Continuous Monitoring of Asthma Control

BME 402

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Abstract

An asthma action plan (AAP) is a set of medication changes custom designed for asthma patients in case of an asthma exacerbation. However, many asthma patients fail to utilize the plan due to the subjective nature of when to implement and insensitivity to early symptoms of an asthma exacerbation. Continuous monitoring of important indicators of asthma exacerbation such as: shortness of breath from decreased respiratory volumes, cough and wheeze allows real time detection of an asthma exacerbation and helps patients utilize their AAP in a timelier manner. The previous team developed an asthma shirt: a portable, affordable, and non-invasive means of monitoring asthma. There were some modifications of the microphones and electronic connections of the current device that needed to be made to allow the patient to notice their symptoms of an asthma exacerbation sooner and allow them to contact their physician for treatment. The new design was evaluated using a virtual testing method in PSpice and produced an oscillating curve around an average output voltage with peaks ranging in size; the trials were consistent with no variance. This paper outlines the human subjects testing protocol and modifications that will be made in the future development of this device to be used as a screening tool in the clinic setting.

Introduction

Motivation

Asthma affects approximately 25 million people in the U.S alone. Furthermore, in 2008, about 12 million people had an asthma attack, but it could have been prevented. In the US, about $56 billion are being spent in medical costs.[1] Asthma is a syndrome which constricts the airways and airflow. A patient must meet with his or her physician in order to establish what is called an Asthma Action Plan (AAP) as a means to prevent asthma exacerbations (see **Appendix A)**[2]. Then, the patient must follow that written plan when they feel asthma-like symptoms. However, with the current protocol, individuals with severe asthma may not be able to prevent an exacerbation in time.

Current Methods

Patients follow their own personalized AAP and when symptoms are moderate to severe, patients will then contact their physician. Although this plan is set up with the patient's personal physician, it is very subjective. This in turn causes delays between the onset of the symptoms and detection. There are no current devices which continuously monitor asthma symptoms. There is a device that is very similar to this design, Hexoskin™,[3] , which measures different parameters utilizing breathing rate sensors; however, it is used to analyze athletes in high performance environments. This device will differ from Hexoskin™, as it will only focus on individuals with asthma. Furthermore, with the software that will be implemented in this application, the only pertinent output information is the detection of asthma symptoms.

Problem Statement

Currently if a person is experiencing an asthma exacerbation, they do not experience symptoms up until two days after they have begun. There is a need for a device which will detect these symptoms sooner, thus decreasing the likelihood of emergency medical procedures.

Background

Relevant Physiology and Biology

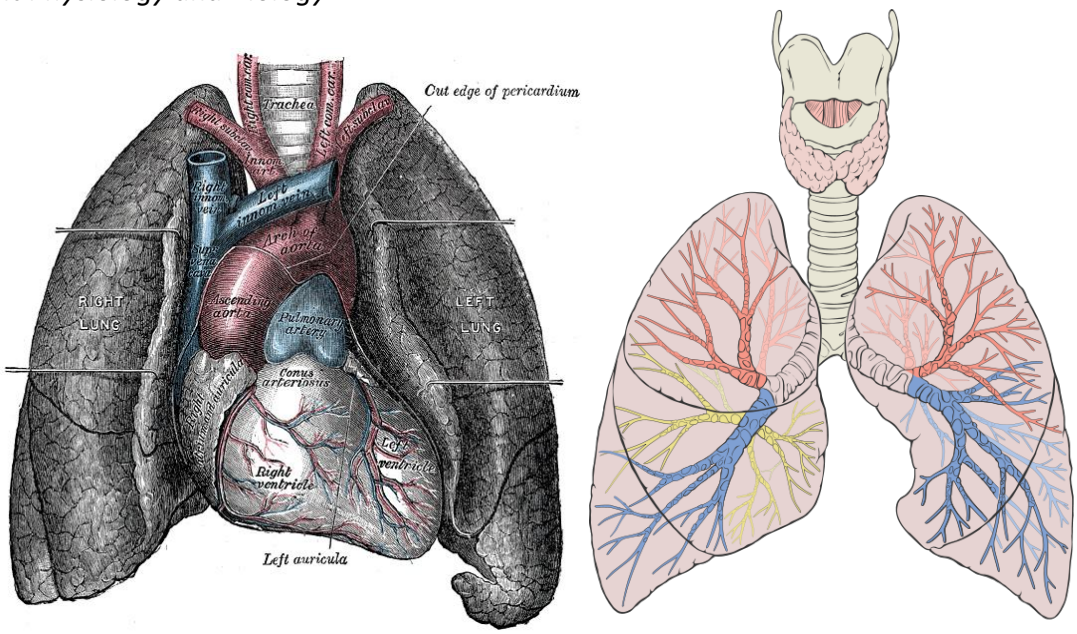

Figure 1. External frontal anatomical view of the lungs and heart (left), internal anatomical view of the lungs and bronchial tree (right)[4],[5]

The lungs are the fundamental organs in the respiratory system. They are located posteriorly and near the heart, shown in **Figure 1**. The lungs extract oxygen from the environment and transfer it to the bloodstream while simultaneously removing the carbon dioxide that has been accumulated in the bloodstream[4]. Air enters the body through the nasal cavity and continues to travel down toward the upper respiratory tract and lower respiratory tract. As it continues to move down, the air is split equally into a right and left bronchus. Then, the lungs receive the air as it progressively splits into the multiple bronchi, bronchioles and respiratory bronchioles[6]. Additionally, mucus is secreted by different cells found in mucous glands in the respiratory system. Mucosal tissues line the airways to prevent small particles from entering the system. While a person experiences illness such as the common cold, the mucus production is increased[7].

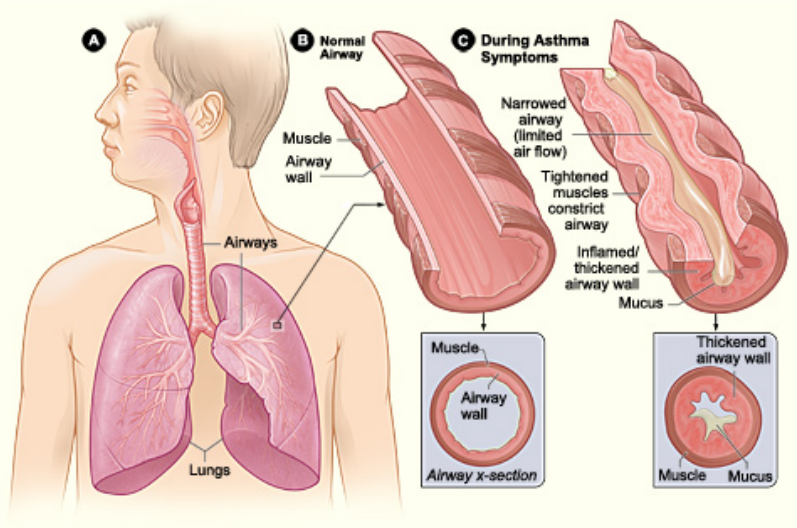

Figure 2. View of: (a) the respiratory tract showing airways and lungs, (b) the normal airway cross section and (c) the change in the cross section during asthma symptom[8]

Asthma is a chronic lung disease which causes wheezing, coughing, breathlessness and chest tightening. The lung's airways are constricted and get smaller in diameter. During an asthma attack, the airways swell making it harder for an individual to breathe. This is also known as hyperresponsive smooth muscle contraction[9]. Additionally, the mucus in your lung increases, further obstructing the airways. Medicine is available which can help with these symptoms, but are meant for quick and short-term treatment[10]. **Figure 2** illustrates these differences in a normal functioning lung versus one with asthma.

Current Treatment and Competing Devices

There are different preventative medications available for patients who suffer from asthma exacerbations. The medicines an individual takes depends on the age, symptoms, asthma triggers and many more. Some options include long term care such as inhaled corticosteroids, leukotriene modifiers, long-acting beta agonists, combination inhales and theophylline[11]. Inhaled steroids have been shown to reduce airway hyperresponsiveness in asthma. Furthermore, results have shown that prolonged use of inhaled steroid can improve airway hyperresponsiveness[12]]. There are also short term medications that act as quick-relief, or rescue, medications that can be used during an asthma attack. These include, but are not limited to: short-acting beta agonists and oral and intravenous corticosteroids. Intravenous corticosteroids, for example, play an important role in the treatment of acute asthma exacerbations post discharge from a medical emergency[12]. Thus, if a patient undergoes an asthma attack and it is detected too late, even with the correct treatment the patient may still need to seek out clinical care.

Figure 3. Men's (left) and women's (right) Hexoskin™ biometric shirt

As mentioned previously, Hexoskin™ is a similar device to our own, but it does not directly measure asthma symptoms. **Figure 3** shows the Hexoskin™ shirt which is available for both men and women for about $399.00 per shirt. This monitor measures heart rate, heart rate recovery, ECG, breathing rate and minute ventilation. It has a 14 hour battery life and more than 150 hours of standalone recording, according to their website. It can also connect via Bluetooth® with iPhone or Android devices. The shirt itself is machine washable, lightweight, quick dry and anti-odor[3]. The software enables the user to download raw data and then use any analytics software to view data. However, this device is advertised as a fitness tracker and wearable health sensor.

Client Information

Dr. Sameer Mathur is board certified in Allergy and Immunology and works at the University of Wisconsin School of Medicine and Public Health. His clinical interests include asthma, hypereosinophilic syndromes (including eosinophilic esophagitis) and chronic urticaria. Dr. Mathur is also recruiting older and younger asthma subjects to determine whether immunosenescence influences airway inflammation, the clinical presentation of asthma, and the therapeutic implications for the elderly asthma patient.

Design Specifications

For testing, the aesthetics and weight of the design are negligible. In the future, it is recognized that these parameters will be taken into account. The device must accurately output data in response to a change in resistance from the resistance bands in the upper and lower trunk regions. The embedded microphones must also detect noise differences in asthma

like symptoms such as coughing and wheezing. The wire must be non restrictive and flexible, as to not constrict the user. It must also fit a large number amount of people. Ideally, the device will be made size adjustable to fit a larger population. Lastly, in order to monitor these symptoms continuously, it must also have a battery life of about 6 hours and have the potential to be recharged in the future. The detailed document of Product Design Specifications (PDS) is listed in **Appendix B.**

Previous Design and Improvements

Previous design

The previous design, as seen in **Figure 5,** included an upper chest stretch sensor, an abdominal stretch sensor, a pocket which housed the electrical components and a battery. On the back side of the shirt, three microphone shells were embedded into the shirt. The microphones wires were then attached. The microphones were housed in cases that mimic the shape and structure of a stethoscope. Since shape and diameter and depth of cavity affect the quality of the signal received at the microphones it was best to use a shape that is currently used in practice [13].

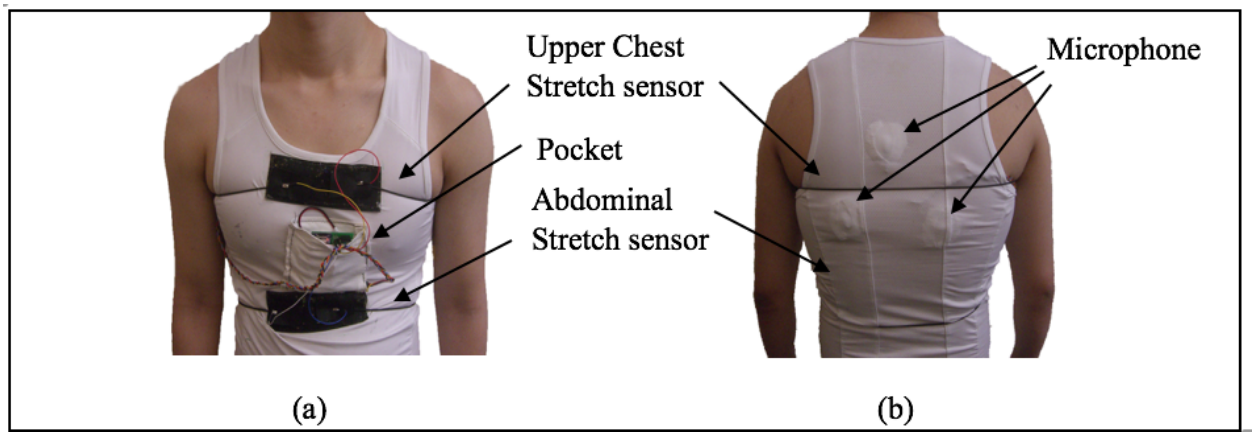

Figure 5. (a) Anterior view of the shirt with stretch sensors and pocket. (b) Posterior view of shirt showing three microphones located on the dorsal region.

Design Changes

The sensors, microcontrollers, and shirt will all stay the same from the previous prototype, however, there will be changes to the microphone holder, the programming logic, and transfer of data. Firstly, the microphone holders will be redesigned (**Figure 6**) to create a hollower structure to further focus the sound onto the microphone. The overall size of the holder will also be smaller (10mm shorter in diameter) to reduce bulk and material. The prototype will be printed in ABS plastic, but future plans could involve the use of metal or injection molded plastics.

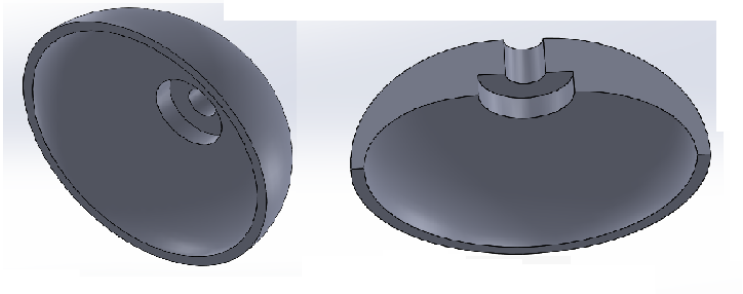

Figure 6. Microphone holder solidworks design. 40mm in diameter, there is a hole for the microphone and wires for connection.

Ventilation will be measured by two stretch sensors (Adafruit Industries) made of carbon-black rubber (**Figure 7**). The rubber essentially acts like a wire that varies resistance proportionally with length. The diameter of the sensor is 2 mm and its resistance value is 140-160 Ohm/cm. The circuit is designed to produce a gain of 22.5*variable current to ensure the signal is amplified in the right range for the arduino. Assuming the stretch sensors are placed tight around the abdomen and the chest, it can measure the relative perimeter of the body. Finally, the tidal volume and respiratory rate can be estimated.

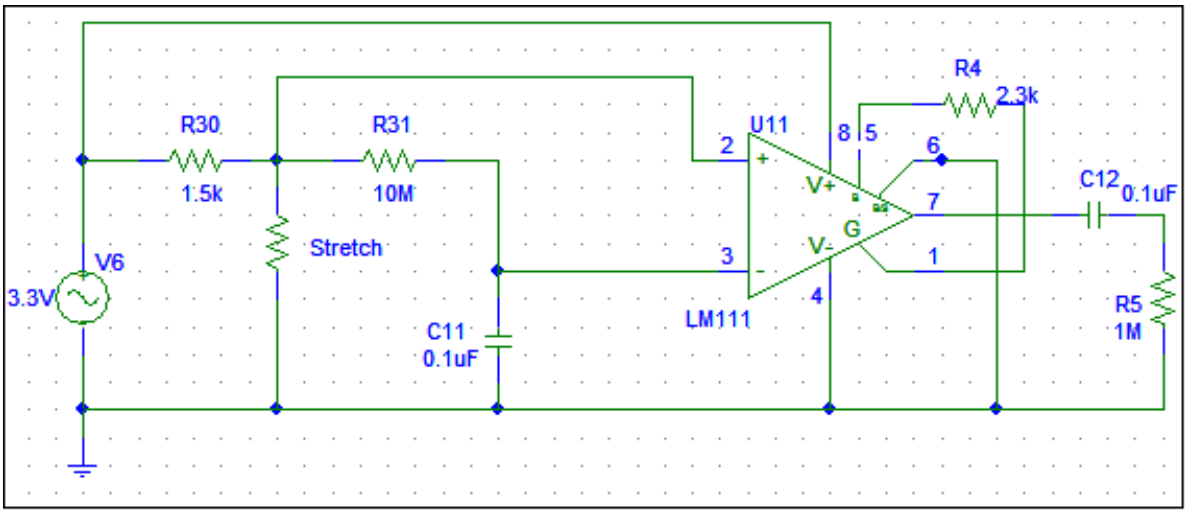

Figure 7. Schematic of ventilation measurement circuit

Respiratory sounds will be measured from the four electret microphones placed in the dorsal region. As shown in **Figure 8**, the gain of stretch sensor is 11 to ensure the input voltage is between 0V and 3.3V for the arduino to recognize. The DC offset is around 0.148V, thus with the gain of 11, the output becomes 1.62V - halfway between 0 and 3.3V. Both sensors will contain a low pass filter with a corner frequency of 0.16Hz (R = 1M Ohm, C = 0.1uF) because the normal breathing rate is around 0.167 Hz. This will help to isolate background noise for the input signal.

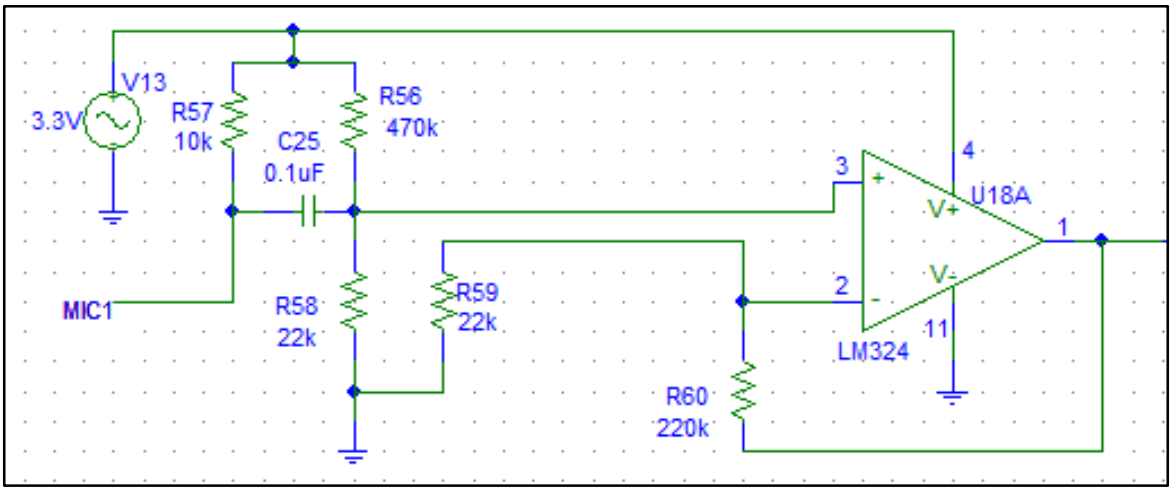

Figure 8. Schematic of respiratory sound measurement circuit

The signals from the six sensors will input into Arduino's analog to digital converter (ADC). The sampling rate of the microcontroller will be 5 kHz, which would be plenty assuming the normal respiratory rate is around 0.2 Hz. The data will be transferred via a Bluetooth® module to the computer and an excel file will be created from the data array. Finally, the data array can be normalized with the baseline measurements, and any significant deviation from the baseline will be noted. If both the stretch sensor and the microphones detect any abnormalities in breathing patterns, the code will alert the user of a potential asthma attack.

Fabrication and Development Process

Materials

Since the invention of the stethoscope in 1816, listening to respiratory sounds over lungs (auscultation of lungs) has been one of the basic medical tools for studying the human respiratory system; stethoscopes serve to promote noninvasive diagnosing and monitoring facilities of respiratory diseases as an alternative to radiation instruments[14]. Therefore, it stands to reason that with more audio channels, the processing of the recorded signal could reach an acceptable level to be able to distinguish both cough and wheeze in this application. Conventional stethoscopes successfully amplify respiratory sounds and transfer them to physicians. Electret microphones are a good alternative to both conventional and electronic stethoscopes. Electret microphones are not only small enough to be placed on shirts, but also they have been successfully used for recording respiratory sounds (Korenbaum et al. 2008, Oletic et al 2014). Four electret microphones will be placed on the back of the shirt over the regions where respiratory auscultation is typically practiced, similar to the layout in **Figure 5.** Building the respiratory measurement circuit requires amplification via an operational amplifier

and the proper resistors, which will be purchased in the future, as well as a means of transmitting the signal to the physician using a microcontroller. The Arduino Pro Mini was purchased and serves as a quick means of sampling the data (from four channels) and transmitting the data wirelessly to any Bluetooth® enabled device via the Bluetooth® module, also already purchased. The fluctuating periodic movements of the upper chest and abdomen requires the use of a flexible stretch sensor; two elastic resistive bands with a maximum length of 1 m were purchased. Other various electronic components were purchased, including the athletic shirts ranging in size from adult small to adult extra-large, to complete the design; however, the 3D printed cases will still need to be purchased once the circuit board is completed and its dimensions are measured (see **Appendix C** for complete material list).

Methods

In order to fabricate the final design of the shirt, the stretch sensors should be removeable and remain tight to the body for accurate readings of the change in volume of the lungs. Pockets could be sewn into the outer lining around the chest and abdomen of each adult-sized shirt using white or light-colored elastic thread and the remaining material of other athletic shirts. The microphones would sit against the body and the pockets would be sewn into the inner lining of the back of the shirt. The wires will be braided together from each microphone following a thin pocket leading to the outer edge of the shirt to be attached to the circuit. The circuit would be composed of four microphone amplifying components and two stretch sensor amplifying components as well as providing connections to the Arduino Pro Mini. In order to maximize the portability of the shirt and minimize the electric circuit the analog circuits for measuring ventilation and respiratory sound would be integrated into a single Printed Circuit Board (PCB).

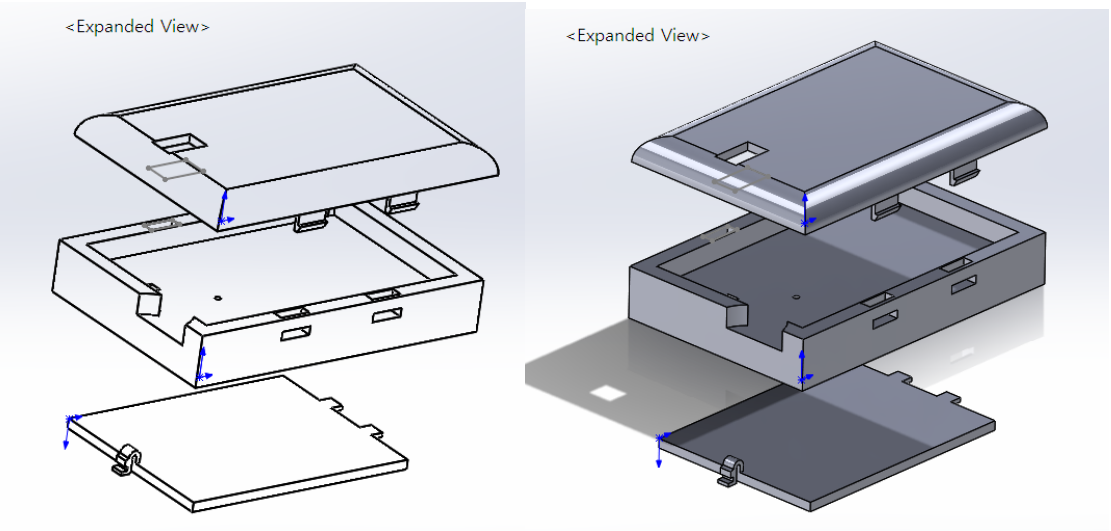

Figure 9. Electronic circuit housing for PCB and battery from previous design[13]

The maximum dimension of the PCB is set as 8.4 cm × 5.3 cm. The entire circuit and the battery power source would be stored within a 3D-printed case (similar to the previous design as shown in **Figure 9**) with maximum dimensions of 8.4 cm × 5.3 cm x 5 cm and a weight limit of less than 5 lbs (~22 N). The electrical components of the device should be easily removeable from the shirt and thus the 3D-printed external electrical storage container is ideal for this application.

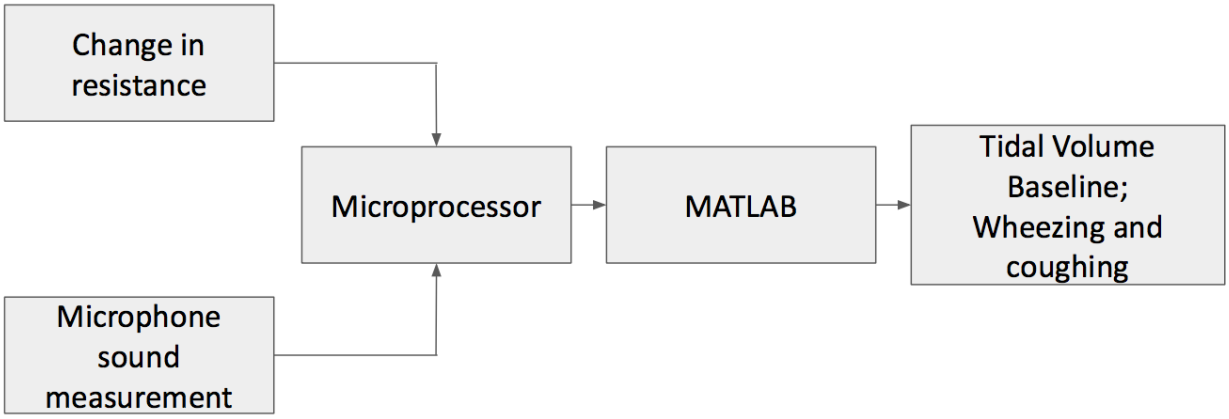

Figure 10. Changes in resistance will be measured using resistance bands and sent to Arduino along with sound measurements. The Arduino microcontroller will send the output signals via Bluetooth® to a computer for MATLAB analysis. MATLAB will be used to analyze several asthma symptoms.

Along with the prototype, a MATLAB code will be implemented simultaneously which will act as the brains of the device, see **Figure 10** for the flow diagram. The MATLAB code will first establish general demographics at the start of the test. For example, it will prompt the user to enter in age, gender, weight, and height. Demographics can be a big help in the researching phase. Next, a calibration curve would need to be used. A physician would prompt the user to breathe normally for 3 periods of time. The wave produced from changes in voltage as picked up by the Arduino will be averaged out to form the baseline. After the induced asthma exacerbation, the calibration curve will be compared to the graph of the new data.

Final Prototype

The black box will encase all circuitry and the battery. On the dorsal region of the shirt, there will be four microphones, rather than two. The wiring will be removable to enable researchers to wash the shirt between patients to abide by IRB guidelines. Compression shirts will be used to get as close to the skin as possible and eliminate errors from clothing. Additionally, since the electrical components of the device will be removable, multiple shirt sizes will be provided to accommodate a larger number of the population. The team looked at the ergonomics of the shirt size using the NIOSH Truck Driver Anthropometric Survey from

2015. The results are shown in **Appendix C.** These calculations were used to determine future shirt sizes needed in order to accommodate a large percentage of the population. The NIOSH Truck Driver Anthropometric Survey was used as it would most commonly reflect an average person who sits for long periods of time. Since these shirts are flexible, some of the values for the percentile of the population accommodated may differ.

Testing

In Environment Testing

For the purpose of this paper, minimal testing was done; however, the team has established protocols for testing once prototype is fabricated. MATLAB will be used analyze the data and compare the data. The flowchart shown below in **Figure 11** depicts the format of the code which will be implemented later on this semester. The following protocol will be implemented with human subject testing. The respiratory sound signal must be able to capture wheeze, whose maximum frequency is known to span up to 1600 Hz; the minimum sampling frequency has to be greater than 3200 Hz. Using four microphones, the Arduino Pro Mini sampling speed is set to 9600 Hz in the code prior to the setup function. For each inspiration/expiration measurement the testing process would follow three steps: calibration, continuous data collection, calculating statistical significance and further steps would set a desired percent change in lung function (tidal volume change) which determines the risk of asthma exacerbation or level in AAP. Calibration requires user input of demographics (i.e., age, weight, height and gender) into MATLAB, starting data collection from Arduino via Bluetooth® and running at least 3 periods of normal breathing before inducing asthma exacerbation. The average tidal volume change would be calculated and a t-test would be run to analyze the distribution of the data ($p < 0.05$). The data would be plotted and the program would ask the medical professional if they would like to continue with experiment. The second step of data collection for continuous monitoring requires collecting data for at least 1 hour. In this step the physician will refer to the methacholine challenge to induce an asthma exacerbation (see **Appendix F** for documentation). The plot of the ventilation data would be overlaid with the plot of the calibration curve. The peaks of the signal would be found using the findpeaks() function and the percent difference for each patient would be calculated (peak to peak differences or average value differences) and stored in a spreadsheet according to each patient. The frequency range of wheeze extends from less than 100 Hz to greater than 1 kHz while the characterization of a cough is a high-amplitude, pulse-like signal. The third step in data collection requires running a T-test for relevance. The Z score would be used to determine if the trial was statistically different from previous trials or from the entire population and find out which asthma symptom which the most significant percent change ($p < 0.05$). In further steps, if the percent change is higher 12-20%[15], a direct message would be sent to physician

directly, instructing them to contact patient ASAP; If the percent change is in between normal values and close to high values, can determine for moderate risk, physician should contact, or watch closely. Finally, If percent change is at 0 or close to being at normal values the display screen will show a message alerting them they are doing okay. MATLAB is an easy programming software that can be downloaded to most computers and allows for easy manipulation of plots as well as containing a vast array of built-in functions to conduct statistical tests. The audio signals and tidal volume changes can be easily assessed by physicians from a plot; thus, MATLAB is the ideal platform for this application.

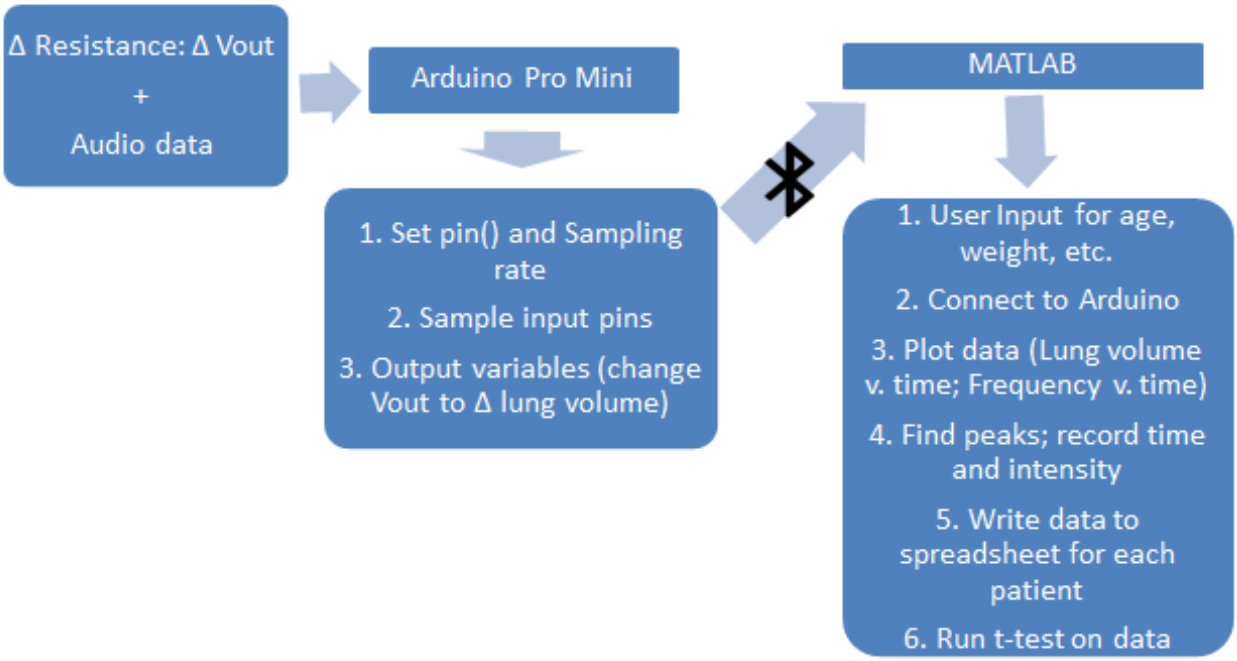

Figure 11. The two variables are measured and sent to the microcontroller. The Arduino microcontroller will send the output signals via Bluetooth® to a computer for MATLAB analysis. MATLAB will be used to analyze plots of the data through calibration and data collection steps.

Virtual testing

Due to limited resources for building the circuit, the team used PSpice to virtually build the first circuit focused on the measurement of ventilation. The value of 3.3 Volts was used as the input voltage, as this is what was used in the previous design. The resistive value of the sensor was alternated accordingly to what was believed to be the detectable resistance. With resistor values ranging from 0Ω to 500Ω, a graph was generated with peaks in the output voltage-time graph in the figure below, **Figure 12,** which attempted to return to the average value (baseline) after a period of time. Once the team is able to actually build the circuit using a breadboard and the ordered resistors, real-time data collection will be able to start for the

'asthma symptoms' testing portion of the timeline. The PDS document clarifies that the detected ventilation signal should be within 0.167 – 0.50 Hz range for the calculated respiratory rate and within 100 - 1600 Hz range for wheeze detection with 95% CI. A Z score for this sample is not relevant since the trials stayed consistent each time they were run in the virtual software with no variance.

Expected outcomes

In the environment testing, the expected plots of the ventilation data would be overlaid with the plot of the calibration curve as tidal volume change over time rather than the voltage output of the signal. The peaks of the signal would be found and the percent difference for each patient would be calculated, including the calculation for respiratory rate by finding the period of the oscillation. The peak to peak value of respiratory volume measurement gave information about the tidal volume and the respiratory rate is calculated by counting how many times a person inhaled during the given period of time. A decrease in respiratory volumes and increase in respiratory rate are both signals associated with shortness of breath, which is an indicator of asthma exacerbation. The calculated respiratory rate would fall within the 0.167 – 0.50 Hz range (10 - 30 times per minute) for elderly healthy adults and any value larger than one standard deviation would qualify as an indicator of an increase in respiratory rate, according to the PDS document (see **Appendix B**). The expected plots of the sound data would plotted as frequency over time with the cough signals as significant peaks and wheezing detected within the 100 - 1600 Hz range. The expected outcome of the environment testing would demonstrate a 95% reliability of detecting a decrease in respiratory volume change and if the patient was coughing concurrently at a 95% confidence level. The type I and type II errors would ideally be less than to be less than 0.1 to reduce the number of false positives (false alarms) and false negatives.

Results

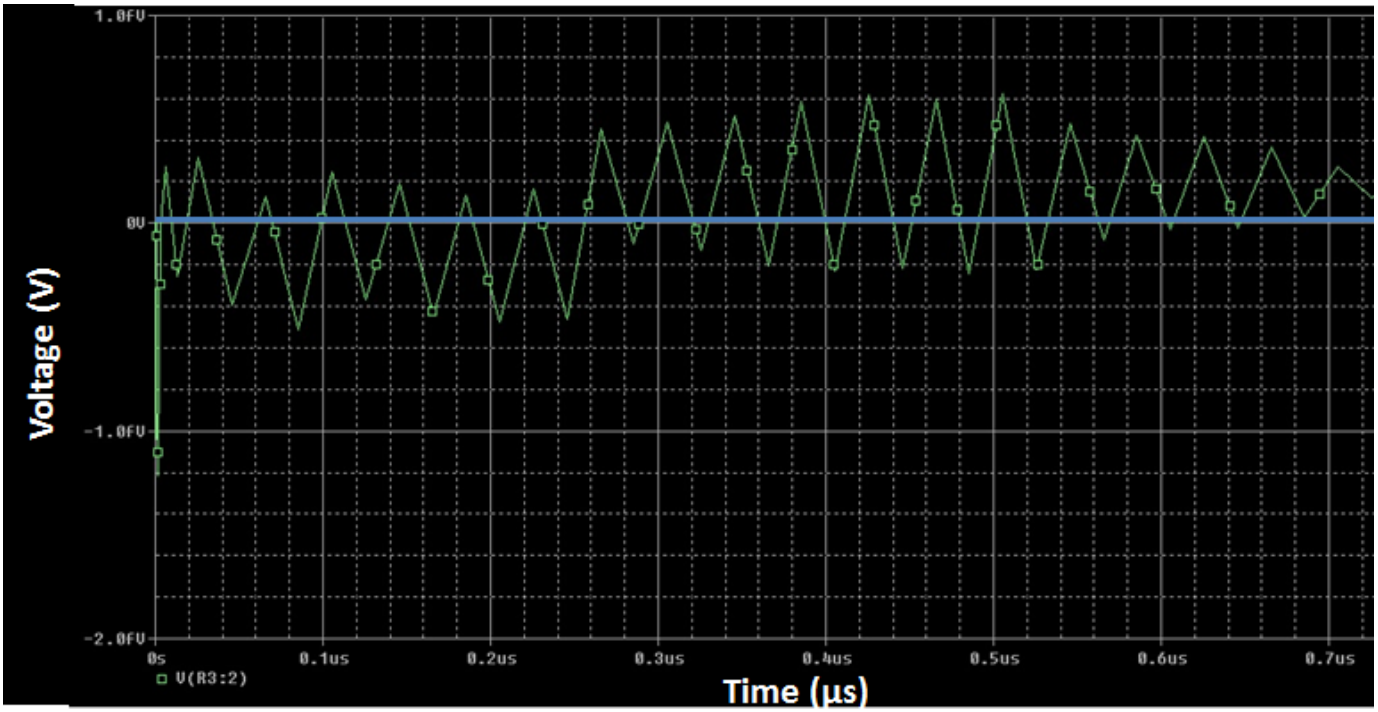

Figure 12. Output voltage graph from ideal ventilation measurement circuit, the green line illustrates the change in voltage as time progressed and the blue line shows the average

The output voltage graph above using the virtual testing method produced an oscillating curve around the average output voltage with peaks ranging in size. The inconsistent reading of the respiratory volume measurement (which is a manipulation of the output voltage graph) suggests that it is unlikely to detecting a decrease in tidal volume, and ultimately, in combination with respiratory sound data, an asthma exacerbation with 95% confidence. The p-value for the peak-to-peak values for this data was above 0.05 indicating that the trial was not statistically different from the other trials. Further manipulation for the output of the ventilation circuit will have to be done in the Arduino code to plot the respiratory volume change over time for accurate comparison. The graphs for this virtual testing method were consistent with each other over each trial with little to no variation. However, the detected changes in voltage did not indicate a volume change greater than 12% and therefore is an indication that this virtual patient would not be at risk of an asthma exacerbation at this time; this could be an accurate conclusion if the sound data was collected simultaneously. The virtual testing method validates the ventilation circuit; however, more work needs to be done on the coding portion to visualize the respiratory volume changes, the target variable.

Discussion

The previous design was used as a reference for the updated design; however, a fourth microphone has been added to help increase the signal-to-noise ratio and isolate cough and wheeze detection. Another modification was the added Bluetooth® module to allow the user to program the microcontroller wirelessly and transmit the respiratory volume and sound data in real-time to be analyzed by the physician. With the added Bluetooth® module, the software coding will need to be changed according to **Figure 11.** The overall output of the device needs to match the expected outcome of the environment testing and demonstrate a 95% reliability of detecting a decrease in respiratory volume change and if the patient was coughing concurrently at a 95% confidence level. The type I and type II errors would be less than to be less than 0.1 to reduce the number of false positives (false alarms) and false negatives over a series of trials. There were several limitations with the previous design's ventilation measurement. One of the limitations was that the device was prone to motion artifact. While consistent reading of ventilation was possible during a resting state, the reading became inconsistent and unstable when the subject was in motion. In addition, the elongation of the resistive bands was hindered and it led to an inaccurate measurement of ventilation when pressure was applied to the back of the subject as in sleeping or sitting on a chair. The new design's addition of the pockets for easy removal of the stretch sensors would allow the sensor to remain tighter against the body to reduce the amount of noise detected[13]. The added microphone would provide supplementary information about the wheezing and cough detection as it would be sampled from four data points rather than three and allow for more accurate statistical tests (a larger sample size). Real-time data collection would allow the physician to quickly analyze the lung function of the patient and compare the values to previous trials for an overall evaluation of the patient's condition over time. The real-time data collection would also allow the physician to analyze the accuracy and reliability of the design in monitoring the patient's asthma with visual cues from the patient in determining if the patient exhibited the indicators of an asthma exacerbation and severity.

Conclusion

In conclusion, the next steps that will be taken include testing the capabilities of the device. The circuitry of the ventilation amplification was validated using PSpice, but it should be tested with a user wearing the shirt. The Arduino will output voltage differences and transmit the via the Bluetooth® device to a nearby laptop. All items will be ordered and final prototype will be assembled. Additionally, all team members are IRB certified and as soon as validation is completed, testing can begin on patients who have already volunteered for Dr. Mathur's

research. Please refer to **Appendix D** to view a timeline for this project. Patients will have induced asthma exacerbations to test the device for approximately one hour under medical supervision. Calibration curves will be used to compare changes in outputs after the asthma exacerbation. After a significant amount of data is collected, the percent difference will be calculated. The percent difference refers to the change in the calibration and asthma curves. After comparing different patients' data, a T-test will be used to establish whether or not the percent change is significant. From there, the team will be able to make a suggestion on a gold standard that can be used in the future with this device.

Ultimately this design will be further improved so that a user can wear it throughout their day to allow for continuous asthma monitoring. It was confirmed that ventilation measurement through stretch sensors provides a simple and an accurate measurement of tidal lung volume changes through the virtual testing. Two signals are available from ventilation measurement: tidal volume and respiratory rate. The peak to peak value of respiratory volume measurement gives information about the tidal volume and the respiratory rate can be calculated by counting how many times a person inhaled during the given period of time. After this semester, a software can be introduced which will link the device and the physician's computer. Using the gold standard and other parameters, this software could be used to alert the physician of asthma exacerbations symptoms much sooner, thus preventing emergency medical care.

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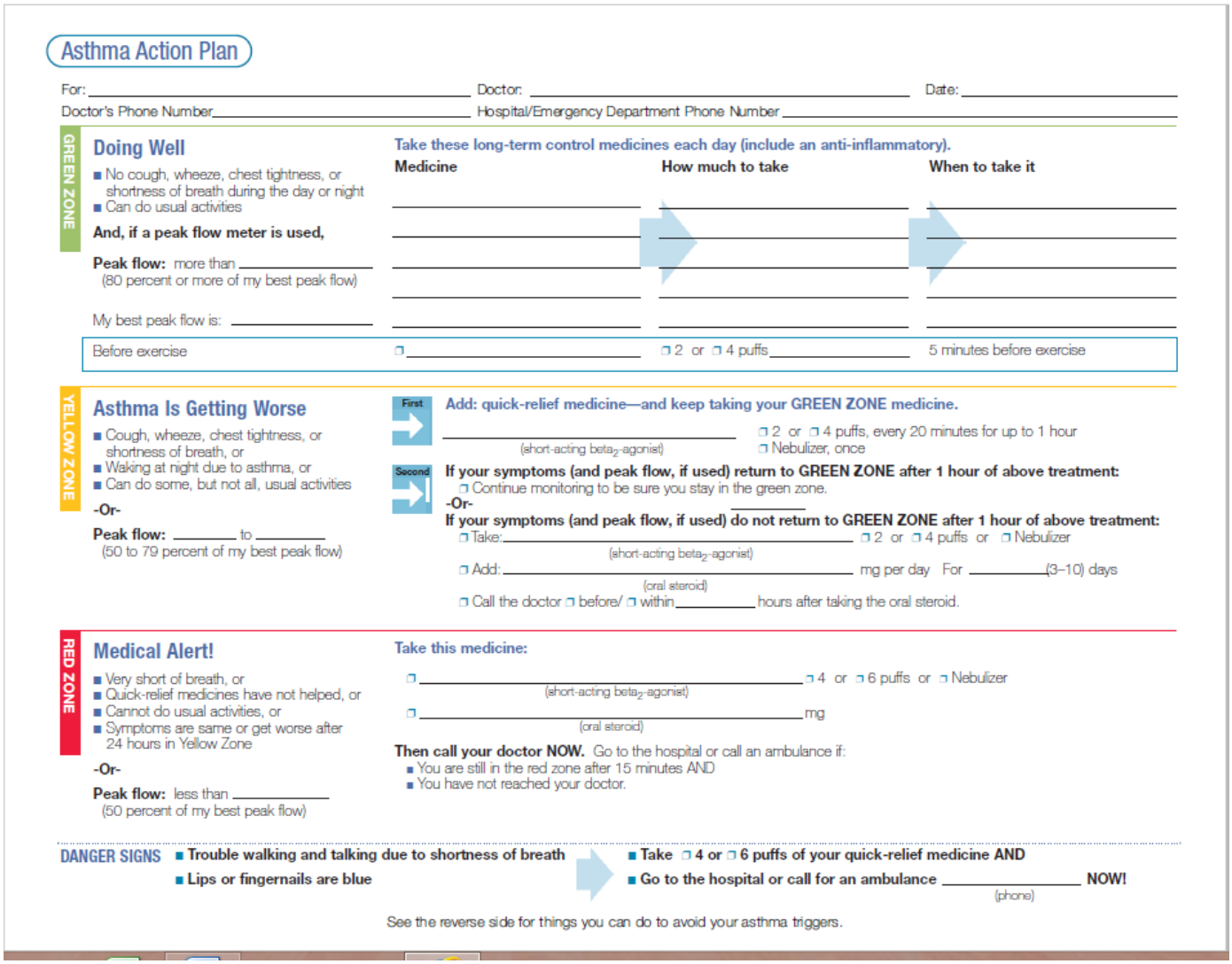
Appendix A.



Asthma Action Plan

For: _____ Doctor: _____ Date: _____

Doctor's Phone Number _____ Hospital/Emergency Department Phone Number _____

GREEN ZONE

Doing Well

- No cough, wheeze, chest tightness, or shortness of breath during the day or night
- Can do usual activities

And, if a peak flow meter is used,

Peak flow: more than _____
(80 percent or more of my best peak flow)

My best peak flow is: _____

Take these long-term control medicines each day (include an anti-inflammatory).

Medicine	How much to take	When to take it
Before exercise ❒ _____	❒ 2 or ❒ 4 puffs _____	5 minutes before exercise

YELLOW ZONE

Asthma Is Getting Worse

- Cough, wheeze, chest tightness, or shortness of breath, or
- Waking at night due to asthma, or
- Can do some, but not all, usual activities

-Or-

Peak flow: _____ to _____
(50 to 79 percent of my best peak flow)

First — **Add: quick-relief medicine—and keep taking your GREEN ZONE medicine.**

_____ (short-acting beta$_2$-agonist) ❒ 2 or ❒ 4 puffs, every 20 minutes for up to 1 hour ❒ Nebulizer, once

Second — **If your symptoms (and peak flow, if used) return to GREEN ZONE after 1 hour of above treatment:**
❒ Continue monitoring to be sure you stay in the green zone.

-Or-

If your symptoms (and peak flow, if used) do not return to GREEN ZONE after 1 hour of above treatment:
❒ Take: _____ (short-acting beta$_2$-agonist) ❒ 2 or ❒ 4 puffs or ❒ Nebulizer
❒ Add: _____ (oral steroid) mg per day For _____ (3–10) days
❒ Call the doctor ❒ before/ ❒ within _____ hours after taking the oral steroid.

RED ZONE

Medical Alert!

- Very short of breath, or
- Quick-relief medicines have not helped, or
- Cannot do usual activities, or
- Symptoms are same or get worse after 24 hours in Yellow Zone

-Or-

Peak flow: less than _____
(50 percent of my best peak flow)

Take this medicine:

❒ _____ (short-acting beta$_2$-agonist) ❒ 4 or ❒ 6 puffs or ❒ Nebulizer

❒ _____ (oral steroid) mg

Then call your doctor NOW. Go to the hospital or call an ambulance if:
- You are still in the red zone after 15 minutes AND
- You have not reached your doctor.

DANGER SIGNS
- **Trouble walking and talking due to shortness of breath**
- **Lips or fingernails are blue**

- **Take ❒ 4 or ❒ 6 puffs of your quick-relief medicine AND**
- **Go to the hospital or call for an ambulance _____ (phone) NOW!**

See the reverse side for things you can do to avoid your asthma triggers.

Asthma Action Plan, provided via National Heart, Lung and Blood (nhlbi.nhi.gov)

How To Control Things That Make Your Asthma Worse

This guide suggests things you can do to avoid your asthma triggers. Put a check next to the triggers that you know make your asthma worse and ask your doctor to help you find out if you have other triggers as well. Then decide with your doctor what steps you will take.

Allergens

❒ Animal Dander

Some people are allergic to the flakes of skin or dried saliva from animals with fur or feathers.

The best thing to do:

- Keep furred or feathered pets out of your home.

If you can't keep the pet outdoors, then:

- Keep the pet out of your bedroom and other sleeping areas at all times, and keep the door closed.
- Remove carpets and furniture covered with cloth from your home. If that is not possible, keep the pet away from fabric-covered furniture and carpets.

❒ Dust Mites

Many people with asthma are allergic to dust mites. Dust mites are tiny bugs that are found in every home—in mattresses, pillows, carpets, upholstered furniture, bedcovers, clothes, stuffed toys, and fabric or other fabric-covered items.

Things that can help:

- Encase your mattress in a special dust-proof cover.
- Encase your pillow in a special dust-proof cover or wash the pillow each week in hot water. Water must be hotter than 130° F to kill the mites. Cold or warm water used with detergent and bleach can also be effective.
- Wash the sheets and blankets on your bed each week in hot water.
- Reduce indoor humidity to below 60 percent (ideally between 30–50 percent). Dehumidifiers or central air conditioners can do this.
- Try not to sleep or lie on cloth-covered cushions.
- Remove carpets from your bedroom and those laid on concrete, if you can.
- Keep stuffed toys out of the bed or wash the toys weekly in hot water or cooler water with detergent and bleach.

❒ Cockroaches

Many people with asthma are allergic to the dried droppings and remains of cockroaches.

The best thing to do:

- Keep food and garbage in closed containers. Never leave food out.
- Use poison baits, powders, gels, or paste (for example, boric acid). You can also use traps.
- If a spray is used to kill roaches, stay out of the room until the odor goes away.

❒ Indoor Mold

- Fix leaky faucets, pipes, or other sources of water that have mold around them.
- Clean moldy surfaces with a cleaner that has bleach in it.

❒ Pollen and Outdoor Mold

What to do during your allergy season (when pollen or mold spore counts are high):

- Try to keep your windows closed.
- Stay indoors with windows closed from late morning to afternoon, if you can. Pollen and some mold spore counts are highest at that time.
- Ask your doctor whether you need to take or increase anti-inflammatory medicine before your allergy season starts.

Irritants

❒ Tobacco Smoke

- If you smoke, ask your doctor for ways to help you quit. Ask family members to quit smoking, too.
- Do not allow smoking in your home or car.

❒ Smoke, Strong Odors, and Sprays

- If possible, do not use a wood-burning stove, kerosene heater, or fireplace.
- Try to stay away from strong odors and sprays, such as perfume, talcum powder, hair spray, and paints.

Other things that bring on asthma symptoms in some people include:

❒ Vacuum Cleaning

- Try to get someone else to vacuum for you once or twice a week, if you can. Stay out of rooms while they are being vacuumed and for a short while afterward.
- If you vacuum, use a dust mask (from a hardware store), a double-layered or microfilter vacuum cleaner bag, or a vacuum cleaner with a HEPA filter.

❒ Other Things That Can Make Asthma Worse

- Sulfites in foods and beverages: Do not drink beer or wine or eat dried fruit, processed potatoes, or shrimp if they cause asthma symptoms.
- Cold air: Cover your nose and mouth with a scarf on cold or windy days.
- Other medicines: Tell your doctor about all the medicines you take. Include cold medicines, aspirin, vitamins and other supplements, and nonselective beta-blockers (including those in eye drops).

U.S. Department of Health and Human Services
National Institutes of Health

National Heart Lung and Blood Institute

For More Information, go to: www.nhlbi.nih.gov

NIH Publication No. 07-5251
April 2007

Appendix B.

Product Design Specifications

Function: The asthma shirt will allow continuous monitoring of tidal volume in lungs, respiratory rate, and detection of coughing or wheezing sounds from patients and send the analyzed data in real time to the patient. The asthma shirt would allow the patient to notice their symptoms of an asthma exacerbation sooner, allowing them to contact their physician for treatment.

Client requirements

- Measure lung volume
    - collect data from chest and lower abdomen
- Detect cough and lower airway wheeze from audio files
    - collect data from 4 regions of back (Right/Left mid-scapular ; Right/Left bottom of rib cage)
- Allow shirt to washable/detachable electronics
- Non-restrictive wires
- Size-adjustable; comfortable; burn-proof
- Battery life is at max 6 hours (for clinical testing)
    - Rechargeable for night-use testing
- Allow for continuous monitoring/transfer information quickly

Design requirements: This device description should be followed by list of all relevant constraints, with the following list serving as a guideline. (Note: include only those relevant to your project):

1. *Physical and Operational Characteristics*
    a. *Performance requirements:* The shirt must detect the severity and the combination of the main indicators of the onset of an asthma exacerbation: cough, shortness of breath, and wheeze over a 6-hr period with a maximum of 3 uses per day.
    b. *Safety:* The electrical wiring should be safe for the user. No electrical components should have direct exposure to the skin.
    c. *Accuracy and Reliability:* The detected signal will be within the 0.167 – 0.50 Hz range for respiratory rate and within the 100 Hz - 1600 Hz range for wheeze detection. The device should capture these signals with 95% CI. The signal-to-noise ratio should be no less than 40 dB [13].
    d. *Life in Service:* The product should last 1000 uses over 6-hr trials.

e. *Shelf Life*: Battery life should last 5 years with the ability to be recharged through a USB port. The product should be stored a dry area at room-temperature (25℃) to prevent cold damage to the electrical components.
f. *Operating Environment:* The product will be used in the clinical setting at room-temperature (25℃) handled by trained providers.
g. *Ergonomics:* The electrical storage container should provide an easy access point to the battery and encapsulate the circuit board so there are no loose wires. The user will be provided with a user manual if any electrical components need to be replaced (microcontroller, operational amplifiers, and other wires will be soldered on a PCB).
h. *Size:* The electrical storage container should not exceed 8.4 cm × 5.3 cm x 5 cm[13]. The shirt design should be modified for each adult shirt size: small, medium, large, extra large.
i. *Weight:* The electrical storage container should not weigh more than 5 lbs.
j. *Materials:* Velcro or any similar material should not be used for the shirt as it may produce additional background noise.
k. *Aesthetics, Appearance, and Finish:* The electrical storage container will have a rectangular shape with a smooth texture so it is comfortable for the user. The shirt should have no visual wires and be tight-fitting to the patient's' upper body.

2. Production Characteristics

a. *Quantity:* 1 shirt, 1 electrical storage container
b. *Target Product Cost:* Under $300 for all materials

3. Miscellaneous

a. *Standards and Specifications:* FDA approval may be required if this becomes a diagnostic tool in the future.
b. *Customer:* The main focus is to record tidal volumes and to audio data. Aesthetics should be considered later in the design process.
c. *Patient-related concerns:* The shirt must be washed between uses, thus the electrical storage container must be detachable. Data will be recorded and must be kept confidential. No identifiers will be used to store data, only the lung volume measurements and deconstructed audio files will be stored on a secure, log-in computer.
d. *Competition:* Hexoskin™ uses a similar setup, but they only focus on breathing patterns of athletes in different conditions.

Appendix C.

Materials

Order Date	Item	ID	Quantity	Website	Cost
2/1/2016	electret microphones	668-1389-ND	10	Digikey	$ 19.89
2/1/2016	resistive band (1m flexible Stretch Sensor cord)	RB-Ada-34	4	Robotshop	$ 48.80
2/1/2016	Arduino Bluetooth® module	Bluetooth® Mate Silver	1	Sparkfun	$ 24.95
2/1/2016	microcontroller: Arduino pro mini (3.3V)	DEV-11114	1	Sparkfun	$ 9.95
2/1/2016	microSD transflash breakout board	BOB-00544	1	Sparkfun	$ 9.95
2/1/2016	polymer lithium ion battery (2000 mAh)	PRT-08483	1	Sparkfun	$ 12.95
2/1/2016	FTDI Basic Breakout	DEV-09873	1	Sparkfun	$ 14.95
2/1/2016	female Headers	PRT-00115	1	Sparkfun	$ 1.50
2/1/2016	break Away Headers - Straight	PRT-00116	1	Sparkfun	$ 1.50
2/1/2016	break Away Male Headers - Right Angle	PRT-00553	1	Sparkfun	$ 1.95
				Total	$146.39

Table 1. Materials ordered for the project, updated on 2/1/2016

Appendix D.

National Institute for Occupational Safety and Health

Shirt Size	Chest (cm)	Waist (cm)
Small	32-34	26-28
Medium	34-36	28-30
Large	38-40	32-34
Extra Large	42-44	36-38

Table 2. Size chart listing chest and waist size in inches as posted on company's website

NIOSH Truck Driver Anthropometric Survey 2015[1]**:**

Chest Width in Men while standing:

Mean	Std. Dev
35.59 cm	4.28

Shirt Size - Chest Size	Z-value		Percentile
Small	32 cm	34 cm	20-36
	0.4672	0.3715	
Medium	34 cm	36 cm	36 - 54
	0.3715	0.09	
Large	38 cm	40 cm	71-85
	0.55	1.04	
Extra Large	42 cm	44 cm	93-98
	1.48	2.05	

Table 3. Percentile of population accommodated with shirt size

Sample calculation:

$$Desired\ value\ = Average - Z \cdot Standard\ Deviation$$

$$34\ = 35.59\ - Z(4.28)$$

$$Z = 0.3715$$

Reference:

[1] NIOSH Truck Driver Anthropometric Survey. (2015). Retrieved from http://www.cdc.gov/niosh/

Appendix E.

Current Timeline

Task	March				April					May
	5	12	19	26	1	8	15	22	29	6
Assemble shirt design										
Testing for tidal volumes										
Patient testing										
Submit for peer review										
Final Poster										

Table 4. Timeline for the rest of the Spring 2016 semester

Appendix F.

Methacholine Challenge

Written by: Chris Harty Date: 7/28/09

Purpose

This SOP describes the responsibilities of the research team members in conducting methacholine challenges to promote adherence to all applicable federal, state, and local laws, policies, and guidelines.

Scope

All investigators and designees responsible for methacholine measurements in patients.

Background

Methacholine testing is performed to measure the severity of bronchial reactivity. Nearly all asthmatics with active disease exhibit narrowing of their airways when they inhale low concentrations of methacholine. In an individual person, there tends to be less bronchial responsiveness as the asthma improves. There can be a wide variability in this test. For this reason, the methacholine challenge test is not a substitute for other measures of asthma activity. If too much methacholine is absorbed into the body, symptoms such as abdominal cramping, diarrhea, sweating, and salivation can occur. The activation of the airway or other organs, nerve receptors by the methacholine can be blocked by the drug atropine, which is the specific antidote for methacholine overdose.

Procedure

Inhalation Methods

Two-minute tidal breathing method:

- Patient breathes relaxed tidal volume breathes for two minutes. This technique is generally performed with a Wright Nebulizer in the pediatric population.

- Five-breath method:
  - Electronically controlled valve allows a pre-determined amount of methacholine from a nebulizer to be inhaled during inspirations. This technique generally utilizes a stand-alone dosimeter or digidoser.

Methacholine, Digidoser, and Nebulizer Setup

- Remove methacholine vials from refrigerator 30 minutes prior to conducting the challenge to allow them to warm to room temperature.
- Order vials in increasing order of administration starting with dilutent (#0).
- Never transfer solution from unmarked vials or syringes to the nebulizer because it is possible to mix up the concentrations.
- If in doubt, discard dose and draw up another.

KoKo Digidoser Setup

- Attach a KoKo filter to the KoKo DigiDoser and insert the nebulizer into the KoKo filter cone.
- Connect the pressure line outlet on the front of the DigiDoser handle to the pressure line inlet on the bottom of the nebulizer with the short piece of supplied tubing.
- Adjust the pressurized air source for 30 psi and connect it to the bottom of the DigiDoser with the long piece of tubing and occlude the nebulizer vent port.

KoKo Dosimeter Setup

- Turn on the dosimeter and adjust the settings as needed.
- Open up the air taink and set the regulator so that the pressure reaching the dosimeter is 30 psi.
- Attach the tubing from the dosimeter to the nebulizer.

Placing Solution #0 in nebulizer

- Swab the top of the vial of Solution #0 with alcohol and use a sterile syringe and needle to draw up 2.0 ml of Solution #0 from the multi-dose vial.
- Fill the nebulizer bowl with exactly 2.0 ml of Solution #0 and screw the bowl tightly into position. Ensure that the mouth of the bowl fits easily into the threads so that the plastic nebulizer threads are not damaged.
- Use a new syringe and new needle to draw up each solution. Do not use solutions which are not visibly clear. Use a new set of syringes and needles for each subject.

The Bronchial Challenge

- The subject may be seated (recommended) or standing, though this must be consistent throughout the study.
- Make sure to meet ATS/ERS standards for acceptability and repeatability during the baseline stage prior to starting the challenge. The highest acceptable FVC and FEV1 are used as baseline value. FEV1 must be greater than 70% predicted to proceed with the challenge.
- If the baseline FEV1 is less than the lower limit indicated in each protocol, the methacholine test should be deferred and the subject rescheduled for a later date.

Administration of Diluent

- Administer the diluent using the selected inhalation technique.
- Visually inspect nebulizer & dosimeter/digidoser for obvious errors or cracks.
- Perform spirometry 30 seconds and 90 seconds after the diluent solution (#0-Saline), with one FVC maneuver and acceptable-quality FEV1 attained at each time point.
- Be sure not to exceed more than four spirometry maneuvers after a dose.
- Spirometry maneuvers should not take more than 3 minutes to complete.
- The highest acceptable FEV1 of post-diluent (Solution #0) is the challenge reference value to which all other dose levels are compared during the challenge.
- If solution #0 does not result in a drop of ≥80% in FEV1 from the baseline reference point, proceed to administer the lowest Methacholine concentration, Solution #1.

- If the test solution (#0) causes the FEV1 to fall ≥80% of the baseline value, then the challenge should be terminated and administration of a bronchodilator is required.
- Calculate and record the post-solution (#0) FEV1 value and the ≥80% of reference. These are used for confirming a positive challenge and post-challenge safety levels.
  Administration of methacholine (Solution #1-10)
- Each concentration is administered in the same fashion. Discard the previous solution in the nebulizer and draw up 2.0 ml with sterile technique from the appropriate vial.
- Empty the container completely before filling with the next solution.
- Do not dry out the container or touch the inside of the nebulizer with your hands.
- Always double-check which dose you are administering. Keep used vials separate.
- Each successive set of inhalations of a methacholine concentration must start roughly five minutes from the end of the fifth inhalation of the previous dose.

Post-Dose Spirometry

- An ATS/ERS acceptable maneuver must be completed at 30 and 90 seconds after the end of the inhalation process of each concentration.

- If the highest acceptable FEV1 is ≥80% of the reference FEV1, continue the challenge with the next concentration.

- If the highest acceptable FEV1 has fallen ≥20% from the control FEV1, terminate the test and administer a bronchodilator.

- If the subject fails to fall ≥20% on the final concentration, terminate the test and administer a bronchodilator.

Bronchodilator reversal

- Administer a bronchodilator if the challenge was terminated because the FEV1 fell to at least 80% of the reference value after inhalation of a solution.
- Wait 15 minutes and then perform spirometry to check that the subject's FEV1 has returned to at least 90% of the baseline FEV1.

PC20 Calculation

- The computer will generally generate a PC20 value, otherwise utilize manual calculations.
- Always enter the value generated by the computer on the data collection form.

Cleaning/Disposal

- Dispose of all the syringes and needles in the proper biohazard (sharps) container.
- Dismantle the nebulizer assembly. Refer to the PFSS cleaning SOP for nebulizers for specific details.