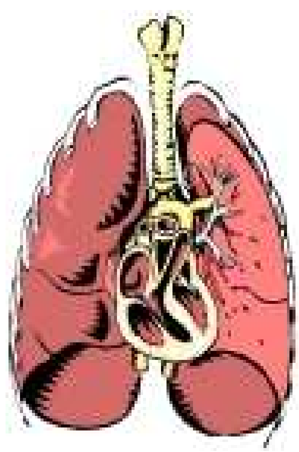
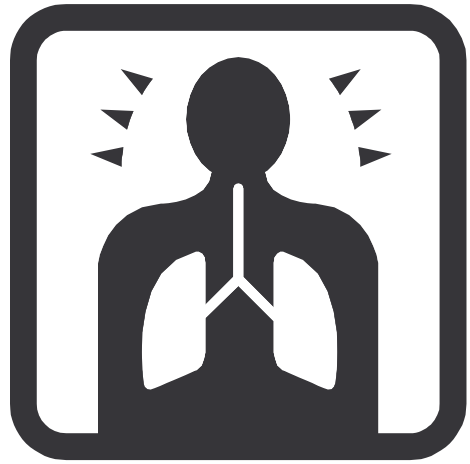
Respiration Laboratory



CleveLabs Laboratory Course System Version 6.0

Introduction



Respiration refers to a sequence of events that ultimately accomplishes the goal of ridding our body of carbon dioxide and replacing it with oxygen. We expand and contract the lungs in order to take air in and out of our body. The exchange of oxygen and carbon dioxide then occurs in the lungs. Measuring respiration becomes important in many applications. For example, monitoring respiration allows doctors to diagnose several types of sleep apneas that occur. Additionally, measuring respiration can give information about the compliance and volume capability of the lungs. Several types of sensors have been developed that allow the measurement of respiration. Pulse oximeters measure the percentage of hemoglobin in the blood that is saturated with oxygen. Respiratory pressures can be measured with sensors placed on a catheter and inserted into the esophagus. Volume-flow rate sensors can estimate lung volume. Gas flow rate can be determined by rotating-vane, ultrasonic, and thermal-convection flow meters. The sensors that we will use to measure respiration in this laboratory include an oral/nasal airflow cannula and a piezoelectric respiratory effort belt.

Materials

- CleveLabs Kit
- CleveLabs Course Software
- Universal Differential Harness
- Nasal Cannula Thermistor
- Respiratory Effort Belt
- Microsoft® Excel, MATLAB® or LabVIEW™

Background

Respiration

Respiration provides oxygen to the body and removes carbon dioxide. Respiration involves pulmonary ventilation, the diffusion of oxygen and carbon dioxide, oxygen transport, and regulation of ventilation. Pulmonary ventilation refers to the inflow and outflow of air between the outside of the body and the alveoli in the lungs. The diffusion of oxygen and removal of carbon dioxide occurs during an exchange between the alveoli and the blood. The oxygen once in the blood must then be transported to tissues and cells. Finally, respiration must be controlled by a higher center in the medulla oblongata and the pons.

Pulmonary ventilation can be achieved by two methods. The first method involves moving the diaphragm up and down to change the length of the chest cavity. The second is by elevation and depression of the ribs to change the diameter of the chest cavity. The compliance of the lungs refers to how much they expand with each unit increase in pressure. The maximum volume that the lungs can be expanded to is an additive function of four pulmonary volumes. These include the tidal volume, the inspiratory reserve volume, the expiratory reserve volume, and the residual volume. Tidal volume refers to the volume of air inspired or expired with each normal breath (approximately 500ml). Inspiratory reserve volume refers to the volume of air that could still be inspired after a normal breath (approximately 3000mL). Expiratory reserve volume is the amount of air that could be forced out of the lungs after a normal breath (approximately 1100mL). Finally, the residual volume refers to the volume of air that is still in the lungs after a forceful expiration (approximately 1200mL).

A common disease of the lungs is emphysema. Emphysema generally refers to an obstructive and destructive process in the lungs that is usually a result of long-term smoking. Emphysema can result in an increased airway resistance and decreased diffusing capacity of the lungs. In turn, this can cause hypoxia (low oxygen) and hypercapnia (increased carbon dioxide) in the body that may result in death.

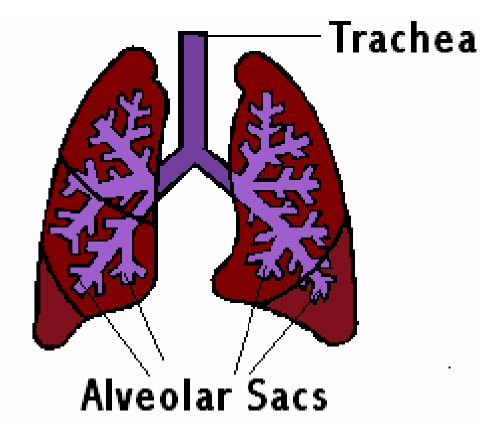


Figure 1: Air is brought into the lungs via the trachea while gas exchange occurs in the alveoli.

Respiratory Sensors

A thermistor is an electronic component similar to a resistor. Unlike a resistor, a thermistor is built using a semiconductor process that makes it extremely sensitive to changes in temperature. Under constant current, a thermistor will change its resistance as a function of the temperature. Normally, manufacturers of resistors attempt to make their components less sensitive to variations in temperature, since a circuit that is designed with a resistor should have the same resistance regardless of the surrounding temperature. On the other hand, thermistor manufacturers need to make their devices extremely sensitive to temperature, so that small changes in temperature can be transduced into voltages. The relationship of the resistance of a thermistor to temperature is given by the following equation:

$$R = Ke^{\beta / T}$$

K represents the intrinsic resistance of the device since R=K when T=0, β is a sensitivity constant that characterizes each different type of thermistor, and T is the temperature in Kelvin.

As you notice from the equation above, the relationship between the temperature and resistance is a non-linear equation. In fact, it is exponential. As a result, if measuring a larger temperature range is desired, some linearization will need to be performed. By linearizing the relationship between temperature and resistance, the thermistor is made useful over a broader range of temperatures. A first order linearization is accomplished by connecting a series resistance with the thermistor, creating a current limiting resistance. The equation for this is given by:

$$R_L = R_m \frac{(\beta - 2T_m)}{\beta + 2T_m}$$

R_L is the value of the resistance desired for linearization, R_m is the resistance of the thermistor at the midpoint of the temperature range desired, and β is a sensitivity constant that characterizes each different type of thermistor.

In this laboratory, the thermistor is located in the oral/nasal cannula. This cannula has three prongs and is taped underneath the subject's nose (Fig 2). Two of the prongs point up and into the person's nostrils and the third is bent around so that it is located in front of the person's mouth. As a person breathes, their air warms up the thermistor, causing a change in voltage, which can be related to breathing rate.

Another tool that is typically used for overnight sleep studies is the respiratory effort belt. This belt is firmly worn around the person's chest or abdomen. It is used to measure the "depth" of a person's breathing during the study. There are two types of respiratory effort belts, the piezoelectric belt and the resistive belt.

The piezoelectric belt works on the principle of piezoelectric materials. Piezoelectric materials, like quartz, exhibit qualities that make them ideal for transducing force into voltage. These materials, when compressed, will show a change in voltage proportional to the change in compression. Similarly, when an electric potential is applied, the piezoelectric material will compress or expand, depending on the polarity of the potential.

Figure 2: The respiratory effort belt and nasal/oral thermistor are used to detect respiration signals.

The equation governing the voltage generated by a piezoelectric belt is given by:

$$\Delta V = \frac{D \Delta F}{\varepsilon (A / X)}$$

ΔV is the change in voltage, D is the amount of charge generated per unit force applied, F is the force applied, ε is the dielectric constant of the material, A is the area of the crystal perpendicular to the force applied, and X is the thickness of the crystal.

Purely resistive belts are also used to measure respiratory effort. These belts rely on the equation that governs the resistance of a material. When the belt stretches, the resistance increases, causing an increased voltage for constant current. When the belt returns to its normal shape, the resistance decreases, causing a lower voltage.

The equation that governs the resistance measured on this type of belt is:

$$R = \frac{\rho L}{A}$$

R is the resistance of the belt, ρ is the resistance per unit length depending on the material, L is the length of the resistive material, and A is the area of the resistive material. As the belt stretches, L increases slightly, increasing resistance.

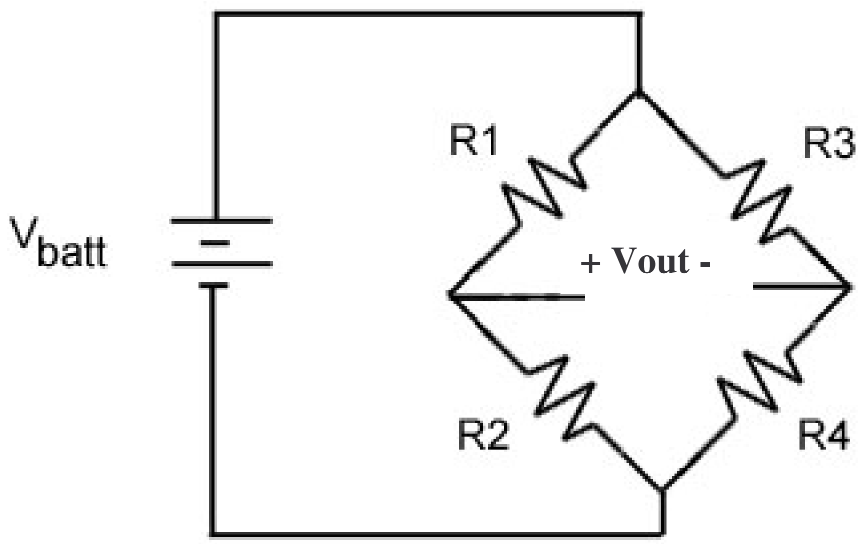


Figure 3: Wheatstone Bridge. R_{out} models the strain gauge resistance.

This resistive belt can be modeled as a strain gauge since the resistance changes as more strain is applied to the device. However, we need a method to create a relationship between the changes in resistance into a change in voltage that can be measured. This time, in order to linearize the effects of the strain gauge, we use the Wheatstone bridge, which converts changes in resistance into changes in voltage.

So, when the length of the strain gauge changes, R_{out} also changes, the V_{out} measured here changes as well, except it is linearly related to R_{out}. The output voltage can be derived as

$$V_{out} = \left(\frac{R_2}{R_1 + R_2} - \frac{R_4}{R_3 + R_4} \right) V_{batt}$$

Experimental Methods

Experimental Setup

This laboratory will use two channels to record respiration using a both a respiratory effort belt and an oral/nasal airflow cannula. You should watch the setup movie provided with the course software prior to setting up the experiment.

1. Your BioRadio should be programmed to the “LabRespiration” configuration.

2. For this laboratory you will need the respiratory effort belt and the oral/nasal airflow cannula provided with your laboratory kit (Fig 2). The oral/nasal thermistor will be used to monitor airflow from the subject. The thermistor should be mounted between the nostrils and upper lip of the subject. There are three prongs on the thermistor. The side with two prongs should point up, one prong slightly into each nostril. The prong on the bottom of the thermistor should be bent around so that the tip is positioned directly in front of, but not in, the subject's mouth. The thermistor can be taped in place and the wires can be run over the ears and over the back of the head. Two other pieces of medical tape can be placed over the wires on the face further hold the thermistor in place and keep the leads from dangling around on the face. Finally, the provided piezoelectric respiratory effort belt should be placed around the torso of the subject. Securely fasten the respiratory effort belt around the subject just above the stomach and below the rib cage. In this position, both diaphragm and chest breathing should be captured.

3. After the sensors have been placed on the subject, connect the leads from the thermocouple into inputs channels +1 and -1. Connect the leads from the respiratory effort belt into input channels +2 and -2.

Procedure and Data Collection

1. Run the CleveLabs Course software. Select the "Respiration" laboratory and click on the "Begin Lab" button.

2. Turn the BioRadio ON.

3. Click on the green "Start" button.

4. In this laboratory, you will monitor the breath rate of the subject at rest and after some mild exercise. First we will measure the breath rate at rest. Click on the tab labeled "Resp Data" and set the time scale to 5 seconds.

5. You should see data from the respiration sensors begin scrolling across the screen. You will probably need to adjust the voltage scale in order to get a better view of each of the signals. Once you have properly adjusted the voltage scales, report a screen shot of this plot.

6. Click on the spectral analysis tab and select the time domain plot.

7. Select the channel to process to be channel 1 (airflow sensor), set the filter type to low pass and select a low pass cutoff of 20Hz. Turn the filter on and off and note if the low pass filter removes any types of artifacts. Report a screen shot of the subject breathing

with a normal inspiration and expiration volume. Also, save a few seconds of this data to a file named “normalairflow”.

8. Now instruct the subject to take very large breaths in and out without increasing their breath rate. Report a screen shot of this.

9. Select the channel to process to be channel 2 (resp belt), set the filter type to low pass and select a low pass cutoff of 20Hz. Turn the filter on and off and note if the low pass filter removes any types of artifacts. Report a screen shot of the subject breathing with a normal inspiration and expiration volume. Also, save a minute of this data to a file named “normalresp”.

10. Now instruct the subject to take very large breaths in and out without increasing their breath rate. Report a screen shot of this.

11. Turn off both the time and frequency plots. Then click on the processing and application tab. In this application you will detect breath rate from either the respiratory effort belt or from the airflow sensor.

12. Set the filtering properties for both sensors to be low pass, a low pass cutoff of 20Hz, and an order of 4 for the filter.

13. First attempt to measure breath rate with the airflow sensor with the subject relaxed. Set the Channel to Plot and Calculate Resp to 1. Turn on the plot filtered respiration plot.

14. Examine where the most prominent peak or valley in the signal occurs. If the most predominant feature is a peak then set the Peak/Valley selector to peak, if it’s a valley set it to valley.

15. Using the plot, determine a proper voltage threshold and time threshold for that peak or valley that defines a breath. Those values should be set using the digital input control with those labels. The voltage threshold refers to the voltage level that the signal must cross in order for it to be considered a breath. The time threshold refers to the amount of time the signal must stay above the voltage threshold for it to be considered a breath. Then turn on the Respiratory Rate Calculator. Make sure the subject is sitting still to reduce motion artifact.

16. This respiratory rate detector calculates the breath rate over the past 30 data collection interval sessions. Therefore, the data collection interval that you choose has an effect on resolution of the respiratory rate detector. Try the running the detector at a data collection interval of 100ms and then again at 500ms. In other words using 3 seconds or 15 seconds of history data to calculate breath rate. It will take up to 30 times the data collection interval that you specify for you to get an accurate respiration rate. Note how the data collection interval affects the resolution of the calculated respiration rate. Capture a screen shot of this.

17. Repeat steps 13-16 for the respiratory effort belt.

18. Have the subject complete some mild exercise to increase their breath rate and then repeat steps 13-17. However, save a minute of data when the subject has an increased respiration rate to a file named "fastresp".

Data Analysis

1. Using Excel, MATLAB, or LabVIEW, or the post processing toolbox, open your collected data files and create plots of the subject breathing normally

2. Also create respiratory plots when their respiration had increased.

3. Using these plots, calculate the respiration rate of the subject in each instance. Do the rates differ how you'd expect? What problems do you have in calculating the respiration from the data plots?

4. Using MATLAB or LabVIEW, create your own automated program to calculate respiratory rate using the data files that you saved.

Discussion Questions

1. What was the difference in amplitudes if any when deeper breaths were taken with the airflow sensor? With the respiratory belt? Why do you think this is?

2. When using the thermistor or respiratory effort belt, why is linearization required, even though there is a proportional change in resistance to a change in either temperature or strain? More clearly, in a circuit, why isn't there a linear relationship between change in resistance and the voltage measured across that resistance? What is done to correct for this?

3. Show how the equation for the Wheatstone bridge is linear. Would it still be linear if R_2 were defined as the input variable and V_{out} as the circuit output? Why?

4. Use the Wheatstone bridge in Figure 4. Assume that R1=R2=R4=10 Ohms. Assume that the battery voltage is 5 Volts. Plot the output voltage if the value of R3 varied from 1 – 20 Ohms.

5. Use the Wheatstone bridge in Figure 4. Assume that R1=R2=R3=10 Ohms. Assume that the battery voltage is 5 Volts. Plot the output voltage if the value of R4 varied from 1 – 20 Ohms.

6. Describe the trade offs between using each type of sensor for monitoring respiratory function.

7. Describe any issues or problems that were encountered using the respiratory rate detector.

8. What improvements could be made to the respiratory rate detector to improve performance?

References

1. Guyton and Hall. Textbook of Medical Physiology, 9th Edition, Saunders, Philadelphia, 1996.

2. Rhoades, R. and Pflanzer, R. Human Physiology, Third Edition. Saunders College Publishing, Fort Worth, 1996.

3. www.library.thinkquest.org/25553/English/basics/brain/index.shtml