Comfort Evaluation of a Customized Additively Manufactured Headset

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COMFORT EVALUATION OF A CUSTOMIZED ADDITIVELY MANUFACTURED HEADSET

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COMFORT EVALUATION OF A CUSTOMIZED ADDITIVELY MANUFACTURED HEADSET

by

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THESIS

Presented to the Faculty of the Graduate School of
The University of Texas at El Paso
in Partial Fulfillment
of the Requirements
for the Degree of

MASTER OF SCIENCE

Department of Industrial, Manufacturing and Systems Engineering
THE UNIVERSITY OF TEXAS AT EL PASO
August 2022
Acknowledgements

During the project, particular individuals contributed and guided the creation of this final thesis. I would like to express my most sincere gratitude to the W.M. Keck Center for 3D Innovation for providing the technical guidance, equipment, and resources. Also, I would like to thank the GN team who provided useful opinions and directions for the research. It is also important to recognize the effort and level of support from my research colleagues Hugo Estrada and Brenda Valadez who along with Raymundo Loera, Joshua Carrillo, Luis Castillo, and Beth Dittberner helped my research significantly as they participated in the human subject investigation themselves. I would also like to thank the IMSE Department, who was supportive of my work and provided me with great opportunities and experience to further my technical knowledge. A sincere thanks to my mentor Dr. Lopes who made this research possible by offering the mentorship for the project and pushing me to strive for greatness in everything I did. To Dr. Espalin, who provided helpful technical inputs, and was also interested in this section through the project. To Dr. Wicker, who opened his doors for me to help conduct this research. To Dr. Contreras who was always understanding and offered me many opportunities, among which is to work as his TA.
Abstract

Comfortability and end user satisfaction are two of the main objectives in any human-centered product. This is especially important when the product requires interaction with the human head and with the brain. For this research, a customized wearable headset fabricated using additive manufacturing (AM) techniques along with three commercial head devices were analyzed to provide an evaluation of comfort and determine the factors that affect comfort score. The customized headset protects users from dangerous sound frequencies and levels that can permanently damage the human ear (around 82 dB, for extended periods of time). This device is designed to preserve spatial cues and enable sound localization. The commercial earmuff and hearing devices (non-hearing protection) were included in this study as a benchmark comparison to analyze the customized headset comfort. The study demonstrated the relationship between force applied by the headsets and hearing devices on a human surface, the head width, and gender to assess the comfortability of the devices. The study indicated that clamping force and location of the devices are the key factors that dictate the comfort of a device. The AM customized device which was the heaviest and had the largest clamping force reading, got the highest comfort score, about five (in a scale from 0 to 10), corresponding to just below discomfort. Future headset designs need to evaluate materials that minimize the clamping force while providing the required hearing protection and optimize the interface with the external ear canal.
# Table of Contents

Acknowledgements ........................................................................................................ iv

Abstract ............................................................................................................................ v

Table of Contents ............................................................................................................. vi

List of Tables .................................................................................................................... ix

List of Figures .................................................................................................................. x

List of Illustrations ......................................................................................................... xii

Chapter 1: Introduction ..................................................................................................... 1

1.1 Additive Manufacturing ......................................................................................... 1

1.2 Custom-Made Earmuff Model .............................................................................. 4

Chapter 2: Literature Review ......................................................................................... 7

2.1 Out of Ear Comfort ................................................................................................. 7

2.1.1 Thermal Comfort ............................................................................................... 7

2.1.2 Acoustic Comfort ............................................................................................... 8

2.1.3 Expectative Comfort ....................................................................................... 9

2.1.4 Physical Comfort .......................................................................................... 10

Chapter 3: Experiment Design & Methodology ........................................................... 13

3.1 Silicon Ear Model Development ............................................................................ 13

3.1.1 Building and Editing the Raw 3D Scan ......................................................... 14

3.1.2 Building a Negative Mold ............................................................................. 16

3.1.3 Building a Base Mold ................................................................................... 19

3.1.4 Silicon Casting ............................................................................................ 22

3.2 Building a Sizable Base ......................................................................................... 24

3.2.1 Lower Resting Base ....................................................................................... 25

3.2.2 Sliding Stand ................................................................................................ 26

3.2.3 Experiment Design, Silicon Model Approach and Summary ......................... 28

3.3 Clamping Force Setup ............................................................................................ 29

3.3.1 Mechanical Gauge ....................................................................................... 29

3.3.2 Base Design .................................................................................................. 30

3.3.3 Sliding Base .................................................................................................. 31

3.3.4 Fixed Side and Sliding Earmuff Holding Base ............................................... 32
3.4 Force Sensing Resistor ........................................................................................................... 34
   3.4.1 Sensor Technical Characteristics .................................................................................. 34
   3.4.2 Elegoo to FSR Sensor Interface .................................................................................... 35
   3.4.3 FSR Calibration ............................................................................................................. 37
   3.4.4 Experiment Design FSR Input ....................................................................................... 39
3.5 Qualitative Input (Questionnaire) ....................................................................................... 40
   3.5.1 Experiment Design and Protocol (Questionnaire) ........................................................ 41
Chapter 4: Results ....................................................................................................................... 44
   4.1 FSR Silicon Model Readings ............................................................................................. 44
   4.2 FSR Human Readings ....................................................................................................... 47
   4.3 Comparing Clamping Force Set Up with FSR Readings .................................................. 48
   4.4 Comparing Clamping Force Set Up with Human Comfort Scores .................................. 50
   4.5 Questionnaire Comfort Score .......................................................................................... 52
   4.6 Questionnaire Area Mapping, Human Input .................................................................... 59
   4.7 Clamping Force Set Up ..................................................................................................... 64
   4.8 Analyzing Bias .................................................................................................................. 69
   4.9 Comparing Sample by Sex Group .................................................................................... 71
   4.10 Weight Vs Comfort Analysis .......................................................................................... 73
Chapter 5: Conclusion ................................................................................................................ 76
   5.1 FSR and Silicon Model ..................................................................................................... 76
   5.2 Comparing Clamping Force Set Up with Human Comfort Scores .................................. 76
   5.3 Area Mapping, Human Input ............................................................................................ 77
   5.4 Analyzing Bias .................................................................................................................. 77
   5.5 Comparing Sample by Sex Group .................................................................................... 77
   5.6 Weight Vs Comfort Analysis ............................................................................................ 78
   5.7 Optimizing Comfort V13 ................................................................................................ 78
   5.8 General Conclusion and Future Analysis ......................................................................... 79
References .................................................................................................................................... 80
Appendix I. Questionnaire ......................................................................................................... 84
List of Tables

Table 3-1 Summary Process Development, Silicon Ear Model .......................................................... 29
Table 3-2 Summary Process Development, Clamping Force Setup .................................................. 34
Table 3-3 Summary Process Development, FSR ............................................................................. 40
Table 4-1 Distances Vs Recorded Forces .......................................................................................... 49
List of Figures

Figure 1.1: MakerBot 3D printer (Makerbot website) .......................................................... 3
Figure 1.1.1: AM Custom Made Earmuff, V13 .................................................................................. 5
Figure 1.2.2: AM Custom Made Earmuff, In Ear Components ...................................................... 5
Figure 1.2.3: AM Custom Made Earmuff, Outer Ear Shape .............................................................. 6
Figure 2.1: Acoustic Comfort Setup (Gaudreau, 2016) ................................................................. 8
Figure 2.2: Expectative Comfort Questionnaire (Veale, 2009) ....................................................... 10
Figure 2.3: Initial Clamping Force Set Up ....................................................................................... 11
Figure 2.4: Sample Setup, TEKSCAN sensor ................................................................................... 12
Figure 3.1: preprocessing on the right, post processing on the left ................................................. 14
Figure 3.2: hollow mesh on the left, solid earmold on the right ...................................................... 15
Figure 3.3: first 3D printing of the negative earmold ..................................................................... 17
Figure 3.4.1: Dimension Orientations ............................................................................................... 18
Figure 3.4.2: 3D software model of the second version for negative ear mold ............................ 18
Figure 3.4.3: physical second version of the negative mold ............................................................. 18
Figure 3.5: Positive ear shape, base creation one, left is the front view, and right is a sideways illustration ........................................................................................................................ 19
Figure 3.6: L shape figure, base ........................................................................................................ 20
Figure 3.7.1: final base assembly ....................................................................................................... 21
Figure 3.7.2: legs and hinges .......................................................................................................... 21
Figure 3.8: final mold, with silicon casted ....................................................................................... 23
Figure 3.9: left; translucent front image, right; translucent image, back ......................................... 24
Figure 3.10: lower resting base for the silicon base ......................................................................... 25
Figure 3.11 sliding stand .................................................................................................................. 26
Figure 3.12: two piece sliding base Design ...................................................................................... 27
Figure 3.13.1: Lower Body component measurements, sliding base, units in mm ....................... 27
Figure 3.13.2: Upper component measurements, sliding base, units in mm .................................. 27
Figure 3.14: finalized silicon model, with adjustable set up ............................................................ 28
Figure 3.15: Baoshishan Mechanical Gauge (Amazon webpage) ............................................... 30
Figure 3.16: base for Clamping Force Setup to the left, same object with dimensions to the right. 30
Figure 3.17: Sliding Base complete assembly left, upper component middle, inferior component right ........................................................................................................................................ 31
Figure 3.18.1: Sliding Base Dimensions ......................................................................................... 31
Figure 3.18.2: Sliding Base Dimensions Pt2 ..................................................................................... 32
Figure 3.19.1: Set up clamping Force, side view ............................................................................. 32
Figure 3.19.2: Set up clamping Force, top view .............................................................................. 33
Figure 3.19.3: Set up clamping Force ............................................................................................... 33
Figure 3.20: Pressure sensor (Amazon website) ............................................................................. 35
Figure 3.21: Wiring Schematic from Arduino to FSR (Adafruit) .................................................... 36
Figure 3.22: Elegoo wiring, left. complete setup with the FSR sensor, right. ............................... 37
Figure 3.23: Intron Machine Setup for Calibration ........................................................................ 37
Figure 3.24: Line Fitting, Sensor Calibration .................................................................................. 38
Figure 3.25: 1hr FSR Human Trial ................................................................................................. 39
Figure 4.1.1 Silicon Model FSR sensor set up .............................................................................. 45
Figure 4.1.2 V13 Earmuff comparison of the two testing surfaces ........................................46
Figure 4.1.3 3M Pro-Grade comparison of the two testing surfaces ..................................46
Figure 4.2.1 FSR Human Readings, comparison of the two earmuff sets ..............................47
Figure 4.3.1 FSR Data Vs. Clamping Force Setup .................................................................48
Figure 4.3.3 Correlation Table Reference ..............................................................................50
Figure 4.3.4 Correlation, Comparing Clamping Force Setup Vs. FSR Reading .....................50
Figure 4.4.1 Clamping Force Setup Vs. Comfort Score .........................................................51
Figure 3.4.2 FSR Vs. Comfort Score .....................................................................................51
Figure 4.5.1 Comfort scale ....................................................................................................52
Figure 4.5.2 Sample size comparison ....................................................................................53
Figure 4.5.3 Grouping for Sample Size Comparison ..............................................................53
Figure 4.5.4 Comfort Score Human Input ............................................................................54
Figure 4.5.5 Grouping for Comfort Score Human Input .......................................................54
Figure 4.5.6 3M Pro Grade Vs. Head Breadth .......................................................................55
Figure 4.5.7 Grouping for 3M Pro Grade Vs. Head Breadth ................................................56
Figure 4.5.8 V13 Vs. Head Breadth .......................................................................................56
Figure 4.5.9 Grouping for V13 Vs. Head Breadth .................................................................57
Figure 4.5.10 V13 Sony wh – 1000xm4 Vs. Head Breadth ....................................................58
Figure 4.5.11 Grouping for Sony wh – 1000xm4 Vs. Head Breadth .......................................58
Figure 4.6.1 Area Mapping color coded ear ..........................................................................60
Figure 4.6.2 GN Discomfort Area Mapping, Pareto Chart ..................................................61
Figure 4.6.3 3M Pro-Grade Discomfort Area Mapping, Pareto Chart .................................62
Figure 4.6.4 wh – 1000xm4 Discomfort Area Mapping, Pareto Chart .................................63
Figure 4.6.5 wf – 1000xm4 Discomfort Area Mapping, Pareto Chart ..................................64
Figure 4.7.1 Clamping Force Set Up .....................................................................................65
Figure 4.7.2 Measuring head breadth with the different calipers (spreading caliper on the left,
sliding extended anthropometer blades on the right) ........................................................66
Figure 4.7.3 Caliper used for this research ..........................................................................66
Figure 4.7.4 head height reference, from bizygomatic breadth to top of the head ................67
Figure 4.7.5 bizygomatic Breadth Reference .......................................................................67
Figure 4.7.6 Clamping Force Readings, Interval Plot Analysis using Analog Gauge ............68
Figure 4.7.7 Grouping for Clamping Force Readings, Interval Plot Analysis using Analog Gauge ........................................................................................................68
Figure 4.8.1 Comparing Vias, V13 .......................................................................................69
Figure 4.8.2 Grouping Comparing Vias, V13 ........................................................................70
Figure 4.8.3 Comparing Vias, 3M Pro Grade ......................................................................70
Figure 4.8.4 Grouping Comparing Vias, 3M Pro Grade ........................................................71
Figure 4.9.1 Gender Comparison .........................................................................................72
Figure 4.9.2 Grouping for Gender Comparison ...................................................................72
Figure 4.10.1 Weight, Head Devices ....................................................................................73
Figure 4.10.2 Sample Size Comparison, Weight Score ......................................................74
Figure 4.10.3 Weight Vs. Weight Score, 5 Human Sample ..................................................74
Figure 4.10.4 Grouping for Weight Vs. Weight Score, 5 Human Sample ..............................75

 xi
List of Illustrations

Illustration 1.1: MEX Print Technique (Evonik website) ...............................................................3
Chapter 1: Introduction

Comfort refers to the absence of pain or constraint and is an important characteristic when designing human centered devices. The interpretation of comfort is subjective, as different people have varying tolerances and physiological characteristics that will change their perception of comfort. Such subjective scenarios require a comprehensive approach to create an experimental design for evaluating comfort. This comfort study was based on the standard human physical characteristics and anthropometry data that established benchmarks for physical characteristics of the human head (Joseph W. Young, 1993). This study targeted the majority demographic of the United States population and demonstrated relevant information needed to quantify the comfortability the user, while wearing the earplug/ear device. In comfort, one frequent practice is to compare subjective responses to qualitative inputs provided by a sensor. The initial intent to correlate comfort in this research was to create one ear simulator using additive manufacturing and compare those results to human inputs. The next section covered a summary of additive manufacturing processes analyzed for developing the prototype needed for the research.

1.1 Additive Manufacturing

This research assessed the comfortability of a specific additively manufactured customized headset along with commercial hearing devices. The initial purpose of the project was to design an earmuff that could keep harmful noises out of the ear and yet provide the ability to communicate with others. The project started to study comfort and optimize the materials used so that the end user perceived comfort. These optimization factors are ongoing and will continue evolving as the project continues to develop. The prototypes of the additively manufactured custom-made earmuff were using 3D printing techniques. Additive manufacturing was included in the study in two ways,
building a testing set up and developing an actual prototype of the earmuffs. There are seven types of additive manufacturing:

- VAT Photopolymerization
- Material Jetting
- Binder Jetting
- Material Extrusion
- Powder Bed Fusion
- Sheet Lamination
- Directed Energy Deposition

Material Extrusion (MEX) selection was constrained by four factors

**Time** – the printer itself did not need heavy manipulation or guidance through the process, as it is automatic after the slicing and placement of the model in the building plate (digitally). meaning the printer continuously was functioning with no human interaction, as prints take several hours, and this time was utilized to do other tasks.

**Budget** – There was not a specific budget for the research, the only guideline was to keep the spendings low and efficient. In terms of budget, this specific technique is one of the least expensive options. As previously mentioned, there is no need for a specialized operator (which elevates costs) and additionally the material cost is lower.

**Fast Learning Curve** – The automatic process allows for these devices (MEX 3D Printer) to have a faster learning curve, which at the end reduces the budget and time simultaneously.

**Post Processing** – Since the support material was water solvable, the way to post process any of the parts was to leave it in the water for a couple of hours and come back. The other techniques
required post processing such as photo sensitive treatments or manual removal of supports. These two increase Budget and time, similarly to the last factor.

The machine used was the METHOD 1 from MakerBot. The printer used filaments including nylon (building material) and PVA (support Material). The steps taken to print were: first step, the user ensured the printer was idle, and no other print was on the building mat. Once that has been accounted for, then the CAD model (previously designed) was loaded and sliced. During the slicing, software loaded the model and calculated the material needed, the print layout was also included. there, any mistakes were spotted and addressed before the last touches. Once all steps are up and running, the printer was ready to start. the printer heated the chamber, to avoid the material drying too quickly therefore causing errors. The extruder also heated to transform the material into malleable state to start building the shape desired. The process the printer did was to place a layer on top of a layer. One small schematic can be appreciated below:

![Illustration 1.1: MEX Print Technique (Evonik website)](image)

Illustration 1.1: MEX Print Technique (Evonik website)

![Figure 1.1: MakerBot 3D printer (Makerbot website)](image)

Figure 1.1: MakerBot 3D printer (Makerbot website)
This technology has increasingly been used over the last couple of years and have a wide set of applications/fields. Prototyping (for any industry), enabling companies to have a click physical look into a new device from dissimilar materials and designs. Customized light weighted parts and tools for the aerospace industry. Finally medical applications, which include organ transplants and hearing aids, both for the design and the comfort analysis (going back on prototyping). The additively manufactured custom-made earmuff used in this research was developed using a 3D printing technique (different to the MEX approach), as it will be described in the next section.

1.2 Custom-Made Earmuff Model

The additively manufactured earmuff used for the experimentation, was an ongoing project and it will continue to evolve, this earmuff uses both (jointly) inner and outer ear configurations. The custom-made earmuff was version 13 or V13, as this was the finished latest version available. The design was reduced in thickness (approximately 10cm) and electrical components were added. The main objective of the earmuff device was to limit the capability of the user to hear dangerous frequencies and allow the user to choose the kind of frequency he/she hears (to communicate). The design and shape of the earmuff mimics the human ear, so sound preservation occurs. The sound will be captured from the outside and the desired frequencies will come through the inner earplug. This study is based on assessing the comfortability of the whole setup, together as a piece, the inner and outer components. The model described can be seen below:
The inner earplug can be seen clearer in the images below, the base where this earplug is positioned is referred to as “the membrane.” The membrane was the latest addition to the earmuff. The earplug is connected to the electronic components, skin-colored rectangle shapes.

the next images show the ear shaped outer portion of the earmuff, that section of the design is removable and modeled the users specific ear shape and physiological characteristics.
Common methods to approach the comfort evaluation of such hearing devices are divided in two sections, clamping force and weight of the earmuffs for the out of ear comfort and inner ear displacement for the in-ear comfort. Below are a set of resources found characterize these factors and parameters.
Chapter 2: Literature Review

Inner and outer ear comfort were needed because one of the earmuffs evaluated was conformed of the two, inner earplug and outer over the ear earmuff. Some of the ideas presented below were used in this research and some were not used because of their complexity and costly investment. This section of the paper was divided in two different sections: out of ear comfort and in the ear comfort.

2.1 Out of Ear Comfort

The initial steps of the study were going to be completely based on the out of ear comfort. In this initial attempt there were four points/aspects to consider, and those were thermal, physical, expectative, and acoustic comfort wearing regular headphones or earmuffs. In the next following paragraphs, there will be a brief description of each parameter.

2.1.1 Thermal Comfort

This section referred to the thermal effects the headphone/ earmuff caused on the user. One article where a similar evaluation took place in a VR (Virtual Reality) headset was referenced (Wang, 2020). Here two humidity/ temperature sensors were placed in the middle (closely allocated to the subject’s nose) and towards the ear, both were placed with a commercial use tape. For this study one of the constants was room temperature and humidity for all the subjects, to keep temperature noise factor as close to zero, and therefore avoid interference in the results. Results demonstrated that the temperature and humidity recorded by the devices were related to comfort subjective responses. Time was a crucial factor as the two characteristics increased as time progressed. For this research, the temperature aspect of comfort was neglected although it is of future interest to include the parameter in a larger sample study. The next parameter also relates closely to temperature as it directly affects this feature with its relation to earmuff size, or area covered by
the earmuff. Size proved to lower temperature in the inside when a larger area was considered, and sealing, which was also lower at places where clamping force is in the lower limits.

2.1.2 Acoustic Comfort

The following section was placed in two dissimilar categories, safety, and comfortability. There are also regulations that are to be followed when building an earmuff. Knowing that any sound that is above 85dB can damage human hearing (American Speech-Language-Hearing Association). A study specifically that was found to be useful, in one research the set up that is used when testing for sound attenuation is as such; a semi anechoic room, a base to mount the human simulator and a sound source that can emit those sound levels (85 dB, and above) (Gaudreau, 2016). The semi anechoic room is like an anechoic room with the exception that it is not as noise proof as the anechoic room, as it will let some sound or electromagnetic waves to enter/leave. The experiment started with the placement of the human simulator inside the semi anechoic room. once the human simulator was placed in the room, then the sound source was introduced. The speaker is directly pointing at the earmuff. The picture below depicts the previously described process/setup.

![Figure 2.1: Acoustic Comfort Setup (Gaudreau, 2016)](image)
The ability of an earmuff to attenuate noise is related to sealing and clamping force (part of the Physical assessment). Another common issue with earmuffs is occlusion (sensation of echo) felt by the user, which often causes the user's absence of comfortability. The acoustic aspects of the study will not be addressed in this research because there was another ongoing investigation on this portion. There was a third response that tightens all the others, which is the user’s input, to correctly access/interpret and correlate the mathematical readings.

2.1.3 Expectative Comfort

This section was to establish a connection between qualitative and quantitative measures. The subjective input is imperative when it comes to rating comfort, and along with the other inputs validates the outcome and decisions. Here an article described an approach to build a questionnaire, not specifically related to comfort, but overall customer satisfaction on wine (Veale, 2009). For example, some of the aspects addressed in this experiment were, does the COM (Country of Manufacture) affect the perception of quality? and does the price affect the perception of quality? These two can easily be translated into the following: Does the COM affect the perception of comfort? and does the price affect the perception of comfort? The two are interesting and worthwhile to explore. The experiment divided in two separate groups: those who knew the COM and price and those who did not. The two were assessed using the same exact questionnaire and results differed significantly. Results in the referenced study proved that extrinsic cues are extremely important as the results for prestigious countries or brands and higher costs, impacted the prediction of comfort on the group that knew that information. Rating those products higher in the scale of comfort. Below is the example previously described (Questionnaire).
The expectative component was pursued yet did not went to examinations related to extrinsic and intrinsic cues, rather the questionnaire itself. Basic ideas of comfort assessment were taken from here and a study closely related to earmuff comfort (Hsu, 2004). The questionnaire implemented in this research was included in the following section, as it directly evaluates the next topic, physical comfort.

### 2.1.4 Physical Comfort

There were two different approaches, the two focused on the clamping force. One being calculating the clamping force using a push pull gage and the other placing a Force Sensing Resistor (FSR) between the area covered by the earmuff in the human subject and the earmuff cushion.

**Push Pull gauge:**

The base model was 3D printed, and the gauge was mechanical. The analog display gauge used was from the brand Baoshishan with a capacity of 50 N about 500 Kg. The initial set up was wood, a fixed and sliding face. The process begins when the headphone/earmuff right side is placed on the sliding platform and the left side is placed on the fixed location. The sliding side is where the push pull gage is, and it holds the platform in place. Once the earmuff is in place, then it will pull the sliding base (the one being hold by the gage) and the gage will provide a reading. Here is a picture of the device:
the second approach was the Force Sensing Resistor (FSR), this second validation point was used in different study/research. These kinds of sensors are like load cells, function wise, yet differ in its accuracy (< 0.1% for most load cells vs. +, - 5% for most FSR of full scale) According to Tekscan official website. Most of the load cells, when compared to FSR are more accurate, but lack the ability to be flexible and thin as FSR’s. One other advantage to FSR’s is that they are significantly less expensive than load cells. With all its benefits there is one major downfall to FSR’s, and that is that they need constant user calibration. Meaning each user will condition the sensor to their specific application additional topics of interest were repeatability, duration of experiment and distribution of force. all these topics of interest are covered in upcoming sections. Proceeding to the study used as the model for this research experimentation, there is a system commercialized by Tekscan, who specializes in sensors for different applications. The system used provides great insight to pressure inputted and location. This kind of sensors are dependent on location and work better on flat surfaces. Due to economic constraints a similar sensor was used, the sensor used for the actual research does not provide information as to what specific area the pressure is felt and which sections are matched with a specific pressure mapping. The way the experiment was conducted was by placing the sensor between the cushion and the human head.

Figure 2.3: Initial Clamping Force Set Up
similarly, the approach used in the experimentation for the research only differed in the sense that area covered diminishes and there will only be one response for the specific pressure reading. Below is a picture of the described setup.

![Sample Setup, TEKSCAN sensor](image)

**Figure 2.4: Sample Setup, TEKSCAN sensor**

The results dealing with pressure are not presented as a single factor or result, they are a combination/input component to a final assessment. The force itself did not determine the total comfort felt by the user, but it did significantly surface as one of the main components to consider. Using a similar idea presented in this paper, two different response surfaces were assessed to see how the results differed, From a human input to a silicon simulator. One of the most complicated to model was the human ear simulator (silicon), this idea came from a research article, in this research a model is developed with a 3D scan (Benacchio, 2018). The model described is more realistic than the one developed for this project, The original intent was to measure the displacement of the ear canal using the inner earplug and CT scans. This approach was really limited to correlating the silicon model to the human subject which also was complicated in nature a project on its own. At last, decision was made to leave that section of the research for a later stage in the process. In the next couple of sections each of the three approaches (Clamping force setup, FSR, and ear simulator) are described in detail.
Chapter 3: Experiment Design & Methodology

This section covers the different approaches, its assumptions, and conditions. It will also briefly describe the initial stages and the finalized result, how experiments were built, corrected and which methods were considered from previous work/ experimentation. The first experiment to explore was the human ear simulator intended to minimize human interaction and provide an insight to the human ear canal displacement. The model is described in the following paragraphs.

3.1 Silicon Ear Model Development

The experiment had two phases, ear model simulator and human input validation. In the first face a model was created to mimic the human physical characteristics. This model has complete modeling since it has the outer ear and the inner ear canal to more closely show how the human ear will react to the pressure exerted in the parts the earplug encounters the human skin/ear canal. The main intention of this study was to correlate three different parameters: stress, displacement, and human subjective questionnaires. The development of the ear model was a complex process of trial and error. The process began with the creation of a 3D scan, which was corrected in a specialized software (Meshmixer). After the corrected and processed model is done, then a mold can be created, using 3D printing techniques. The preliminary stages of the study involved the creation of an ear canal mold, which was only casted so that the technique and material could be analyzed. With satisfactory results, a new model was developed, in which there was a complete earpiece with accurate and representative dimensions. This model’s purpose is to provide an accurate representation of the human ear avoiding human testing for the initial study. The material used in the molding process is silicon (TC 5110) and the 3D printed mold. The model was developed in four steps, presented below
3.1.1 Building and Editing the Raw 3D Scan

The human subject was placed where there are no other figures/obstructions or interruptions, in this way a simpler model is created (less memory consuming), also intended to diminish excessive/time consuming post processing. In this step the 3D scan was taken using the HEGES app, a specialized software for doing scans. the device used to run this software was the iPhone 12 pro, with its LIDAR sensor. The only disadvantage of this app/software is that it only worked with the front camera of the iPhone which made it challenging to get a clear scan of the specific ear. To summarize this app took a 3D scan which later was exported to an editing app, Meshmixer. Below is a figure of the pre and post processing.

![Figure 3.1: preprocessing on the right, post processing on the left](image)

The first image in the left depicts the raw scan, in the left part of this first image a pink/salmon color shape can be seen, which was the group member taking the scan. Since the scan must be taken from several angles, at some point the person taking the scan was captured by the sensors, this was the first object to be removed. The right ear was selected arbitrarily, although the
experiment was consistent and did use the same side for any different scans. before removing any of the other parts the human head solid was converted to a solid object, so modeling could be done. This was decided after a couple of trial-and-error sessions. This was after attempting to cut first giving no satisfactory results, with an uneven surface and irregular shape, which was not favorable for the mold design. The figure on the right is the area needed for this experiment anything else was omitted from the model, below is a back view of the hollow and solid earpiece (right picture).

![Hollow mesh and solid earmold](image)

**Figure 3.2:** hollow mesh on the left, solid earmold on the right.

A couple of blue spots are seen in the first image, before the figures were created into a solid, there needed to be an inspection for such spaces that are not part of the mesh. The wholes/spots were repaired and finally those disappeared, leading the way for the mesh to be converted into a solid. In the first image a hollow scan is seen, here was one of the first trials, which failed for the reason previously described (not solid before editing). In the second image, the mold/scan is now solid while still preserving the inside ear canal. The area covered or chosen for the experiment is simply to fit the whole earmuff within the model, so the human factor can be modeled as realistic as
possible. The dimensions of the ear model (actual silicon model, not the 3D printed mold) will be as follows; 13.3 cm in height, 11 cm in width and 4.5 cm in thickness.

3.1.2 Building a Negative Mold

The software used for this section and the following section was Fusion 360, part of the Autodesk portfolio. This step was the most difficult related to 3D modeling since it involved using the final processed model from Meshmixer. Due to the complexity of the ear shape and definition, this model was heavy in terms of space consumption and had a high mesh definition, meaning the model took long to load and any movements also were really delayed. The best approach to work on the model was to edit in mesh format. In this model the home figure was a square, and the cut figure was the solid mesh. As previously discussed, this square had to be converted into mesh and placed in the desired position. Once the two figures were positioned correctly then an extrusion cut was executed. When the figure finished compiling and placing the cut, then the negative mold was exported to Meshmixer again to refine, give the final additions, correct any measurements discrepancies, final approval for the model definition and 3D printing procedure. It is important to say that the model needed to be rebuilt before exporting to Meshmixer, the rebuilt facet was important to avoid any errors such as not being able to join mesh objects or assign adequate mesh definitions to the models. Once the correct parameters were applied, then the model was exported. This process was repeated a couple of times, when the desired quality of mesh was obtained, then this was established as the standard threshold. The main reason for the file to be exported was that the conversion from mesh to solid is much faster in Meshmixer than in Fusion 360. Mesh to solid conversion was important because in 3D printing the models need to be solid, if the models are not solid, then errors will more than likely occur. The first model developed from this was a clear example of why models need to be solid. The second model which was more detailed and robust
than the first, really proved to be more exact and useful for the requirements of the project. Below there are the images for this specific procedure (depicting the first and second printed models).

![Figure 3.3: first 3D printing of the negative earmold](image)

Here it is seen that the model, did not executed as planned, due to its non-solid state in the 3D model. The white material was part of the support structure (dissolvable), and the actual model was the orange object. Some parts were not there, and the internal shape of the ear was lost, making the model unsatisfactory for the desired purposes.

In the following pictures there is a representation and final product of the process described in step 2. Also referred to as the second version of the negative mold. The images below showed the model in the 3D modeling software and below the actual printed version. This second version was the one used to cast the silicon. the size and definition of the print was close to the 3D design. The complete measurements of this mold were 14.45 in height (H), 12.10 in width (W)
and 6.60 in thickness (T). (All in cm) Note the measurements are oriented as the pictures below.

Figure 3.4.1: Dimension Orientations

Figure 3.4.2: 3D software model of the second version for negative ear mold

Figure 3.4.3: physical second version of the negative mold
3.1.3 Building a Base Mold

In this phase of the design the base for the mold was created, the base served two purposes, one seal the negative mold with the ear shape and two, hold the silicon piece in a testable environment/setup. This process started by using the positive ear mold and cutting a 90-degree (in two different directions, creating two planar faces) shape in such a way that it will accommodate the shape of the negative ear mold, following the irregular shape in a planar course to a small distance. The shape and process described is depicted in the pictures below.

![Positive ear shape, base creation](image)

Figure 3.5: Positive ear shape, base creation one, left is the front view, and right is a sideways illustration.

The figure main objective was to fit inside the cavity in the negative mold, in such a way that no silicon was to leak and reducing the size and amount of silicon material to be utilized.

After the shape described above was created, then a L shaped figure was developed just behind the positive ear shape. This shape was created in such a way that it matched the size and shape of this figure above. The first phase of the base (L shaped figure) was designed to measure 3.33 cm, which was later redesigned, so it measured half (1.65 cm). this design was reduced using a plane cut in Meshmixer software. the main objective of reducing the thickness was to reduce the use of 3D filament. Both designs were solid, and the thickness was not a decisive factor when it came to
accuracy and stiffness of the base. Both figures were joined using a combine feature in the software Fusion 360, the specific function was “join”. Joined with the previous shape, this became a new shape (one single solid figure). This shape described can be illustrated below, the height of the figure was just enough to fit the negative mold and leave exact measurements for some error.

![Image of L shape figure, base]

Figure 3.6: L shape figure, base

The last two steps to finish the creation of the base was to add four legs and five hinge shapes. The four legs are for the whole base to fit in an experimental setup, the base was be inserted in the cavities specifically designed for those four legs. This fixed base (where the L shape base will be placed) will be described later. The four legs were added in the bottom of the base, there were two types of legs, front (thicker) and back (thinner). There was no specific reason as to why the legs were different. The other five shapes were designed for two reasons. one, pull the silicon shape out of the negative mold and two, hold the silicon shape in place. Two of the five shapes were different because they were inside an incision within the slant of the right side (referring to the positive base of the first section), that was because these were not covering enough area inside the silicon shape for the hinge to be useful. The hinges were not built higher because the shape of the negative mold did not allow for such dimensions. The size of the hole was close to the shape of the upper portion of the hinge for these two objects. The other three hinges are .50 cm in the neck
and .50 cm in the head, so the total height is 1cm. once these other two features were added then a final representation of the shape can be seen below.

Here are the dimensions of the shape to the left.

Length (L): 10.99 cm
Width (W): 5.79 cm
Height (H): 16.16 cm

Figure 3.7.1: final base assembly

Figure 3.7.2: legs and hinges
Hinges

Blue color; is the same exact structure with 0.50 cm in the neck and 0.50 in the head (upper part). Orange color; are those inside the cavities, those measure 1 cm in the neck and .50 cm in the head. The diameter of the hole/cavity is 2 cm, and the diameter of the hinge head is around 1.90 cm.

Legs

The blue set are those pair of legs that have the thickest extrusions, and following the same orientation as the previous figures, of 1.95L x 2.10W x 0.84H. the orange set has similar dimensions to the last pair with the following dimensions: 1.95L x 0.15W x 0.84H (only change is in the width).

3.1.4 Silicon Casting

This is the final part related to the silicon model creation. In this step the silicon was casted into the negative ear mold. This process begins in the selection of the specific silicon desired to approach the complexity of human physical characteristics more closely. In the research process the material selected was TC-5110 (a type of silicon) as some of the properties were like the human skin, and it was also a flexible material, a previous silicon piece was casted with the same material and the results were satisfactory. characteristics of the material was that it is a translucent silicone rubber, and it is ideal for molds that need flexibility to be worked with. Since the ear shape has several complex shapes, it is necessary to work with something that is malleable. The mixing ratio (by weight) is 100 A/ 100 B which means that you must mix one hundred grams of substance A with one hundred grams of substance B. the material were weighted and mixed. The total weight was around 120 grams of each component. The two components were mixed for about 5-7 minutes by hand, and the mixed content was sent to the vacuum, were all the air pockets were to be
eliminated. Once the vacuum process was done, the material was poured in the negative ear mold, the back of the base was facing the table where the mold was placed to rest and cure. On top of this was the base developed in section three, the silicon was cured for 4 days. Below are a couple of images that will provide an insight into the process described above.

![Final mold with silicon casted](image)

Figure 3.8: final mold, with silicon casted.

On the image above the position in which the model was placed to maintain a uniform distribution of the silicon is observed. A second set of images was included below, the part that is transparent is the negative ear mold. The other piece is the base where the silicon will rest, the last part (hollow) is where the silicon will be. The first image is the front of the model and the second is the back.
As this section was being developed, a new piece was to be created, and that was a base to hold the silicon model, which was to hold the ear and adapt to the diverse types of sizes (5, 50 and 95 percentiles).

3.2 Building a Sizable Base

This section described the development of the sizable base where the silicon model was placed. The purpose of the base is to provide an adaptable testing environment to accommodate for different head sizes, as they may vary from the lower fifth percentile (13.01 cm, around 5.12 in) to 50th percentile (13.99 cm, around 5.51 in) and 95th percentile (15.01 cm, around 5.91 in). These measurements are referred to as Head breadth, the previously mentioned are male measurements. Similarly, the female measurements are 12.29, 13.20 and 13.99 (all measurements are on cm and percentiles are order is the same). The development of the base is conformed of two pieces or sections, section 1: lower resting base for the silicon model, and section 2: sliding stand.
3.2.1 Lower Resting Base

This section covers the object that is directly below the silicon base, the way this was created was using the cutting feature (cut extrusion) to cut the downward section of the silicon base into a new square. This square was edited to only have the lower half, and appropriately placed the dimensions of the base. Once the shape and dimensions were as desired, then there were two different incisions created, these are to house the socket head bolts. The size of the bolts is as follows; from head to tail 4.54533 cm, and width (threaded section) 0.78994 cm, the head measured (vertically) 0.80137 cm. so the total length of the threaded section is 3.74396 cm. The hole was all the way through. Below is an image of the previously described part. The image on the left is a solid depiction of the base, the one on the right is to show all the hidden holes and their depth. The dimensions are length x width x height with the numbers (11.30cm x 6.12cm x 1.30cm).

Figure 3.10: lower resting base for the silicon base
3.2.2 Sliding Stand

This part of the sliding base is the final piece to complete the set, this piece is where the other earmuff will rest. The development was not time consuming; the dimensions were taken based on the other two pieces; the object was bulkier than the other two. Section 2 is depicted below:

![Figure 3.11 sliding stand](image)

The figure was done using five different extrusions, three of which are cuts. The hole to the right end is where the part designed in section 1 is to be placed, the shape allowed for the base to freely move to the desired length. There was a fillet added at the 90-degree junction of the resting base, to provide a more stable support, the fillet radio was 2 mm. On the upper piece of the part there is an ellipse, the main purpose of this ellipse was to accommodate for the inner earpiece of the additive manufacturing custom made earmuffs. This design was divided in two parts due to its size, which did not fit within the printer design space. The two pieces were divided into the upper and lower base, both joined similarly to the base for the ear and the silicon ear with four different positive extrusions. These two pieces are depicted below
Figure 3.12: two piece sliding base Design

Figure 3.13.1: Lower Body component measurements, sliding base, units in mm

Figure 3.13.2: Upper component measurements, sliding base, units in mm
With this last illustration, the complete ear silicon simulator is concluded. From the design of the silicon model the following step is to address how each of the experiments were conducted, starting with the silicon model.

### 3.2.3 Experiment Design, Silicon Model Approach and Summary

The main intention for this setup was to have a comparable model, and a different surface. This model was to provide the first surface on which tests are to be conducted, and it was also meant to avoid human interaction for the first steps of the investigation. This model is also an initial step to create a human like ear, which closely imitated the physiological characteristics of the human ear. If there exist a correlation between the two (human and model), then this silicon piece was to be considered valid for more advance tests, such as CP Scan comparisons. The CP scan was to be able to estimate the human ear canal displacement which will then be related to the human comfort and its effect while using an inner component. For this research, the silicon model was only used as an alternate/additional surface and the way the experiment was conducted was by placing the
sensor in the model and then positioning the earmuffs on top. From this approach the focus was the second method, which is the clamping force set up. Below is a summary of the section.

Table 3-1 Summary Process Development, Silicon Ear Model

<table>
<thead>
<tr>
<th>Silicon Ear Model Development step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building and Editing the Raw 3D Scan</td>
<td>A 3D scan was taken, the model was edited and made solid.</td>
</tr>
<tr>
<td>Building a Negative Mold</td>
<td>From the 3D scan a rectangle shape in overlapped and the solid ear shape is subtracted from the rectangle, leaving a negative ear mold.</td>
</tr>
<tr>
<td>Building a Base Mold</td>
<td>The base mold is to be placed on top of the negative mold, this will help the silicon shape come off and hold the ear shape in shape</td>
</tr>
<tr>
<td>Silicon Casting</td>
<td>Once the two previous shapes were created, then the silicon was casted.</td>
</tr>
<tr>
<td>Lower Resting Base</td>
<td>This base is to be the interface, between the base mold and the sliding stand. Created from the overlap of a square and the lower part of the base mold.</td>
</tr>
<tr>
<td>Sliding Stand</td>
<td>The last piece was created using the dimensions of the lower resting base and the height of the finished ear model. Form here the final assembly was created.</td>
</tr>
</tbody>
</table>

3.3 Clamping Force Setup

This section of the paper Described a widely accepted approach to commonly evaluate the clamping force of earmuffs and headphones in general. The setup consisted of two flat surfaces, one that is fixed and the other attached to one end of an analog pressure gauge, which earmuffs pulled, returning a reading. As described before the initial set up was made of wood, which evolved into a 3D printed set up that provided more stability and accuracy. Below is a detailed guide of all the components used in this second approach.

3.3.1 Mechanical Gauge

In this set up the gauge used was a mechanical gauge from the brand Baoshishan, with a capacity of 500N, and its resolution is 2.5N. the accuracy is ±1%, its weight is around 1.3kg. The gauge
included other accessories among which an extensive shaft and a tensile end. Below is an image of the gauge and its accessories.

![Baoshishan Mechanical Gauge (Amazon webpage)](image)

Figure 3.15: Baoshishan Mechanical Gauge (Amazon webpage)

The gauge has two distinct functions, tensile, and applied force.

### 3.3.2 Base Design

The base was designed to fit in a breadboard, this was to avoid future costly investments and increased its stability, therefore its accuracy.

![Base for Clamping Force Setup](image)

Figure 3.16: base for Clamping Force Setup to the left, same object with dimensions to the right.

This setup had an FEA validation where a 15 N force (pulling force) was applied to the square right at the top, where the other sliding base was to be placed. The two long circular shapes serve as a modular sliding rail, where the top piece will be arranged to the desired distance, which will
accommodate for the appropriate head breadth. Note, the measurements in the above depiction are all in mm. The following piece to be created was the sliding base which will be described in the next paragraph.

### 3.3.3 Sliding Base

This next component was responsible for holding in place the mechanical gauge and moved that piece to the desired distance. The piece had to be sectioned to fit into the printing space, the division was right after the two pieces holding the shaft, below is a picture of the piece and its measurements.

![Figure 3.17: Sliding Base complete assembly left, upper component middle, inferior component right.](image)

![Figure 3.18.1: Sliding Base Dimensions](image)

Figure 3.18.1: Sliding Base Dimensions
As previously mentioned, the measurements are in mm.

3.3.4 Fixed Side and Sliding Earmuff Holding Base

This last sub-section is where all the pieces become one assembly, the sliding base along with the gauge and base. This will be on one side, and the other side will be a fixed end, with no modular functionality. The setup is below:
Figure 3.19.2: Set up clamping Force, top view

Figure 3.19.3: Set up clamping Force
The white base is where the head devices were placed, and its dimensions are 199 mm in diameter and 5 mm in thickness. The distance from the bridge to the center of the base that holds the earmuff is 77 mm.

Below is a summary of the process, and brief description of the way these were designed.

Table 3-2 Summary Process Development, Clamping Force Setup

<table>
<thead>
<tr>
<th>Clamping Force Setup</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Step</strong></td>
<td><strong>Description</strong></td>
</tr>
<tr>
<td>Base Design</td>
<td>the base design is the main base where all other components will rest, height was based on earmuff size and the shape was optimized. These optimizations went through a FEA validation with a force of 15N, slots in the top face were to accommodate for modularity.</td>
</tr>
<tr>
<td>Sliding Base</td>
<td>The sliding base goes on the top of the base design, and its function was to house the mechanical gauge and modulate to the desired size. Developed from the base design dimensions and slot positions. size constraint of 17 cms (3D Printer), piece was divided in two sections.</td>
</tr>
<tr>
<td>Fixed Side and Sliding Earmuff Holding Base</td>
<td>This last component was the white-faced round object, which was fixed to the mechanical gauge and provided a direct interface base for the earmuff. This was created in consideration of the earmuff dimensions and inner components</td>
</tr>
</tbody>
</table>

3.4 Force Sensing Resistor

The pressure plate/sensor used in the experimentation will be a small sensor, model RP-C10-ST which is flexible, thin, and conductive in nature. The company selling the sensor, in a brief sentence describes how specifically the sensor works and is as follows “When there is pressure on sensitive area, the disconnected circuit on the bottom will be connected by top pressure-sensitive layer, and the output resistance of the port changes along with pressure.”

3.4.1 Sensor Technical Characteristics

Thickness: 0.4 mm

Trigger force: 20 g
Range (pressure sensing): 20g (lower end) - 2kg (higher end)

Operating temperature: -40°C - 85°C

Dimensions:

![Pressure Sensor Dimensions](image)

Figure 3.20: Pressure sensor (Amazon website)

### 3.4.2 Elegoo to FSR Sensor Interface

The sensor was connected to a UNO R3 from Elegoo, a device like an ARDUINO. The interface between the pressure sensor and the UNO device was created using Dupont Wire (female-to-male), breadboard jumper wires, and soldering was also implemented to combine the two ends of the Force Sensing Resistor and Dupont Wires. This setup can be represented by the following schematic (not exact setup, a graphical representation)
The wiring was not connected directly from the Elegoo device to the sensor, it was connected through a breadboard. The first step to connect the device was to use a Dupont wire male to male form the Elegoo port named GND (Ground) to the breadboard. Next, one of the legs for the 10K resistor was connected directly in front on the GND connection, the other leg was placed in the same line. Right next to that resistor leg, another Dupont cable was connected which also connected to the Analog Port A0. In that same line, there was another cable which connected that end to one of the FSR legs. The ultimate step was for the sensor to receive power, the remaining end of the FSR connected with the same type of cable through the 5V power port. As a note, the sensor ends were welded to the ends of the Dupont cables and those were then attached to their described position. Below is a depiction of the actual wiring for this setup.
3.4.3 FSR Calibration

This section of the sensor process describes the way the sensor was calibrated. The sensor program only displayed the digital response according to its value in Voltage. The response was mapped from 0 to 1023 which represented 0 to 5V, meaning each unit in the digital scale represented 0.005V. Sensors on the lower tier will require specific calibration, depending on the application. The sensor was calibrated using a Instron Machine (Hydraulic press) by comparing the digital responses and the force applied by the machine. The setup for this calibration is the following:

![Instron Machine Setup for Calibration](image)

There were ten samples taken, and those were different forces ranging from 0.64N to 19N, just above and below the sensing limits for the sensor. Those then were averaged in intervals of sixty
outputs (representing one-minute intervals) up to 600, 10-minute mark. Those results were in the y-axis while the Newton response was on the x-axis, the two were used to fit a line to describe the behavior of the sensor. The best fit for the line was a power function described by \( f(x) = -471.8 \times x^{-0.5801} + 856.9 \), the analysis was conducted in MATLAB, here is a picture of the line fit and its respective points

![Figure 3.24: Line Fitting, Sensor Calibration](image)

The line did have a good fit for most of the data points, and it had a R-squared of 0.9971, which is not a complete confirmation of a good fit, but still a benign signal for the fit.

The calibration was designed to be accurate or valid during the first 10 minutes only, from which the accuracy was within 10 - 20% off from the reading given in the program and the reading given in the Instron machine (10 to 20 % higher in the Instron machine than the reading in the FSR response). The ten-minute time frame was validated during a one-hour trial in the first practice run with humans. During the initial trials, the humans were asked to wear the FSR while wearing the commercial earmuff, the process was repeated one time for two different subjects. In the table below are the results:
In the table above results show that the outputs fluctuate in the 1 to 2 N force range. It is also important to note that the force does not go above or below 0.5 Newtons from its initial value (averaged value, every ten minutes). Using this as a reference, it can be said that the first ten minutes of the test are an accurate representation of the complete hour sample with a + 0.5 N tolerance. The decision to only record readings for the first ten minutes was taken to help reduce comfortability absence and/or noise factors in the actual tests. It is important to dully note that the sensor must be constantly evaluated and calibrated to assure its accuracy. Sometimes the program will require a factor to correctly follow the behavior of the line.

3.4.4 Experiment Design FSR Input

The FSR was used in an analogous manner as it was for the silicon model. The sensor was placed in the human, then the earmuff was worn by the human. The intention here was to get results of the pressure felt by the sensor when the different earmuffs were placed on that specific person. The image can be referred in section 3.2.3.

Below is a figure to summarize all the previous described work.
**Table 3-3 Summary Process Development, FSR**

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elegoo to FSR Sensor Interface</td>
<td>The FSR was interfaced to the elegoo device by one leg being connected to the power source and the other to an analog port, preceded by a resistor and the direct connection to ground.</td>
</tr>
<tr>
<td>FSR Calibration</td>
<td>Once the wiring was done, the FSR sensor was calibrated with the use of a hydraulic press. Using a 10-minute time frame and line fit in MATLAB.</td>
</tr>
<tr>
<td>Final Code Modification</td>
<td>Line fit equation was then included in code, to return a Force value instead of a digital response.</td>
</tr>
</tbody>
</table>

### 3.5 Qualitative Input (Questionnaire)

One of the key components to evaluate a product is to gather qualitative data through different methods, the tool used for this research was a questionnaire built from similar evaluations in academic research and samples commonly used in product satisfaction surveys. This evaluation has five different components, and they are meant to target different areas of interest and follow a systematic approach to maintain consistency among the output of the samples. It is broken in six different sections, Exploratory initial questions, a one-hour trial, comfort scores and a graphic mapping of discomfort, weight, tightness, additional questions, and additional comments. These will be discussed in the next following paragraphs. The questionnaire was also meant to target future questions to be evaluated at a study with a denser population and wider set of parameters. Appendix I. is the questionnaire used for this research,

The questionnaire starts with a title, and a prompt to provide identifiers for the subject being evaluated, these are sex and age. right after there is a brief description/ set of instructions of what the user will be doing for that specific section. The first page also includes a brief description of the scale used for the comfort score.
3.5.1 Experiment Design and Protocol (Questionnaire)

Sample size: ten and five subjects

Age group: 20 to 27

Sex: six males, four Females

Location: Keck facilities (mostly on cotton facility)

Model of head devices: V13 (Developed by Keck Students), 3M Pro Grade, Sony wh -1000xm4 and Sony wf – 1000xm4.

There were four different devices in the study of which two were over the ear (one was a earmuff and the other a regular headphone) these are the 3M Pro Grade and the Sony wh – 1000xm4 respectively, then there was an in-ear device which was the Sony wf – 1000xm4 and at last a hybrid of the two which is the V13 Earmuff. The reason to choose two non-protective devices was to have a reference of how different the results were from those that were protection devices (benchmark).

Paying close attention to the difference in clamping force and the effect of it in the comfort score.

The experiments begins when the user was given a brief explanation and a set of instructions for what they will be doing in the experiment, at which point they were then asked to answer two questions that assessed or stablished the users experience with Earmuffs. Note it was important to warn the user that regular headsets are not the same as earmuffs, as they are hearing protectors.

Once they had read all the instructions and then answered the two questions, they were prompted to start wearing the earmuffs, at this moment the user and the researcher ceased to have any sort of communication. In the first section, the user was asked to evaluate the comfortability felt by that specific device every ten minutes. They circled the level of comfortability they felt, according to the scale presented in the first page. This scale goes from zero to ten, zero being no discomfort, to ten extremely discomfort, cannot bare to wear it, the points in between increasingly score the
levels of discomfort felt by the user. Each time frame contained ten minutes, meaning the first interval went from zero to ten, then the second one from ten to 20 minutes and the order followed accordingly up to 60, representing the total study time of one hour. At the end of this section there is a seventh bar which asked for the whole experience, meaning how did that user rate that specific earmuff as a complete experience.

As the user was doing this first part, he/she also completed the second section in parallel order, which is the assessment and placement of discomfort areas in a diagram. The user was asked to point to the areas in which he/she felt discomfort, to characterize areas of interest in design improvements. The subject pointed to these areas similarly as the last sections (every ten minutes). Once the one-hour experiment was done, then there were two different questions that the subjects will be asked to answer. These are weight and tightness. The user will be asked two questions, number one “How will you assess the Earmuff weight?” and number two “How will you assess the Earmuff weight?” the answers will vary from barely noticeable to unbearable and the user will only have to check on one of the boxes provided.

The second to last sections is a set of questions, the intention of these questions is to target future subjects/parameters to be evaluated at a study with a higher volume of testing subjects, environments, and time frames. This will serve as a reassuring agent justifying the additional time and effort for these specific experiments. Note the idea comes from other works, not the specific questions, the general ideas. Such topics are inner ear comfort, and other components related to discomfort directly affected by the temperature and sweating.

The last part of the questionnaire was the additional comment section. This section is to provide the interviewer additional details as to what the user felt in the experience.
The additional comment section is also there to help the user feel more comfortable, create conversation, ideas flow and lead to more realistic/accurate answers. With this third approach this section is concluded, having described all the methods and approaches used for the investigation and experimentation. The next step is to present the results obtained using the three different approaches. The experiments specifics are discussed in each of the following sections and each sub section will contain a description of what was done during that comparison.
Chapter 4: Results

The second to last section of the investigation is where all the results will be presented, the results are to be divided in three sections. One for the readings in the FSR, while wearing on a human and the other on the silicon model. The third set of results will be the clamping force setup.

4.1 FSR Silicon Model Readings

The first approach or method to be examined was the silicon model and its comparison to the human readings, with the intention to establish a correlation between the two to provide a safe way to do a future study related to the ear canal displacement. This comparison was performed on one of the subjects, where this person’s ear was modeled in a silicon ear. The 3D scan was used to create a silicon model as described in the section 3.1. The intention is to find a pattern between the readings provided by the FSR while in the silicon model and while in the human head. The experiments consisted of two surfaces and two Earmuffs, the ones designed at the GN project and the commercial 3M Pro-Grade. The two surfaces are the human head and the silicon model. The results of the experimentation were used in two diverse ways, one to compare the results among the two surfaces and the other to compare the earmuffs difference in that same surface.

Since the initial intent was to correlate a specific person to a specific ear model, only the measurements for the specific subject were of interest for the investigation. The specific head measurement was the bizygomatic breadth with 147.60 mm, additionally the earmuffs were adjusted first on the human and then on the model, so the headband was precisely placed the same distance in both the human and the silicon model. The way to assure an accurate placement of the earmuff on the silicon model was to place the earmuff in such a way that the whole ear area was covered, similarly to the human’s head. Once placement and sliding silicon model base is adjusted
to represent the human, then the test begins. The way the test begins is by placing the sensor (FSR) in between the silicon model and the earmuff (both earmuffs). The sensor is hold in place by two steel rings that go in the silicon model, and they serve the purpose of keeping the sensor straight and in the same location for both tests with the two different earmuffs. The set up described can be represented by the following image, note the earmuffs being evaluated at this picture are the 3M Pro-Grade Model.

![Figure 4.1.1 Silicon Model FSR sensor set up.](image)

The results of the FSR readings are summarized in the following tables, each table representing the comparisons of the two surfaces using the two different models of earmuffs. The first table (below) models the V13 Earmuffs.
Figure 4.1.2 V13 Earmuff comparison of the two testing surfaces

For the V13 Earmuff the average reading for the silicon model was 0.63N, while the human averaged 0.86N, a difference of 0.23N between the two surfaces.

Figure 4.1.3 3M Pro-Grade comparison of the two testing surfaces.

The commercial earmuff (3M Pro-Grade) results from the table above where as follows; the silicon model averaged 0.60N and the human averaged 0.84N, for this model, the difference between the two surfaces was close to the difference in V13 Earmuff model with 0.24N (0.01N in difference).

In both tables a pattern is constant were both readings for each of the surfaces have similar averages, in both cases the human output was higher than the silicon model by around 0.23N.
Additionally both intervals for each of the two surfaces were close to each other and they were grouped together, meaning there is not a significant variability. This approach was not pursued because it implicated heavy time consumption, additionally the accuracy and correlation of the FSR sensor was not adequate as described in the following sections.

4.2 FSR Human Readings

Similarly, the tests on humans were conducted in the same manner as the previous section, except for the steel rings (not present), and the questionnaire (responded by humans). The Questionnaire results were presented in the following section, for this specific part the results are as follows. Note, this study was only done in the first two sets of head devices (V13 and 3M Pro Grade) and only on the four initial subjects. This was because the method did not prove to be effective regarding time or accuracy.

![Averaged Comparisons, FSR Human Testing](image)

Figure 4.2.1 FSR Human Readings, comparison of the two earmuff sets.

Here the results indicated that the FSR sensor captured the forces going from below 0.685N (Newtons) to above 0.715N for the two models. The 3M Pro-Grade Earmuff model has the lowest interval value at 0.6844N and the highest value of 0.7053 or an interval of (0.6844, 0.7053) and an average of 0.6949N. the other (GN) has an interval of (0.6924, 0.7152) and an average of
0.7038N. The readings are similar, yet the earmuff model with the highest level of averaged force applied is the V13 Earmuff by 1.26% or 0.01N. The other set of data acquired with the human input was the comfort score assigned by the perception of comfort felt by the user at that specific period (from cero to 60 minutes). This input is covered in the following section.

4.3 Comparing Clamping Force Set Up with FSR Readings

This section focuses on the relationship between the clamping force reading obtained in the mechanical gauge and the FSR reading obtained with the sensor. Using the table presented below x-axis being the Clamping Force Setup with the units as Newtons and the y-axis the FSR Data Input with Newtons as unit also.

As presented in the legend the red dots are the V13 earmuff and the blue solid line is the 3M Pro-Grade model. The data from left to right goes from the smallest distance 148.264mm to 155.958mm. For the modeled data 75 % of all the user’s recordings showed that the V13 earmuff recordings are on top of the 3M Pro-Grade Recordings for the corresponding data in each of the distance ranges. For instance, when taking the second data point from the 3M, it is noticeable that the second point of the V13 is higher.

![Figure 4.3.1 FSR Data Vs. Clamping Force Setup](image)

Figure 4.3.1 FSR Data Vs. Clamping Force Setup
Analyzing data in the 3M Pro-Grade Model; These dots do follow a pattern were as force increased in Clamping Setup, so did the Output for the FSR, the only data not following that pattern was Subject 3. When analyzing the data in the V13 Model; once again there were discrepancies in terms of the third subject, now joined by the first subject. Both lines follow a similar path and results for each of the subject using the different models if earmuffs are not significantly different. In the table below all the data is seen, this table follows an order from smallest to largest distance.

*Table 4-1 Distances Vs Recorded Forces*

<table>
<thead>
<tr>
<th>Distances</th>
<th>3M Pro Grade Clamping Setup</th>
<th>FSR input</th>
<th>V13 Clamping Setup</th>
<th>FSR Input</th>
<th>Subject #</th>
</tr>
</thead>
<tbody>
<tr>
<td>155.96</td>
<td>10.5625</td>
<td>0.714786311</td>
<td>11</td>
<td>0.726388113</td>
<td>Subject one</td>
</tr>
<tr>
<td>150.96</td>
<td>10.25</td>
<td>0.668182389</td>
<td>10.5625</td>
<td>0.682149833</td>
<td>Subject three</td>
</tr>
<tr>
<td>149.498</td>
<td>10.0625</td>
<td>0.703027818</td>
<td>10.3125</td>
<td>0.728769871</td>
<td>Subject four</td>
</tr>
<tr>
<td>148.264</td>
<td>10</td>
<td>0.693450829</td>
<td>10.1875</td>
<td>0.67781305</td>
<td>Subject two</td>
</tr>
</tbody>
</table>

The next step was to do a correlation study on the data collected. This was to see if there was a strong relation between the two factors analyzed in this section. Below is a reference as to what is accepted as a strong correlation, this comes from the article (Napitupulu, 2018). This table depicts that a score above 0.60 is considered a strong correlation.
The analyzed results are below, these are from the data collected in the first four samples, and two model earmuffs.

<table>
<thead>
<tr>
<th>Coefficient Interval</th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00 – 0.199</td>
<td>Very Weak</td>
</tr>
<tr>
<td>0.20 – 0.399</td>
<td>Weak</td>
</tr>
<tr>
<td>0.40 – 0.599</td>
<td>Medium</td>
</tr>
<tr>
<td>0.60 – 0.799</td>
<td>Strong</td>
</tr>
<tr>
<td>0.80 – 1.000</td>
<td>Very Strong</td>
</tr>
</tbody>
</table>

Figure 4.3.3 Correlation Table Reference

The correlation score here is 0.455 using a Pearson Correlation. The result is within the medium correlation level, not what was desired. So, there was not a strong correlation between the two factors, which was the reason the FSR reading were only taken in the first four subjects, as it was considered not dependable the next comparisons to analyze were the clamping force Setup and the FSR readings with its corresponding comfort score provided by the humans. The first to analyze will be the clamping Force.

4.4 Comparing Clamping Force Set Up with Human Comfort Scores

Here the results followed a similar path to the last comparison, and the results did show that 75% of all the participants comfort rating increased as the Force reading increased. The only exceptions
to this are subject three in the 3M earmuffs with a force of 10.25N and a comfort score of 1.67 and subject four with a force of 10.31N and a comfort score of 6. For the V13 earmuffs the slope was less noticeable, but there was an increasing relation with subjects two, three and one. Consistently the results for the V13 model tend to be above those of the 3M Pro-Grade results. In fact, only one of the results is not consistent with this statement and that is subject one.

Figure 4.4.1 Clamping Force Setup Vs. Comfort Score

Figure 2.4.2 FSR Vs. Comfort Score
This concludes the participation of the FSR in the research study, due to its limitations and inaccuracies, this path was not followed or pursued for the larger sample studies.

4.5 Questionnaire Comfort Score

The questionnaire did evolve from a basic level to a more specific evaluation, with simplified instructions. The editions of the Questionnaire were guided by the human’s inputs (Additional Comments) and other research investigation, previously mentioned. The main editions where to add an additional ear diagram in between each of the time frames (seven pictures, instead of one) also some more questions, in the beginning and in the end. (Note, the questionnaire described on the top already reflects the most up to date version.). The average score was based on the six different comfort evaluations (six different time frames). scores are given a qualitative input, and that reference figure can be seen below

![Comfort Scale Image](image)

Figure 4.5.1 Comfort scale

The scale goes from cero (no discomfort) to ten (very significant discomfort, cannot wear anymore). The subject’s responses ranged from 1.5 to 5 on the Complete sample. Below there are the results of the evaluation. These results were only considering the five subjects in the developing team. The reason this did not take into consideration the whole ten sample size was because there was a study/ comparison to see if sample size of five differed from sample size of ten. This to reduce the time frame, The results showed there was no significant difference, these tables can be appreciated below

52
This graph demonstrates that there is no significant difference between the results of the five subjects used for the second part of the study, were there was only five subjects and four headsets, and the first initial section were there was ten subjects and only two headsets. Additionally, from the Grouping comparison while there is no significant difference between the same head device and different sample size, there is a significant difference from one headset device to the other. Here as in the other comparisons the V13 model proves to be at a higher ranking than the 3M Pro Grade by about 1.5.
In the following table the results presented are the comfort scores for the four devices, as previously stated with only five subjects. There is a difference of approximately 1.7 in between the two headphones in the far right and the 3M Pro Grade model and similarly between that last one and V13. Here the model with the highest score is the V13 earmuff, followed by the 3M Pro Grade and the two Sony models (which do not significantly differ).

![Headset Model Vs. Comfort Score](image)

*The pooled standard deviation is used to calculate the intervals.*

**Figure 4.5.4 Comfort Score Human Input**

<table>
<thead>
<tr>
<th>Factor</th>
<th>N</th>
<th>Mean</th>
<th>Grouping</th>
</tr>
</thead>
<tbody>
<tr>
<td>V13</td>
<td>30</td>
<td>4.907</td>
<td>A</td>
</tr>
<tr>
<td>3M Pro Grade</td>
<td>30</td>
<td>3.200</td>
<td>B</td>
</tr>
<tr>
<td>SONY wh - 1000xm4</td>
<td>30</td>
<td>1.600</td>
<td>C</td>
</tr>
<tr>
<td>SONY whf - 1000xm4</td>
<td>30</td>
<td>1.533</td>
<td>C</td>
</tr>
</tbody>
</table>

*Means that do not share a letter are significantly different.*

**Figure 4.5.5 Grouping for Comfort Score Human Input**
from the table the average response for the 3M Pro-Grade was below insignificant discomfort or in between very insignificant discomfort and Insignificant Discomfort. While for the GN the average response was in between insignificant Discomfort and Discomfort. The last two devices are below very Insignificant comfort. This first part of the study provides quantitative inputs for the analysis, in terms of the comfort score given to the specific devices by the users. In the next section there is an area mapping assessment, to see where most discomfort was felt by the user and how this was to be used to focus on specific areas of the devices to redesign.

At last, there was a set of three different Graphs all with the same finality, prove the that as distance increases the discomfort increases. These graphs are only on three devices, because one of those devices was not an over the ear device. the first comparison is the 3M Pro Grade, here results tend to point that there is no direct relation between the head breadth and the comfort score.

Figure 4.5.6 3M Pro Grade Vs. Head Breadth
Figure 4.5.7 Grouping for 3M Pro Grade Vs. Head Breadth

There were two groups, one data point that stands out is the smallest distance (136.79mm) on the group with the largest means, which is not congruent to distance and force. The second model to analyze is V13 earmuff, which also showed nonconclusive data points. There is no relation between the comfort score and its corresponding distance.

The pooled standard deviation is used to calculate the intervals.

Figure 4.5.8 V13 Vs. Head Breadth
Grouping Information Using the Tukey Method and 95% Confidence

<table>
<thead>
<tr>
<th>Factor</th>
<th>N</th>
<th>Mean</th>
<th>Grouping</th>
</tr>
</thead>
<tbody>
<tr>
<td>139.014</td>
<td>6</td>
<td>6.833</td>
<td>A</td>
</tr>
<tr>
<td>154.21</td>
<td>6</td>
<td>6.67</td>
<td>A</td>
</tr>
<tr>
<td>149.18</td>
<td>6</td>
<td>6.00</td>
<td>A</td>
</tr>
<tr>
<td>136.786</td>
<td>6</td>
<td>4.333</td>
<td>A</td>
</tr>
<tr>
<td>155.96</td>
<td>6</td>
<td>4.000</td>
<td>A</td>
</tr>
<tr>
<td>143.292</td>
<td>6</td>
<td>3.833</td>
<td>A</td>
</tr>
<tr>
<td>152.49</td>
<td>6</td>
<td>3.833</td>
<td>A</td>
</tr>
<tr>
<td>145.264</td>
<td>6</td>
<td>3.667</td>
<td>A</td>
</tr>
<tr>
<td>150.96</td>
<td>6</td>
<td>3.667</td>
<td>A</td>
</tr>
<tr>
<td>152.452</td>
<td>6</td>
<td>3.000</td>
<td>A</td>
</tr>
</tbody>
</table>

Means that do not share a letter are significantly different.

Figure 4.5.9 Grouping for V13 Vs. Head Breadth

One important fact here is that there is only one group, which meant there is no significant difference between any of the data points, From the lowest to the highest.

At last, the results for the Sony wh – 1000xm4 (the only over the ear device that was not an earmuff) these had lower scores than the previous two models and had a pattern where the comfort score did increase as the distance increased. Here the reading 152.45 was omitted because due to time constraints and its similarity to 152.49 (result scores were not significantly different in the last two devices).
There are three distinct groups formed here, two of which are similar for the exception of one value in each group. For group A, the comfort score for the 150.96 distance and group B the score for the 155.96 mm.
4.6 Questionnaire Area Mapping, Human Input

This section will focus on describing the areas of discomfort and the assessment of the humans in the different questions.

Part I. consists of two questions, the intention in these two questions was to inquire in the experience of the user. The two questions are:

- Do you regularly use earmuffs, or have experience wearing earmuffs?
- If so, how long do you wear them daily (in one session)?

In this research the subjects were not experienced, meaning they did not wear earmuffs regularly. The results are presented in two sets, ten participants with two earmuffs (V13 and 3M Pro Grade) and the second set, five participants and the remaining devices (Sony headphones).

Part II. Graphical mapping of discomfort Location

This section is where the user assessed the location of discomfort in a 2D diagram of the ear. There were four different pareto charts, representing each of the concentrations of discomfort in each of the four devices. The ear was divided into eleven areas to be able to more accurately map where most of the discomfort was felt. Here is a diagram of the nine areas color coded.
Figure 4.6.1 Area Mapping color coded ear

V13 Earmuff discomfort areas constantly pointed mostly to the entrance of the ear canal and the helix. 3M Pro-Grade earmuff showed that results were closer to each other and the area where most of the discomfort was captured was the area behind the Helix. A visual representation can be appreciated below with the following Pareto charts:
The Pareto chart addressed four different sets of information; labeled Area of Discomfort, Times Area was Selected, percent and Cum %. Those four were also included for the Pareto chart below. The four areas were described as follows; **Area of Discomfort**: the numeric representation of the area studied, as previously mentioned these went from one to eleven. The second label was the **Times Area was Selected**: this set of information showed the number of times the specific area was selected by the users. One point was awarded for each time one user selected that area in a particular time frame. If the user did not select any area, that specific time frame was left as zero, the maximum number of times an area could be selected by one subject for the whole duration of the one-hour trial was six times, meaning there could be a total of 66 points at the end of the experiment (11 discomfort areas multiplied by six time frames). The third, **Percent**: is a percentage representation of the amount each comfort mapping area contributed adding up to 100%. At last,
Cum % (Cumulative %) which was an addition of the current percentage and all its preceding data points.

The results for V13 Earmuff were as follows, the areas in order (higher to lower score) go from Area 7 (External Auditory Canal) with 38 times selected, followed by Area 1 (Helix) with 28 times selected, then Concha (Area 6) with 22 times selected, front of Tragus (Area 10) with 21 times selected, area behind the Helix (Area 11) with 11 times selected, Tragus (Area 4) and area below the Lobule (Area 8) with 10 times selected, Antitragus (Area 5) with seven times selected, Antihelix (Area 3) with six, second to last the crus of helix (Area 9) with five, and at last the Lobule (Area 2) with four. As previously mentioned, the two mayor areas of discomfort where eleven and four with a noticeable change and cumulative percentage of 40.7%.

Figure 4.6.3 3M Pro-Grade Discomfort Area Mapping, Pareto Chart
Following the same schematic and descriptions the results for 3M Pro-Grade Earmuff set were the following; At the top of all the scored areas is the Area behind the Helix (Area 11) with a score of 35, followed by the area below the Lobule (Area 8) with 28, area in front of Tragus (Area 10) with 19, then the Helix (Area 1) with 11, Followed by Tragus (Area 4) with 10 times, next Areas, Antitragus (Area 5) with seven, crus of helix (Area 9) with five, Followed by the Concha (Area 6) and Area 7 (External Auditory Canal) with a score of four each. The second to last is the Lobule (Area 2) with two and at last the Antihelix (Area 3) with one. Results in this second pareto chart are less apart to each other than the results in the previous analysis. The highest score was the area behind the helix with a 27.8 % followed by the Lobule and a cum % of fifty.

Figure 4.6.4 wh – 1000xm4 Discomfort Area Mapping, Pareto Chart

The next headset to consider was the Sony wh – 1000xm4 (over the ear headphone), these only contain the results/inputs from five human samples, and the data was more populated towards the left of the chart. There were four areas not selected by any of the users which were area four, five,
six and seven. The highest scoring area here was number one (Helix) with 13 and a 33.3 % followed by number two (lobule) with a seven and a cumulative percentage of 51.3 %. The lowest scoring area was the crus of the Helix with a one and a percentage of 7.7%.

![Image](image_url)

**Figure 4.6.5 wf – 1000xm4 Discomfort Area Mapping, Pareto Chart**

The last pareto chart was for the Sony wh – 1000xm4 (the only fully in ear device). The results were different to the other models, as almost 43 % of the cumulative percent is within the Highest-ranking area (External Auditory Canal) with a score was twenty-four. The lowest selected score was the crus of the helix with a score of four and percentage of 7.0. For this sample there were five areas not selected one, two, eight, 10, and 11.

### 4.7 Clamping Force Set Up

The last examination or experiment done for the investigation was the set up to test for clamping force. the setup had four main components, these were the sliding base which is the black and orange structure in the picture below. The mechanical analog gauge (white object on top of the
sliding base). The white platform (on the left) where one of the earmuffs side rests (this will move, in a horizontal manner). And at last, the fixed side to the right (where the other side of the earmuff rests), the rectangle metal sheet. Here is an image of V13 Earmuffs being assessed.

![Image of V13 Earmuffs being assessed](image)

Figure 4.7.1 Clamping Force Set Up

The experiments started by the adjustment of the sliding base to match the size of the head for the specific human examined. These ranged from 155.96 mm to 136.79 mm for this specific analysis there was a total of thirteen head sizes that were part of the sample, measurements taken from the human samples (all measurements were taken with the device below). this device was composed of two different components, one caliper and two rulers. The rulers were attached to the calipers end in such a way that they followed the same straight path as the calipers ends. This was to imitate the methodology followed in another research where a Soldiers physiological characteristics were examined (Choy-Rokas & Garlie, 2014). Below is an actual depiction of the devices in the referenced paper, two calipers, one is a sliding and the other a spreading with the extended anthropometer blades.
Figure 4.7.2 Measuring head breadth with the different calipers (spreading caliper on the left, sliding extended anthropometer blades on the right)

The following image is the device used for this research, closer to the second caliper. In the illustrations above.

Figure 4.7.3 Caliper used for this research.

There were two purposes to use this approach, one establishes a connection of clamping force and discomfort scores and two, a connection between clamping force and distance.

For this experiment the upper direction (height) was kept constant at 14.5 cm or 145 mm. (Lee, 2006)
Figure 4.7.4 head height reference, from bizygomatic breadth to top of the head.

The highlighted row was where the information resided, and to the left an image to reference the area that is being measured. The area starts where the bizygomatic distance starts and it ends at the top of the head, this is labeled four in the diagram.

Similarly, the measurements considered for the distance in between the two flat faces in the clamping force set up was the bizygomatic breadth. To the left side is a visual representation of this area, labeled twelve on the diagram.

Figure 4.7.5 bizygomatic Breadth Reference

<table>
<thead>
<tr>
<th>No</th>
<th>Dimensions</th>
<th>Mean</th>
<th>St. Dv</th>
<th>Min.</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Height</td>
<td>176.2</td>
<td>9.7</td>
<td>152.4</td>
<td>198.1</td>
</tr>
<tr>
<td>2</td>
<td>Weight</td>
<td>80.6</td>
<td>15.0</td>
<td>54.4</td>
<td>136.1</td>
</tr>
<tr>
<td>3</td>
<td>Menton-top of head</td>
<td>24.1</td>
<td>2.5</td>
<td>19</td>
<td>29.1</td>
</tr>
<tr>
<td>4</td>
<td>Head breadth</td>
<td>14.5</td>
<td>1.3</td>
<td>10.2</td>
<td>17.4</td>
</tr>
</tbody>
</table>
The following tables depicted the results obtained using the previously mentioned characteristics. The first table showed a comparison of the Distance (mm) versus the Force recorded (N), this was done in the three over the ear devices.

![Figure 4.7.6 Clamping Force Readings, Interval Plot Analysis using Analog Gauge](image)

**Figure 4.7.6 Clamping Force Readings, Interval Plot Analysis using Analog Gauge**

**Grouping Information Using the Tukey Method and 95% Confidence**

<table>
<thead>
<tr>
<th>Factor</th>
<th>N</th>
<th>Mean</th>
<th>Grouping</th>
</tr>
</thead>
<tbody>
<tr>
<td>V13</td>
<td>50</td>
<td>10.3438</td>
<td>A</td>
</tr>
<tr>
<td>3M Pro Grade</td>
<td>50</td>
<td>10.0375</td>
<td>B</td>
</tr>
<tr>
<td>Sony wh-1000xm4</td>
<td>50</td>
<td>3.2258</td>
<td>C</td>
</tr>
</tbody>
</table>

*Means that do not share a letter are significantly different.*

**Figure 4.7.7 Grouping for Clamping Force Readings, Interval Plot Analysis using Analog Gauge**

The table above demonstrates that the V13 Earmuff had the highest level of force applied in Newtons. The 3M Pro-Grade interval was (9.817, 10.621) and an average of 10.04. for V13 Earmuff, the interval is (9.945, 11.068) and an average of 10.35. at last, there was the Sony wh – 1000xm4 headset, which was notably lower with an average of 3.23, Note all numbers are in Newtons. the difference of the averages is 0.31 Newtons from 3M Pro Grade to V13, and 6.81N
from 3M to Sony. The largest difference is from Sony device to V13 with 7.10N. It is important to note that all data points are in separate groups, which meant they are all significantly different from each other. The largest set of readings here are the ones for V13 and the smallest is the ones for the Sony device. The next set of sections compared the different results to see if there are any additional relationship.

4.8 Analyzing Bias

This section analyzed vias between those that were participants of the project (developing phase) and those that were not participant, since there was only four persons outside the project, only four samples of the project were able to be considered for the analysis. These four were assigned a number and chosen randomly using excel randbetween function. These analyses were only conducted on two earmuffs, as they were the only devices tried by the two groups. The first sample presented here is the comparison for the V13 Model

Figure 4.8.1 Comparing Vias, V13

The pooled standard deviation is used to calculate the intervals.
Figure 4.8.2 Grouping Comparing Vias, V13

From this graph and its grouping information it can be said that there is no significant difference between the two groups. This established that there is no evident vias in this sample and this earmuff.

Figure 4.8.3 Comparing Vias, 3M Pro Grade
The second set of data points are for the 3M Pro Grade device, again, there was no evidence that the sampled data had a vias. So, it can again be said that there was no significant difference.

### 4.9 Comparing Sample by Sex Group

The following comparison was done to see if there was any significant difference between the sex groups (male and female). The sample size used for this comparison was eight (four male, four female), the reason for this adjustment was because there was only a total of four females in the sample of ten people. The table below had comfort score as the y-axis and earmuff model along with the sex description on the x-axis. The first set of data points, coversV13, which did not show any evidence of significant difference. The second set of points are those regarding the 3M Pro Grade headset, again the results do not provide enough evidence to say that there was significant difference within the two samples.
This last table proves again that the score was not significantly different, regardless of the sex. What was important to say is that between the headset devices, there is significant difference. Meaning V13 female and male are significantly different than 3M Pro Grade female and male.
4.10 Weight Vs Comfort Analysis

The first table included was a comparison of the weight for each hearing device. Two are over the ear, one was an in-ear device, and at last a hybrid of the two (V13). The objective was to see if there is any direct relation between the weight and the weight score assigned by the user.

![Figure 4.10.1 Weight, Head Devices](image)

The devices were weighted five times in a Mettler Toledo weight as appreciated in the table above, there is no significant variability between those readings. Results did show that the data points are significantly different, meaning all weight values were significantly different from each other.

The table below is used as a reinforcement agent, as it proved that five sample data points are not significantly different from the 10-sample data set. On the y-axis there are the weight scores, and on the x-axis, there are the weights, followed by the model
and at last the sample size. Note that this was only conducted for the first two Ear Devices (V13 and 3M Pro Grade), intended to reduce the time of the protocol.

Figure 4.10.2 Sample Size Comparison, Weight Score

The last set of results was the final comparison between the weight score (assigned by the user) and its weight.

Figure 4.10.3 Weight Vs. Weight Score, 5 Human Sample
### Grouping Information Using the Tukey Method and 95% Confidence

<table>
<thead>
<tr>
<th>Factor</th>
<th>N</th>
<th>Mean</th>
<th>Grouping</th>
</tr>
</thead>
<tbody>
<tr>
<td>455.47 (M13)</td>
<td>5</td>
<td>2.400</td>
<td>A</td>
</tr>
<tr>
<td>250.06 (SONY wh - 1000x</td>
<td>m4</td>
<td>5</td>
<td>2.000</td>
</tr>
<tr>
<td>377.78 (3M Pro Grade)</td>
<td>5</td>
<td>2.000</td>
<td>B</td>
</tr>
<tr>
<td>1428 (SONY wf - 1000xm4)</td>
<td>5</td>
<td>1.000</td>
<td>B</td>
</tr>
</tbody>
</table>

Means that do not share a letter are significantly different.

**Figure 4.10.4 Grouping for Weight Vs. Weight Score, 5 Human Sample**

Using Tukey comparison, there were two groups, but there is no significant difference apart from the largest to the smallest value (which is the largest difference weight wise). Using this table as a reference it was not concluded that weight has a direct effect on the weight score provided by the user.
Chapter 5: Conclusion

The research focused on assessing the level of comfortability provided by a set of head devices. One additively manufactured custom-made earmuff, another a commercial earmuff and at last two regular hearing devices. This experiment was developed from the initial two devices and four people to four devices and ten people. The conclusions of the project are described below, in the same order as the results were presented.

5.1 FSR and Silicon Model

Using a sample of four persons, no connection or correlation was found between any of the factors (silicon model or FSR). None of the comparisons used proved that there was a pattern between the readings obtained in the human or the silicon model. no apparent relation between the clamping force and the clamping force device recordings (FSR). The use and calibration of the sensor was not reliable and inaccurate, in the future there is an intention to do another attempt to prove them accurate using a different model or brand. Another path will be to use the readings as a reference and not as an accurate parameter.

5.2 Comparing Clamping Force Set Up with Human Comfort Scores

The results in section 4.5 are consistent with this thesis, and while individual forces do not increase as distance increase, there is a pattern were the higher the forces the most discomfort there is, considering group/whole sample population. The main tables to compare here are Figure 4.5.2, a comparison of headphone device and the score given to it by human samples. And Figure 4.7.6: a comparison of the headphone device and its corresponding Force reading. For both tables, it is important to say that all the variables are significantly different from each other. Also, there was a pattern where V13 is the highest on both tables and the Sony headset is the lowest, only considering the head devices that had head band. generally, as the force increases, so
does the discomfort level assigned by the user. Under one condition, it should be a population analysis, not an individual study.

5.3 Area Mapping, Human Input

This section was key on determining other factors (physically) that affected the comfort of the users. This is also a critical area to focus for design purposes, where most effort should be placed in the areas where most discomfort occurs. The four different devices, were divided in two groups. 3M Pro Grade and Sony WH-1000xm4 presented the same areas of discomfort. Those areas were the area below the lobule and the area behind the helix. On the other hand, there was V13 and Sony WF – 1000xm4 which indicated that most of the discomfort occurred in the external ear canal. People complained about V13 more often than they did with any of the other devices. Having stated the areas were discomfort occurred, there resides the best component optimization for these specific ear devices.

5.4 Analyzing Bias

This section was done to study vias between the sample members, since six participants participated in the development phase of V13. The results are on tables 4.8.1 and 4.8.3. In both studies, there was no proof of any significant difference, which does not prove that there exists a significant comfort score difference from the group that did the experiment and were part of the project and those who did not participate in the project (development).

5.5 Comparing Sample by Sex Group

This section intended to locate anomalies between the female and male subjects. From the results in 4.9, there is no significant difference between the two groups. It is important to say that even if the results from male vs. female did not show any significant difference, there still existed a significant difference between the models. Meaning the results from male V13 were significantly
different than the results for the male 3M Pro Grad. Similarly, results in Female V13 are significantly different than the female 3M Pro Grade Results. In both cases V13 was the highest score.

5.6 Weight Vs Comfort Analysis

Weight was evaluated in section 4.10 and from this comparison the relation between the weight of the device and the weight score assigned by the user. For the analysis from five subjects, there was no evidence that the weight of the device was significant in the evaluation of the end user. Position and force exerted were more relevant in the scores and evaluations.

5.7 Optimizing Comfort V13

The design of the additively manufactured earmuff device is to be improved considering two measures, number one the questionnaire score and number two the area mapping. The first section to improve the earmuffs is to interpret the results of the comfort score, looking into the clamping force results in figure 4.7.6 the V13 recorded forces are higher at that point. The solution to this is to reduce the size (thickness of the earmuff), as 3M Pro Grade ear devices provided a lower score and lower recorded forces using the same headband. The additional distance is contributing to the additional force applied in the clamping force, therefore increasing the discomfort score assigned by the user. To address this issue, it is important to fix the thickness of the earmuffs (more specifically the concha) The second metric is the Areas of Discomfort. From Figure 4.6.2 the results obtained showed that most discomfort mapping for this model was in the helix and the external auditory canal. This is due to the area of contact, mainly the inner components, most of the users also commented on the large space occupied by what is known as “the membrane” that was what caused the disturbances in the helix. This is to be fixed by the removal of the membrane and adding a direct line from the outer sound receiver into the inner component of the ear. Another
measure to increase the comfortability of the inner component is to explore new shape designs and ear buds, such as Foam ear buds.

5.8 General Conclusion and Future Analysis

This last section covers general recommendations for readers and future researchers in the field. From the results in the research study, future areas of interest are psychological approaches, were neural and cardiac responses are included into a final evaluation. These to complement readings obtained from the mechanical gauge and possible FSR readings. They are meant to study the effect of the different cerebral activities, heart frequencies, and their corresponding comfort score. It is also intended to continue testing with the FSR sensors and this to follow on the silicon model. The final objective with the silicon model is to find correlations and study how displacements in the inner ear affect comfort scores. The displacement of the ear canal will be studied in the silicon model while wearing the device and taking a CT scan. Those will be developed in a larger study with a broader time frame and subject sample size. The main intention with these new studies is to see if there exist any relevant differences from the data obtained in this study to this new set of data points. Results were conclusive with the fact that as forces recorded increased, so does the discomfort perceived by the user. FSR are evolving and trending topic, and should be considered for further examination, newer and more sophisticated models, that offer higher levels of accuracy and software manipulation. For readers and future researchers, it is important to assure consistency, overall statistical differences and sample sizes should always be accounted for, and a systematic approach will be the best option.
References


https://www.mmgonline.org/ear-nose-throat/ human ear figure 1.1


*adafruit*, learn.adafruit.com/assets/434.


www.researchgate.net/publication/273134617_Characterizing_the_Size_of_the_Encumbered_Soldier.


TOP SEVEN INDUSTRIES FOR ADDITIVE MANUFACTURING APPLICATIONS, luxcreo.com/top-seven-industries-for-additive-manufacturing-applications/.

Appendix I. Questionnaire

Earmuff Comfort evaluation

Sex:

Age:

Instructions

Below is a scale to evaluate the discomfort level according to a numeric value, please assess the following time frames. assign a value of discomfort at every 10-minute mark. the six inspections have already taken place, then a last evaluation will be asked to record the overall comfort (with earmuffs taken off already). Shade the level you feel appropriate. Make sure you are not wearing any other:

Earbud, ear accessories, earrings, hearing aids or anything that goes within the area being studied (Ear and surrounding areas, all within the earmuff covered area).

Make sure to also cease from eating or chewing

Please NOTE, once the study starts, the investigator will only be handing you the different sections of the Questionnaire, there will be no communication between the investigator and the subject once the session begins. DO NOT REMOVE THE EARMUFFS once the timer starts.

Below is a brief set of questions, to assess the level of experience you have with wearing earmuffs:

Part I. evaluating the users experience wearing Earmuffs (Hearing Protection, Not headphones)

Do you regularly use earmuffs, or have experience wearing earmuffs?

If so, how long do you wear them daily (in one session)?

Part II. Comfort Score
Below is the scale you will be using to assess the level of comfortability. Apart from the scale, you will also be able to assess the location were most of the discomfort is felt with an illustration.

First inspection (0-10 minutes)

<table>
<thead>
<tr>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>8</th>
<th>10</th>
</tr>
</thead>
</table>

Subjective Discomfort Location Placement

In this second part assign a circular pattern in the area you feel discomfort, and evaluate the discomfort area in ascending order, in which the higher it goes, the most discomfort felt.
Second inspection (10-20 minutes)

<table>
<thead>
<tr>
<th>Subjective Discomfort Location Placement</th>
</tr>
</thead>
<tbody>
<tr>
<td>No discomfort</td>
</tr>
<tr>
<td>Very insignificant Discomfort</td>
</tr>
<tr>
<td>Insignificant Discomfort</td>
</tr>
<tr>
<td>Discomfort</td>
</tr>
<tr>
<td>Significant Discomfort</td>
</tr>
<tr>
<td>Very Significant Discomfort, cannot wear anymore</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>8</th>
<th>10</th>
</tr>
</thead>
</table>

Subjective Discomfort Location Placement

In this second part assign a circular pattern in the area you feel discomfort, and evaluate the discomfort area in ascending order, in which the higher it goes, the most discomfort felt.
Third inspection (20-30 minutes)

Subjective Discomfort Location Placement

In this second part assign a circular pattern in the area you feel discomfort, and evaluate the discomfort area in ascending order, in which the higher it goes, the most discomfort felt.
Subjective Discomfort Location Placement

In this second part assign a circular pattern in the area you feel discomfort, and evaluate the discomfort area in ascending order, in which the higher it goes, the most discomfort felt.
Subjective Discomfort Location Placement

In this second part assign a circular pattern in the area you feel discomfort, and evaluate the discomfort area in ascending order, in which the higher it goes, the most discomfort felt.
Sixth inspection (50-60 minutes)

Subjective Discomfort Location Placement

In this second part assign a circular pattern in the area you feel discomfort, and evaluate the discomfort area in ascending order, in which the higher it goes, the most discomfort felt.
Subjective Discomfort Location Placement

In this second part assign a circular pattern in the area you feel discomfort, and evaluate the discomfort area in ascending order, in which the higher it goes, the most discomfort felt.
Part III. Evaluating Tightness
How will you assess the Earmuff in terms of tightness?

- Barely Noticeable
- Lightly Tight
- Tight
- Really Tight
- Unbearable

Part IV. Weight Evaluation
How will you assess the Earmuff weight?

- Barely Noticeable
- Light Weighted
- Heavy
- Really Heavy
- Unbearable

Part V. Additional Questions
Do you feel any sort of discomfort related to the temperate in the ear?

Do you felt you sweat, while wearing the earmuffs? If so, how uncomfortable do you think that is?

How comfortable are the cushions?

How comfortable was the headband?

Do you happen to feel an occlusion feeling?

Do you feel the ear plug on the inside is comfortable?

Do you feel the Ear plug is appropriate, would you change anything?
What area would you say the earmuff needs work in?

Part VI. Additional comments
VITA

Rene Dominguez
Email: radominguezgar@miners.edu

EDUCATION

M.S. in Manufacturing Engineering aspirant, the University of Texas at El Paso, currently working in ergonomics project for the W.M Keck Center. Assessing the levels of comfort with the use of qualitative and quantitative tools, looking forward to developing innovative ideas and methods to assess such parameters. BS in manufacturing, Industrial and systems Engineering, acquired essential skills to further analyze data collected and develop new ways of thinking. Pursing a Doctorate degree in the same area of interest with the W.M. Keck Department.

Practical certifications in software programs such as: Systems and Industrial Engineering Bootcamp, National Association of State Boards of Accountancy (NASBA)- Excel 2019 essential training, Excel: Introduction to Macros and VBA, Program: PMI® Registered Education Provider -Microsoft Excel: Using Solver for Decision Analysis, and NASBA -Learning Excel What-If Analysis

EXPERIENCE

Program manager/ coordinator for the IMSE department, as the profound respect and admiration to my department, to serve and honor new students with new insights into the programs offered. TA and RA with the same department, were all the pieces came together and vocation was at sight, always serving and assessing students to the best of my abilities. Tutor at El Paso Community College were the hunger to teach was discovered.