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Building SoundWorks, the New Revolutionary Computer-Based Audiometer

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Abstract

The goal of this engineering project was to design a computer-based audiometer called SoundWorks to provide users with a simple and cheap way to monitor hearing loss. SoundWorks was created to test people for their hearing loss in an automatic manner. It generates test tones of specific frequencies at specific ascending sound levels for which the testee responds on hearing the tone through a calibrated headphone set/amplifier setup. It covers a normal (100Hz-8000Hz) and an extended range up to 20,000Hz and covers sound levels from 0dB to 120dB. An audiogram (plot of threshold values) is updated in real time. A report is generated automatically after both ears are tested for audiologist interpretation. Options include pulse or continuous test tone, silence or white noise in ear not being tested. Differentiating enhancements of SoundWorks include hysteresis of threshold, multilingual voice and text prompts, manual mode for spot checks, speech mode, and tinnitus matching mode. This product was developed in C# language on Microsoft Windows 7, debugged, and fully validated for complete functionality. Calibration of all sound levels, frequencies, and channels has been completed. This product aims to provide a portable/affordable hearing test capability for under-served economies, volunteer organizations, and frontline military medical units for quick screening of personnel exposed to excessive sound levels. Future plans include medical certification and porting to mobile devices such as smartphones and tablets.

I. Introduction

Hearing Loss

Hearing loss has become an undeniably large problem in the world today. The leading cause of hearing loss used to be excessive noise exposure in the workplace, but today many young people are losing their hearing at alarming rates due to excessive noise exposure from portable stereo earphones (Stony Brook). With the unprecedented proliferation of certain personal listening devices such as iPods and other Mp3 players, more and more people affected by hearing loss. Recent studies have shown that listening to personal devices at high volumes for extended amounts of time can lead to a significant degree of hearing loss (Blue). Personal listening devices have led to a dramatic increase in individuals with hearing loss. The current approximation stands at nearly 50 million American citizens (Bowman). Personal listening devices are the catalyst for a specific form of hearing loss called Noise Induced Hearing Loss (NIHL). NIHL can be caused by a one-time exposure to a deafening sound, like an explosion, or caused by continuous exposure to loud sounds (NIDCD). When the ears are exposed to loud noises, the hair cells in the cochlea begin to fall off which decreases the function of the cochlea. Because the cochlea's effectiveness is decreased, hearing loss occurs.

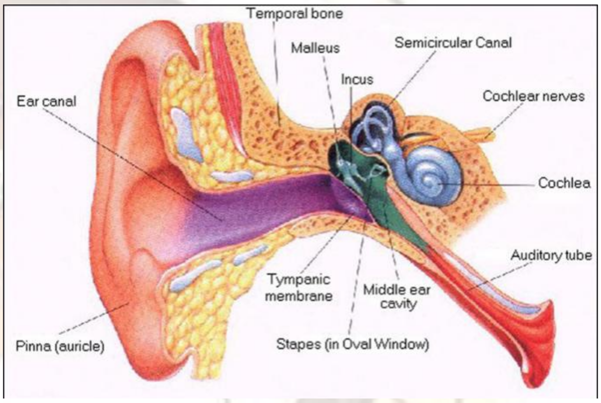

Figure 1. *Anatomy of the ear*

Possible Solution

One reasonable option for cutting down hearing loss is initiating mandatory hearing tests for all citizens so that proper diagnosis by a professional audiologist can occur. The drawbacks to this plan of action, however, are that hearing tests can be large economic burdens on most people and can also be difficult to obtain, as they require a prescription from a certified doctor. Considering all of these circumstances, the only viable option left to tackle hearing loss is to create a simple and portable audiometer (device which administers hearing test) that appeals to the mass market. The audiometer created in this engineering project was called SoundWorks.

How Audiometers Work

An audiometer evaluates an individual's hearing loss by analyzing their ability to hear a myriad of tones with ranging frequencies, or pitches of sound, and amplitudes, or volumes of sound. Frequencies are measured in Hertz (Hz) and amplitudes are measured in decibels (dB) (Gelfand). Most standard audiometers test in frequencies ranging from 100Hz to 8,000Hz which is the threshold of human speech (Appendix A). Some audiometers can test in frequencies up to 20,000Hz which is the threshold of human hearing. At the end of each hearing test, an audiogram (visual display of results) is created for an audiologist to analyze (Wikimedia).

II. Engineering Goal

The primary goal of this engineering project was to create an audiometer that could be used by anybody, anywhere, and at anytime. Current consumer audiometers do exist, but have several disadvantages. They can be very expensive to purchase (Appendix A) and maintain for further use in the future, due to their required calibration (Wikimedia, Audiometer). Also, they contain a myriad of different functions, which can appear convoluted to consumers who have very little expertise in the area of audiology. To best meet the needs of the consumer market, SoundWorks was designed and specified to be a computer-based audiometer application. Software like SoundWorks is extremely portable, inexpensive, and also easy to use in comparison to the bulky and complex audiometers on the market today.

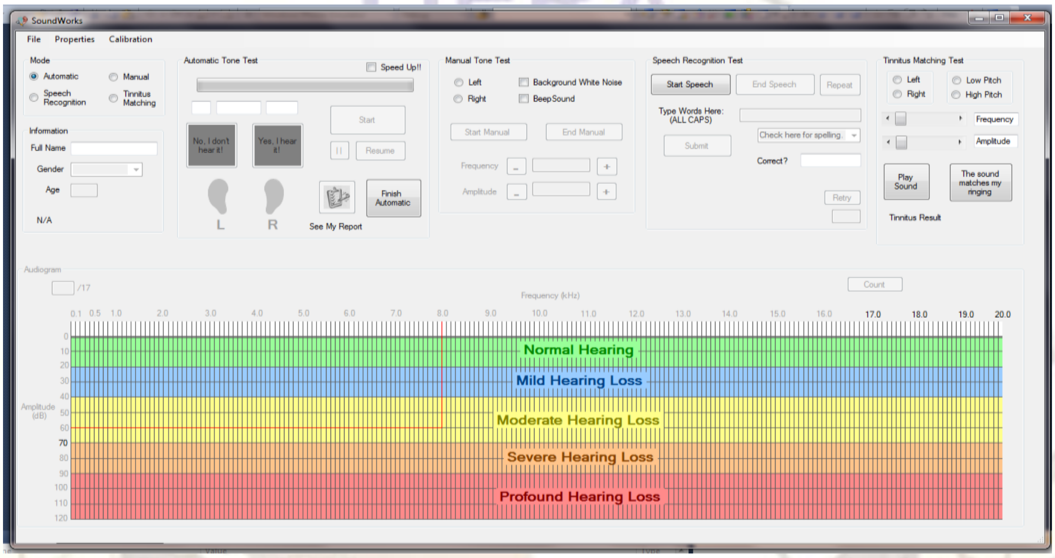

Figure 2. *SoundWorks Audiometer Application*

III. Specifications

The first step in engineering a product is setting specifications for the product. The specifications for SoundWorks were set based on extensive research conducted on other popular consumer audiometers in the market (Appendix A).

Automation

Most popular consumer audiometers today, like the Welch-Allyn AM 182 Audiometer, are manual, which means that the consumer has to individually operate the device in order to progress through the hearing test (Welch Allyn). Considering the variety of different knobs, buttons, and switches on the audiometer, this is a very daunting process for most consumers. In order to create the simplest product possible, SoundWorks was designed to be a completely automatic audiometer, requiring no expertise by the user. It goes through all of the set frequencies with the user simply responding whether they heard the sound or whether they did not hear the sound. After finishing the left ear, the test moves on to the right ear. Automation can make the hearing test much simpler, as expertise by the user is no longer required.

Figure 3. *The Welch-Allyn AM 182 Manual Audiometer (above) is one of the most popular on the market, but contains several flaws.*

Frequency Range

Another weakness to consumer audiometers is the frequency range within which they operate.

Most of them will test from set frequencies in the range of 100Hz to 8,000Hz, which only covers a small spectrum of the range of human hearing (Appendix A). SoundWorks was set to have frequencies ranging from 100Hz to 20,000Hz, which is the threshold of human hearing. Testing frequencies beyond 8,000Hz allows for the users to see the amount of Sensorineural Hearing Loss (SSHL) they may have. SSHL is a type of hearing loss that occurs overtime, as the hair cells in the cochlea essential for interpretation of sound begin to degenerate (ASHA). This is why, over time, humans lose their abilities to hear high frequencies, which require more hair cells in the cochlea. Testing higher frequencies allows for users to simply track how much SSHL they have obtained over time and estimate how much hearing they may lose in the future (CIBA).

Amplitude Range

The amplitude range is the range of volumes, or levels of sound, that will be potentially tested for each frequency. SoundWorks was set to have an amplitude range starting at 0dB, which is the quietest sound that can be heard, to 120dB, which is the pain threshold of human hearing (Galen Carol Audio). Increments of 10dB were incorporated. All amplitudes presented to the user were calibrated using an industry grade decibel meter.

Testing Left and Right Ear

Sound Works was specified to evaluate the hearing loss of both the right and left ear. Once all frequencies for the left ear have been covered, the program will automatically begin playing frequencies in order to test the right ear.

Audiogram

Another weakness discovered was the manner in which results are displayed. Textual displays are most common with consumer audiometers, but they don't always convey the results coherently to the user. SoundWorks was specified to have an audiogram (visual display of results) that is modified as the user progresses through the test. An audiogram allows a user to more clearly understand what frequencies they have trouble hearing and how bad, in general, their hearing is. This is also because audiograms tend to be divided into five colored sections based on the severity of hearing loss (Johns Hopkins Medicine). The five sections are based on the decibel level ranges as follows:

- 0-20dB - No Hearing Loss
- 21-40dB - Mild Hearing Loss
- 41-70dB - Moderate Hearing Loss
- 71-90dB - Severe Hearing Loss
- 91-120dB - Profound Hearing Loss

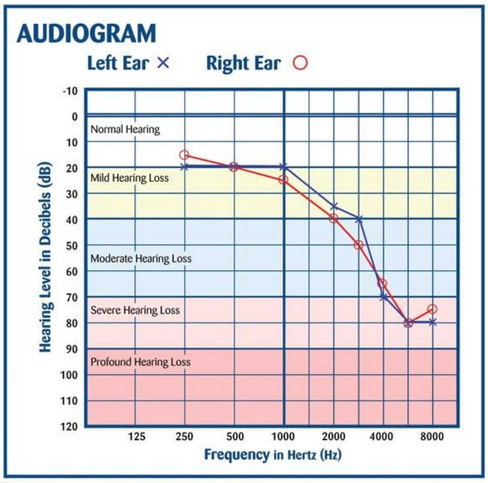

Figure 4. *Typical Audiogram with categories of hearing loss*

Patient Test Report

A unique specification set was the creation of an official patient test report at the culmination of every hearing test. The test report contains the user's personal information and textual results of the test. The purpose of SoundWorks is to prevent further hearing loss, so a record of test results can be extremely beneficial. A user can obtain this report, save it, and give it to certified doctor for further interpretation.

IV. Differentiating Features

As more research was conducted during the development of SoundWorks, more and more discerning features were incorporated into the audiometer.

Pulse Tones

Traditional audiometers tend to use a pure-tone stimulus to test users; however, some will have the option of taking the test using pulse-tone stimulus. This is primarily because some people are keener to hearing pulse tones than pure tones (Roeser). This feature was incorporated into SoundWorks in order to appeal to as many users as possible.

Masking White Noise

This is simply a method of reducing the distraction for users. While the tone is being played in one ear, a masking noise will be played in the other in order to allow the stimulated ear to focus on interpreting the tone (Roeser). This feature was incorporated into SoundWorks in order to appeal to as many users as possible.

Identification of Hearing Disorders

There are typically three hearing disorders that can be identified using an audiometer. Although audiometers do not guarantee that the patient has this disorder, they can warn those patients. Meniere's disease, a deficiency of the inner ear, disrupts the ear's ability to interpret low frequencies, usually in the range of 100Hz to 1000Hz (Schwartz). Noise-Induced Hearing Loss (NIHL), caused by exposure to loud noise, results in a disability to hear frequencies from 3000Hz to 8000Hz (NIDCD). Sensorineural Hearing Loss (SSHL), caused by hair cell degeneration and sometimes by exposure to chemicals, results in a disability to hear high frequencies from 9000Hz to 20000Hz (ASHA). In the patient file report, the results of the hearing test will indicate whether there is a possibility that the patient has one of these disorders.

Hysteresis

The concept of hysteresis states that there is a greater chance of an individual hearing a sound when the amplitude is decreasing rather than when it is increasing (Wikimedia Foundation, Absolute threshold of hearing). If a quieter and previously inaudible tone is heard the second time around as the amplitude decreases, the user possesses hysteresis. This process of rechecking amplitudes is typically done manually in current audiometers by audiologists. However, SoundWorks automatically incorporates the concept of hysteresis into its testing process.

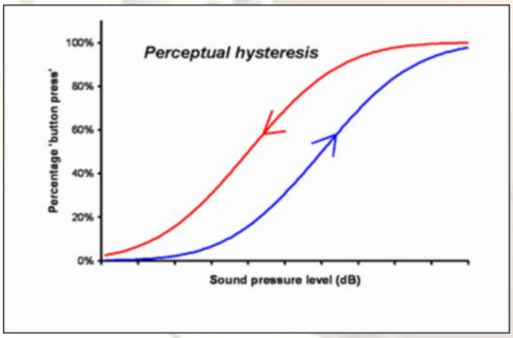

Figure 5. *Diagram of Concept of Hysteresis*

Manual Test

The manual test was incorporated primarily for spot checking purposes. If a user wants to verify his results in specific frequencies, it is not necessary to retake the automatic test. The manual test will allow for the user to choose a particular frequency and retest themselves if any doubt exists.

Speech Recognition Test

This test is another method of evaluating a person's hearing loss. It focuses on sentences as stimuli rather than tones. The sentences used in SoundWorks are certified sentences that other audiologists use in order to test their patients' ability to recognize speech. The speech recognition test can offer a more complete view of a patient's hearing situation as it assesses one's ability to understand words and sentences spoken at an everyday listening level (Hearing Loss Education Center).

Tinnitus Matching Test

This test is specifically designed for patients who have tinnitus. Tinnitus is a constant ringing which occurs in the ear. Tinnitus can have adverse effects on people including interfering with one's sleeping patterns and also causing depression (Snow). Nearly 1 in 5 people in the United States has tinnitus (Mayo Clinic Staff). This test will simply allow the user to modify the frequency and amplitude of the sound output in one ear in order to match the frequency and amplitude of their "ringing" in another ear. This test will inevitably allow a user with tinnitus to obtain a special hearing aid, which helps to mask the tinnitus (Snow).

Voice and Text Commands

Throughout the test, voice and text commands are given to the user in order to guide them through the hearing test. This additional feature makes SoundWorks an extremely user-friendly product.

Multilingual

SoundWorks has the ability to be modified to operate in several different languages, making it a product that can be compatible with the worldwide market. Thus far, it can operate in both English and Spanish.

V. Functionality

Automatic Test

The user begins the automatic test by entering personal information which will be inserted into a patient test report created at the culmination of the test. Then, users will select whether they want masking white noise and/or pulse tones incorporated into the test. The defaults for the automatic test are silence in the ear not being tested and continuous tones as stimuli.

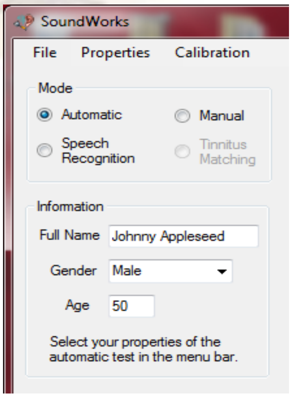

Figure 6. *Entering personal information for patient test report*

The test will start with the left ear and then progress to the right ear. Once the user begins the test, voice and text commands will guide the user to respond when a sound is heard. A sound of the first frequency and first amplitude will be played. If the user presses the button, "Yes, I heard it," signifying that the sound was heard, the test will move on to the next frequency. If the user does not press that button, the amplitude will increase to the next amplitude level. The amplitude continues to increase until the user presses "Yes, I heard it." The amplitude will then decrease to the next lowest amplitude level in order to verify whether the user could not hear that quieter sound. Voice and text commands guide the user to respond when the sound is no longer heard. If the user presses "No, I don't hear it," then hysteresis does not influence them, and the test moves on to the next frequency. If this button is not pressed, the amplitude will continue to decrease until the user presses "No, I don't hear it," signifying that the sound can no longer be heard. The test will then progress to the next frequency. Once all the frequencies have been tested in the left ear, the test will progress to the right ear and repeat the same processes.

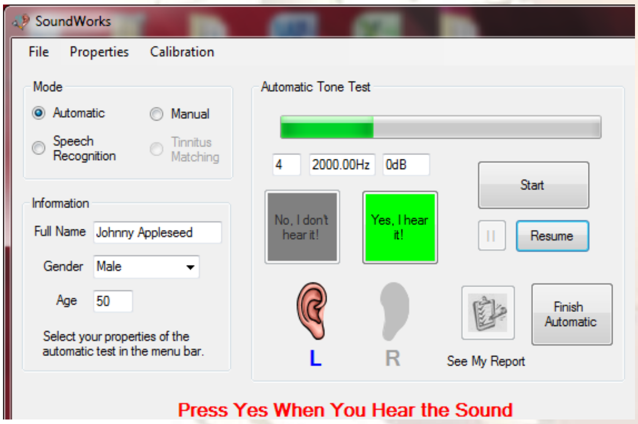

Figure 7. *Automatic Test in progress*

The results of the test will be plotted in real time in an audiogram at the bottom of the application. If the user hears the frequency at the lowest amplitude level, then a dot will be plotted at 0dB for that specific frequency. For all other scenarios, the average of amplitude level when the sound was heard and the amplitude level when the sound was not heard will be plotted on the audiogram for that specific frequency.

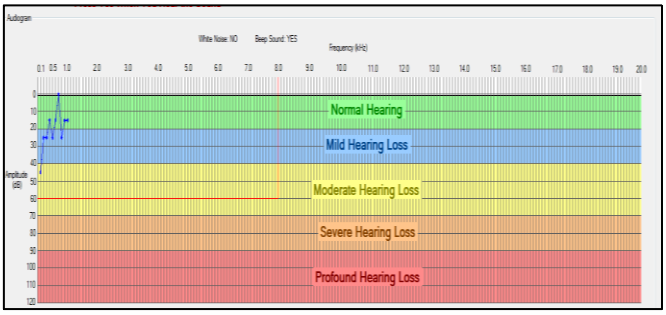

Figure 8. *Audiogram updated as user progresses through test*

Patient Test Report

At the culmination of each automatic test, SoundWorks will create a file with all results and then save it to a specific folder. Then, the user can press "See My Report" in order to view their test report. They can also print out this report in order to give to a doctor for further interpretation.

Manual Test

The manual test is primarily for users to verify the results they obtained at a specific frequency. Instead of having to endure the long automatic test, it would be much easier to check wanted frequencies only. When the manual test option is selected, the user can manually change the frequency and amplitude to the sound that they want to retest themselves in. Options for masking white noise and pulse tones can be selected for this test as well.

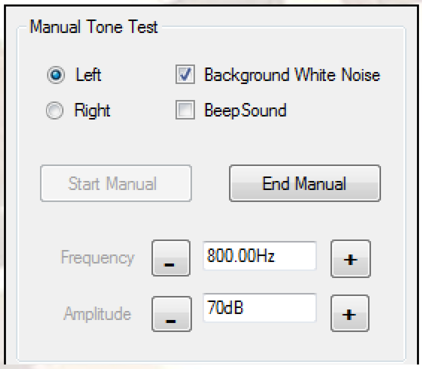

Figure 9. *Manual Test in Progress*

Speech Recognition Test

The speech recognition test is primarily an add-on to the automatic tone test. It will allow users to test their ability to hear and interpret human speech. Once the user selects the option for the Speech Recognition Test, a sentence from a set list of certified sentences will be randomly selected and read to the user at the highest amplitude level (80dB). The program utilizes a Speech Synthesizer function in order to read these sentences to the user. The user then types the sentence into a text box the way they heard it. If the sentence wasn't heard, the user can press "Repeat" to listen to a new sentence at the same amplitude level. If the user types the sentence correctly, a new sentence will be randomly played at the next lowest amplitude level (60dB). If the user types the sentence back incorrectly, then the speech recognition test will end, advising the user to visit a doctor to fix their hearing deficiency. As the user continues to correctly type the sentence back, the amplitude will continue to decrease until it reaches the lowest amplitude level (0dB).

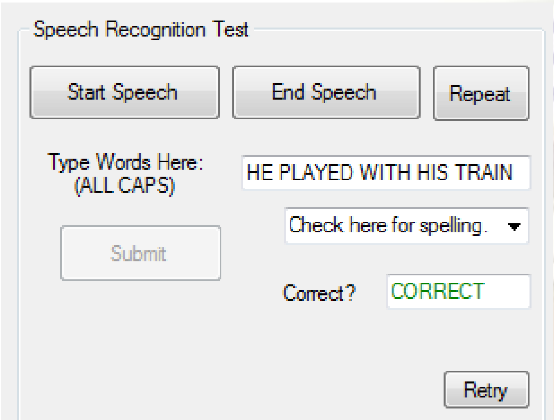

Figure 10. *Speech Recognition Test in Progress*

Tinnitus Matching Test

Tinnitus is merely a "ringing" in an ear and doesn't affect everybody. The purpose of this Tinnitus Matching Test is to match the frequency and amplitude of that "ringing." When the user selects the option for Tinnitus Matching Test, they will select whether their tinnitus is in the right or left ear and whether it is high-pitched or low-pitched. Then, they will adjust the frequency and amplitude of the sound in order to match their "ringing." When the sound does match the "ringing," the user presses "This sound matches my ringing." This information can then be taken to an audiologist for further evaluation and treatment.

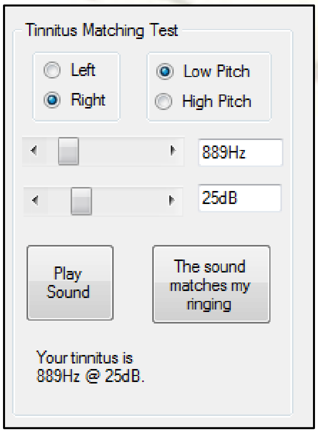

Figure 11. *Culmination of Tinnitus Matching Test with tinnitus specifications.*

VI. Development

SoundWorks was developed in a C# environment in Microsoft Visual Studio. The specifications were followed throughout the development and the features were incorporated as the process continued. At the end, all aspects of the application were validated.

Sound Generation

The sounds were generated using a wave generator function. The first part of the wave generator function is an input of information to create the wave. This includes the frequency and amplitude of the wave, left or right ear, pulse or continuous tone, and masking white noise or silence. Then the duration of the wave is set for 10 seconds. The final part of the wave generator function is creating a .wav file called "Test Sound File," saving "Test Sound File" to a specific folder and then playing "Test Sound File" in the running application.

Calibration

Calibration is the process of assuring that the sound outputted from the application matches the intended amplitude or volume. This is necessary because it ensures that the function of the application is legitimate and the results it offers can be interpreted (Wikimedia Foundation, Audiometer). Calibration required the use of a computer to run the application, an industry grade sound level meter, high quality headphones, and a headphone amplifier. First, the sounds outputted from the computer running the application were transmitted to the headphones through a headphone amplifier. A decibel meter was then used to measure the volume of the sound in dB in order to match the desired decibel level. The amplitude of the wave generator function in the application was modified in order to reach the desired decibel level. This process was repeated for all set frequencies at all dB levels for both the left and right ear.

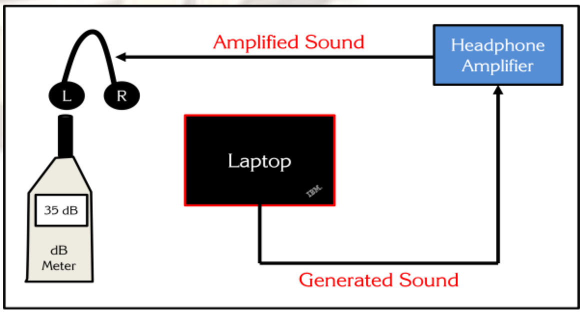

Figure 12. *Calibration Diagram*

VII. Validation

The final step in engineering a product is validation. This process is to ensure that all aspects of the product function well and meet the specifications made at the start.

Sound Generation Validation

Using Audio Editor Software, the outputted sounds from SoundWorks were verified to ensure that SoundWorks was producing the correct type of wave. The frequency, which is the number of cycles per second, was verified. Also, the same software was used to verify that the sounds were being produced in the desired ear, pulse tones were being produced correctly, and that masking white noise was being produced when applicable.

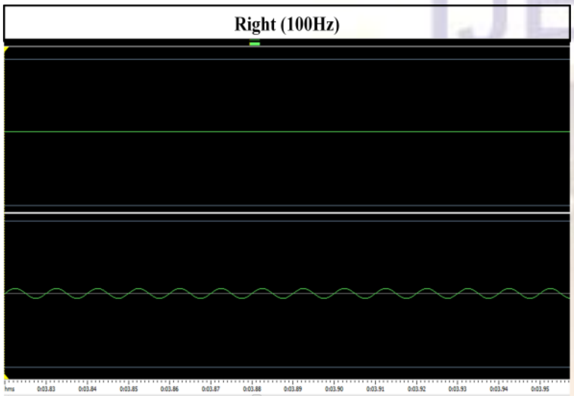

Figure 13. *Validation of Right Ear Tone*

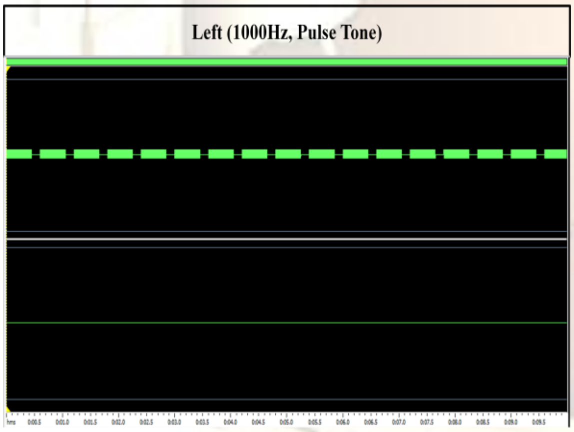

Figure 14. *Validation of Left Ear Pulse Tone*

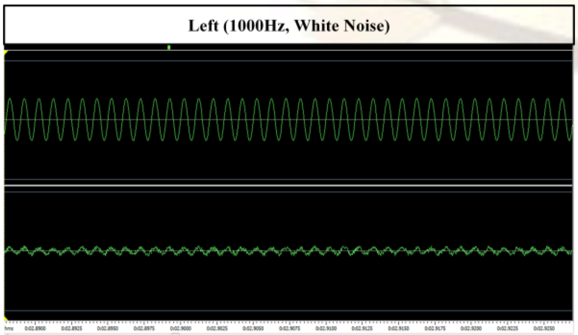

Figure 15. *Validation of Left Ear Tone with Masking White Noise*

Test Scenario Validation

The following validation plan verifies that all aspects of the SoundWorks application are functioning soundly. This was essential in ensuring the legitimacy of the application.

Table 1. *Validation Plan*

Test Scenario	Yes or No?
All frequencies are being generated correctly	Yes
All amplitudes are being generated correctly	Yes
Users can access help to utilize SoundWorks	Yes
Automatic Mode	
Allows users to enter personal information for patient test report	Yes
User has option of trying to identify a pulse tone rather than a continuous tone	Yes
User has option of having masking white noise in ear not being tested rather than having silence	Yes
Sound Command, "Press Yes When You Hear The Sound" is working	Yes
Sound Command, "Press No When You Don't Hear The Sound" is working	Yes
If user hears sound at lowest amplitude, frequency increases	Yes
If user does not hear sound at lowest amplitude, amplitude increases	Yes
If user hears sound at higher amplitude, amplitude is decreased for user to try and hear the originally inaudible sound (Hysteresis)	Yes
If user can hear originally inaudible sound, amplitude decreases	Yes
If user cannot hear originally inaudible sound, frequency increases	Yes
If user reaches maximum amplitude (120dB) without hearing, frequency increases	Yes
If user completes last frequency in left ear, then the right ear test begins	Yes
Sound Command, "You Are Now Switching From Left to Right" is working	Yes
User can pause and resume test at any time	Yes
User can switch between masking white noise and silence during the test	Yes
User can switch between pulse tone and continuous tone testing during the test	Yes
Displaying Results Visually	
For every frequency, average of "Yes, I hear it" amplitude and "No, I don't hear it" amplitude are being displayed as a data point on audiogram	Yes
If user can't hear highest amplitude, point	Yes

is plotted at highest amplitude (120dB)	
If user can hear lowest amplitude, point is plotted at lowest amplitude (0dB)	Yes
Patient Report	
A patient report is created at the culmination of each hearing tests	Yes
All test results can be displayed in exported text file for both Left and Right ears	Yes
All standard categories of hearing loss can be displayed in text file	Yes
Information about hearing disorders can be displayed in text file	Yes
Report file can be viewed at culmination of automatic test	Yes
Manual Mode	
Users can test either left or right ear	Yes
Users have options of using masking white noise and pulse tones	Yes
Users can manually increase and decrease frequency and amplitude	Yes
User can change ear type during manual test	Yes
User can end manual mode at any time	Yes

VIII. Conclusion

SoundWorks was completed successfully because it satisfied each of the test scenarios outlined in the validation plan and also met the specifications that were set before the development. Features were incorporated successfully as well.

IX. Discussion

One of the areas where SoundWorks can be beneficial is in the military, in which hearing loss is a prevalent problem. In fact, hearing loss is the most popular disability for soldiers leaving the military (Briggs). This is primarily because of the intense noises that these veterans have been exposed to. Because SoundWorks is a computer application, it can be carried anywhere at all times in order to administer a hearing test and can help prevent further hearing loss. Another area where SoundWorks is beneficial is in underserved economies where medical resources are very scarce and awareness of hearing loss is very low. For example, in sub-Saharan countries, nearly 1.2 million children suffer from hearing loss (South African Hearing Institute). Unfortunately, these countries can't receive consistent treatment because the lack of medical resources. The tests could greatly help curb hearing loss in an area which truly needs some awareness. The final area where SoundWorks could have a great impact is in the consumer market. The rise of personal listening devices like iPods and other MP3s (Wikimedia Foundation, iPods) has led to an unprecedented rise in hearing loss. In fact, nearly 50 million Americans reported having some degree of hearing loss, the highest in history (Bowman). SoundWorks will increase awareness about the hearing loss epidemic while simultaneously, helping consumers to treat their hearing. Hearing is vital to human communication, so it is important that it can be sustained for as long as possible.

There are several expansions that can be incorporated to this application. For one, this application needs to be approved by the Food and Drug Administration (FDA) in order to become a marketable product. This approving requires official medical calibration and verification by the Acoustical Society of America (ASA). The ASA uses its American National Standard Specifications for Audiometers (ANSI S3.6) in order to approve of audiometers. Another expansion for this application is incorporating a Rinne test, or bone conduction test, in addition to the air conduction test, which is what SoundWorks currently uses. A bone conduction test uses a device that outputs sound to the mastoid, a bone at the top of the ear (Wikimedia Foundation, Rinne Test). The user then assesses whether he can hear those bone conduction sounds or not. The final expansion for this application is porting it onto smartphones like iPhones, Android and Windows Phones. Over the last couple of years, there has been an undeniable increase in smartphones and smartphone applications (Whittaker). If SoundWorks was created into a mobile application, consumers can test themselves even easier, as their smartphones are usually always accessible.

Appendix A

Table 2. *Comparison of different consumer audiometers*

	Duddu Inc. SoundWorks V 1.2 	**Welch Allyn AM 282 Manual Audiometer** 	**Smart Tone Automatic Audiometer** 	**Ear Scan 3 Manual Audiometer** 	**Digital Recordings Digital Audiometer** 
Test Type(s)	Automatic, Manual, Speech, Tinnitus Matching	Manual	Automatic	Manual	Automatic, Manual
Frequency Range (Hz)*	**Quick Screening:** Same as Welch Allyn **Normal:** 100-1000 (100 intervals), 2000-8000 (1000 intervals) **Extended:** Normal + 9000-20000 (1000 intervals)	125, 250, 500, 750, 1000, 1500, 2000, 3000, 4000, 6000, 8000	500, 750, 1000, 2000, 3000, 4000, 6000, 8000	250, 500, 750, 1000, 1500, 2000, 3000, 4000, 6000, 8000	**Normal:** 100-1000 (100 intervals), 2000-8000 (1000 intervals) **Extended:** Normal + 9000-20000 (1000 intervals)
Amplitude Range (dB)	0dB to 120dB (10dB Intervals)	**125 Hz**: -10 to 50 **500 to 6000**: -10 to 90 **250 and 8000 Hz**: -10 to 70 (5dB Intervals)	0dB to 95dB (5dB Intervals)	-10dB to 80dB (5dB Intervals)	-20dB to 100dB (5dB Intervals)
Test Tones^	Continuous, Pulse	Continuous, Pulse, Frequency Modulated (Warble)	Continuous, Pulse	Continuous, Pulse	Continuous, Frequency Modulated (Warble)

Results Display	**Audiogram** modified in real time, **Saved Report** with all results	**Audiogram** pad provided which is manually filled out	**Audiogram** modified in real time	**NO AUDIOGRAM**	**Audiogram** modified in real time
Operating Temps (C^o)	Dependent on Computer (**i3-** 0^o to 90^o**)**	15^o to 40^o	5^o to 40^o	UNKNOWN	Dependent on Computer
Weight	Dependent on Computer	2.55 lbs. or 1.15kg	5 lbs. or 2.27 kg	0.28 kg or 0.61 lbs.	Dependent on Computer

Works Cited

[1] ASHA. (2012). Sensorineural Hearing Loss. Retrieved February 2, 2013, from American Speech-Language-Hearing Association website: http://www.asha.org/public/hearing/sensorineural-hearing-loss/ The purpose of this source is to outline Sensorineural Hearing Loss (SSHL), which is a type of hearing loss occurring high frequencies. It is reliable because it comes from the ASHA, which is an organization with expertise in the field of audiology. This source inspired the incorporation of high-frequency testing (8k-20k Hz) in SoundWorks, which allows it to be a more complete hearing test.

[2] Blue, L. (2008, July 28). How Bad Are iPods for Your Hearing? *TIME Magazine*. Retrieved from http://www.time.com/time/health/article/0,8599,1827159,00.html This source is an article from the TIME magazine concerned specifically with the effect of iPods on hearing loss. It is an extremely reliable article because it comes from a highly respected magazine as well. Much of the information is also consistent with other sources as well. This article was essential for background research, as it focused on the prevalence of hearing loss and the low awareness of the epidemic.

[3] Bowman, L. (2012, June 5). Medical: Hearing loss increasing among young, old. Retrieved February 2, 2013, from Evansville Courier and Press website: http://www.courierpress.com/news/2012/jun/05/medical-hearing-loss-increasing-among-young-old/ The purpose of this source was to underscore the growing problem of hearing loss within American society. It offers statistics pertaining to how many people have hearing loss, making it a valuable source of information. It specifically offers information about hearing loss in the younger generation like children and adolescents. This source was helpful for background research for the development of this application.

[4] Briggs, B. (2012, November 13). Hearing loss the most prevalent injury among returning veterans. Retrieved February 4, 2013, from U.S. News website: http://usnews.nbcnews.com/_news/2012/11/13/14728839-hearing-loss-the-most-prevalent-injury-among-returning-veterans?lit The purpose of this source is to underline the problem of hearing loss specifically in the military. It is a reliable source of information becomes it comes from a respected news source. This source

wasn't particularly helpful in the development of the application, but it helped set a foundation of where this product might be particularly helpful.

[5] CIBA Foundation Symposium. (2009). *Sensorineural Hearing Loss*. Philadelphia, PA: Churchill This source covers, in a highly detailed manner, a type of hearing loss called Sensorineural Hearing Loss (SSHL). The information comes from a highly respected scientific organization, making it a very reliable source. This source inspired the incorporation of high-frequency testing in SoundWorks, which helps offer a more complete and comprehensive hearing test.

[6] Galen Carol Audio. (2007). Decibel (Loudness) Comparison Chart. Retrieved February 2, 2013, from Galen Carol Audio website: http://www.gcaudio.com/resources/howtos/loudness.html This source is primarily focused on how loud some things in our daily lives are. It gives a brief introduction of decibels, which is the unit of measure of sound. It is a reliable source of information because it comes from an audio company with expertise in the field of sound. This source was primarily used to obtain a basic understanding of the concept of amplitude, but also led to the specification of amplitude range in SoundWorks.

[7] Gelfand, S. A. (2009). *Essentials of Audiology* (3rd ed.). New York, NY: Thieme. The purpose of this source is to inform readers about the concept of audiometer including the concepts behind it, and how it works. It is a very valuable and accurate source of information because it originates from a professor of Linguistics at Queens College in New York. This book was imperative in understanding the field of audiology and how one can go about creating their own audiometer. It was extremely beneficial for this engineering project.

[8] Hearing Loss Education Center. (2012, February). Hearing Tests. Retrieved February 4, 2013, from Hearing Loss Education Center website: http://www.hearinglosseducation.com/hearing-tests The purpose of this source is to inform readers about the different ways an individual's hearing can be evaluated. It specifically talks about speech tests and their significance. This source was extremely reliable because it came from a trusted organization with a high level of expertise in the field of audiology. This source helped inspire the incorporation of a speech recognition test in SoundWorks.

[9] Johns Hopkins Medicine. (2007). Understanding Your Audiogram. Retrieved February 2, 2013, from Hopkins Hearing website: http://www.hopkinsmedicine.org/hearing/hearing_testing/understanding_audiogram.html This source is primarily concerned with informing readers about an audiogram and how it should be interpreted. This information is reliable because it comes from a highly respected university, which excels in medicine. This website helped inspire the incorporation of an easy-to-read audiogram in the SoundWorks application.

[10] Mayo Clinic Staff. (2010, July 31). Tinnitus. Retrieved February 4, 2013, from Mayo Clinic website: http://www.mayoclinic.com/health/tinnitus/DS00365 The purpose of this source is to explain the effect that tinnitus has had on society today. It is a reliable source because it comes from a respected organization that has a high level of expertise in the field of audiology, specifically hearing disorders. The source helped underline the dilemma of tinnitus and also helped inspire the incorporation of the tinnitus matching test.

[11] NIDCD. (2008, October). Noise Induced Hearing Loss. Retrieved February 2, 2013, from Research to Improve the Lives of People with Communication Disorders website: http://www.nidcd.nih.gov/health/hearing/pages/noise.aspx The purpose of this source was to scientifically explain what Noise-Induced Hearing Loss (NIHL) is and how it is caused. It is an extremely reliable source of information because it comes from the National Institute on Deafness and Other Communication Disorders (NIDCD), which is an organization with a high level of expertise in hearing loss. This was a very useful source for this project because it offered an in-depth understanding of NIHL, which is the primary type of hearing loss in our society today.

[12] Roeser, R. J., Valente, M., & Hosford-Dunn, I. (2007). *Audiology: Diagnosis* (2nd ed., Vol. 1). Philadelphia, PA: Thieme. The purpose of this source is to explain in detail the variety of methods in audiometry to analyze an individual's hearing loss. It is an extremely reliable source because it originated from experts in the fields of audiology and audiometry. The features of pulse tones and masking white noise were

incorporated because of the information obtained from this source.

[13] Schwartz, S., & Zieve, D. (Eds.). (2012, August 31). Meniere's disease. Retrieved from PubMed Health website: http://www.ncbi.nlm.nih.gov/pubmedhealth/PMH0001721/ The purpose of this source is to describe Meniere's disease, which is a type of hearing loss that occurs at low frequencies. It is a reliable source of information because it was reviewed and approved by two doctors of audiology who have a high level of expertise in the field. The information didn't specifically impact the project, but was helpful in establishing a basic understanding of the primary types of hearing loss.

[14] Snow, J. B. (2004). *Tinnitus: Theory and Management*. Pmph USA. The purpose of this source is to describe the theories behind the disorder of tinnitus and how it is treated by an audiologist after patients are diagnosed with it. This book originates from a medical professor at Harvard University, making it a very reliable source of information. This source helped to obtain a basic understanding of the disorder of tinnitus and how it can be diagnosed through a hearing test. It helped inspire the incorporation of a tinnitus matching test in SoundWorks.

[15] South African Hearing Institute. (2011). Prevalence of Hearing Loss. Retrieved February 4, 2013, from South African Hearing Institute website: http://www.sahi.org.za/hearing_loss_statistics.html The purpose of this source was to specifically describe the prevalence of hearing loss in the continent of Africa, where there is very little awareness about the epidemic. This information in this source was cross checked with many other sources of information. Although this source wasn't particularly helpful in the development of SoundWorks, it helped underline the importance of this product.

[16] Stony Brook Surgery. (2012, August 23). Headphones and Earphones Can Cause Permanent Hearing Loss: What You Need to Know. Retrieved February 2, 2013, from Stony Brook School of Medicine Department of Surgery website: http://www.stonybrooksurgery.org/blog/headphones-and-earphones-can-cause-permanent-hearing-loss-what-you-need-to-know The purpose of this source was to introduce the problem of hearing loss and it's increasing prevalence. It specifically talks about personal listening devices and their impact on hearing. It is an extremely reliable source because it comes from a reliable organization which has a high level of expertise in this field. The source was particularly useful for background research before the development of the application, specifically understanding hearing loss and how it can occur.

[17] Welch Allyn. (2010). *Welch Allyn AM 282 Manual Audiometer* [Pamphlet]. The purpose of this brochure is to outline the specifications of the one of the most popular consumer audiometers on the market, the Welch-Allyn AM 282 Manual Audiometer. Because the pamphlet is from the company that created the audiometer, it obviously contains accurate and reliable information. This was extremely helpful in setting specifications because specifications for SoundWorks were set primarily in order to improve the features of current consumer audiometers.

[18] Whittaker, Z. (2012, November 14). Smartphone sales up 47 percent as Android increases its lead. Retrieved February 4, 2013, from CNET website: http://news.cnet.com/8301-1035_3-57549482-94/smartphone-sales-up-47-percent-as-android-increases-its-lead The purpose of this source was to illustrate the rise of smartphones and smartphone applications. It's a reliable source of information because much of the information was cross checked with other sources as well in order to ensure accuracy. This source helped understand how SoundWorks can be expanded to better fit the needs of the consumer market.

[19] Wikimedia Foundation. (2012, December 19). Absolute threshold of hearing. Retrieved February 2, 2013, from Wikipedia, the Free Encyclopedia website: http://en.wikipedia.org/wiki/Absolute_threshold_of_hearing The purpose of this source is to outline the different characteristics of human hearing like the different hearing thresholds at each frequency. It also contains a section about the concept of hysteresis in audiology. Although it is a free encyclopedia, much of the information was cross checked with other sources to ensure its accuracy. This source was extremely helpful in shaping the automatic test in SoundWorks because the concept of hysteresis was incorporated.

[20] Wikimedia Foundation. (2013, January 1). Audiometer. Retrieved February 2, 2013, from Wikipedia, the Free Encyclopedia website:

http://en.wikipedia.org/wiki/Audiometer#Calibration_of_Audiometers The purpose of this source was to explain the many features of an audiometer and how they become certified. The source focuses heavily on the calibration of audiometers, which ensures legitimacy. Although this source can be modified by anybody in the world, much of the information is very detailed and accurate. The information was cross checked with other sources in order to ensure its accuracy. The calibration of SoundWorks was enhanced due to the information in this source.

[21] Wikimedia Foundation. (2013, January 16). Audiometry. Retrieved February 2, 2013, from Wikipedia, the Free Encyclopedia website: http://en.wikipedia.org/wiki/Audiometry#Process The purpose of this source is to offer a basic understanding of the field of audiometry such as methods used and significance. It is not fully reliable because the information can be biased and easily modified. However, the information was crosschecked with several other sources to ensure its complete accuracy. This source was particularly useful in setting primary specifications for the SoundWorks application.

[22] Wikimedia Foundation. (2013, January 30). iPod. Retrieved February 4, 2013, from Wikipedia, the Free Encyclopedia website: http://en.wikipedia.org/wiki/IPod#Sales The purpose of this source was to inform readers about the iPod. Although it is a free, open source of information, much of the information was cross checked with other sources to ensure accuracy. This source was primarily used to understand the sales of iPods, which helps underline the growing problem of personal listening devices in our society which leads to increased prevalence of hearing loss.

[23] Wikimedia Foundation. (2013, February 3). Rinne Test. Retrieved February 4, 2013, from Wikipedia, the Free Encyclopedia website: http://en.wikipedia.org/wiki/Rinne_test The purpose of this source was to describe the method of Rinne Test, which is simply a bone conduction testing. Even though the source is a free, open source, the information used was cross checked with other sources to ensure accuracy. This source was helpful in understanding the potential expansions of the application.