SmHeart Headphones Preliminary Report

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BME 200/300

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Abstract

The team was given the task to properly monitor and record the pulse wave velocity and pulse transit time of an individual in order to properly determine their blood pressure and overall cardiovascular health. Current devices like blood pressure cuffs already exist to measure blood pressure but require manual usage typically and are not continuous in their recording of blood pressure over long periods of time. Smart watches alone are capable of tracking pulse, but they tend to remain inaccurate in their overall tracking analysis. To solve this issue, an over the ear headphone design that utilized a microphone to listen to the user's heartbeat was utilized. This device would be capable of measuring the pulse transit time via the time between the recording of the heartbeat and the pulse being picked up by a connected smartwatch via bluetooth. Initial testing of the prototype would utilize three methods. The first would track the microphone's ability to cancel out outside noises in order to focus on the sound of the heartbeat, the second would then see how well data collection is when compared to a blood pressure cuff in order to determine accuracy. The intended results should thus display the headset being capable of ignoring outside noise and being able to listen and track blood pressure levels in a similar accuracy to that of blood pressure cuffs. Intended results should show little to no variance data blood pressure tracking between headphones and existing devices as well as efficiently ignoring outside noises.

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I. Introduction

Over the past couple of years, since the outbreak of COVID-19, high blood pressure has been on the rise for much of the U.S. population. In order to properly track and identify cases of high blood pressure, tools such as blood pressure cuffs and pulse tracking technologies (smart watches, phones, etc.) are used to tackle this problem. However, such devices tend to be unable to provide constant, accurate tracking of blood pressure over a prolonged period of time. Many smart watches in this case are only about 34% accurate when tracking pulse [10]. This project will focus on developing an accurate, easy to use headphone device that is capable of continuously measuring their blood pressure while providing statistical representation of the data via an app. The cost effective design of this device will also provide practical usage for much of the population.

II. Background

Explaining Blood Pressure

Blood pressure is defined as the pressure exerted on a person's arterial walls. This can be split into two types of pressure, systolic and diastolic. Systolic pressure is the blood pressure produced when the heart contracts. During this time, blood pressure is at a peak pressure value. Diastolic is the opposite of systolic, this is the low points in blood pressure produced by the relaxation of the heart after contraction. A general healthy blood pressure range is 120/80 mmHg (≈16kPa/10.7kPa)[7] with the first number being the systolic pressure and the second one being diastolic.

Pulse Wave Velocity and Pulse Transit Time

Pulse wave velocity is the speed at which blood travels from one arterial node of the body to the other. It can be utilized in blood pressure applications for its direct correlation between the two as the higher the blood pressure, the higher the pulse wave velocity[4]. This correlation is due to the same amount of blood being pushed through an increasingly smaller tubular space thus causing pressure to increase. Pulse transit time is the time blood takes to travel from one arterial node to the other. To track this, it is possible to simply listen or feel for the heartbeat and then track how long it takes to feel that same pulse somewhere else in the body. To connect these two measurements, a simple equation can be used[4]:

$$PWV = \frac{Distance\ between\ nodes}{PTT}$$

Current Styles of Measuring Blood Pressure

Figure 1. Blood Pressure Cuff

Currently, blood pressure is commonly measured by a blood pressure cuff (see figure above). However, this method is considered uncomfortable by most and requires someone else to operate the device. Because of its accuracy, it is used by professionals in a clinical setting. There are far significantly more smart watches on the market that are able to measure pulse than those that are able to measure blood pressure this

Clinical Significance

A constant measurement of blood pressure would give a better idea into one's own heart health and would provide more insight into when high blood pressure situations occur. PTT and PWV are both good indicators of blood pressure and being able to have convenient measurement of this data could provide an earlier insight into worrying circulatory health conditions.

Client

Dr. Jeffrey Koziol is an ophthalmologist with 48 years of experience in the medical field [3]. He is interested in creating smart headphones for patients with elevated blood pressure to help them monitor their own health.

Product Design Specifications

The client had asked that headphones be designed and fabricated that would be capable of pairing with a second device and measuring the user's Pulse Wave Velocity and Pulse Transit Time through a microphone. Because the measurements are taken by a microphone, background noise must be blocked out. The headphones must also contain speakers, so that the user can use them like ordinary headphones. When designing these headphones, it is important that the headphones should have similar mass and size to that of average headphones on the market. The measurements taken should be recorded on an app or program for the user to reference. For more information, see the Full PDS in Appendix A.

III. Preliminary Designs

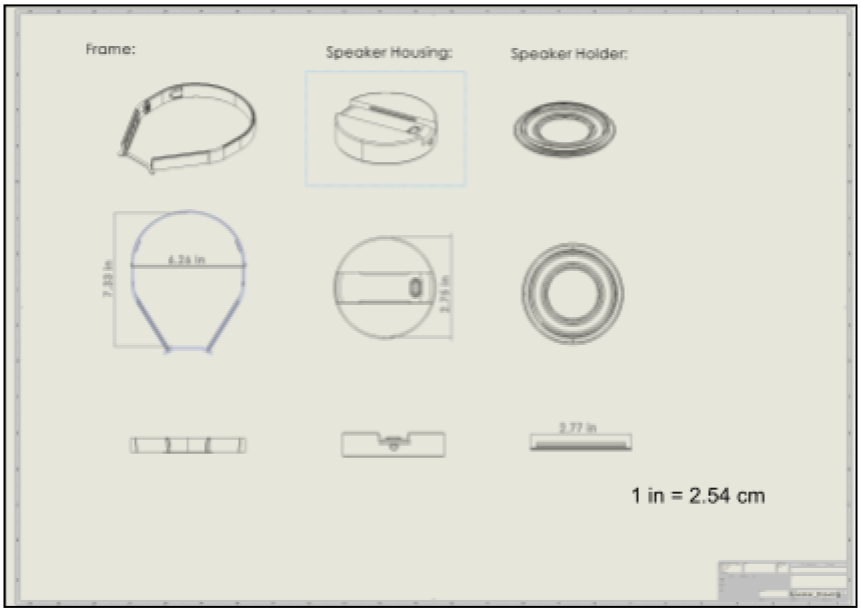


Figure 2. Drawing of Design #1

Design #1 Headband

The headband design is an addition onto a pair of traditional style over the ear headphones that would have a microphone attached near the base of the padding around one of the ears. This would allow an auditory input to be taken along the carotid artery. This digital signal could be transmitted via bluetooth to the smartphone where calculations would be done to calculate the PTT and PWV.

An advantage of using this design is that it would allow the microphone signal to be encased within the sound canceling barrier. This would allow a minimized need for algorithms used to isolate the heart beat signal. It is also a commonly used design on the market, so it is known that this design is comfortable and safe.

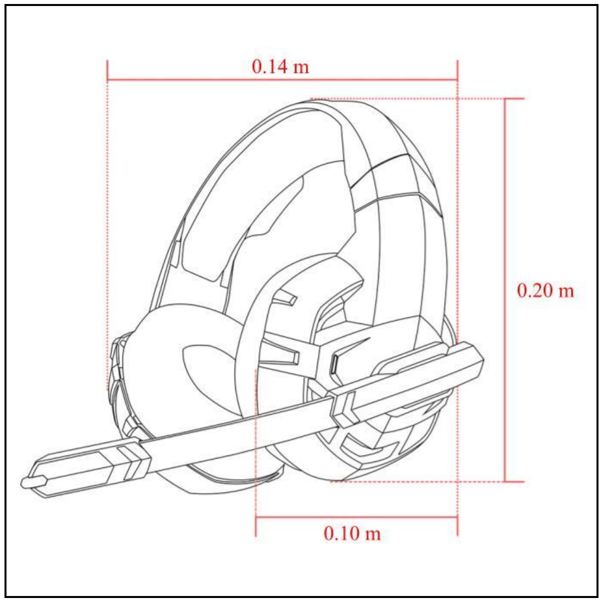


Figure 3. Drawing of Design #2

Design #2 Gamer Headphones

The gamer headphones design is a depiction of gaming headsets in shape and parts. The microphone that comes out from the left side of the headphone should be easily adjusted and reaches the artery area in the neck. The team will alter the programming system of a normal gaming headphone to add different modes. First mode will be the default mode such that the user would be able to use the microphone for inputting audio. Second mode would be the pulse hearing in which the microphone is adjusted next to the artery to record pulse sound. In the pluse hearing mode, the team will use computer algorithms to eliminate background noises and convert sound waves into PTT and PWV measurements.

The idea of this design is simple but it would be hard to implement due to the need to rely on algorithms. In addition, it would not be comfortable for the user to keep adjusting the microphone around different modes.

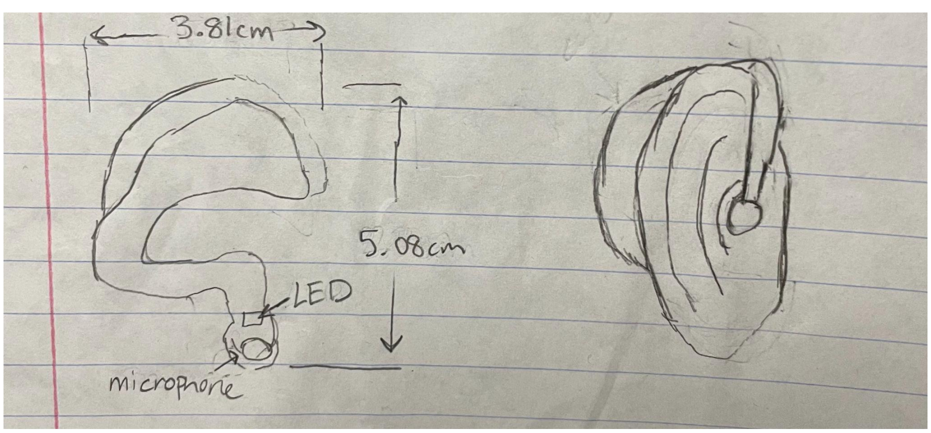


Figure 4. Drawing of Design #3

Design #3 Wrap Around

The wrap around design is a modified version of in-ear earbuds that wrap around the ear.

A microphone would be installed to the tip of the earbud and would be used to capture the user's heartbeat. An LED would also be added to the earbud that would be used in combination with a smartwatch to record the user's heart rate using a PPG signal.

This lightweight design would provide comfort and security to the user. However, the small, complex parts would result in a more difficult fabrication process. The in-ear design instead of over-the-ear would also result in more interference from outside noise, possibly making it difficult for the microphone to pick up the heartbeat.

IV. **Preliminary Design Evaluation**

Design Matrix

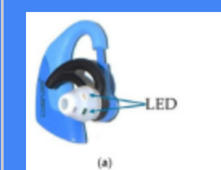
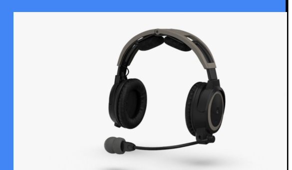
		Design 1 - Headband		Design 2 - Wrap Around		Design 3 - Gamer Headphones	
							
Criteria	Weight	Score (10 max)	Weighted Score	Score (10 max)	Weighted Score	Score (10 max)	Weighted Score
Effectiveness of measurements	25	10	25	10	25	7	18
Ease of fabrication	20	10	20	6	12	10	20
Ease of use	20	7	14	10	20	6	12
Comfort	15	9	14	8	12	10	15
Cost	10	5	5	7	7	8	8
Safety	10	10	10	10	10	10	10
Sum	**100**	**Sum**	**88**	**Sum**	**86**	**Sum**	**83**

Table 1: Completed Design Matrix of the three preliminary designs

Criteria 1: Effectiveness of measurements

This was given the highest weight (25) because it was highly stressed by the client. It is extremely important that the design is able to measure the user's heart accurately. Design 1 was given a perfect score for this. This can be explained by the placement of the microphone inside the speaker housing. This location would allow the microphone to experience little to no disturbance from background noise which would tamper with the recordings. Design 2 was also given a perfect score because of the microphone's proximity to a spot on the ear that is responsible for highly accurate measurements. Design 3 was given a weighted score of 18/20 because of the microphone's susceptibility to exposure of background noise

Criteria 2: Ease of fabrication

This was given a high valued weight (20) because it is an essential design requirement. Because of the amount of components that are involved in these headphones, it will be easier to start with headphones larger in size than ones that are smaller in size. This is why a perfect score was given to both Design 1 and Design 3. These designs are relatively similar in size; therefore, its fabrication process will be similar. Design 2 was given a lower score because of its smaller size. This could pose a problem because fitting many components in a smaller skeleton is difficult to perfect.

Criteria 3: Ease of use

This was given a relatively high weight of 20 due to its importance towards gathering accurate data. One of the main motivations for this project was to create a way of measuring blood pressure that is simple and can be done quickly. Also, due to the age range of the projected users, it is important that the technology be easy to understand. The wrap-around design was given a perfect score in this category because it would automatically connect and start gathering data as soon as it is placed in the ear. The headband design was given a lower score because it needs to be manually connected by the user. Finally, the gamer design was given the lowest score due to the complications with the different modes.

Criteria 4: Comfort

This was given a weight of 15 due to the criteria's importance for the user's experience while wearing the headphones. It is crucial that the user is still comfortable wearing the device while completing daily activities. However, this design aspect is less important than the overarching goal of obtaining accurate numbers. Design 2 was scored the lowest in this field because

Criteria 5: Cost

This was tied for the lowest weighted category because the team was given a high budget of $5,000 for this project, so the difference in cost for each design would be relatively negligible. The gamer design was given the highest score in this category (8) because it involves simply modifying an already existing headset rather than starting from scratch. The wrap-around design was given a slightly lower score for similar reasons, however the use of more complex parts combined with smaller design may result in more fabrication errors, thus driving the cost up. Finally, the headband design was given the lowest score of 5 because of the material cost of 3d printing the headset.

Criteria 6: Safety

This was tied for the lowest weighted category because, due to the nature of the project, none of the designs have any aspects that could really be considered unsafe. For that reason, each design was given a perfect score in this category.

Proposed Final Design

Due to its highest score on the design matrix, the proposed final design is the headband. Out of the three, this design has the best ability to reduce background noise which is imperative for getting proper measurements. It also will be comfortable for the user to complete daily activities with. Lastly, this design will be relatively easy to fabricate making it feasible for project completion.

V. Fabrication/Development Process

Materials:

Arduino Materials

For testing with an arduino we will need to test a few types of microphones in order to finalize what kind will work best for minimizing background noise. Along with this we will need a breadboard, wires, resistors, capacitors, operational amplifier and an auxiliary port for testing wiring and listening to the microphone input or displaying the signal via the arduino.

Headphone Material

The headphones will be 3D printed using ABS plastic. This is because it is widely accessible and fairly inexpensive compared to other plastics[1]. We will cover the speaker/microphone housing with standard ear cushions compatible with average sized headphones. This will block out background noise and make the user's experience with these headphones as comfortable as possible.

Methods

The methods for collecting will consist of 2 major sensors, the microphone in the headphones and the already in use heart rate sensor inside of the user's smart watch. Since the headphones will be designed with implementation with a variety of smart watches, much more freedom of data collection is possible with the microphone. The microphone is planned to be implemented inside the noise canceling cuff of the headphones such that effort put into isolating the heart rate signal is minimized. Any computing should be done within the program so the signal from the microphone input should be broadcast via bluetooth to the smartphone where it will do the calculations.

Testing:

Testing will occur in several stages, finding a suitable microphone in order to pick up heartbeat signals, designing our headphone enclosure such that it will comfortably sit in the location that will pick up this signal reliably, taking that input and estimating the PTT and PWV to estimate blood pressure and comparing that to a reading from a blood pressure cuff. Once all of these steps are proven possible we will be able to revise our design or calculations in order to make the final reading more accurate until it is within an acceptable range.

Microphone Testing

The microphone's accuracy will be gauged by attempting to measure the heart beat when placed in an ear in a quiet environment and compared against a stethoscope. The microphone will then be gauged in an environment with moderate background noise and an environment with loud background noise. The microphone that is capable of picking up the heartbeat sound best when compared to a stethoscope in the various environments will be used for the proto-type design.

Microphone testing will also require a combination of other factors including but not limited to: placement of microphone, type of microphone and applied algorithms to isolate heartbeat signal. The placement of the microphone should be close enough to the carotid artery on any given user that it is able to hear the signal clearly and minimize unwanted background noise. The type of microphone will also matter because different microphones have differing pickup range patterns, ideally the one we will use will be small enough to comply with size restraints, light enough to comply with weight requirements and have a pickup pattern that is effective for our application. Finally, an algorithm to minimize background noise may be needed in order to isolate heart rate signals to more accurately estimate our results. This could help to make our readings more accurate, but reliance on this could use a lot of computing power and ultimately lead to a less reliable final output. As well as requiring an advanced understanding of computer science that may not be possible within this project's timeline.

Data Testing

The accuracy of the data gathered with the prototype will be determined by comparing the calculated blood pressure from the headphones with the blood pressure found by using a blood pressure cuff similar to those used by physicians.

VI. <u>Results</u>

The data from the testing will be analyzed by firstly collecting baseline data utilizing instruments such as a stethoscope and a blood pressure cuff. The testing data can be statistically tested against the baseline data allowing for standard deviation, ANOVA, and variance calculations to determine the best performing setup and equipment for the proto-type.

VII. <u>Discussion</u>

No testing has been conducted and no data has been collected to analyze.

VIII. <u>Conclusion</u>

The client wants a device that will be able to be paired with a smartwatch in order to estimate blood pressure from an auditory input. This device should add minimal weight to a traditional style of headphones, be accurate, be able to be in use over extended periods, and be comfortable for the user. Our team plans to propose a design that will prove this idea possible and refine our design in order to make it as accurate as possible. This device also should pair with an app or program that can display and record a record of blood pressure over time. Our group plans to design a rudimentary program that can display our results that would be able to be refined into a more polished product later.

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X. Appendix

Appendix A: Product Design Specifications (PDS)

Problem Statement:

The team has been tasked by the client to design and develop headphones to record a cardiac pulse signal and pair this with a smart watch to measure PTT and PWV. The design of the headphones should be small and portable with a microphone that would be attached instead of a speaker. A bluetooth link to the user's watch and phone with the headphones will be required. Both the headphone and the user's watch will create a pulse that should thus measure the Pulse Transit Time and Pulse Wave Velocity of the body. This data will be recorded and shown on an app that can be accessed by the user on their phone or smart watch. The design of the headphones should be similar to that of Apple airpods and should work with ios systems.

Function:

Heart disease and high blood pressure are a rising phenomenon that has been affecting the U.S. The need to track and monitor such issues has thus become a much more important goal for many to ensure their cardio health is properly monitored. This device will cover such issues by utilizing a highly receptive microphone that is attached to the headphones that will be capable of listening and recording the rate of the pulse. The headphones will be paired with a smartwatch via bluetooth and will track the pulse rate from the wrist node of the artery to the arterial node the headphones are listening to and thus be capable of calculating and recording the Pulse Transit Time (PTT) and Pulse Wave Velocity (PWV). An app will also be provided where the recorded data will be stored and showcased to the user in an informative and graphical manner.

Client Requirements:

- The device must be able to connect via bluetooth to phone
    - Headphones should be linked to an app
    - Data recording should be continuous and stored on the app
- Headphones should be able to work like regular headphones (i.e. able to play music)
- Headphones and accompanying devices should be capable of gathering and calculating Pulse Wave Velocity (PWV) and Pulse Transit Time (PTT)
- App should be capable of displaying user's cardio health and statistics

Design Requirements:

1. **Physical and Operational Characteristics**

a. *Performance Requirements:*
    i. The device should be able to function for everyday use.
    ii. Block out noise so that the heart measurements are not tampered with.
b. *Safety:*
    i. Ensure that material will not be invasive to the ear.
    ii. The audio levels (decibels) should be within range of comparable items on the market.
c. *Accuracy and Reliability:*
    i. It is expected that the blood pressure measurements from the headphones should mirror that from a typical blood pressure cuff device.
        1. For healthy individuals: The diastolic should be within the range of 50-80. The systolic should be within the range of 100-120[1].
        2. For individuals with heart problems, these values should be either significantly higher or lower than these ranges.
d. *Life in Service:*
    i. Lifespan is approximately two years.
e. *Operating Environment:*
    i. The headphones will be exposed to a variety of conditions.
        1. The device will pick up measurements under heavy background noise.
        2. When used outside, the device will withstand environmental conditions such as severe humidity.
f. *Ergonomics:*
    i. The headphones should be portable and easy to wear for the user with little to no weight difference to regular headphones.
        1. Exercise and most daily activities with this device should feel comfortable.
g. *Size:*
    i. The headphones should not be too bulky on the head/ear.
    ii. The size will be similar to that of an average headphone.
h. *Weight:*
    i. Mass and weight of the smart headphones shouldn't exceed 20% more than the mass and weight of normal air-pods or headphones
        1. A singular air-pod weighs 4.00 grams
        2. An average headphone weighs about 0.65 lbs

i. *Materials:*
    i. The material should be smooth for the inner ear. The materials that can be used for this include several types of plastic, rubber, and bendable metals

ii. To detect signals, a microphone and/or an LED will be used.

2. **Production Characteristics**
   a. *Target Product Cost:*
      i. The research, development, and initial production should be within a $5,000 budget.
   b. *Quantity:*
      i. One set of headphones will be created for this project.
3. **Miscellaneous**
   a. *Standards and Specifications:*
      i. A user must not exceed over 80dB of sound over 48 hours[2]
   b. *Customer:*
      i. Adults from the age of 40 to 80 years old
   c. *Patient Related Concerns:*
      i. The user's data will be stored on the app.
   d. *Competition:*
      i. No known competing designs found.

Appendix B: Preliminary Design Sketches

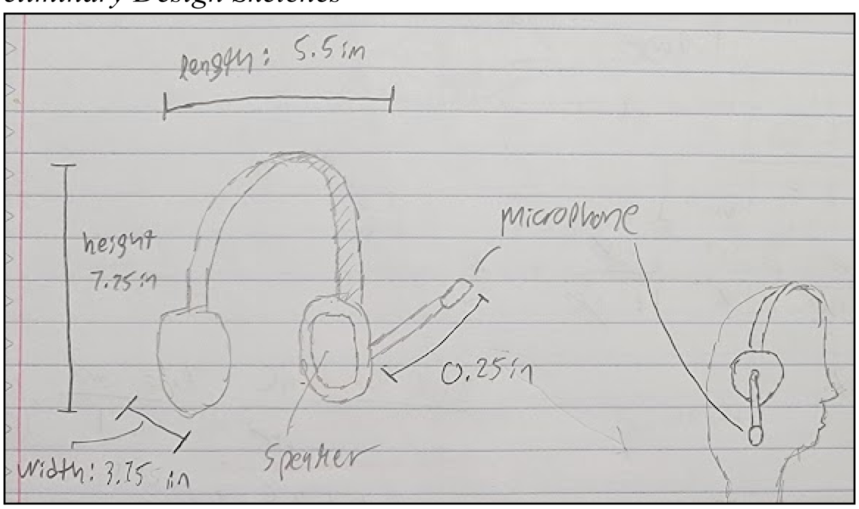

Figure 5. Preliminary Gamer Headphones design Sketch