Application of Adapted Greek Version of Hidden Hearing Loss Test

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***Abstract*— Hidden hearing loss is a subject of recent scientific interest and consequently an insufficiently researched type of hearing impediment. There are indications of a link between hidden hearing loss and repetitive exposure to loud noise as well as development of more significant hearing problems in the future. Because of the absence of diagnostic tools on this matter, we proceeded at developing a hidden hearing loss test application, which despite the fact that it can not be used as an accurate diagnostic mechanism, due to insufficient research data and incomplete theoretical knowledge, is a very important self-evaluation tool which could boost research on that subject.**

The application presented is using Greek sentences and gradually increasing pink noise in order to test the user's ability of hearing when presented with a loud background. Furthermore, the users are capable of self-evaluation, as their answers are compared with the expected ones resulting in a final percentage of correct sentence understanding.

I. Introduction

The term "Hidden Hearing Loss" is used to describe cell degeneration of a certain group of neural synapses along the auditory pathway, currently believed to be mainly caused by repeated exposure to high levels of noise [1], [2]. The loss of synaptic connections between hair cells and the auditory nerve, while there is still no hair cell loss, may lead to threshold shifts, but these shifts are reversible and they return to normal after a couple of days [2]. Another reason why this loss of hearing is "hidden" is that auditory nerve fibers with high thresholds are mostly affected, which are complementary when quiet but crucial for understanding speech in noise [3], [4]. This results in a normal hearing performance in the conventional audiometric test, which is assessing the ability to understand speech in a quiet environment [1], [3] .

Studies have been carried out on several groups of people that indicate a correlation between cochlear synaptopathy and understanding speech in noise [1]–[3]. The studies showed that young people with normal audiograms can face difficulty in performing on a noisy environment, and these people display signs that are consistent with cochlear synaptopathy [5]. It was also found that people who had been exposed to loud noises on a regular basis in the past, were more susceptible to encountering difficulty in the speech-in-noise test [5], [6]. In addition to the above, it has been found that there is a significant percentage of people who are found with a normal audiogram but still complain about having trouble coping with everyday conversation. Even though they demonstrate no difficulty in a quiet environment, the presence of noise impairs their understanding of speech and, generally, their overall hearing-in-noise performance appears to be poorer than expected [2], [5], [7].

Although research has only recently focused on the problem of hidden hearing loss, the aforementioned observations indicate its interference with everyday social performance and quality of life for the majority of people. Taking into consideration the latter remark, it is evident that there is great value in developing an evaluation tool that indicates whether a presumable patient actually has a hearing problem related with hidden hearing loss.

II. Background

In this section, we present the basic theoretical concepts that played a crucial role in designing and parameterizing our application.

A. Choice of Noise

Improving the current testing methods lies in modifying the level and type of noise used. The aim is to reproduce as accurately as possible everyday challenging environments in respect to the background noise that is generated, i.e. in city traffic, restaurants, offices and working sites [8].

In order to satisfy the above, pink noise was used as the background noise in our application. Pink or flicker noise is a type of stochastic signal characterized by some quite interesting attributes, regarding our application design. One of these is that its power spectral density is inversely proportional to its frequency. Another aspect of this signal that directly derives from the above definition is that the overall power of the signal is evenly distributed amongst proportionally wide frequency bands. In other words, the power density of the signal is reduced by 10 dB/decade, or 3 dB/octave.

The aforementioned remarks stand as a first indicator of the appropriateness of choosing pink noise as the kind of noise to be used in our test. Namely, it is well known that the human auditory system processes frequency on a logarithmic scale. In simple words, a human perceives the distance (in terms of pitch) between a frequency and its double and the distance between its double and its fourfold as equal (this doubling of frequency is referred to as an octave in many fields such as signal theory and music). This implies that pink noise is perceived as almost evenly intense across all frequencies by the human ear.

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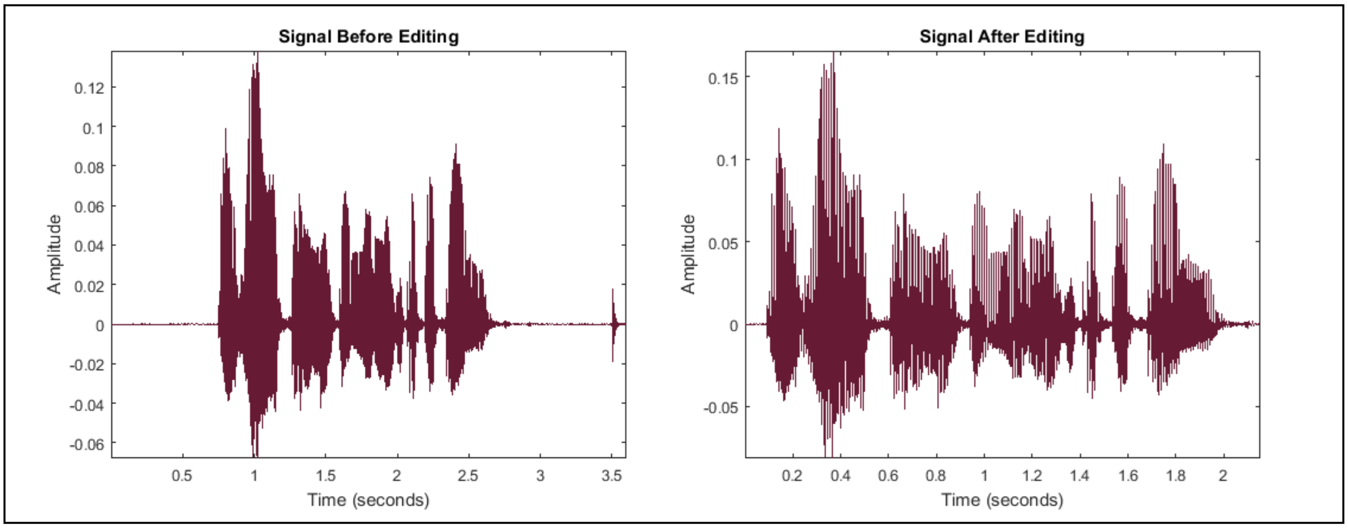

Figure 1 Processing of the recording of the sentence "ΕΓΩ ΈΠΛΥΝΑ ΤΑ ΜΗΛΑ ΣΤΟ ΠΟΤΑΜΙ" ("I washed the apples by the river")

B. Choice of Words

The words used in the application originate from an Auditec, Inc recording with a selection from Greek word lists in noise, used for audiological tests by the University General Hospital of Thessaloníki and the University General Hospital of Patras.

III. Application

At this point, it is important to mention that the test we developed is inspired and based on an existent test in English, designed as an exercise prepared for The Associated Press by the Mailman Center for Child Development at the University of Miami (https://soundcloud.com/user-186673023/hidden-hearing-loss).

We proceeded at developing an application, which uses Greek sentences in a noisy background to give people that do not have knowledge of English language or simply are not adequately familiar with understanding English speech, a way to check their hearing ability through challenging their understanding of speech in a noisy background. As our ultimate goal is that the target group of our application consists of people of all age groups, and having in mind that the elderly generally lack knowledge of foreign languages, especially in Greece, we tried to give them the ability to perform the test in their native tongue

A. Recorded Sentences

The application uses a database of 30 recorded sentences in Greek, that consist of four to seven words, taken from the word selection mentioned earlier. The database is designed so that it can easily be expanded or updated. All the sentences were recorded by a male speaker, in Waveform Audio File Format (.wav) and with a sampling frequency of 44.1 KHz.

The intensity of the original recordings ranges from 55 dB SPL (Sound Pressure Level) to 60 dB SPL. For the purposes of the test, it is necessary to ensure the uniformity of the recordings in terms of intensity. In order to achieve that, each recording was processed separately using Praat (http://www.fon.hum.uva.nl/praat/). Namely, the silence at the beginning as well as at the end of each recording was cropped and the intensity of each signal was set to exactly 60 dB SPL. An example of the recorded signals before and after this process are shown in Fig. 1.

B. Noise Signal Generation

The pink noise sound signal that was used as increasing background noise in the application was generated using Matlab R2015a. Apart from the generation of the signal, a Matlab script was written to ensure that the following specifications are met:

- power spectral density of the signal must be inversely proportional to its frequency, so that the power is distributed evenly amongst frequency bands that are proportionally wide.
- mean value of the signal must be equal to 0.
- standard deviation of the signal must be equal to 1.
- signal amplitude must be normalized to values in the range of [-1, +1].

As previously mentioned, the intensity of the recorded sentences used in the application is fixed at 60 dB SPL. On the other hand, the intensity of the background pink noise is gradually being increased during the test, beginning at 40 dB SPL and increasing in 4 dB steps until reaching 64 dB SPL. Hence, the Signal-to-Noise (S/N) ratio is decreased by 4 dB in each stage of the test, ranging from 20 dB S/N to -4 dB S/N. The choice of a 4 dB step is not random, since a 3.5 dB S/N is the critical meaningful difference between two test cases in a Speech-in-Noise test [9]. In other words, a true change in the results of the test can be concluded with 95% certainty as long as the two results differ by more than 3.5 dB. Subsequently, the S/N intensity levels of noise used in the application are bound to represent any variation in the test's results.

In conclusion, the background noise of the application consists of seven different pink noise signals, with increasing intensity ranging from 40 dB SPL to 64 dB SPL. These noise signals were generated in Praat, using the original pink noise signal that has been described above and each time setting its intensity to the appropriate value.

C. *Technical Specifications*

The application was developed using the Python 2 script language, which is used to perform all necessary tasks including text processing of the input that the users have to give in order to compare their personal understanding of the test sentences with what they should have heard. Furthermore, the pydub python module is used to process and produce the audio output of the application. The pydub module is publicly available for download and usage from GitHub.

At first, we recorded 30 sentences in .wav format, paying attention to the consistency of the voice volume in every sentence as well as the relation between the intensity levels of all sentences. The selection of the words that form these sentences was made with some criterias in mind. For example, we chose words that are relatively small; most words consist of one or two syllables, and only a few of them consist of three syllables. Our aim was to be harder to assume the whole word based on just a part of it. Furthermore, most words are easily confused with others because of similar phonemes between them. The second stage was the creation and editing of different pink noise signals.

IV. Results

The application starts with a welcome prompt, asking by the user to press the <Enter> button to start the test. Afterwards, we randomly choose 14 out of a total of 30 sentences recorded in a random order. Special care was taken in order to ensure that no sentence is heard more than once. This choice was made to give the users the ability of repeating the test without already knowing the answers – a larger database of sentences would greatly help to achieve that goal (see *Discussion*). The users listen to the first sentence with the lowest level of noise. The intensity of noise in the background is increased every two sentences, in order to help both the user and the application to better assess their speech-in-noise performance at every noise level, by giving them two tries. That also helps the user to adapt easier to the subsequent changes in noise level and lays more weight on the achievement of the purpose of the test.

The user hears the sentences (recorded without noise) and the pink noise simultaneously. That is achieved by the usage of certain functions provided by the pydub module that overlay two (or more) audio files and play them as a single audio signal. The usage of these functions results in giving an audio output of a sentence in a noisy background with the noise being increased as the test proceeds.

After the audio finishes playing, the user receives an instruction, prompting them to type the sentence according to what they heard in Greek uppercase letters without special characters, such as the accents that are used in Greek lowercase writing. In case the user did not use Greek uppercase letters as advised or typed special characters, we ask them to repeat what they typed with the correct text format this time. Once the text input is in the correct form, the evaluation of the answer takes place.

Both the correct (reference) sentence and the sentence given by the user are converted to sentences that use the simplest spelled options (misspelled most of the time). We applied several conversion rules, implying that a misspelled version of a sentence inputted by the user will be also converted to the exact original sentence, greatly simplifying the process of comparison between the original sentence and the input of the user, regardless of their knowledge on Greek spelling rules.

Afterwards, the comparison of the two sentences takes place (the simplified version of both of them) and, if they are the same, the test assumes that the user heard the correct sentence regardless of potential spelling mistakes. It is important to point out that the rules we had to add imply the need for a casuistic treatment of certain test cases, given that the spelling mistakes ignoring mechanism remains as simple as presented here.

In case the user hears the correct sentence, they are presented with a message, where the subsequent lines inform the user about what they typed and what the correct sentence was (Fig. 2 "*Πρόταση 1 από 14" part)* . In case the sentence is misheard (and thus wrongly inputed), the user is presented with a message, indicating a wrong answer (Fig. 2 "*Πρόταση 10 από 14" part)*. This is repeated for all 14 sentences (with the pink noise increasing every two sentences) and, finally, the user score is displayed (Fig. 2 "*Ακούσατε σωστά 10 στις 14 προτάσεις (71.43%)" part*).

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~~~~~ Hidden Hearing Loss Test ~~~~~
Θα ακούσετε 14 προτάσεις. Πληκτρολογήστε αυτό
που νομίζετε ότι ακούσατε, με κεφαλαίους
ελληνικούς χαρακτήρες (χωρίς τόνους).
Πατήστε <Enter> για να ξεκινήσετε.

Πρόταση 1 από 14
Πληκτρολογήστε αυτό που νομίζετε πως ακούσατε
(κεφαλαία χωρίς τόνους):
ΤΟ ΚΟΡΙΤΣΙ ΘΕΛΕΙ ΤΟ ΣΚΟΥΦΙ

Σωστή απάντηση
Γράψατε    -> ΤΟ ΚΟΡΙΤΣΙ ΘΕΛΕΙ ΤΟ ΣΚΟΥΦΙ
Ακούστηκε -> ΤΟ ΚΟΡΙΤΣΙ ΘΕΛΕΙ ΤΟ ΣΚΟΥΦΙ
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Πρόταση 10 από 14
Πληκτρολογήστε αυτό που νομίζετε πως ακούσατε
(κεφαλαία χωρίς τόνους):
Ο ΠΑΠΠΟΥΣ ΕΔΕΣΕ ΤΟ ΔΕΜΑ ΣΤΗ ΜΗΤΕΡΑ


Λάθος απάντηση
Γράψατε    -> Ο ΠΑΠΠΟΥΣ ΕΔΕΣΕ ΤΟ ΔΕΜΑ ΣΤΗ ΜΗΤΕΡΑ
Ακούστηκε -> Ο ΠΑΠΠΟΥΣ ΕΔΩΣΕ ΤΟ ΔΕΜΑ ΣΤΗ ΜΗΤΕΡΑ

..............................................................................
Ακούσατε σωστά 10 στις 14 προτάσεις (71.43%)
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Figure 2 Partial Excerpts from a completed test in Greek

The reason we decided to print the input of the user along with the correct sentence in every step of the test is the simplicity of our spelling mistakes ignoring mechanism. As we explained before, the mechanism does not guarantee that the user actually misheard a sentence in certain cases of misspelling. For example, if the user makes a typographic mistake, this mechanism cannot predict and ignore it. Therefore, it is important to let the user judge by themselves the correctness of their input along with the application. The importance of the above design choice would be greatly illustrated in the case of an upcoming update of the application, which would result in the expansion of the test cases database.

V. Discussion

A. Need for Quantitative Data

As background noise increases in our test, it is quite certain that the subject will face more difficulty in identifying words or even the entire sentence they heard. However, being led to an accurate diagnosis can only be based on a well-defined quantitative test.

As we mentioned earlier, after the completion of the test, the user is informed about their overall score, it being the percentage of sentences they inputted correctly. This result is interesting for the user, but cannot be further used in a diagnostic procedure. Further research is needed in order to exploit these results as fully as possible towards a diagnostic conclusion, regarding the expected hearing-in-noise performance in relation to a plethora of factors, e.g. the intensity of the speech and/or the background noise, along with their relation.

Furthermore, people may experience the difficulty they are facing differently, and the same problem may be perceived by one person as crucial and by another as insignificant. That is to say that individual judgment has to be taken into consideration, as people have different estimations and expectations regarding their hearing abilities and performance. It is needed to achieve a distinction between a patient who claims to have a hearing impediment and has a normal audiogram and/or a normal speech-in-noise test score, and a patient who may or may not consider having a problem but shows abnormalities in tests.

B. Need for Larger Database

Our test is currently using a database of 30 sentences, based on words used by audiological tests performed across Greece. A larger database of test cases would be greatly beneficial to the accuracy of our test.

However, a larger database would also need a firmer theoretical background regarding the relation between certain words, phonemes, syllables and the expected hearing-in-noise performance of a healthy individual. The current lack of quantitative data regarding the expected hearing-in-noise performance highlights the hazard that an expansion of the current test cases database would potentially result to a deviation from the goal of our test.

C. Need for a more accurate Spelling Ignoring Mechanism

The spelling mistakes ignoring mechanism is rather simplified. A larger database would need a better and more accurate mechanism, in order to cope with the plethora of spelling mistakes that can occur in Greek language.

A fast, elegant and sophisticated solution would be the usage of finite state transducers (FSTs) which would compare the user input and the correct sentence without any need for the dictionary we have currently implemented (i.e. by implementing the Levenshtein distance algorithm and setting a threshold above which the input would be marked as incorrect).

VI. Conclusion

The audiogram serves as a diagnostic tool for the detection of a loss in hearing threshold sensitivity. However, hearing in noise is untraceable from the audiogram and has been overlooked in the past. Further scientific and medical research could be beneficial in determining specific possible therapies, but it is clear that a reliable diagnostic tool is essential for a proper assessment of the patient's condition.

The test presented in this paper is a computer application, based on the concept of the hearing-in-noise performance evaluation of the subject, which is the prevalent theory for early estimation of the possibility of hidden loss of hearing. The application is meant to test the ability of a person to correctly hear a sentence in a gradually louder environment. The interface of the application and the sentences that are used are in Greek. Taking into consideration all current scientific material and research data, we tried to design the test as optimally as possible, regarding its evaluation accuracy and its compliance with all scientific knowledge around the subject of hidden hearing loss so far.

However, as there is currently a significant lack of potent scientific theories and quantitative research data in this field, it is crucial to clarify that the application we have developed and present in this paper is not an accurate diagnostic tool and should not be used as one. Contrariwise, its recommended usage is that of a tool for an early study on the extent of the problem, mainly regarding the percentage of the general population that might be suffering from hidden hearing loss, as well as an outline for the design of more complicated and reliable diagnostic tools, as knowledge and research around this field advance.

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