

Simulating the Effects of Hearing Impairments on Children for Parent/ Patient Education

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Abstract

Six newborns per 1000 are born with congenital hearing loss, yet no tool exists to allow caretakers of hearing-impaired children to hear as the children hear. The purpose of this project is to assist the parents of these children by developing computer software that simulates the patient's hearing for parent/ patient education and reassurance. In conjunction with advisors James Squire Ph.D., from the Virginia Military Institute and Roger Ruth M.D., from the University of Virginia, an interactive computer program was created that is simple to use, can be easily distributed to the general public, and gives parents a tool to help understand their children's capabilities and limitations. When armed with a greater, more experiential understanding of how the world sounds to their children, parents will be able to confidently raise and teach them. Users may record short sound clips onto the computer or select provided samples such as music, sirens, and speech. The program then uses the results of a standard audiogram from infant screening tests with optional additional data to create a personalized audio output that constructs what the patient actually hears. The signal processing that is used to convert the input sound was originally coded in Matlab, while the rest of the program was written in the C# language using the Microsoft .NET development environment. Combining Matlab and C# allowed us to use the design tools of .NET for creating the program and the mathematical power of Matlab to process the audio signal. However, in order to improve project development and deployment, we replaced the Matlab processes with a C# native mathematics library. This allows the simulation run faster and improves the effectiveness of the program, which will be evaluated by directed questionnaires given before and after use. In addition to the primary goal of parent/ patient education, other possible benefits of the program include increased safety for hearing impaired children, improved teacher interaction with the children, and potential academic use as a teaching aid for medical students.

1. Background

A hearing impairment is defined as any condition that reduces a patient's ability to perceive auditory information.¹ An impairment alters the way a person hears everything from speech to music to fire alarms. The causes vary widely from case to case, and the effects can be mild to profound. A genetically-caused hearing impairment from birth is known as congenital hearing loss. Congenital hearing loss is common in infants and studies estimate that up to six newborns per 1000 are born with some degree of hearing loss.²

1.1 Purpose

Despite the large number of families that are affected by hearing loss, there is currently no product on the market that simulates what a hearing impaired child actually hears.³ Some clinics have prerecorded CDs that represent generalized hearing loss, but it is not customized to the patient's actual test results. Doctors and audiologist must try

to explain to parents in words the difference between normal hearing and their children's hearing. The lack of real, experiential understanding can cause unnecessary apprehension in parents. For these mothers and fathers, there has been no answer to the question "what does the world sound like to my child?" The Hearing Impairment Simulator was designed to answer just that question.

Users may record short sound clips onto a computer or select provided samples such as a lullaby, barking dogs, or a spoken sentence. The program then uses the results of a standard audiogram from infant screening tests and any other audiologist's data to create a personalized audio output that constructs what the patient actually hears.

1.2 Audiograms

It is extremely important to detect a hearing impairment as early as possible in a child's development. When caught early enough, many children have the ability to develop and learn normal language and speech skills.⁴ Thirty-eight states, including Virginia, now mandate infant screening tests. If an infant does not pass the preliminary screening, more sensitive tests are given. The results of these tests are put into a standard chart, called an audiogram, that graphs what frequencies and hearing level a patient can hear. Figure 1 shows an example audiogram from a healthy child. The graph stays near the 0 dB line, and there is only a very mild 10 dB loss in the right ear at 500 Hz.

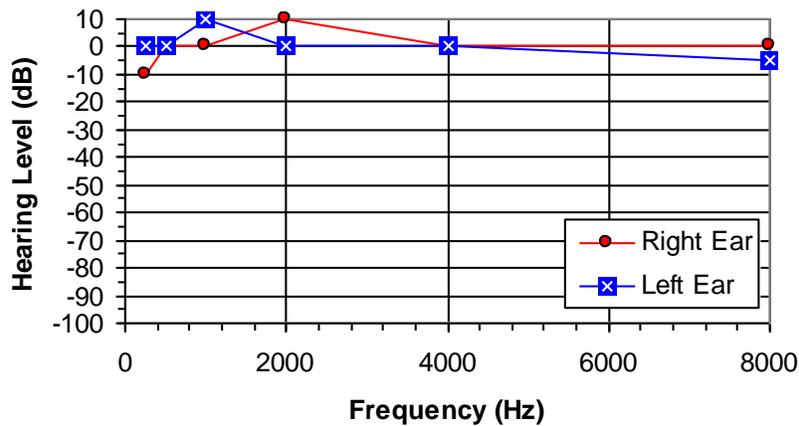


Figure 1. Audiogram, normal hearing. The audiogram graphs the results of medical hearing test. Standard hearing test measure six frequencies. As a result, most audiograms have six data points per ear at 250, 500, 1k,2k, 4k, and 8k Hz.

Audiograms from patients with hearing impairments will have reduced hearing levels at specific frequencies. A straight loss is when all frequencies are evenly depressed. The common cold can temporarily cause this condition in anybody, which can appear on an audiogram as a mild, straight loss. A low frequency or high frequency hearing loss, on the other hand, is a sloping loss. Figure 2a shows a severe low frequency loss, while figure 2b shows a moderate high frequency loss. These audiograms will slope or curve down, depending on the graph's scale.

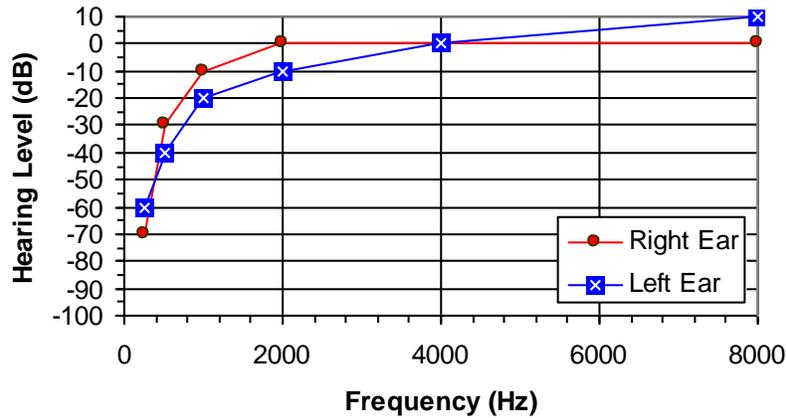


Figure 2a. Audiogram, severe low frequency loss. Meniere's disease can cause this pattern of hearing loss, particularly in the low frequencies.⁵

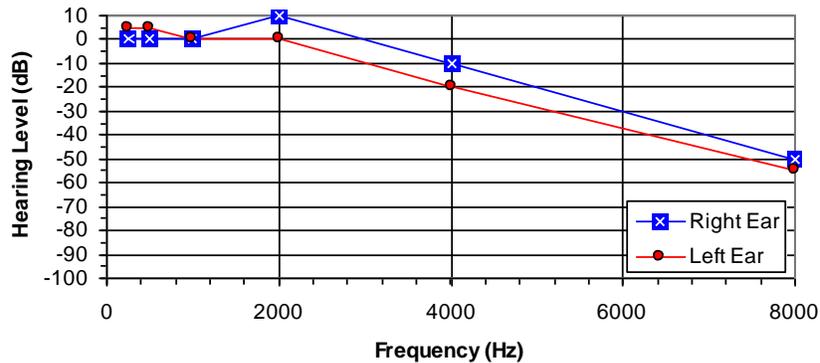


Figure 2b. Audiogram, mild high frequency loss. High frequency loss occurs more commonly in adults than infants because of exposure and age.

The Hearing Impairment Simulator uses audiograms, the standardized results of a hearing test, to simulate what the patient hears. The software thus simulates exactly what a particular patient hears. It should be noted that although the program was created specifically for congenital hearing loss, it works equally well for acquired hearing loss.

2. Interface

The Hearing Impairment Simulator was designed to be free, useful, easy to use, and widely distributed to the general public. Once installed from the internet, at www.jimsquire.com under the research tab, or from a CD, the program can be accessed from the Start menu or a desktop icon. The software is displayed as an eight screen graphic user interface.

2.1 Design Theory

The user interface was designed to be simple, accessible, and professional. The objective was to present the technical and medical information in a way that is intuitive to an untrained audience. However, for the Hearing Impairment Simulator to be effective, it must not only be easy to understand, but also easy to use. As a result, simplicity and accessibility became the main focus when creating the user interface portion of the program. The display was built so as little as possible was left to the user's assumptions. An application of this principle is in error checking. Error messages have been written so they warn of an error, as well as telling the user how to rectify the

error. One of the largest challenges in designing the program was to ensure that it was easy to use, but not at the expense of functionality. The final design principle was professionalism. The simulator had to look professional in order to establish and keep the trust of the users. Parents and other users who do not have access to the signal processing that takes place in the program must trust that the output they hear is technically accurate. One way to generate and maintain this trust was to create the interface with a professional finish, avoiding clutter and unnecessarily flashy colors and fonts.

2.2 Layout

The Hearing Impairment Simulator has a home screen and eight supporting screens. The home screen, shown in figure 3, is the hub for the program. The page is divided into three columns numbered 1 to 3 in order to guide users through the program. The first column is for creating or loading an audiogram. This is the first step in completing the simulation. To create a new audiogram, users are brought to the “Patient File” screen, figure 4. This screen is formatted to represent a medical audiogram and has two graph fields. The first is for the left ear results; commonly show as a blue line or as X on an audiogram. The second field is for the right ear; usually a red line or O. Each field is subdivided into frequency columns and decibel rows. A user would select the frequency and decibel level from a patient’s audiogram and put that information into the appropriate column and row. Check boxes have been placed on the bottom of the screen to account for conditions that significantly alter a patient’s hearing, such as a cold. For example, checking the cold box will apply a $\{-2, -5, -20, -40, -40, -45\}$ dB reduction in the audiogram data.



Figure 3: The Home screen is the hub for the Hearing Impairment Simulator user interface. All supporting screens return to the home screen.

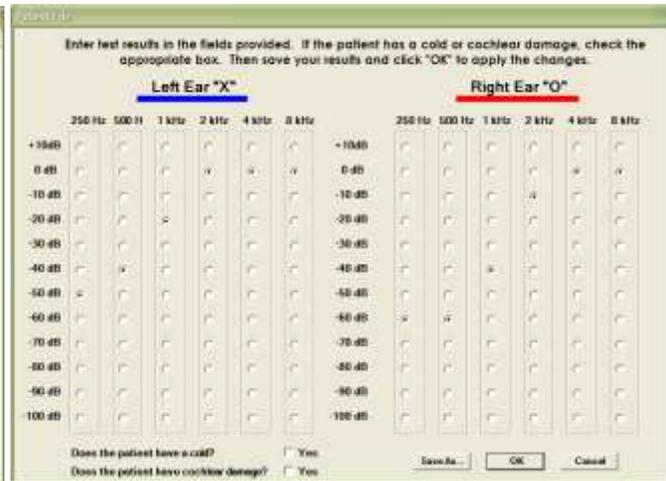


Figure 4: The Patient file screen was designed to look similar to a standard audiogram. This allows users to ‘recognize’ the screen and gives them an intuitive idea of how to input the audiogram data.

The next column in the Home screen describes the sound source, with options for selecting a previously saved sound to put into the simulation, or to record a new sound over a microphone. The microphone selection leads to the recording screen shown in figure 5. Sounds up to ten seconds in length may be recorded on this screen. A bar graph displays the length of the recording, and a light bulb shows whether or not a recording is in process.



Figure 5:. Recording screen. The recording screen allows users to record their voice or other sounds over a microphone. To prevent large audio files, the recording length has been restricted to 10 seconds.

The third column in the home screen is for playing back sounds. Users may choose to hear either the original sound or the processed sound that the patient hears. This function takes place on the home screen. The lower portion of this column is for saving sounds through a standard Windows “Save file” dialogue box.

3. Programming

The Hearing Impairment Simulator was coded in two programming languages, C# and Matlab. These two distinct programs were originally combined through COM objects. The entire user interface was written with the Microsoft .NET Development Environment in C# and the signal processing code was written in Matlab. The program implemented both languages at runtime through COM components. However, complications described below prompted a switch to rewrite the Matlab code into C# using a free-source mathematics library.

3.1 C#/Matlab

C# was chosen as the primary programming language because of Microsoft .NET’s robust design tools. The .NET Environment provided an efficient way to develop and debug the user interface and all supporting code. Because C# lacks a strong mathematics library, Matlab was used to write and perform all the signal processing in a single .M file. The Matlab COM toolbox was used to convert the Matlab code into a COM object that could then be accessed through C#. Combining the two languages with COM objects allows the use of the design tools in .NET for creating the program and the mathematical power of Matlab to process the audio signal.

Although the C#/Matlab combination allows designers to use the best features of both languages, there are drawbacks. After building and debugging the program, it was noted that the final deployment files were unexpectedly large. This is because Matlab requires users to have an extensive COM support tool installed on their computer in order to work. As a result, the installment package was 126MB; 100MB larger than the version that was eventually released after being entirely recoded in C#.

3.2 C# Solution

A C# native mathematics library was needed to implement all the audio processing aspects of the Hearing Impairment Simulator. Two libraries were brought up for evaluation. One was a commercially available product, and the other was a free-source code. Both libraries had the required components, especially the Fast Fourier Transform function. The free MathNet.Numerics library was chosen to replace the Matlab code due to its open source coding. Because the for-profit library was not open source, it would have been difficult to debug and analyze the program. The only visible change in the transition from Matlab to C# is in the smaller size of the installment package. This makes the program much more accessible to download from the internet, which was the primary distribution medium.

In both the C#/Matlab version and the revised C# version, Alvas.Audio was used to record and play .wav files. The well-supported package was an attractive off-the-shelf solution to handling .wav files. For simplicity, all .audio files used are relatively high-quality 16 bit, mono, 22050k Hz .wavs, although Alvas.Audio is capable of handling all of the variants specified in Microsoft Corporation's .wav standard.

3.3 Coding Description

The audiogram information entered into the "Patient File" screen of the program is converted to a double, multi-dimensional array. At this time, the Cochlear Damage and Cold options are entered as Boolean values. The user then selects a .wav file by either recording a new file or by choosing a pre-recorded file. This .wav is also converted into an array for processing. All arrays and inputs are fed into a C# class where the audio array is manipulated according to the signal processing principles listed in the following section. The resulting new array is converted back into a .wav file, where it is finally played by Alvas.Audio.

4. Digital Signal Processing

The Hearing Impairment Simulator uses a Finite Impulse Response (FIR) frequency sampling filter to process the input sound signal. The frequency sampling method has been implemented in this project because of its ability to create filter coefficients directly from the audiogram, which is displayed in as decibels verses frequency. The audiogram array, created from the eight sampling frequencies, is interpolated into a high resolution, 1024 element array. The frequency coefficients are then determined from this array by taking the inverse Fourier transform of the audiogram's frequency domain, which generates a new filter coefficient array in the time domain (power verses time). A complete description of this method is described in Rabiner and Gold.⁶ The new array is convolved with the input signal (the selected speech or music array) using cascaded FIR sections, to produce the final processed signal.⁷ This is converted back into a .wav file, where it ready to be played.

4.1 Hearing Comparison

Figures 6a and 6b show the normal time domain and frequency domain of the spoken sentence, "The quick, brown fox jumps over the lazy dog." These figures display graphically what the average human hears. It should be noted from figure 6b that the majority of voice communication takes place in the lower frequencies, in the 1 to 1000 Hz range.

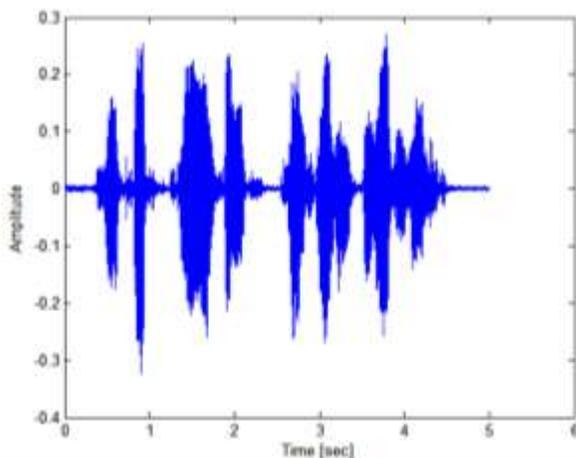


Figure 6a. Time domain, normal hearing.

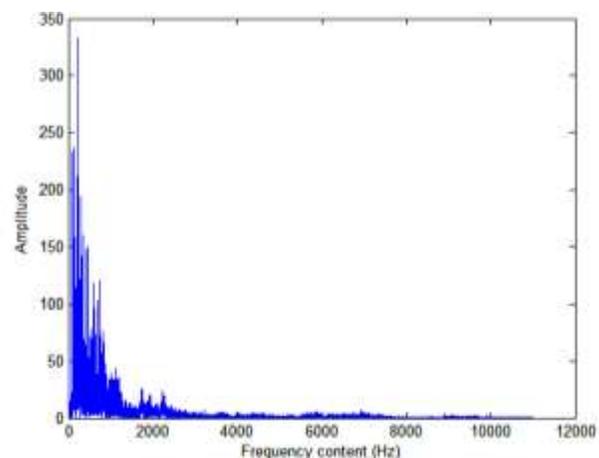


Figure 6b. Frequency domain, normal hearing.

Figure 6a, 6b The recorded sentence "The quick, brown fox jumps over the lazy dog." was graphed in the time and frequency domain in Matlab.

A low frequency, sloping hearing loss can be simulated by using the Hearing Impairment Simulator to convolve the quick brown fox sentence used in the above example with the audiogram from figure 1. The resulting time and frequency domain graphs are shown in figures 7a and 7b. Comparing the two frequency domain graphs, 6b and 7b, it is apparent that most of the speech information in the low frequencies was lost, while the high frequencies remain unchanged. The patient likely has significant trouble hearing speech.

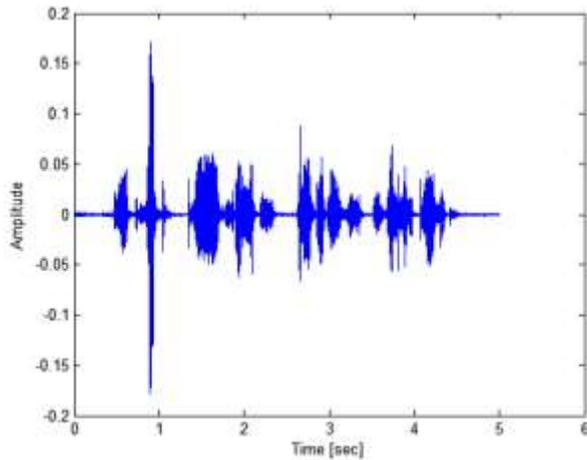


Figure 7a. Time domain, low frequency loss

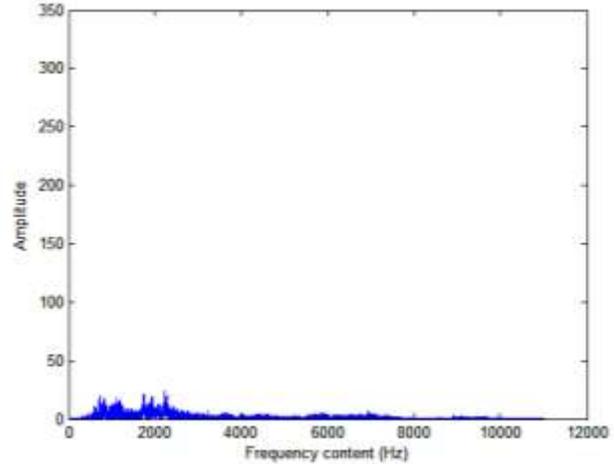


Figure 7b. Frequency domain, low frequency loss

Figure 7a, 7b The quick brown fox sentence was processed in the simulator using a low frequency loss audiogram and was then graphed in the time and frequency domains in Matlab.

5. Conclusion

The Hearing Impairment Simulator is now ready for public release. Its simple, accessible, and professional design will allow the program to accomplish the purpose as a parental resource for reassurance, education, and understanding. Beyond this primary purpose, another important and tangible use is as an academic tool for medical students who want to know more about how hearing impairments alter a patient's hearing.

5.1 Distribution

As stated before, hearing impairments affect many families across America. In order to help these people, the Hearing Impairment Simulator must be distributed as widely as possible. In order to accomplish this, it was designed to be free, to ensure that cost would not inhibit anyone from using the program, and to be small enough to be released and downloaded from the internet. Both of these goals have been successfully accomplished.

With the help of Dr. Roger Ruth and the graduate student program, the project will be presented at a professional audiologist conference for further distribution in the medical community. Finally, the public will be directly accessed through the media. The project has been the focus of a WSLs TV interview, and an article describing the simulator will be submitted to magazines such as *Parents*. Furthermore, the State of Virginia may consider referencing the program in material given to parents whose children do not pass Virginia's required hearing screening.⁸

5.2 Future Research

Future research revolves around clinical evaluation, advanced users version and a children's museum display. The program will be tested and evaluated in the clinical setting. The effects will be measured through directed questions given to parents before and after product use. Based on these tests, a second version of the simulator will be developed that will be focused as an advanced users version. This version will have more options to simulate a larger variety of hearing impairments. Finally, using the Hearing Impairment Simulator as a foundation, a children's museum display will be created that explores hearing loss. The highly interactive display will be especially designed to warn children of the risks of acquired hearing loss from repeated exposure to loud music.

6. Acknowledgements

The Author wishes to express appreciation to faculty advisor Dr. James Squire for the important help in developing the program, and to Dr. Roger Ruth for his professional input.

7. References

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