.1: When were the alpha wave levels highest?

_____

_____

_____

E. Refer to Table 4.1: How do your results compare with the information presented in the Introduction?

F. Did Subject need to concentrate during math problems? Yes No
How would the level of concentration required affect the data?

G. What might account for the amplitude difference of waves recorded from a subject tested alone, in a darkened room, and subjects tested in a lab full of students?

H. Which conditions produced the lowest alpha activity?

III. OPTIONAL Active Learning Portion

A. ***Hypothesis***

B. ***Materials***

C. ***Method***

D. ***Set Up***

E. ***Experimental Results***

End of Lesson 4 Data Report

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Biopac Student Lab® Lesson 5

ELECTROCARDIOGRAPHY (ECG) I
Introduction

Rev. 08272013

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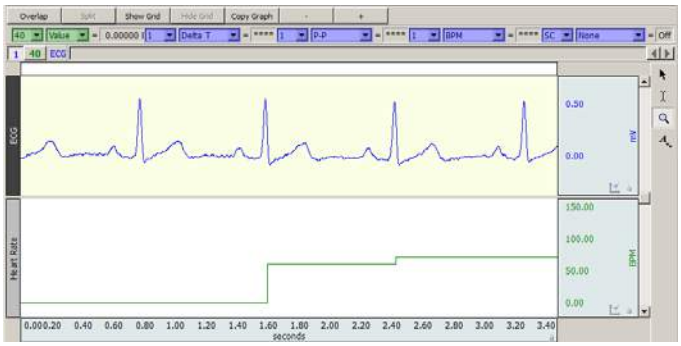


I. INTRODUCTION

The main function of the heart is to pump blood through two circuits:

1. **Pulmonary circuit**: through the lungs to oxygenate the blood and remove carbon dioxide; and
2. **Systemic circuit**: to deliver oxygen and nutrients to tissues and remove carbon dioxide.

Because the heart moves blood through two separate circuits, it is sometimes described as a dual pump.

In order to beat, the heart needs three types of cells:

1. Rhythm generators, which produce an electrical signal (SA node or normal pacemaker);
2. Conductors to spread the pacemaker signal; and
3. Contractile cells (myocardium) to mechanically pump blood.

The Electrical and Mechanical Sequence of a Heartbeat

The heart has specialized **pacemaker** cells that start the electrical sequence of **depolarization** and **repolarization**. This property of cardiac tissue is called **inherent rhythmicity** or **automaticity**. The electrical signal is generated by the **sinoatrial node (SA node)** and spreads to the ventricular muscle via particular conducting pathways: **internodal pathways** and **atrial fibers**, the **atrioventricular node (AV node**,) the **bundle of His**, the right and left **bundle branches**, and **Purkinje fibers** (Fig. 5.1).

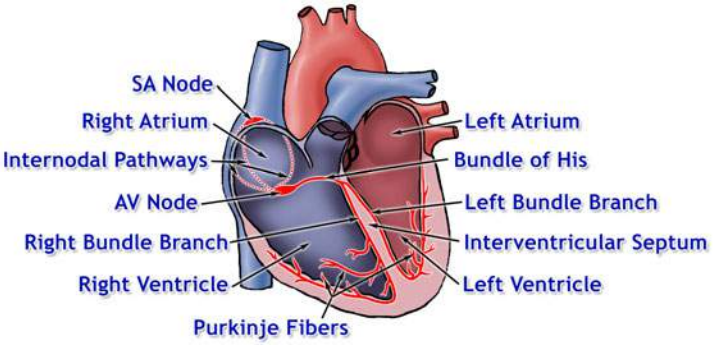


Fig. 5.1 The Heart

When the electrical signal of a depolarization reaches the contractile cells, they contract—a mechanical event called **systole**. When the repolarization signal reaches the myocardial cells, they relax—a mechanical event called **diastole**. Thus, the electrical signals cause the mechanical pumping action of the heart; mechanical events always follow the electrical events (Fig. 5.2).

The **SA node** is the normal pacemaker of the heart, initiating each electrical and mechanical cycle. When the SA node depolarizes, the electrical stimulus spreads through atrial muscle causing the muscle to contract. Thus, the SA node depolarization is followed by atrial contraction.

The SA node impulse also spreads to the **atrioventricular node (AV node**) via the **internodal fibers**. (The wave of depolarization does not spread to the ventricles right away because there is nonconducting tissue separating the atria and ventricles.) The electrical signal is delayed in the AV node for approximately 0.20 seconds when the atria contract, and then the signal is relayed to the **ventricles** via the **bundle of His, right** and **left bundle branches**, and **Purkinje fibers**. The Purkinje fibers relay the electrical impulse directly to ventricular muscle**,** stimulating the ventricles to **contract** (ventricular **systole**). During ventricular systole, ventricles begin to repolarize and then enter a period of diastole (Fig. 5.2).

Although the heart generates its own beat, the heart rate (beats per minute or BPM) and strength of contraction of the heart are modified by the **sympathetic** and **parasympathetic** divisions of the autonomic nervous system.

- The sympathetic division increases automaticity and excitability of the SA node, thereby increasing heart rate. It also increases conductivity of electrical impulses through the atrioventricular conduction system and increases the force of atrioventricular contraction. Sympathetic influence increases during inhalation.
- The parasympathetic division decreases automaticity and excitability of the SA node, thereby decreasing heart rate. It also decreases conductivity of electrical impulses through the atrioventricular conduction system and decreases the force of atrioventricular contraction. Parasympathetic influence increases during exhalation.

The Electrocardiogram (ECG)

Just as the electrical activity of the pacemaker is communicated to the cardiac muscle, "echoes" of the depolarization and repolarization of the heart are sent through the rest of the body. By placing a pair of very sensitive receivers (**electrodes**) on other parts of the body, the echoes of the heart's electrical activity can be detected. The record of the electrical signal is called an **electrocardiogram (ECG).** You can infer the heart's mechanical activity from the ECG. Electrical activity varies through the ECG cycle as shown below (Fig. 5.2):

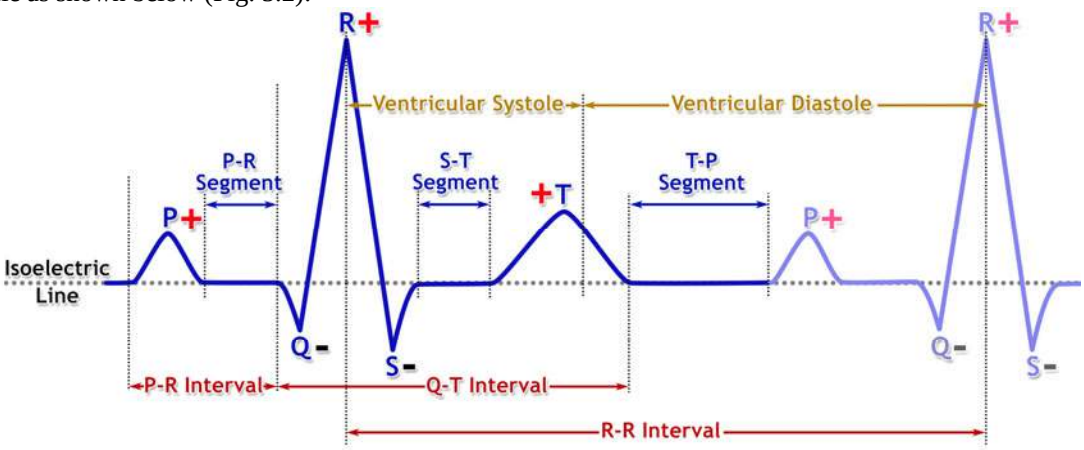


Fig. 5.2 Components of the ECG & Electrical and mechanical events of the cardiac cycle

Because the ECG reflects the electrical activity, it is a useful "picture" of heart activity. If there are interruptions of the electrical signal generation or transmission, the ECG changes. These changes can be useful in diagnosing changes within the heart. During exercise, however, the position of the heart itself changes, so you cannot standardize or quantify the voltage changes.

Components of the ECG

The electrical events of the heart (ECG) are usually recorded as a pattern of a baseline (isoelectric line,) broken by a **P** wave, a **QRS** complex, and a **T** wave. In addition to the wave components of the ECG, there are intervals and segments (Fig. 5.2).

- The **isoelectric line** is a point of departure of the electrical activity of depolarizations and repolarizations of the cardiac cycles and indicates periods when the ECG electrodes did not detect electrical activity.
- An **interval** is a time measurement that includes waves and/or complexes.
- A **segment** is a time measurement that does not include waves and/or complexes.

Table 5.1 Components of the ECG & Typical Lead II Values*

ECG COMPONENT		*Measurement area…*	*Represent…*	**Duration** *(seconds)*	**Amplitude** (millivolts)
Waves	**P**	begin and end on isoelectric line (baseline); normally upright in standard limb leads	depolarization of the right and left atria.	0.07 – 0.18	< 0.25
	QRS complex	begin and end on isoelectric line (baseline) from start of Q wave to end of S wave	depolarization of the right and left ventricles. Atrial repolarization is also part of this segment, but the electrical signal for atrial repolarization is masked by the larger QRS complex (see Fig. 5.2)	0.06 – 0.12	0.10 – 1.50
	T	begin and end on isoelectric line (baseline)	repolarization of the right and left ventricles.	0.10 – 0.25	< 0.5
Intervals	**P-R**	from start of P wave to start of QRS complex	time from the onset of atrial depolarization to the onset of ventricular depolarization.	0.12-0.20	
	Q-T	from start of QRS complex to end of T wave	time from onset of ventricular depolarization to the end of ventricular repolarization. It represents the refractory period of the ventricles.	0.32-0.36	
	R-R	from peak of R wave to peak of succeeding R wave	time between two successive ventricular depolarizations.	0.80	
Segments	**P-R**	from end of P wave to start of QRS complex	time of impulse conduction from the AV node to the ventricular myocardium.	0.02 – 0.10	
	S-T	between end of S wave and start of T wave	period of time representing the early part of ventricular repolarization during which ventricles are more or less uniformly excited.	< 0.20	
	T-P	from end of T wave to start of successive P wave	time from the end of ventricular repolarization to the onset of atrial depolarization.	0.0 – 0.40	

* Notes: Tabled values represent results from a typical Lead II setup (wrist and ankle electrode placement) with Subject heart rate ~75 BPM. Values are influenced by heart rate and placement; values for torso placement would be different.

Leads

The particular arrangement of two electrodes (one **positive**, one **negative**) with respect to a third electrode (the **ground**) is called a **lead**. The electrode positions for the different leads have been standardized. For this lesson, you will record from **Lead II**, which has a positive electrode on the left ankle, a negative electrode on the right wrist, and the ground electrode on the right ankle. Typical Lead II values are shown in Table 5.1.

The dominant ECG component in any normal standard lead record is the QRS complex. Usually, in a Lead II record the Q and S waves are small and negative and the R wave is large and positive as shown in Fig. 5.2. However, it is important to note many factors, normal and abnormal, determine the duration, form, rate, and rhythm of the QRS complex.

- Normal factors include body size (BSA) and distribution of body fat, heart size (ventricular mass,) position of the heart in the chest relative to lead locations, metabolic rate, and others.

For example, in a person who has a high diaphragm, the apex of the heart may be shifted slightly upward and to the person's left. This change in the position of the heart alters the "electrical picture" of ventricular depolarization seen by the Lead II electrodes, resulting in decreased positivity of the R wave and increased negativity of the S wave. In other words, the positive amplitude of the R wave decreases and the negative amplitude of the S wave increases.

Similar changes in the Lead II QRS complex may be observed in a person, an athlete for example, who has no cardiac disease but does have a larger than normal left ventricular mass. In fact the decrease in R wave positivity coupled with the increase in S wave negativity may be so extreme as to give rise to the mistaken impression that the R wave has become inverted, when in reality the inverted spike is an enlarged S wave preceded by a much smaller but still positive R wave. When the amplitudes of Lead II Q, R, and S waves are all negative, the result is an abnormal inverted QRS complex.

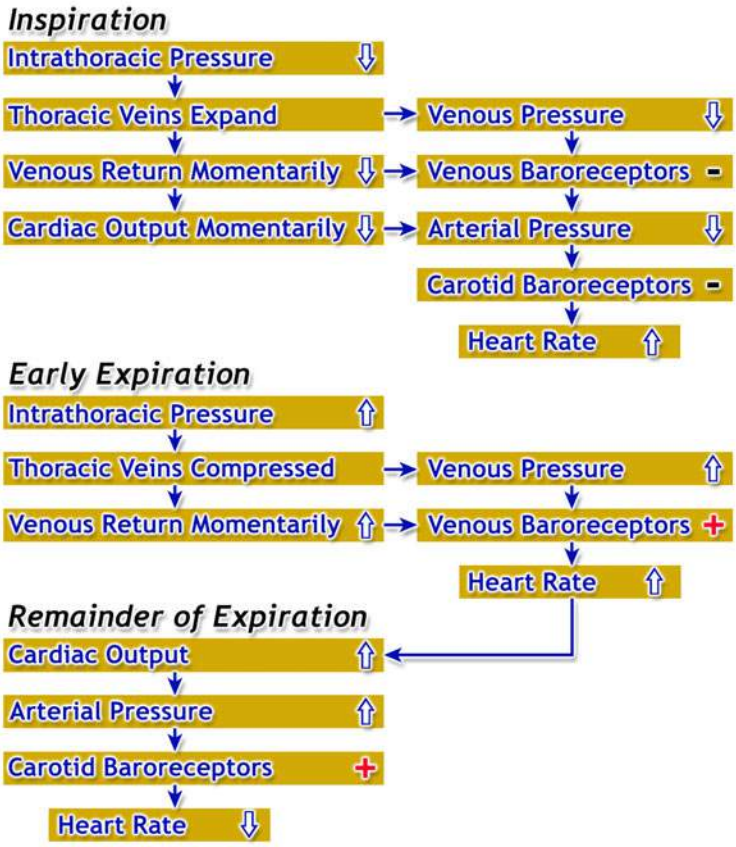
- Abnormal factors include hyper- and hypothyroidism, ventricular hypertrophy (observed for example, in chronic valvular insufficiency,) morbid obesity, essential hypertension and many other pathologic states. A more detailed discussion of QRS changes in response to normal and abnormal factors requires an introduction to cardiac vectors, for which the reader is referred to Lesson 6.

Effects of the Resting Respiratory Cycle on Heart Rate

Temporary minor increases and decreases in heart rate associated with the resting respiratory cycle reflect heart rate adjustments made by systemic arterial and systemic venous pressure receptor (baroreceptor) reflexes in response to the cycling of intrathoracic pressure (Fig. 5.4).

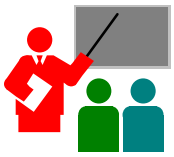
When inspiratory muscles contract, pressure within the thorax (intrathoracic pressure) decreases, allowing thoracic veins to slightly expand. This causes a momentary drop in venous pressure, venous return, cardiac output, and systemic arterial blood pressure. The carotid sinus reflex normally decreases heart rate in response to a rise in carotid arterial blood pressure. However, the momentary drop in systemic arterial blood pressure during inspiration reduces the frequency of carotid baroreceptor firing, causing a momentary increase in heart rate.

When inspiratory muscles relax, resting expiration passively occurs. During early resting expiration, intrathoracic pressure increases causing compression of thoracic veins, momentarily increasing venous pressure and venous return. In response, systemic venous baroreceptors reflexively increase heart rate. However, the slight increase in heart rate is temporary because it increases cardiac output and systemic arterial blood pressure, which increases carotid baroreceptor firing causing heart rate to decrease.



Source: Richard Pflanzer, Ph.D., Associate Professor
Indiana University School of Medicine, Purdue University School of Science

Fig. 5.3 Effects of the Resting Respiratory Cycle on Heart Rate



The average resting heart rate for adults is between 60-80 beats/min. (Average 70 bpm for males and 75 bpm for females.) Slower heart rates are typically found in individuals who regularly exercise. Athletes are able to pump enough blood to meet the demands of the body with resting heart rates as low as 50 beats/min. Athletes tend to develop larger hearts, especially the muscle in the left ventricle—a condition known as "left ventricular hypertrophy." Because athletes (usually) have larger and more efficient hearts, their ECGs may exhibit differences other than average resting heart rate. For instance, low heart rate and hypertrophy exhibited in sedentary individuals can be an indication of failing hearts but these changes are "normal" for well-trained athletes.

Because ECGs are widely used, basic elements have been standardized to simplify reading ECGs. ECGs have standardized grids of lighter, smaller squares and, superimposed on the first grid, a second grid of darker and larger squares (Fig. 5.4). The smaller grid always has time units of 0.04 seconds on the x-axis and the darker vertical lines are spaced 0.2 seconds apart. The horizontal lines represent amplitude in mV. The lighter horizontal lines are 0.1 mV apart and the darker grid lines represent 0.5 mV. In this lesson, you will record the ECG under four conditions.

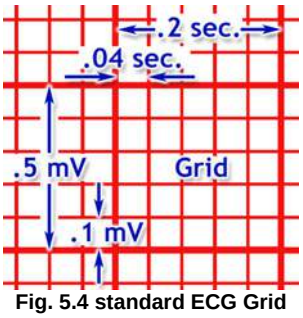


Fig. 5.4 standard ECG Grid

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II. EXPERIMENTAL OBJECTIVES

1) To become familiar with the electrocardiograph as a primary tool for evaluating electrical events within the heart.
2) To correlate electrical events as displayed on the ECG with the mechanical events that occur during the cardiac cycle.
3) To observe rate and rhythm changes in the ECG associated with body position and breathing.

III. MATERIALS

- BIOPAC Electrode Lead Set (SS2L)
- BIOPAC Disposable Electrodes (EL503,) 3 electrodes per subject
- BIOPAC Electrode Gel (GEL1) and Abrasive Pad (ELPAD) *or* Skin cleanser or alcohol prep
- Mat, cot or lab table and pillow for Supine position
- Biopac Student Lab System: BSL 4 software, MP36, MP35 or MP45 hardware
- Computer System (Windows or Mac)

IV. EXPERIMENTAL METHODS

A. SETUP

FAST TRACK Setup

1. Turn the computer ON.
   - If using an MP36/35 unit, turn it **OFF**.
   - If using an MP45, make sure USB cable is connected and "Ready" light is **ON**.
2. **Plug the equipment in** as follows:
   Electrode Lead Set (SS2L)—CH 1
3. Turn **ON** the MP36/35 unit.
4. Clean and abrade skin.
5. Attach three electrodes on **Subject** as shown in Fig. 5.6.

Setup continues…

Detailed Explanation of Setup Steps

Fig. 5.5 MP3X (top) and MP45 (bottom) hardware connections

If the skin is oily, clean electrode sites with soap and water or alcohol before abrading.

If electrode is dry, apply a drop of gel.

Remove any jewelry on or near the electrode sites.

Place one electrode on the medial surface of each leg, just above the ankle. Place the third electrode on the right anterior forearm at the wrist (same side of arm as the palm of hand).

For optimal electrode contact, place electrodes on skin at least 5 minutes before start of Calibration.

6. Clip the Electrode Lead Set (SS2L) to the electrodes following the color code (Fig. 5.6).
   - RIGHT forearm = WHITE lead
   - RIGHT leg = BLACK lead (ground)
   - LEFT leg = RED lead

Fig. 5.6 Lead II Setup

The pinch connectors work like a small clothespin, but will only latch onto the nipple of the electrode from one side of the connector.

7. **Subject** gets in supine position (lying down, face up) and relaxes (Fig. 5.7).

Position the electrode cables so that they are not pulling on the electrodes. Connect the electrode cable clip to a convenient location on **Subject's** clothes.

Fig. 5.7 Positioning (supine)

8. Start the BIOPAC Student Lab program.
9. Choose lesson "**L05 – Electrocardiography (ECG) I**" and click **OK**.

Start Biopac Student Lab by double-clicking the Desktop shortcut.

10. Type in a unique **filename** and click **OK**.
11. ***Optional***: Set Preferences.
    - Choose File > **Lesson Preferences**.
    - Select an option.
    - Select the desired setting and click **OK**.

A folder will be created using the filename. This same filename can be used in other lessons to place the **Subject's** data in a common folder.

This lesson has optional Preferences for data and display while recording. Per your Lab Instructor's guidelines, you may set:

Grids: Show or hide gridlines
ECG filter: Set bandwidth
Heart Rate Data: Calculate and display Heart Rate data
Time Scale: Set the full screen time scale with options from 10 to 20 seconds.
Lesson Recordings: Specific recordings may be omitted based on instructor preferences.

END OF SETUP

B. CALIBRATION

The Calibration procedure establishes the hardware's internal parameters (such as gain, offset, and scaling) and is critical for optimal performance. **Pay close attention to Calibration.**

FAST TRACK Calibration

1. **Subject** is supine and relaxed, with eyes closed.
2. Click **Calibrate**.
   - **Subject** remains relaxed with eyes closed.
   - Wait for Calibration to stop.
3. Verify recording resembles example data.
   - If similar, click **Continue** and proceed to Data Recording.
   - If necessary, click **Redo Calibration**.

END OF CALIBRATION

Detailed Explanation of Calibration Steps

Subject must remain relaxed and as still throughout calibration to minimize baseline shift and EMG artifact.

Calibration lasts eight seconds.

There should be a recognizable ECG waveform with a baseline at or near 0 mV, little EMG artifact and no large baseline drift.

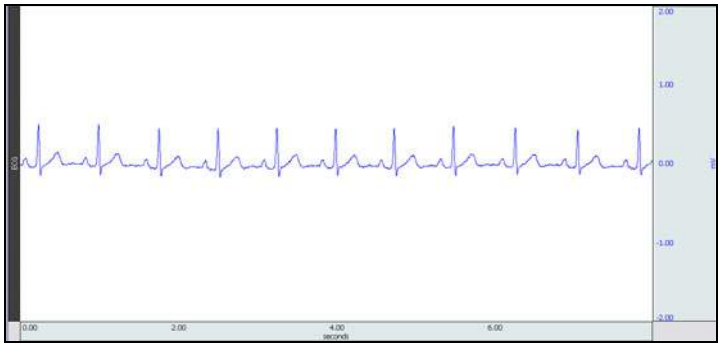

Fig. 5.8 Example Calibration data

If recording does not resemble the Example Data

- If the data is noisy or flatline, check all connections to the MP unit.
- If the ECG displays baseline drift or excessive EMG artifact:
  - Verify electrodes are making good contact with the skin and that the leads are not pulling on the electrodes.
  - Make sure Subject is in a relaxed position.

Click **Redo Calibration** and repeat Steps 1 – 3 if necessary.

C. DATA RECORDING

FAST TRACK Recording

1. **Subject** remains supine and relaxed, with eyes closed.
   - **Subject** must remain still.
   - **Review** recording steps.

Supine

2. Click **Record**.
3. **Subject** remains supine and relaxed, with eyes closed.
4. Record for 20 seconds.
5. Click **Suspend**.
6. Verify recording resembles the example data.
   - If similar, click **Continue** and proceed to next recording.
   - If necessary, click **Redo**
   - If all required recordings have been completed, click **Done**.

Recording continues…

Detailed Explanation of Recording Steps

Four conditions* will be recorded: Supine, Seated, Breathing deeply, and After exercise. **Subject** performs tasks in the intervals between recordings.

***IMPORTANT**

This procedure assumes that all lesson recordings are enabled in Lesson Preferences, which may not be the case for your lab. Always match the recording title to the recording reference in the journal and disregard any references to excluded recordings.

Hints for obtaining optimal data:

To minimize EMG artifact and baseline drift:

- **Subject's** arms and legs must be relaxed.
- **Subject** must remain still and should not talk during any recordings.
- Make sure electrodes do not peel up and that the leads do not pull on the electrodes.

The ECG waveform should have a baseline at or near 0 mV and should not display large baseline drifts or significant EMG artifact. The Heart Rate (BPM) data will not be accurate until after the first two cardiac (ECG) cycles after which there should not be sporadic variations that go out of the visible range.

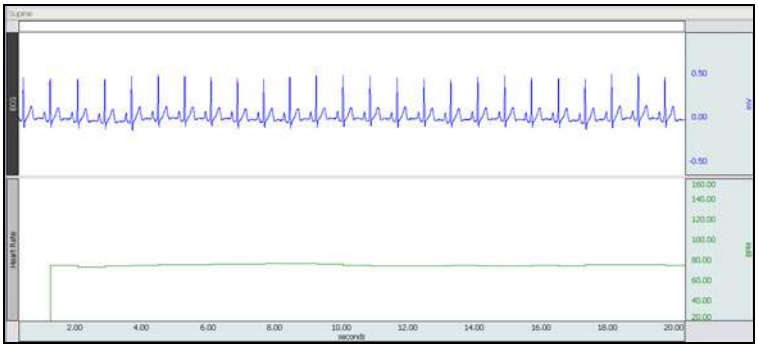

Fig. 5.9 Example Supine data

<u>If recording does not resemble the Example Data</u>

- If the data is noisy or flatline, check all connections to the MP unit.
- If the ECG displays excessive baseline drift or EMG artifact, or if the Heart Rate (BPM) data shows sporadic values:
  - Verify electrodes are making good contact with the skin and that the leads are not pulling on the electrodes.
  - Make sure **Subject** is in a relaxed position.
- Click **Redo** and repeat Steps 2 – 6 if necessary. Note that once **Redo** is clicked, the most recent recording will be erased.

Seated

- **Review** recording steps.

7. **Subject** gets up quickly and then settles into a seated position (Fig. 5.10).

Subject should sit with arms relaxed at side of body and hands apart in lap, with legs flexed at knee and feet supported for seconds 21 – 40.

Fig. 5.10 Positioning (seated)

8. Once **Subject** is seated and still, click **Record**.
9. Record for 20 seconds.
10. Click **Suspend**.
11. Verify recording resembles the example data.
    - If similar, click **Continue** and proceed to the next recording.

In order to capture the heart rate variation, click Record as quickly as possible after **Subject** sits and relaxes.

Subject remains seated, relaxed, and breathing normally.

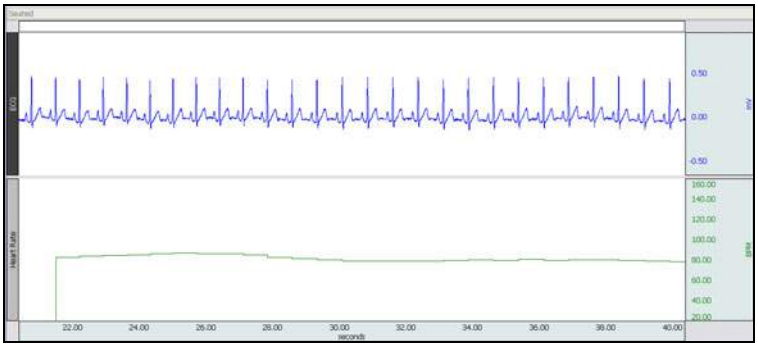

Fig. 5.11 Example Seated data

- If necessary, click **Redo**.
- If all required recordings have been completed, click **Done**.

The data description is the same as outlined in Step 6.

Click **Redo** if necessary. The **Subject** must return to the Supine position for at least 5 minutes before repeating Steps 7 – 11.

Note that once **Redo** is clicked, the most recent recording will be erased.

Recording continues…

Deep Breathing

- **Review** recording steps.

12. Click **Record**.
13. **Subject** inhales and exhales slowly and completely as possible for five prolonged (slow) breath cycles.
    - **Recorder** presses F4 at the start of each inhale.
    - **Recorder** presses F5 at the start of each exhale.
14. Click **Suspend**.
15. Verify recording resembles the example data.
    - If similar, click **Continue** and proceed to the next recording.
    - If necessary, click **Redo**.
    - If all required recordings have been completed, click **Done**.

Subject remains seated.

Note It is important to breathe with long, slow, deep breaths to help minimize EMG artifact.

If possible, the **Subject** should breathe through nose so the **Recorder** can clearly observe the start of each inhale and exhale.

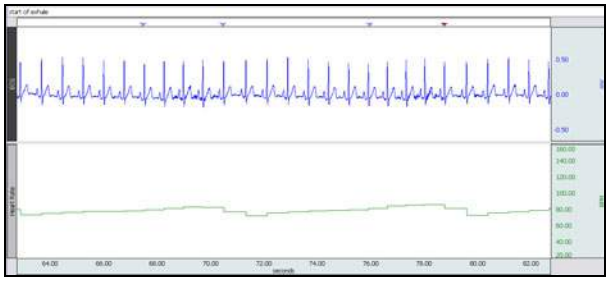

Fig. 5.12 Example Deep Breathing data

The data description is the same as outlined in Step 6 with the following exception:

- The ECG data may exhibit some baseline drift during deep breathing which is normal and unless excessive, does not necessitate **Redo**.

Click **Redo** and repeat Steps 12 – 15 if necessary. Note that once **Redo** is clicked, the most recent recording will be erased.

After exercise

- **Review** recording steps.

16. **Subject** exercises to elevate heart rate.
    - If electrode leads were unclipped, clip them back on.
    - Following exercise, **Subject** sits down and relaxes.
17. **Record** for 60 seconds.
18. Click **Suspend**.
19. Verify recording resembles the example data.
    - If similar, click **Continue** to proceed to optional recording section, or click **Done** if finished.

Recording continues…

Subject should perform an exercise to elevate his/her heart rate fairly rapidly, such as running up stairs, push-ups, or jumping-jacks.

Note You may remove the electrode cable pinch connectors so that **Subject** can move about freely, but **do not remove the electrodes**.

If you do remove the cable pinch connectors, you must reattach them following the precise color placement in Fig. 5.6 prior to clicking **Record**.

When seated, **Subject's** arms must be relaxed and at sides of body, with arms relaxed and feet supported.

In order to capture the heart rate variation, it is important that you resume recording as quickly as possible after **Subject** has performed the exercise. However, it is also important that you do not click **Record** while **Subject** is exercising or you will capture motion artifact.

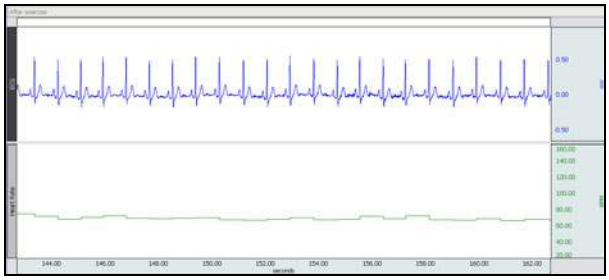

Fig. 5.13 Example After Exercise data

- If necessary, click **Redo**.

The data description is the same as outlined in Step 6, with the following exception:

- The ECG data may exhibit some baseline drift which is normal and unless excessive, does not necessitate **Redo**.

Click **Redo** and repeat Steps 16 – 19 if necessary. Note that once **Redo** is clicked, the most recent recording will be erased.

OPTIONAL ACTIVE LEARNING PORTION

With this lesson you may record additional data segments by clicking **Continue** following the last recording segment. Design an experiment to test or verify a scientific principle(s) related to topics covered in this lesson. Although you are limited to this lesson's channel assignments, the electrodes may be moved to different locations on the **Subject**.

Design Your Experiment

Use a separate sheet to detail your experiment design, and be sure to address these main points:

A. ***Hypothesis***

Describe the scientific principle to be tested or verified.

B. ***Materials***

List the materials you will use to complete your investigation.

C. ***Method***

Describe the experimental procedure—be sure to number each step to make it easy to follow during recording.

Run Your Experiment

D. ***Set Up***

Set up the equipment and prepare the subject for your experiment.

E. ***Record***

Use the **Continue**, **Record** and **Suspend** buttons to record as many segments as necessary for your experiment.
Click **Done** when you have completed all of the segments required for your experiment.

Analyze Your Experiment

F. Set measurements relevant to your experiment and record the results in a Data Report.

20. After clicking **Done**, choose an option and click **OK**.

If choosing the **Record from another Subject** option:

- Repeat Setup Steps 6 – 9, and then proceed to Calibration.

21. Remove the electrodes.

Remove the electrode cable pinch connectors and peel off all electrodes. Discard the electrodes. (BIOPAC electrodes are not reusable.) Wash the electrode gel residue from the skin, using soap and water. The electrodes may leave a slight ring on the skin for a few hours which is quite normal.

END OF RECORDING

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Indiana University School of Medicine
Purdue University School of Science

William McMullen
Vice President, BIOPAC Systems, Inc.

V. DATA ANALYSIS

In this section, you will examine ECG components of cardiac cycles and measure amplitudes (mV) and durations (msecs) of the ECG components.

Note: Interpreting ECGs is a skill that requires practice to distinguish between normal variation and those arising from medical conditions. Do not be alarmed if your ECG is different than the normal values and references in the Introduction.

FAST TRACK Data Analysis

1. Enter the **Review Saved Data** mode.

   - Note Channel Number (CH) designation:

     CH 1 **ECG** (Lead II)
     CH 40 **Heart Rate**

   - Note measurement box settings:

     Channel *Measurement*
     CH 40 **Value**
     CH 1 **Delta T**
     CH 1 **P-P**
     CH 1 **BPM**

Data Analysis continues…

Detailed Explanation of Data Analysis Steps

If entering **Review Saved Data** mode from the Startup dialog or lessons menu, make sure to choose the correct file.

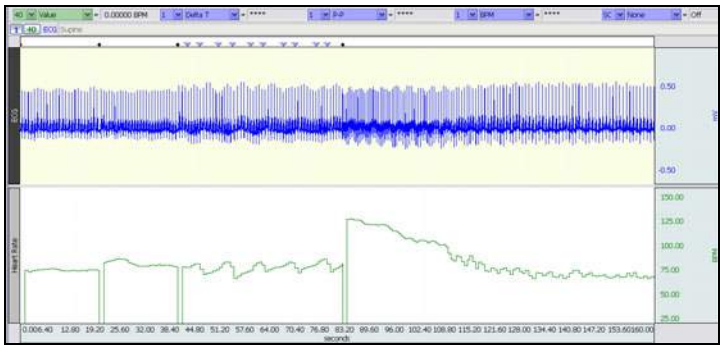


Fig. 5.14 Example data

The measurement boxes are above the marker region in the data window. Each measurement has three sections: channel number, measurement type, and result. The first two sections are pull-down menus that are activated when you click them.

Brief definition of measurements:

Value: Displays the amplitude value at the point selected by the I-beam cursor. If an area is selected, displays the value of the endpoint based on the direction the cursor was dragged.

- CH 40 heart rate data is only updated at the end of an R-R interval so it remains constant within an R-R interval; therefore, the Value (BPM) measurement will be accurate from any selected point in the R-R interval.
- Single point Values will be shown when placing the Arrow cursor over the data while holding down the left mouse button.

Delta T: Displays the amount of time in the selected area (the difference in time between the endpoints of the selected area).

P-P (Peak-to-Peak)**:** Subtracts the minimum value from the maximum value found in the selected area.

BPM: *Use only if CH 40 was not recorded.* The **B**eats **P**er **M**inute measurement first calculates the difference in time between the beginning and end of the selected area (seconds/beat,) and divides this value into 60 seconds/minute.

Rate Mean: If CH 40 Heart Rate data was recorded, use the Rate Mean measurement, which is designed specifically for rate data and calculates accurate statistical means using one value only for every cardiac cycle. This avoids any unintentional weighting due to time variation in heart rate, unlike the amplitude "Mean" measurement.

The “selected area” is the area selected by the **I-beam** tool (including endpoints).

2. Set up your display window for optimal viewing of three complete cardiac cycles from the initial "**Supine**" segment.

NOTE: For accurate BPM data go past the first two cardiac cycles.

Textual notes (such as identifying components of the ECG wave) can be inserted into the graph by using the **Annotation** tool. This tool will place a small editable text box anywhere in the waveform.

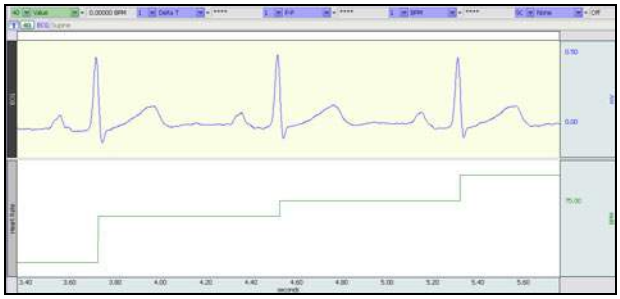


Fig. 5.15 Zoom in on "Supine" data

Note: The append event markers mark the beginning of each recording. Click (activate) the event marker to display its label.

Useful tools for changing view:

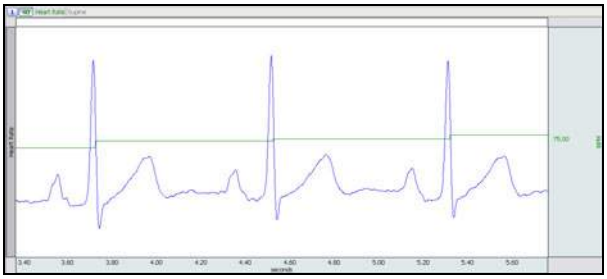
Display menu: Autoscale Horizontal, Autoscale Waveforms, Zoom Back, Zoom Forward

Scroll Bars: Time (Horizontal); Amplitude (Vertical)

Cursor Tools: Zoom Tool

Buttons: Overlap, Split, Adjust Baseline (Up, Down,) Show Grid, Hide Grid, -, +

Hide/Show Channel: "Alt + click" (Windows) or "Option + click" (Mac) the channel number box to toggle channel display.



The Heart Rate channel is updated at the end of each R-R interval, so it will initially appear "out of sync," or delayed by one interval. (See Fig. 5.17 for illustration.)

Fig. 5.16 Overlap sample: Heart Rate and ECG after supine Subject is seated

Adjust Baseline allows you to position the waveform up or down in small increments so that the baseline (isoelectric line) can be exactly zero. After **Adjust Baseline** is pressed, **Up** and **Down** buttons are generated. Simply click these to move the waveform up or down. This is not needed to get accurate amplitude measurements, but may be desired before making a printout, or when using grids.

3. For measuring heart rate, use the cursor to select any data point within an R-R interval.

A

Note that the CH 40 Value measurement displays the BPM for the interval preceding the current R-R interval.

If CH 40 Heart Rate data was not recorded, use CH 1 BPM measurement to determine the heart rate; select from R wave peak to R wave peak as precisely as possible.

Follow the examples shown above to complete all the measurements required for the Data Report.

Data Analysis continues…

4. Take measurements within two other R-R intervals in the current segment.

   A

5. Repeat measurements on the other segments as required for the Data Report.

   A

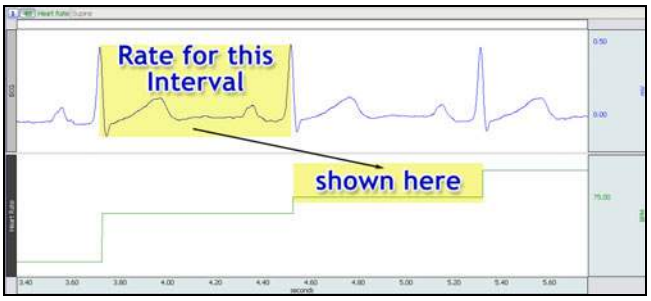


Fig. 5.17 Data point selection for Heart Rate data correlated to ECG data

6. Hide CH 40.

The remaining measurements use ECG data only. To hide Heart Rate data display and focus on ECG data, Alt + click (Windows) or Option + click (Mac) the "40" channel number box.

7. **Zoom** in on a single cardiac cycle from "**Supine**" segment.
8. Measure Ventricular Systole and Diastole.

   B

For Ventricular Systole and Diastole measurements, the T wave reference point for the selected area is 1/3 of the way down the descending portion of the T wave; if necessary, see Fig. 5.2 and Table 5.1 in the Introduction PDF for selected area details.

9. Repeat measurements for "**After exercise**" segment.

   B

Measurement data starts at the append event marker labeled "**After exercise**."

10. **Zoom** in on a single cardiac cycle from "**Supine**" segment.
11. Use the I-Beam cursor to select segments and measure the durations and wave amplitudes required for the Data Report. Use P-P measurement to obtain amplitudes.

    C

Select the components of the ECG as specified in the Introduction and gather wave amplitude data for 3 cycles using the P-P measurement. If necessary, see Fig. 5.2 and Table 5.1 in the Introduction for selected area details.

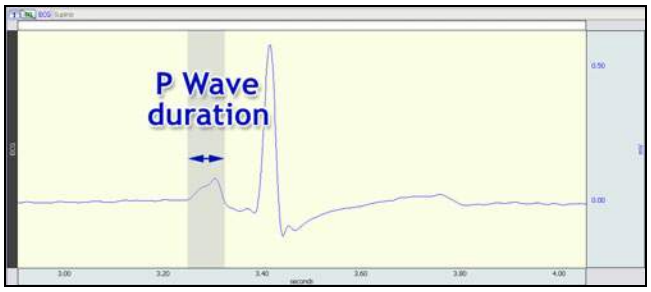


Fig. 5.18 Measuring P wave duration (Delta T) and amplitude (P-P)

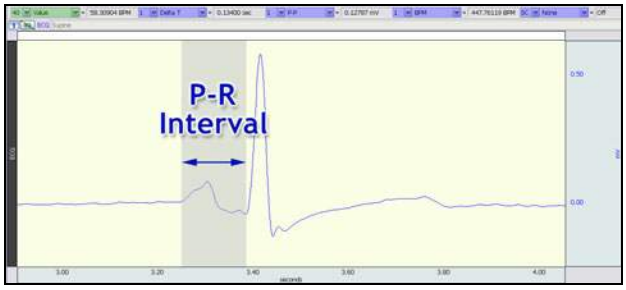


Fig. 5.19 Selection of P-R Interval

12. **Zoom** in on a single cardiac cycle from "**After exercise**" segment.
13. Repeat duration and amplitude (P-P) measurements using "**After exercise**" data as required for the Data Report.

    C

Follow the examples shown above to complete all the measurements required for your Data Report.

Data Analysis continues…

14. **OPTIONAL:** Using the **Annotation** tool, insert text boxes identifying the ECG components in the selected area. Copy and paste this graph to the Data Report at the end of Section C.

Use the **Annotation** Tool to insert text boxes into the graph identifying the ECG components in the selected portion, and then drag them to their correct locations within the ECG waveform.

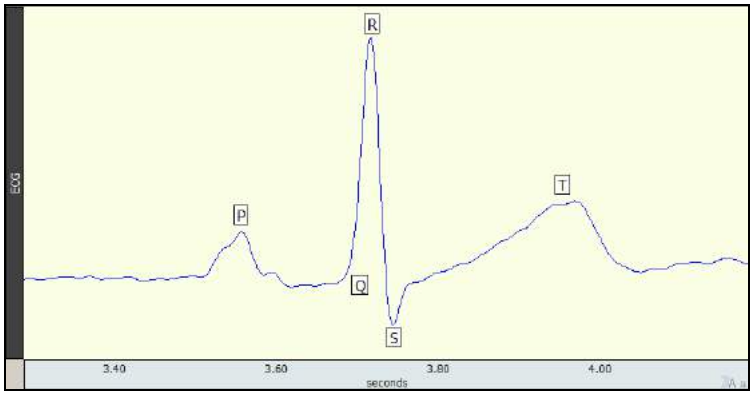


Fig 5.20 Example of ECG Component Annotations

- Use the **Copy Graph** button to copy the selected area.
- Use the contextual menu in the Journal to paste the graph into the Data Report.

15. Answer the questions at the end of the Data Report.
16. **Save** or **Print** the data file.
17. **Quit** the program.

An electronically editable **Data Report** is located in the journal (following the lesson summary,) or immediately following this Data Analysis section. Your instructor will recommend the preferred format for your lab.

END OF DATA ANALYSIS

END OF LESSON 5

Complete the Lesson 5 Data Report that follows.

ELECTROCARDIOGRAPHY I

- *ECG I*

DATA REPORT

Student's Name: _____
Lab Section: _____
Date: _____

I. Data and Calculations

Subject Profile

Name:_____ Height:_____

Age:_____ Gender: Male / Female Weight:_____

A. Heart Rate

Complete the following tables with the lesson data indicated, and calculate the Mean as appropriate;

Table 5.2

Recording: Condition	Cardiac Cycle 40 Value 1	2	3	Mean (calculate)
Supine				
Seated				
Start of inhale				
Start of exhale				
After exercise				

- If CH 40 was not recorded, use 1 BPM.

B. Ventricular Systole and Diastole

Table 5.3

Condition	Duration (ms) 1 Delta T	
	Ventricular Systole	Ventricular Diastole
Supine		
After exercise		

C. Components of the ECG

Table 5.4

Condition: Supine Recording (measurements taken from 3 cardiac cycles)										
ECG Component	Normative Values Based on resting heart rate 75 BPM		Duration (ms) 1 Delta T				Amplitude (mV) 1 P-P			
			1	2	3	Mean (calc)	1	2	3	Mean (calc)
Waves	Dur. (sec)	Amp. (mV)								
P	.07 - .18	< .20								
QRS Complex	.06 - .12	.10 – 1.5								
T	.10 - .25	< .5								
Intervals	Duration (seconds)									
P-R	.12 - .20									
Q-T	.32 - .36									
R-R	.80									
Segments	Duration (seconds)									
P-R	.02 - .10									
S-T	< .20									
T-P	0 - .40									

Table 5.5

Condition: After Exercise Recording (measurements taken from 1 cardiac cycle)				
ECG Component	**Normative Values** Based on resting heart rate 75 BPM		**Duration (ms)** 1 Delta T	**Amplitude (mV)** 1 P-P
Waves	Dur. (sec)	Amp. (mV)		
P	.07 - .18	< .20		
QRS Complex	.06 - .12	.10 – 1.5		
T	.10 - .25	< .5		
Intervals	Duration (seconds)			
P-R	.12 - .20			
Q-T	.32 - .36			
R-R	.80			
Segments	Duration (seconds)			
P-R	.02 - .10			
S-T	< .20			
T-P	0 - .40			

Note Interpreting ECGs is a skill that requires practice to distinguish between normal variation and those arising from medical conditions. Do not be alarmed if your ECG does not match the "Normative Values."

II. Questions

D. Using data from table 5.2:

1) Explain the changes in heart rate between conditions. Describe the physiological mechanisms causing these changes.

2) Are there differences in the cardiac cycle with the respiratory cycle ("Start of inhale-exhale" data)?

E. Using data from table 5.3:

1) What changes occurred in the duration of systole and diastole between resting and post-exercise?

F. Using data from tables 5.4 and 5.5:

1) Compared to the resting state, do the durations of the ECG intervals and segments decrease during exercise? Explain

2) Compare your ECG data to the normative values. Explain any differences.

3) Compare ECG data with other groups in your laboratory. Does the data differ? Explain why this may not be unusual. _____

_____

G. In order to beat, the heart needs three types of cells. Describe the cells and their function.

1) _____
2) _____
3) _____

H. List in proper sequence, starting with the normal pacemaker, elements of the cardiac conduction system.

1) _____
2) _____
3) _____
4) _____
5) _____
6) _____
7) _____
8) _____

I. Describe three cardiac effects of increased sympathetic activity, and of increased parasympathetic activity.

Sympathetic _____

_____

_____

Parasympathetic _____

_____

_____

J. In the normal cardiac cycle, the atria contract before the ventricles. Where is this fact represented in the ECG?

_____

_____

K. What is meant by "AV delay" and what purpose does the delay serve?

_____

_____

L. What is the isoelectric line of the ECG?

_____

_____

M. Which components of the ECG are normally measured along the isoelectric line?

_____

_____

III. OPTIONAL Active Learning Portion

A. ***Hypothesis***

B. ***Materials***

C. ***Method***

D. ***Set Up***

E. ***Experimental Results***

End of Lesson 5 Data Report

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Biopac Student Lab® Lesson 6

ELECTROCARDIOGRAPHY (ECG) II
Introduction

Rev. 01152013

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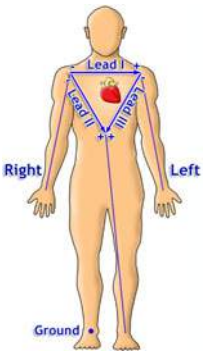

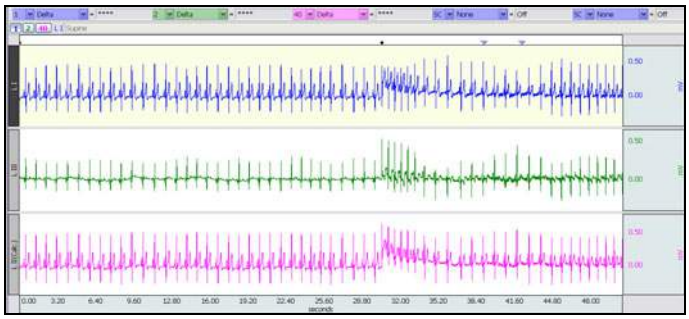

I. INTRODUCTION

Willem Einthoven developed a "string galvanometer" in 1901 that could record the electrical activity of the heart. Although it was not the first such recorder, it was a breakthrough in that it was accurate enough to duplicate the results on the same patient. Einthoven's work established a standard configuration for recording the ECG and won him the Nobel Prize in 1924. Since then, the ECG has become a powerful tool in diagnosing disorders of the heart. [It should be noted that the clinical interpretation of the ECG is quite empirical in practice, and has evolved from a long history of reference to and correlation with known cardiac disorders.]

About Willem Einthoven:
1860-1927
Born in Semarang, Java
Dutch physician
Professor, University of Leiden, 1885-1927
Nobel Prize: 1924

The electrical activity of each cardiac cycle begins with depolarization of the sinoatrial (SA) node, the primary pacemaker of the heart. The wave of depolarization spreads throughout the atria initiating contraction of atrial myocardium (see Lesson 5 ECG I for details.) Depolarization of the atria is recorded as the P wave of the ECG. Repolarization of the atria immediately follows the depolarization and occurs during the PR segment of the ECG. At the AV node, transmission of the electrical signal is slowed, allowing the atria sufficient time to complete their contraction, before the signal is conducted down the AV bundle, the left and right bundle branches, and the Purkinje fibers to ventricular myocardium. Depolarization of the ventricles is recorded as the QRS complex in the ECG, and repolarization of the ventricles is recorded as the T wave.

During the cardiac cycle, the current spreads along specialized pathways and depolarizes parts of the pathway in the specific sequence outlined above. Consequently, the electrical activity has directionality, that is, a spatial orientation represented by an electrical axis. The preponderant direction of current flow during the cardiac cycle is called the *mean electrical axis*. Typically, in an adult the mean electrical axis lies along a line extending from the base to the apex of the heart and to the left of the interventricular septum pointing toward the lower left rib cage.

The magnitude of the recorded voltage in the ECG is directly proportional to the amount of tissue being depolarized. Most of the mass of the heart is made up of ventricular myocardium. Therefore, the largest recorded waveform, the QRS complex, reflects the depolarization of the ventricles. Furthermore, since left ventricular mass is significantly greater than right ventricular mass, more of the QRS complex reflects the depolarization of the left ventricle, and orientation of the mean electrical axis is to the left of the interventricular septum.

The body contains fluids with ions that allow for electrical conduction. This makes it possible to measure electrical activity in and around the heart from the surface of the skin (assuming good electrical contact is made with the body fluids using electrodes.) This also allows the legs and arms to act as simple extensions of points in the torso. Measurements from the leg approximate those occurring in the groin, and measurements from the arms approximate those from the corresponding shoulder.

Ideally, electrodes are placed on the ankles and wrists for convenience to the subject undergoing the ECG evaluation. In order for the ECG recorder to work properly, a ground reference point on the body is required. This ground is obtained from an electrode placed on the right leg above the ankle. To represent the body in three dimensions, three planes are defined for electrocardiography (Fig. 6.1.) The bipolar limb leads record electrical activity of the cardiac cycle in the frontal plane and will be used in this lesson to introduce principles of vectorcardiography.

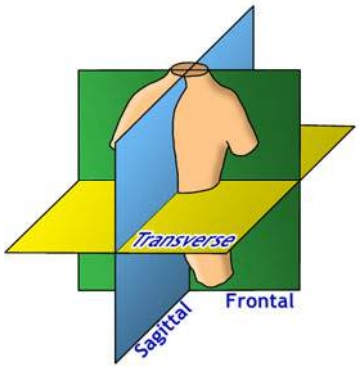

Fig. 6.1 ECG planes

A *bipolar lead* is composed of two discrete electrodes of opposite polarity, one positive and the other negative. A hypothetical line joining the poles of a lead is called the *lead axis.* The electrode placement defines the recording direction of the lead, when going *from the negative to the positive electrode*. The ECG recorder computes the difference (magnitude) between the positive and negative electrodes and displays the changes in voltage difference with time. A standard clinical electrocardiograph records 12 leads, three of which are called standard (bipolar) limb leads.

The standard bipolar limb leads, their polarity and axes are as follows:

Lead	Polarity	Lead Axis
Lead I	right arm (-) to left arm (+)	± 180° - 0°
Lead II	right arm (-) to left leg (+)	-120° - +60°
Lead III	left arm (-) to left leg (+)	-60° - + 120°

The relationships of the bipolar limb leads are such that the sum of the electrical currents recorded in leads I and III equal the sum of the electric current recorded in lead II. This relationship is called *Einthoven's law*, and is expressed mathematically as:

Lead I + Lead III = Lead II

It follows that if the values for any two of the leads are known, the value for the third lead can be calculated.

A good mathematical tool for representing the measurement of a lead is the vector. A *vector* is an entity that has both magnitude and direction, such as velocity. At any given moment during the cardiac cycle, a vector may represent the net electrical activity seen by a lead. An electrical vector has magnitude, direction, and polarity, and is commonly visualized graphically as an arrow:

- The length of the shaft represents the magnitude of the electrical current.
- The orientation of the arrow represents the direction of current flow.
- The tip of the arrow represents the positive pole of the electrical current.
- The tail of the arrow represents the negative pole of the electrical current.

The electric current of the cardiac cycle flowing toward the positive pole of a lead axis produces a positive deflection on the ECG record of that lead. An electric current flowing toward the negative pole produces a negative deflection. The amplitude of the deflection, negative or positive, is directly proportional to the magnitude of the current. If the current flow is perpendicular to the lead axis, no deflection is produced in the record of that lead. It follows that for as given magnitude of electrical current, the largest positive deflection will be produced by current flowing along the lead axis toward the positive pole, and the largest negative deflection produced by current flowing along the lead axis toward the negative pole (Fig.6.2) When the direction of current flow is between the lead axis and its perpendicular, the deflection is smaller. This is true for current flowing away from as well as toward the positive pole.

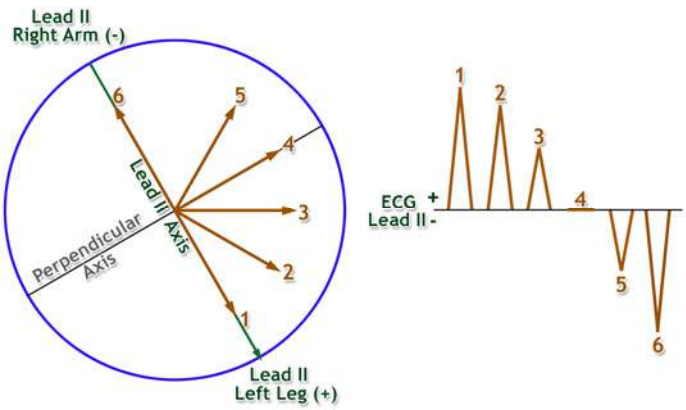

Fig. 6.2

Due to the anatomy of the heart and its conduction system, current flow during the electrical cardiac cycle is partly toward and partly away from the positive pole of the bipolar limb leads. This may produce a biphasic (partially +, partially -) deflection on ECG lead record. A good example is the coupled Q-R or R-S deflections of the QRS complex typically seen in Lead II. At any given moment, the bidirectional electric current can be represented by a single mean vector that is the average of all the negative and positive electrical vectors at that moment (Fig. 6.3.)

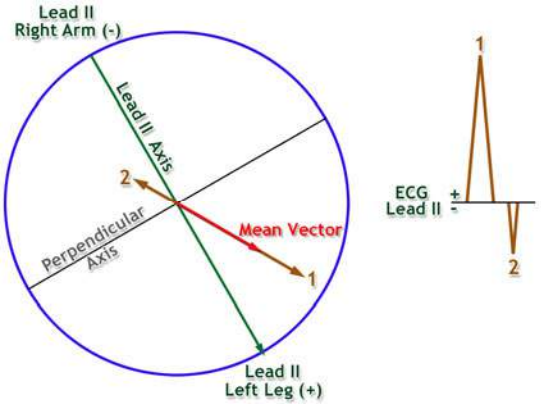

Fig. 6.3

The bipolar limb lead axes may be used to construct an equilateral triangle, called Einthoven's triangle, at the center of which lies the heart (Fig. 6.4.) Each side of the triangle represents one of the bipolar limb leads. The positive electrodes of the three bipolar limb leads are electrically about the same distance from the zero reference point in the center of the heart. Thus, the three sides of the equilateral triangle can be shifted to the right, left, and down without changing the angle of their orientation until their midpoints intersect at the center of the heart (Fig. 6.4.) This creates a standard limb lead vectorgraph with each of the lead axes forming a 60-degree angle with its neighbors. The vectorgraph can be used to plot the vector representing the mean electrical axis of the heart in the frontal plane.

A vector can represent the electrical activity of the heart at any instant in time. The mean electrical axis of the heart is the summation of all the vectors occurring in a cardiac cycle.

Since the QRS interval caused by ventricular depolarization represents the majority of the electrical activity of the heart, you can approximate the mean electrical axis by looking only in this interval, first at the R wave amplitude, and then at the combined amplitudes of the Q, R, and S waves. The resultant vector, called the QRS axis, approximates the mean electrical axis of the heart.

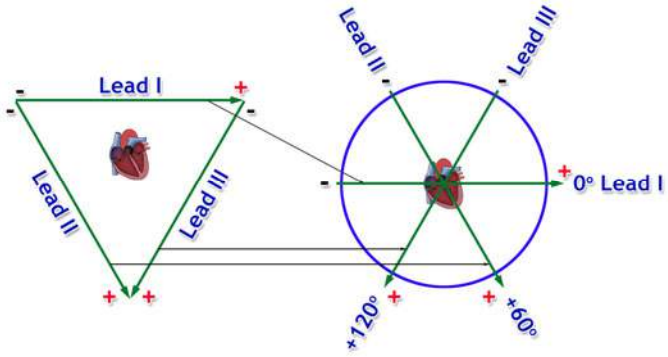

Fig. 6.4

An initial approximation of the mean electrical axis in the frontal plane can be made by plotting the magnitude of the R wave from Lead I and Lead III (Fig. 6.5.) To plot R wave magnitude:

1. Draw a perpendicular line from the ends of the vectors (right angles to the axis of the Lead.)
2. Determine the point of intersection of these two perpendicular lines.
3. Draw a new vector from point 0,0 to the point of intersection.

The direction of the resulting vector approximates the mean electrical axis of the heart. The length of the vector approximates the mean potential of the heart.

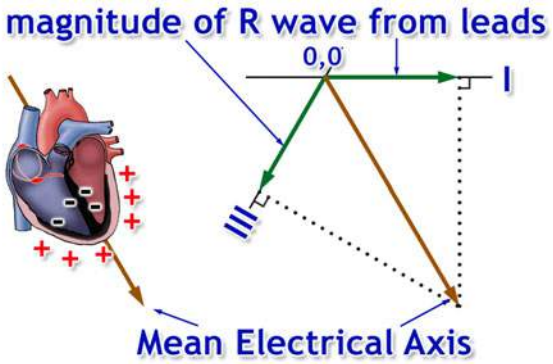

Fig. 6.5

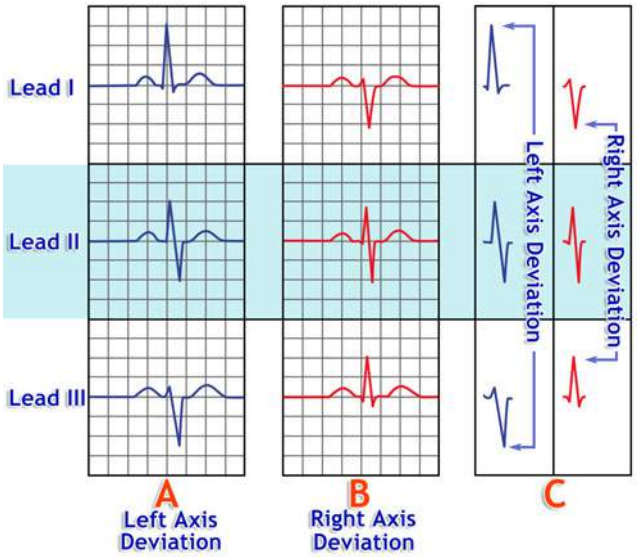

Fig. 6.6

A more accurate method of approximating the mean electrical axis is to algebraically add the Q, R, and S potentials for one lead, instead of using just the magnitude of the R wave. The rest of the procedure would be the same as outlined above.

The normal range of the mean electrical axis of the ventricles is approximately -30° to +90°. The axis may shift slightly with a change in body position (e.g., standing versus supine) and variation among individuals within the normal range occur as a result of individual differences in heart mass, orientation of the heart in the thorax, body mass index, and the anatomic distribution of the cardiac conduction system.

A shift in the direction of the QRS axis from normal to one between -30° and -90° is called left axis deviation (LAD.) Left axis deviation is abnormal and results from conditions that cause the left ventricle to take longer than normal to depolarize. One example is hypertrophy (enlargement, and hence a longer conduction pathway)) of the left ventricle associated with systemic hypertension or stenosis (narrowing) of the aortic valve.

Left axis deviation may also occur when the conduction pathway or the left ventricular myocardium is damaged, creating blockage and slowing of the depolarization signal. Common causes of this include coronary occlusion (spasm, thrombosis, etc.) and injuries resulting from drug usage. Fig. 6.6A shows typical ECG patterns of Leads I, II, and III associated with LAD.

A shift in the direction of the QRS axis from normal to one between +90° and +180° is called right axis deviation (RAD.) In some cases right axis deviation may be normal, such as in young adults with long narrow chests and vertical hearts, but in the majority of adults, right axis deviation generally is associated with hypertrophy of the right ventricle or damage to the conduction system in the right ventricle. In both conditions, the right axis deviation results from a slowing or blockage of the depolarization signal for the right ventricle. Fig. 6.6B shows typical ECG patterns of Leads I, II, and III associated with RAD. A convenient method of differentiating LAD and RAD is to examine the QRS patterns of Leads I and III. A pattern where the apices of the QRS complexes go away from each other is left axis deviation (Fig. 6.6C.) A pattern where the apices approach one another is right axis deviation.

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II. EXPERIMENTAL OBJECTIVES

1) Record ECG from Leads I and III in the following conditions: supine, seated, and breathing deeply while seated.
2) Compare the displayed calculated ECG Lead II to recorded ECG Leads I and III, and use the R wave amplitudes to confirm Einthoven's Law.
3) Approximate the mean electrical axis of the ventricles on the frontal plane using vectors derived from the amplitude and polarity of the QRS complex in ECG Leads I and III.
4) Approximate the mean electrical potential of the ventricles on the frontal plane using the resultant vector derived from the vectors of Leads I and III.

III. MATERIALS

- BIOPAC Electrode Lead Set x 2 (SS2L)
- BIOPAC Disposable Electrodes (EL503,) 6 electrodes per subject
- BIOPAC Electrode Gel (GEL1) and Abrasive Pad (ELPAD) *or* Skin cleanser or alcohol prep
- Mat, cot or lab table and pillow for Supine position
- Protractor
- Two different colored pens/pencils
- Biopac Student Lab System: BSL 4 software, MP36, MP35 or MP45 hardware
- Computer System (Windows or Mac)

IV. EXPERIMENTAL METHODS

A. SETUP

FAST TRACK Setup

1. Turn the computer **ON**.
   - If using an MP36/35 unit, turn it **OFF**.
   - If using an MP45, make sure USB cable is connected and "Ready" light is **ON**.
2. **Plug the equipment in** as follows:
   Electrode Lead Set (SS2L)—CH 1
   Electrode Lead Set (SS2L)—CH 2
3. Turn **ON** the MP36/35 unit.

Setup continues…

Detailed Explanation of Setup Steps

Fig. 6.7 MP3X (top) and MP45 (bottom) hardware connections

4. Clean and abrade skin.
5. Attach six electrodes to **Subject**, as follows:
   - One above right wrist
   - Two above left wrist
   - Two above right ankle
   - One above left ankle

Attach six electrodes to flat spots inside wrists and ankles as shown in Fig. 6.8

If the skin is oily, clean electrode sites with soap and water or alcohol before abrading.

If electrode is dry, apply a drop of gel.

Remove any jewelry on or near the electrode sites.

For optimal electrode contact, place electrodes on skin at least five minutes before start of Calibration.

Fig. 6.8 Electrode Placement

6. Clip the first Electrode Lead Set (SS2L) from CH 1 to the electrodes, following LEAD I in Fig. 6.9.
   - RED = LEFT wrist
   - WHITE = RIGHT wrist
   - BLACK = RIGHT ankle
7. Clip the second Electrode Lead Set (SS2L) from CH 2 to the electrodes, following LEAD III in Fig. 6.9.
   - WHITE = LEFT wrist
   - RED = LEFT ankle
   - BLACK = RIGHT ankle

Carefully follow the color code placement of each electrode lead

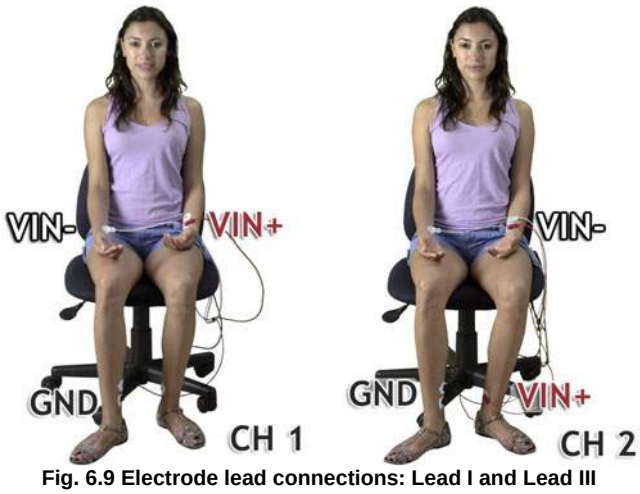

Fig. 6.9 Electrode lead connections: Lead I and Lead III

The pinch connectors work like a small clothespin, but will only latch onto the nipple of the electrode from one side of the connector.

Setup continues…

8. **Subject** gets in supine position (lying down, face up) and relaxes (Fig. 6.10).

Position the electrode cables so that they are not pulling on the electrodes.

Connect the electrode cable clip to a convenient location on **Subject's** clothes.

Fig. 6.10

9. Start the BIOPAC Student Lab program.

Start Biopac Student Lab by double-clicking the Desktop shortcut.

10. Choose lesson "**L06 – Electrocardiography (ECG) II**" and click **OK**.

11. Type in a unique **filename** and click **OK**.

No two people can have the same filename, so use a unique identifier, such as **Subject's** nickname or student ID#.

A folder will be created using the filename. This same filename can be used in other lessons to place the **Subject's** data in a common folder.

12. Optional: Set Lesson Preferences.
    - Choose File > **Lesson Preferences**.
    - Select an option.
    - Select the desired setting and click **OK**.

This lesson has optional Preferences for data and display while recording. Per your Lab Instructor's guidelines, you may set:

Grids: Show or hide gridlines

ECG filter: Set bandwidth

Heart Rate Data: Calculate and display Heart Rate data

Time Scale: Set the full screen time scale with options from 10 to 20 seconds.

Lesson Recordings: Specific recordings may be omitted based on instructor's preferences.

All setting changes will be saved.

END OF SETUP

B. CALIBRATION

The Calibration procedure establishes the hardware's internal parameters (such as gain, offset, and scaling) and is critical for optimal performance. **Pay close attention to Calibration.**

FAST TRACK Calibration

1. **Subject** is supine and relaxed, with eyes closed.
2. Click **Calibrate**.
   - **Subject** remains relaxed with eyes closed.
   - Wait for Calibration to stop.
3. Verify recording resembles the example data.
   - If similar, click **Continue** and proceed to Data Recording.
   - If necessary, click **Redo Calibration**.

END CALIBRATION

Detailed Explanation of Calibration Steps

Subject must remain relaxed and as still throughout calibration to minimize baseline shift and EMG artifact.

Calibration lasts eight seconds.

Both channels should show recognizable ECG waveforms with a baseline at or near 0 mV, little EMG artifact and no large baseline drift.

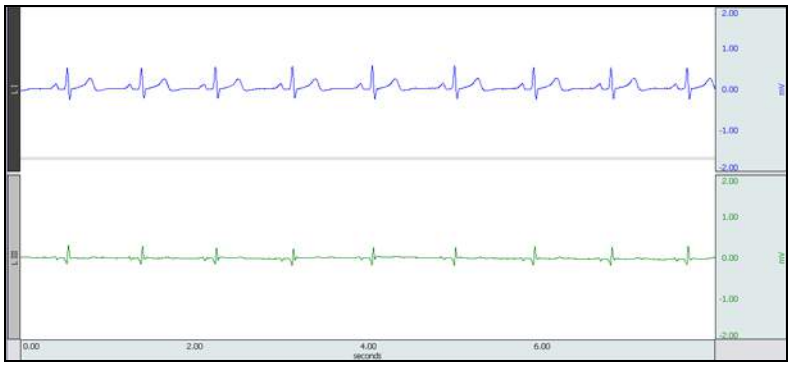

Fig. 6.11 Example Calibration data

If recording does not resemble the Example Data

- If the data is noisy or flatline, check all connections to the MP unit.
- If the signals look reversed, verify that transducers are plugged into the correct channels. (CH 1 for Lead I and CH 2 for Lead III.)
- If the ECG displays baseline drift or excessive EMG artifact:
  - Verify electrodes are making good contact with the skin and that the leads are not pulling on the electrodes.
  - Make sure Subject is in a relaxed position

C. DATA RECORDING

FAST TRACK Recording

1. Prepare for the recording.
   - **Subject** remains supine and relaxed, with eyes closed.
   - **Review** recording steps.

Supine

2. Click **Record**.
3. Record for 30 seconds.
4. Click **Suspend**.
5. Verify recording resembles the example data.
   - If <u>similar</u>, click **Continue** and proceed to next recording.
   - If necessary, click **Redo**.
   - If all required recordings have been completed, click **Done**.

Recording continues…

Detailed Explanation of Recording Steps

Two conditions will be recorded*, one with **Subject** supine and another with **Subject** seated.

***IMPORTANT**

This procedure assumes that all lesson recordings are enabled in lesson Preferences, which may not be the case for your lab. Always match the recording title to the recording reference in the journal and disregard any references to excluded recordings.

Hints for obtaining optimal data

To minimize muscle (EMG) artifact and baseline drift:

- **Subject's** arms and legs must be relaxed.
- **Subject** must remain still and should not talk during any recordings.
- Make sure electrodes do not peel up and that the leads do not pull on the electrodes.

Subject remains supine and relaxed, with eyes closed.

Both ECG waveform should have a baseline at or near 0 mV and should not display large baseline drifts or significant EMG artifact.

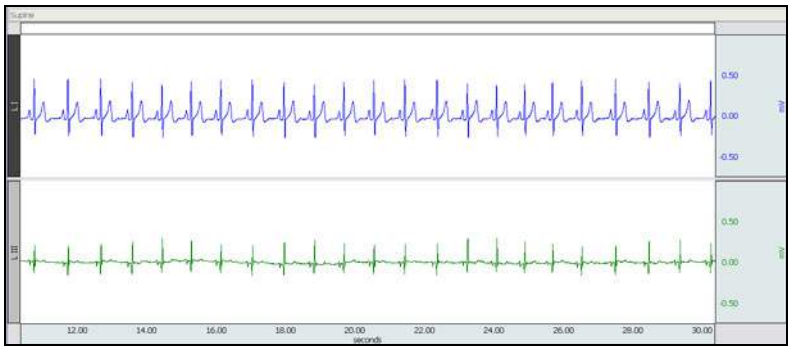

Fig. 6.12 Example Supine data

<u>If recording does not resemble the Example Data</u>

- If the data is noisy or flatline, check all connections to the MP unit.
- If the ECG displays baseline drift or excessive EMG artifact:
  - Verify electrodes are making good contact with the skin and that the leads are not pulling on the electrodes.
  - Make sure Subject is in a relaxed position

Click **Redo** and repeat Steps 2 – 5 if necessary. Note that once **Redo** is clicked, the most recent recording will be erased.

Seated

- **Review** recording steps.

6. **Subject** gets up quickly and then settles into a seated position (Fig. 6.13).

Subject should sit with arms relaxed at side of body and hands apart in lap, with legs flexed at knee and feet supported.

Fig. 6.13 Proper position for "Seated" recording

7. Once **Subject** is seated and still, click **Record**.

In order to capture the heart rate variation, click Record as quickly as possible after **Subject** sits and relaxes.

8. **Subject** remains seated and relaxed.
   - Record for 10 seconds and then ask **Subject** to increase depth of breathing.
   - **Subject** inhales audibly, **Recorder** presses F4 on the inhale.
   - **Subject** exhales audibly, **Recorder** presses F5 on the exhale.

Note: **Subject** should not breathe in too deeply as to cause excessive EMG artifact or baseline drift.

9. Record for 5 more seconds.
10. Click **Suspend.**
11. Verify that recording resembles the example data.
    - If similar, click **Continue** to proceed to optional recording section, or click **Done** if finished.

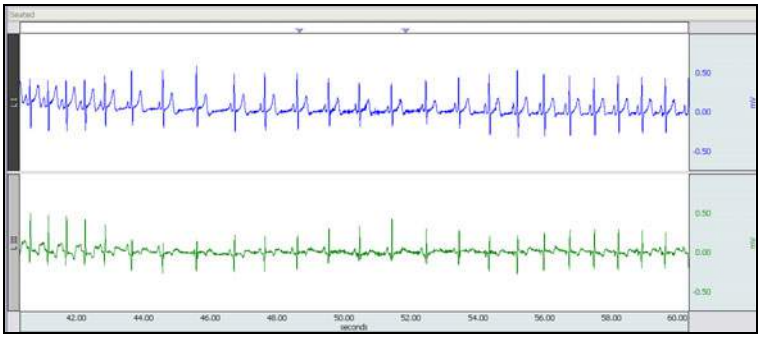

Fig. 6.14 Example Seated data

The data description is the same as outlined in Step 5 with the following exception:

- The ECG data may exhibit some baseline drift during deep breathing which is normal and unless excessive, does not necessitate **Redo**.

- If necessary, click **Redo**.

Click **Redo** if necessary. Note that the **Subject** must return to the Supine position for at least 5 minutes before repeating Steps 6 – 11. Once **Redo** is clicked, the most recent recording will be erased.

Recording continues…

OPTIONAL ACTIVE LEARNING PORTION

With this lesson you may record additional data by clicking **Continue** following the last recording. Design an experiment to test or verify a scientific principle(s) related to topics covered in this lesson. Although you are limited to this lesson's channel assignments, the electrodes or transducers may be moved to different locations on the **Subject**.

Design Your Experiment

Use a separate sheet to detail your experiment design, and be sure to address these main points:

A. ***Hypothesis***

Describe the scientific principle to be tested or verified.

B. ***Materials***

List the materials you will use to complete your investigation.

C. ***Method***

Describe the experimental procedure—be sure to number each step to make it easy to follow during recording.

Run Your Experiment

D. ***Set Up***

Set up the equipment and prepare the subject for your experiment.

E. ***Record***

Use the **Continue**, **Record**, and **Suspend** buttons to record as much data as necessary for your experiment.

Analyze Your Experiment

F. Set measurements relevant to your experiment and record the results in a Data Report.

12. After clicking **Done**, choose an option and click **OK**.

If choosing the **Record from another Subject** option:

- Repeat Setup Steps 6 – 9, and then proceed to Calibration.

13. Remove the electrodes.

Remove the electrode cable pinch connectors and peel off all electrodes. Discard the electrodes. (BIOPAC electrodes are not reusable.) Wash the electrode gel residue from the skin, using soap and water. The electrodes may leave a slight ring on the skin for a few hours which is quite normal.

END RECORDING

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V. DATA ANALYSIS

FAST TRACK DATA ANALYSIS

1. Enter the **Review Saved Data** mode.
   - Note Channel Number (CH) designations:

Channel	*Displays*
CH 1	**Lead I**
CH 2	**Lead III**
CH 40	**Lead II** (calculated)

   - Note measurement box settings:

Channel	*Measurement*
CH 1	**Delta**
CH 2	**Delta**
CH40	**Delta**

2. Set up the display window for optimal viewing of the first data recording.

Data Analysis continues…

DETAILED EXPLANATION OF DATA ANALYSIS STEPS

If entering **Review Saved Data** mode from the Startup dialog or lessons menu, make sure to choose the correct file.

Note: After **Done** was pressed in the final recording section, the program used Einthoven's Law to automatically calculate Lead II from Leads I and III and added a channel for Lead II to the initial two channel recording (Fig. 6.15).

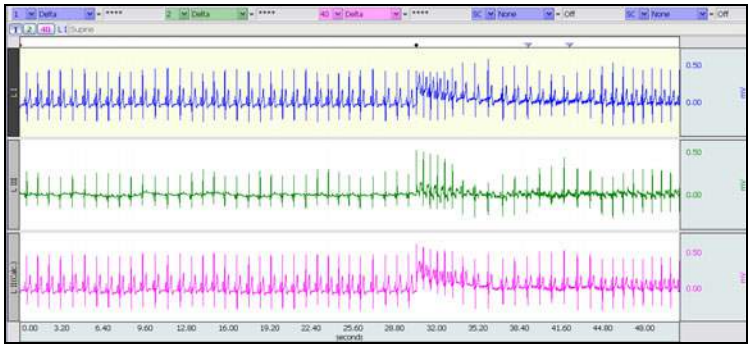


Fig. 6.15 Example data

The measurement boxes are above the marker region in the data window. Each measurement has three sections: channel number, measurement type, and result. The first two sections are pull-down menus that are activated when you click them.

Brief definition of measurements:

Delta: Computes the difference in amplitude between the first point and the last point of the selected area. It is particularly useful for taking ECG measurements, because the baseline does not have to be at zero to obtain accurate, quick measurements.

Rate Mean: If CH 40 Heart Rate data was recorded, use the Rate Mean measurement, which is designed specifically for rate data and calculates accurate statistical means using one value only for every cardiac cycle. This avoids any unintentional weighting due to time variation in heart rate, unlike the amplitude "Mean" measurement.

The "selected area" is the area selected by the **I-beam** tool (including endpoints).

Note: The append event markers ◆ mark the beginning of each recording. Click on (activate) the event marker to display its label.

Useful tools for changing view:

Display menu: Autoscale Horizontal, Autoscale Waveforms, Zoom Back, Zoom Forward

Scroll Bars: Time (Horizontal); Amplitude (Vertical)

Cursor Tools: Zoom Tool

Buttons: Overlap, Split, Show Grid, Hide Grid, -, +

Hide/Show Channel: "Alt + click" (Windows) or "Option + click" (Mac) the channel number box to toggle channel display.

The data window should resemble Fig. 6.16.

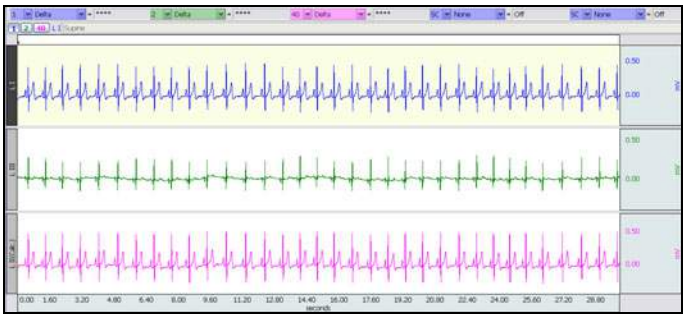


Fig. 6.16 Supine data

3. Zoom in to select two consecutive "clean" cardiac cycles in the "**Supine**" recording.
4. Place an **event marker** above the second R-wave to indicate which cardiac cycle will be used for measurements.

A clean cardiac cycle has ECG components that are easy to discern (Fig. 6.17).

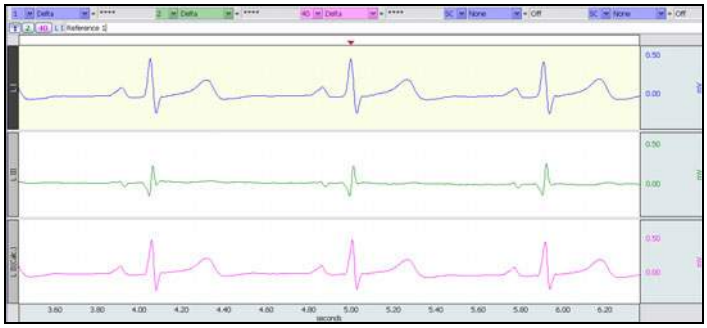


Fig. 6.17 Zoom in on Supine data

Insert the event marker directly above the R wave of the second cardiac cycle in the display.

To place an event marker (inverted triangle,) Right-click with the cursor in the event marker region and choose the contextual menu item "Insert New Event." You can then move the marker by holding down the "Alt" key while clicking and dragging it.

Type "**Reference 1**" to label the marker.

5. Use the **I-Beam** cursor to select the area from the midpoint between the cycles (baseline) and the R-wave of the second cycle

   A, B

Start at the midpoint between the T-wave of cardiac cycle 1 (left) and the P-wave of cardiac cycle 2. Press and hold the mouse and sweep the cursor to the right until the end of the selected area is at peak of the desired wave—monitor the Delta measurement to determine when the actual peak is reached; small movements to the right or left may be necessary.

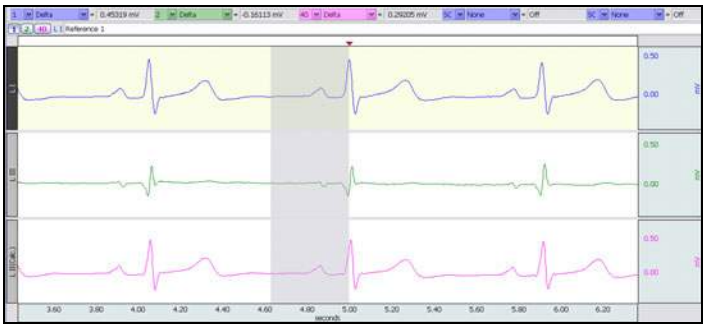


Fig. 6.18 Selection from baseline to R wave peak

Note R-waves may be inverted on some of the leads; include the polarity of the Delta result in the Data Report tables.

6. Scroll to the "**Seated**" recording, select two consecutive cardiac cycles and repeat the procedure described in Steps 4 and 5.

   Data Analysis continues…

Do not use a section between the "**Start of inhale**" and "**Start of exhale**" event markers.

Note All remaining measurements are taken on Lead I and Lead III only so you may choose to hide Lead II (CH 40).

7. Scroll to the "**Start of inhale**" section and select two consecutive cardiac cycles and repeat the procedure described in Steps 4 and 5.

   B

8. Scroll to the "**Start of exhale**" section and select two consecutive cardiac cycles and repeat the procedure described in Steps 4 and 5.

   B

9. Go back to the "**Reference 1**" marker created in Step 4.

10. Measure the waves of the **QRS** complex and record the amplitudes for **Lead I** and **Lead III**.

    C

11. Fill in the vectorgrams.
12. Answer the questions at the end of the Data Report.
13. **Save** or **Print** the data file.
14. **Quit** the program.

END OF DATA ANALYSIS

Type "**Reference 2**" to label the marker.

Type "**Reference 3**" to label the marker.

Use the event marker left and right arrows to move to different markers.

To measure a wave, select the area from the baseline (Isoelectric Line) to the peak of the wave.

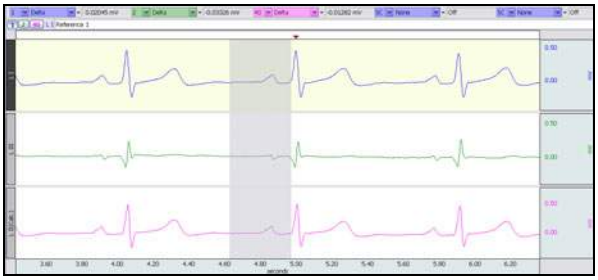


Fig. 6.19 Sample measurement of the Q wave

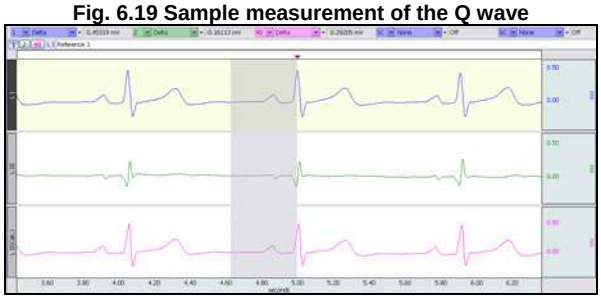


Fig. 6.20 Sample measurement of the R wave

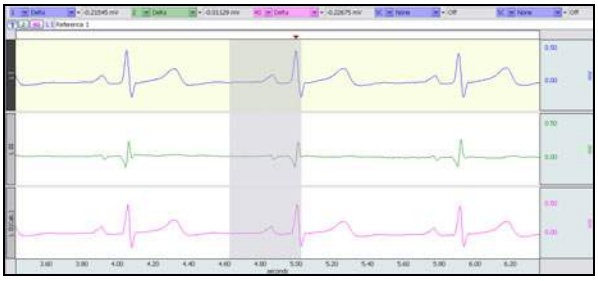


Fig. 6.21 Sample measurement of the S wave

- The L06 Vectorgrams are contained in the printed manual, or can be printed directly from the Help menu.
- An electronically editable **Data Report** is located in the journal (following the lesson summary,) or immediately following this Data Analysis section. Your instructor will recommend the preferred format for your lab.

END OF LESSON 6

Complete the Lesson 6 Data Report that follows.

ELECTROCARDIOGRAPHY II

- *Bipolar Leads (Leads I, II, III,) Einthoven's Law, and*
- *Mean Electrical Axis on the Frontal Plane*

DATA REPORT

Student's Name: _____

Lab Section: _____

Date: _____

Subject Profile

Name:_____ Height:_____

Age:_____ Gender: Male / Female Weight:_____

I. Data and Plots

A. **Einthoven's Law—Simulated Confirmation: Lead I + Lead III = Lead II**

Table 6.1 Supine

Lead	*Same Single Cardiac Cycle*	mV*
Lead I	1 Delta	
Lead III	2 Delta	
Lead II	40 Delta	

*Include the polarity (+ or -) of the Delta result since R-waves may be inverted on some of the leads.

B. **Mean Electrical Axis of the Ventricles (QRS Axis) and Mean Ventricular Potential—Graphical Estimate**

Use Table 6.2 to record measurements from the Data Analysis section:

Table 6.2

CONDITION	QRS	
	Lead I 1 Delta	Lead III 2 Delta
Supine		
Seated		
Start of inhale		
Start of exhale		

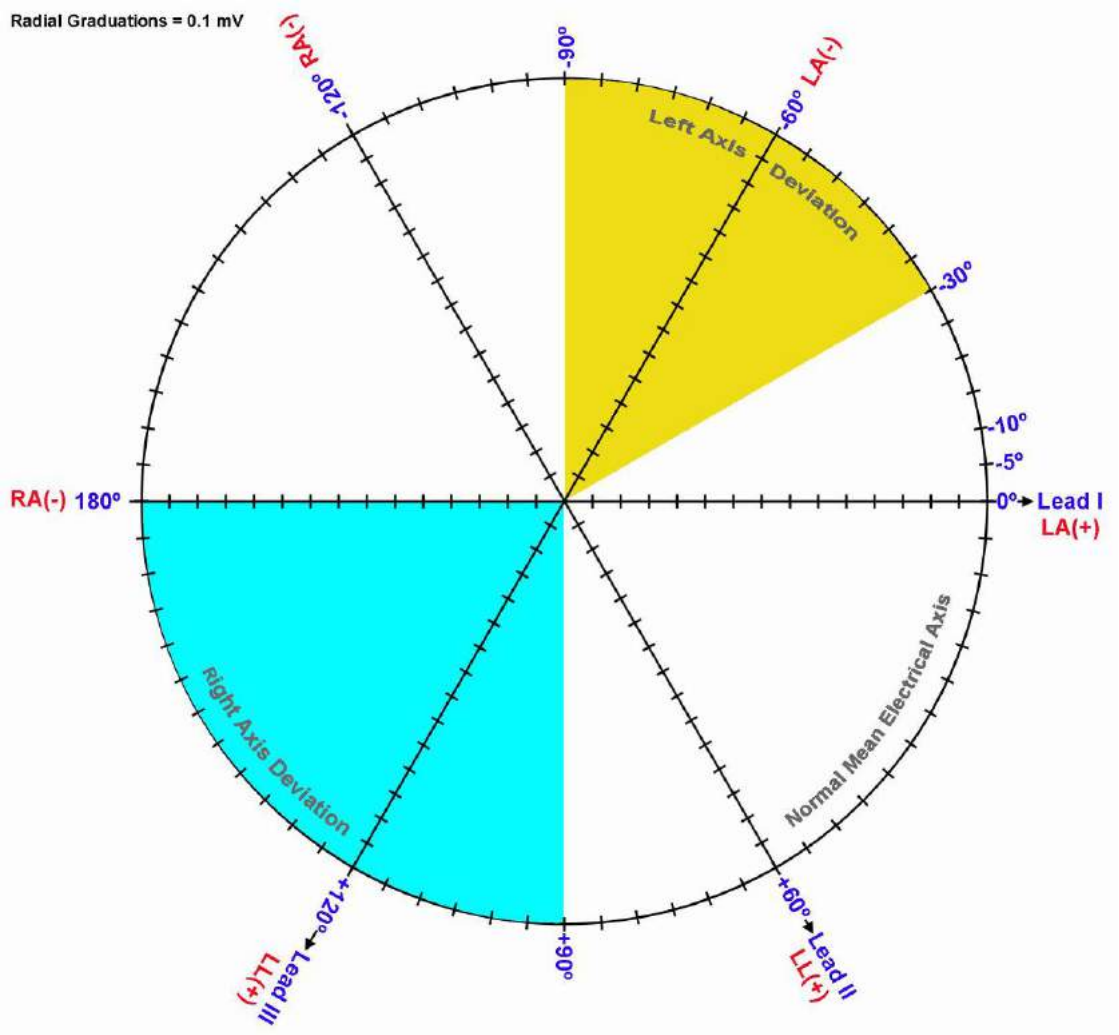
One way to approximate the mean electrical axis in the frontal plane is to plot the magnitude of the R wave from Lead I and Lead III, as shown in the Introduction (Fig. 6.4).

1. Draw a perpendicular line from the ends of the vectors (right angles to the axis of the Lead) using a protractor or right angle guide.
2. Determine the point of intersection of these two perpendicular lines.
3. Draw a new vector from point 0.0 to the point of intersection.

The direction of this resulting vector approximates the mean electrical axis (QRS Axis) of the ventricles. The length of this vector approximates the mean ventricular potential.

Create two plots on each of the following graphs, using data from Table 6.2. Use a different color pencil or pen for each plot.

Graph 1: *Supine and Seated*



From the above graph, find the following values:

Condition	Mean Ventricular Potential	Mean Ventricular (QRS) Axis
Supine	_____	_____
Seated	_____	_____

Explain the difference (if any) in Mean Ventricular Potential and Axis under the two conditions:

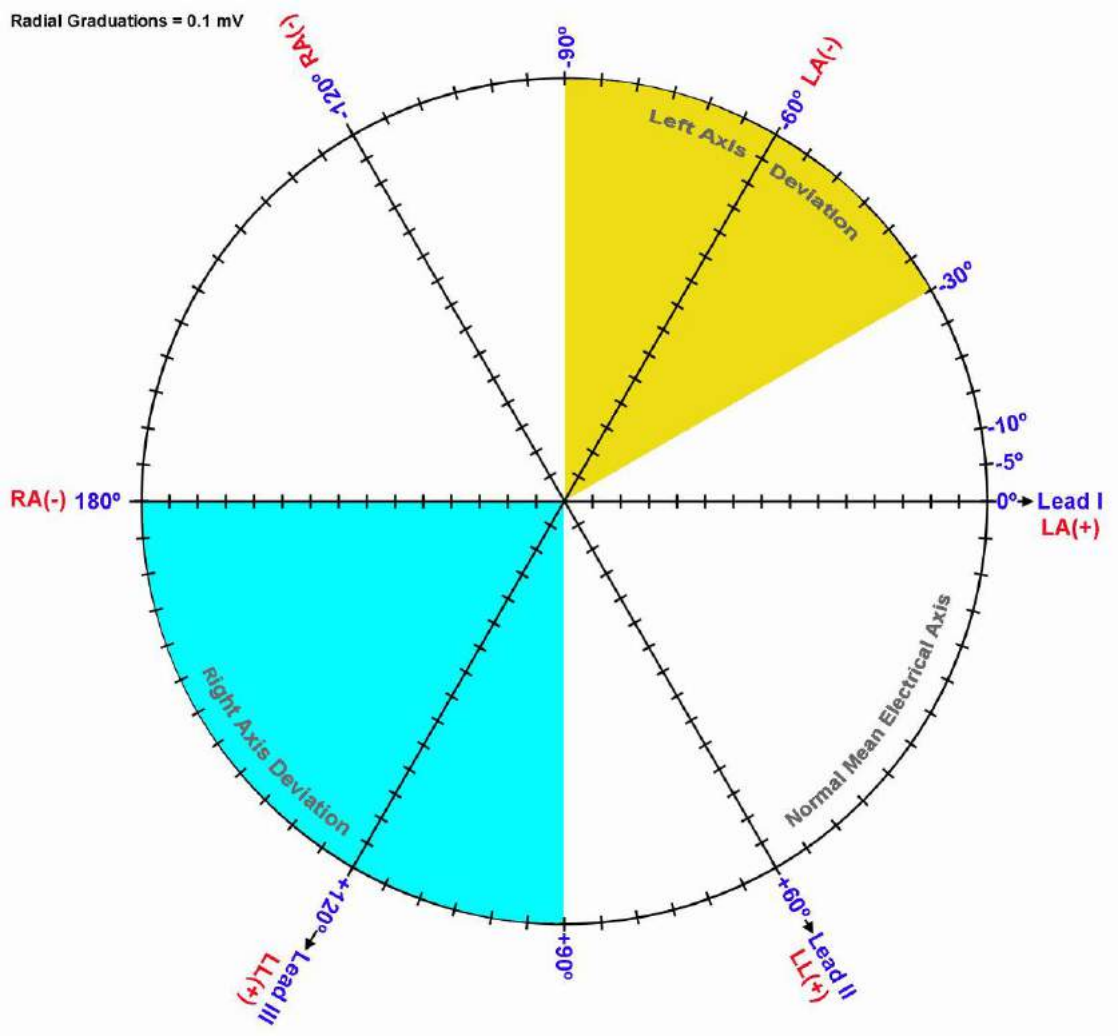
_____

_____

_____

_____

Graph 2: *Inhale /Exhale*



From the above graph, find the following values:

Condition	Mean Ventricular Potential	Mean Ventricular (QRS) Axis
Start of inhale		
Start of exhale		

Explain the difference (if any) in Mean Ventricular Potential and Axis under the two conditions:

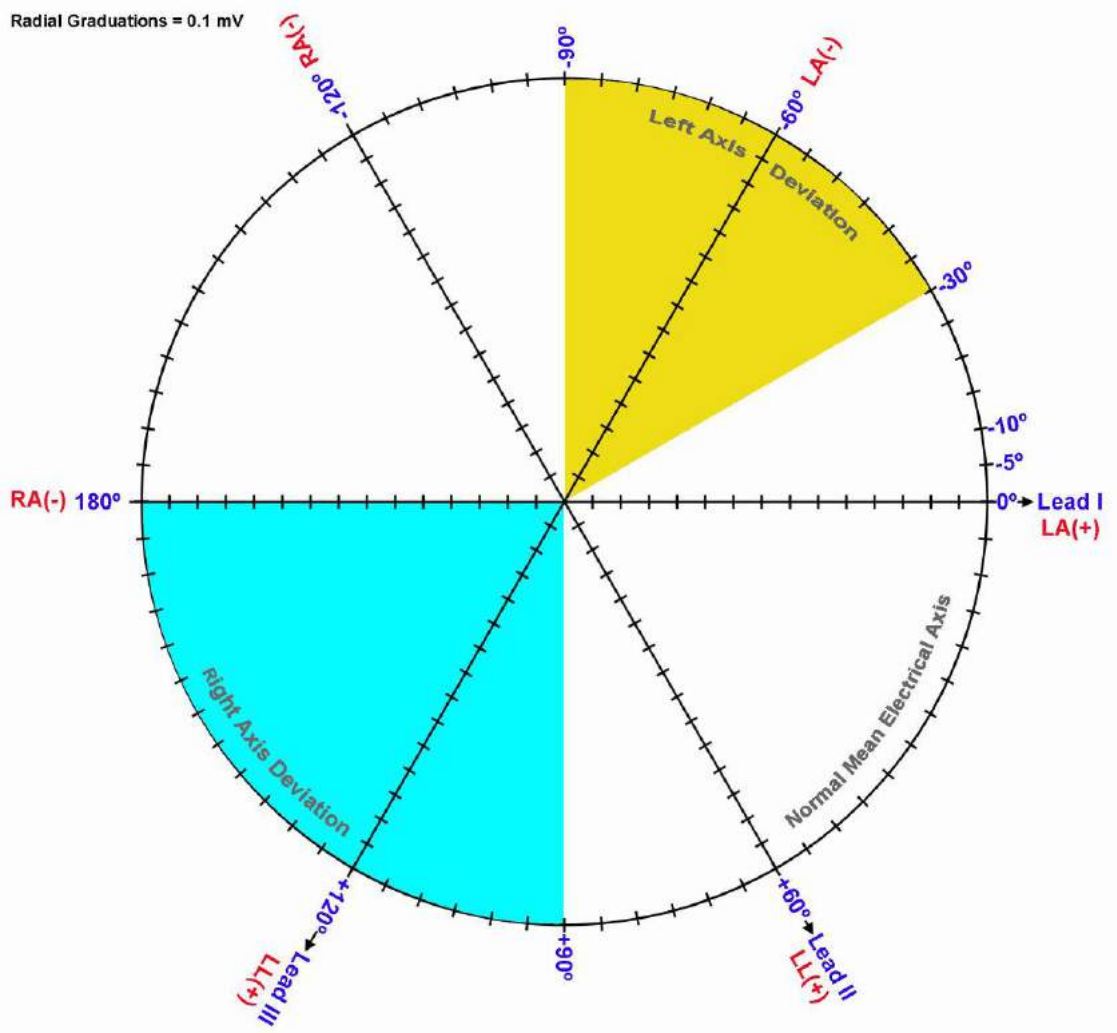
C. **Mean Electrical Axis of the Ventricles (QRS Axis) and Mean Ventricular Potential—More Accurate Approximation**

Use Table 6.3 to add the Q, R, and S potentials to obtain net potentials for Recording 1—Supine.

Table 6.3

POTENTIAL	QRS	
	Lead I 1 Delta	Lead III 2 Delta
Q		
R		
S		
QRS Net		

Graph 3: *Supine*



From the above graph, find the following values:

Condition	Mean Ventricular Potential	Mean Ventricular (QRS) Axis
Supine	_____	_____

Explain the difference in Mean Ventricular Potential and Axis for the Supine data in this plot (Graph 3) and the first plot (Graph 1).

_____

_____

_____

II. Questions

D. Define **ECG**.

E. Define **Einthoven's Law**.

F. Define **Einthoven's Triangle** and give an example of its application.

G. What normal factors effect a change the orientation of the **Mean Ventricular (QRS) Axis**?

H. Define **Left Axis Deviation (LAD)** and its causes.

I. Define **Right Axis Deviation (RAD)** and its causes.

J. What factors affect the amplitude of the R wave recorded on the different leads?

III. OPTIONAL Active Learning Portion

A. ***Hypothesis***

B. ***Materials***

C. ***Method***

D. ***Set Up***

E. ***Experimental Results***

End of Lesson 6 Data Report

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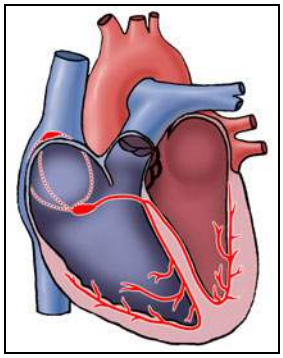

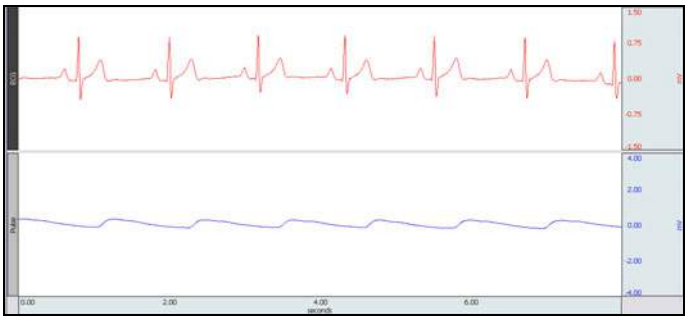

I. INTRODUCTION

The primary purpose of the heart is to pump blood throughout the body. To pump blood, the heart has a rhythmical sequence of both electrical and mechanical events, the **cardiac cycle**. The electrical activity, recorded as an **electrocardiogram** (**ECG**,) initiates the mechanical activity of the heart (contraction and relaxation of atria and ventricles). When the heart chambers contract, they pump blood to the next section of the cardiovascular system. This lesson will focus on the actions of the left ventricle, which pumps blood to the systemic circulatory system, producing a pulse.

During the cardiac cycle the electrical activity of the ventricles, as represented by the QRS complex of the ECG, precedes the mechanical event of ventricular muscle contraction (**ventricular systole**). Within the range of normal resting heart rates, systole begins at the time of the R wave peak and ends at the end of the T wave. The T wave, which represents repolarization of the ventricles, occurs during the time the ventricles are in systole. **Ventricular diastole**, a period of relaxation of ventricular muscles, begins at the end of systole and lasts until the next R wave peak. Since each cardiac cycle contains one period of ventricular systole immediately followed by one period of ventricular diastole, the duration of one cardiac cycle, or heartbeat, can be measured as the time between successive R waves (Fig. 7.1). In the ECG cycle, electrical activity precedes and initiates mechanical activity.

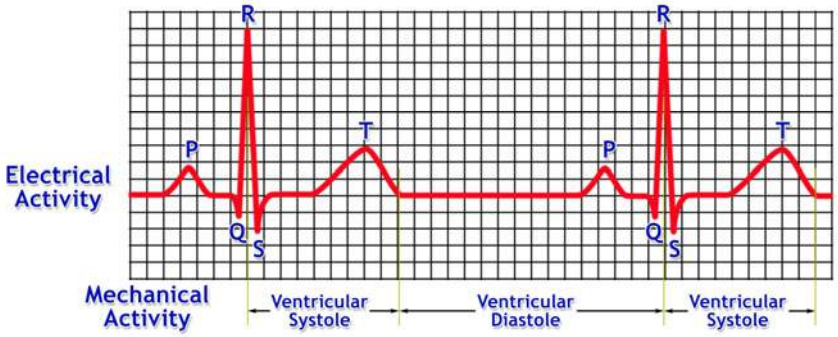

Fig. 7.1 Cardiac cycle

Contraction of the ventricles (ventricular systole) pushes a volume of blood (stroke volume) into arteries. From the left ventricle, the blood goes into the aorta and throughout the rest of the body. Each section of blood "bumps" the downstream, neighboring section of blood to facilitate *blood flow*. The aorta and other arteries have muscular walls, which allow the arterial walls to expand slightly to receive the volume of blood during systole and then, elastic recoil of the arteries helps to continue "pushing" the blood through the rest of the system. The arterial pressure throughout the cardiac cycle is the main force for blood flow.

The pumping action of the ventricles also initiates a pressure wave that is transmitted via the arterial walls. The pressure increases with systole and decreases with diastole. The stiffness of the vessel walls helps transmit the pressure wave. The stiffer the walls, the faster the transmission of the *pressure wave*, but the more work is required by the heart to move the same blood volume.

When the pressure wave is transmitted to the periphery, e.g., fingertip, there is a **pulse** of increased blood volume. The tissues and organs change in volume as blood vessels dilate or constrict and as pulses of blood pass through the blood vessels during each cardiac cycle. Changes in blood volume of organs may be brought about by the autonomic nervous system acting on the cardiovascular system, environmental factors (such as temperature,) metabolic activity of an organ, and a variety of other variables.

For example, temperature regulation involves controlling blood flow to the skin; when heat needs to be conserved, blood flow to the skin is minimized and when excess heat is being generated, the opposite occurs.

The actual blood flow is slower than the transmission of the pressure wave. The aorta has the fastest blood flow in the body at approximately 40-50 cm/sec (approximately 1 mile per hour) whereas the speed of the pressure wave can be much faster.

The travelling speed of the pressure wave from the heart to the periphery can be affected by many interrelated factors, including the heart's ability to contract strongly, blood pressure, the relative elasticity of the arteries, and the diameters of systemic arteries and arterioles. These factors change in response to body positions, sympathetic nervous system input, emotions, etc. For example, the travelling speed of the pressure wave has been shown to correlate with sympathetic influence and systolic blood pressure.

The study of blood volume changes within an organ by using volume displacement techniques is known as plethysmography. In this lesson, you will simultaneously record the ECG and subsequent pulse. The SS4LA transducer will be used to record changes in blood volume via optical photoplethysmography (PPG) methods. The transducer works by shining a beam of Near-infrared light through the skin and measuring the amount of light that is reflected. Blood is highly reflective of Near-infrared light due to the hemes subunit of hemoglobin (red pigment in blood). When the transducer is placed on the skin, in proximity to capillaries, the reflectance of the infrared light from the emitter to the detector will change in accordance to capillary blood volume. Greater blood flow will cause greater signal amplitude. Note that the PPG signal provides a relative (dimensionless,) not absolute, measure of blood flow, however in this lesson we display in units of millivolts (mV).

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II. EXPERIMENTAL OBJECTIVES

1) To become familiar with the principle of plethysmography and its usefulness in qualitatively assessing peripheral changes in blood volume.
2) To observe and record changes in peripheral blood volume and pressure pulse under a variety of both experimental and physiological conditions.
3) To determine the approximate speed of the pressure pulse wave traveling between the heart and the finger.
4) To illustrate the electrical activity associated with normal cardiac activity and how it relates to the flow of blood throughout the body.

III. MATERIALS

- BIOPAC Electrode Lead Set (SS2L)
- BIOPAC Disposable Electrodes (EL503,) 3 electrodes per subject
- BIOPAC Pulse Transducer (SS4LA or SS4L)
- Ruler or Measuring Tape
- Ice water or warm water in plastic bucket
- BIOPAC electrode gel (GEL1) and abrasive pad (ELPAD) *or* skin cleanser
- Biopac Student Lab System: BSL 4 software, MP36 or MP35 hardware
- Computer System (Windows or Mac)

IV. EXPERIMENTAL METHODS

A. SETUP

FAST TRACK Setup

1. Turn the computer **ON**.
2. If the MP36/35 unit is on, turn it **OFF**.
3. **Plug the equipment in** as follows:

   Electrode Lead Set (SS2L) — CH 1

   Pulse Transducer (SS4LA) or

   Pulse Transducer (SS4L) — CH 2
4. Turn **ON** the MP36/35 unit.

5. Clean and abrade skin.
6. Attach three electrodes on the **Subject** (Fig. 7.3).

Setup continues…

Detailed Explanation of Setup Steps

Fig. 7.2 MP connections

If the skin is oily, clean electrode sites with soap and water or alcohol before abrading.

If electrode is dry, apply a drop of gel.

Remove any jewelry on or near the electrode sites.

Fig. 7.3

- One electrode on the medial surface of the left leg, just above the ankle bone.
- One electrode on the medial surface of the right leg, just above the ankle bone.
- One electrode on the right anterior forearm just above the wrist (same side of arm as the palm of hand.)

Note: For optimal electrode contact, place electrodes on skin at least five minutes before start of Calibration.

7. Clip the Electrode Lead Set (SS2L) to the electrodes, following the color code (Fig. 7.4).
   - RED = LEFT ankle
   - WHITE = RIGHT wrist
   - BLACK = RIGHT ankle

Fig. 7.4

Setup continues…

8. Clean the window of the pulse transducer.

This will prevent any oil or dirt on the window from interfering with the signal. Use a soft cloth, Q-tip, or other non-abrasive material to wipe it clean.

9. Put pulse transducer sensor on tip of **RIGHT** index finger (Fig. 7.5) wrap Velcro snugly around finger, but not too tightly.

The transducer should be snug, but not so much that blood circulation is cut off—it's a fine line between snug and too tight.

Fig. 7.5 Sensor position on RIGHT hand

10. **Subject** gets in proper seating position, facing away from monitor and adjusts the leads and cables (Fig. 7.6).

The cables should have enough slack to not pull on the electrodes or the transducer when hands are in lap, and must be positioned to allow unrestricted movement when right hand is raised above the head.

Connect the electrode cable clip to a convenient location on Subject's clothes.

11. Start the Biopac Student Lab Program.

Start Biopac Student Lab by double-clicking the Desktop shortcut.

12. Choose lesson **"L07 – ECG & Pulse"** and click **OK**.
13. Type in a unique **filename** and Click **OK**.

No two people can have the same filename, so use a unique identifier, such as **Subject's** nickname or student ID#.

A folder will be created using the filename. This same filename can be used in other lessons to place the **Subject's** data in a common folder.

14. Set Preferences.
    - Choose File > **Lesson Preferences**.
    - Select an option.
    - Select the desired setting and click **OK**.

This lesson has optional Preferences for data and display while recording. Per your Lab Instructor's guidelines, you may set:

Grids: Show or hide gridlines

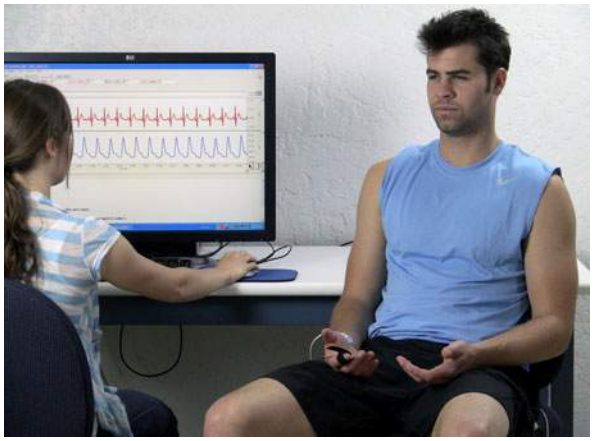
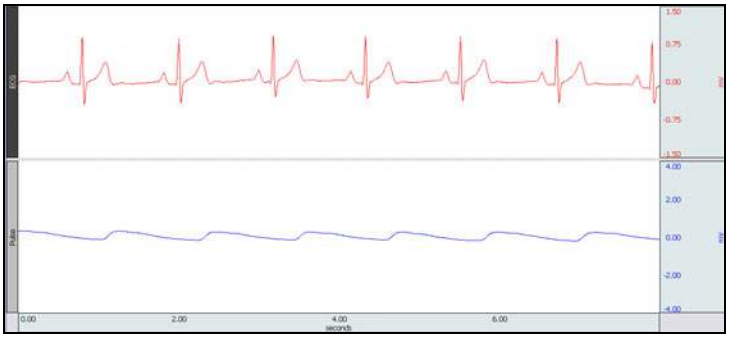
Heart Rate Data: Calculate and display Heart Rate data.

Lesson Recordings: Specific recordings may be omitted based on instructor preferences.

END OF SETUP

B. CALIBRATION

The Calibration procedure establishes the hardware's internal parameters (such as gain, offset, and scaling) and is critical for optimal performance. **Pay close attention to Calibration.**

FAST TRACK Calibration	Detailed Explanation of Calibration Steps
1. **Subject** is seated relaxed and still, facing away from monitor (Fig. 7.6).	 Fig. 7.6 Proper seating position for Calibration and Lesson **Subject** must be seated in a chair, arms at side of body and knees flexed with feet supported.
2. Click **Calibrate**.	**Subject** must remain relaxed and as still throughout calibration to minimize baseline shift and EMG artifact.
3. **Wait** for Calibration to stop.	Calibration lasts eight seconds.
4. Verify recording resembles the example data. • If similar, click **Continue** and proceed to Data Recording. • If necessary, click **Redo Calibration**.	There should be a recognizable ECG waveform with a baseline at or near 0 mV, little EMG artifact and no large baseline drift. The lower channel should display a visible pulsatile waveform.  Fig. 7.7 Example Calibration data If recording does not resemble the Example Data ▪ If the data is noisy or flatline, check all connections to the MP unit. ▪ If the ECG displays baseline drift or excessive EMG artifact: o Verify electrodes are making good contact with the skin and that the leads are not pulling on the electrodes. o Make sure Subject is in a relaxed position ▪ If the Pulse Signal is not present, change the position or tightness of the transducer. Some **Subjects** may not produce a good pulse signal and it may be necessary to use a different **Subject**.
END OF CALIBRATION	

C. DATA RECORDING

FAST TRACK Recording

1. **Subject** is seated and relaxed, arms supported, breathing normally, facing away from monitor.
   - **Review** recording steps.

Seated and relaxed

2. Click **Record**.
3. Record for **15 seconds**.
4. Click **Suspend**.
5. Verify that recording resembles the example data.
   - If <u>similar</u>, click **Continue** and proceed to the next recording.
   - If necessary, click **Redo**.
   - If all required recordings have been completed, click **Done**.

Recording continues…

Detailed Explanation of Recording Steps

Three conditions will be recorded*: Arm relaxed, hand in hot or cold water, and hand held up.

***IMPORTANT**

This procedure assumes that all lesson recordings are enabled in Lesson Preferences, which may not be the case for your lab. Always match the recording title to the recording reference in the journal and disregard any references to excluded recordings.

Hints for obtaining optimal data:

To minimize muscle (EMG) artifact and baseline drift:

- **Subject** must be relaxed.
- Make sure electrodes do not peel up and that the cables and leads do not pull on the electrodes or transducer.

Subject remains seated and relaxed.

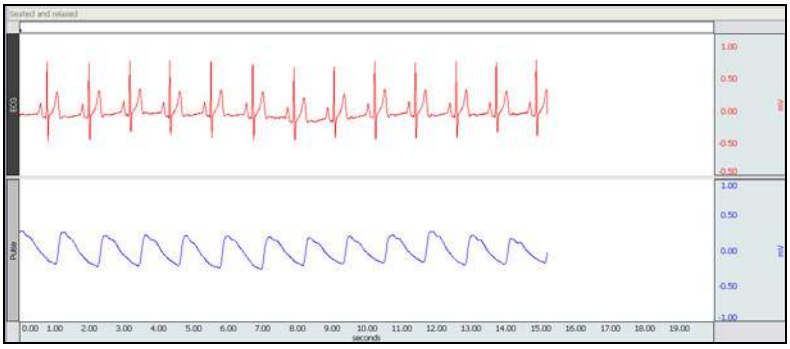


Fig. 7.8 Example Seated and relaxed data

The data description is the same as outlined in Step 4 of the Calibration procedure.

Click **Redo** and repeat Steps 2 – 5 if necessary. Note that once **Redo** is clicked, the most recent recording will be erased.

Seated, left hand in water

6. **Subject** remains seated and relaxed, facing away from monitor.
   - **Review** recording steps.
7. Put **Subject's** left (non-recording) hand into a plastic bucket filled with water (Fig. 7.9).

WARNING
The container for the water must not be metal, as this poses the potential danger of bypassing the electrical isolation of the MP unit.

Warm water should be approximately 40° C (104 deg F,) cold water approximately 20° C (68 deg. F.)

Fig. 7.9 Positioning

8. Once **Subject** is still, click **Record**.

In order to capture the heart rate and pulse variation, click Record as quickly as possible after **Subject's** hand is in water and they are still.

9. Record for 30 seconds.

Subject remains seated, relaxed with left hand in water.

10. Click **Suspend**.
11. **Subject** removes hand from water.
12. Verify recording resembles the example data.
    - If similar, click **Continue** and proceed to the next recording.

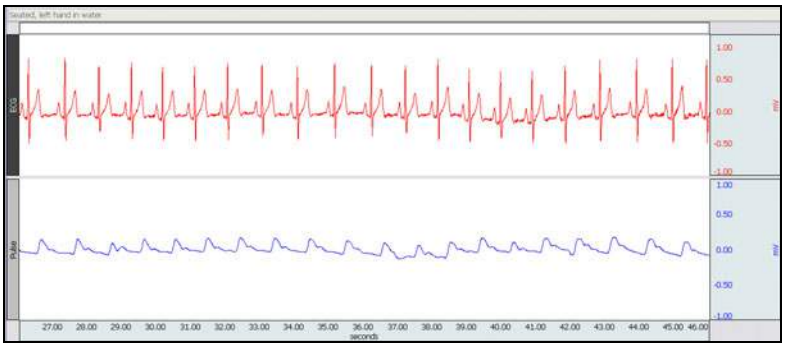


Fig. 7.10 Example Left hand in water data

- If necessary, click **Redo**.
- If all required recordings have been completed, click **Done**.

The data description is similar to that outlined in Step 4 of the Calibration procedure; however the pulse signal will most likely have a different amplitude and shape.

Click **Redo** and repeat recording if necessary. Note that if cold water was used; wait for the **Subject's** hand to return to normal temperature before repeating Steps 7 – 12. Once **Redo** is clicked, the most recent recording will be erased.

Recording continues…

Seated, right hand above head

13. **Subject** remains seated, relaxed, facing away from monitor.
    - If cold water was used, wait for **Subject's** hand to return to normal temperature before continuing.
    - **Subject** raises right hand above head, arm extended, pulse transducer attached (Fig. 7.11).
    - **Review** recording steps.

Fig. 7.11

Adjust any leads or cables that are pulling on the electrodes or transducer.

14. Click **Record.**

Subject remains seated with right arm extended above head.

15. Record for 60 seconds.

16. Click **Suspend**.

17. Verify recording resembles the example data.
    - If similar, click **Continue** to proceed to the optional recording section, or **Done** to finish the lesson.

There could be more EMG artifact in the ECG recording and there could be more baseline drift than in previous recordings. The pulse recording will vary greatly between **Subjects**; some displaying greater pulse amplitude and some less.

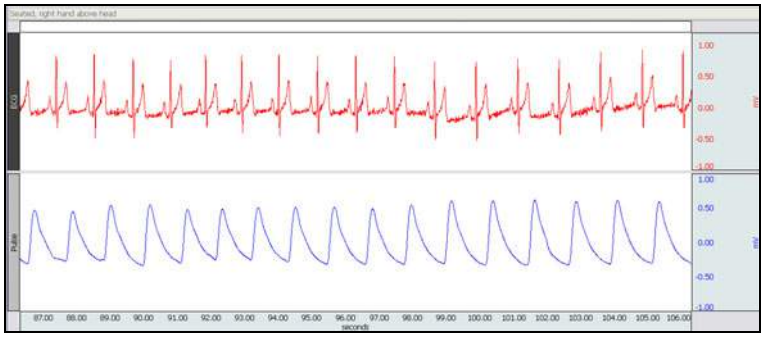


Fig. 7.12 Example Hand raised above head data

- If necessary, click **Redo**.

The data might be different for the reasons detailed in Step 4 of the Calibration procedure.

Click **Redo** and repeat Steps 13 – 17 if necessary. Note that once **Redo** is clicked, the most recent recording will be erased.

Recording continues…

OPTIONAL ACTIVE LEARNING PORTION

With this lesson you may record additional data by clicking **Continue** following the last recording. Design an experiment to test or verify a scientific principle(s) related to topics covered in this lesson. Although you are limited to this lesson's channel assignments, the electrodes or transducers may be moved to different locations on the **Subject**.

Design Your Experiment

Use a separate sheet to detail your experiment design, and be sure to address these main points:

A. ***Hypothesis***

Describe the scientific principle to be tested or verified.

B. ***Materials***

List the materials you will use to complete your investigation.

C. ***Method***

Describe the experimental procedure—be sure to number each step to make it easy to follow during recording.

Run Your Experiment

D. ***Set Up***

Set up the equipment and prepare the subject for your experiment.

E. ***Record***

Use the **Continue**, **Record** and **Suspend** buttons to record as much data as necessary for your experiment.

Click **Done** when you have completed all of the recordings required for your experiment.

Analyze Your Experiment

F. Set measurements relevant to your experiment and record the results in a Data Report.

18. After clicking **Done**, choose an option and click **OK**.

If choosing the **Record from another Subject** option:

- Repeat Setup Steps 5 – 10, and then proceed to Calibration.

19. Remove the electrodes and the transducer.

Remove the electrode cable pinch connectors and peel off all electrodes. Discard the electrodes (BIOPAC electrodes are not reusable.) Wash the electrode gel residue from the skin, using soap and water. The electrodes may leave a slight ring on the skin for a few hours which is quite normal.

END OF RECORDING

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V. DATA ANALYSIS

FAST TRACK DATA ANALYSIS

1. Enter the **Review Saved Data** mode and choose the correct file.

   - Note Channel Number (CH) designations:

Channel	*Displays*
CH 1	**ECG**
CH 40	**Pulse**

   - Note measurement box settings:

Channel	*Measurement*
CH 1	**Delta T** (time interval)
CH 1	**BPM** (rate)
CH 1	**P-P**
CH 40	**P-P**

2. **Zoom** in on a small section of the "**Seated and relaxed**" data.

Data Analysis continues…

DETAILED EXPLANATION OF DATA ANALYSIS STEPS

If entering **Review Saved Data** mode from the Startup dialog or lessons menu, make sure to choose the correct file.

The data window should resemble Fig. 7.13.

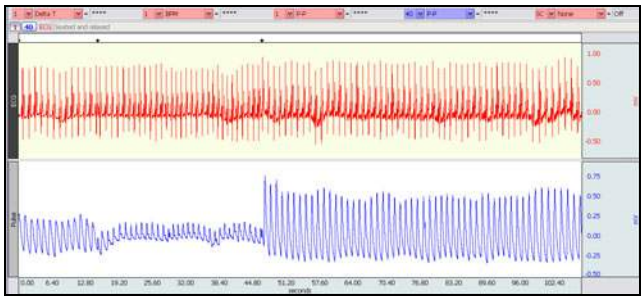

Fig. 7.13 Example data

The measurement boxes are above the marker region in the data window. Each measurement has three sections: channel number, measurement type, and result. The first two sections are pull-down menus that are activated when you click on them.

Brief definition of measurements:

Delta T: Displays the amount of time in the selected area (the difference in time between the endpoints of the selected area.)

BPM: The **B**eats **P**er **M**inute measurement first calculates the difference in time between the beginning and end of the selected area (seconds/beat,) and divides this value into 60 seconds/minute.

P-P (Peak-to-Peak)**:** Subtracts the minimum value from the maximum value found in the selected area.

Rate Mean: If CH 40 Heart Rate data was recorded, use the Rate Mean measurement, which is designed specifically for rate data and calculates accurate statistical means using one value only for every cardiac cycle. This avoids any unintentional weighting due to time variation in heart rate, unlike the amplitude "Mean" measurement.

The "selected area" is the area selected by the I-Beam (including endpoints.)

Note: The append event markers ◆ mark the beginning of each recording. Click on (activate) the event marker to display its label.

Useful tools for changing view:

Display menu: Autoscale Horizontal, Autoscale Waveforms, Zoom Back, Zoom Forward

Scroll Bars: Time (Horizontal); Amplitude (Vertical)

Cursor Tools: Zoom Tool

Buttons: Overlap, Split, Show Grid, Hide Grid, -, +

Hide/Show Channel: "Alt + click" (Windows) or "Option + click" (Mac) the channel number box to toggle channel display.

Be sure to zoom in far enough so that you can easily measure the intervals between peaks, approximately 4 cardiac cycles.

3. Using the **I-Beam** cursor, select the area between two successive R waves (one cardiac cycle).

   A

4. Repeat the above measurements for each of the data recordings.

   A

5. Using the **I-Beam** cursor, select the area between two successive pulse peaks (one cardiac cycle).

   A

6. Repeat the above measurements for each of the data recordings.

   A

7. Select individual pulse peaks for each recording and determine their amplitudes.

   B

Data Analysis continues…

Try to go from R wave peak to R wave peak as precisely as possible (Fig. 7.14).

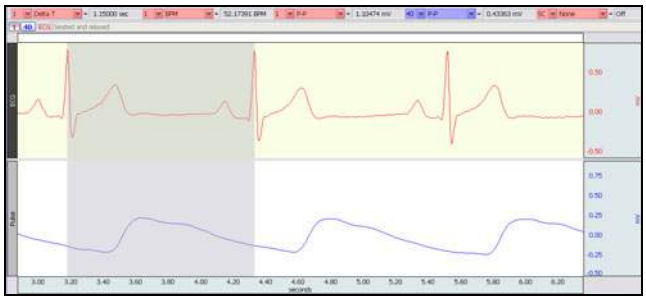

Fig. 7.14 R-R interval selected

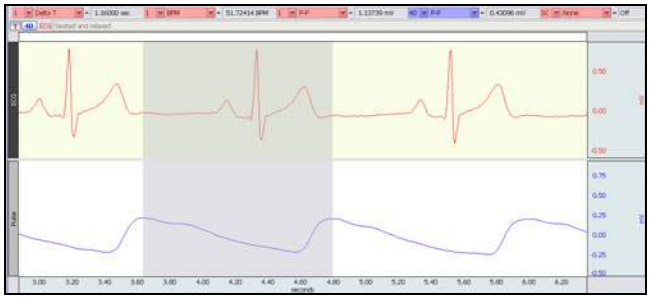

Fig. 7.15 Area between two successive pulse peaks

Use the **P-P** (CH 40) measurements.

Note: It is best to take measurements on data immediately following the start of the recording (after marker) because the body's homeostatic regulation of blood pressure and volume occurs quickly. The increase or decrease in your results will be dependent on the timing of your data relative to the speed of physiological adjustments.

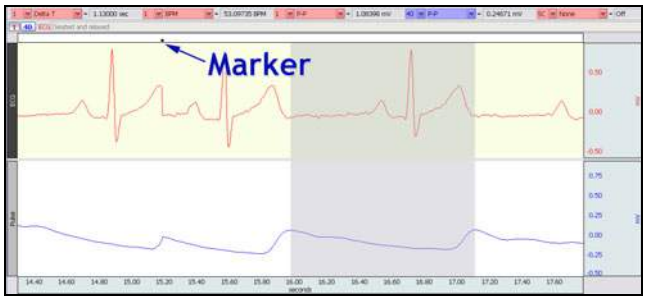

Fig. 7.16 Selection for amplitude measurements

8. Using the I-Beam cursor, select the interval between the R-wave and pulse peak.

   C

Record two time intervals (**Delta T;)** one from "Seated and Relaxed" data and "Seated, right hand above head" data.

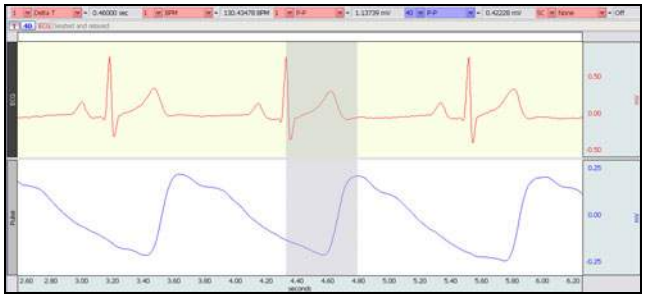

Fig. 7.17 R-wave to next pulse peak

9. Answer the questions at the end of the Data Report.
10. **Save** or **Print** the data file.
11. **Quit** the program.

END OF DATA ANALYSIS

An electronically editable **Data Report** can be found in the journal (following the lesson summary,) or immediately following this Data Analysis section. Your instructor will recommend the preferred format for your lab.

END OF LESSON 7

Complete the Lesson 7 Data Report that follows.

ECG & PULSE

- *Mechanical Action of the Heart, Peripheral Pressure Pulse, and Plethysmography*

DATA REPORT

Student's Name: _____

Lab Section: _____

Date: _____

I. Data and Calculations

Subject Profile

Name:_____ Height:_____

Age:_____ Gender: Male / Female Weight:_____

A. Comparison of ECG with Pulse Plethysmogram

Complete Table 7.1 with data from three cycles from each acquired recording and calculate the Means.

Table 7.1

Condition	Selected Area	Measurement	Cycle I	Cycle 2	Cycle 3	Mean
Arm Relaxed	R-R Interval	**DeltaT** CH 1				
	Heart Rate	**BPM** CH 1				
	Pulse Interval	**DeltaT** CH 1				
	Pulse Rate	**BPM** CH 1				
Temp. Change	R-R Interval	**DeltaT** CH 1				
	Heart Rate	**BPM** CH 1				
	Pulse Interval	**DeltaT** CH 1				
	Pulse Rate	**BPM** CH 1				
Arm Up	R-R Interval	**DeltaT** CH 1				
	Heart Rate	**BPM** CH 1				
	Pulse Interval	**DeltaT** CH 1				
	Pulse Rate	**BPM** CH 1				

B. Relative Volume Changes

Complete Table 7.2 with data from each acquired recording.

Table 7.2

Measurement	Arm Resting	Temperature	Arm Up
QRS Amplitude CH1 P-P			
Relative Pulse Amplitude (mV) CH 40 P-P			

C. **Calculation of Pulse Speed**

Distance between Subject's sternum and shoulder? _____cm

Distance between Subject's shoulder and fingertip? _____cm

Total distance? _____cm

Data from 'Arm relaxed' recording of the recording (measure with I-Beam)

Time between R-wave and Pulse peak? _____secs

Speed?_____cm/sec

Data from 'Arm up' recording of the recording (measure with I-Beam)

Time between R-wave and Pulse peak? _____secs

Speed?_____cm/sec

II. Questions

D. Referring to data in table 7.1, are the values of heart rate and pulse rate similar for each condition? Yes / No

Explain why the values might differ or be similar.

_____

_____

_____

E. Referring to Table 7.2 data, how much did the amplitude of the QRS complex change between conditions?

Extreme temp – Arm Resting? _____ mV

Arm up – Arm Resting? _____ mV

F. Referring to Table 7.2 data, how much did the pulse amplitude change between arm positions?

Extreme temp – Arm Resting? _____ mV

Arm up – Arm Resting? _____ mV

G. Referring to Table 7.2 data, does the amplitude of the QRS complex change with the pulse amplitudes? Why or why not?

_____

_____

_____

H. Describe one mechanism that causes changes in blood volume to your fingertip.

_____

_____

_____

I. Referring to data from section C of this report, how would you explain the difference in speed, if any?

_____

_____

_____

J. Which components of the cardiac cycle (atrial systole and diastole, ventricular systole and diastole) are discernible in the pulse tracing?

_____

_____

_____

K. Would you expect the calculated pulse wave velocities of other students to be very close if not the same as yours? Why or why not?

L. Explain any amplitude or frequency changes that occurred with arm position.

III. OPTIONAL Active Learning Portion

A. ***Hypothesis***

B. ***Materials***

C. ***Method***

D. ***Set Up***

E. ***Experimental Results***

End of Lesson 7 Data Report

BIOPAC Systems, Inc.
Registered to ISO 9001:2008
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ELECTRODERMAL ACTIVITY & POLYGRAPH

Introduction

Rev. 01152013

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Purdue University School of Science

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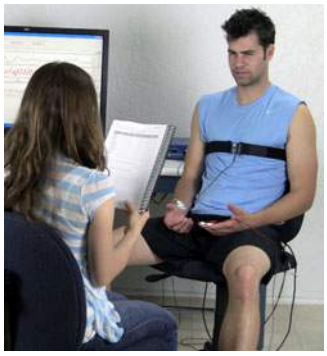

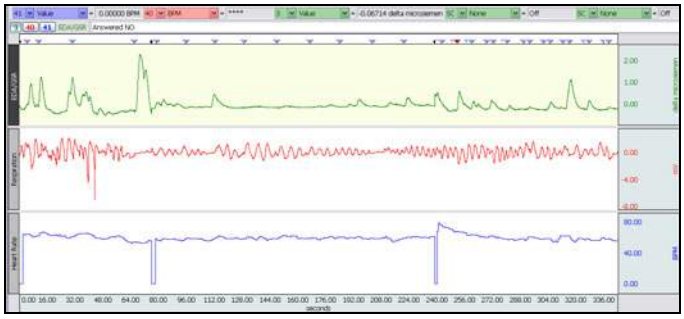

I. INTRODUCTION

Electricity flows through an electrical circuit because of a difference in electrical pressure between the beginning and the end of a circuit. Electrical pressure or **electromotive force** (E) is measured in volts (V). The flow of electricity, called **current** (I,) is measured in **amperes** (A) or amps for short. As electricity flows through the circuit, resistance to flow occurs. Electrical **resistance** (R) is measured in ohms (Ω).

In a simple circuit of direct electrical current, the relationship between the electromotive force causing the electrical current, the resistance to flow of electricity and the resultant magnitude of the current is described by Ohm's Law.

Ohm's Law: I (Amps) = E (Volts) / R (Ohms)

If two of the three variables are known, the unknown third variable can be calculated.

> ***For example***, if voltage and resistance values for a simple circuit are known, the above formula can be used to calculate the value for current; if the values for current and resistance are known, then the formula for computing voltage is E = IR.

Ohm's Law implies that if a constant current is applied across a resistance, changes in the resistance will produce a voltage change directly proportional to the resistance change.

> ***For example***, if a constant current of 1.0 ampere is applied across a resistance of 2.0 ohms, the measured voltage would be 2.0 volts (I = E/R, 1.0 ampere = 2.0 volts/2.0 ohms). If the resistance dropped to 0.5 ohm, the voltage would also fall to 0.5 volt (I = E/R, 1.0 amperes = 0.5 volt/0.5 ohm).

In this lesson, you will apply principles of Ohm's Law and record changes in the electrical resistance of the skin.

The human skin displays several forms of bioelectric phenomena, especially in areas of the extremities such as the fingers, palms of the hands, and soles of the feet.

- **Galvanic skin resistance (GSR)** — When a feeble electric current is steadily applied between two electrodes placed about an inch apart, the recorded electrical resistance between them, referred to as the galvanic skin resistance (GSR,) varies in accordance with the emotional state of the subject.
- **Galvanic skin potential (GSP**) — Similarly, if the electrodes are connected to a suitable voltage amplifier, but without any externally applied current, the voltage measured between them, referred to as the galvanic skin potential (GSP,) varies with the emotional state of the subject.

The combined changes in the GSR and GSP related to the emotion of the subject constitute the **galvanic skin response (GSR).**

Electrodermal activity (EDA) has replaced galvanic skin response (GSR) as the collective term used to describe changes in the skin's ability to conduct electricity. The preferred measure of EDA is conductance (inverse of resistance) in units of microsiemens. Conductance is preferred over resistance because the skin does not act as a single resistor, but rather a series of many resistors in parallel. The normal human EDA range is from 1 to 20 microsiemens.

The physiological basis of EDA is a change in autonomic tone, largely *sympathetic*, occurring in the skin and subcutaneous tissue in response to a change in the affective state of the subject. Changes in peripheral autonomic tone alter sweating and cutaneous blood flow, which in turn change EDA.

> ***For example***, if a painful stimulus such as a pinprick is applied to the skin in an area distant to the electrode, the stimulus will reflexively elicit a general phasic sympathetic discharge to sweat glands, increasing secretion. The increase in sweat, although generally small, lowers the electrical resistance of the skin because sweat contains water and electrolytes, both of which increase electrical conductivity of the skin.

As in the case of somatic sensory stimuli (e.g., pain, pressure, touch,) changes in emotion elicit changes in peripheral autonomic tone and hence the EDA. A common example is the vasodilation of cutaneous blood vessels of the face (blushing) and increased sweating that often occurs in the emotional state of embarrassment.

Special sensory stimuli (vision, hearing, equilibrium, taste, smell) also affect a person's emotional state, as any aficionado of classical music or hard rock can attest. Interestingly, although highly subjective, the perception of color may elicit changes in autonomic tone, which in turn, affect the subject's mood and behavior. Warm colors such as red, orange, and yellow evoke emotions of warmth and comfort in some persons, feelings of anger and hostility in others. The phrase "seeing red" refers to an angry person. Cool colors such as green, pink, and blue evoke feelings ranging from enviousness ("green with envy",) tranquility, and sadness or indifference ("feeling blue").

The influence of color on the affective state was well known to ancient Egyptians, Chinese, and other cultures who used colors to promote healing. The therapy, called **chromotherapy**, is still used today in holistic medical practice. It must be noted that most clinicians are skeptical of color therapy. The effects of color therapy vary from person to person and tend to be short-lived or temporary. In this lesson we will explore the short-term influence of color on the affective state of the subject as revealed by changes in EDA.

The detection and recording of the EDA is often combined with the detection and recording of other autonomic-dependent psychophysiological variables such as heart rate, respiratory rate, and blood pressure. The device that detects and records these variables is called a **polygraph**. Although many people think polygraph is synonymous with lie detector, the literal meaning is "many measures" (*poly* - many, *graph* – write).

This lesson is a polygraph in the true sense of the word since it uses three types of measures: (a) EDA, (b) respiration, and (c) heart rate.

One of the underlying principles involved in using the polygraph as a lie detector is that autonomic nervous system control of heart rate, respiratory rate, blood pressure and flow, and sweating cannot consciously be altered. Another principle is that changes in emotion associated with intentional falsification of answers to carefully selected and worded questions involuntarily and subconsciously alters autonomic output in such a way as to cause recognizable changes in recorded physiological variables.In the experiments that follow, you will record respiration, EDA, and heart rate under various experimental procedures so as to gain a better understanding of polygraphy, its applications, and its limitations.

The BIOPAC EDA transducer works by placing one electrode at ground (0 Volts) and the other at a constant 0.5 Volts DC. The internal circuit measures the amount of current required to maintain .5 Volts across the two electrodes. These two electrodes are connected to two different fingers, so there will be an effective resistance (R) placed across the electrodes. The current measured (I = E/R) is proportional to the conductance (1/R) because the voltage (E) is constant. Normal human EDA ranges from 1 to 20 microsiemens, so the maximum current flow would be approximately 10 micro amps. For this lesson we are only interested in changes in EDA over short periods of time (after a question is asked, etc.) To help in interpreting the data, the software applies a .05 Hz High Pass filter to allow the baseline to always settle to 0. For this reason the units for EDA are "**delta microseimens**" to indicate that it is measuring changes in EDA.

> ***It is important to keep in mind*** that although the recording procedures and measures used are similar to those that might be used in a real polygraph recording, this is not a "lie detector test." All you will do here is record the subject's physiological responses to certain questions. Some types of physiological responses are typically associated with "lying," although even under the best conditions about one-third of innocent people "fail" lie detector tests. The best you can hope for here is to get a better understanding of how these types of procedures work.

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William McMullen
Vice President, BIOPAC Systems, Inc.

II. EXPERIMENTAL OBJECTIVES

1) To become familiar with procedures for recording electrodermal activity.
2) To observe and record changes in respiratory rate, heart rate, and skin resistance associated with somatic and special sensory stimuli.
3) To observe and record changes in respiratory rate, heart rate, and skin resistance associated with cognitive behavior and emotion.
4) To analyze a 3-channel polygram recorded under various experimental conditions to gain a better understanding of polygraphy and its potential for use and misuse.

III. MATERIALS

- BIOPAC Disposable Electrodes (EL503,) 3 electrodes per Subject
- BIOPAC Electrode Lead Set (SS2L) or BIOPAC Pulse Transducer (SS4LA/L)
- BIOPAC EDA setup
  - Disposable setup: EDA Lead (SS57L) and EDA Electrodes (EL507 x 2)
  - Reusable setup: EDA Transducer (SS3LA/L) and Electrode gel (GEL101)
- BIOPAC Respiratory Transducer (SS5LB or older SS5LA or SS5L)
- BIOPAC PAPER1 or nine sheets of different colored paper. Recommended: 8-1/2"x 11" sheets in white, black, green, red, blue, yellow, orange, brown, pink
- Biopac Student Lab System: BSL 4 software, MP36 or MP35 hardware
- Computer System (Windows or Mac)

IV. EXPERIMENTAL METHODS

A. SETUP

FAST TRACK Setup

1. Turn the computer **ON**.
2. Turn **OFF** MP36/35 unit.
3. **Plug the transducers in** as follows:
   Respiratory Transducer (SS5LB) — CH 1
   Electrode Lead Set (SS2L) **or** Pulse Transducer (SS4L)* — CH 2
   EDA (SS3LA OR SS57L) — CH 3
4. Turn **ON** the MP36/35 unit.

***Optional:** A Pulse Transducer can be used in place of the default SS2L Electrode Lead Set by selecting the "**SS4LA/L: PPG-Pulse**" option in the "Cardiac Signal" Preference. This option is available in BSL 4.1.1 and higher only. (See Figs. 9.2 and 9.3)

Setup continues…

Detailed Explanation of Setup Steps

Fig. 9.1 Hardware Connections with SS2L (ECG)

Fig. 9.2 Hardware Connections with SS4L (Pulse)

If using the optional SS4L Pulse Transducer, attach it to the **Subject's** right index finger (Fig. 9.3).

Wrap the Velcro strap tightly around the index finger, but not too tightly.

Instead of an ECG waveform, the SS4L measures a pulse photoplethysmogram signal, and very accurately detects small changes in pulse rate and pressure.

Fig. 9.3 SS4L Placement

5. Attach the Respiratory Transducer (SS5L) around the **Subject's** chest (Fig. 9.4).

Transducer should be placed below the armpits and above the nipples.

IMPORTANT: The tension must be slightly tight at the point of maximal expiration (chest contracted).

Fig. 9.4 SS5L Placement

If using the SS5LA, loop the nylon straps through the corresponding slots in the transducer to hold it in place when tightened (Fig. 9.5).

IMPORTANT: The SS5LA is fragile. Do not pull hard on the ends of the rubber portion.

Fig. 9.5 SS5LA

6. Place the EDA Transducer on the index and middle finger of the left hand.

Attach two EL507 electrodes to the **Subject's** fingertips and clip the SS57L Lead, as shown in Fig. 9.6.

If electrode is dry, apply a drop of gel.

Fig. 9.6 SS57L and EL507 Setup

- **If using SS57L EDA Lead and EL507**

- **If using SS3LA and GEL101**

  → **Clean and fill** both cavities of the EDA Transducer (SS3L/SS3LA) with isotonic gel and then **attach** to the **Subject**. (Do not abrade skin for EDA.)
  (Fig. 9.7)

- CLEAN: Each cavity of the EDA Transducer should be carefully cleaned with an abrasive pad to remove any residue from the electrode. Data quality may suffer if the transducer becomes gummed with dried gel from previous uses.
- FILL: Fresh isotonic gel (GEL101) must fill the cavity to create contact between the skin and the electrodes.

Fig. 9.7 SS3L/SS3LA attachment and connection

Position the electrodes are over the pads of the fingers and wrap the Velcro® tape so the electrodes fit snugly but not so tight that blood circulation is cut off.

Setup continues…

7. Set up the LEAD II recording.
   a) Clean and abrade skin.
   b) Attach three electrodes on **Subject** as shown in Fig. 9.8 and 9.9.
   c) Connect the Electrode Lead Set (SS2L) to the electrodes following the color code (Fig. 9.9).

If the skin is oily, clean electrode sites with soap and water or alcohol before abrading.

If the **Subject's** hands are excessively dry or cold, instruct the **Subject** to rub hands together to warm them and slightly activate the sweat glands prior to calibration or recording.

If electrode is dry, apply a drop of gel.

Remove any jewelry on or near the electrode sites.

Place one electrode on the medial surface of each leg, just above the ankle. Place the third electrode on the right anterior forearm at the wrist (same side of arm as the palm of hand).

For optimal electrode contact, place electrodes on skin at least 5 minutes before start of Calibration.

- WHITE = RIGHT wrist
- RED = LEFT ankle
- BLACK = RIGHT ankle

Fig. 9.8 Lead II Setup

Fig. 9.9 Electrode Leads

The pinch connectors work like a small clothespin, but will only latch onto the nipple of the electrode from one side of the connector.

8. **Start** the Biopac Student Lab program.

Start Biopac Student Lab by double-clicking the Desktop shortcut.

9. Choose "**L09 – EDA & Polygraph"** and click **OK**.
10. Type in a unique **filename** and click **OK**.

No two people can have the same filename, so use a unique identifier, such as **Subject's** nickname or student ID#.

A folder will be created using the filename. This same filename can be used in other lessons to place the **Subject's** data in a common folder.

Important: The Respiratory Transducer model number must be specified in Lesson Preferences or the recorded signal may be out of range or too low or too high. See Step 12 below.

11. If you will be recording "**Colored Squares,**" get colored paper in the proper order.

Ordering from top to bottom: white, black, red, blue, green, yellow, orange, brown, pink.

12. *Optional*: Set Preferences.
    - Choose File > **Lesson Preferences**.
    - Select an option.
    - Select the desired setting and click **OK**.

This lesson has optional Preferences for data and display while recording. Per your Lab Instructor's guidelines, you may set:

Grids: Show or hide gridlines
Respiratory Transducer: Specify the model as SS5LB, SS5LA, or SS5L.

Cardiac Signal: Specify the cardiac transducer model as SS2L (ECG) or SS4LA/L (Pulse).

Lesson Recordings: Specific recordings may be omitted based on instructor preferences.

END OF SETUP

B. CALIBRATION

The Calibration procedure establishes the hardware's internal parameters (such as gain, offset, and scaling) and is critical for optimal performance. **Pay close attention to Calibration.**

FAST TRACK Calibration

1. **Subject** is seated, relaxed, breathing normally, and facing away from monitor.
   - **IMPORTANT**: Subject must be at resting heart rate prior to recording.
2. Click **Calibrate.**
3. Three seconds after Calibration begins, a beep will sound. When heard, Subject will inhale once quickly and deeply, and then return to normal breathing.
4. **Wait** for Calibration to stop.
5. Verify recording resembles example data.
   - If similar, click **Continue** and proceed to Data Recording.
   - If necessary, click **Redo Calibration**.

END OF CALIBRATION

Detailed Explanation of Calibration Steps

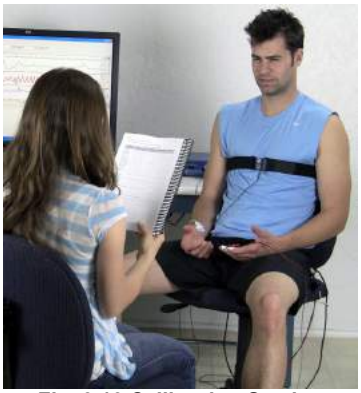
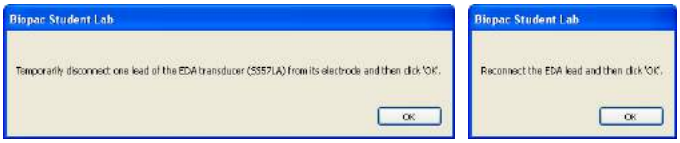


Fig. 9.10 Calibration Seating

The **Subject** should sit with arms relaxed at side of body and hands apart in lap, with legs flexed at knee and feet supported.

The program needs to see a change in the EDA during Calibration. The **Subject** should try to minimize chest movement, as this may cause excessive EMG artifact. **NOTE:** If using the SS57LA EDA transducer (BSL 4.1 only) you will see the following prompts during Calibration:



Calibration lasts ten seconds.

The Respiration channel should show variations, particularly during deep inhale/exhale. The ECG waveform should have a baseline at or near 0 mV, no excessive EMG artifact, and no excessive baseline drift before or after the deep inhale/exhale. The EDA data should increase a few seconds after the deep inhale/exhale, and then slowly return to baseline.

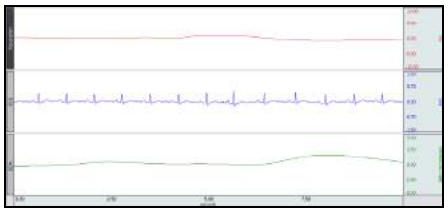


Fig. 9.11 Example Calibration data

If recording does not resemble Example Data...

- If no beep was heard, redo Calibration and begin deep, quick, inhale after three seconds.
- If data is noisy or flatline, check all connections to MP unit.
- If Respiration channel shows no variation:
  - Verify Respiratory Transducer has not slipped and strap is snug.
  - Verify preference is set correctly (after Redo – see setup Step 12).
- If the ECG displays excessive baseline drift or EMG artifact:
  - Verify electrodes are making good contact with the skin and that the leads are not pulling on the electrodes.
  - Make sure Subject is in a relaxed position.
- Despite your best efforts, it may not be possible to obtain measurable EDA from some **Subjects**. If this occurs, move on to another **Subject**.

C. DATA RECORDING

FAST TRACK Recording	Detailed Explanation of Recording Steps
1. **Subject** faces **Director** and listens for instructions. • **Carefully review** upcoming steps.	Three recordings will be acquired* while the **Subject** is: performing mental math, being touched, looking at colored paper, and answering a series of "yes" or "no" questions. ***IMPORTANT** This procedure assumes that all lesson recordings are enabled in lesson Preferences, which may not be the case for your lab. Always match the recording title to the recording reference in the journal and disregard any references to excluded recordings. ***Hints for obtaining optimal data:*** ▪ **Subject** must be relaxed, still, and facing away from monitor. ▪ **Subject** should be at his/her resting heart rate in a relaxed mental and physical state, and should not have performed any recent physical or mental exertion. ▪ The environment must be quiet, and unrelated sensory input kept at a minimum. ▪ **Subject** should answer questions quietly, with minimal movement of the mouth. ▪ Only **Redo** a recording if it is absolutely necessary as the **Subject** would most likely habituate and elicit less of a response to a repeated procedure. ▪ Make sure to insert event markers at the right time during the recording. If an event marker is missed, manually insert it after the recording has stopped, rather than Redoing. To add a marker, right click in the marker region and choose "Insert New Event" then type in the event label. You can move the marker by holding down the "Alt" key while dragging the marker.
Count and touch	
2. Click **Record**.	
3. Five seconds into recording, **Director** asks **Subject** to say full name. 4. **Recorder** presses **F2** and waits five seconds. 5. **Director** asks **Subject** to count backwards from 10. 6. **Recorder** presses **F3** and waits five seconds. 7. **Director** asks **Subject** to count backwards from 30 by subtracting increasing odd numbers: (30, 29, 26, 21, etc.) 8. **Recorder** presses **F4** and waits five seconds. 9. **Director** touches **Subject** on side of face. 10. **Recorder** presses **F5** and waits five seconds.	The 5-second wait intervals are important to re-establish the baseline. **Recorder** must insert an event marker at the precise moment that **Subject** answers each question. Each event marker has a pre-assigned label: **F2**—Name **F3**—Count from 10 **F4**—Count from 30 **F5**—Face touched
11. Click **Suspend**. 12. Verify recording resembles the example data.	**Suspend** will halt the recording, allowing time to review the data.
Recording continues…	

- If similar, click **Continue** and proceed to the next recording.

All three channels should show variations in the data and all four event markers should be present. Use the horizontal scroll bar to look at different portions of the recording.

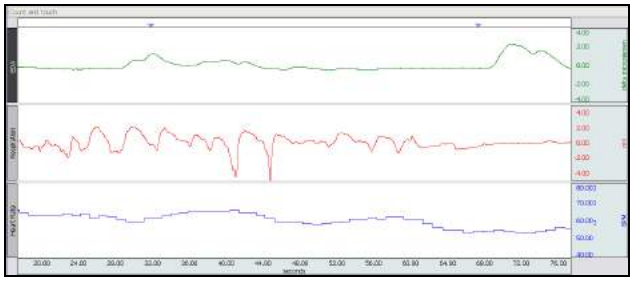


Fig. 9.12 Example Count and touch data

If recording does not resemble Example Data...

- If data is noisy or flatline, check all connections to MP unit.
- If Respiration channel shows no variation:
  - Verify Respiration Transducer has not slipped and that strap is snug.
  - Verify preference is set correctly (after Redo – see setup Step 12).
- If the ECG displays excessive baseline drift or EMG artifact:
  - Verify electrodes are making good contact with the skin and that the leads are not pulling on the electrodes.
  - Make sure Subject is in a relaxed position
- Despite your best efforts, it may not be possible to obtain measurable EDA from some **Subjects**. If this occurs, move on to another **Subject**.

- If necessary, click **Redo**.
- If all required recordings have been completed, press **Done**.

Click **Redo** and repeat Steps 2 – 12 only if absolutely necessary as the **Subject** would most likely habituate and elicit less of a response to the repeated procedure.

Note that once **Redo** is clicked, the most recent recording will be erased.

Colored squares

13. **Director** arranges colored paper in specified sequence.
    - **Subject** faces **Director**.
    - **Recorder** prepares to insert event markers at color changes.
    - **Carefully review** upcoming steps.

Arrange colors in this sequence: White, black, red, blue, green, yellow, orange, brown, pink. This ordering is important as pre-assigned event marker labels will be inserted.

Recorder must listen for **Director's** instructions to **Subject** in order to know when to press F9 to place event markers.

14. Click **Record.**
15. Director holds colored paper in front of Subject.

The paper should be held close enough to the **Subject** to cover a significant part of the field of view.

16. **Director** instructs **Subject** to concentrate on each colored square for about 10 seconds, and then lowers paper for five seconds before presenting next color.

The 5-second time intervals between paper presentations are important to re-establish the baseline.

17. **Recorder** inserts an event marker (F9 key) each time paper color is changed.
18. Click **Suspend**.

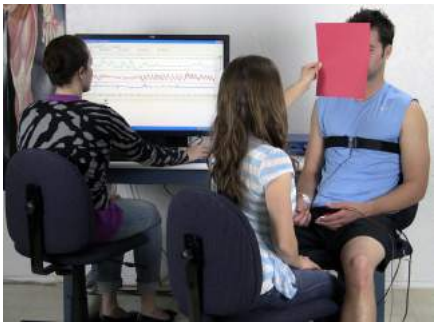


Fig. 9.13

Recording continues…

19. Verify recording resembles the example data.
    - If similar, click **Continue** and proceed to the next recording.
    - If necessary, click **Redo**.
    - If all required recordings have been completed, click **Done**.

All three channels should show variations in the data and all nine event markers should be present. Use the horizontal scroll bar to look at different portions of the recording.

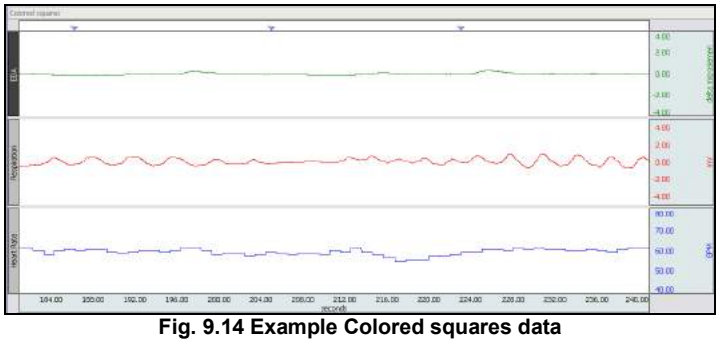


Fig. 9.14 Example Colored squares data

The data could be different for the reasons detailed on Page 6.

If a mistake is made in the paper ordering (see Step 13,) manually change the event marker labels rather than redoing the recording.

If an event marker is missing, manually enter it at the approximate location rather than redoing. See Step 1 "Hints." for more information.

Click **Redo** and repeat Steps 13 – 19 only if absolutely necessary as the **Subject** would most likely habituate and elicit less of a response to the repeated procedure.

Note that once **Redo** is clicked, the most recent recording will be erased.

Yes-No Questions

20. **Subject** faces the **Director** and listens for instructions.
    - **Subject** remains seated and relaxed.
    - **Carefully review** upcoming steps.
21. Click **Record.**
22. **Director** asks **Subject** ten prepared questions and notes **Subject's** response.
23. **Subject** responds "yes" or "no."
24. **Recorder** inserts event markers by pressing:
    - **F6** when question is asked
    - **F7** if answer is "Yes"
    - **F8** if answer is "No"
25. **Director** waits five seconds after question is answered before asking next question.

Each question-answer should take about 10 seconds.

Subject may answer truthfully or dishonestly.

The 5-second time interval between **Subject** answering the question and **Recorder** asking the next question is important to re-establish the baseline.

Recording continues…

Questions:

a) Are you currently a student? **Y N**
b) Are your eyes blue? **Y N**
c) Do you have any brothers? **Y N**
d) Did you earn an "A" on the last physiology exam? **Y N**
e) Do you drive a motorcycle? **Y N**
f) Are you less than 25 years of age? **Y N**
g) Have you ever traveled to another planet? **Y N**
h) Have aliens from another planet visited you? **Y N**
i) Do you watch "Survivor"? **Y N**
j) Have you answered all of the preceding questions truthfully? **Y N**

26. Click **Suspend**.
27. Verify recording resembles example data.
    - If similar, click **Continue** to proceed to optional recording section, or **Done** to finish the lesson.

All three channels should show variations in the data and all event markers should be present. Use the horizontal scroll bar to look at different portions of the recording.

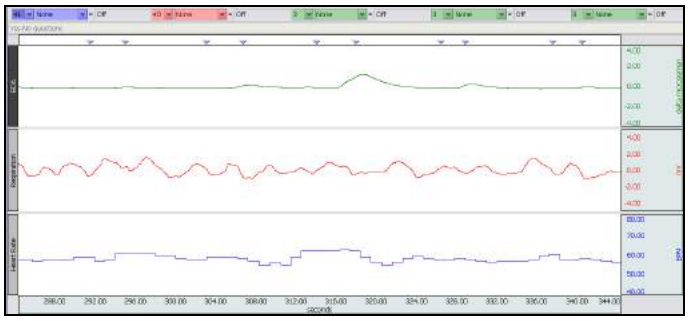


Fig. 9.15 Example Yes-No data

The data could be different for the reasons detailed on Page 6.

If an event marker is missing, manually enter it at the approximate location rather than redoing. See Step 1 "Hints" for more information.

- If necessary, click **Redo**.

Click **Redo** and repeat Steps 20 – 26 only if absolutely necessary as the **Subject** would most likely habituate and elicit less of a response to the repeated procedure.

Note that once **Redo** is clicked, the most recent recording will be erased.

28. Ask **Subject** whether or not each question was answered honestly and note this in the Data Report.

C

Recording continues…

OPTIONAL Active Learning Portion

With this lesson you may record additional data by clicking **Continue** following the last recording. Design an experiment to test or verify a scientific principle(s) related to topics covered in this lesson. Although you are limited to this lesson's channel assignments, the electrodes or transducers may be moved to different locations on the **Subject**.

Design Your Experiment

Use a separate sheet to detail your experiment design, and be sure to address these main points:

A. ***Hypothesis***

Describe the scientific principle to be tested or verified.

B. ***Materials***

List the materials you will use to complete your investigation.

C. ***Method***

Describe the experimental procedure—be sure to number each step to make it easy to follow during recording.

Run Your Experiment

D. ***Set Up***

Set up the equipment and prepare the subject for your experiment.

E. ***Record***

Use the **Continue**, **Record** and **Suspend** buttons to record as much data as necessary for your experiment.

Click **Done** when you have completed all of the recordings required for your experiment.

Analyze Your Experiment

F. Set measurements relevant to your experiment and record the results in a Data Report.

29. After clicking **Done**, choose an option and click **OK.**

After clicking **Done**, a dialog with options will be generated. Make a selection, and continue as directed.

If choosing the **Record from another Subject** option:

- Repeat Setup Steps 5 – 7, and then proceed to Calibration.

30. Carefully remove all transducers and electrodes.

If using the SS57L EDA transducer, remove the electrode pinch connectors and peel off all electrodes. Discard the electrodes. (BIOPAC electrodes are not reusable.)

If using the SS3LA EDA transducer, clean the electrode gel from each cavity.

Wash the electrode gel residue from the skin, using soap and water.

END OF RECORDING

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V. DATA ANALYSIS

FAST TRACK Data Analysis

1. Enter the **Review Saved Data** mode and choose the correct file.
   - Note Channel Number (CH) designations:

Channel	*Displays*
CH 3	**EDA**
CH 40	**Respiration**
CH 41	**Heart Rate**

   - Note measurement box settings:

Channel	*Measurement*
CH 41	**Value**
CH 40	**BPM**
CH 3	**Value**

2. Set up your display window for optimal viewing of the first 5 seconds of the recording.

Data Analysis continues…

Detailed Explanation of Data Analysis Steps

Enter **Review Saved Data** from the **Lessons** menu.

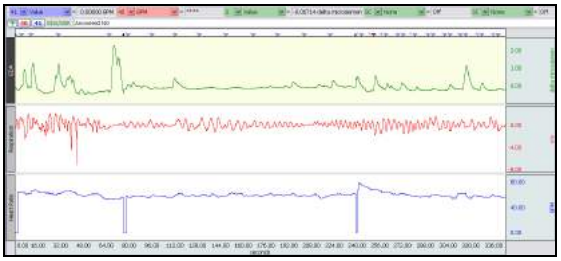

Fig. 9.16 Example data

The measurement boxes are above the marker region in the data window. Each measurement has three sections: channel number, measurement type, and value. The first two sections are pull-down menus that are activated when you click them.

Brief definition of measurements:

Value: Displays the amplitude value at the selected point. If an area is selected, the value is the endpoint of the selected area.

BPM: The Beats or Breaths Per Minute measurement first calculates the difference in time between the beginning and end of the selected area (seconds,) and divides this value into 60 seconds/minute.

The "selected area" is the area selected by the I-Beam tool (including the endpoints).

Note: The append event markers mark the beginning of each recording. Click on (activate) the event marker to display its label.

Useful tools for changing view:

Display menu: Autoscale Horizontal, Autoscale Waveforms, Zoom Back, Zoom Forward

Scroll Bars: Time (Horizontal); Amplitude (Vertical)

Cursor Tools: Zoom Tool

Buttons: Overlap, Split, Show Grid, Hide Grid, -, +

Hide/Show Channel: "Alt + click" (Windows) or "Option + click" (Mac) the channel number box to toggle channel display.

3. Using the I-Beam cursor, choose a point at the 2-second mark and record the heart rate and EDA values (Fig. 9.17).

   A

4. Using the I-Beam cursor, select an area from the start of one inhale to the start of the next inhale (Fig. 9.18,) and record the respiration rate (BPM).

   A

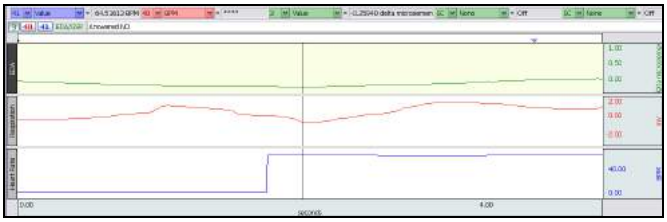

Fig. 9.17 Measurement at 2 second mark

The respiration transducer records chest expansion (inhalation) as positive values and chest deflation (exhalation) as negative values. Therefore, the start of inhalation is recorded as the beginning of the ascending positive waveform.

Note This measurement may be difficult to perform, depending on your data, because small dips in chest expansion can occur within the normal cycle and when the **Subject** answers questions. It may help to zoom further out on the data or to first scroll to better data to get an idea of the expected respiration rate.

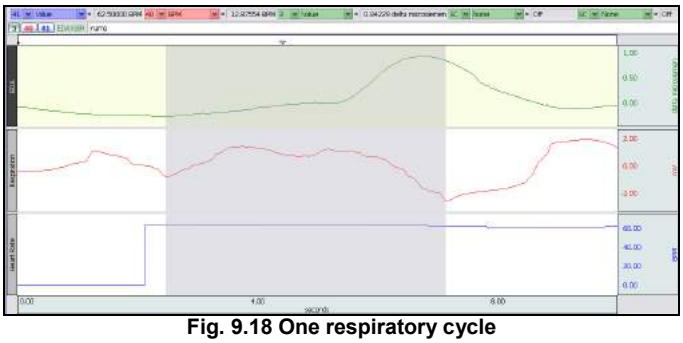

Fig. 9.18 One respiratory cycle

5. Scroll to view a 10-second interval beginning at the first event marker inserted **in Data Recording Step 4.**

6. Find the point of maximal EDA within this 10-second recording and record the heart rate and EDA values at this point.

   A

This 10-second interval in the Respiration data (CH 40) should show the **Subject's** response to the first instruction of the recording.

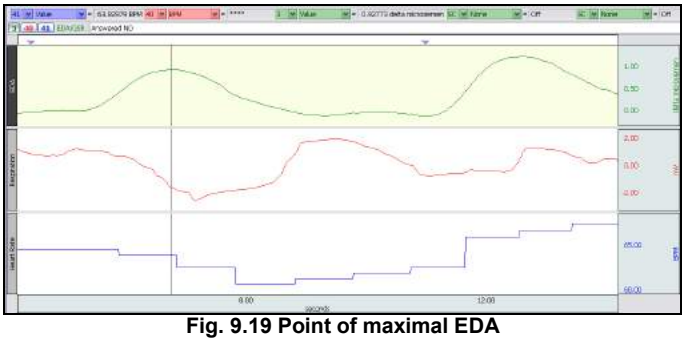

Fig. 9.19 Point of maximal EDA

7. Using the I-Beam cursor, select an area from the start of one inhale to the start of the next inhale, closest to the point used in Step 6, and record the respiration rate (BPM).

   A

8. Repeat Steps 6 – 7 for each condition in "**Count and touch**" recording of your data.

   A

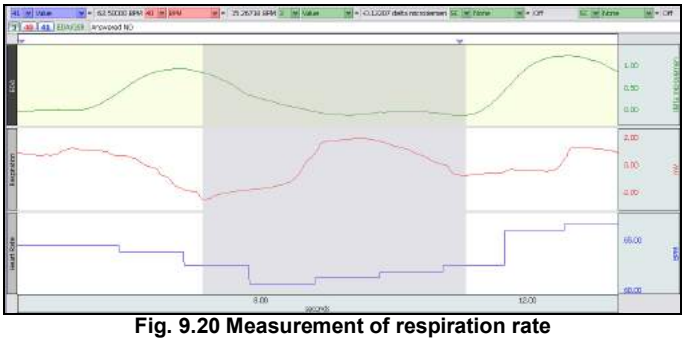

Fig. 9.20 Measurement of respiration rate

Data Analysis continues…

9. Perform Steps 5 – 7 for "**Colored squares**" data.

   B

10. Perform Steps 5 – 7 for "**Yes-No questions**" data, using a 5-second interval beginning at the "A" marker.

    C

11. Answer the questions at the end of the Data Report
12. **Save** or **Print** the data file.
13. **Quit** the program.

END OF DATA ANALYSIS

Measurements should be taken in the interval that begins when the **Subject** started to answer.

An electronically editable **Data Report** is located in the journal (following the lesson summary,) or immediately following this Data Analysis section. Your instructor will recommend the preferred format for your lab.

END OF LESSON 9

Complete the Lesson 9 Data Report that follows.

ELECTRODERMAL ACTIVITY & POLYGRAPH

DATA REPORT

Student's Name: _____

Lab Section: _____

Date: _____

Subject Profile

Name:_____ Height:_____

Age:_____ Gender: Male / Female Weight:_____

I. Data and Calculations

A. **Complete Table 9.1 with "Count and touch" data.**

Mark **I** for increase, **D** for decrease, and **NC** for no change relative to baseline. (Add or paste results into the Measurement column.)

Table 9.1 "Count and touch" Data

Procedure	Heart Rate (41 Value)		Respiratory Rate (40 BPM)		EDA (3 Value)	
	Mark	Meas	Mark	Meas	Mark	Meas
Resting (baseline)						
Quietly say name						
Count from 10						
Count from 30						
Face touched						

B. **Complete Table 9.2 with "Colored squares" data.**

Mark **I** for increase, **D** for decrease, and **NC** for no change relative to baseline. (Paste measurements in cells on right)

Table 9.2 "Colored squares" Data

Square Color	Heart Rate (41 Value)		Respiratory Rate (40 BPM)		EDA (3 Value)	
	Mark	Meas	Mark	Meas	Mark	Meas
white						
black						
red						
blue						
green						
yellow						
orange						
brown						
pink						

C. **Complete Table 9.3 with "Yes-No questions" data.**

Mark **I** for increase, **D** for decrease, and **NC** for no change relative to baseline. (Paste measurements to cells on right)

Table 9.3 "Yes-No questions" Data

Question	Answer	Truth	Heart Rate 41 Value		Respiratory Rate 40 BPM		EDA 3 Value	
			Mark	Meas	Mark	Meas	Mark	Meas
Student?	Y N	Y N						
Blue eyes?	Y N	Y N						
Brothers?	Y N	Y N						
Earn "A"?	Y N	Y N						
Motorcycle?	Y N	Y N						
Less than 25?	Y N	Y N						
Another planet?	Y N	Y N						
Aliens visit?	Y N	Y N						
"Survivor"?	Y N	Y N						
Truthful?	Y N	Y N						

II. Questions

D. Of what practical value is the EDA information obtained from the color experiment?

E. What major physiological changes account for the electrodermal activity?

F. Give three reasons why polygraph testing of a person's sincerity and honesty may yield inconclusive results.

III. OPTIONAL Active Learning Portion

A. ***Hypothesis***

B. ***Materials***

C. ***Method***

D. ***Set Up***

E. ***Experimental Results***

End of Lesson 9 Data Report

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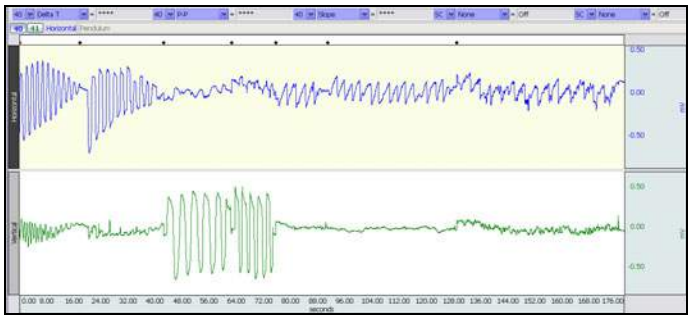


I. INTRODUCTION

A cross-section of the eye is illustrated in Fig. 10.1. Together the *cornea* and the *lens* act like the lens of a camera. They bend the light rays entering the eye and focus them on the retina.

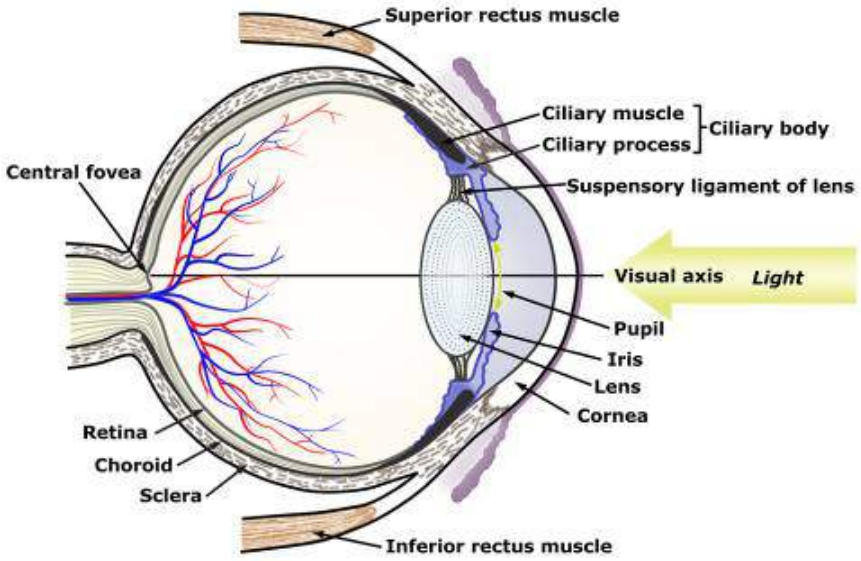


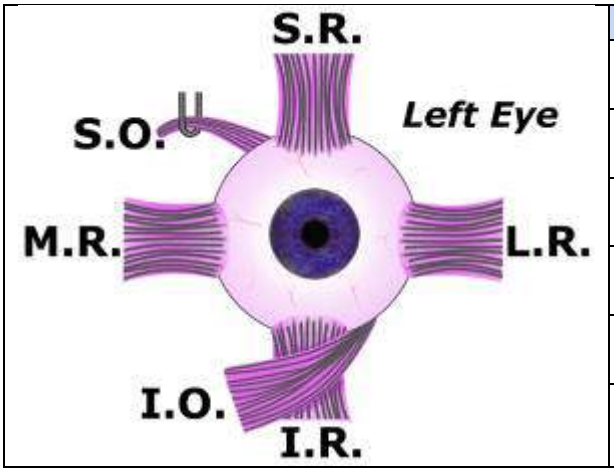
Fig. 10.1 The Eye

Focusing a camera changes the distance between the lens and the film. Our eyes accomplish this feat by changing the shape of the lens. The *ciliary muscle*, a circular muscle attached to the lens by a *suspensory ligament*, contracts, reducing tension on the suspensory ligament thereby allowing the lens to thicken, when focusing on nearby objects. The ciliary muscle relaxes to make the lens thinner and focus on objects that are far away. The *retina* contains a layer of two kinds of light-sensitive *photoreceptors*: cones and rods. *Cones* are used for day vision and color vision. They are most concentrated in the *fovea*, where focused light produces the sharpest image. *Rods* are used for vision in dim light and for the detection of movement in the visual field. Rods are concentrated in the periphery of the retina, hence, the tendency to focus away from the fovea ("look to the side of the eye") in darkness.

Muscular control of the eye works to keep the image on the fovea, regardless of whether the object is stationary or moving. This process is called *visual fixation*. Two primary mechanisms are used to fixate on objects in the visual field, defined as the field of view without moving your head: 1. Voluntary fixation, 2. Involuntary fixation.

Voluntary fixation involves a conscious effort to direct your gaze to a selected object in your visual field and "lock on" to it. This mechanism is used to initially select objects in your visual field. Involuntary fixation involves subconscious mechanisms that operate to keep the selected object in your field of view once you have locked on to it. After you have visually locked on to an object, your eyes continue to move in repetitive, involuntary, imperceptible, minute, jerky movements called *microsaccades* (*micro*-small, *saccade*-jerky movement). These movements counteract perceptual fading, a consequence of rapid adaptation of retinal receptor systems to constant input, by slightly shifting the position of the retinal image within the fovea. Microsaccades also sharpen visual acuity. The recording and measurement of microsaccades is difficult and beyond the scope of this lesson.

The movement of each eyeball in its orbit is caused by the individual contractions of six small voluntary muscles attached to the surface of the eyeball. Four of the six muscles run straight from origin to insertion, and thus are termed recti muscles (*rectus*, straight): the *superior rectus*, the *inferior rectus*, the *medial rectus*, and the *lateral rectus*. The remaining two muscles are obliquely attached to the eyeball surface and are called the *superior oblique* and the *inferior oblique* (Fig. 10.2). Collectively, the four recti muscles and the two oblique muscles are called *extrinsic eye muscles*.



Muscle	Eye Direction
Inferior Rectus (I.R.)	Downward
Superior Rectus (S.R.)	Upward
Lateral Rectus (L.R.)	Laterally
Medial Rectus (M.R.)	Medially
Superior Oblique (S.O.)	Down and Laterally
Inferior Oblique (I.O.)	Up and Laterally

Fig. 10.2 Extrinsic Eye Muscles

Contractions of the extrinsic muscles are controlled by way of motor pathways in the brain and three pairs (one right, one left) of cranial nerves. Cranial Nerve III, the *oculomotor nerve*, supplies all extrinsic eye muscles except the superior oblique and the lateral rectus. Cranial Nerve IV, the *trochlear nerve*, supplies the superior oblique. Cranial Nerve VI, the *abducens nerve*, innervates the lateral rectus.

When a normal person gazes at an adequately illuminated object, the fixation point of the gaze is projected onto corresponding sensory areas in the foveas of the retinas. The occipital lobe cortex integrates the sensory information from each retina, producing normal, single, sharp image of the object. If there is a disruption in the alignment of the eyes, as may occur, for example, in weakness of one or more extraocular muscles, there is a loss of retinal correspondence and the result may be *diplopia* or double vision. Nine cardinal directions of gaze in concerted eye movement and the extraocular muscles moving the eyes to the gaze position are shown in Fig. 10.3.

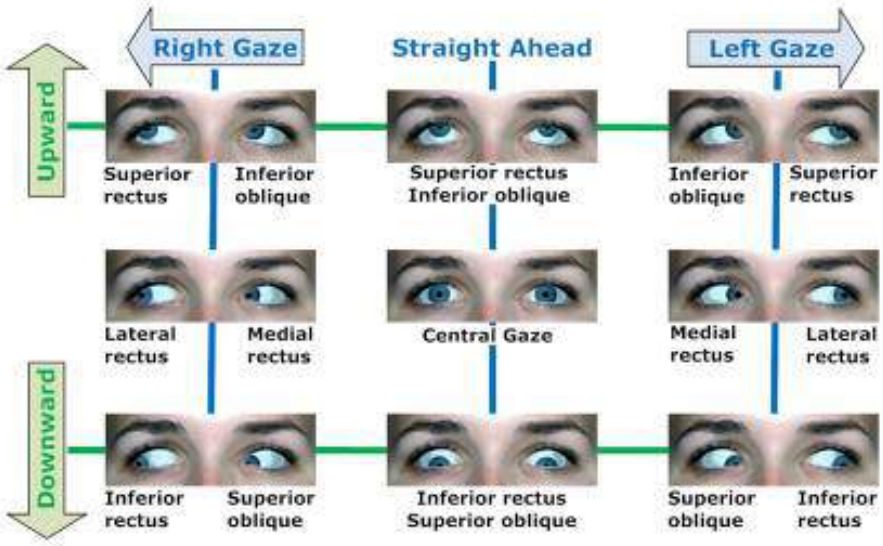


Fig. 10.3 Nine Cardinal Directions of Gaze

As a person voluntarily fixates on a moving object and then involuntarily maintains the visual fix without moving the head, such as in watching the swinging pendulum of a clock, each eye must move precisely and in concert with the other for the brain to receive the sensory information required to produce a clear, single image of the moving object. The eyeball movement involves the extraocular muscles, associated cranial nerves, and motor control centers in the brain. For example, as the clock pendulum swings from left to right, the left eye moves medially (medial rectus / cranial nerve III) and the right eye moves laterally (lateral rectus / cranial nerve VI). When the pendulum swings back, the eye movements are reversed.

The brain subconsciously grades the contractions of extraocular muscles so as to maintain the visual fixation point as the pendulum slows and speeds up during its swing by using visual sensory information regarding change of position of the moving pendulum. The oscillating, or back and forth involuntary movements of the eyes are a form of *tracking movement* in which the eyes maintain a visual fix on an object moving within the visual field.

Coordinated voluntary and involuntary eye movements are controlled by motor centers in the frontal lobe cortex and the motor centers of cranial nerves III, IV, and VI in the brainstem. Cortical activity associated with motor control of the extraocular muscles can be detected and recorded using conventional EEG techniques.

The human eye is an electrical dipole with the positive terminal in front at the cornea, and the negative terminal behind at the retina of the eyeball (Fig. 10.4). The potential between the front and the back of the eyeball, called the *corneal – retinal potential* (CRP,) is about 0.4 – 1.0 mV, and is primarily due to hyperpolarizations and depolarizations of nerve cells in the retina. *Electrooculography* is a technique for recording voltage changes as the eyeballs move in their orbits. The *electrooculogram* (EOG,*)* is an electroencephalographic record of the voltage changes obtained while the subject, without moving the head, moves the eyes from one fixation point to another within the visual field.

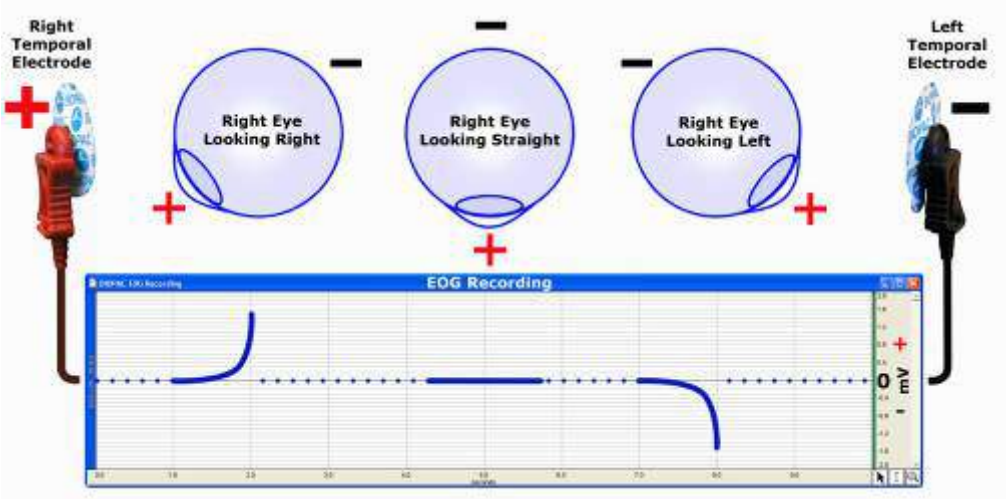


Fig. 10.4 Dipole Model of the Eye and EOG

By placing an electrode on the temporal side of each orbit to detect horizontal eye movement, and another pair above and below the right eye to detect vertical movement, eye movement up to ± 70° can be measured, where 0° is in front and ± 90° is directly lateral or vertical to the eye. The electrodes detect changes in the potential as the cornea moves nearer or further from the recording electrodes (Fig. 10.4). When the eye is looking straight ahead, it is about the same distance from either electrode, so the signal is essentially zero. When the front of the eyeball, the cornea, is closer to the positive electrode, a positive difference in voltage is recorded. The EOG signal is linearly proportional to eye movement, changing approximately 20 microvolts for each degree of eye movement. The EOG signal ranges from 0.05 – 3.5 mV in humans, and is the result of a number of factors, including eyeball rotation and movement, eyelid movement, EEG, head movement, and changing luminescence.

The EOG measurement is susceptible to baseline drift due to minor electrode/skin offset potential changes occurring over several minutes as well as potential baseline shifts due to electrode displacement on the skin surface (typically from electrode leads tugging on the electrodes). To help minimize baseline changes, for this lesson, a 0.05 Hz High Pass filter is used. This filter has minimal effect on the recorded data because the filter's 3.18 second time constant is large compared to the signal variations recorded in this lesson. This filter limitation should be kept in mind when designing additional experiments (optional active learning section); if the eyes fixate on a position for several seconds, the recorded signal will slowly return to baseline (0 mV).

Any movement of the facial muscles or jaw can introduce EMG (muscle) artifact or cause slight baseline shifts due to movement of the EOG electrodes. For this reason it is important to minimize facial and jaw movement when recording EOG data.

An EOG recorded from temporal electrodes placed at the lateral margin of the orbits of a subject visually tracking the movement of a pendulum is shown in Fig. 10.5. The sinusoidal nature of the tracing disappears when the pendulum, and hence the visual tracking, is stopped.

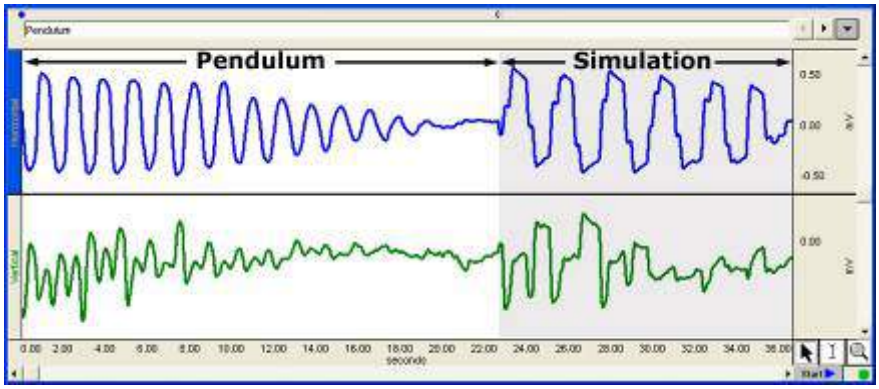


Fig. 10.5 EOG Recording

If the subject, with eyes open, *imagines* a swinging pendulum and attempts to visually track it, the EOG again becomes sinusoidal but jerky, suggesting a reduction in neuromuscular control of the eyes due to the loss of visual sensory input to the brain.

Other changes in the EOG may be recorded when a subject is asked to silently read a brief paragraph, pause, then reread aloud the same paragraph. As the words in each sentence are read, the eyes move quickly and in a jerky manner from one fixation point (a word) to another. Quick, jerky, voluntary movements of the eyes are called **saccades** (*saccade*- jerky). The time interval between saccades is the time spent looking at the word. When the reading is silent, the eyes move quickly from word to word as a line is read, and the interval between saccades is short. When the lines are read aloud, the auditory input slows eye movement to allow time for each seen word to be spoken, and the interval between saccades is longer. Generally, the interval between saccades is longer when reading a difficult passage than when reading an easy passage because more time is required by the brain for information processing.

Electrooculography is commonly used to assess visual defects involving neuromuscular control of the eyes, such as in diagnosis and treatment success of sixth nerve palsy (paralysis of the lateral rectus). Similar eye movement/cranial nerve tests using other cardinal gazes (Fig. 10.3) may be employed in diagnosis and assessment of eye disorders. In addition, recent applications include the use of electrooculography in the design of robotics, such as motorized wheelchairs and other devices that can be guided or otherwise controlled by movement of the subject's eyes.

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II. EXPERIMENTAL OBJECTIVES

1) Record EOG and compare eye movements during real and simulated tracking of a pendulum.
2) Record EOG and compare eye movements during real and during simulated tracking of an object in the vertical plane.
3) Record and compare the "saccadic" eye movements when reading three different ways; silently (easy,) silently (challenging) and aloud (challenging).

III. MATERIALS

- 2 x BIOPAC Electrode Lead Set (SS2L)
- BIOPAC Disposable Electrodes (EL503,) 6 electrodes per subject
- BIOPAC Electrode Gel (GEL1) and Abrasive Pad (ELPAD)
- *Optional*: BIOPAC Adhesive Tape (TAPE 2)—use to tape wires to reduce cable strain
- Pendulum: Can be made by attaching any object (i.e. 50 gm force calibration weight) to approx. 61 cm (24 inches) of string.
- Pen or other real object for vertical tracking
- Passages for reading: Passage 1 – easily understandable (i.e., entertainment article)
  Passage 2 – challenging material (i.e., scientific article)

Note *A sample reading passage in printable PDF format is available in the lesson Help menu.*

- Biopac Student Lab System: BSL 4 software, MP36, MP35 or MP45 hardware
- Computer System (Windows or Mac)

IV. EXPERIMENTAL METHODS

A. SETUP

FAST TRACK Setup

1. Turn the computer ON.
   - If using an MP36/35 unit, turn it **OFF**.
   - If using an MP45, make sure USB cable is connected and "Ready" light is **ON**.
2. **Plug the Electrode Lead Sets** (SS2L**)** in as follows:
   Horizontal lead — CH 1
   Vertical lead — CH 2
3. Turn **ON** the MP36/35 unit.

Setup continues…

Detailed Explanation of Setup Steps

Fig. 10.6 MP3X (top) and MP45 (bottom) equipment connections

4. Gently clean and abrade skin.
5. Attach six electrodes to **Subject**'s face as shown in Fig. 10.7.

IMPORTANT
For accurate recordings, attach the electrodes so they are horizontally and vertically aligned.

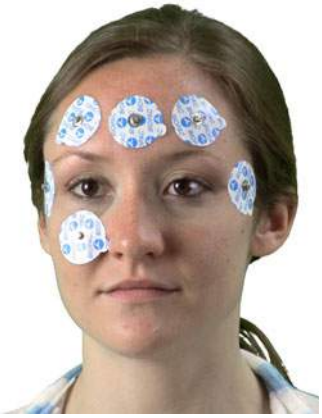

Fig. 10.7 Proper electrode placement

- If the skin is oily, clean electrode sites with soap and water or alcohol before abrading.
- If electrode is dry, apply a drop of gel.
- Attach one electrode above the right eye and one below, such that they are aligned vertically.
- Attach one electrode to the right of the right eye and one to the left of the left eye, so they align horizontally.
- The other two electrodes are for ground, and alignment is not critical.

For optimal electrode contact, place electrodes on skin at least five minutes before start of Calibration.

6. Clip CH 1 Electrode Lead Set (SS2L) in the horizontal placement, following the color code (Fig. 10.8).

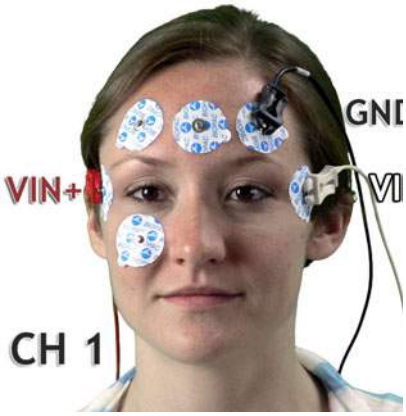

Fig. 10.8 Horizontal (CH 1) Lead Placement

- Drape the electrode lead cables behind the ears, as shown, to give proper cable strain relief.
- Connect the electrode cable clip to a convenient location to help relieve cable strain.
- Electrodes must lay flat on skin.

7. Clip CH 2 Electrode Lead Set (SS2L) in the vertical placement, following the color code (Fig. 10.9).

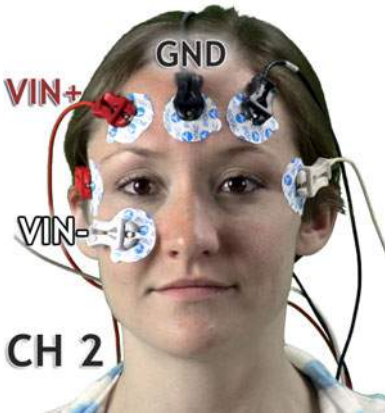

Fig. 10.9 Vertical (CH 2) Lead Placement

Setup continues…

8. **Start** the Biopac Student Lab Program.

Start Biopac Student Lab by double-clicking the Desktop shortcut.

9. Choose lesson "**L10 – Electrooculogram (EOG) I"** and click **OK**.
10. Type in a unique **filename** and click **OK**.

No two people can have the same filename, so use a unique identifier, such as **Subject's** nickname or student ID#.

A folder will be created using the filename. This same filename can be used in other lessons to place the **Subject's** data in a common folder.

11. *Optional*: Set Preferences.
    - Choose File > **Lesson Preferences**.
    - Select an option.
    - Select an option and click **OK**.

This lesson has optional Preferences for data and display while recording. Per your Lab Instructor's guidelines, you may set:

Grids: Show or hide gridlines

Lesson Recordings: Specific recordings may be omitted based on instructor's preferences.

END OF SETUP

B. CALIBRATION

The Calibration procedure establishes the hardware's internal parameters (such as gain, offset, and scaling) and is critical for optimal performance. **Pay close attention to Calibration.**

FAST TRACK Calibration

1. **Subject** is seated, relaxed, breathing normally, and facing away from monitor.
   - **Carefully review** upcoming steps.
2. Click **Calibrate**.
3. **Subject** must:
   - Complete four horizontal eye movement cycles (extreme left-extreme right-return to center) and four vertical eye movement cycles (extreme up-extreme down-return to center).
   - Wait for Calibration to stop.
4. Verify recording resembles example data.
   - If <u>similar</u>, click **Continue** and proceed to Data Recording.
   - If necessary, click **Redo Calibration**.

END OF CALIBRATION

Detailed Explanation of Calibration Steps

- **Subject** should sit with arms relaxed at side of body, legs flexed at knee and feet supported.
- **Subject** prepares to move eyes horizontally and vertically for Calibration procedure.
- **Subject** must try to keep head still and avoid blinking.
- Calibration lasts 20 seconds.

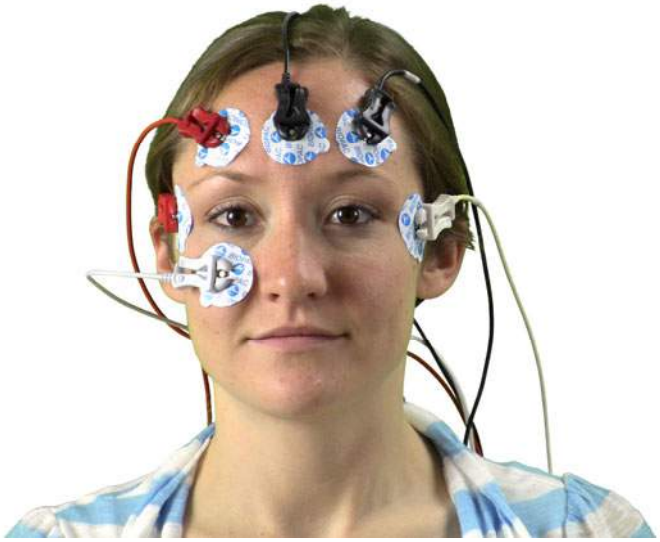

Fig. 10.10 Proper head positioning

The four cycles of horizontal and vertical eye movement should be clearly visible in the appropriate data channel.

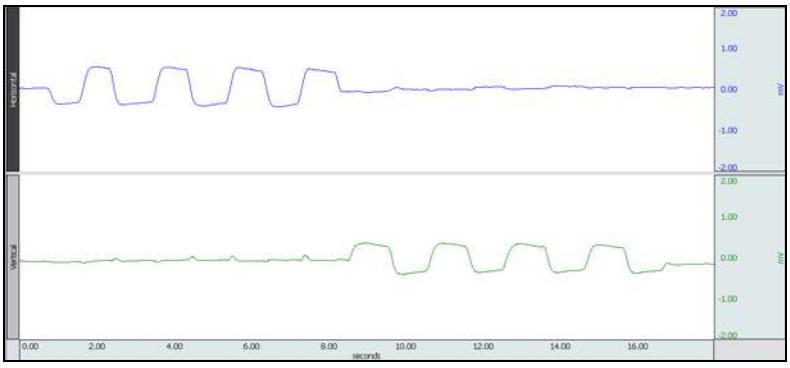

Fig. 10.11 Example Calibration data

<u>If recording does not resemble Example Data…</u>

- If data is flatline, check all connections to MP unit.
- If there is excessive noise or baseline drift, check that electrodes are making good contact with the skin (lying flat) and that leads are not pulling on the electrodes.
- If **Subject** blinked, resulting in a large data spike, redo the calibration.

C. DATA RECORDING

FAST TRACK Recording

1. Prepare for the recordings.

Pendulum

2. **Prepare** for the recording.
   - **Director** holds pendulum in front of **Subject**, ready to release (Fig. 10.12).
   - **Subject** must focus on pendulum.
   - **Review** recording steps.

Recording continues…

Detailed Explanation of Recording Steps

Seven data recordings will be acquired*:

Recording 1 – 2: real and simulated pendulum
Recording 3 – 4: real and simulated vertical tracking
Recording 5 – 6: read silently (easy and challenging)
Recording 7: read aloud (challenging)

***IMPORTANT**
This procedure assumes that all lesson recordings are enabled in lesson Preferences, which may not be the case for your lab. Always match the recording title to the recording reference in the journal and disregard any references to excluded recordings.

For all recordings, the **Subject** is seated and relaxed, facing away from the monitor.

Hints for obtaining optimal data:

- Review recording steps in advance.
- Make sure all electrodes are making good contact with skin (lying flat) and that leads are not pulling on the electrodes.
- **Subject** must remain in a seated, relaxed state for all recordings.
- **Subject** must keep head still, move only eyes and try to avoid blinking.
- In order to record sufficient amplitude variation, eye movements should be as large as possible. When tracking a moving object, eye movements should cover a significant portion of the visual range along at least one axis. When reading, the reading material must be held as close to the **Subject** as possible, while maintaining focus.

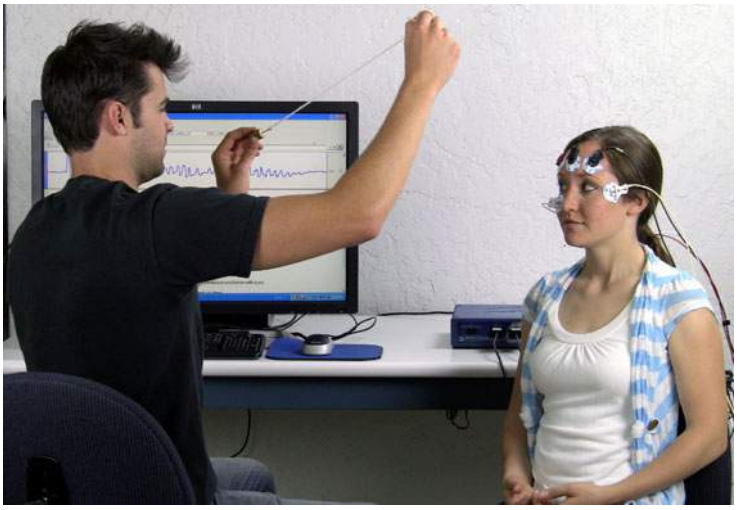

Fig. 10.12 Pendulum positioning

Details...

- **Subject** should be seated about 25 cm (10 inches) from pendulum—adjust as necessary to maintain focus.
- Bottom of pendulum swing should align with bottom of **Subject's** nose.
- Pendulum should be lifted approximately 45 degrees to **Subject's** right while maintaining a taut string, ready to release when recording starts.
- **Director** must hold pendulum string at a constant position.

3. Click **Record**.
   - **Director** releases pendulum.
4. **Subject** tracks pendulum with eyes only.
5. Wait for pendulum to stop swinging.
6. Click **Suspend**.
7. Verify recording resembles the example data.
   - If similar, click **Continue** and proceed to the next recording.

There should be cyclical variation in the data and the amplitude should progressively decrease. The Horizontal data should display greater amplitude variation than the Vertical data.

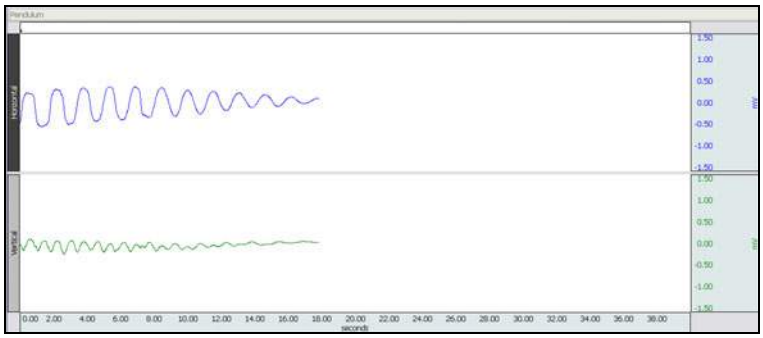

Fig. 10.13 Example Pendulum data

If recording does not resemble Example Data...

- If data is flatline, check all connections to MP unit.
- If there is excessive noise or baseline drift, check that electrodes are making good contact (lying flat) and that leads are not pulling on the electrodes.
- If there is not sufficient amplitude variation, make sure that the horizontal range of the pendulum swing covers a large portion of the **Subject's** visual range.
- If **Subject** blinked, resulting in a large data spike, redo the recording.

- If necessary, click **Redo**.
- If all required recordings have been completed, click **Done**.

Click **Redo** and repeat Steps 2 – 7 if necessary.

Note that once **Redo** is clicked, the most recent recording will be erased.

Simulate Pendulum

8. **Prepare** for the recording.
   - **Subject** prepares to simulate eye-tracking an imaginary pendulum.
   - **Subject** places eyes at the 2 o'clock position
   - **Review** recording steps.
9. Click **Record**.
10. **Subject** tracks an imaginary pendulum with decreasing swing cycles.
11. **Director** observes horizontal channel until there is little or no eye movement.
12. Click **Suspend**.

This simulates the starting position of the pendulum.

Subject must try to visualize the pendulum movement of the previous recording and track the imaginary pendulum with the eyes only. The initial swing should take up a large portion of the **Subject's** visual range along the horizontal axis and each successive swing should be reduced in amplitude until the eyes are still.

Recording continues…

13. Verify recording resembles the example data.
    - If similar, click Continue and proceed to the next recording.

There should be cyclical variation in the Horizontal data and the amplitude should progressively decrease.

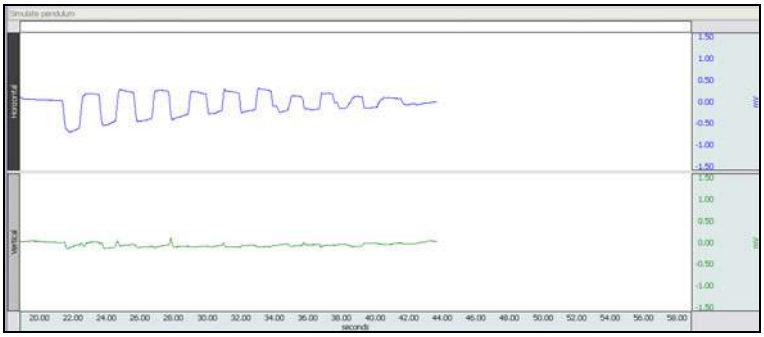

Fig. 10.14 Example Simulated Pendulum data

    - If necessary, click **Redo**.

Data would be different for reasons detailed in Step 7.

Click **Redo** and repeat Steps 8 – 13 if necessary.

Note that when **Redo** is clicked, the most recent recording will be erased.

Vertical Tracking

14. **Prepare** for the recording
    - **Director** positions a pen about 25 cm (10 inches) from **Subject**.
    - **Subject** tracks pen.
    - **Director** moves pen vertically up and down to determine the limits of the **Subject's** visual range.
    - **Review** recording steps.

Director holds pen centered with the eyes - adjust as necessary to maintain focus (Fig. 10.15). **Subject** must pick a focal point on the pen and track its movement WITHOUT moving head.

Director determines (and mentally notes) the upper and lower edges of the **Subject's** visual field by moving the pen up and down until **Subject** indicates it is out of view.

Director returns pen to a center position (eyes looking straight ahead) and the recording is ready to begin.

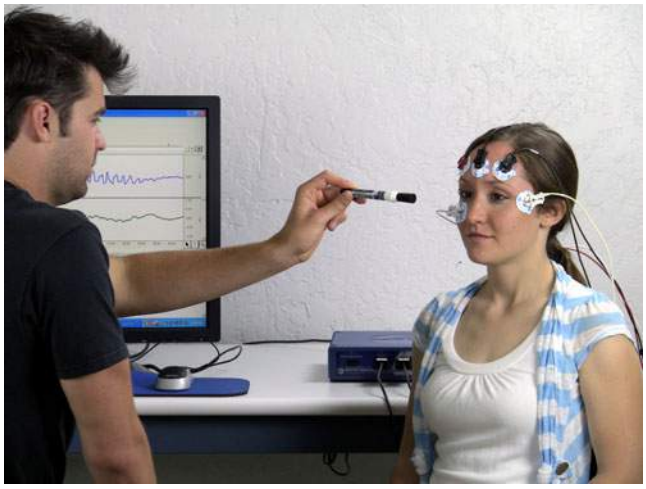

Fig. 10.15 Vertical tracking positioning

Recording continues…

15. Click **Record**.

16. **Subject** tracks pen while **Director** moves it from center to upper and lower edges of visual field.
    - Repeat for a total of five cycles.
17. Click **Suspend**.

18. Verify recording resembles the example data.
    - If similar, click **Continue** and proceed to the next recording.

Subject must track pen movement with the eyes only, trying not to move head or blink.

Director moves the pen through five vertical tracking cycles as follows:

- From center to upper then lower edges of visual field and then back to center.

The five cycles should be clearly visible in the Vertical channel data.

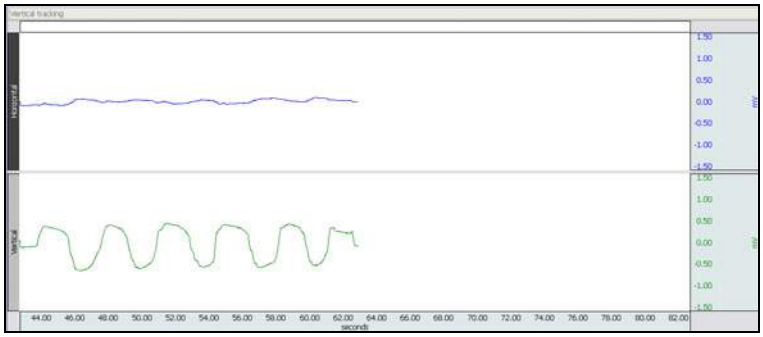

Fig. 10.16 Example Vertical Tracking data

If recording does not resemble Example Data...

- If data is flatline, check all connections to MP unit.
- If there is excessive noise or baseline drift, check that electrodes are making good contact (lying flat) and that leads are not pulling on the electrodes.
- If there is not sufficient amplitude variation, make sure that the vertical range of the pen covers the **Subject's** visual range.
- If **Subject** blinked, resulting in a large data spike, redo the recording.

- If necessary, click **Redo**.
- If all required recordings have been completed, click **Done**.

Click **Redo** and repeat Steps 14 – 18 if necessary.

Note that once **Redo** is clicked, the most recent recording will be erased.

Simulate Vertical Tracking

19. **Prepare** for the recording.
    - **Subject** centers eyes and prepares to simulate vertical eye-tracking.
    - **Review** recording steps.
20. Click **Record**.

21. **Subject** tracks an imaginary pen moving vertically through visual field for five cycles.
22. **Director** observes vertical channel until there is little or no eye movement.
23. Click **Suspend**.

Subject tracks the imaginary pen with eyes only, imagining the pen moving to the upper then lower edges of visual field, then returning to center. This upper/lower cycle should be repeated five times.

Recording continues…

24. Verify recording resembles the example data.
    - If similar, click **Continue** and proceed to the next recording.

The five cycles should be clearly visible in the Vertical channel data.

Fig. 10.17 Example Simulated Vertical Tracking data

- If necessary, click **Redo**.

Data would be different for reasons detailed in Step 18.

Click **Redo** and repeat Steps 19 – 24 if necessary.

Note that when **Redo** is clicked, the most recent recording will be erased.

Read Silently (Easy)

25. **Prepare** for the recording
    - **Director** holds reading material centered in front of **Subject** as close as possible, while maintaining focus (Fig. 10.18).
    - **Review** recording steps.

This passage should be easy to read. The upper passage will be used for this recording. You may hide the lower passage by folding the paper in half.

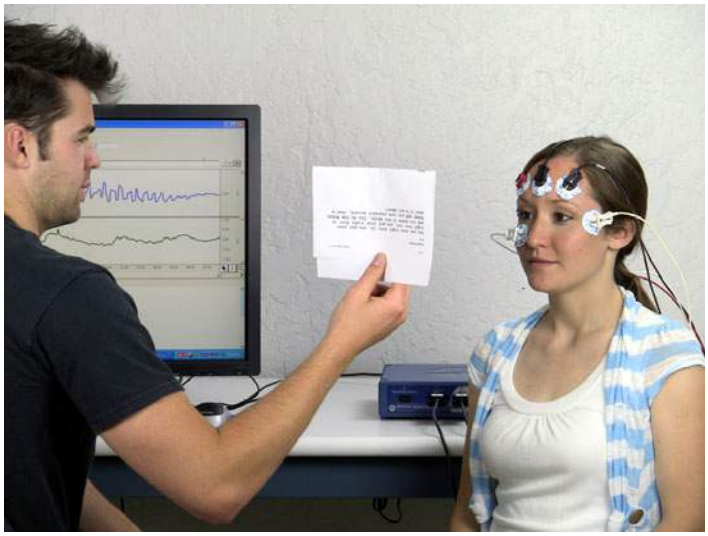

Fig. 10.18 Reading material positioning

Details...

- **Subject** must be able to read entire passage without moving head.
- **Subject** must keep head still, move only eyes, and try to avoid blinking.
- **Director** must hold the reading material as still as possible.

26. Click **Record**.
27. **Subject** reads material silently and announces when finished.
28. Click **Suspend**.

Recording continues…

29. Verify recording resembles the example data.
    - If similar, click **Continue** and proceed to the next recording.

There should be a visible "saw tooth" pattern in the Horizontal data.

Fig. 10.19 Example Read Silently (Easy) data

If recording does not resemble Example Data...

- If data is flatline, check all connections to MP unit.
- If there is excessive noise or baseline drift, check that electrodes are making good contact (lying flat) and that leads are not pulling on the electrodes.
- If there is not sufficient amplitude variation, make sure that the reading material was held as close as possible to the **Subject's** face while maintaining focus.
- Make sure the **Director** held the reading material as still as possible.
- If **Subject** blinked, resulting in a large data spike, redo the recording.

- If necessary, click **Redo**.
- If all required recordings have been completed, click **Done**.

Click **Redo** and repeat Steps 25 – 29 if necessary.

Note that once **Redo** is clicked, the most recent recording will be erased.

Read Silently (Challenging)

30. **Prepare** for the recording.
    - **Director** holds reading material centered in front of **Subject** as close as possible, while maintaining focus.
    - **Review** recording steps.
31. Click **Record**.
32. **Subject** reads material silently and announces when finished.
33. Click **Suspend**.
34. Verify recording resembles the example data.
    - If similar, click **Continue** and proceed to the next recording.

This passage should be more challenging then that from "**Read Silently (Easy).**" You may hide the upper passage by folding the paper in half.

Review the "Details" listed in Step 25.

There should be a visible "saw tooth" pattern in the Horizontal data.

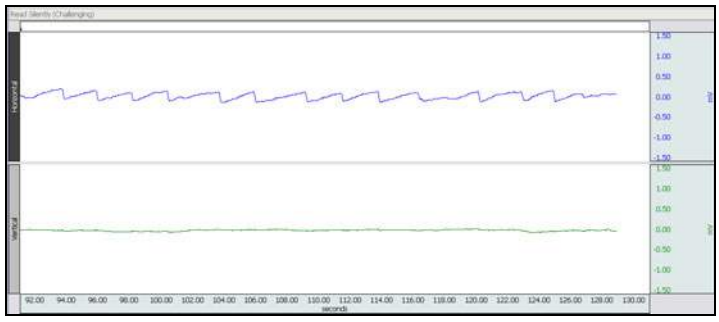

Fig. 10.20 Example Read Silently (Challenging) data

- If necessary, click **Redo**.
- If all required recordings have been completed, click **Done**.

Recording continues…

Data would be different for the reasons detailed in Step 29.

Click **Redo** and repeat Steps 30 – 34 if necessary.

Note that when **Redo** is clicked, the most recent recording will be erased.

Read Aloud (Challenging)

35. **Prepare** for the recording
    - **Director** holds reading material centered in front of **Subject** as close as possible, while maintaining focus.
    - **Review** recording steps.

This passage should be the same as that used in "**Read Silently (Challenging).**"
Review the "Details" listed in Step 25.

36. Click **Record.**
37. **Subject** reads passage aloud.
38. Click **Suspend.**

Subject reads passage aloud until material is complete. **Subject** should try to minimize mouth and jaw movement as this can add signal artifact to the EOG.

39. Verify recording resembles example data.
    - If similar, click **Continue** to proceed to optional recording section, or **Done** to finish the lesson.

The Horizontal data will most likely show less of a consistent pattern than in the Read silently recordings.

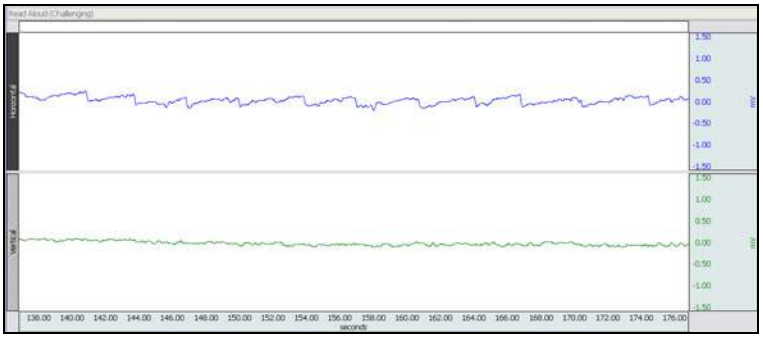

Fig. 10.21 Example Read Aloud (Challenging) data

- If necessary, click **Redo**.

Data might be different for the reasons detailed in Step 29.

If the signal is too difficult to interpret, redo and have the **Subject** use less mouth and jaw movement.

Click **Redo** and repeat Steps 35 – 39 if necessary. Note that when **Redo** is clicked, the most recent recording will be erased.

Recording continues…

OPTIONAL ACTIVE LEARNING PORTION

With this lesson you may record additional data by clicking **Continue** following the last recording. Design an experiment to test or verify a scientific principle(s) related to topics covered in this lesson.

Design Your Experiment

Use a separate sheet to detail your experiment design, and be sure to address these main points:

A. ***Hypothesis***

Describe the scientific principle to be tested or verified.

B. ***Materials***

List the materials you will use to complete your investigation.

C. ***Method***

Describe the experimental procedure—be sure to number each step to make it easy to follow during recording.

Run Your Experiment

D. ***Set Up***

Set up the equipment and prepare the subject for your experiment.

E. ***Record***

Use the **Continue**, **Record** and **Suspend** buttons to record as much data as necessary for your experiment.

Click **Done** when you have completed all of the recordings required for your experiment.

Analyze Your Experiment

F. Set measurements relevant to your experiment and record the results in a Data Report.

40. After clicking **Done**, choose an option and click **OK**.

If choosing the **Record from another Subject** option:

- Repeat Setup Steps 4 – 7, and then proceed to Calibration.

41. Remove the electrodes.

Remove the electrode cable pinch connectors and peel off all electrodes. Discard the electrodes. (BIOPAC electrodes are not reusable.) Wash the electrode gel residue from the skin, using soap and water. The electrodes may leave a slight ring on the skin for a few hours which is quite normal.

END OF RECORDING

Richard Pflanzer, Ph.D.
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Indiana University School of Medicine
Purdue University School of Science

William McMullen
Vice President, BIOPAC Systems, Inc.

V. DATA ANALYSIS

FAST TRACK Data Analysis

1. Enter the **Review Saved Data** mode.

   - Note Channel Number (CH) designations:

Channel	*Displays*
CH40	**Horizontal**
CH 41	**Vertical**

   - Note measurement box settings:

Channel	*Measurement*
SC	**Delta T**
CH 40	**P-P**
CH 41	**P-P**

2. Set up your display window for optimal viewing of the "**Pendulum tracking**" data.

Data Analysis continues…

Detailed Explanation of Data Analysis Steps

If entering **Review Saved Data** mode from the Startup dialog or Lessons menu, make sure to choose the correct file.

Example data:

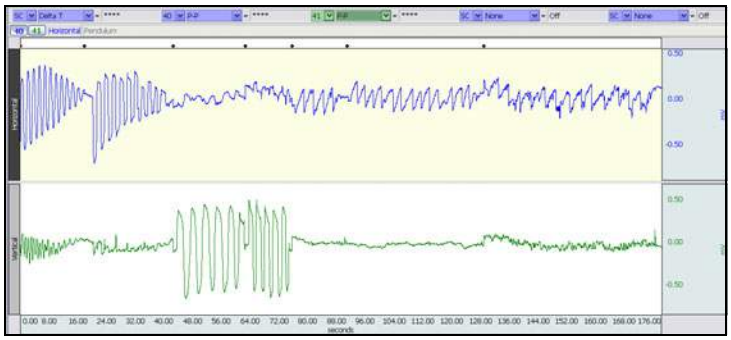


Fig. 10.22 Example data

The measurement boxes are above the marker region in the data window. Each measurement has three sections: channel number, measurement type, and result. The first two sections are pull-down menus that are activated when you click them.

SC is the Selected Channel; the one with the darkened channel label. Channels are selected clicking on the channel selection box or by clicking within the channel display region.

Brief definition of measurements:

Delta T: Displays the amount of time in the selected area (the difference in time between the endpoints of the selected area).

P-P (Peak-to-Peak): Subtracts the minimum value from the maximum value found in the selected area.

The "selected area" is the area selected by the I-beam tool (including endpoints).

Note: The append event markers mark the beginning of each recording. Click on (activate) the event marker to display its label.

Useful tools for changing view:

Display menu: Autoscale Horizontal, Autoscale Waveforms, Zoom Back, Zoom Forward

Scroll Bars: Time (Horizontal); Amplitude (Vertical)

Cursor Tools: Zoom Tool

Buttons: Overlap, Split, Show Grid, Hide Grid, -, +

Hide/Show Channel: "Alt + click" (Windows) or "Option + click" (Mac) the channel number box to toggle channel display.

3. Referencing the Horizontal data, select the area of the first tracking cycle. Record the Delta T (period) and P-P measurements. Repeat for each successive tracking cycle.

   A (Table 10.1)

At the start of the tracking cycle, the eyes were looking straight ahead and the data was approximately centered between minimum and maximum values.

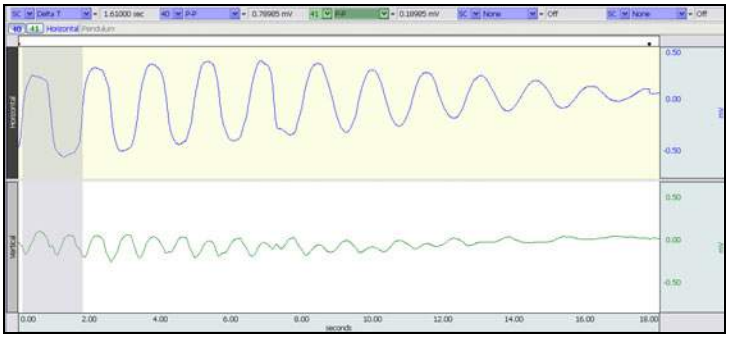


Fig. 10.23—Selection of first Horizontal tracking cycle.

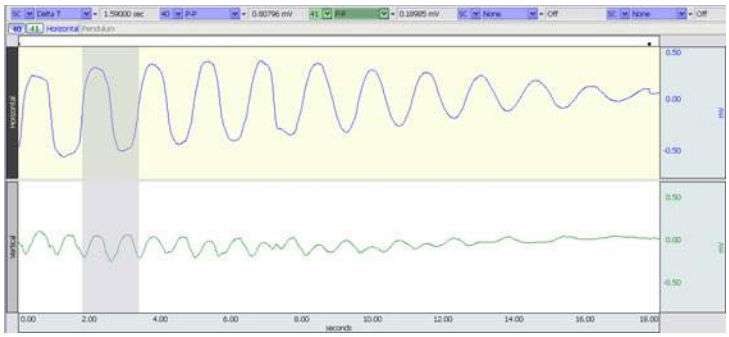


Fig. 10.24—Selection of second Horizontal tracking cycle.

4. Scroll to "**Simulate pendulum**" data and record the measurements for each successive cycle as in Step 3.

   A

5. Scroll to "**Vertical tracking"** data.

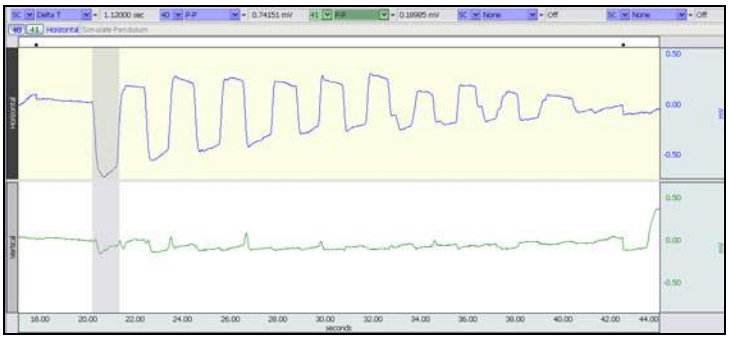


Fig. 10.25—Selection of first Horizontal cycle.

6. Referencing the Vertical data, select the area of the first tracking cycle. Record the Delta T (period) and P-P measurements. Repeat for each successive tracking cycle.

   B (Table 10.2)

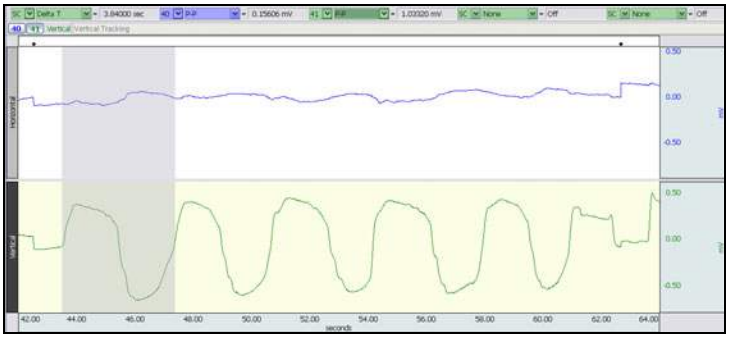


Fig. 10.26—Selection of first Vertical tracking cycle.

Data Analysis continues…

7. Scroll to "**Simulate vertical tracking**" data and record the measurements for each successive cycle as in Step 6.

   B

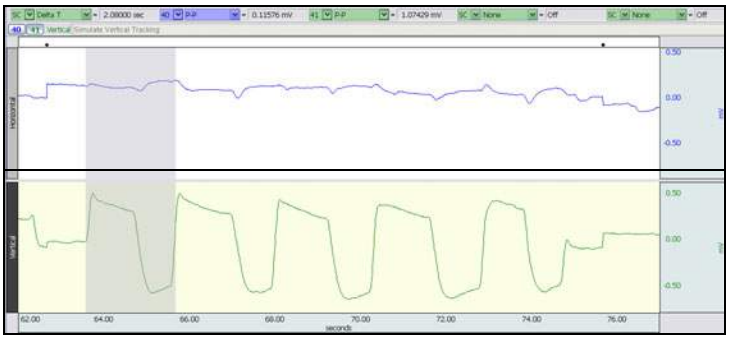


Fig. 10.27—Selection of first Vertical tracking cycle.

8. Set up your display window for optimal viewing of the "**Read silently 1**" data.

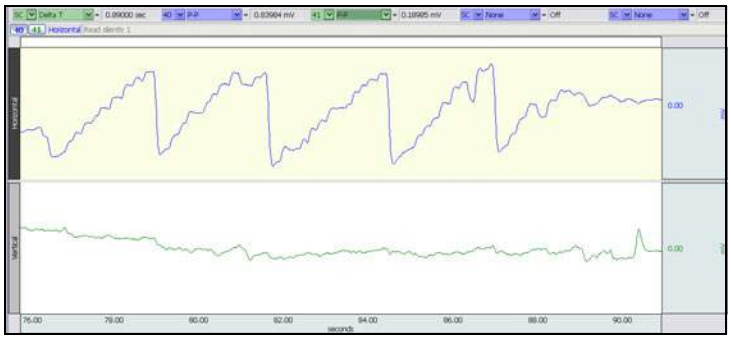


Fig. 10.28—Example Read Silently 1 data.

9. Record the number of words in line 1 and line 2 of each passage.

   C (Table 10.3)

10. Zoom in on the data recorded during the reading the first line.
11. Count and record the number of saccades that occurred while reading the line.

    C

12. Measure and record each time interval (period) between saccades (Delta T).

    C

13. Scroll to the data recorded during the reading of the second line and repeat Steps 11 and 12.

    C

In the following examples, the Vertical channel is hidden since all measurements are made on the Horizontal data.

The data for the reading of each line should be easy to discern as there is a large, fast transition when the eyes move from the end of one line to the beginning of the next.

Saccades are the fast transitions in the positive trending data. The period between saccades is the time the **Subject** looked at each word.

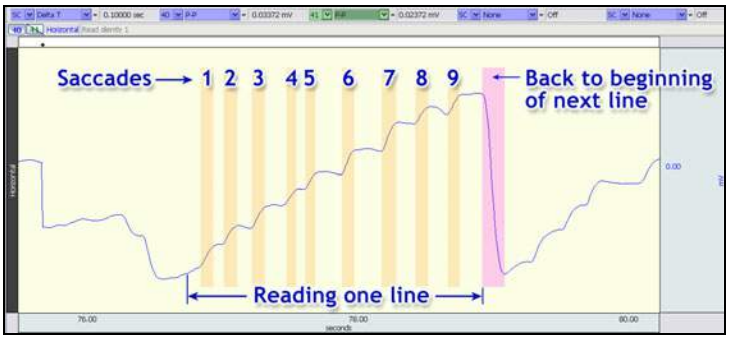


Fig. 10.29—Highlight shows saccade intervals.

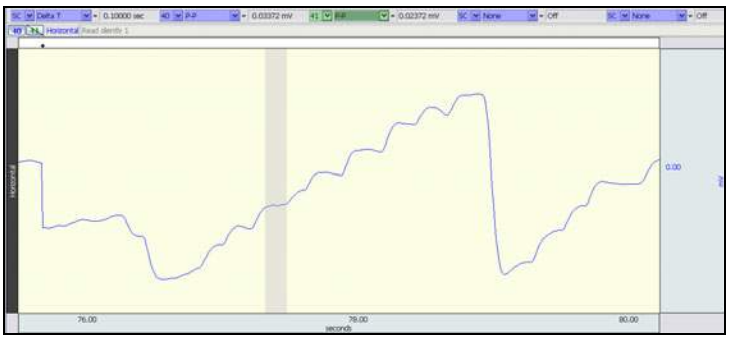


Fig. 10.30—Example of interval between saccades.

Data Analysis continues…

Scroll to "**Read silently 2**" data and repeat Steps 10 through 13.

C

14. Scroll to "**Read Aloud**" data and repeat Steps 10 through 13.

C

It may be more difficult to distinguish the saccades and the interval between saccades because eye movement is more complex when reading aloud. The movement of the facial muscles can also create signal artifact. The following example shows typical data with an interval selected. It is only necessary to measure the intervals between saccades that are clearly distinguished.

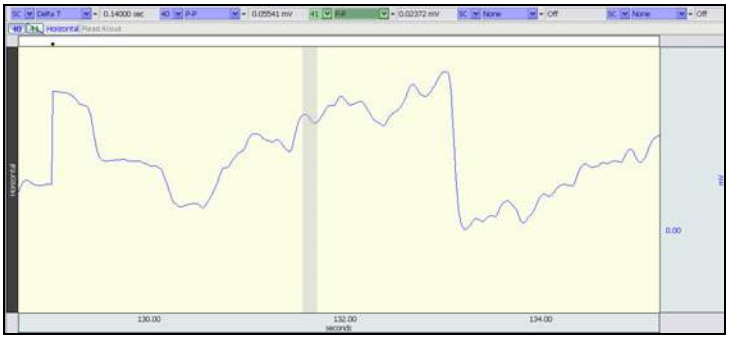


Fig. 10.31—Example of interval between saccades.

15. Answer the questions at the end of the Data Report.
16. **Save** or **Print** the data file.
17. **Quit** the program.

An electronically editable **Data Report** can be found in the journal (following the lesson summary,) or immediately following this Data Analysis section. Your instructor will recommend the preferred format for your lab.

END OF DATA ANALYSIS

END OF LESSON 10

Complete the Lesson 10 Data Report that follows.

ELECTROOCULOGRAM

- *EOG*

DATA REPORT

Student's Name: _____

Lab Section: _____

Date: _____

I. Data and Calculations

Subject Profile

Name:_____ Height:_____

Age:_____ Gender: Male / Female Weight:_____

A. **Pendulum Tracking**—Complete Table 10.1.

Note: Your data may have more or fewer cycles than the 7 allotted in the tables.

Table 10.1 Pendulum Tracking vs. Simulation Tracking (using Horizontal data)

Cycle	Pendulum		Simulation	
	40 Delta T	40 P-P	40 Delta T	40 P-P
1				
2				
3				
4				
5				
6				
7				

B. **Vertical Tracking**—Complete Table 10.2.

Table 10.2 Vertical Tracking vs. Simulation

Cycle	Real Object		Simulation	
	41 Delta T	41 P-P	41 Delta T	41 P-P
1				
2				
3				
4				
5				
6				
7				

C. **Saccades**—Complete Table 10.3.

Table 10.3 Saccades

Measurement	*Read Silently 1*		*Read Silently 2*		*Read Aloud*	
	1st line	*2nd line*	*1st line*	*2nd line*	*1st line*	*2nd line*
Number of words						
Number of saccades						
Time interval between saccades						
#1						
#2						
#3						
#4						
#5						
#6						
#7						
#8						
#9						
Average time interval between saccades (Calculate)						

II. Questions

D. Focusing a camera changes the distance between the lens and the film. Does the eye focus by changing the distance between the lens and the retina? Explain your answer.

E. Define the following terms:

Cone

Rod

Fovea

Visual Field

Visual Fixation

Saccade / Microsaccade

F. Why is vision in darkness more effective when focusing away from the fovea rather than focusing directly on the fovea?

G. Explain the difference between “voluntary fixation” and “involuntary fixation”:

H. Examine the data in Table 10.1 and answer the following questions

a.) Did the amplitude continue to decrease with each successive swing cycle during pendulum tracking? Explain

b.) Did the amplitude continue to decrease with each successive swing cycle during simulated pendulum tracking? Explain

c.) Did the time interval (period) of each successive swing cycle increase, decrease, or remain constant during pendulum movement? Explain

d.) Did the time interval (period) of each successive swing cycle increase, decrease, or remain constant during simulated movement? Explain

e.) Are the waveform shapes different between tracking and simulated tracking data? Explain

I. Examine the data in Table 10.2 and answer the following questions:

a.) Do the cycle amplitudes increase, decrease, or remain constant during vertical tracking? Explain

b.) Do the cycle amplitudes increase, decrease, or remain constant during simulated vertical tracking? Explain

c.) Do the cycle periods increase, decrease, or remain constant during vertical tracking? Explain

d.) Do the cycle periods increase, decrease, or remain constant during simulated vertical tracking? Explain

e.) Are the waveform shapes different between vertical tracking and simulated vertical tracking data? Explain

J. Examine the data in Table 10.3 and answer the following questions:

a.) Did the number of saccades match the number of words for each line? Explain any differences.

b.) Is the average time interval between saccades different when reading an easy passage vs. a challenging passage? Explain

_____

_____

c.) Is the average time interval between saccades different when reading the same passage silently vs. aloud?

_____

_____

d.) Are the waveform shapes different between Read Silently 2 and Read Aloud data? Explain

_____

_____

K. Name the cranial nerves tested and the extraocular muscles tested when the subject is asked to follow the eraser on a pencil when moved in a one foot circle, two feet from face.

Cranial Nerves	Extraocular Muscles
_____	_____
_____	_____
_____	_____
	_____
	_____
	_____

L. Define corneal–retinal potential (CRP) and explain its relation to electrooculography and the electrooculogram.

_____

_____

_____

_____

_____

III. OPTIONAL Active Learning Portion

A. ***Hypothesis***

B. ***Materials***

C. ***Method***

D. ***Set Up***

E. ***Experimental Results***

End of Lesson 10 Data Report

Sample Readings

Easy:

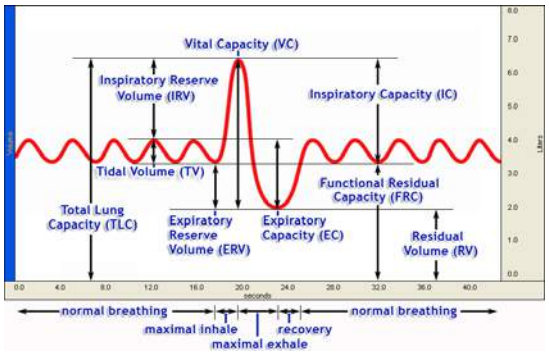
You put your right foot in, you put your right foot out, you put your right foot in and you shake it all about. You do the Hokey Pokey and you turn yourself around, that's what it's all about!

Difficult:

O proud right foot, that ventures quick within, then soon upon a backward journey lithe. Anon, once more the gesture, then begin: Command sinistral pedestal to writhe. Commence thou then the fervid Hokey Poke. A mad gyration, hips in wanton swirl. To spin! A wilde release from heaven's yoke, Blessed dervish! Surely canst go, girl. The Hoke, the Poke – banish now thy doubt. Verily, I say, 'tis what it's all about!

Richard Pflanzer, Ph.D.
Associate Professor Emeritus
Indiana University School of Medicine
Purdue University School of Science

William McMullen
Vice President, BIOPAC Systems, Inc.



I. Introduction

All animals require oxygen to carry out cellular processes of energy transformation essential for life. During cellular metabolism, oxygen is consumed when nutrients such as protein, carbohydrate, and fat are oxidized, and carbon dioxide is produced as a gaseous waste product. Collectively, the processes whereby oxygen is taken up from the atmosphere, delivered to body cells, and consumed, and the processes of producing carbon dioxide and delivering it to the lungs for excretion into the atmosphere constitute *respiration.*

Processes of respiration fall into one of three categories: external respiration, gas transport, and internal respiration. *External respiration* refers to mechanisms by which a person obtains oxygen from the external environment and eliminates carbon dioxide into the external environment. *Gas transport* refers to mechanisms used to distribute oxygen to and remove carbon dioxide from cells. *Internal respiration* refers to the chemical reactions of cellular metabolism in which oxygen is consumed and carbon dioxide is produced. In this lesson we will focus on mechanisms of human external respiration.

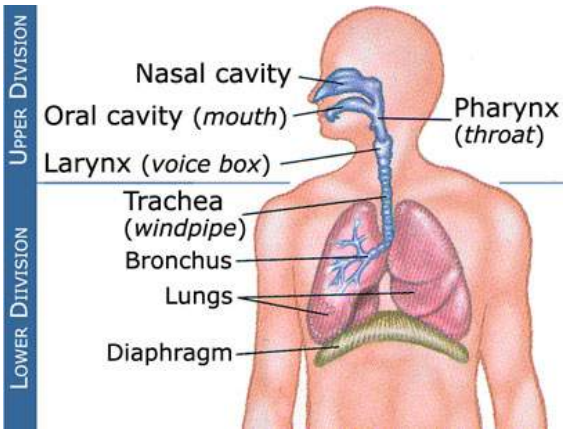


Fig. 12.1 The Respiratory System

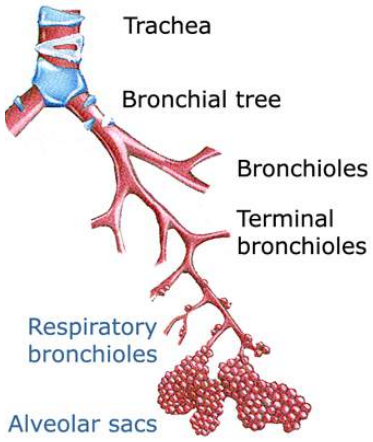


Fig. 12.2 The Respiratory Tree

The human respiratory system (Fig. 12.1) consists of an upper division and a lower division. The *upper division* is made up of the nasal and oral cavities, the pharynx (throat,) and the larynx (voice box). The *lower division* consists of a system of sequentially arranged and progressively smaller airways that resemble an inverted tree. Often called the respiratory tree (Fig. 12.2,) it consists of the trachea (wind pipe,) a right and a left primary bronchus, the lobar bronchi, segmental bronchi, sub-segmental bronchi, terminal bronchioles, respiratory bronchioles, alveolar ducts, alveolar sacs, and individual alveoli. Gas exchange with the blood occurs only in the smaller, thin-walled terminal parts of the tree beginning with the respiratory bronchioles. The remainder of the respiratory tree, and the entire upper division, collectively comprise *anatomical dead space*, space that is ventilated but plays no direct role in gas exchange.

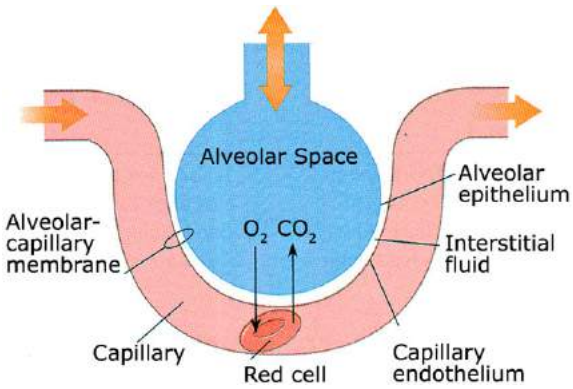


Fig. 12.3 Pulmonary Gas Exchange

Gas exchange between the air in the lung and the blood is a process of simple diffusion (Fig. 12.3). A gas diffuses from a region of higher concentration to a region of lower concentration, or, from an area of higher partial pressure to an area of lower partial pressure. Partial pressure is simply a way of expressing the concentration of gas molecules. It is the pressure exerted by a gas when it is in a mixture with other gases, and is equal to the pressure the same volume of the gas would exert if no other gases were present. The partial pressure of a gas is easily computed if its percentage of the gas mixture and the total pressure of the mixture is known. For example, the atmosphere at sea level exerts a pressure of 760 mm of Hg. If oxygen were to make up 20% of the atmosphere, its partial pressure would be 20% of 760 mm of Hg, or 152 mm of Hg.

Blood transports gases to and from the body's cells. The respiratory system supplies oxygen to the blood, and removes carbon dioxide from the blood. Most of the gas exchange occurs at the level of the alveoli and the process is completely dependent on the maintenance of gas partial pressures favorable for adequate diffusion of oxygen and carbon dioxide. During inspiration (inhalation) the alveoli enlarge and take in fresh air. During expiration (exhalation) the alveoli get smaller, forcing some of the air back out into the atmosphere. The process of continually and cyclically moving air into and back out of the respiratory tree is called *pulmonary ventilation*. This process serves to maintain favorable partial pressures of oxygen and carbon dioxide in the alveoli, thereby facilitating oxygen uptake by the blood and carbon dioxide removal from the blood.

The mechanics of pulmonary ventilation are best understood by applying *Boyle's law*, which states the volume of a given quantity of gas at a constant temperature varies inversely with the pressure of the gas. In other words, as the volume of a gas at constant temperature increases, the pressure of the gas decreases. If the volume instead decreases, then the pressure increases. Mathematically, the product of the pressure and volume of a gas at constant temperature is itself a constant (PV = K). Ignoring units, if P = 6 and V = 3, then K = 18. If P decreases to 2, then V must increase to 9 because the value of K is 18 and constant as long as the temperature is constant.

The lungs are enclosed by the thoracic cage, which is comprised of the sternum, ribs, vertebral column, and the diaphragm (Fig. 12.1). The tissues of the thoracic cage form the thoracic cavity that is partitioned into smaller cavities by membranes. Each lung is covered with a thin membrane called the visceral pleura. At the root of each lung, where the bronchi enter, the visceral pleura is reflected back around the lung to form the parietal pleura, a lubricating membrane which lines the thorax and covers part of the diaphragm (Fig. 12.4). Normally, each lung completely fills its pleural cavity formed by the reflection of the visceral pleura. The pleural membranes allow the lung to slide freely within the pleural cavity during the respiratory cycle. The space between visceral and parietal pleura, called the pleural space, is only a potential space. Normally, only a thin layer of lubricating fluid separates the two layers of pleura. The pleural cavities are airtight and form part of the thoracic cavity; however, the interior of the lungs is open to the atmosphere via the airways. Therefore, whenever the thoracic cavity enlarges, the pleural cavities along with the lungs also enlarge.

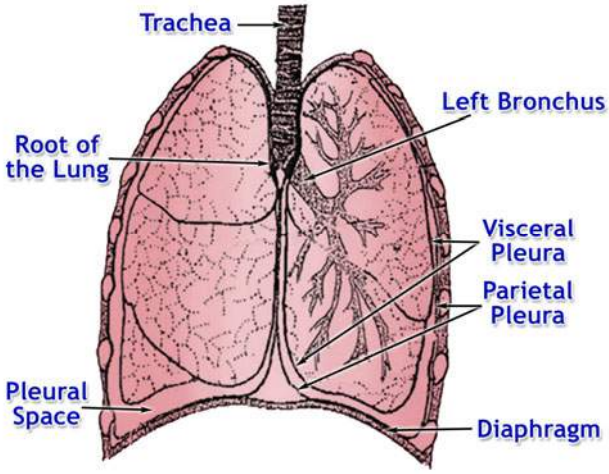


Fig. 12.4 Pleural Cavities (frontal aspect)

Changes in the volume of the thorax are produced by contraction of skeletal muscles collectively called respiratory muscles. They are arbitrarily divided into two groups. *Inspiratory muscles* contract and increase thoracic volume. The diaphragm and the external intercostals muscles are examples. *Expiratory muscles* contract and decrease thoracic volume. Examples include the internal intercostals muscles and the abdominal muscles.

At the beginning of inspiration, the thoracic cavity is enlarged by contraction of the diaphragm and the external intercostals (Fig. 12.5). The diaphragm, normally dome-shaped at rest, becomes flatter when its muscle fibers contract, thereby increasing thoracic volume. The external intercostals elevate the ribs, a kind of bucket-handle lift that increases the diameter, and hence the volume of the thorax. An increase in thoracic volume is accompanied by an increase in intrapulmonic volume, and, according to Boyle's law, a decrease in intrapulmonic pressure. As soon as intrapulmonic pressure falls below atmospheric pressure, air flows down the pressure gradient from the atmosphere through the airways and into the expanded air spaces in the lungs, continuing to flow until intrapulmonic pressure is again equal to atmospheric pressure (Fig. 12.5). At the end of inspiration, intrapulmonic pressure equals atmospheric pressure and airflow ceases even though intrapulmonic volume is larger than at the beginning of inspiration.

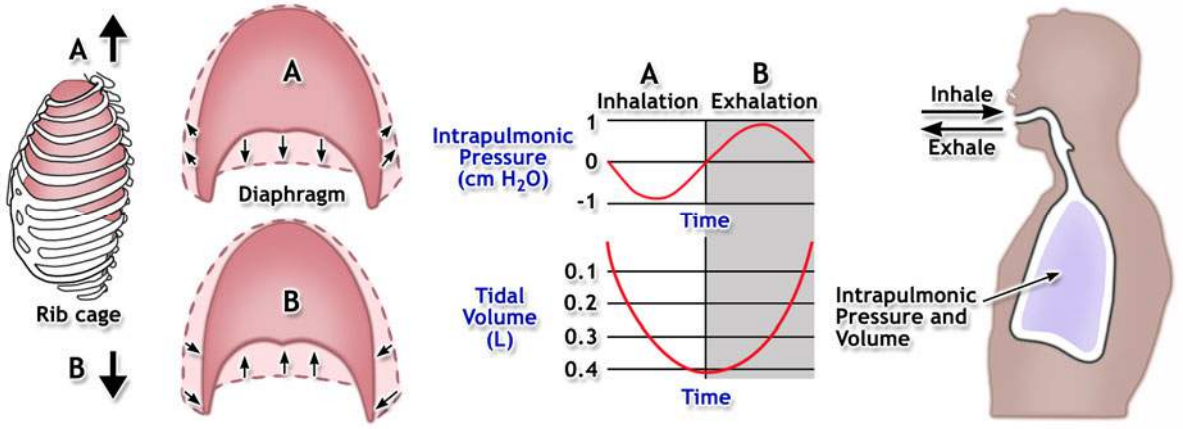


Fig. 12.5 Intrapulmonic pressure and volume changes during one respiratory cycle

Expiration begins when the inspiratory muscles relax. The diaphragm returns to its resting dome shape, decreasing thoracic and intrapulmonic volume. Relaxation of the external intercostals allows the ribs to fall to their resting position, thereby reducing the diameter, and thus the volume of the thorax and lungs (Fig. 12.5). A reduction in intrapulmonic volume is accompanied by an increase in intrapulmonic pressure. As soon as intrapulmonic pressure increases above atmospheric pressure, air flows down the pressure gradient from the expanded air spaces in the lung through the airways and back into the atmosphere, continuing to flow until intrapulmonic pressure is again equal to atmospheric pressure (Fig. 12.5).

The volume of air a person inhales (inspires) and exhales (expires) can be measured with a **spirometer** (*spiro* = breath, *meter* = to measure). A bell spirometer consists of a double-walled cylinder in which an inverted bell filled with oxygen-enriched air is immersed in water to form a seal (Fig. 12.6). A pulley attaches the bell to a recording pen that writes on a drum rotating at a constant speed. During inspiration, air is removed from the bell and the pen rises, recording an inspired volume. As expired air enters the bell, the pen falls and an expired volume is recorded. The resultant record of volume change vs. time is called a **spirogram**.

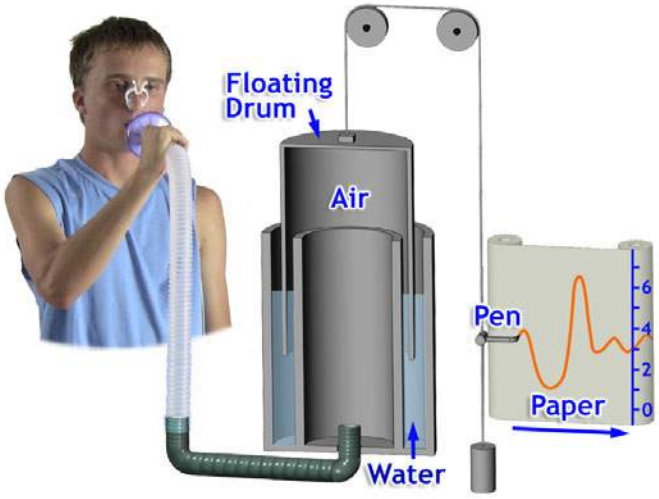


Fig. 12.6 Bell Spirometer

In this lesson, you will use the BIOPAC airflow transducer and the software will convert airflow to volume, thus approximating the volume measurements from a spirometer. Air flows through a sealed head which is divided in half by a fine mesh screen. The screen creates a slight resistance to airflow resulting in a higher pressure on one side than the other. A Differential Pressure Transducer measures the pressure difference, which is proportional to the airflow, and converts it to a voltage, which is then recorded by the BIOPAC MP unit. After the airflow recording is complete, the software calculates volume by integrating the airflow data. This integration technique is a simple method for obtaining volume but is very sensitive to baseline offset. For this reason the calibration and recording procedures must be followed **exactly** to obtain accurate results.

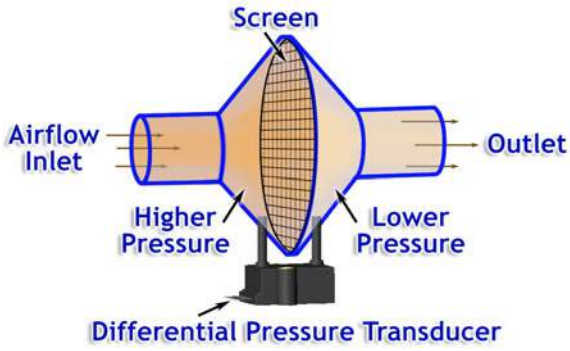


Fig. 12.6b Airflow Transducer

There are four non-overlapping primary compartments of total lung capacity (Fig. 12.7):

1. Tidal volume
2. Inspiratory reserve volume
3. Expiratory reserve volume
4. Residual volume

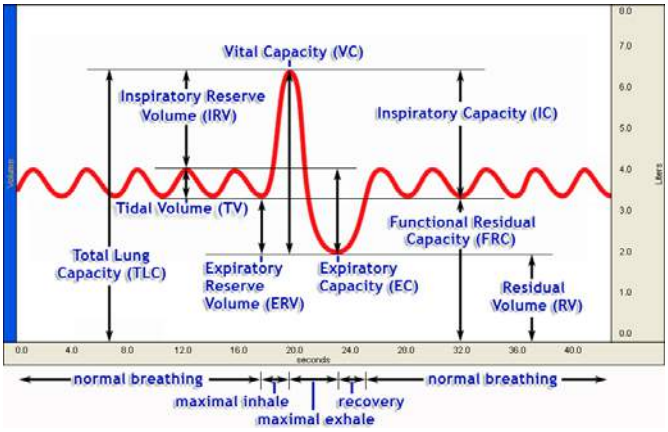


Fig. 12.7 Example of respiratory volumes and capacities

- **Tidal Volume** (TV) is the volume of air inspired or expired during a single breath. When a resting person breathes normally, tidal volume is approximately 500 ml. During exercise, tidal volume can be more than 3 liters.
- **Inspiratory Reserve Volume** (IRV) is the volume of air that can be maximally inhaled at the end of a tidal inspiration. Resting IRV is approximately 3,300 ml in young adult males and 1900 ml in young adult females.
- **Expiratory Reserve Volume** (ERV) is the volume of air that can be maximally exhaled at the end of a tidal expiration. Resting ERV is approximately 1,000 ml in young adult males and 700 ml in young adult females.
- **Residual Volume** (RV) is the volume of gas remaining in the lungs at the end of a maximal expiration. In contrast to IRV, TV, and ERV, residual volume does not change with exercise. Average adult values for RV are 1,200 ml for males and 1,100 ml for females. Residual volume reflects the fact that after the first breath at birth inflates the lungs, they are never completely emptied during any subsequent respiratory cycle.

Pulmonary Capacity is the sum of two or more primary lung volumes. There are five pulmonary capacities, which can be calculated as shown below:

1. **Inspiratory Capacity** (IC) IC = TV + IRV
2. **Expiratory Capacity** (EC) EC = TV + ERV
3. **Functional Residual Capacity** (FRC) FRC = ERV + RV
4. **Vital Capacity** (VC) VC = IRV + TV + ERV
5. **Total Lung Capacity** (TLC) TLC = IRV + TV + ERV + RV

Each of these capacities is represented graphically in Fig. 12.7 above.

Pulmonary volumes and capacities are generally measured when assessing health of the respiratory system because the volume and capacity values change with pulmonary disease. For example, inspiratory capacity is normally 60-70% of the vital capacity.

In this lesson, you will measure tidal volume, inspiratory reserve volume, and expiratory reserve volume. Residual volume cannot be measured using a spirogram or airflow transducer. You will then calculate inspiratory capacity, vital capacity, and the % observed vital capacity to the average values for comparison. Next, you will compare your observed vital capacity with the predicted vital capacity.

The following equations can be used to obtain the predicted vital capacities for men or women of your height and age. Vital capacities are dependent on other factors besides age and height. Therefore, 80% of the calculated values are still considered normal.

Table 12.1

Equations for Predicted Vital Capacity (Kory, Hamilton, Callahan: 1960)	
Male	V.C. = 0.052H – 0.022A – 3.60
Female	V.C. = 0.041H – 0.018A – 2.69

Where V.C. Vital Capacity in liters
H Height in centimeters
A Age in years

Using the equation in Table 12.1, you can estimate the vital capacity of a 19 year old female who is 167 centimeters tall (about 5’6”) as 3.815 liters:

0.041 x (167) – 0.018 x (19) – 2.69 = 3.815 liters

Richard Pflanzer, Ph.D.
Associate Professor Emeritus
Indiana University School of Medicine
Purdue University School of Science

William McMullen
Vice President, BIOPAC Systems, Inc.

II. EXPERIMENTAL OBJECTIVES

1.) To observe experimentally, record and/or calculate selected pulmonary volumes and capacities.
2.) To compare the observed values of volume and capacity with average values.
3.) To compare the normal values of pulmonary volumes and capacities of subjects differing in sex, age, weight, and height.

III. MATERIALS

- BIOPAC Airflow Transducer (SS11LA or SS11LB for BSL 4.1.1 and higher only)
- BIOPAC Bacteriological Filter (AFT1): one per subject. If using calibration syringe, one dedicated to syringe.
- BIOPAC Disposable Mouthpiece (AFT2)
- BIOPAC Noseclip (AFT3)
- BIOPAC Calibration Syringe: 0.6-Liter (AFT6 or AFT6A+AFT11A) *or* 2-Liter (AFT26)
- *Optional*—BIOPAC Autoclavable Mouthpiece (AFT8) or combination mouthpiece/filter (AFT36, for SS11LB only)
- Biopac Student Lab System: BSL 4 software, MP36, MP35 or MP45 hardware
- Computer System (Windows or Mac)

IV. EXPERIMENTAL METHODS

A. SETUP

FAST TRACK Setup

1. Turn your computer **ON**.
2. Turn **OFF** MP36/35 unit.
   - If using an MP45, make sure USB cable is connected and "Ready" light is **ON**.
3. **Plug the Airflow Transducer** (SS11LA or SS11LB) into Channel 1.
4. Turn **ON** the MP36/35 unit.

Setup continues…

Detailed Explanation of Setup Steps

Fig. 12.8 MP3X (top) and MP45 (bottom) equipment connections

5. **Start** the Biopac Student Lab program.
6. Choose "**L12 – Pulmonary Function I**" and click **OK**.
7. Type in a unique **filename** and click **OK**.

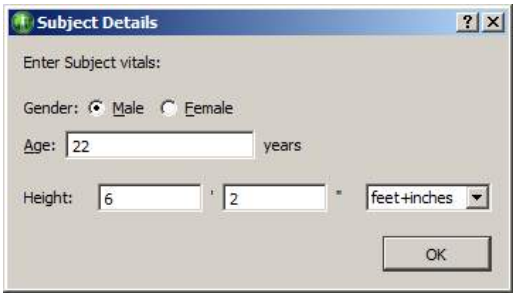
Start Biopac Student Lab by double-clicking the Desktop shortcut.

No two people can have the same filename, so use a unique identifier, such as **Subject's** nickname or student ID#.

A folder will be created using the filename. This same filename can be used in other lessons to place the **Subject's** data in a common folder.

8. Enter the "**Subject Details**" and click **OK**. (BSL 4.0.1 and higher only.)

Subject Details records the gender, age and height of the **Subject** prior to beginning the lesson. Domestic or metric units may be selected. These details are displayed in the Journal following the lesson. (BSL 4.0.1 and higher only.)



9. ***Optional***: Set Preferences.
   - Choose File > **Lesson Preferences**.
   - Select an option.
   - Select the desired setting and click **OK**.

This lesson has optional Preferences for data and display while recording. Per your Lab Instructor's guidelines, you may set:

Residual Volume: RV cannot be determined using a normal spirometer or airflow transducer, so the BSL software sets a value between 0 and 5 liters (default is 1 L).

Grids: Show or hide gridlines.

Calibration Syringe Values:

"*Set each time lesson is launched*": Syringe (Stage 2) calibration is required the first time the lesson is run. After the lesson is re-run without closing the application, Syringe calibration is not required.

"*Set once and use stored values*": After Syringe calibration is performed once, it will not be performed again. This is only recommended when specific SS11LA Airflow Transducers are matched to specific MP units.

Calibration Syringe Size:

0.61 L (AFT6A/6,) 1 L, 2 L (AFT26,) 3 L, 4 L, or 5 L

SS11LB Calibration Option

"Use factory calibration": Bypasses the Syringe (Stage 2) calibration and uses factory settings.

"Require calibration syringe": Follows the "Calibration Syringe Values" protocol described above.

The SS11LB Airflow Transducer is supported in BSL versions 4.1.1 and higher only.

END OF SETUP

B. CALIBRATION

Calibration establishes the hardware's internal parameters (such as gain, offset, and scaling) and is critical for optimal performance. Calibration will vary based on the Preference set by your lab instructor.

FAST TRACK Calibration

Stage 1 – Always required

1. Hold the Airflow Transducer upright and still, making sure no air is flowing through it (Fig. 12.9).
2. Click **Calibrate**.
   - Wait for Calibration to stop
3. Check Calibration data:
   - Verify data is flat and centered. If necessary, **click Redo Calibration**.
   - To proceed, click **Continue**.

Stage 2 – If required

4. ***IF CALIBRATION STAGE 2 IS REQUIRED—***Attach Calibration Syringe and filter to SS11LA Airflow Transducer. The filter is not required if using the SS11LB Airflow Transducer. (Fig. 12.11).

   IMPORTANT!
   Always insert on the side labeled "Inlet."

   - Pull Calibration Syringe plunger all the way out.
   - Hold syringe horizontally. Airflow Transducer must be vertical and unsupported.
   - Review Calibration procedure.

Calibration continues…

Detailed Explanation of Calibration Steps

Calibration Stage 1 precisely zeroes the baseline. Any baseline shift during this calibration can cause errors in the subsequent recordings. Baseline shift can occur from:

a) Airflow through the transducer from movement, an HVAC duct or even from breathing close to the unit.

b) Changes in transducer orientation. The transducer should be held still and in the same orientation that will be used during the recording.

Fig. 12.9

Calibration lasts from 4 to 8 seconds.

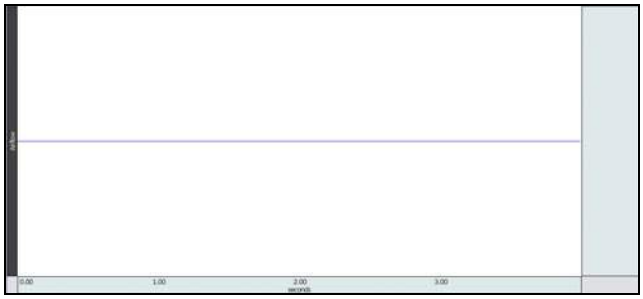


Fig. 12.10 Example calibration stage 1 data

Based on Lesson Preference settings, the calibration syringe may not be required. If not required, proceed to Step 9.

Notes:

- If using the SS11LA transducer, a bacteriological filter must be used between the transducer and syringe in order for calibration to be accurate. The SS11LB calibration does not require this filter.
- Different syringe sizes are supported via File > Lesson Preferences > Calibration Syringe Size. Check the pictures in the SET UP > Calibration tab to make sure they match your setup. If incorrect, the lesson must be re-run and the preference changed prior to calibration Stage 1. If you are using a non-BIOPAC syringe, always check the Preference setting prior to beginning calibration Stage 1.

Fig. 12.11 Example AFT6A/6 connections (SS11LA and SS11LB)

Stage 2 - Continued

5. Click **Calibrate**.

6. Cycle plunger in and out five times (10 strokes total).
   - Wait two seconds between each stroke.

7. Click **End Calibration**.

8. Verify recording resembles the example data.
   - If similar, click **Continue** to proceed.
   - If necessary, click **Redo Calibration**.

Calibration continues…

Fig. 12.12 Example AFT26 connections (SS11LB)

Never hold onto the Airflow Transducer handle when using the Calibration Syringe or the syringe tip may break. Always insert syringe assembly on the transducer side labeled "**Inlet**" so that the transducer cable exits on the left.

Fig. 12.13 AFT6A calibration stage 2 starting position

Fig. 12.14 AFT26 calibration stage 2 starting position

Important:

- Complete exactly five cycles. Less or more cycles will result in inaccurate volume data.
- Syringe must be pushed in and pulled out all the way.
- Hold the assembly as still as possible.
- Use a rhythm of about one second per stroke with two seconds rest between strokes.

There must be five downward deflections and five upward deflections. The first deflection must be downward. If the first stroke (push) resulted in an upward data deflection, the syringe/filter assembly must be reversed by inserting the assembly into the other port of the airflow transducer and rerunning the Calibration.

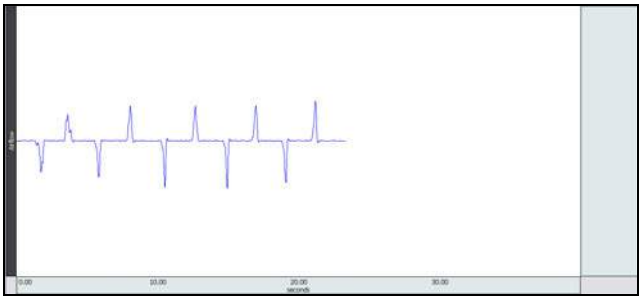


Fig. 12.15 Example calibration (stage 2) data

OPTIONAL

9. *Optional* Validate Calibration.
   a) Click **Record**.
   b) Cycle the syringe plunger in and out completely 3 times (6 strokes,) waiting about two seconds between strokes.
   c) Click **Stop**.
   d) Measure P-P on CH2 Volume (Fig. 12.15) to confirm the result matches the syringe volume:
   - AFT6 = 0.61 L acceptable range: 0.57 to 0.64 liters
   - AFT26 = 2 L acceptable range: 1.9 to 2.1 liters

   e) If measurements are correct, click **Redo** and proceed with **Subject** recording.
   f) If measurements are not correct:
   - Click **Redo** then choose File > **Quit**.

10. Re-launch the application and re-run the lesson.

END OF CALIBRATION

It is advisable to validate calibration once per lab session. Syringe must be pushed in and pulled out all the way.

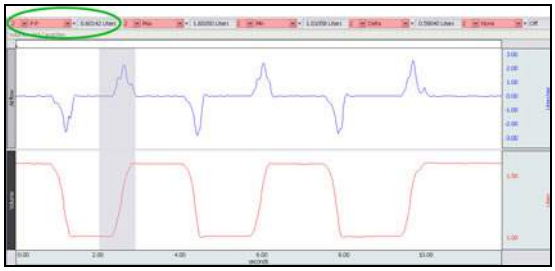


Fig. 12.16 Calibration validation shows P-P result 0.6 liters

If recording does not resemble the Example Data

- If the data is noisy or flatline, check all connections to the MP unit.

Clicking **Redo** will erase the validation data and allow the **Subject** recording to continue.

It is necessary to re-launch the application in order to allow a new Stage 2 (Syringe) calibration. Prior to the next recalibration, make sure the lesson preference setting "Calibration Syringe Values" is assigned "Set each time lesson is launched" (see Setup Step 8).

C. DATA RECORDING

FAST TRACK Recording

1. **Prepare** for the recording.
   - Remove calibration syringe/filter assembly (if used).

IMPORTANT!
Subject must be relaxed to obtain accurate measures.

2. Insert the filter into the "Inlet" side of the transducer, and then attach the mouthpiece (Fig. 12.17).
   - If your lab does not use disposable filters, attach a sterilized mouthpiece (AFT8) directly to the "Inlet" side of the transducer (Fig. 12.18).

Recording continues…

Detailed Explanation of Recording Steps

The filter used during calibration should not be re-used by the **Subject** as it will not be sterile.

Hints for obtaining optimal data:

- **Subject** should wear loose clothing so clothing does not inhibit chest expansion.
- **Subject** must try to expand the thoracic cavity to its largest volume during maximal inspiratory efforts.
- Air leaks will result in inaccurate data. Make sure all connections are tight, noseclip is attached and that Subject's mouth is sealed around the mouthpiece.
- Keep the Airflow Transducer vertical and in a constant position (Fig. 12.20).
- If recording is started on an inhale, try to stop recording on an exhale, or vice versa. (A breath is considered a complete inhale-exhale cycle.)

IMPORTANT: Each **Subject** must use a personal filter, mouthpiece and noseclip. The first time they are used, the **Subject** should personally remove them from the plastic packaging. It is advisable to write **Subject's** name on the mouthpiece and filter with a permanent marker so they can be reused later (i.e. Lesson 13).

If your lab sterilizes the airflow heads after each use, make sure a clean head is installed prior to **Subject** use.

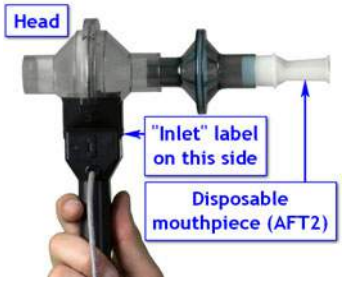


Fig. 12.17 SS11LA with unsterilized head

Fig. 12.18 SS11LA/LB with sterilized head

Fig. 12.19 SS11LB with reusable filter/mouthpiece combination

3. Prepare the **Subject**:
   - **Subject** must be seated, relaxed and still, facing away from the monitor.
   - Place noseclip on **Subject's** nose.
   - **Subject** holds airflow transducer vertically, breathing through mouthpiece.
   - Before recording, **Subject** acclimates by breathing normally for 20 seconds.
   - **Review** recording steps.

Verify there are no air leaks; mouthpiece and filter are firmly attached, the noseclip is snug and the **Subject's** mouth is tightly sealed around mouthpiece.

Fig. 12.20 Keep Airflow Transducer vertical at all times

4. Click **Record**.
   - Breathe normally for five cycles.
   - Inhale as deeply as possible then exhale completely.
   - Breathe normally for five more cycles.

1 cycle = inspiration + expiration

If a recording is started on an inhale, try to stop recording on an exhale, or vice versa. (A breath is considered a complete inhale/exhale cycle.)

5. Click **Stop**.

After clicking **Stop**, the Biopac Student Lab software will automatically calculate volume data based on the recorded airflow data. At the end of the calculation, both waveforms will be displayed on the screen (Fig. 12.21).

Recording continues…

6. Verify that Volume channel reading resembles the example data.

   - If similar, proceed to Step 7.

The deep inhale/exhale should be clearly seen in the Volume data and there should be five normal breathing cycles both before and after deep breathing. It is common to have some "tilt" in the volume data as shown in Fig. 12.21. If the volume data exhibits excessive tilt (Fig. 12.22,) redo the recording.

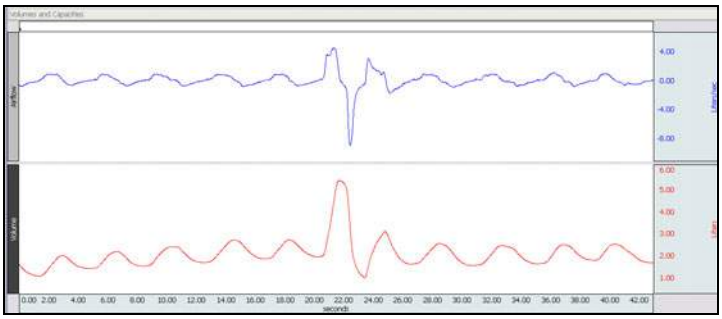


Fig. 12.21 Example Data

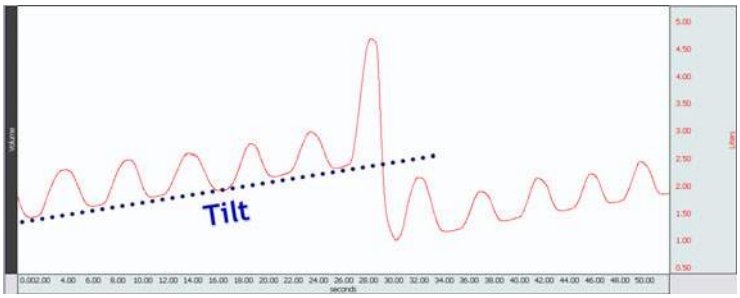


Fig. 12.22 Excessive tilt in the Volume data

   - If necessary:

   Click **Redo** and repeat Steps 4 – 6

   OR

   Re-run the lesson and perform **Stage 1 Calibration.**

If recording does not resemble Fig. 12.21:

- If the data is noisy or flatline, check all connections to the MP unit.
- If there is excessive "tilt" in the data (Fig. 12.22):
- Make sure there are five normal breathing cycles on either side of the deep inhale/exhale.
- Verify there are no air leaks; mouthpiece and filter are firmly attached, the noseclip is snug and the **Subject's** mouth is sealed around mouthpiece.
- If a recording is started on an inhale, try to stop recording on an exhale, or vice versa.
- Verify the airflow transducer is kept vertical and still for the entire recording.

Click **Redo** and repeat Steps 4 – 6 if necessary.

If redoing the recording does reduce data "tilt," Stage 1 calibration (baseline adjust) must be repeated. To re-run lesson and redo stage 1 calibration:

- Click Redo.
- Choose "L12 – Pulmonary Function I" from the Lessons menu.
- Re-enter your name and proceed with calibration and recording.

Note that once **Redo** is clicked or the lesson is re-run, the most recent recording will be erased.

7. Click **Done**.

When **Done** is clicked, a dialog with options will be generated. Make a selection and click OK.

8. Choose an option and click **OK**.

If choosing the **Record from another Subject** option:

- Repeat Calibration Steps 1 – 3, and then proceed to Recording.

END OF RECORDING

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Indiana University School of Medicine
Purdue University School of Science

William McMullen
Vice President, BIOPAC Systems, Inc.

V. DATA ANALYSIS

FAST TRACK Data Analysis

1. Enter the **Review Saved Data** mode.
   - Note channel number (CH) designations:

Channel	*Displays*
CH 1	**Airflow** (hidden)
CH 2	**Volume**

   - Note the measurement box settings:

Channel	*Measurement*
CH 2	**P-P**
CH 2	**Max**
CH 2	**Min**
CH 2	**Delta**

Data Analysis continues…

Detailed Explanation of Data Analysis Steps

If entering **Review Saved Data** mode from the Startup dialog or Lessons menu, make sure to choose the correct file.

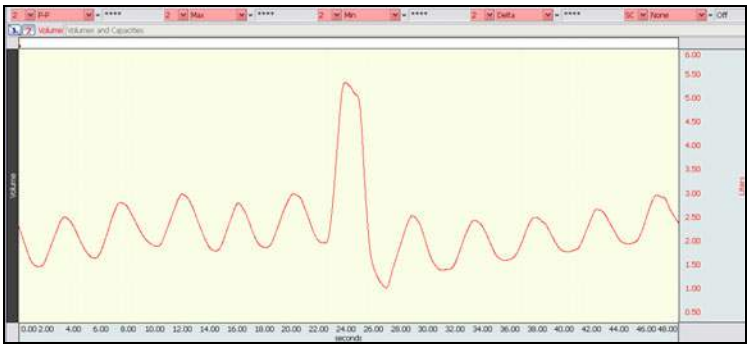

Fig. 12.23 Example data

All measurements will be performed on the Volume (CH 2) data. The Airflow (CH 1) data, used to calculate volume, is hidden to avoid confusion. It can be shown by "Alt + click" (Windows) or "Option + click" (Mac) the channel number box.

The measurement boxes are above the marker region in the data window. Each measurement has three sections: channel number, measurement type, and result. The first two sections are pull-down menus that are activated when you click them.

Brief definition of measurements:

P-P (Peak-to-Peak): Subtracts the minimum value from the maximum value found in the selected area.

Max: Displays the maximum value in the selected area.

Min: Displays the minimum value in the selected area.

Delta: Computes the difference in amplitude between the last point and the first point of the selected area.

The "selected area" is the area selected by the I-Beam tool (including endpoints).

Useful tools for changing view:

Display menu: Autoscale Horizontal, Autoscale Waveforms, Zoom Back, Zoom Forward

Scroll Bars: Time (Horizontal); Amplitude (Vertical)

Cursor Tools: Zoom Tool

Buttons: Overlap, Split, Show Grid, Hide Grid, -, +

Hide/Show Channel: "Alt + click" (Windows) or "Option + click" (Mac) the channel number box to toggle channel display.

2. Review the measurements described in the Introduction to identify the appropriate selected area for each.

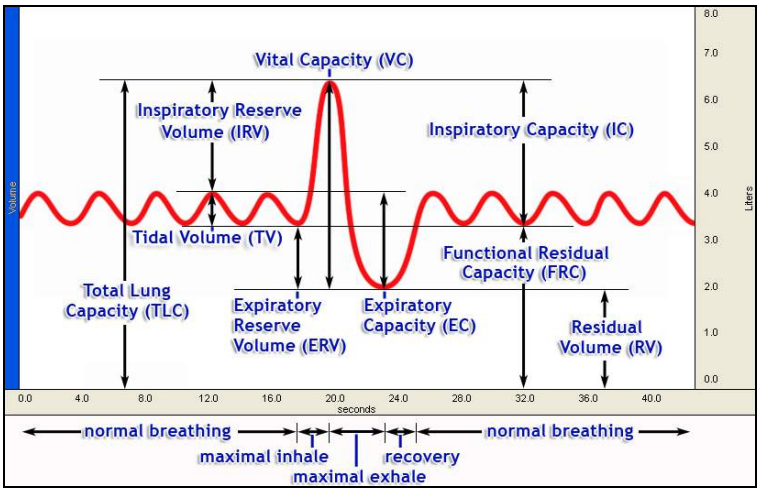

Fig. 12.24 Measurement areas for respiratory volumes and capacities

3. Calculate the Predicted Vital Capacity, then measure VC and then compare the two.

A

The selected area should start just prior to the maximum peak and end just after the minimum peak. The **P-P** (peak to peak) measurement displays the VC.

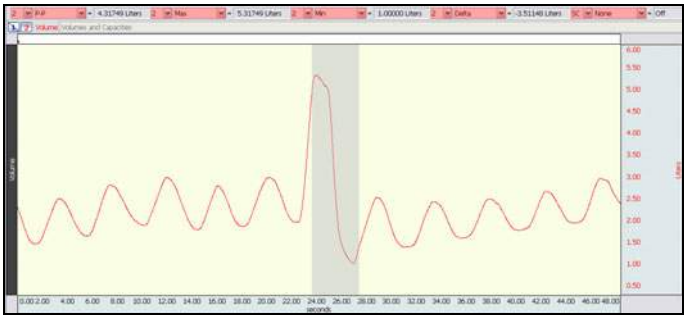

Fig. 12.25 Example selected area; P-P measures VC

4. Take two measures on the third TV cycle:
   a) Use the **I-beam** cursor to select the **inhalation** of cycle 3 and note the P-P result (Fig. 12.26). The selected area should be from the valley to the peak of the third cycle.

B

The **P-P** measurement in Fig. 12.26 represents the first value required for the averaged TV calculation.

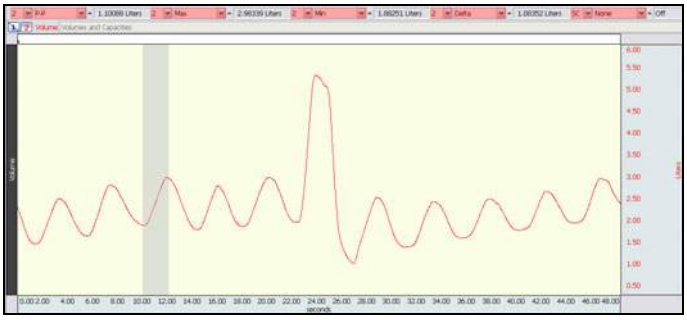

Fig. 12.26 Example of cycle 3 – Inhale selection to measure TV

   b) Use the **I-beam** cursor to select the **exhalation** of cycle 3 and note the P-P result (Fig. 12.27). The selected area should be from the peak to the valley of the third cycle.

B

The **P-P** measurement in Fig. 12.27 represents the second value required for the averaged TV calculation.

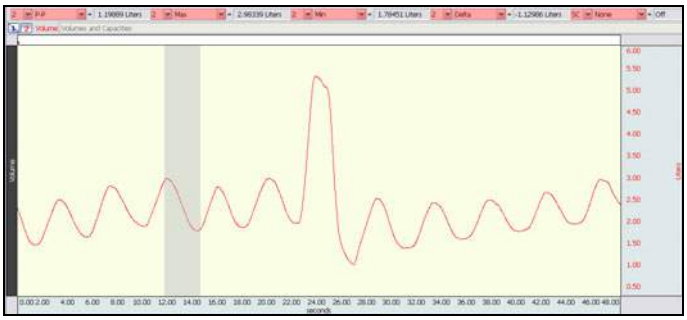

Fig. 12.27 Example of cycle 3 – Exhale selection to measure TV

Data Analysis continues…

5. Repeat TV measurements, as in Step 4, but on cycle 4 data. Calculate average value of all four TV measurements.

   B

6. Use the I-beam cursor and measurement tools to record the volumes and capacities required by the data report (defined in Fig. 12.24).

   B

7. Answer the questions at the end of the Data Report.
8. **Save** or **Print** the data file.
9. **Quit** the program.

END OF DATA ANALYSIS

Note that the Delta measurement requires precise placement of the selected area.

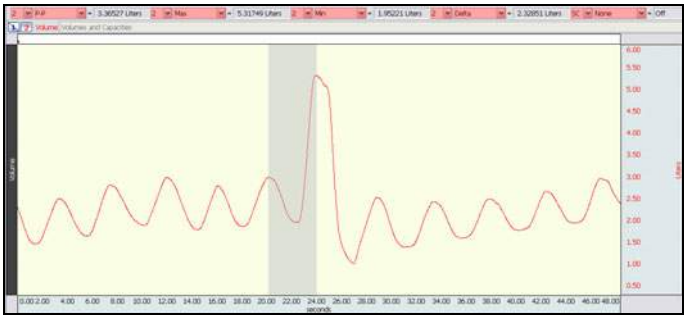

Fig. 12.28 Example selection for measurements of TLC (Max) and IRV (Delta)

An electronically editable **Data Report** is located in the journal (following the lesson summary,) or immediately following this Data Analysis section. Your instructor will recommend the preferred format for your lab.

END OF LESSON 12

Complete the Lesson 12 Data Report that follows.

PULMONARY FUNCTION I

- *Volumes and Capacities*

DATA REPORT

Student's Name: _____

Lab Section: _____

Date: _____

Subject Profile

Name:_____ Height:_____ Gender: Male / Female

Age:_____ Weight:_____

I. Data and Calculations

A. Vital Capacity

i) Predicted: Use the equation below to calculate your **Predicted Vital Capacity**:_____

Equations for Predicted Vital Capacity (Kory, Hamilton, Callahan: 1960)	
Male	V.C. = 0.052H - 0.022A – 3.60
Female	V.C. = 0.041H - 0.018A – 2.69

Where

V.C.	Vital Capacity in liters
H	Height in centimeters
A	Age in years

ii) Observed: Use the P-P result to note **Observed Vital Capacity**: _____

= 2 P-P

iii) Observed *vs.* Predicted

What is Subject's observed Vital Capacity to predicted Vital Capacity as a percentage?

Observed/Predicted VC = _____ x 100= _____%

Note: Vital capacities are dependent on other factors besides age and height. Therefore, 80% of predicted values are still considered "normal."

B. Volume & Capacity Measurements

Complete Table 12.2 with the requested measurement results and calculate results per the formulas provided.

Table 12.2 Measurements

Title		Measurement Result		Calculation	
Tidal Volume	TV	a = 2 P-P Cycle 3 inhale: b = 2 P-P Cycle 3 exhale: c = 2 P-P Cycle 4 inhale: d = 2 P-P Cycle 4 exhale:		(a + b + c + d) / 4 =	
Inspiratory Reserve Volume	IRV	2 Delta			
Expiratory Reserve Volume	ERV	2 Delta			
Residual Volume	RV	2 Min		Default = 1 (*Preference setting*)	
Inspiratory Capacity	IC	2 Delta		TV + IRV =	
Expiratory Capacity	EC	2 Delta		TV + ERV =	
Functional Residual Capacity	FRC			ERV + RV =	
Total Lung Capacity	TLC	2 Max		IRV + TV + ERV + RV =	

C. Observed vs. Predicted Volumes

Using data obtained for Table 12.2, compare Subject's lung volumes with the average volumes presented in the Introduction.

Table 12.3 Average Volumes *vs.* Measured Volumes

Volume Title		Average Volume	Measured Volume
Tidal Volume	TV	Resting subject, normal breathing: TV is approximately 500 ml. During exercise: TV can be more than 3 liters	greater than equal to less than
Inspiratory Reserve Volume	IRV	Resting IRV for young adults is males = approximately 3,300 ml females = approximately 1,900 ml	greater than equal to less than
Expiratory Reserve Volume	ERV	Resting ERV for young adults is males = approximately 1,000 ml females = approximately 700 ml	greater than equal to less than

II. Questions

D. Why does predicted vital capacity vary with height?

E. Explain how factors other than height might affect lung capacity.

F. How would the volume measurements change if data were collected after vigorous exercise?

G. What is the difference between volume measurements and capacities?

H. Define **Tidal Volume**.

I. Define **Inspiratory Reserve Volume**.

J. Define **Expiratory Reserve Volume**.

K. Define **Residual Volume**.

L. Define **Pulmonary Capacity**.

M. Name the **Pulmonary Capacities**.

End of Lesson 12 Data Report

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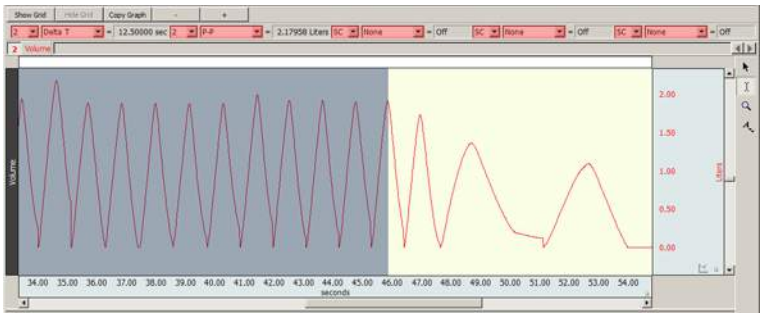


I. Introduction

The **respiratory** or **pulmonary** system performs the important functions of supplying oxygen (O_2) during inhalation, removing carbon dioxide (CO_2) during exhalation, and adjusting the acid-base balance (pH) of the body by removing acid-forming CO_2. Because oxygen is necessary for cellular metabolism, the amount of air that the pulmonary system provides is important in setting the upper limits on work capacities or metabolism. Therefore, the measurement of lung volumes and the rate of air movement (airflow) are important tools in assessing the health and capacities of a person.

In this lesson, you will measure:

- **Forced Vital Capacity** (FVC,) which is the maximal amount of air that a person can forcibly exhale after a maximal inhalation.
- **Forced Expiratory Volume** (FEV,) which is the percentage of FVC that a person forcibly expels in intervals of 1, 2, and 3 seconds. ($FEV_{1.0}$, $FEV_{2.0}$, $FEV_{3.0}$)
- **Maximal Voluntary Ventilation** (MVV,) which is a pulmonary function test that combines volume and flow rates to assess overall pulmonary ventilation.

These measurements indicate the upper limit of work that the person can do based on the capabilities of his or her respiratory system. When a person takes in maximal inhalation and then follows this with maximal exhalation the volume of expired air is that person's **Single Stage Vital Capacity** (SSVC). The time required to achieve maximal exhalation is not a factor in determining SSVC.

Because the lungs reside in the thoracic cavity, vital capacity is ultimately restricted by the size of a person's thoracic cavity. Therefore, size-related variables (e.g., age, gender, weight) affect the capacities of the respiratory system (Table 13.1).

Using the equation in Table 13.1, you can estimate the vital capacity of a 19 year old female who is 167 centimeters tall (about 5'6") as 3.815 liters:

$$0.041 \times (167) - 0.018 \times (19) - 2.69 = 3.815 \text{ liters}$$

For adults, the average pulmonary capacities decrease with age. Women tend to have smaller volumes than men of the same age and weight. As weight increases, volumes increase, with the exception that overweight people tend to have decreased volumes.

Table 13.1

Equations for Predicted Vital Capacity (Kory, Hamilton, Callahan: 1960)	
Male	V.C. = 0.052H - 0.022A – 3.60
Female	V.C. = 0.041H - 0.018A – 2.69

V.C. Vital Capacity (L) **H** Height (cm) **A** Age in years

Even within one person, respiratory supply and demand differs with activity levels and health. Accordingly, the rate and depth of **ventilation** (the volume of gas you breathe in and out per minute) are not static but rather must constantly adjust to the changing needs of the body. As you increase your activity levels from rest, the volume and rate of air flowing in and out of your lungs also changes. The changes in volume and how fast those changes in volume (airflow) are effected can be used to assess the health of a person's respiratory system.

Pulmonary volumes, pulmonary capacities, and pulmonary airflow rates are often measured in diagnosing and assessing the health of the respiratory system (Fig. 13.1).

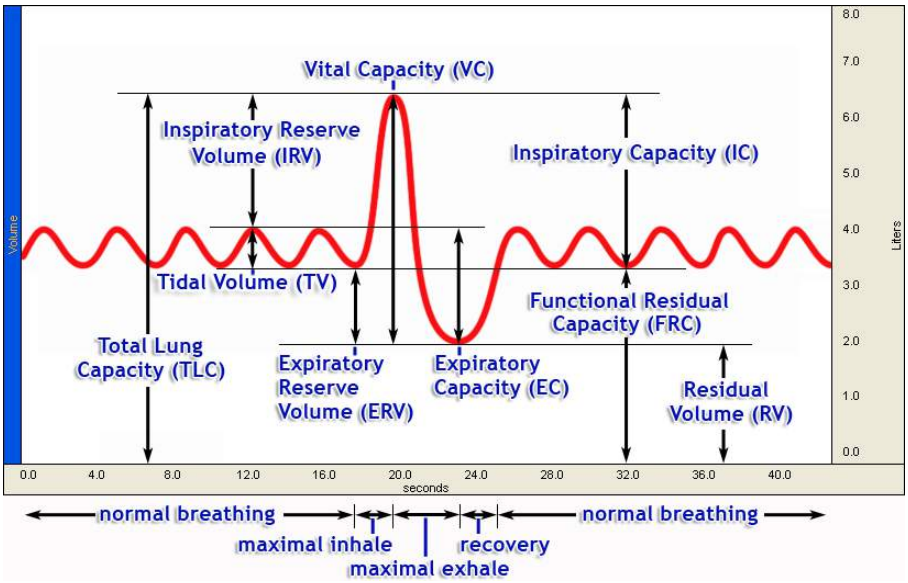


Fig. 13.1 Examples of commonly measured pulmonary volumes and capacities

In this lesson, you will perform two tests to measure pulmonary flow rates:

1. Forced Expiratory Volume (FEV)
2. Maximal Voluntary Ventilation (MVV)

Test #1: Forced Expiratory Volume (FEV)

Forced Expiratory Volume (also referred to as forced vital capacity or timed vital capacity) is a test in which a limit is placed on the length of time a Subject has to expel vital capacity air. $FEV_{1.0,}$ $FEV_{2.0,}$ $FEV_{3.0}$ are defined as the percentage of vital capacity that can be forcibly expelled after a maximal inhalation in the period of one second, two seconds, and three seconds, respectively (Fig. 13.2).

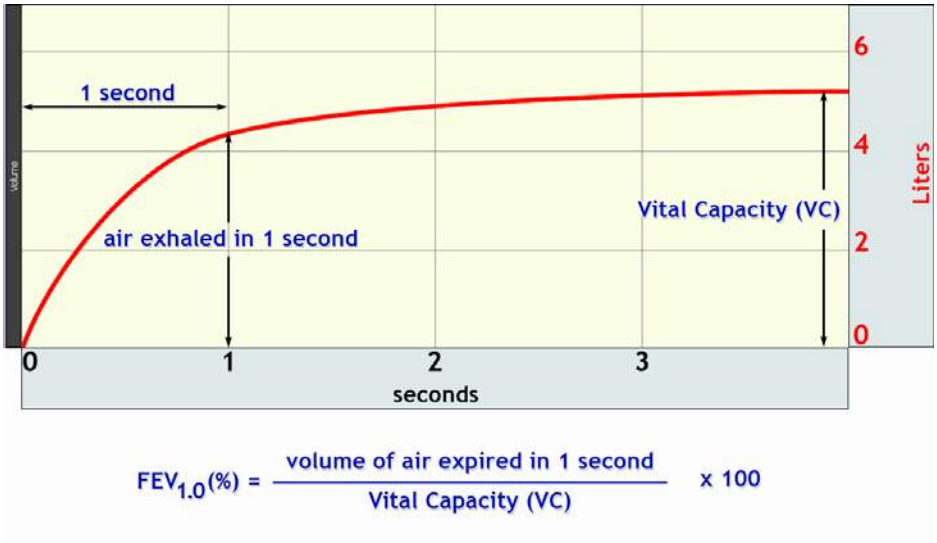
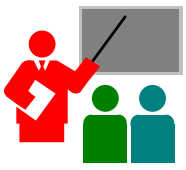


Fig. 13.2 Section of a record of Forced Expiratory Volume in one second ($FEV_{1.0}$)

The normal adult is able, with maximal effort, to expire about 66-83% of his/her vital capacity in one second ($FEV_{1.0}$,) 75-94% of vital capacity in the second second ($FEV_{2.0}$,) and 78-97% of vital capacity by the end of the third second ($FEV_{3.0}$).



A person with asthma may have a normal or near-normal vital capacity as measured in a Single Stage Vital Capacity test, which allows as long as necessary to maximally inhale and exhale. However, when an asthmatic exhales vital capacity with maximal effort, FEV measurements are all reduced because heavy mucus secretion and smooth muscle action reduces airway diameter and it takes longer to completely exhale vital capacity against increased airway resistance.

Test #2 Maximal Voluntary Ventilation (MVV)

The Maximal Voluntary Ventilation (also known as *maximal breathing capacity*) measures peak performance of the lungs and respiratory muscles. MVV is calculated as the volume of air moved through the pulmonary system in one minute while breathing as quickly and deeply as possible (hyperventilation). In performing this test, Subject inspires and expires as deeply and as rapidly as possible (> 1 breath/sec) while the tidal volume and the respiratory rate are measured. Because the maximal breathing rate is difficult to maintain, Subject hyperventilates for a maximum of 15 seconds. Then, to calculate MVV, the average volume per respiratory cycle (liters) is multiplied by the number of cycles per minute (liters/min).

MVV can also be extrapolated from the total volume of air moved in a 12-sec period (total volume in 12-sec X 5 = MVV).

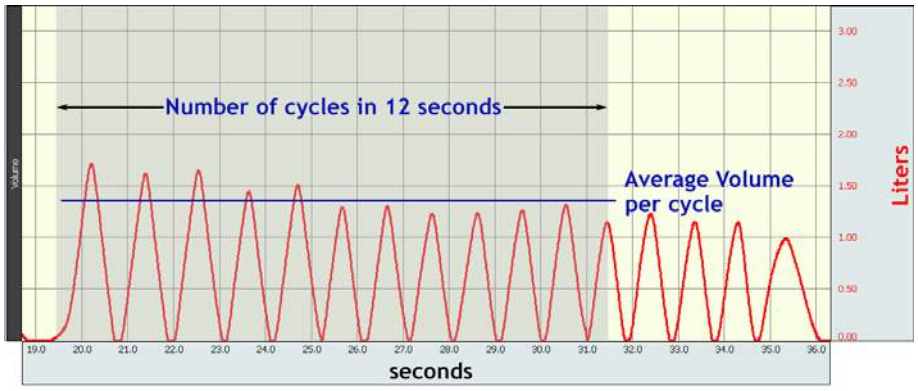
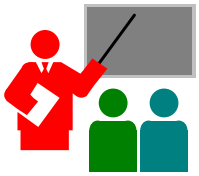


Fig. 13.3 MVV example

Normal values vary with sex, age and body size. MVV is a measure of how much your pulmonary system limits your capacity to work or exercise.



You can rarely exceed your MVV, even for brief periods of time. Therefore, MVV ultimately limits how much oxygen is available for exercising muscles. In general, a maximum of 50% of your MVV can be used for exercise beyond 10 minutes. Most people have trouble breathing when only using the available 30-40% MVV. MVV tends to be reduced in both restrictive and obstructive pulmonary diseases.

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II. EXPERIMENTAL OBJECTIVES

1.) To observe experimentally, record, and/or calculate forced expiratory volume (FEV) and maximal voluntary ventilation (MVV).
2.) To compare observed values of FEV with predicted normals.
3.) Compare MVV values with others in your class.

III. MATERIALS

- BIOPAC Airflow Transducer (SS11LA) or SS11LB for BSL 4.1.1 and higher only)
- BIOPAC Bacteriological Filter (AFT1): one per subject. If using calibration syringe, one dedicated to syringe.
- BIOPAC Disposable Mouthpiece (AFT2)
- BIOPAC Noseclip (AFT3)
- BIOPAC Calibration Syringe: 0.6-Liter (AFT6 or AFT6A+AFT11A) *or* 2-Liter (AFT26)
- *Optional*—BIOPAC Autoclavable Mouthpiece (AFT8) or combination mouthpiece/filter (AFT36, for SS11LB only
- Biopac Student Lab System: BSL 4 software, MP36, MP35 or MP45 hardware
- Computer System (Windows or Mac)

IV. EXPERIMENTAL METHODS

A. SETUP

FAST TRACK Setup

1. Turn your computer **ON**.
2. Turn **OFF** MP36/35 unit.
   - If using an MP45, make sure USB cable is connected and "Ready" light is **ON**.
3. **Plug the Airflow Transducer** (SS11LA) into Channel 1.
4. Turn **ON** the MP36/35 unit.

Detailed Explanation of Setup Steps

Fig. 13.4 MP3X (top) and MP45 (bottom) equipment connections

Setup continues…

5. **Start** the Biopac Student Lab program.
6. Choose "**L13 – Pulmonary Function II**" and click **OK**.
7. Type in a unique filename and click **OK**.

Start Biopac Student Lab by double-clicking the Desktop shortcut.

No two people can have the same filename, so use a unique identifier, such as **Subject's** nickname or student ID#.

A folder will be created using the filename. This same filename can be used in other lessons to place the **Subject's** data in a common folder.

8. ***Optional:*** Set Preferences.
   - Choose File > **Lesson Preferences**.
   - Select an option.
   - Select the desired setting and click **OK**.

This lesson has optional Preferences for data and display while recording. Per your Lab Instructor's guidelines, you may set:

Residual Volume: RV cannot be determined using a spirometer or airflow transducer, so the BSL software sets a default value of 1 liter. This can be changed to any value between 0 and 5 liters.

Grids: Show or hide gridlines

Calibration Syringe Values:

"*Set each time lesson is launched*": Syringe (Stage 2) calibration is required the first time the lesson is run. If the lesson is re-run without closing the application, Syringe calibration is not required.

"*Set once and use stored values*": After Syringe calibration is performed once, it will not be performed again. This is only recommended when specific SS11LA Airflow transducers are matched to specific MP units.

Calibration Syringe Size:

0.61 L (AFT6A/6,) 1 L, 2 L (AFT26,) 3 L, 4 L, or 5 L

SS11LB Calibration Option

"Use factory calibration": Bypasses the Syringe (Stage 2) calibration and uses factory settings.

"Require calibration syringe": Follows the "Calibration Syringe Values" protocol described above.

The SS11LB Airflow Transducer is supported in BSL versions 4.1.1 and higher only.

END OF SETUP

B. CALIBRATION

Calibration establishes the hardware's internal parameters (such as gain, offset, and scaling) and is critical for optimal performance. Calibration will vary based on the Preference set by your lab instructor.

Stage 1 – Always required

FAST TRACK Calibration

1. Hold the Airflow Transducer upright and still, making sure no air is flowing through it (Fig. 13.5).

2. Click **Calibrate**.
   - Wait for Calibration to stop
3. Check Calibration data:
   - Verify data is flat and centered. If necessary, click Redo Calibration.
   - To proceed, click Continue.

Stage 2 – If required

4. *IF CALIBRATION STAGE 2 IS REQUIRED*—Attach Calibration Syringe and filter to Airflow Transducer . The filter is not required if using the SS11LB Airflow Transducer. (Fig. 13.7).

   IMPORTANT! Always insert on the side labeled "Inlet."

   - Pull Calibration Syringe plunger all the way out.
   - Hold syringe horizontally. Airflow Transducer must be vertical and unsupported.
   - **Review** Calibration procedure.

Calibration continues…

Detailed Explanation of Calibration Steps

Calibration Stage 1 precisely zeroes the baseline. Any baseline shift during this calibration can cause errors in the subsequent recordings. Baseline shift can occur from:

a) Airflow through the transducer from movement, an HVAC duct or even from breathing close to the unit.

b) Changes in transducer orientation. The transducer should be held still and in the same orientation that will be used during the recording.

Fig. 13.5

Calibration lasts from 4 to 8 seconds.

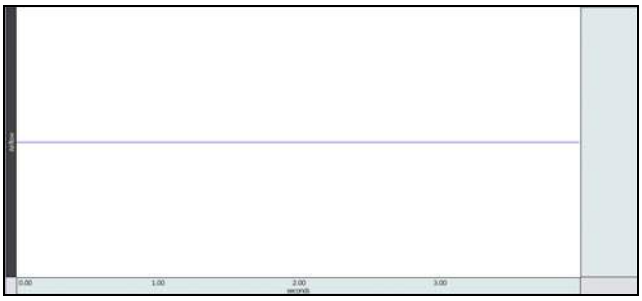


Fig. 13.6 Example Calibration Stage 1 data

Based on Lesson Preference settings, the Calibration Syringe may not be required. If not required, proceed to Step 9.

Notes:

- If using the SS11LA transducer, a bacteriological filter must be used between the transducer and syringe in order for calibration to be accurate. The SS11LB calibration does not require this filter.
- Different syringe sizes are supported via File > Lesson Preferences > Calibration Syringe Size. Check the pictures in the SET UP > Calibration tab to make sure they match your setup. If incorrect, the lesson must be re-run and the preference changed prior to calibration Stage 1. If you are using a non-BIOPAC syringe, always check the Preference setting prior to beginning calibration Stage 1.

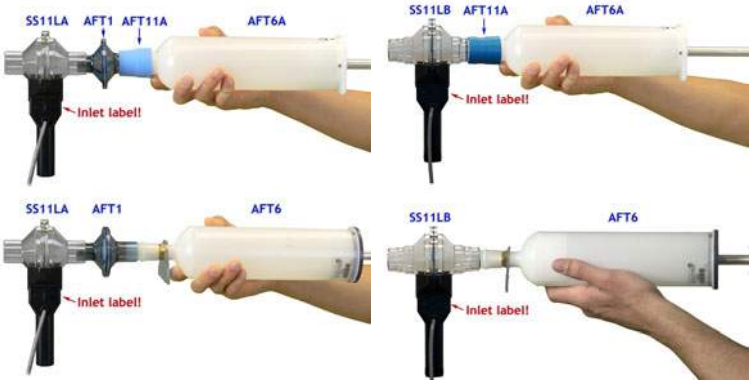


Fig. 13.7 Example AFT6A/6 connections (SS11LA and SS11LB)

Fig. 13.8 Example AFT26 connections (SS11LB)

Stage 2 - Continued

5. Click **Calibrate**.

Never hold onto the Airflow Transducer handle when using the Calibration Syringe or the syringe tip may break. Always insert syringe assembly on the transducer side labeled "**Inlet**" so that the transducer cable exits on the left.

Fig. 13.9 AFT6A calibration stage 2 starting position

Fig. 13.10 AFT26 calibration stage 2 starting position

6. Cycle plunger in and out five times (10 strokes total).
   - Wait two seconds between each stroke.

Important:

- Complete exactly five cycles. Less or more cycles will result in inaccurate volume data.
- Syringe must be pushed in and pulled out all the way.
- Hold the assembly as still as possible.
- Use a rhythm of about one second per stroke with two seconds rest between strokes.

7. Click **End Calibration**.

8. Verify recording resembles the example data.
   - If <u>similar</u>, click **Continue** and proceed to Data Recording.
   - If necessary, click **Redo Calibration**.

There <u>must</u> be five downward deflections and five upward deflections. The first deflection must be downward. If the first stroke (push) resulted in an upward data deflection, the syringe/filter assembly must be reversed by inserting the assembly into the other port of the airflow transducer and rerunning the Calibration.

Calibration continues…

Fig. 13.11 Example calibration Data

OPTIONAL

9. *Optional* Validate Calibration.
   a) Click **Record**.
   b) Cycle the syringe plunger in and out completely 3 times (6 strokes,) waiting about two seconds between strokes.
   c) Click **Stop**.
   d) Measure P-P on CH2 Volume (Fig. 12.16) to confirm the result matches the syringe volume:
   - AFT6 = 0.61 L acceptable range: 0.57 to 0.64 liters
   - AFT26 = 2 L acceptable range: 1.9 to 2.1 liters

   e) If measurements are correct, click **Redo** and proceed with **Subject** recording.
   f) If measurements are not correct:
   - Click **Redo** then choose File > **Quit**.

10. Re-launch the application and re-run the lesson.

END OF CALIBRATION

It is advisable to validate calibration once per lab session. Syringe must be pushed in and pulled out all the way.

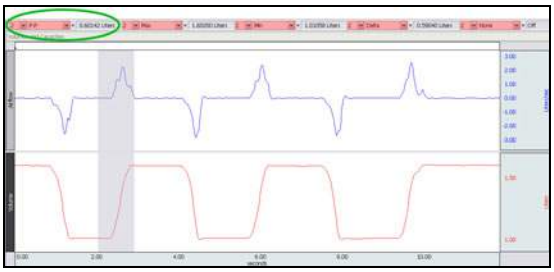


Fig. 13.12 Calibration validation shows P-P result 0.6 liters

If recording does not resemble the Example Data

- If the data is noisy or flatline, check all connections to the MP unit.

Clicking **Redo** will erase the validation data and allow the **Subject** recording to continue.

It is necessary to re-launch the application in order to allow a new Stage 2 (Syringe) calibration. Prior to the next recalibration, make sure the lesson preference setting “Calibration Syringe Values” is assigned “Set each time lesson is launched” (see Setup Step 8).

C. DATA RECORDING

FAST TRACK Recording

1. Prepare for the recording.
   - Remove Calibration Syringe/filter assembly (if used).

2. Insert the filter into the “Inlet” side of the transducer, and then attach the mouthpiece (Fig. 13.13).
   - If your lab does not use disposable filters, attach a sterilized mouthpiece (AFT8) directly to the “Inlet” side of the transducer (Fig. 13.14).

Setup continues...

Detailed Explanation of Recording Steps

In this recording, two conditions will be performed to measure pulmonary flow rates:

Forced Expiratory Volume (FEV)

Maximal Voluntary Ventilation (MVV)

Each test will be saved as a separate data file.

Hints for obtaining optimal data:

- Review onscreen “Tasks” to prepare for the recording steps in advance.
- **Subject** should wear loose clothing so clothing does not inhibit chest expansion.
- **Subject** must try to expand the thoracic cavity to its largest volume during maximal inspiratory efforts.
- Air leaks will result in inaccurate data. Make sure all connections are tight, noseclip is attached and that **Subject’s** mouth is sealed around the mouthpiece.
- Keep the Airflow Transducer vertical and in a constant position. (Fig. 13.16).

IMPORTANT: Each Subject must use a personal filter, mouthpiece and noseclip. The first time they are used, the **Subject** should personally remove them from the plastic packaging. It is advisable to write **Subject’s** name on the mouthpiece and filter with a permanent marker so they can be reused later (i.e. Lesson 12).

If your lab sterilizes the airflow heads after each use, make sure a clean head is installed prior to Subject use.

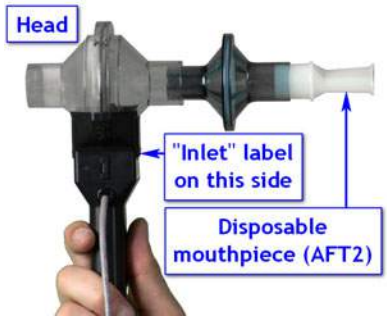


Fig. 13.13 SS11LA with unsterilized head

Fig. 13.14 SS11LA/LB with sterilized head

Fig. 13.15 SS11LB with reusable filter/mouthpiece combination

3. Prepare the **Subject:**
   - **Subject** must be seated, relaxed and still, facing away from the monitor.
   - Place noseclip on **Subject's** nose.
   - **Subject** holds Airflow Transducer vertically, breathing through mouthpiece.
   - Before recording, **Subject** acclimates by breathing normally for 20 seconds.
   - **Review** recording steps.

Verify there are no air leaks; mouthpiece and filter are firmly attached, the noseclip is snug and the Subject's mouth is tightly sealed around mouthpiece.

Fig. 13.16 Keep Airflow Transducer upright at all times

Part 1 — FEV

4. Click **Record FEV.**
5. **Subject** performs the following procedure:
   - Breathe normally for three cycles.
   - Inhale as deeply as possible (maximum inspiration).
   - Hold breath for just an instant.
   - Forcefully and maximally exhale (maximum expiration).
   - Resume normal breathing for three more cycles.

1 cycle = inspiration + expiration

After maximum inspiration, hold breath for an instant so that when analyzing the data the beginning of the exhale can be clearly seen.

For the maximum expiration, it is important to expel all air, which should take more than 3 seconds.

6. Click **Stop**.

If a recording is started on an inhale, try to stop recording on an exhale, or vice versa.

Upon **Stop**, the Biopac Student Lab software will automatically convert the air flow data to volume data as shown in Fig. 13.17.

7. Verify recording resembles the example data.
   - If similar, click **Continue** and proceed to the next recording.

The maximal inhale and maximal exhale should be clearly visible in the data and there should be three normal breathing cycles both before and after.

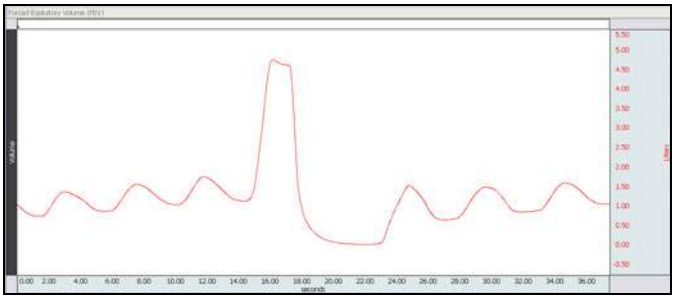


Fig. 13.17 Example FEV Data

Recording continues…

- If necessary, click **Redo**.

If recording does not resemble the Example Data

- If the data is noisy or flatline, check all connections to the MP unit.
- If there are not three normal breathing cycles on either side of the maximal inhale/exhale, Redo the recording.
- If it is difficult to determine the beginning of maximal expiration, the Subject may not have held breath for an instant after maximal inhalation; consider redoing the recording.
- If the maximal inhale/exhale data is not much greater in amplitude than that during normal breathing; verify there are no air leaks; mouthpiece and filter are firmly attached, the noseclip is snug and the Subject's mouth is firmly sealed around the mouthpiece.

Click **Redo** and repeat Steps 4 – 6 if necessary. Note that once **Redo** is clicked the data will be erased.

8. Zoom in using the zoom tool, on the area of maximal exhale.

The selected area should include some data both before and after maximal exhale.

9. Use the I-beam cursor to select the area of from beginning of maximal expiration to the end of maximal expiration. At least three seconds must be selected (Fig. 13.18).

The left mouse button is held down while selecting with the I-beam cursor.

The first measurement box will display **Delta T** so you can make sure the selected area is longer than 3 seconds.

If Delta T is less than 3 seconds, the Subject may not have expelled all air during maximum expiration. Click **Redo** and repeat Steps 4 – 6 if necessary.

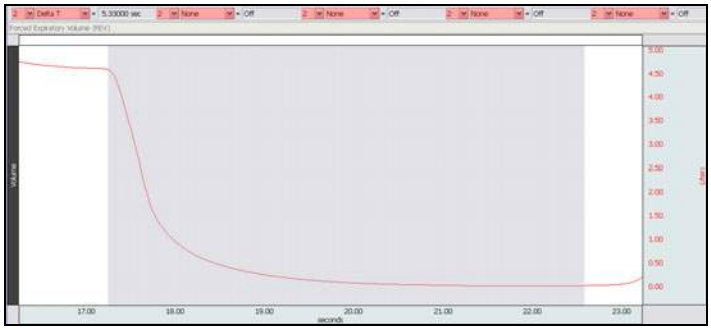


Fig. 13.18 Selected area for maximal exhale

10. Click **Calculate FEV**.

The program will cut out the selected area, invert it, zero the offset, and paste it into a new channel (Fig. 13.19). The original volume data will be deleted.

11. Verify the FEV plot resembles the example data.
    - If similar, click **Continue** and proceed to the MVV recording.
    - If necessary, click **Redo** to reselect area of maximal exhale and recalculate FEV.
    - If you will not be recording MVV, click **Done** and proceed to the Data Analysis section.

If the data was selected properly in Step 8, the first data sample should be the minimum (0 Liters) and the data should continue to increase for at least 3 seconds.

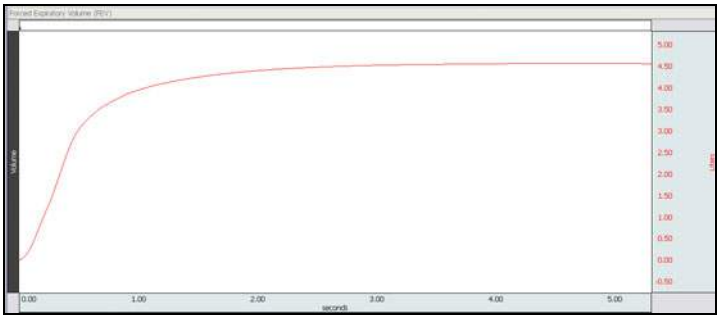


Fig. 13.19 Example FEV Plot

Upon **Continue**, the FEV data will be automatically saved for later analysis.

Recording continues…

Part 2 — MVV

12. Prepare the **Subject**.
    - **Subject** must be seated, relaxed and still, facing away from monitor.
    - Place noseclip on **Subject's** nose.
    - **Subject** holds airflow transducer vertically, breathing through mouthpiece.
    - **Subject** breathes normally for 20 seconds prior to starting recording.
    - **Review** recording steps.
13. Click **Record MVV**
14. **Subject** performs the following procedure:
    - Breathe normally for five cycles.
    - Breathe quickly and deeply for 12 – 15 seconds.
    - Breathe normally for five additional cycles.
15. Click **Stop**.
16. Verify that recording resembles the example data.
    - If similar, proceed to Step 15.

Recording continues…

1 cycle = inspiration + expiration

WARNING: This procedure can make Subject dizzy and light headed. Subject should be sitting down and Director should watch Subject. Stop the procedure if Subject feels sick or excessively dizzy.

Upon **Stop**, the Biopac Student Lab software will automatically convert the airflow data to volume data as shown in Fig. 13.20.

The rapid, deep breathing data should be clearly visible in the data.

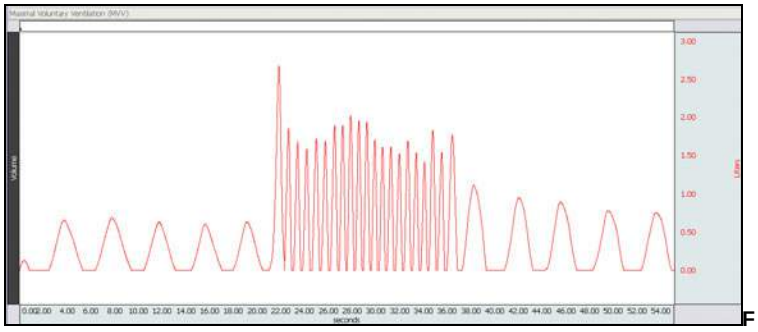


Fig. 13.20 Example MVV data

Note:

The software zeros the baseline after each cycle, which can result in data resembling the example to the right. It is not necessary to redo the recording, as data analysis will not be affected.

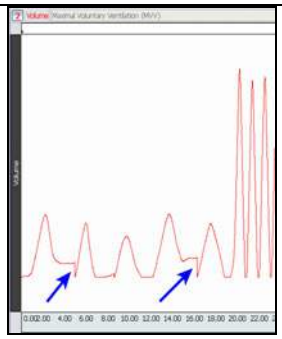


Fig. 13.21 Example of baseline reset

- If necessary, click **Redo**.

If recording does not resemble the Example Data

- If the data is noisy or flatline, check all connections to the MP unit.
- If the rapid, deep breathing data is not much greater in amplitude than that during normal breathing; verify there are no air leaks; mouthpiece and filter are firmly attached, the noseclip is snug and the Subject's mouth is firmly sealed around the mouthpiece.

Click **Redo** and repeat Steps 13 – 15 if necessary. Note that once **Redo** is clicked the data will be erased.

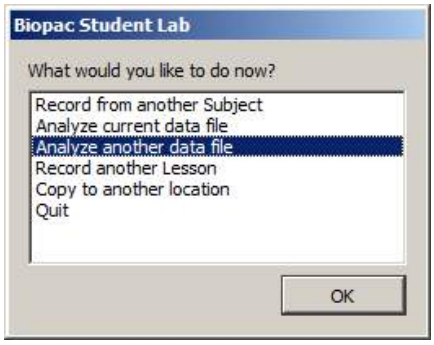
17. Click **Done**.
18. Choose an option and click **OK**.

This lesson creates two data files; one for FEV data and one for MVV data, as indicated by the file name extension.

When **Done** is clicked, a dialog with options will be generated. Make a selection and click OK.

If FEV and MVV recordings were both performed, choosing the "Analyze current data file" option will open the MVV file, but the FEV data file should be opened first, as this file is referenced in Part 1 of the Data Analysis section that follows.

To open the FEV file first, choose "Analyze another data file" from the list of options and navigate to the correct "FEV – L13" file in the **Subject's** folder.



If choosing the "**Record from another Subject**" option:

- Repeat Calibration Steps 1 – 3, and then proceed to Recording.

END OF RECORDING

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V. DATA ANALYSIS

FAST TRACK Data Analysis

1. Enter the **Review Saved Data** mode.

   - Note channel number (CH) designations:

Channel	*Displays*
CH 2	**Volume**

   - Note measurement box settings:

Channel	*Measurement*
CH 2	**Delta T**
CH 2	**P-P**

2. Use the **I-beam** cursor to select the area from time zero to the end of the recording. Record the Vital Capacity (VC).

   A

Data Analysis continues…

Detailed Explanation of Data Analysis Steps

If entering **Review Saved Data** mode from the Startup dialog or Lessons menu, be sure to choose the file with "**FEV – L13"** file name extension.

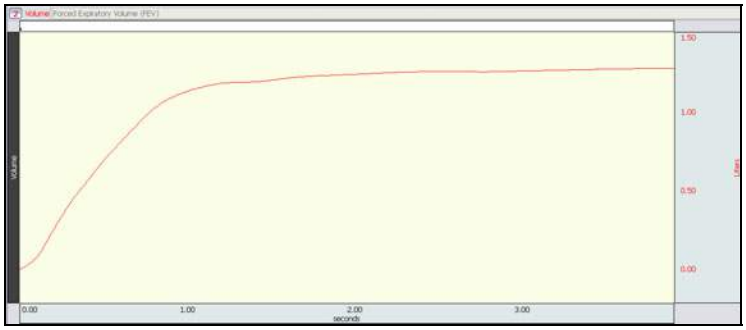

Fig. 13.22 Example FEV data

The measurement boxes are above the marker region in the data window. Each measurement has three sections: channel number, measurement type, and result. The first two sections are pull-down menus that are activated when you click them. The following is a brief description of these specific measurements.

Brief definition of measurements:

Delta T: Displays the amount of time in the selected area (the difference in time between the endpoints of the selected area).

P -P (Peak-to-Peak): Subtracts the minimum value from the maximum value found in the selected area.

The "selected area" is the area selected by the I-Beam tool (including endpoints).

Useful tools for changing view:

Display menu: Autoscale Horizontal, Autoscale Waveforms, Zoom Back, Zoom Forward

Scroll Bars: Time (Horizontal); Amplitude (Vertical)

Cursor Tools: Zoom Tool

Buttons: Show Grid, Hide Grid, -, +

The **P-P** measurement for the selected area represents the Vital Capacity (VC).

Note: In the example, the Grids have been enabled to assist in data selection.

Fig. 13.23 All data selected

3. Use the **I-beam** cursor to select the first one-second interval (Fig. 13.24). Record the volume expired and calculate $FEV_{1.0}$.

   B

4. Use the **I-beam** cursor to select the first two-second interval (Fig. 13.25). Record the volume expired and calculate $FEV_{2.0}$.

   B

5. Use the **I-beam** cursor to select the first three-second interval (Fig. 13.26). Record the volume expired and calculate $FEV_{3.0}$.

   B

6. Answer the **FEV**-related questions in the Data Report before continuing to the **MVV** section.
7. Select File > **Save Changes**.
8. Pull down the **Lessons** menu, select **Review Saved Data**, and choose the correct **MVV – L13** file.
9. Use the **zoom** tool to set up your display window for optimal viewing of the deep, fast breathing portion of the recording (Fig. 13.27).

10. Use the **I-beam** cursor to select a twelve-second area that is convenient to count the number of cycles in the interval (Fig. 13.28).

    C

Data Analysis continues…

The selected area should be from Time 0 to the one-second reading, as displayed in the Delta T measurement. The grid can be used as a reference. The volume expired is indicated by the **P-P** measurement.

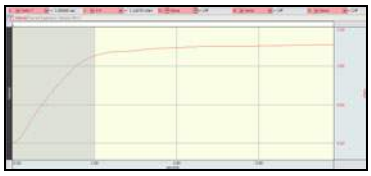

Fig. 13.24 $FEV_{1.0}$

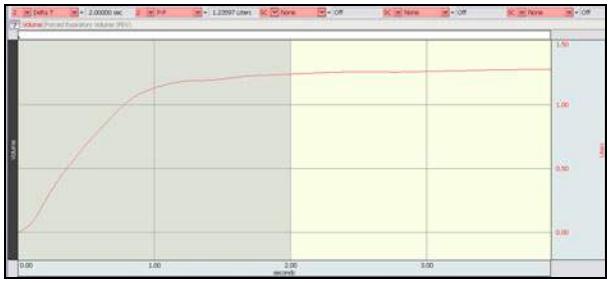

Fig. 13.25 $FEV_{2.0}$

Fig. 13.26 $FEV_{3.0}$

Choose the data file that was saved with "**MVV – L13"** extension.

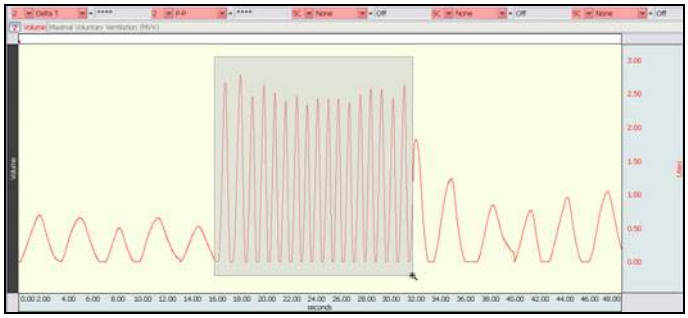

Fig. 13.27 Zoom in on rapid/deep breathing data

Use the Delta T measurement to determine the time interval. In the example below, 13 cycles are in the 12 second interval.

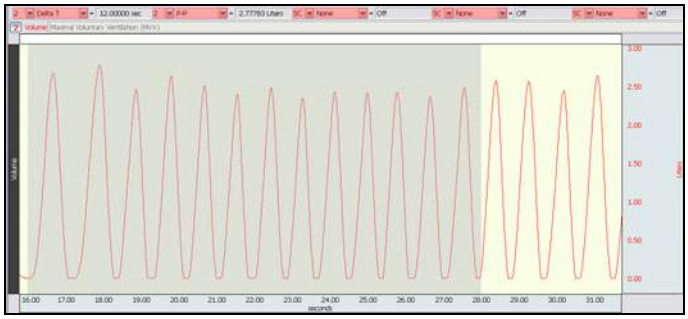

Fig. 13.28 Example of 12 second data selection

11. Place an event marker at the end of the 12 second selected area (Fig. 13.29).

It's helpful to clearly mark the end of the individual cycle measurement area by placing an **event marker** at the end of the selected 12 second interval. To place an event marker, right-click in the marker region just above the data display and select "Insert New Event." If the event marker is not placed correctly, it can be moved by holding down the Alt key and dragging with the mouse.

You may also enter event text in the field above the marker.

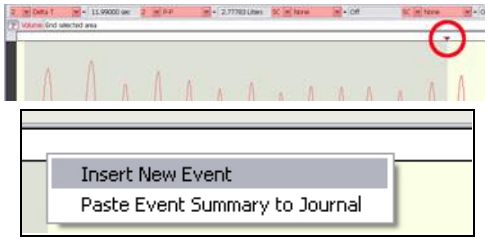

Fig. 13.29 Event Marker insertion

12. Use the **I-beam** cursor to select <u>each complete individual cycle</u> in the 12-second interval defined in Step 9. Record the volume of each cycle.

C

13. Calculate the average volume per cycle (AVPC) and then the Maximal Voluntary Ventilation (MVV).

C

The Volume is measured by the P -P (Peak-to-Peak) measurement.

Fig.13.30 shows the first cycle of the 12-second interval defined in Fig. 13.28 selected:

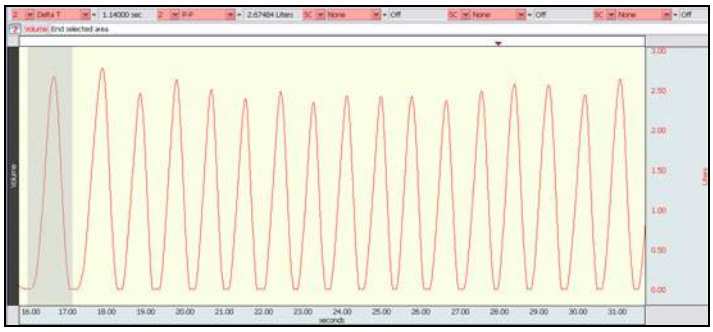

Fig. 13.30 Example of first cycle selection

14. Answer the MVV-related questions at in the Data Report.
15. **Save** or **Print** the data file.
16. **Quit** the program.

An electronically editable **Data Report** is located in the journal (following the lesson summary,) or immediately following this Data Analysis section. Your instructor will recommend the preferred format for your lab.

END OF DATA ANALYSIS

END OF LESSON 13

Complete the Lesson 13 Data Report that follows.

PULMONARY FUNCTION II

- *Pulmonary Flow Rates*
- *Forced Expiratory Volume (FEV)*
- *Maximal Voluntary Ventilation (MVV)*

DATA REPORT

Student's Name: _____

Lab Section: _____

Date: _____

Subject Profile

Name:_____ Height:_____

Age:_____ Gender: Male /Female Weight:_____

I. Data and Calculations

A. Vital Capacity (VC)

2 P-P = _____

B. Forced Expiratory Volumes: $FEV_{1.0}$, $FEV_{2.0}$, $FEV_{3.0}$

Table 13.2

Time Interval (sec)	Forced Expiratory Volume 2 P-P	Vital Capacity (VC) *from A*	FEV/VC *calculate*	(FEV/VC) x 100 = % *calculate*	= FEV_x	*Normal Adult Range*
0-1				%	$FEV_{1.0}$	66% - 83%
0-2				%	$FEV_{2.0}$	75% - 94%
0-3				%	$FEV_{3.0}$	78% - 97%

C. MVV Measurements (Note, all volume measurements are in liters)

1) Number of cycles in 12-second interval: _____

2) Calculate the number of respiratory cycles per minute (RR):

RR = Cycles/min = Number of cycles in 12-second interval x 5

Number of cycles in 12-second interval (from above): _____ x 5 = _____cycles/min

3) Measure each cycle

Complete Table 13.3 with a measurement for each individual cycle. If Subject had only 5 complete cycles/12-sec period, then only fill in the volumes for 5 cycles. If there is an incomplete cycle, do not record it. (The Table may have more cycles than you need.)

Table 13.3

Cycle Number	Volume Measurement 2 P-P		Cycle Number	Volume Measurement 2 P-P
Cycle 1			Cycle 9	
Cycle 2			Cycle 10	
Cycle 3			Cycle 11	
Cycle 4			Cycle 12	
Cycle 5			Cycle 13	
Cycle 6			Cycle 14	
Cycle 7			Cycle 15	
Cycle 8			Cycle 16	

4) Calculate the average volume per cycle (AVPC):

Add the volumes of all counted cycles from Table 13.3.

Sum = _____ liters

Divide the above sum by the number of counted cycles. The answer is the average volume per cycle (AVPC)

AVPC = _____ / _____ = _____liters
Sum # of counted cycles

5) Calculate the MVV_{est}

Multiply the AVPC by the number of respiratory cycles per minute (RR) as calculated earlier.

MVV = AVPC x RR = _____ x _____ = _____liters/min
AVPC RR

II. Questions

D. Define **Forced Expiratory Volume** (FEV).

E. How do Subject's FEV values compare to the average per Table 13.2?

$FEV_{1.0}$	*less than*	*same as*	*greater than*
$FEV_{2.0}$	*less than*	*same as*	*greater than*
$FEV_{3.0}$	*less than*	*same as*	*greater than*

F. Is it possible for a Subject to have a vital capacity (single stage) within normal range but a value for $FEV_{1.0}$ below normal range? Explain your answer.

G. Define **Maximal Voluntary Ventilation** (MVV.)

H. How does Subject's MVV compare to others in the class? *less than* *same as* *greater than*

I. Maximal voluntary ventilation decreases with age. Why?

J. Asthmatics tend to have smaller airways narrowed by smooth muscle constriction, thickening of the walls, and mucous secretion. How would this affect vital capacity, $FEV_{1.0}$, and MVV?

K. Bronchodilator drugs open up airways and clear mucous. How would this affect the FEV and MVV measurements?

L. Would a smaller person tend to have less or more vital capacity than a larger person? ☐ Less ☐ More

M. How would an asthmatic person's measurement of $FEV_{1.0}$ and MVV compare to an athlete?

Explain your answer.

End of Lesson 13 Data Report

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Purdue University School of Science

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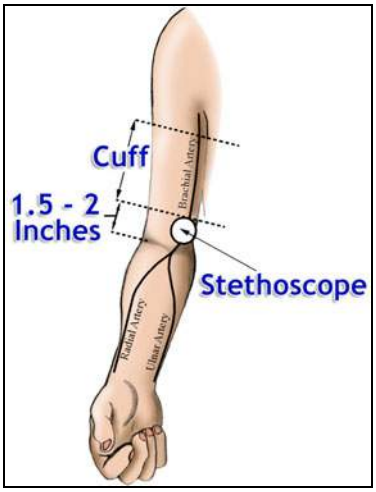
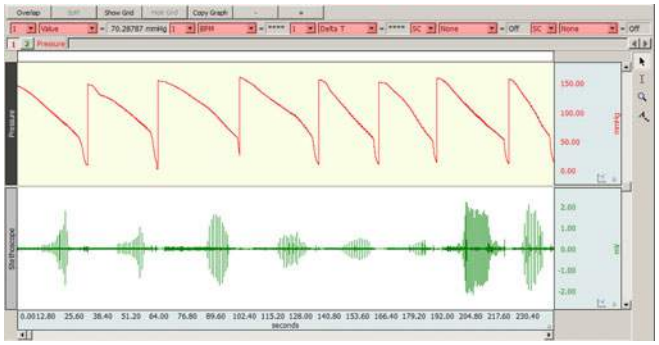
Vice President, BIOPAC Systems, Inc.





I. INTRODUCTION

In this lesson, you will record your blood pressure, which is comprised of two numbers: systolic pressure (the force of blood in your arteries as the heart contracts and pushes it out) and diastolic pressure (the force of your blood between heartbeats). Understanding circulation will help you understand and accurately measure your blood pressure.

Circulating blood provides a transportation and communication system between the body's cells and serves to maintain a relatively stable internal environment for optimum cellular activity. Blood circulates because the heart pumps it through a closed circuit of blood vessels (Fig. 16.1 and 16.2).

Blood flow through the heart and the blood vessels is unidirectional, flowing into the heart from the pulmonary and systemic veins, and out of the heart into pulmonary and systemic arteries.

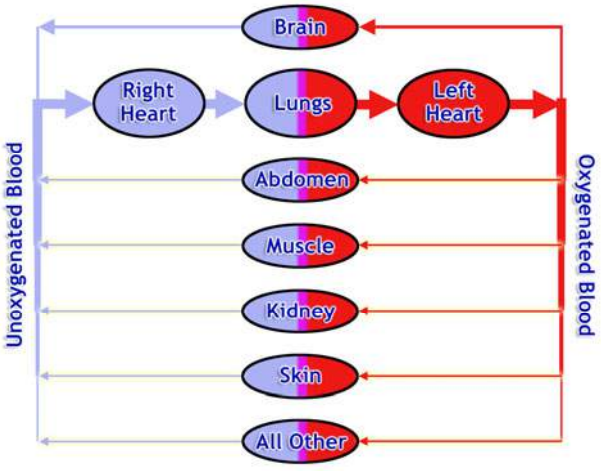


Fig. 16.1

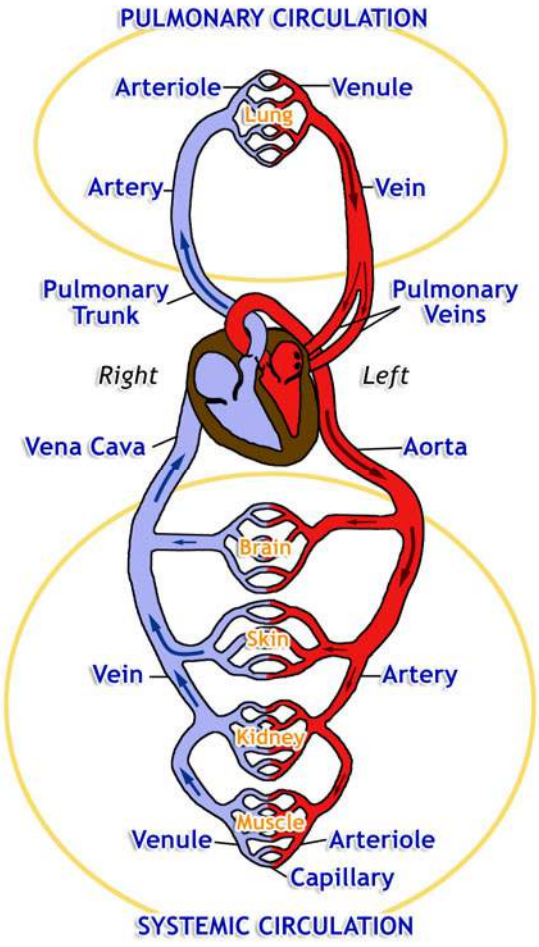


Fig. 16.2

Blood flow through the chambers of the heart is unidirectional because of the action of four valves inside the heart (see Fig. 16.3) that normally prevent retrograde or backward flow during the cardiac cycle (one heartbeat).

- The **right atrioventricular valve** (tricuspid) and the **left atrioventricular valve** (bicuspid or mitral) prevent the backward flow of blood from the ventricles into the atria.
- The **pulmonary semilunar valve** and the **aortic semilunar valve** prevent the backward flow of blood from arteries into the ventricles.

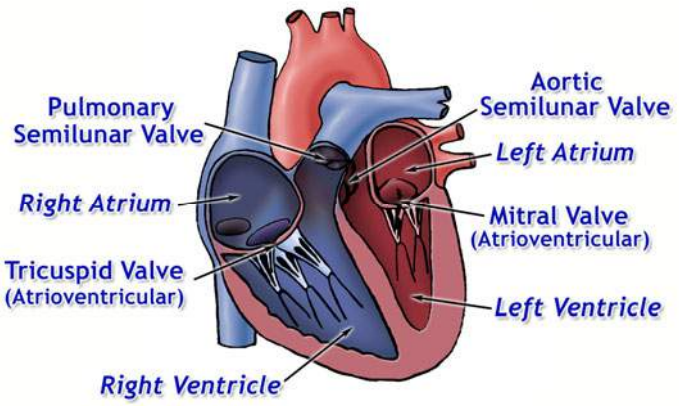


Fig. 16.3 Heart valves

The left and right ventricles are the primary pumping chambers of the heart. During relaxation of the ventricles (**ventricular diastole**) the atrioventricular valves open and the semilunar valves close, allowing the ventricles to fill with blood. During contraction of the ventricles (**ventricular systole**) the atrioventricular valves close and the semilunar valves open, allowing the ventricles to eject blood into the arteries.

As the heart works at pumping blood, the ventricles relax and fill with blood, then contract and eject blood, then repeat the cycle of filling and ejecting. Due to the nature of the cardiac cycle the ejection of blood by the ventricles into the arteries is not continuous. Therefore, both blood pressure and blood flow in the arteries is **pulsatile**, increasing during ventricular systole and decreasing during ventricular diastole.

Fig. 16.4 represents a graphic recording of changes in systemic arterial blood pressure measured directly by inserting a small catheter into an artery and attaching the catheter to a pressure measuring and recording device.

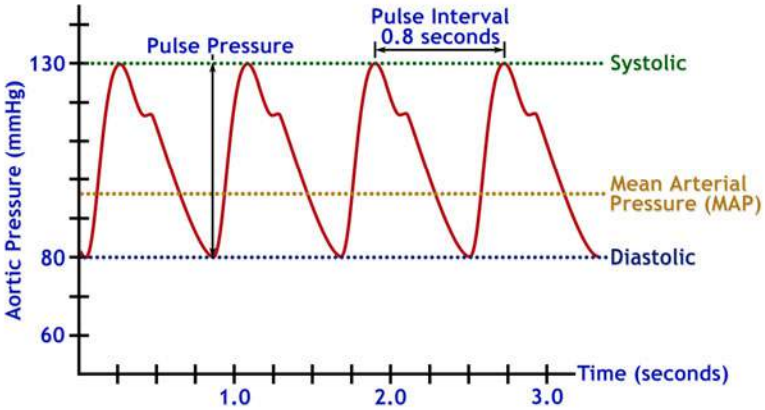


Fig. 16.4 Example of systemic arterial blood pressure changes

Systolic pressure is the highest arterial pressure reached during ventricular systole. The normal range of systolic pressures for a resting adult is 100 - 139 mm Hg.

Diastolic pressure is the lowest arterial pressure reached during ventricular diastole. The normal range of diastolic pressures for a resting adult is 60 - 89 mm Hg.

The mathematical difference between systolic pressure and diastolic pressure is called **pulse pressure**. Pulse pressure is directly related to stroke volume of the heart and inversely related to heart rate and peripheral resistance.

- For example, when the volume of blood ejected per beat (called **stroke volume**) increases at the beginning of exercise, systolic pressure increases more than diastolic pressure, resulting in an increase in pulse pressure.

In the systemic circuit (refer back to Fig. 16.2,) blood flows out of the left ventricle into systemic arteries and then serially through arterioles, capillaries, venules, and veins before returning to the heart to be pumped through the pulmonary circuit. Flow through a closed circuit such as the systemic circuit is determined by the pressure energy causing the flow, and the resistance to flow offered by the blood vessel walls (friction) and the internal viscosity of the blood.

The relationship between flow (F,) pressure (P) causing the flow and resistance (R) to the flow is expressed as: **F = P/R**

Flow is expressed as liters/min., pressure is expressed as **mm Hg** (**torr**,) and resistance is expressed as peripheral resistance units.

The pressure (P) is neither systolic nor diastolic but rather a pressure in between the two, called **mean arterial pressure** (**MAP**). Mean arterial pressure converts a pulsatile pressure (systolic/diastolic) into a continuous pressure that determines the average rate of blood flow from the beginning of the circuit (left ventricle) to the end of the circuit (right atrium).

During the cardiac cycle, or one heartbeat, the ventricle spends more time in diastole than it spends in systole. As a result, mean arterial pressure is not the mathematical average of systolic and diastolic pressure but rather an approximation of the geometric mean. Mean Arterial Pressure (MAP) can be calculated using either of the following equations:

$$\text{MAP} = \frac{\text{pulse pressure}}{3} + \text{diastolic pressure} \qquad \textit{OR} \qquad \text{MAP} = \frac{(\text{systolic pressure} + 2\ \text{diastolic pressure})}{3}$$

If systolic pressure were 130 mm Hg and diastolic pressure were 80 mm Hg, then the mean arterial pressure would be 96.67 mm Hg, as calculated below:

$$\text{MAP} = \frac{50}{3} + 80 = 16.67 + 80 = 96.67 \text{ mm Hg} \qquad \textit{OR} \qquad \text{MAP} = \frac{(130 + 2(80))}{3} = \frac{(130 + 160)}{3} = \frac{290}{3} = 96.67 \text{ mm Hg}$$

IMPORTANT CONCEPT!

Systemic arterial blood pressure is commonly measured with indirect methods because direct methods of measurement are invasive and neither practical nor convenient for routine use. It is important to recognize the limitations of indirect measurement:

- Indirect methods can only give an approximation of the actual blood pressure.
- Indirect methods may be influenced by the person taking the measurement—for example, the person may not be able to hear the sound changes accurately.
- Indirect methods can be influenced by the quality and calibration of the equipment being used.

The most common indirect method of measuring systemic arterial blood pressure is referred to as an **auscultatory** method, which simply means external diagnostic monitoring of the sounds made by internal organs. This involves the use of a stethoscope and a sphygmomanometer. The **sphygmomanometer** is comprised of an inflatable cuff to restrict blood flow, an inflation bulb with release valve, a pressure gauge (which can be a mercury or mechanical manometer,) or an on-screen gauge. The BIOPAC stethoscope contains a microphone that picks up sounds traveling through the tubing. The microphone is very sensitive and can pick up sounds that may not be heard. It is useful to compare the sounds heard to those recorded by the microphone.

> The sounds detected during blood pressure measurement are referred to as **Korotkoff Sounds** and were first identified by Russian surgeon Nicolai Sergeivich Korotkov in 1905.

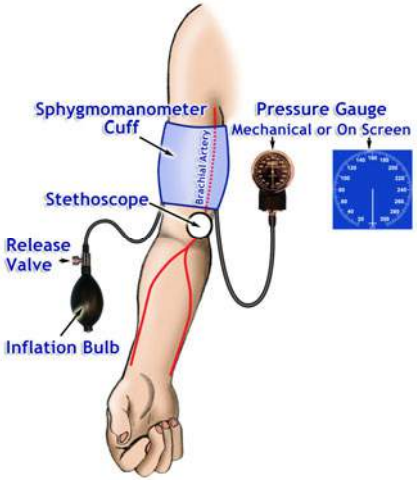


Fig. 16.5 Blood pressure cuff placement

Arterial pressure is determined by placing an inflatable rubber cuff, attached to a pressure gauge, around the arm, inflating it to collapse the underlying artery, and listening over the vessel below the cuff with a stethoscope or microphone (Fig. 16.5).

Sound is created by the turbulent flow of blood through the compressed vessel. When cuff pressure exceeds systolic arterial pressure, the artery is collapsed, blood flow through it ceases, and no sound is produced. As cuff pressure is slowly reduced, blood flow through the artery begins when cuff pressure falls just below systolic arterial pressure.

At this point, a sharp tapping sound (the first sound of **Korotkoff**) may be heard with the stethoscope or microphone over the artery. The cuff pressure when this sound is first heard is taken as an approximation of systolic pressure.

As cuff pressure is further reduced, the sounds increase in intensity (and may resemble swishing,) then suddenly become muffled (the second sound of Korotkoff) at the level of diastolic pressure, then disappear. Sounds disappear when the vessel is no longer compressed by the pressure cuff and normal non-turbulent blood flow resumes.

Since it is easier to determine when the sound disappears than when it becomes muffled, and since only a few millimeters of mercury pressure differential exist between the two, the disappearance of sound is commonly used as an indicator of diastolic pressure.

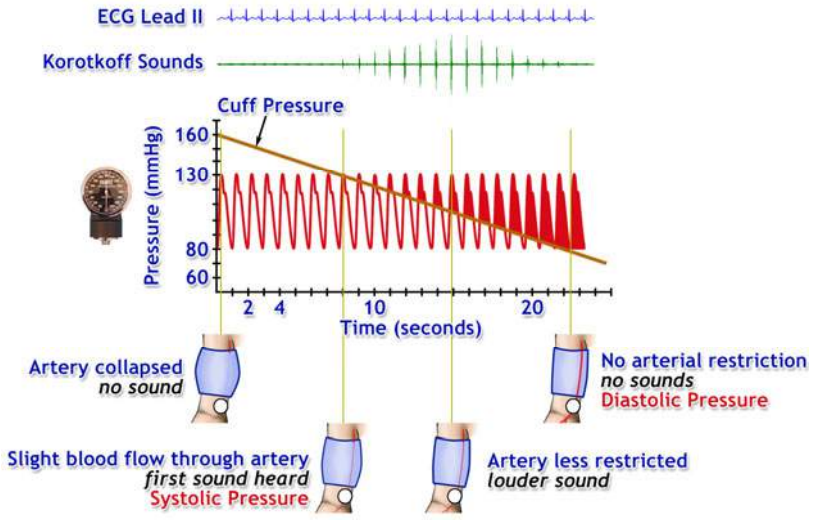


Fig. 16.6

Fig. 16.6 (above) is a graphic display that summarizes this concept. The diagram shows the relationship in time between the ECG waveform, the Korotkoff sounds (as heard through the stethoscope,) the cuff pressure, the blood pressure pulse waveform (at the arm,) and the condition of the brachial artery under the cuff. The pulse waveform represents the brachial pressure in the artery above the cuff. The shaded area of the Aortic pressure wave represents the blood flow that can pass below the cuff as soon as the aortic pressure exceeds the cuff pressure.

One concept that can be examined in this lesson is the timing of the Korotkoff sounds with respect to the ECG waveform. The sounds appear at about the time of the T-wave. This sound occurs approximately near the time of peak pressure (systole,) which, if measured at the heart, would occur immediately after the R-wave. However, there is a delay due to the time it takes the pressure wave to reach the arm, so the sounds are shifted in time with respect to the R-wave. Although the ECG wave will vary based on the experimental condition (i.e., pre-exercise, post-exercise,) the relationship of the P-wave to the sound should be a consistent interval within each condition. Using this fact, you will be able to distinguish actual Korotkoff sounds from extraneous noise.

In some cases (such as when a Subject has hypertension) you may notice what is called an “auscultatory gap.” This occurs when you hear sound at a higher cuff pressure, but it fades out as the pressure is decreased, and then reappears at a still lower pressure. This may require an alternate method of blood pressure measurement, using a strictly palpatory technique.

By convention, blood pressures determined by indirect methods are expressed in the form of a ratio: systolic pressure/diastolic pressure. For example, if systolic pressure was measured as 135 mm Hg and diastolic pressure was measured as 80 mm Hg, systemic arterial blood pressure would be expressed as 135/80, and pulse pressure would be 55 mm Hg. If the sound became muffled at 85 mm Hg and disappeared at 80 mm Hg, the systemic arterial blood pressure would be expressed as 135/85-80.

A note about your BP reading from this lab

There are many factors that influence blood pressure measurement, such as: genetics, age, body weight, state of physical activity, level of salt, caffeine or other drugs in the system, monitor’s hearing, etc.

The Journal of the American Medical Association published the following blood pressure classification data (Table 16.1) from the Seventh Report of the National High Blood Pressure Education Program’s Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure (JNC 7):

CLASSIFICATION OF BLOOD PRESSURE for Adults Aged 18 Years or Older				
BP CLASSIFICATION	**Systolic** mmHg		**Diastolic** mmHg	*LIFESTYLE MODIFICATION*
Normal	< 120	and	< 80	Encourage
Prehypertension	120-139	or	80-89	Yes
Stage 1 hypertension	140-159	or	90-99	Yes
Stage 2 hypertension	≥ 160	or	≥ 100	Yes
Note:Diagnosis of high blood pressure is based on the average of two or more readings taken at each of two or more visits after initial screening. Unusually low readings should be evaluated for clinical significance. © 2003 AMA				

Table 16.1 JNC 7 Blood Pressure Classifications

If your blood pressure as determined from this lesson is "high," you should not be too concerned. A mistake may have been made in the measurement, or there may be other factors affecting your system that resulted in a temporarily high reading.

If you are concerned about it, please consult your doctor. Do not try to diagnose or treat yourself based on the laboratory blood pressure readings.

Please review the following procedure before you come into the lab so recording can proceed quickly.

Blood Pressure Measurement

The following is a review of the basic clinical blood pressure measurement procedure using the sphygmomanometer and stethoscope, with an explanation of the logic behind each step.

As discussed earlier, this is an indirect blood pressure measurement. It can be fairly accurate if performed exactly as described, but will nonetheless provide only an approximation of the absolute blood pressure.

It is important that you try to minimize errors by following the measurement procedure as detailed, and it is also important that you realize it is impossible to eliminate all errors.

Note: The actual procedure used in this lesson will have a few additional steps since you will be simultaneously recording the parameters.

Basic measurement step	*Reason*
1. Select the proper size cuff for your Subject. ❖ The BIOPAC sphygmomanometer cuff is designed for arms with a circumference from 25.4 cm (10 inches) to 40.6 cm (16 inches). This is the standard adult range, and is marked on the cuff to make sure you fall within it. If this cuff does not fit your Subject, you should use another Subject for this lesson so the readings are accurate.	Cuffs come in several sizes and it is important that you select the right size cuff for Subject's arm because if the cuff is too large you may get incorrect low readings, and if it is too small you may get incorrect high readings.
2. Make sure all the air in the sphygmomanometer cuff is expelled before use. ❖ Turn the release valve fully counter-clockwise and roll the cuff up while squeezing it.	If air is left in the cuff you may get a false high reading because an excessive amount of pressure will be required to occlude the brachial artery.
3. Close the valve. ❖ Turn the release valve fully clockwise.	
4. Position Subject's arm at heart level. ❖ Hold up Subject's arm, or ❖ Have Subject rest his/her arm on the lab table.	You need to minimize the effects of gravity. Arm above heart level can give false low readings, and arm below heart level can give false high readings.
5. Place the cuff so that the "Artery" label is over Subject's brachial artery (with the arrow on the label facing down). ❖ There is an "Artery" label (with arrow) that is sewn into the cuff.	The cuff pressure must be applied directly to the artery, which requires the bladder inside the cuff to be in the proper position.
6. Position the cuff such that the lower edge of the cuff is 1.5 to 2 inches above the antecubital fossa (inner aspect of elbow).	The cuff edge should be high enough to avoid covering any part of the stethoscope diaphragm. This is to minimize any extraneous noise cause by the cuff rubbing against the diaphragm.
7. Wrap the cuff evenly and snugly around Subject's arm and allow the Velcro® to hold it in place. ❖ After it is snugly in place, you may wish to inflate the cuff slightly (10-20 mmHg) so that it will stay in place.	A loose cuff can give a false high reading because of the increased pressure required to occlude the brachial artery.
8. Make sure all the rubber tubing and cables of both the sphygmomanometer cuff and stethoscope are not tangled or pinched.	Any tubing on the sphygmomanometer that is pinched can cause false pressure reading and if the stethoscope tubing is pinched, it can greatly reduce the loudness of the Korotkoff sounds.

Basic measurement step	*Reason*
9. Position the sphygmomanometer pressure dial indicator such that you can read the face of the dial straight on. ❖ The dial indicator can be clipped to the strap sewn into the cuff above the "Artery" label.	Reading the dial at an angle can cause inaccurate readings due to parallax error.
Notes for the following steps: a) It is important to not inflate the cuff higher than is needed.	Besides causing pain for Subject, an overinflated cuff may produce a vasospasm, which can cause incorrect pressure readings.
b) It is important to not leave the cuff at a high pressure for an extended period of time.	Besides discomfort for Subject (which can elevate blood pressure,) occlusion of blood caused by the cuff creates venous congestion in the forearm. The blood must be allowed to drain or it can lead to incorrect pressure readings. For the same reason, it important to wait at least one (1) minute between successive blood pressure measurements.
Step we will use: 10. Palpate the brachial artery between the antecubital fossa and the lower edge of the cuff to find where the pulse is best felt. ❖ Use your first and second fingers to feel the pulsation of the brachial artery on the inside of your elbow. ❖ During the actual lesson, you can note this position by marking the spot with a washable felt pen.	The stethoscope diaphragm needs to be placed over the brachial artery where the Korotkoff sounds are best heard. This procedure can be a bit tricky so take note: The pulse is felt when the artery is compressed over bone or firm tissue. To feel the pulse, compress the artery firmly then ease up on the pressure slightly. After a few tries you should get the hang of it.
<u>*Alternate technique*</u>: 10. Inflate the cuff to 110 mmHg and place the stethoscope diaphragm over the brachial artery between the antecubital fossa and the lower edge of the cuff and move it around to find the place where the sounds are best heard.	This alternate procedure can result in optimal placement of the stethoscope diaphragm, but it can take longer to find. As noted above, it is not safe to inflate the cuff for a long period of time, so this technique is not used in the lesson because when you add the steps required to perform the recording, it simply takes too long.
Step we will use: 11. Inflate the cuff to 160 mmHg. ❖ Pump the cuff rapidly then release to reduce distal vasculatory engorgement. ❖ It is assumed that the majority of Subjects in the physiology lab will have systolic pressures below this pressure.	If cuff is not inflated high enough, true systolic pressure may be missed. This technique has the advantage of being quick and easy, and for reasons discussed above, it is preferable to minimize the amount of time the cuff is at high pressure. The disadvantage of this technique is that it uses more pressure than most Subjects probably need, and (in rare cases) it may miss the point of diastolic pressure. However, because a simultaneous recording will be per-formed, and time will be time spent reviewing the recording procedure, this is the best technique because it is fast.
<u>*Alternate technique*</u>: 11. Either by listening through the stethoscope, or by palpating the radial artery (on flexor surface of wrist,) inflate the cuff 20 to 30 mmHg above the point at which the sounds or pulse disappear.	This technique makes sure the cuff pressure does not go excessively high.
12. Place the stethoscope in the correct position. ➢ Do not push down excessively on it and try to maintain a constant pressure against the skin.	Excessive pressure could distort the artery and give incorrect pressure indications (usually gives a diastolic pressure reading that is too low). Also, excessive pressure can cause the stethoscope to rub on Subject's skin, which may generate extraneous noise.

Basic measurement step	*Reason*
13. Release the pressure at a rate of 2 to 3 mmHg/second.	Deflating too slowly produces venous congestion, which can give false high diastolic pressure readings. Deflating too rapidly leads to inaccuracies because the actual point of systolic or diastolic pressure could lie between heartbeats. The slower the heart rate, the more inaccurate the reading.
14. Note the pressure at which the Korotkoff sounds first appear (systolic).	This sound indicates the pressure closest to the **systolic pressure**.
15. Continue to listen and note the pressure when the sounds completely disappear (diastolic).	This pressure is close to the point of **diastolic pressure.** Note: The point at which the sounds become muffled is closer to the diastolic pressure but since it's easier to detect the disappearance of sound—and the difference between the two is small—we will use the point of disappearance of sound.
16. Deflate the cuff as rapidly as possible after all the sounds disappear.	This will minimize patient discomfort and reduce venous congestion.

When evaluating a patient or Subject, you will normally take blood pressure readings at different points in time and/or under different circumstances (at rest vs. after exercise, etc). to see how the blood pressure changes. With this in mind, it becomes important that your technique is consistent every time you do it. If two people use different techniques, they may get slightly different readings, but the difference (or delta)—which can be the more important factor—will be very consistent for each person.

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Indiana University School of Medicine
Purdue University School of Science

William McMullen
Vice President, BIOPAC Systems, Inc.

II. EXPERIMENTAL OBJECTIVES

1. To use an auscultatory method for an indirect determination of systemic arterial systolic and diastolic blood pressures and to correlate the appearance and disappearance of vascular sound with systolic and diastolic pressures respectively.
2. To measure, record, and compare systemic arterial blood pressure in the right arm and the left arm of the same Subject under identical conditions.
3. To compare the systemic arterial systolic and diastolic blood pressures detected audibly to those recorded by the stethoscope microphone.
4. To measure, record, and compare systemic arterial blood pressures in the same Subject under different experimental conditions of rest and exercise.
5. To compute and compare pulse pressure and mean arterial pressure under different experimental conditions of rest and exercise.
6. To compute the pulse pressure wave velocity by measuring the time between the R-wave of the ECG and the Korotkoff sounds.

III. MATERIALS

- BIOPAC Pressure Cuff (SS19L with gauge dial or SS19LA/LB with onscreen gauge display)
- BIOPAC Stethoscope (SS30L)
- BIOPAC Electrode Lead Set (SS2L)
- BIOPAC Disposable Electrodes (EL503,) 3 electrodes per Subject
- Rubbing alcohol and swab (to clean stethoscope earpieces and stethoscope diaphragm)
- *Optional*: felt pen (to mark stethoscope placement on arm)
- Biopac Student Lab System: BSL 4 software, MP36, MP35 or MP45 hardware
- Computer System (Windows or Mac)
- Stopwatch or watch/clock with a second hand.
- Fabric tape measure
- *Optional:* BIOPAC Headphones (OUT1/OUT1A for MP3X or 40HP for MP45)

IV. EXPERIMENTAL METHODS

A. SETUP

FAST TRACK Setup

CAUTION!
Subject selected must not have had or now have any disorder, hypertension, heart surgery, stroke, or any history of cardiovascular degeneration.

Subject should not have consumed caffeine, smoked, or performed heavy exercise within one hour of the recording.

1. Turn the computer **ON**.
   - If using an MP36/35 unit, turn it **OFF**.
   - If using an MP45, make sure USB cable is connected and "Ready" light is **ON**.

Setup continues…

Detailed Explanation of Setup Steps

Lab Group Requirements:

You should work in a group of at least 3 people. One person will be **Subject**, one (**Recorder**) will operate the computer, and another person (**Director**) will perform the blood pressure measurement.

Subject must meet the qualifications listed to the left.

Recorder is responsible for starting and stopping the recording, and adding markers to the recording. Only **Recorder** should look at the computer screen.

Director should perform the measurement normally, without regard to the recording aspect, but should call out the points of systolic and diastolic pressure so that **Recorder** can add the markers to the data recording.

2. **Plug the equipment in** as follows (Fig. 16.7):

   BP Cuff (**SS19L/LA/LB**) — **CH 1***
   Stethoscope (**SS30L**) — **CH 2**
   Electrode Lead Set (**SS2L**) — **CH 3** **

   _____

   If MP45 is used for recording:
   *The SS19L cuff must be used.
   (SS19LB/A not compatible with MP45.)
   ** ECG is not recorded

   OPTIONAL – BSL 4.0.2 and higher: Korotkoff sounds transmitted through the SS30L stethoscope may also be heard via headphone connection with the MP device. This can be useful when a second observer wishes to monitor the stethoscope output. (See page 8 for details.)

3. Turn **ON** the MP36/35 unit.
4. Select your lab group.

Fig. 16.7 MP3X (top) and MP45 (bottom) equipment connections

IF ECG is not used, proceed to Step 8.

5. Clean and abrade skin.
6. Attach three electrodes on the **Subject** as shown (Fig. 16.8).

ECG may or not be recorded depending on hardware used and/or lesson preference setting.

If the skin is oily, clean electrode sites with soap and water before abrading.

If electrode is dry, apply a drop of gel.

Remove any jewelry on or near the electrode sites.

Place one electrode on the medial surface of each leg, just above the ankle. Place the third electrode on the right anterior forearm at the wrist (same side of arm as the palm of hand).

For optimal electrode contact, place electrodes on skin at least 5 minutes before start of Calibration.

Fig. 16.8 Standard Electrode placement

Setup continues…

7. Clip the Electrode Lead Set (SS2L) to electrodes in a Lead II setup as shown, paying close attention to the lead colors (Fig. 16.9).
   - RIGHT forearm = WHITE lead
   - RIGHT leg = BLACK lead (ground)
   - LEFT leg = RED lead

Fig. 16.9 Standard electrode lead attachment

The pinch connectors work like a small clothespin, but will only latch onto the nipple of the electrode from one side of the connector.

8. **Subject** gets in a seated, relaxed, position.

Subject should sit with arms relaxed at side of body and hands apart in lap, with legs flexed at knee and feet supported.

Position the cables and leads such that they do not pull on the electrodes; connect the electrode cable clip to a convenient location on **Subject's** clothes. Arrange leads so **Subject's** arms can be easily raised.

Do not place pressure cuff on **Subject** until after calibration.

Fig. 16.10 Calibration positioning

Setup continues…

9. Clean the stethoscope earpieces and diaphragm.

Clean each earpiece with rubbing alcohol and allow it to dry completely. You should also clean the surface of the stethoscope diaphragm (the part that comes in contact with the skin) for each new **Subject**.

10. Open cuff valve, flatten and roll to remove <u>all</u> air and close valve.

The pressure release valve must be in the open (counter-clockwise) position to allow air to be released.

11. **Start** the Biopac Student Lab Program.

Start Biopac Student Lab by double-clicking the Desktop shortcut.

12. Choose lesson **"L16 – Blood Pressure"** and click **OK**.

13. Type in a unique **filename** and click **OK**.

A folder will be created using the filename. This same filename can be used in other lessons to place the **Subject's** data in a common folder.

14. Make sure the pressure cuff shown in the journal (Hardware tab) matches your setup. If it does not, change the "**Blood Pressure Cuff Type**" preference as described in Step 15.

The SS19L uses a mechanical pressure gauge and the SS19LA/LB uses an on-screen gauge.

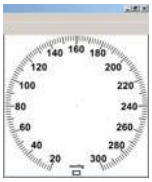
15. ***Optional*** Set Preferences.
    - Choose File > **Lesson Preferences**.
    - Select an option.
    - Select the desired setting and click **OK**.

This lesson has optional Preferences for data and display while recording. Per your Lab Instructor's guidelines, you may set:

Grids: Show or hide gridlines.

Blood Pressure Cuff Type: Select type of Blood Pressure Cuff Transducer.

Gauge Color*:
Choose blue or white background with contrasting dial



* *Only available when default SS19LA/LB Gauge Preference is selected*

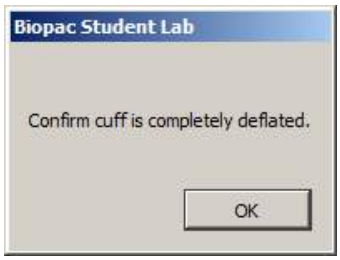
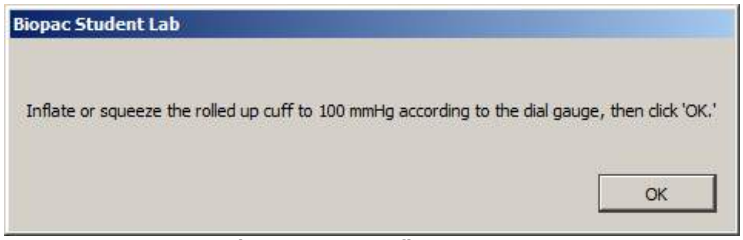
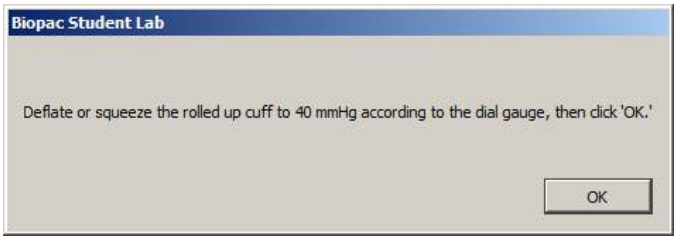
Lesson Recordings: Specific recordings may be omitted based on instructor's preferences.

ECG Lead II data: Set option to show or hide ECG Lead II channel.

END OF SETUP

B. CALIBRATION

Calibration establishes the hardware's internal parameters (such as gain, offset, and scaling) and is critical for optimal performance. **Pay close attention to Calibration**. (Click the **Calibration** tab to view example Calibration video.)

FAST TRACK Calibration	Detailed Explanation of Calibration Steps
Cuff is not on Subject **during calibration. Follow instructions for cuff type used.** (SS19LA/LB or SS19L)	**Calibration is only required once for multiple subjects.**
1. **Subject** is seated, relaxed and still. 2. Click **Calibrate**.	**Subject** must remain relaxed and as still throughout calibration to minimize baseline shift and EMG artifact.
If using SS19LA/LB • At the prompt, confirm cuff is completely deflated and click **OK**. • Continue to **Step 3**.	The SS19LA/LB cuff uses the on-screen pressure gauge.  **Fig. 16.11 SS19LA/LB prompt**
If using SS19L (with mechanical gauge) • At the first prompt, roll the cuff onto itself so the Velcro will prevent unrolling when inflated. • Inflate the cuff to 100 mmHg and click **OK**. *Alternate method:* Inflate the rolled cuff slightly, and then squeeze to obtain the desired calibration pressures. • At the second prompt, deflate cuff to 40 mmHg and click **OK**. • Continue to **Step 3**. **Calibration continues…**	The SS19L cuff uses the mechanical pressure gauge. Make sure the pressure release valve is closed (fully clockwise). Do not click **OK** until the pressure is stabilized at 100 mmHg.  **Fig. 16.12 SS19L first prompt**  **Fig. 16.13 SS19L second prompt** Slowly turn the pressure release valve counter-clockwise to deflate the cuff pressure to 40 mmHg, and then close the valve (fully clockwise). Do not click **OK** until the pressure is stabilized at 40 mmHg. **BSL 4.0.3 and earlier:** The calibration recording will begin after clicking **OK** in the second prompt (Fig. 16.13). **BSL 4.1 and later**: The calibration recording will begin after clicking **OK** in an additional "lightly tap the stethoscope" prompt (Fig 16.14).

3. **Director** lightly taps stethoscope diaphragm twice. (Prompt at right will appear in versions BSL 4.1 and later.)
4. Wait for Calibration to stop.
5. Verify recording resembles example data.
   - If similar, click **Continue** and proceed to Data Recording.

     NOTE*: The ECG channel may or not be displayed depending on hardware used and/or lesson preference setting.

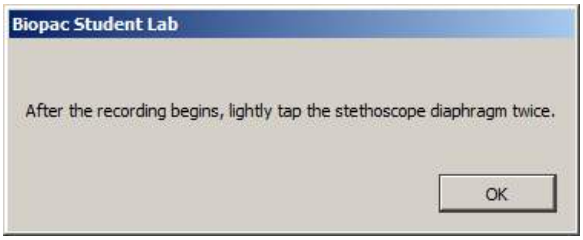


Fig. 16.14 Stethoscope prompt (BSL 4.1 and later)

Calibration will stop automatically after 8 seconds.

The pressure data will be a flatline at either 0 (SS19LA/LB) or 40 mmHg (SS19L). The stethoscope data must show clear spikes to indicate when it was tapped. If ECG is displayed*, it should be a recognizable ECG waveform with baseline at or near 0 mV, no large baseline drift and no significant EMG artifact.

Fig. 16.15 Example Calibration Data

If recording does not resemble the Example Data…

- If data is noisy or flatline, check all connections to MP unit.
- If indicated Pressure is less than 0 mmHg, redo calibration and follow the steps precisely.
- If the ECG displays baseline drift or excessive EMG artifact:
  - Verify all electrodes are making good contact with the skin and that the leads are not pulling on the electrodes.
  - Make sure the **Subject** is in a relaxed position. (Fig. 16.10)

- If necessary, click **Redo Calibration**.

Click **Redo Calibration** and repeat Steps 2 – 5 if necessary.

END OF CALIBRATION

PRACTICE PRESSURE RELEASE

To obtain accurate measurements, it is important that the cuff pressure is released at a rate of 2 – 3 mmHg per second. You are encouraged to practice pressure release several times before proceeding to the recording. To practice, you'll need a watch or clock with a second hand. The following steps will help you develop a consistent pressure release technique:

a) Open the cuff valve and roll the cuff in on itself, then press to flatten and close the valve.
   - This will release all pressure from the cuff.

b) Pump the cuff bulb until the pressure dial reads 160 mmHg.

c) Tell the timer when you are ready, and slowly turn the valve counter-clockwise to begin releasing the cuff pressure.
   - Open the valve slowly so that you don't have a large pressure drop, and try to maintain an even release.
   - To keep the release rate constant, you may need to open the valve more as the cuff pressure diminishes.

d) When pressure is at 100 mmHg, say "Stop" and ask the timer how much time elapsed.
   - It should take you about 20 – 30 seconds to drop 60 mmHg.

e) Repeat as necessary until you can release cuff pressure at 2 – 3 mmHg per second.

C. DATA RECORDING

FAST TRACK Recording

1. Prepare for the recording.

> **CAUTION!**
> Do not inflate the cuff higher than is needed. Never leave the cuff on the **Subject** at high pressure (more than 120 mmHg) for more than 1 minute.

2. Make sure all air is expelled from cuff and close the pressure release valve.
3. Locate the brachial artery on <u>each arm</u> and mark the stethoscope position with a felt pen.
4. **Review** Cuff placement and positioning:
   - "Artery" label should be positioned over the brachial artery (with the arrow on the label facing down).
   - Lower edge of cuff should be 40 – 50 mm (1.5 – 2 inches) above the antecubital fossa (inner aspect of elbow).
   - Wrap the cuff evenly and snugly on **Subject's** arm.
   - When in the seated position, the arm must rest at heart level; use books or a pillow to raise arm if necessary (Fig. 16.17).
   - Find a position that is comfortable for **Director** and Subject (Fig. 16.17).
   - Place stethoscope diaphragm over brachial artery, with firm pressure.

Detailed Explanation of Recording Steps

Seven data recordings will be acquired*:

Recording 1 – 2: Left arm, seated.
Recording 3 – 4: Right arm, seated.
Recording 5 – 6: Right arm, supine.
Recording 7: Right arm, seated, after exercise.

***IMPORTANT**
This procedure assumes that all lesson recordings are enabled in lesson Preferences, which may not be the case for your lab. Always match the recording title to the recording reference in the journal and disregard any references to excluded recordings.

Hints for obtaining optimal data:

- **Subject** should relax for a few minutes before each recording begins.
- **Director** must be positioned to easily inflate cuff while viewing the pressure dial indicator.
- For greater stethoscope comfort, twist the earpieces slightly forward before inserting.
- Room must be quiet in order to easily hear sounds through stethoscope.
- To minimize EMG artifact and baseline drift:
  - **Subject's** arms and legs must be relaxed.
  - **Subject** must remain still and should not talk during any recordings.
  - Make sure electrodes do not peel up and that the leads do not pull on the electrodes.

Turn the release valve fully counter-clockwise and roll the cuff up while squeezing it. Turn the pressure release valve fully clockwise.

Use your first (index) and second (middle) fingers to feel the pulsation of the brachial artery on the inside of the elbow. This can be tricky, but after a few tries you should get the hang of it. It may help if **Subject** makes a fist while you are trying to locate the pulse.

Once you have located the pulse, mark the spot by tracing along the edge of the top and bottom of the stethoscope diaphragm.

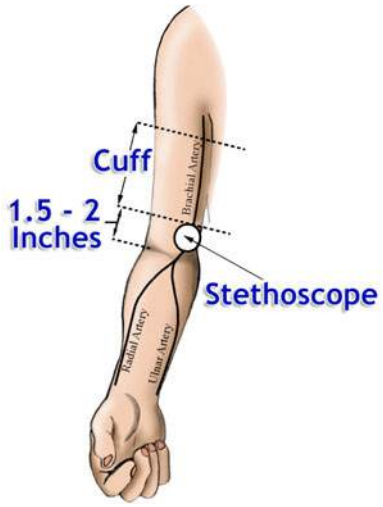


Fig. 16.16 Cuff and stethoscope placement

The cuff edge should be high enough to avoid covering any part of the stethoscope diaphragm.
The Velcro® wrap should hold the cuff in place.
Make sure rubber tubing and cables do not become tangled or pinched.
Exert enough pressure on stethoscope diaphragm to establish good contact, but do not press too hard.

Recording continues…

- **Director** should hold the pump bulb with both fingers on the release valve so it can be easily turned.

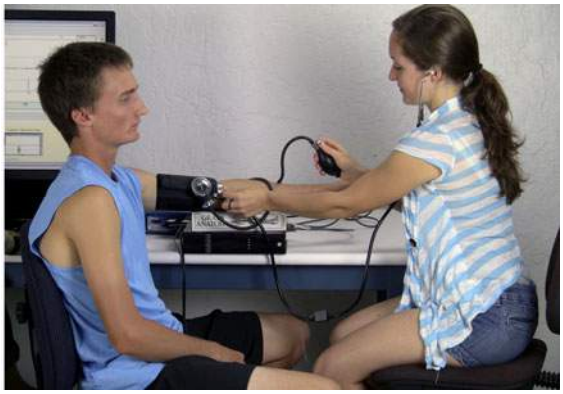


Fig. 16.17 Subject and Director Positioning

- For greater Stethoscope comfort, rotate the ear tubes slightly forward (Fig. 16.18).

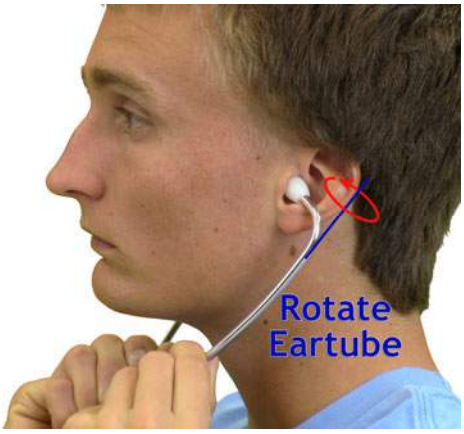


Fig. 16.18 Rotate ear tube for comfort

OPTIONAL – BSL 4.0.2 and higher: Korotkoff sounds from the SS30L stethoscope may also be heard via the following MP headphone connections:

- OUT1 headphones into Analog Out (MP35).
- OUT1 headphones into Analog Out or OUT1A into the headphone output jack (MP36).
- 40HP headphones into the headphone output jack (MP45).

This can be useful when a second observer wishes to monitor the stethoscope output.

To enable or mute headphone output, toggle the "Headphones ON/Headphones OFF" buttons while data recording is in progress.

CAUTION:
Cuff pressure release sounds may be very loud through the headphones. It's advisable to toggle "Headphones OFF" prior to pressure release. Then toggle back ON during the next data recording.

Recording continues…

Problems you may encounter:

a) **You can't hear the Korotkoff sounds**.

Some **Subjects** may not produce loud enough Korotkoff sounds. This does not mean that anything is wrong with the person's physical state. If this is the case, wait one minute and repeat the measurement using a slightly different position for the stethoscope diaphragm and/or using the other arm.

Another possibility is that your hearing is not acute enough to detect the sounds, but the recording is picking them up, which for the purposes of this lesson is ok. In a real clinical setting, if you could not hear the sounds, you would need to try a strictly palpatory method to get the reading. For this lab, since you probably have a time constraint, consider changing **Subjects**.

b) **You hear an auscultatory gap**.

Wait at least 1 minute, and then try the measurement again. If this second reading fails, then use the palpatory method with the brachial or radial artery while inflating the cuff and note the point where the pulse is no longer felt. This value will be **Subject's** approximate systolic pressure value. The diastolic value should be found the normal way (disappearance of all sounds). The recording will not be accurate, but it will allow you to finish the lessons and answer the questions.

Left arm, Seated 1

5. Prepare for Recording:
   - **Subject** is seated, relaxed and still.
   - Left arm is positioned at heart level.
   - Cuff and stethoscope are placed on left arm following guidelines in Step 4.
   - **Review** recording steps.

6. Inflate cuff to 160 mmHg.

The majority of **Subjects** in the physiology lab will have systolic pressures below this pressure.

Note that the gauge display (when using SS19LA/LB) may respond slowly.

7. Click **Record**.

Upon start of the first recording, a confirmation prompt will appear. Click OK to proceed.

CAUTION!
Do not leave the cuff at this pressure for more than 1 minute.

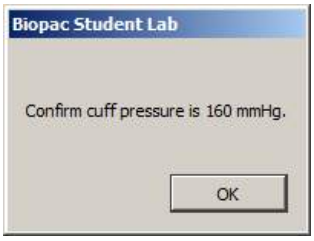


Fig. 16.19 Confirmation prompt

If Korotkoff Sounds appear at the *start* of the recording, click **Suspend**, **Redo**, inflate cuff to 180 mmHg.

8. Release pressure at a constant rate of 2 to 3 mmHg/second.

The first sound (which may resemble a sharp tapping) indicates the pressure closest to the **systolic pressure**.

9. **Director** announces when Korotkoff sounds first appear **(systolic).**
   - **Recorder** presses **F4 = ∇ Systolic**

10. **Director** continues listening, and announces when sounds disappear completely **(diastolic).**
    - **Recorder** presses **F5 = ∇ Diastolic**

This pressure is close to the point of **diastolic pressure**.

- If sound diminishes but never disappears, note diastolic at the point sound diminishes.

11. Wait an additional five seconds, and then click **Suspend**.

Waiting an additional five seconds will allow the stethoscope microphone to pick up any final Korotkoff sounds that may be inaudible to **Director.**

12. Deflate cuff as rapidly and completely as possible.

When the cuff is deflated rapidly, the stethoscope will pick up significant noise artifact. Try to click Suspend before deflating the cuff.

Release cuff pressure rapidly to reduce distal vasculatory engorgement (reduce venous congestion) and minimize patient discomfort.

13. Verify recording resembles the example data.
    - If similar, click **Continue** and proceed to the next recording.
    - If necessary, click **Redo**.
    - If all required recordings have been completed, click **Done**.

The pressure data should decline linearly, at approximately 2 – 3 mmHg/sec. To verify:

- Select one second of data (Delta T) and note Delta measurement for rate of pressure release.

The Korotkoff sounds (data “spikes”) should be visible in the Stethoscope data and there should be minimal noise artifact. IF ECG is displayed, the waveform should show little baseline drift or EMG artifact. Both event markers should be present (use horizontal scroll bar to search all data).

Recording continues…

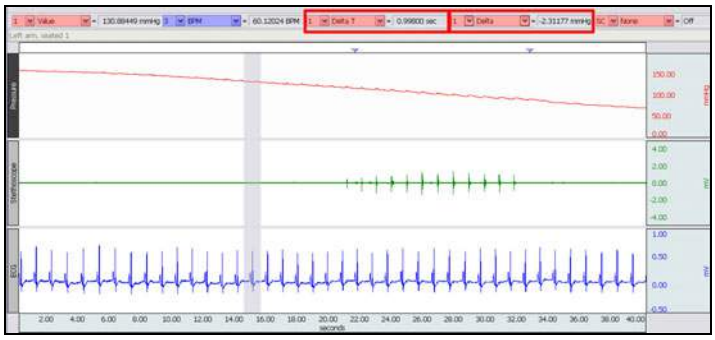


Fig. 16.20 Example data

If recording does not resemble the Example Data…

- If data is noisy or flatline, check all connections to MP unit.
- If the cuff pressure was released before clicking Suspend, the stethoscope data will include noise artifact from the rapidly deflating cuff – this is normal.
- If event markers are missing, redo and remind Recorder to press F4 and F5 at the appropriate times.
- If the Korotkoff sounds are not present, make certain the diaphragm is properly located over brachial artery and try applying more pressure.
- If there is too much noise artifact in the stethoscope data, make sure to hold the stethoscope with constant pressure and to minimize movement of the Subject's arm, the cuff, the tubing and the stethoscope.
- If the ECG baseline is not stable, or there is excessive EMG artifact, verify electrodes are making good contact and that the leads are not pulling on the electrodes.

If necessary, click **Redo** to repeat the last recording. Note that once **Redo** is clicked, the most recent recording will be erased.

Left arm, seated 2

14. Repeat Steps 6 through 12.

The **Subject's** arm should rest for a few minutes after the first recording (with no cuff pressure).

15. Verify recording resembles the example data.
    - If similar to Fig. 16.20, click **Continue** and proceed to the next recording.
    - If necessary, click **Redo**.
    - If all required recordings have been completed, click **Done**.

Data requirements are the same as described in Step 13.

If necessary, click **Redo** and repeat the last recording.

Note that when **Redo** is clicked, the most recent recording will be erased.

Recording continues…

Right arm, seated 1

16. **Subject** remains seated and relaxed, with cuff attached to right arm.
    - Right arm is positioned at heart level.
    - Cuff and stethoscope are placed on right arm following guidelines in Step 4.
17. Repeat Steps 6 through 12.
18. Verify recording resembles the example data.
    - If similar to Fig. 16.20, click **Continue** and proceed to the next recording.
    - If necessary, click **Redo**.
    - If all required recordings have been completed, click **Done**.

Data requirements are the same as described in Step 13.

If necessary, click **Redo** and repeat the last recording.

Note that when **Redo** is clicked, the most recent recording will be erased.

Right arm, Seated 2

19. Repeat Steps 6 through 12.

The **Subject's** arm should rest for a few minutes after the first recording (with no cuff pressure).

20. Verify recording resembles the example data.
    - If similar to Fig. 16.20, click Continue and proceed to the next recording.
    - If necessary, click **Redo**.
    - If all required recordings have been completed, click **Done**.

Data requirements are the same as described in Step 13.

If necessary, click **Redo** and repeat the last recording.

Note that when **Redo** is clicked, the most recent recording will be erased.

Right arm, Supine 1

21. **Subject** is Supine (lying down, face up) and relaxed with cuff attached to right arm.
    - Right arm is positioned at heart level.
    - Verify cuff and stethoscope placement as described in Step 4.
22. Repeat Steps 6 through 12.

Fig. 16.21 Supine positioning (SS19LA/LB Shown)

Recording continues…

23. Verify recording resembles example data.
    - If similar to Fig. 16.20, click **Continue** and proceed to the next recording.
    - If necessary, click **Redo**.
    - If all required recordings have been completed, click **Done**.

Data requirements are the same as described in Step 13.

If necessary, click **Redo** and repeat the last recording.

Note that when **Redo** is clicked, the most recent recording will be erased.

Right arm, Supine 2

24. Repeat Steps 6 through 12.

The **Subject's** arm should rest for a few minutes after the first recording (with no cuff pressure).

25. Verify recording resembles the example data.
    - If similar to Fig. 16.20, click **Continue** and proceed to the next recording.
    - If necessary, click **Redo**.
    - If all required recordings have been completed, click **Done**.

Data requirements are the same as described in Step 13.

If necessary, click **Redo** and repeat the last recording. Note that when **Redo** is clicked, the most recent recording will be erased.

Right arm, after exercise

26. Unclip leads and remove cuff to allow **Subject** to perform moderate exercise to elevate heart rate.

Confirm that **Subject** has no history of disorders and meets the requirements listed to the left before performing any exercise.

> **CAUTION**!
> **Subject** selected must not have had or now have any disorder, hypertension, heart surgery, stroke, or any history of cardiovascular degeneration.
> **Subject** must not have consumed caffeine, smoked, or performed heavy exercise within one hour of the recording.

Subject does 50 push-ups or runs in place for 5-minutes to elevate heart rate to a moderate level.

27. After exercise, **Subject** sits down to recover.
28. Reattach leads and attach cuff to **Subject's** right arm.
    - Right arm is positioned at heart level.
    - Verify cuff and stethoscope placement as described in Step 4.
29. Inflate cuff to **180** mmHg.

The starting cuff pressure is higher than in previous recordings.

30. Repeat Steps 6 through 12.
31. Verify recording resembles the example data.
    - If similar to Fig. 16.20, click **Continue** to proceed to optional recording section, or **Done** to finish the lesson.
    - If necessary, click **Redo**.

Data requirements are the same as described in Step 13.

If necessary, click **Redo** and repeat the last recording.
Note that when **Redo** is clicked, the most recent recording will be erased.

Recording continues…

OPTIONAL ACTIVE LEARNING PORTION

With this lesson you may record additional data by clicking **Continue** following the last recording. Design an experiment to test or verify a scientific principle(s) related to topics covered in this lesson. Although you are limited to this lesson's channel assignments, the electrodes or transducers may be moved to different locations on the subject.

Design Your Experiment

Use a separate sheet to detail your experiment design, and be sure to address these main points:

A. ***Hypothesis***

Describe the scientific principle to be tested or verified.

B. ***Materials***

List the materials you will use to complete your investigation.

C. ***Method***

Describe the experimental procedure—be sure to number each step to make it easy to follow during recording.

Run Your Experiment

D. ***Set Up***

Set up the equipment and prepare the subject for your experiment.

E. ***Record***

Use the **Continue**, **Record**, and **Suspend** buttons to record as much data as necessary for your experiment.

Click **Done** when you have completed all of the recordings required for your experiment.

Analyze Your Experiment

F. Set measurements relevant to your experiment and record the results in a Data Report.

32. After clicking **Done**, choose an option and click **OK**.

If choosing the **Record from another Subject** option: Repeat Setup Steps 4 – 9 then proceed directly to Recording (re-calibration not required*).

33. Remove the Pressure cuff and electrodes.

Note*: If Recalibration is desired, Quit then re-launch the application.

If ECG was recorded, remove the electrode cable pinch connectors and peel off all electrodes. Discard the electrodes. (BIOPAC electrodes are not reusable.) Wash the electrode gel residue from the skin, using soap and water. The electrodes may leave a slight ring on the skin for a few hours which is quite normal.

END OF RECORDING

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Indiana University School of Medicine
Purdue University School of Science

William McMullen
Vice President, BIOPAC Systems, Inc.

V. DATA ANALYSIS

FAST TRACK Data Analysis

1. Enter the **Review Saved Data** mode and choose the correct file.
   - Note Channel Number (CH) designations:

Channel	*Displays*	*Units*
CH 1	Pressure	mmHg
CH 2	Stethoscope	mV
CH 3*	ECG Lead II	mV

*ECG may not have been recorded.

   - Note measurement box settings:

Channel	*Measurement*
CH 1	**Value**
CH 3	**BPM**
CH 1	**Delta T**

2. Setup your display window for optimal viewing of the first recording.

3. Use the **I-Beam** cursor to select the point at the first event marker and record the pressure (CH 1 – Value).

   A

Data analysis continues…

Detailed Explanation of Data Analysis Steps

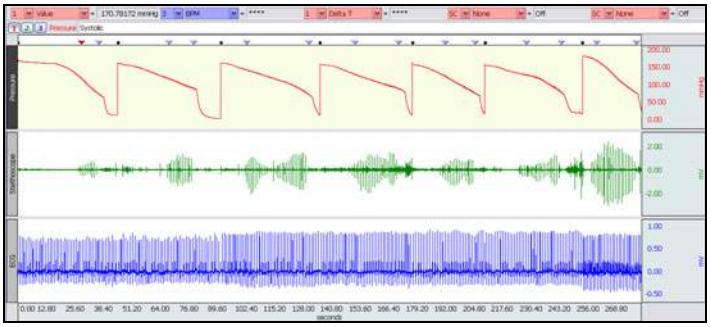

Fig. 16.22 Example Data

The measurement boxes are above the marker region in the data window. Each measurement has three sections: channel number, measurement type, and result. The first two sections are pull-down menus that are activated when you click them.

Brief definition of measurements:

Value: Displays the amplitude value for the channel at the point selected by the I-beam cursor. If a single point is selected, the value is for that point, if an area is selected, the value is the endpoint of the selected area.

BPM: **B**eats **P**er **M**inute first calculates the difference in time between the end and beginning of the area selected by the I-Beam tool (same as Delta T,) and then divides this value into 60 seconds/minute.

Delta T: Measures the difference in time between the end and beginning of the selected area.

The "selected area" is the area selected by the I-Beam tool (including endpoints).

Note: The append event markers mark the beginning of each recording. Click on (activate) the event marker to display its label.

Useful tools for changing view:

Display menu: Autoscale Horizontal, Autoscale Waveforms, Zoom Back, Zoom Forward

Scroll Bars: Time (Horizontal); Amplitude (Vertical)

Cursor Tools: Zoom Tool

Buttons: Overlap, Split, Show Grid, Hide Grid, -, +

Hide/Show Channel: "Alt + click" (Windows) or "Option + click" (Mac) the channel number box to toggle channel display.

This is the Systolic pressure that was audibly detected; event marker manually inserted.

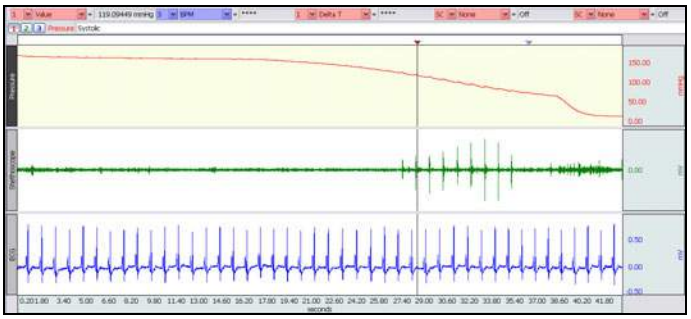

Fig. 16.23 Point of audibly detected Systolic pressure

Note: In the figure, the **Value** measurement represents cuff pressure at the selected point and the **BPM** measurement is not giving an accurate reading because only one point is selected with the I-beam cursor.

4. Select the point that corresponds to the first Korotkoff sound the stethoscope detected and record the pressure.

   A

This is the Systolic pressure that was detected by the stethoscope.

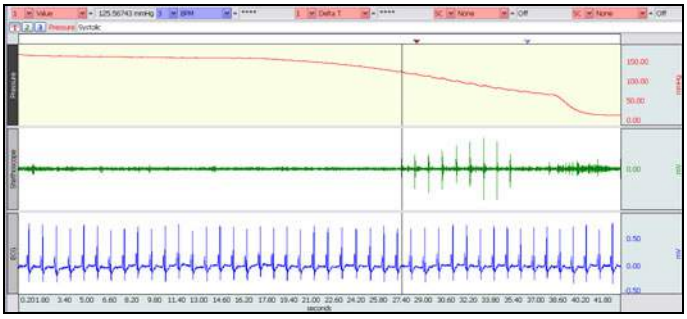

Fig. 16.24 Point of first Korotkoff sound

IF ECG is recorded: To help distinguish a Korotkoff sound from noise artifact, note that the sound normally appears near the time of the ECG T-wave. If needed, zoom in the data to see the details.

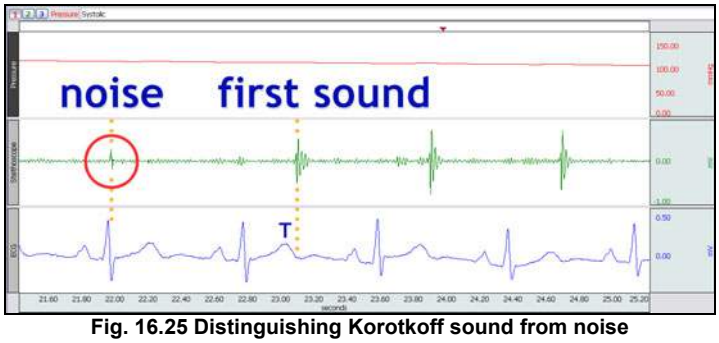

Fig. 16.25 Distinguishing Korotkoff sound from noise

5. Select the point that corresponds to the second event marker and record the pressure.

   B

This is the Diastolic pressure that was audibly detected.

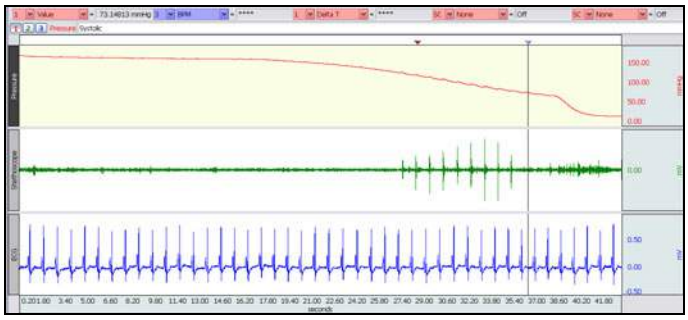

Fig. 16.26 Point of audibly detected Diastolic pressure

Data Analysis continues…

6. Select the point that corresponds to the last Korotkoff sound the stethoscope detected and record the pressure.

   B

This is the Diastolic pressure that was detected by the stethoscope.

As in Step 4, the ECG – T wave can be used to distinguish a Korotkoff sound from noise artifact.

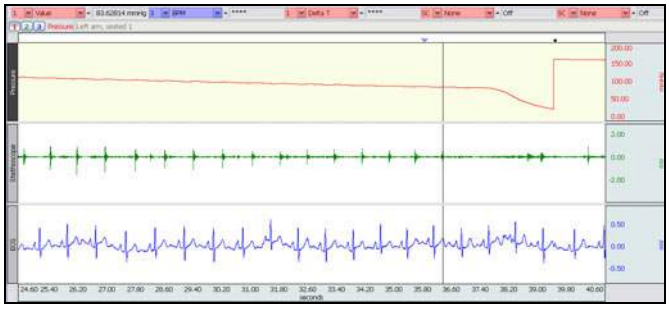

Fig. 16.27 Last sound detected by stethoscope

7. Measure BPM.
   - Using ECG signal:

     In the region between Systolic and Diastolic pressure, select one R-R interval and record the BPM measurement (Fig. 16.28).

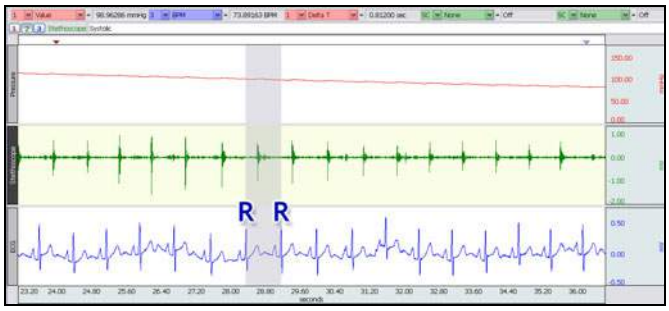

Fig. 16.28 One R-R interval selected

   - Using Korotkoff sounds:

     If ECG was not recorded, select the area between two successive Korotkoff sound peaks and record the BPM measurement (Fig. 16.29).

     C

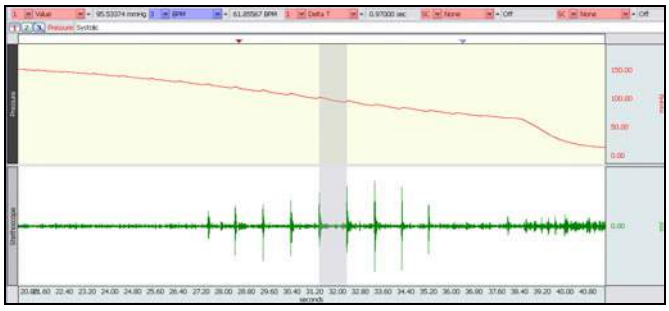

Fig. 16.29 Sound interval selection approximates R-to-R interval

Repeat this measurement on two successive R-waves (or sound peaks).

C

BPM changes on a beat-by-beat cycle, so for more accurate measurement you should take BPM (R-R) measurements on 3 successive R-waves and find the average BPM.

TIP: You may hide CH 1 (Pressure) to make it easier to see the other channels. (Alt + click on PC, option + click on Mac.)

8. *If ECG was not recorded skip to Step 9.* Zoom in on one of the ECG complexes in the time between systolic and diastolic pressure.
9. Using the I-beam cursor, select the area from the peak of the R-wave to the beginning of the sound detected by the stethoscope.

   Note the Delta T measurement.

   E

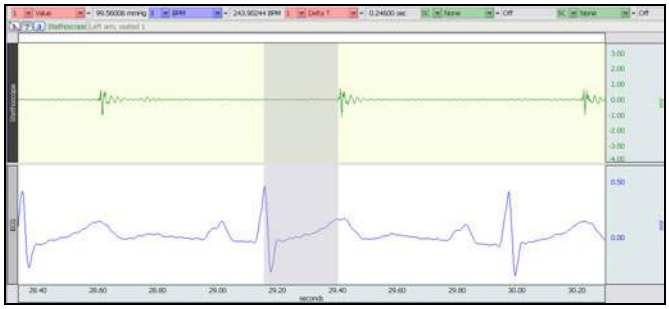

Fig. 16.30 Timing of Korotkoff Sounds

Data Analysis continues…

10. Repeat Steps 3 – 8 for each recording to complete the Data Report.
11. Perform measurements and calculations for Pulse Speed per Table 16.7.
12. Answer the questions at the end of the Data Report.
13. **Save** or **Print** the data file.
14. **Quit** the program.

END OF DATA ANALYSIS

This lesson acquired seven recordings (unless modified for your lab session). Recordings are identified by their append event markers.

An electronically editable **Data Report** is located in the journal (following the lesson summary,) or immediately following this Data Analysis section. Your instructor will recommend the preferred format for your lab.

END OF LESSON 16

Complete the Lesson 16 Data Report that follows.

BLOOD PRESSURE

- *Indirect measurement*
- *Ventricular Systole & Diastole*
- *Korotkoff sounds*
- *Mean Arterial pressure*

DATA REPORT

Student's Name: _____

Lab Section: _____

Date: _____

I. Data and Calculations

Subject Profile

Name:_____ Height:_____

Age:_____ Time: _____ Gender: Male / Female Weight:_____

A. Systolic Measurements

Complete Table 16.2 with the systolic measurements for all data recordings. Note the pressure measurement at the event marker insertion point (where Director audibly detected and marked systolic) and where the first Korotkoff sound was detected with the stethoscope microphone. Calculate the Delta difference (Δ) between the trials for each condition, the trial average pressure, and the Delta difference between the event marker and stethoscope microphone average pressure measurements.

Table 16.2 Systolic Data

Systolic Pressure mmHg 1 Value						
Condition	**Trial**	**Audibly Detected Pressure (Event marker)**	**Average Pressure (Calculate) A**	**Microphone Detected Pressure (In data, unmarked)**	**Average Pressure (Calculate) B**	**Δ Average Pressure B minus Average Pressure A**
Left arm, seated	1					
	2					
	Δ					
Right arm, seated	1					
	2					
	Δ					
Right arm, lying down	1					
	2					
	Δ					
Right arm, after exercise*	1					

*For 'Right arm, after exercise' recording, calculate the Delta difference between the 'Audibly Detected Pressure' and the 'Microphone Detected Pressure' values, and record the result in the right column.

B. Diastolic Measurements

Complete Table 16.3 with the diastolic measurements for all data recordings. Note the pressure measurement at the event marker insertion point (where Director audibly detected and marked diastolic) and where the sound disappeared from the stethoscope microphone. Calculate the Delta difference (Δ) between the trials for each condition, the trial average pressure, and the Delta difference between the event marker and stethoscope microphone average pressure measurements.

Table 16.3 Diastolic Data

Diastolic Pressure mmHg 1 Value						
Condition	**Trial**	**Audibly Detected Pressure (Event marker)**	**Average Pressure (Calculate) A**	**Microphone Detected Pressure (In data, unmarked)**	**Average Pressure (Calculate) B**	**Δ Average Pressure B minus Average Pressure A**
Left arm, seated	1					
	2					
	Δ					
Right arm, seated	1					
	2					
	Δ					
Right arm, lying down	1					
	2					
	Δ					
Right arm, after exercise*	1					
*For 'Right arm, after exercise' recording, calculate the Delta difference between the 'Audibly Detected Pressure' and the 'Microphone Detected Pressure' values, and record the result in the right column.						

C. BPM Measurements

Complete Table 16.4 with the BPM measurements from three cycles of each data recording and calculate the mean BPM for each.

* **Cycle** measurements: If ECG was recorded, use 3 BPM; if ECG was not recorded, use 1 BPM.

Table 16.4 BPM

Condition	**Trial**	**Cycle***			**Calculate the Mean**	
		1	**2**	**3**	of Cycles 1 – 3	of Trial 1 – 2 means
Left arm, seated	1					
	2					
Right arm, seated	1					
	2					
Right arm, lying down	1					
	2					
Right arm, after exercise	1					

D. Summary of Mean Blood Pressure Data

Complete Table 16.5 with the average from sound data from tables 16.2 and 16.3 and then calculate the pulse pressure and the mean Arterial Pressure (MAP). Note the pressure measurements at the event marker insertion points (where Director audibly detected and marked systolic and diastolic).

Pulse pressure = Systolic pressure – Diastolic pressure

$$\text{MAP} = \frac{\text{pulse pressure}}{3} + \text{diastolic pressure} \qquad \textit{OR} \qquad \text{MAP} = \frac{(\text{systolic pressure} + 2\,\text{diastolic pressure})}{3}$$

Table 16.5 Average Systolic Pressure/Average Diastolic Pressure

CONDITION	SYSTOLE Table 16.2 Sound Average	DIASTOLE Table 16.3 Sound Average	BPM Table 16.4	Calculations: Pulse pressure	MAP
Left arm, seated					
Right arm, seated					
Right arm, lying down					
Right arm, after exercise					

E. **Timing of Korotkoff Sounds** NOTE: This table requires ECG data, which is not recorded on MP45 systems.
Complete Table 16.6 with the Delta T for each condition, and calculate the means.

Table 16.6

Condition	Trial	Timing of Sounds 1 Delta T	Mean (calc)
Left arm, seated	1		
	2		
Right arm, seated	1		
	2		
Right arm, lying down	1		
	2		
Right arm, after exercise	1		

F. **Calculation of Pulse Speed**
Complete the calculation in Table 16.7 using "Right arm, seated" data.

Table 16.7

Distance	Distance between Subject's sternum and right shoulder	cm
	Distance between Subject's right shoulder and antecubital fossa	cm
	Total distance	cm
Time	Time between R-wave and first Korotkoff sound	secs
Speed	Speed = distance/time = _____cm / _____sec	cm/sec

II. Questions:

1. Note the difference in systolic pressure value between when (a) the sound actually began, (b) was detected by the stethoscope transducer, and (c) was recorded, and the time when the observer first heard the sound and pressed the event marker keystroke. (Example: 141 mmHg – 135 mmHg = 6 mmHg.) What factors could account for this difference? Would the observed difference be the same if measured by another observer? Explain your answer.

_____

_____

_____

2. a) Does your systolic and/or diastolic arterial pressure change as your heart rate increases?

_____

_____

_____

b) How does this change affect your pulse pressure?

c) How would you expect the systolic, diastolic and pulse pressures to change in a normal healthy individual as the heart rate increases?

3. Give three sources of error in the indirect method of determining systemic arterial blood pressure.

4. Use an equation that relates flow, pressure, and resistance to define mean arterial pressure:

5. Blood flow (liters per min). through the pulmonary circuit equals blood flow through the systemic circuit, but pulmonary resistance to flow is 5 times less than the systemic resistance to flow. Using the equation in Question 4, show that mean pulmonary pressure is 5 times less than mean systemic pressure.

6. Define the first and second sounds of **Korotkoff**. Which sound is used to approximate systolic pressure and which sound is used to approximate diastolic pressure?

7. Why is mean arterial pressure not equal to (systolic pressure – diastolic pressure)/2?

8. Define **pulse pressure**. Explain, in terms of changes in systolic and diastolic pressures, why pulse pressure increases during exercise.

9. Give one reason why blood pressure in the left arm may be different than blood pressure in the right arm of a Subject at rest.

_____

_____

_____

10. Name an artery other than the brachial that could be used for an indirect measurement of blood pressure and explain your choice.

_____

_____

_____

III. OPTIONAL Active Learning Portion

A. ***Hypothesis***

B. ***Materials***

C. ***Method***

D. ***Set Up***

E. ***Experimental Results***

End of Lesson 16 Data Report

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Biopac Student Lab® Lesson 17

HEART SOUNDS
Introduction

Rev. 01152013

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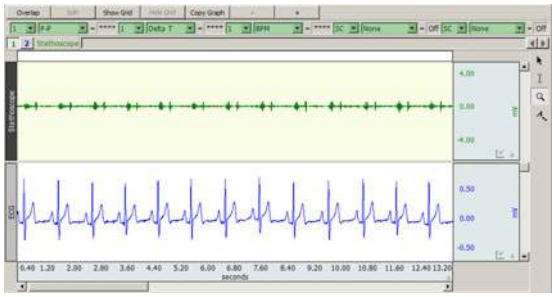
Purdue University School of Science

William McMullen
Vice President, BIOPAC Systems, Inc.



I. INTRODUCTION

In this lesson you will record sounds of the cardiac cycle, producing a record called a phonocardiogram, while simultaneously recording Lead II electrocardiogram. You will compare and correlate electrical events of the cardiac cycle to mechanical events of the cardiac cycle.

The human cardiovascular system consists ofs the heart and blood vessels arranged to form a double circulation: the systemic circulation and the pulmonary circulation. The circulatory pattern resembles a figure 8 with the heart located at the center (Fig. 17.1). The primary function of the heart is to receive blood from the pulmonary veins and pump it into the systemic arteries, and to receive blood from the systemic veins and pump it into the pulmonary arteries. The sequence of electrical and mechanical events of the heart associated with receiving blood from the venous systems and pumping it out into the arterial systems during one heartbeat is known as the **cardiac cycle**.

A simplistic mechanical analogy of the heart is that of a double-pump. The left and right sides are separate, but pump in unison to move blood through the heart.

The normal flow of blood through the heart and blood vessels is unidirectional, and is as follows:

> **left ventricle** - systemic arterial vessels - systemic capillaries - systemic venous vessels - **right atrium - right ventricle** - pulmonary arterial vessels - pulmonary capillaries - pulmonary venous vessels - **left atrium - left ventricle**.

Blood flowing through the left side of the heart is kept separate from blood flowing through the right side of the heart by the septa (walls) between the atria and between the ventricles.

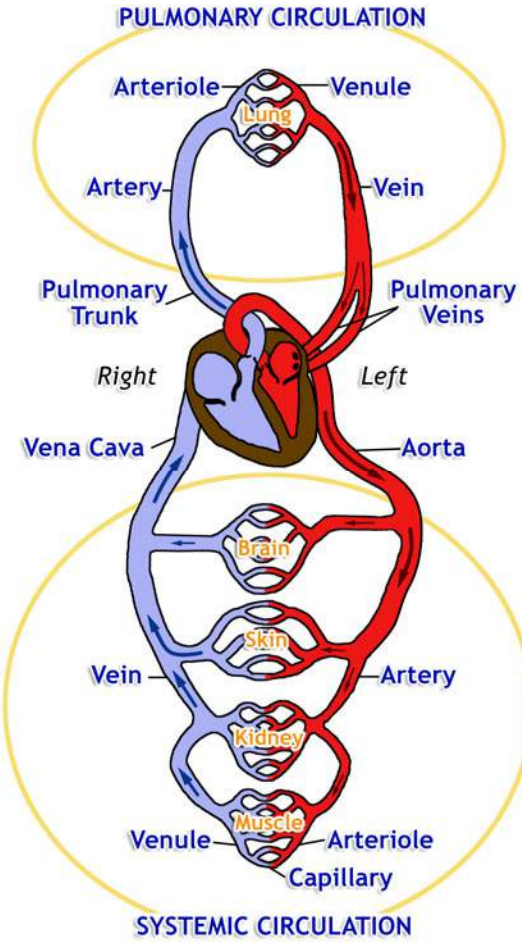


Fig. 17.1 Circulatory Pattern

The unidirectional flow of blood through the chambers on each side of the heart is ensured by an **atrioventricular valve** and a **semilunar valve** (Fig. 17.2).
On the left side of the heart the atrioventricular valve is called the *mitral valve*, and the semilunar valve is called the *aortic valve*.
On the right side of the heart the atrioventricular valve is called the *tricuspid valve*, and the semilunar valve is called the *pulmonary valve*.
The atrioventricular valve opens into the ventricle, allowing blood to flow from the atrium into the ventricle but not in the reverse direction (retrograde flow). The valve is open when ventricular pressure is less than atrial pressure, thereby allowing the ventricle to fill with blood. The valve is closed when ventricular pressure is greater than atrial pressure, thereby preventing the backward flow of blood.

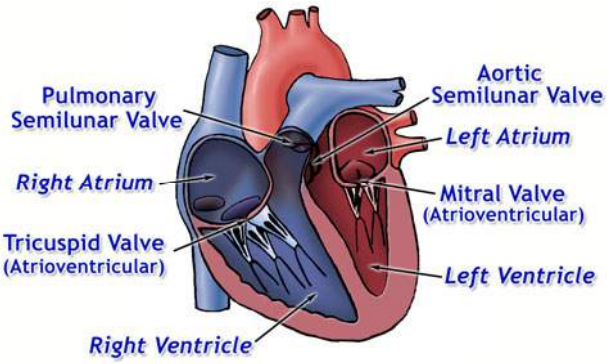


Fig. 17.2 Heart valves

The semilunar valve opens into the artery (pulmonary trunk or aorta) allowing blood to flow out from the ventricle when ventricular pressure is greater than pressure in the artery. The valve is closed when ventricular pressure is less than arterial pressure, thereby preventing the backward flow of blood. During the cardiac cycle, the semilunar valves (pulmonary and aortic) open and close in unison, as do the atrioventricular valves (tricuspid and mitral). This is the “double-pump” action of the heart.

Four major heart sounds are associated with the opening and closing of the valves and the flow of blood within the heart during the cardiac cycle. These sounds may be heard by placing a stethoscope in the corresponding position on the anterior surface of the chest over the heart.

1. The **first heart sound** occurs during ventricular systole (contraction of ventricular muscle) and is caused by closure of the atrioventricular valves and opening of the semilunar valves. This sound is the “lub” of the characteristic “lub-dub” that can be heard with each heartbeat.
2. The **second heart sound** occurs during ventricular diastole (relaxation of ventricular muscle) and is caused by closure of the semilunar valves and opening of the atrioventricular valves. This sound is the “dub.”
3. The **third heart sound** is caused by turbulence associated with rapid filling of the ventricles shortly after opening of the atrioventricular valves.
4. The **fourth heart sound** is caused by turbulence associated with the passage of blood from the atria into the ventricles during atrial systole. This sound is heard immediately before the ventricles begin to contract and force the atrioventricular valve to close.

Note: The first and second heart sounds are sharp and distinct, easily heard by the untrained ear. The third sound closely follows the second and is of lower amplitude (muffled,) which makes it hard to distinguish. The fourth sound is often of such low amplitude that it cannot be detected. For these reasons, discussion of heart sound measurement often refers to only the first and second heart sounds.

Hearing deficits may affect detection and interpretation of the heart sounds. The BIOPAC stethoscope contains a microphone that picks up sounds traveling through the tubing. The microphone is very sensitive and can pick up sounds that may not be heard.
Placement of stethoscope diaphragm to hear corresponding valve sounds is shown in Fig. 17.3.

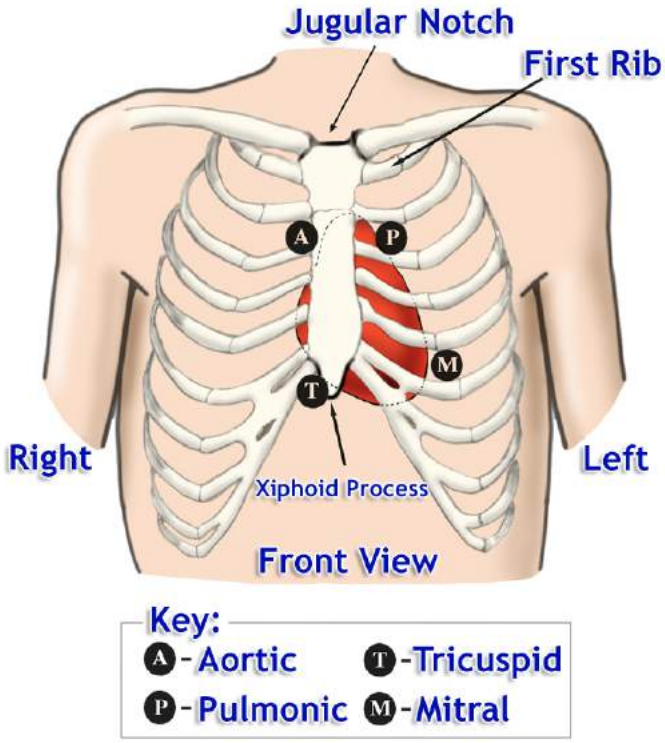


Fig. 17.3 Stethoscope Positions for Optimal Detection of Heart Valve Function

A *heart murmur* is an atypical sound usually produced by abnormal closure of a cardiac valve, narrowing (stenosis) of the valvular orifice, or defects in the atrial septum or ventricular septum. The fundamental cause of the change in sound is increased turbulence. Murmurs may be heard during ventricular systole (systolic murmurs) or during ventricular diastole (diastolic murmurs).

- For example, if the mitral valve fails to completely close, thereby allowing retrograde flow, a systolic murmur may occur. On the other hand, if the aortic valve is diseased and incompetent causing a murmur, the sound will be heard during ventricular diastole.

The opening and closing of cardiac valves and the sounds they produce are mechanical events of the cardiac cycle. They are preceded by the electrical events of the cardiac cycle.
Each heartbeat begins with a signal generated by the sinoauricular (SA) node, commonly called the pacemaker. As the signal spreads through atrial muscle the atria respond by contracting (atrial systole). At this time the ventricles are relaxing (ventricular diastole) and the atrioventricular valves are open, the semilunars are closed. The ventricles are filling with blood, preparing for ejection.
The atrioventricular (AV) node picks up the pacemaker signal and, after a short delay that allows the atria to complete systole and enter diastole, sends the signal down the atrioventricular conduction system to the ventricles stimulating them to contract (ventricular systole). When the ventricles contract, ventricular pressure increases above atrial pressure and the atrioventricular valves close (1st heart sound).
Ventricular pressure continues to increase, and when it exceeds arterial pressure, the semilunars open and blood is rapidly ejected into the pulmonary trunk and aorta. The ventricles complete systole and enter diastole. As the ventricles relax ventricular pressure falls below arterial pressure and the semilunar valves close (2nd heart sound).
When ventricular pressure falls below atrial pressure, the atrioventrcular valves open and ventricular filling begins again. At this time (a period called diastasis) the atria and the ventricles are relaxed and awaiting the pacemaker to signal the next cardiac cycle.
The electrical events of the cardiac cycle can be recorded in the form of an electrocardiogram (ECG).

- At this point, students should review Lesson 5, ECG I, for the meaning of the waveforms, time intervals and segments of Lead II.

Fig. 17.4 shows the timing relationship of the heart sounds and the ECG electrical signal. It also includes aortic, ventricular and atrial pressure plots for the left side of the heart. Pressure waves for the right side (not shown) would have similar shape but be of less amplitude. This is because the pressure that builds up in the chambers of the left side of the heart is much greater than that on the right. The higher pressure on the left causes the valves to snap shut harder and faster, so the valves on the left side create the majority of the sound heard through the stethoscope.

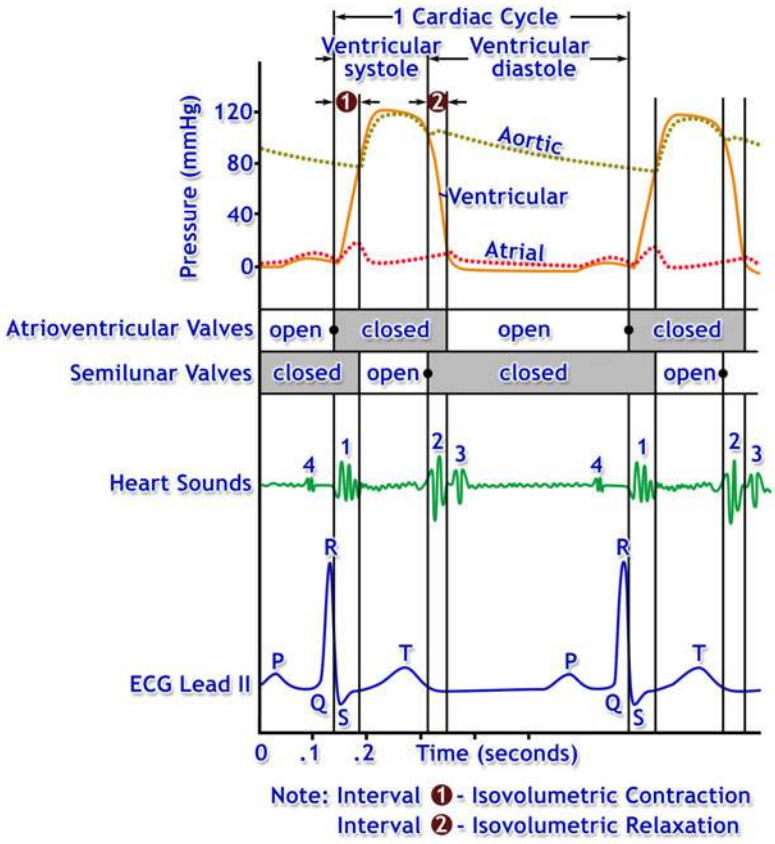


Fig. 17.4 Timing of Events in the Cardiac Cycle

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Purdue University School of Science

William McMullen
Vice President, BIOPAC Systems, Inc.

II. EXPERIMENTAL OBJECTIVES

1. To listen to human heart sounds and describe them qualitatively in terms of intensity or loudness, pitch, and duration.
2. To correlate the human heart sounds with the opening and closing of cardiac valves during the cardiac cycle and with systole and diastole of the ventricles.
3. To determine the nature of the change in the relationship between electrical and mechanical events of the cardiac cycle as heart rate increases.

III. MATERIALS

- BIOPAC Stethoscope (SS30L)
- BIOPAC Electrode Lead Set (SS2L)
- BIOPAC Disposable Electrodes (EL503,) 3 electrodes per Subject
- BIOPAC Electrode Gel (GEL1) and Abrasive Pad (ELPAD)
- Biopac Student Lab System: BSL 4 software, MP36, MP35 or MP45 hardware
- Computer System (Windows or Mac)
- *Optional:* BIOPAC Headphones (OUT1/OUT1A for MP3X or 40HP for MP45)

IV. EXPERIMENTAL METHODS

A. SETUP

FAST TRACK Setup

1. Turn the computer **ON**.
   - If using an MP36/35 unit, turn it **OFF**.
   - If using an MP45, make sure USB cable is connected and "Ready" light is **ON**.
2. **Plug the equipment in** as follows:
   Stethoscope (SS30L) — CH 1
   Electrode lead set (SS2L) — CH 2
3. Turn **ON** the MP36/35 unit.

OPTIONAL – BSL 4.0.2 and higher:
Heart sounds from the SS30L stethoscope may also be heard via the following MP headphone connections:

- OUT1 headphones into Analog Out (MP35).
- OUT1 headphones into Analog Out or OUT1A into the headphone output jack (MP36).
- 40HP headphones into the headphone output jack (MP45).

This can be useful when a second observer wishes to monitor the stethoscope output.

Setup continues…

Detailed Explanation of Setup Steps

Fig. 17.5 MP3X (top) and MP45 (bottom) equipment connections

4. Select a **Subject**, a **Recorder** and, if appropriate in your lab group, a **Director**.

CAUTION!
Subject selected must not have had or now have any disorder, hypertension, heart surgery, stroke, or any history of cardiovascular degeneration.

This lesson teaches the clinical detection of heart sounds, which are monitored in four positions on the upper chest (between ribs two and six).

Normally, this involves one person (**Director**) listening to the heart sounds of another individual (**Subject**). However, in a lab setting this may not be comfortable or appropriate due to gender differences and personal preference. In such cases:

- **Subject** may listen to his/her own heart sounds by acting as and following instructions for the **Director**.
- When a **Subject** listens to his/her own heart sounds, it is imperative that the right arm remains relaxed so EMG artifact does not corrupt the ECG signal.—this means that Subject must hold the stethoscope with the left hand.
- The stethoscope may be placed over clothing for female **Subjects** or for male **Subjects** who are not comfortable removing shirt. (Fig. 17.6)

Fig. 17.6 Stethoscope Placement

Subject should not have consumed caffeine, smoked, or performed heavy exercise within one hour of the recording.

A **Recorder** is always required to run the lesson and insert event markers.

5. Clean and abrade skin.

If the skin is oily, clean electrode sites with soap and water or alcohol before abrading.

If electrode is dry, apply a drop of gel.

Remove any jewelry on or near the electrode sites.

6. Attach three electrodes and clip leads in Lead II setup.
   - RIGHT forearm = WHITE lead
   - RIGHT leg = BLACK lead (Ground)
   - LEFT leg = RED lead

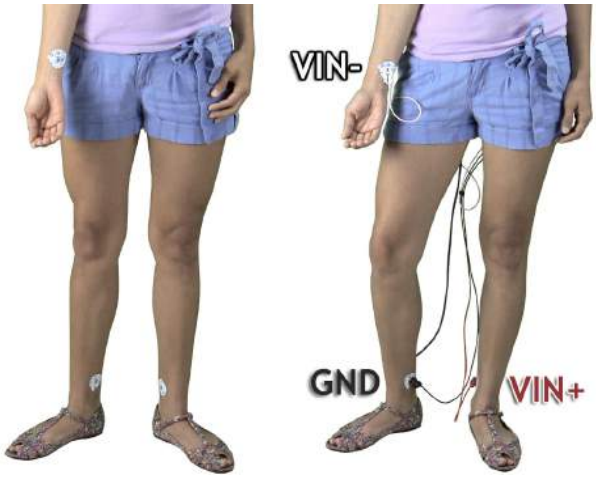

Fig. 17.7 Electrode placement & lead attachment

Details

- Place one electrode on the medial surface of each leg, just above the ankle. Place the third electrode on the right anterior forearm at the wrist (same side of arm as the palm of hand).

Setup continues…

- Lead II is WHITE = right wrist, BLACK = right ankle, RED = left ankle.
- The pinch connectors work like a small clothespin, but will only latch onto the nipple of the electrode from one side of the connector.
- For optimal electrode contact, attach all electrodes to Subject at least five minutes prior to recording.

7. **Subject** gets in a seated, relaxed, position.

Subject should sit with arms relaxed at side of body and hands apart in lap, with legs flexed at knee and feet supported.

Position the cables and leads such that they do not pull on the electrodes; connect the electrode cable clip to a convenient location on **Subject's** clothes.

Fig. 17.8 Calibration Positioning

8. Clean the stethoscope earpieces and diaphragm.

Clean each earpiece with rubbing alcohol and allow it to dry completely. You should also clean the surface of the stethoscope diaphragm (the part that comes in contact with the skin) for each new **Subject**.

9. **Start** the Biopac Student Lab Program.

Start Biopac Student Lab by double-clicking the Desktop shortcut.

10. Choose lesson "**L17 – Heart Sounds"** and click **OK**.
11. **Type** in your filename and click **OK**.

A folder will be created using the filename. This same filename can be used in other lessons to place the **Subject's** data in a common folder.

12. ***Optional*** Set Preferences.
    - Choose File > **Lesson Preferences**.
    - Select an option.
    - Select the desired setting and click OK.

This lesson has optional Preferences for data and display while recording. Per your Lab Instructor's guidelines, you may set:

Grids: Show or hide gridlines

Lesson Recordings: Specific recordings may be omitted based on instructor's preferences.

END OF SETUP

B. CALIBRATION

Calibration establishes the hardware's internal parameters (such as gain, offset, and scaling) and is critical for optimal performance. **Pay close attention to Calibration**. (Click the **Calibration** tab to view example Calibration video.)

FAST TRACK Calibration	Detailed Explanation of Calibration Steps
1. **Subject** remains seated, relaxed and still.	**Subject** must remain relaxed and still throughout calibration to minimize baseline shift and EMG artifact.
2. Click **Calibrate**.	
3. Lightly tap the stethoscope diaphragm twice.	
4. Wait for Calibration to stop.	Calibration will stop automatically after 8 seconds.
5. Verify recording resembles the example data. • If similar, proceed to next step. • If necessary, click **Redo Calibration**.	The stethoscope data must show clear spikes to indicate when it was tapped. There should be a recognizable ECG waveform with baseline at or near 0 mV with no large baseline drift and no significant EMG artifact.

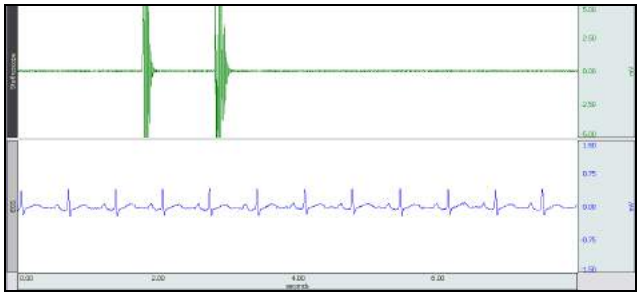

Fig. 17.9 Example Calibration data

If recording does not resemble the Example Data.

- If the data is noisy or flatline, check all connections to the MP unit.
- If the ECG displays baseline drift or excessive EMG artifact:
  - Verify all electrodes are making good contact with the skin and that the leads are not pulling on the electrodes.
  - Make sure the **Subject** is in a relaxed position. (Fig. 17.8)

END OF CALIBRATION

POSITIONING THE STETHOSCOPE

- **Director** determines optimal stethoscope diaphragm position for listening to heart sounds 1 and 2 ("lub-dub",) and should mark the location with a water-soluble pen.
- For suggested stethoscope placements, see the **Stethoscope Position Reference** below.
- If not performing the optional Note Sounds setup, click **Continue** to proceed to the Data Recording section.

OPTIONAL: "NOTE SOUNDS" SETUP

OPTIONAL: Click Note Sounds to enter detailed descriptions of heart sounds at each valve position.

- Refer to **Stethoscope Position Reference** (below) OR Help menu Valve Positions.
- After completing descriptions, click **Continue** to proceed with the recording.

Stethoscope Position Reference
(Fig. 17.12)

END OF NOTE SOUNDS SETUP

- **For greater stethoscope comfort**, rotate the Eartubes slightly forward.

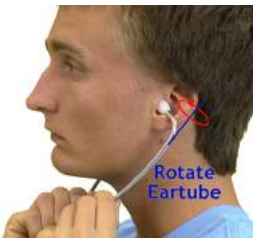

Fig. 17.10 Rotate Eartube for comfort

- Refer to the Stethoscope Position Reference section below.
- The best stethoscope position may be the one that produces the loudest sounds, but it is important that heart sounds 1 and 2 ("lub-dub") are recorded. This may only be possible by "trial and error" after reviewing the first data recording and redoing if necessary.

The **Director** should describe the sound as to its pitch, loudness, and duration, and the **Recorder** types in the description. Begin with the aortic valve and compare it to the others.

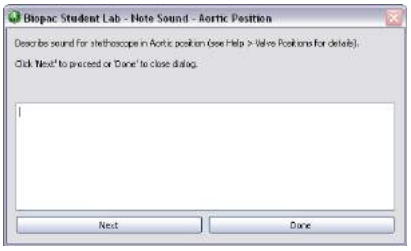

Fig. 17.11 Sound description entry dialog

Click **Next** to proceed to the next valve position, and repeat the description/entry process. Repeat for all valve positions then click **Done**. (All descriptions will appear in the Journal when the lesson is reviewed in Analysis mode.)

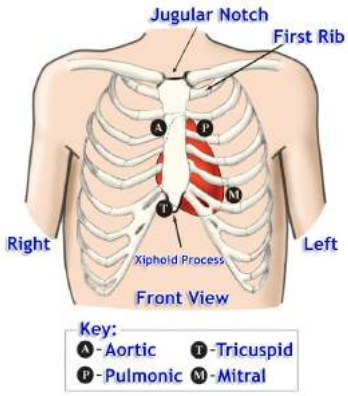

Fig. 17.12 Heart valve position and corresponding stethoscope placement

Aortic and Pulmonic positions: Follow the collarbone to the jugular (supraclavicular) notch, which is a little depression just below the Adam's apple. Go down vertically 64 mm (2.5") and 38 mm (1.5") to the right for Aortic or 38 mm (1.5") to the left for Pulmonic. Position stethoscope between the ribs. Note that this description only works on adults.

Tricuspid position: Just to the right of the tip of the sternum (xiphoid process) immediately below the rib cage.

Mitral position: Roughly on the same horizontal plane as the tricuspid position to the left of the tip of the sternum (xiphoid process) between the fifth and sixth ribs.

C. DATA RECORDING

FAST TRACK Recording

1. Prepare for the recording.
   - **Subject** remains seated, relaxed, breathing normally (Fig. 17.8).
   - **Review** recording steps before proceeding.

Seated, at rest

2. **Recorder** clicks **Record**.
   - **Subject** remains seated relaxed, breathing normally.
   - Stethoscope diaphragm is held in optimal position.
3. Record for 20 seconds.
4. After 20 seconds, **Subject** begins a slow, deep inhale/exhale cycle.
   - **Recorder** presses **F4** at start of inhale and **F5** at start of exhale.
   - Wait for deep exhale to complete.
5. Click **Suspend**.
6. Verify that recording resembles the example data.
   - If similar, proceed to Step 7.
   - If different, click **Redo**.

Recording continues…

Detailed Explanation of Recording Steps

Two data recordings will be acquired*: One with **Subject** at rest and one after moderate exercise.

***IMPORTANT**
This procedure assumes that all lesson recordings are enabled in Lesson Preferences, which may not be the case for your lab. Always match the recording title to the recording reference in the journal and disregard any references to excluded recordings.

Hints for obtaining optimal data:

- If Subject is holding the stethoscope diaphragm, it must be held in left hand, with right hand relaxed in order to minimize EMG artifact.
- To avoid noise artifact, the stethoscope must be held still.
- The room should be quiet in order to easily hear sounds through the stethoscope.

If the Stethoscope data displays very low amplitude, you can choose **Display > Autoscale Waveforms** DURING the recording.

Subject begins a slow, deep inhalation, hold for one second and continue with a slow exhalation, then return to normal breathing.

- Subject should breathe through the nose. Recorder should listen and watch the Subject to detect the start of inhale and exhale.
- To minimize baseline shift and EMG artifact, do not inhale or exhale quickly and try to minimize chest expansion.

The heart sounds should be clearly seen in the stethoscope data. The ECG data should show little baseline drift or EMG artifact except during the deep breathing portion. The two event markers must be present.

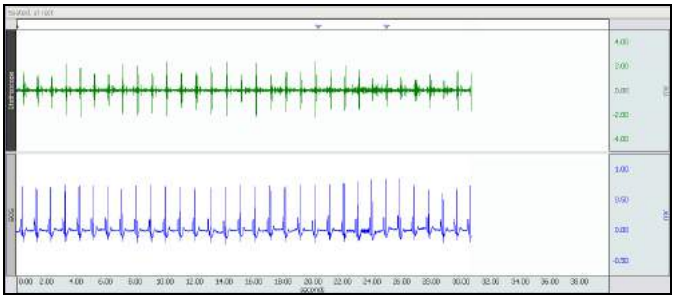

Fig. 17.13 Example data

If recording does not resemble the Example Data…

- If the data is noisy or flatline, check all connections to the MP unit.
- If the stethoscope data is of very low amplitude, choose Display > Autoscale Waveforms. If the heart sounds are not distinguishable from baseline noise, redo and try a different diaphragm position and/or apply more pressure to the stethoscope diaphragm. If the diaphragm position changes, make sure to mark it with a water-soluble pen.
- If there is too much noise artifact in the stethoscope data, make sure to hold the stethoscope with constant pressure and to minimize movement.
- If the ECG displays baseline drift or excessive EMG artifact:
  - Verify all electrodes are making good contact with the skin and that the leads are not pulling on the electrodes.
  - Make sure the **Subject** is in a relaxed position (Fig. 17.8).
- If event markers are missing, redo and remind Recorder to press F4 and F5 at the appropriate times.

Click **Redo** and repeat Steps 1 – 6 if necessary. Note that once **Redo** is clicked, the most recent recording will be erased.

7. Zoom in to verify heart sounds 1 and 2 are recorded.
   - If heart sounds 1 and 2 are present, proceed to next recording.
   - If necessary, click **Redo**.
   - If all required recordings have been completed, click **Done**.

Zoom in to see the details of the cardiac cycles. All four heart sounds may be seen in your data, but it is important that at least heart sounds 1 and 2 are recorded for proper data analysis.

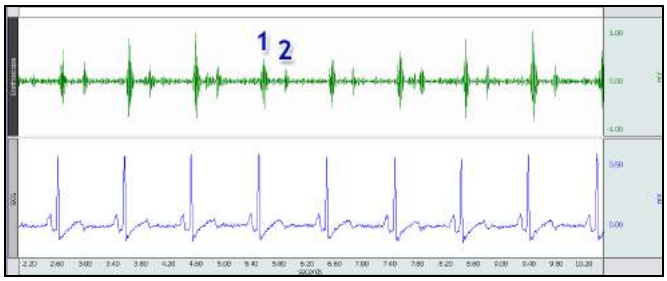

Fig. 17.14 Zoom to verify heart sounds 1 and 2 are recorded

If only one heart sound is recorded, **Redo** and try a slightly different diaphragm position and/or apply more pressure to the stethoscope diaphragm.

After exercise

8. Unclip electrode leads from **Subject**.

Subject must be able to move about freely to exercise and elevate the heart rate.

9. **Subject** exercises to elevate heart rate to 1.5 x resting HR and then sits down to recover.

The exercise required will vary depending on **Subject** and the level of physical fitness. Generally, 20 – 30 push-ups/jumping-jacks or running in place for 25 – 40 steps will suffice. After exercise, **Subject** sits down and remains relaxed and still.

10. Check that electrodes are still making good contact with skin and re-clip leads in Lead II configuration.

Check electrode adhesion and reconnect leads after exercise. Pay attention to the lead color for proper placement, as shown in Fig. 17.7.

11. **Subject** places stethoscope in same optimal position as previous recording.
12. Click **Record**.
    - **Subject** remains seated, recovering from exercise.
    - Stethoscope diaphragm is held in optimal position.

Recording continues…

13. Record for 20 seconds.
14. Click **Suspend**.
15. Verify recording resembles the example data.
    - If similar, click **Continue** and proceed to optional recording section, or **Done** to finish the lesson.
    - If necessary, click **Redo**.

The heart sounds should be clearly seen in the stethoscope data and will typically be of greater amplitude than the last recording (at rest). The ECG may show more baseline drift or EMG artifact than in the first recording.

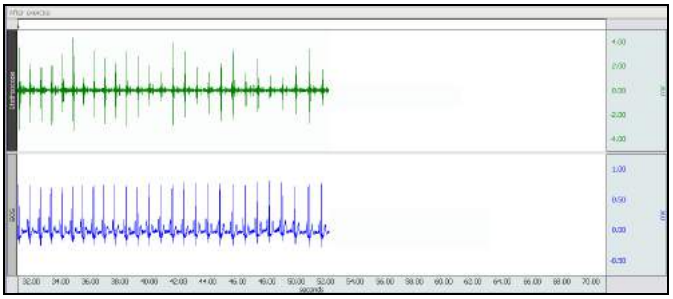

Fig. 17.15 Post-Exercise example data

Click **Redo** and repeat Steps 8 – 15 if necessary.

Note that when **Redo** is clicked, the most recent recording will be erased.

OPTIONAL ACTIVE LEARNING PORTION

With this lesson you may record additional data by clicking **Continue** following the last recording. Design an experiment to test or verify a scientific principle(s) related to topics covered in this lesson. Although you are limited to this lesson's channel assignments, the electrodes or transducers may be moved to different locations on the subject.

Design Your Experiment

Use a separate sheet to detail your experiment design, and be sure to address these main points:

A. ***Hypothesis***

Describe the scientific principle to be tested or verified.

B. ***Materials***

List the materials you will use to complete your investigation.

C. ***Method***

Describe the experimental procedure—be sure to number each step to make it easy to follow during recording.

Run Your Experiment

D. ***Set Up***

Set up the equipment and prepare the subject for your experiment.

E. ***Record***

Use the **Continue**, **Record**, and **Suspend** buttons to record as much data as necessary for your experiment.

Click **Done** when you have completed all of the recordings required for your experiment.

Analyze Your Experiment

F. Set measurements relevant to your experiment and record the results in a Data Report.

16. After clicking **Done**, choose an option and click **OK**.

If choosing the **Record from another Subject** option:

- Repeat Setup Steps 4 – 8, and then proceed to Calibration.

17. Remove the electrodes.

Remove the electrode cable pinch connectors and peel off all electrodes. Discard the electrodes. (BIOPAC electrodes are not reusable.) Wash the electrode gel residue from the skin, using soap and water. The electrodes may leave a slight ring on the skin for a few hours which is quite normal.

END OF RECORDING

Richard Pflanzer, Ph.D.
Associate Professor Emeritus
Indiana University School of Medicine
Purdue University School of Science

William McMullen
Vice President, BIOPAC Systems, Inc.

V. DATA ANALYSIS

FAST TRACK Data Analysis

1. Enter the **Review Saved Data** mode and choose the correct file.
   - Note Channel Number (CH) designations:

Channel	*Displays*
CH 1	**Stethoscope**
CH 2	**ECG**

   - Note measurement box settings:

Channel	*Measurement*
CH 1	**P-P**
CH 1	**Delta T**
CH 1	**BPM**

2. Set up the display window for optimal viewing of the first recording.
3. **Zoom** in on an area of two complete cardiac cycles, prior to the start of deep inhalation.
4. Use the **I-Beam** cursor to select the area from one R-wave to the next R-wave.

   Note the **BPM** measurement.

   A

Data Analysis continues…

Detailed Explanation of Data Analysis Steps

If entering **Review Saved Data** mode from the Startup dialog or Lessons menu, make sure to choose the correct file.

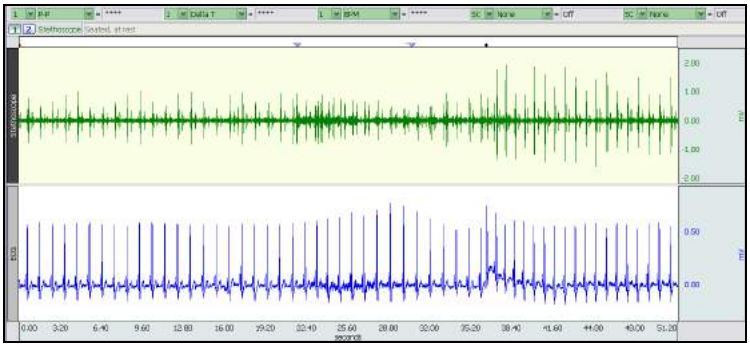

Fig. 17.16 Example data

The measurement boxes are above the marker region in the data window. Each measurement has three sections: channel number, measurement type, and result. The first two sections are pull-down menus that are activated when you click them.

Brief definition of measurements:

P-P (Peak-to-Peak): Subtracts the minimum value from the maximum value found in the selected area.

Delta T: Measures the difference in time between the end and beginning of the selected area.

BPM: Calculates the difference in time between the first and last selected points and then divides this value into 60 seconds/minute.

The "selected area" is the area selected by the I-Beam tool (including endpoints)

Note: The append event markers mark the beginning of each recording. Click on (activate) the event marker to display its label.

Useful tools for changing view:

Display menu: Autoscale Horizontal, Autoscale Waveforms, Zoom Back, Zoom Forward

Scroll Bars: Time (Horizontal); Amplitude (Vertical)

Cursor Tools: Zoom Tool

Buttons: Overlap, Split, Show Grid, Hide Grid, -, +

Hide/Show Channel: "Alt + click" (Windows) or "Option + click" (Mac) the channel number box to toggle channel display.

Note: Try and choose two cardiac cycles that have clearly defined ECG components and whose corresponding hear sounds have minimal noise artifact. Scroll to other cardiac cycles if necessary.

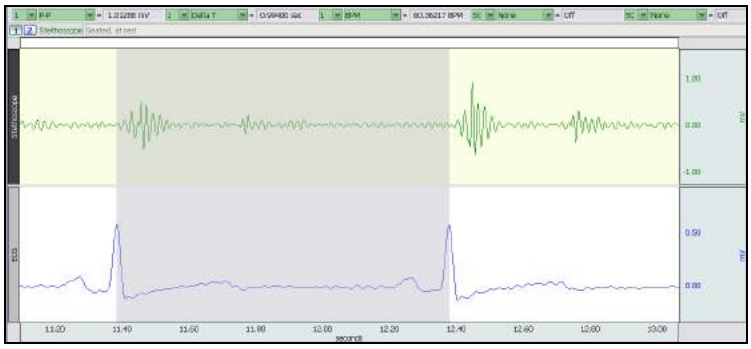

Fig. 17.17 R-R interval

5. Use the **I-Beam** cursor to select an area from the start of the 2nd heart sound to the start of the 1st heart sound of the next cardiac cycle. (Refer to Stethoscope data only (CH1); do not use the ECG channel for this portion of the experiment.)

   Note the **Delta T** measurement.

   A

Heart Sounds in Stethoscope channel (CH1) will lag slightly behind the R-wave (ECG CH2).

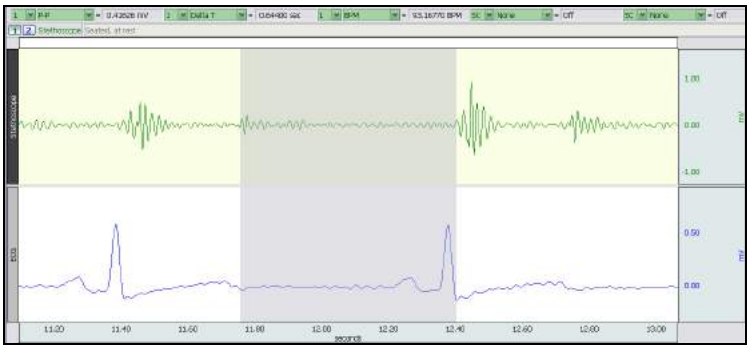

Fig. 17.18 2nd heart sound to 1st heart sound of next cardiac cycle

6. Zoom in on an area of one complete cardiac cycle.

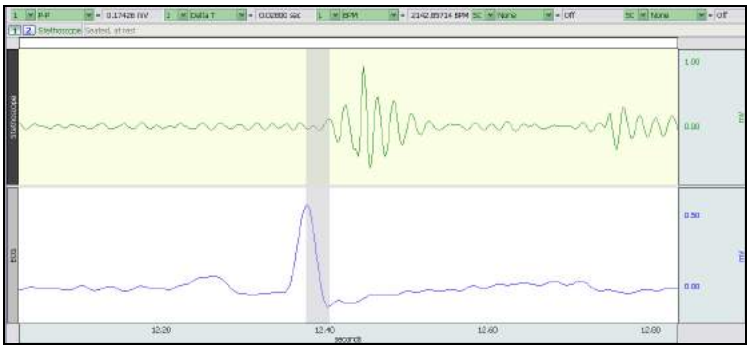

Fig. 17.19 R-wave to 1st heart sound

7. Use the **I-Beam** cursor to select an area from the R-wave peak to the start of the 1st heart sound.

   Note the **Delta T** measurement.

   A

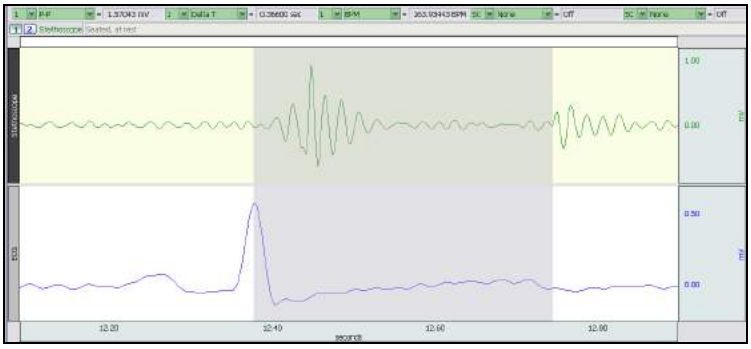

Fig. 17.20 R-wave to 2nd heart sound

8. Use the **I-Beam** cursor to select an area from the R-wave peak to the start of the 2nd heart sound.

   Note the **Delta T** measurement.

   A

Data Analysis continues…

9. Use the **I-Beam** cursor to select an area that encompasses the 1st heart sound.
   Note the **P-P** measurement.
   A

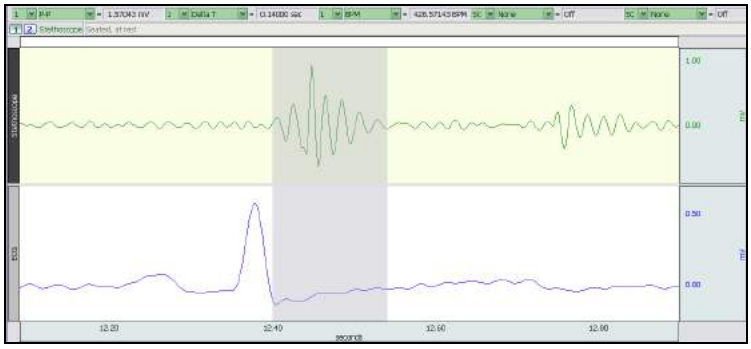

Fig. 17.21 1st heart sound interval

10. Use the **I-Beam** cursor to select an area that encompasses the 2nd heart sound.
    Note the **P-P** measurement.
    A

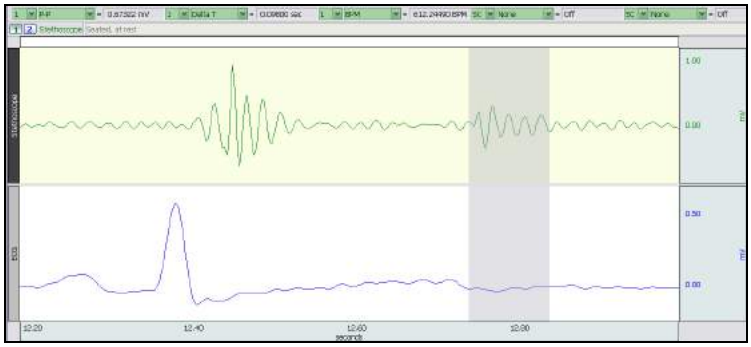

Fig. 17.22 2nd heart sound interval

11. Scroll to the Inhale interval of the "Seated, at rest" recording and take the measurements described above (in Steps 3 – 10) as required to complete Table 17.1.
    A

    This interval begins with the event marker labeled "Inhale." Choose cardiac cycles that are a few cycles after the event marker.

12. Scroll to the **Exhale** interval of the first recording and take the measurements described above (in Steps 3 – 10) as required to complete Table 17.1.
    A

    This interval begins with the event marker labeled "Exhale." Choose cardiac cycles that are a few cycles after the event marker.

13. Scroll to the "**After exercise"** recording and take the measurements described above (in Steps 3 – 10) as required to complete Table 17.1.
    A

    This recording begins with the append event marker labeled "After exercise."

    Note: The ECG data may contain more baseline drift and/or EMG artifact than the first recording and the stethoscope data may contain more noise artifact. It may be necessary to scroll through the data until acceptable cardiac cycles and corresponding heart sounds are found.

14. Answer the questions at the end of the Data Report.

    An electronically editable **Data Report** is located in the journal (following the lesson summary,) or immediately following this Data Analysis section. Your instructor will recommend the preferred format for your lab.

15. **Save** or **Print** the data file.
16. **Quit** the program

END OF DATA ANALYSIS

END OF LESSON 17

Complete the Lesson 17 Data Report that follows.

HEART SOUNDS

- *Cardiac valve functions*
- *Relationship between electrical and mechanical events of the cardiac cycle*

DATA REPORT

Student's Name: _____

Lab Section: _____

Date: _____

Subject Profile

Name:_____ Height:_____ Gender: Male / Female

Age:_____ Weight:_____

Note: This Data Report assumes that all lesson recordings were performed, which may not be the case for your lab. Please disregard any references to excluded recordings.

I. Data and Calculations

A. Heart Sound Measurements

Complete Table 17.1 with **"Seated, at rest"** and "**After exercise"** data and complete the required calculations.

Table 17.1

Selected area	Measurement	Seated, at rest			After exercise
		At Rest	Inhalation	Exhalation	
R-wave to next R-wave	1 BPM				
R-wave to 1st heart sound	1 Delta T				
R-wave to 2nd heart sound	1 Delta T				
1st to 2nd heart sound	1 Delta T				
2nd sound to next 1st sound	1 Delta T				
1st heart sound interval	1 P-P				
2nd heart sound interval	1 P-P				

B. Description of Heart Sounds

Note: You may copy and paste descriptions from the Lesson 17 journal below.

Describe the sounds of each of the following heart valves in terms of intensity (loudness,) pitch (frequency) and duration (length). Begin with the aortic valve and compare others to it. This is a subjective description.

Aortic _____

_____

Pulmonic _____

_____

Tricuspid _____

_____

Mitral _____

II. Questions

1. Relative to the electrical and mechanical events of the cardiac cycle, what do each of the measurements in *Table 17.1* represent?

   BPM: _____

   Delta T: R-wave to 1st sound _____

   R-wave to 2nd sound _____

   1st to 2nd _____

   2nd sound to next 1st sound _____

   P-P: 1st sound _____

   2nd sound _____

2. Note whether the measured values in *Table 17.1* increased, decreased or did not change from the resting value when heart rate increased.

Table 17.2

Measured Value		Increased	Decreased	No Change
BPM				
Delta T	R-wave to 1st sound			
	R-wave to 2nd sound			
	1st to 2nd			
	2nd sound to next 1st sound			
P-P	1st sound			
	2nd sound			

3. Explain why each of these would change.

4. Briefly describe the cause of the turbulence associated with each of the four heart sounds:

   1st sound _____

   2nd sound _____

   3rd sound _____

   4th sound _____

5. Which of the four heart sounds is loudest? Give a reason.

6. Does ventricular ejection occur during ventricular depolarization or during ventricular repolarization? Refer to your experimental record before you answer, and explain your answer.

7. Which cardiac valves close during ventricular systole? Which cardiac valves close during ventricular diastole?
   Systole:
   Diastole:

8. Define "**systolic murmur**" and give one example of a cause.

9. Define "**diastolic murmur**" and give one example of a cause.

10. Define "**cardiac cycle**."

11. Briefly characterize the relationship between the electrical events and the mechanical events of the cardiac cycle.

III. OPTIONAL Active Learning Portion

A. ***Hypothesis***

B. ***Materials***

C. ***Method***

D. ***Set Up***

E. ***Experimental Results***

End of Lesson 17 Data Report