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## A Computational Platform for Hearing Assessments With Virtualization of Sound Sources

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### Abstract

When considering audiological monitoring and diagnosis, there are several tests aimed at assessing speech perception, however, they do not necessarily simulate real listening situations, and often do not follow a pattern in the way of application and interpretation of results. Therefore, an attempt was made to develop an accessible software solution that aims to address these points. In order to direct the development of a software, audiological examination protocols were studied, and based on results from interviews with students and professors of audiology a catalog of requirements was elaborated enabling the development of an academic version of a software using MATLAB. Subsequently, in order to reach speech therapists, the construction of a more robust and accessible platform was pursued, using C# and Visual Studio to develop the perSONA software compatible with Windows 64 bits. While initially planned entirely for speech recognition assessment the platform was improved with an educational module for pure tone audiometry (PTA). Sound reproduction in perSONA is entirely conducted by Virtual Acoustics (VA) [Institute for Hearing Technologies and Acoustics, RWTH Aachen University], which allows spatially distributed reproduction with total control of levels. Validation of the software took place through many steps by students and professors of the speech therapy course as well as measurements of the sound reproduction quality using different computers and audio drivers together with common and audiometric headphones and a manikin. For PTA module sound pressure levels, hearing levels and pure tones frequencies were successfully validated using the ASIO4ALL sound card driver. Also, the software currently features structures that allow the storage of personal and clinical data using the popular J-son file format. The adaptive speech in noise perception test provides spatially distributed reproduction of speech and noise using phonetically balanced sentence lists, bringing the test closer to real listening situations.

**Keywords:** software, hearing assessment, Windows platform, teaching.

**PACS:** 43.58.Ta; 43.66.Yw; 43.10.Sv.



## 1. INTRODUCTION

In the healthcare sector, technological advancements are of great relevance, and therefore new instruments, products, tools and software are introduced and perfected every year [1]. However, new technologies to help with diagnosis and rehabilitation in audiology are created less often if compared to the remaining health areas [2], especially when they are dependent on *hardware* or involve complex physical processes. Also, technologies to help with diagnosis and rehabilitation in audiology are often proprietary and expensive to buy and maintain. Costs associated to standardized test procedures and materials also is responsible for the very limited use of standardized speech recognition protocols in several countries, including Brazil [3].

To help with cost reduction, and to promote standardized tests for evaluating hearing loss with trustworthy results, the freely available software perSONA was created.

This article has the goal of describing the modules currently present in perSONA and to explain what functionalities are built in each module.

## 2. DEVELOPMENT

In the current section, a brief description of the most important thoughts underlying coding are given and illustrated.

### 2.1 Modular software architecture

For software development different software architectures are available. Modular architectures are often used to make it easier to develop and maintain large software programs by breaking them up into smaller parts. By separating a program's functions into independent pieces or building blocks made to execute a single aspect of the functionality, it makes the code easier to read, test and update.

Taking into account that the perSONA software platform was designed to integrate different tests (currently speech perception and pure tone audiometry module), to allow for a common patient database, to have different calibration functionalities, a modular architecture was considered to be the best for maintain all different functionalities, update them and build in more. Also, a modular

architecture favors links with third-party code or even software.

### 2.2 Windows forms

The perSONA platform is based on many different Windows Forms, each with their own set of elements. The different Windows Forms, such as the interface shown in Figure 1, were created utilizing tools available through the Visual Studio platform, using mainly the following tools:

**tool box:** providing ease in the use of objects like buttons, graphs, text boxes and others, to be used in the form;

**navigation tools:** for viewing and editing the windows forms graphically;

**properties:** for adjustments to objects' names, looks and positioning.

For each window, created using the aforementioned tools, the events triggered by each object were programmed in C# using object oriented programming (OOP).

**Code 1:** Example for the creating of data types and the logic behind an event trigger

```
public partial class ↵
    ↵ manualAudiometricTest : Form
{
    private readonly IvAInterface ↵
        ↵ vAInterface;

    public double[] intensitRef = new ↵
        ↵ double[11];
    // .....

    String Side = "Right";
    String Via = "Air";

    // .....

    private void changeSide_Click(object ↵
        ↵ sender, EventArgs e)
    {
        if (Side == "Left")
        {
            sideLightLeft.BackColor = Color.↵
                ↵ Silver;
            sideLightRight.BackColor = Color↵
                ↵ .Yellow;
            Side = "Right";
        }
        else
        {
            sideLightLeft.BackColor = Color.↵
                ↵ Yellow;
            sideLightRight.BackColor = Color↵
                ↵ .Silver;
            Side = "Left";
        }
        updateCorrectAnswers(correctAnswers↵
            ↵ = 0);
    }
}
```



**Figure 1:** Graphic interface for Windows Forms creation inside Visual Studio.

```
// .....
}
```

As seen in Code 1, the event trigger is “changeSide\_Click”. On clicking the button the code within the brackets will act, and in this case, since string “Side” starts as “Right” it will switch the yellow visual indicator on for “Left” and off for “Right”, and the string “Side” will be equal to “Left” too. Pressing the button again the opposite action will happen.

To ease programming, some functions may be created to act as support. This is usually done if the function will be used in more than one event, so the programmer don’t have to write it twice, or if the function can be broken down into smaller functions. Another way that programming can be made easier is by taking functions from existing libraries within C#. These libraries are codes made by other programmers and can be called as a shortcut for a function when needed.

Code 2 is an example of a code used in multiple areas, defining how the graphs are created and how they act. These lines of code are initialized at perSONA’s main interface (Figure 4) and they can be called in other modules that use graphs like in the pure tone audiometry module, speech perception module and patient data management module. Still within this code there is also an example of a code downloaded from the ZedGraphControl li-

brary that allows the graph to be fully customized.

#### Code 2: Example of a code used in multiple areas

```
public void plotSceneGraph(
    ZedGraphControl graph, double[] radius, double[] angle)
{
    GraphPane myPane = graph.GraphPane;
    myPane.CurveList.Clear();

    PointPairList speechList = new PointPairList();
    PointPairList noiseList = new PointPairList();
    PointPairList circle = new PointPairList();
    PointPairList head = new PointPairList();
    PointPairList speakers = new PointPairList();
    PointPairList nose = new PointPairList();

    double roomLength = 5;
    double roomWidth = 5;
    double radiusSpeakers = 0.2;

    // .....
}
```

### 3. EVALUATION OF USABILITY

During the development different methods were used to assess the usability of the software, as well as to obtain *feedback* from users. For instance, to evaluate the pure tone audiometry teach-



ing module, the module was made available for use in part of the discipline of “Research in Audiology”, a discipline taught in the third phase of the Speech-Language Pathology and Audiology undergraduate course at UFSC. At the end of the course, an **electronic form** with questions regarding usability and opinions about the new functionality was sent to users (students). *Focus group discussions* with students and professors of the Speech-Language Pathology and Audiology course carried out through the Google Meet were another form of evaluation.

## 4. RESULTS

This section will describe the main features of the perSONA software platform, showing its most important modules and functionalities within those modules.

### 4.1 Installer

To help facilitate obtaining the new software, a Windows compatible installer was generated using the Advanced Installer software, which allows the creator of the project to build a installer with the needed features and files. The installer, compatible with Windows 64 bit, was made available on the page <https://persona.ufsc.br/download/>.

### 4.2 The modular architecture of the platform

The software platform perSONA was developed using Visual Studio and C# and it is compatible with any new version of Windows 64-bit operating systems, including Windows 11. As seen in Fig-

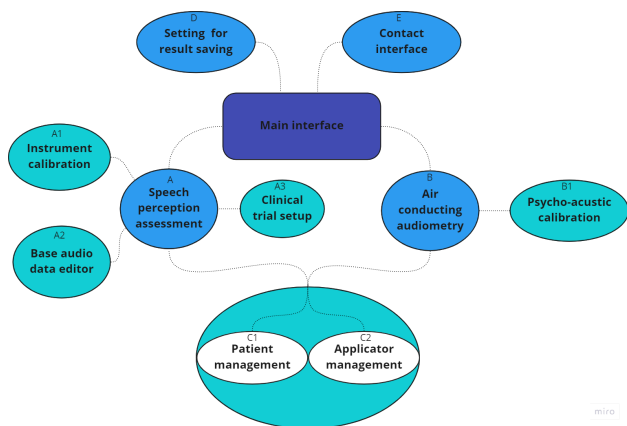


Figure 2: perSONA's modular structure.

ure 2, the software was created using a modular structure. Different modules can share information between them, such as test results from the

speech perception module and the pure tone audiometry module with patient management data, patient and applicator name.

### 4.3 Choice of the sound reproduction system

During perSONA's startup, the user will have to select the sound reproduction system<sup>1</sup> from three available options: “Fones de ouvido” (headphones), “Campo livre Cabine Audiométrica” (2 speakers) and “Sistema de 8 canais UFSC” (8 speakers). Having selected one of the options, the user can launch perSONA (Figure 4) by pressing the “Iniciar perSONA” button.

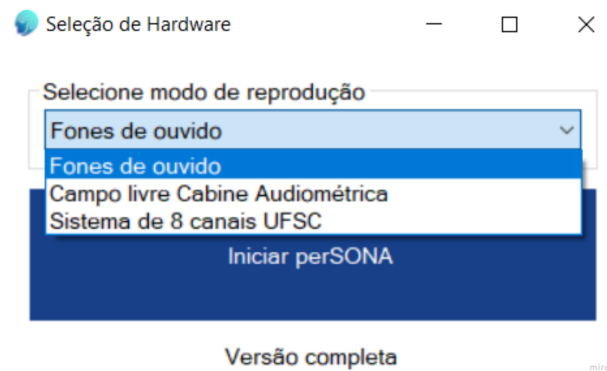


Figure 3: Interface for perSONA's startup and selection of the sound reproduction system.

### 4.4 Main interface

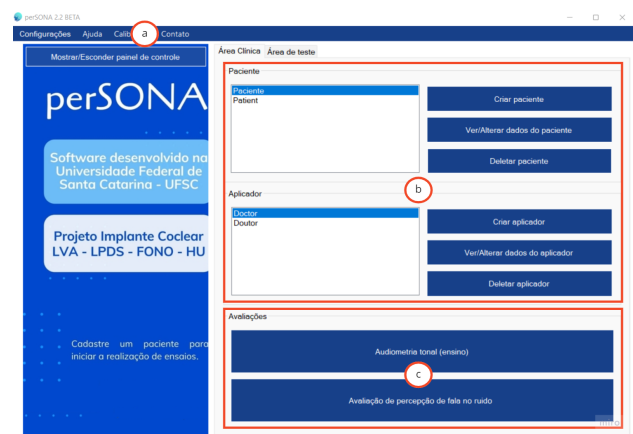


Figure 4: Interface for perSONA's main interface.

Figure 4 shows perSONA's main interface, where the user is able to access most of the other mod-

<sup>1</sup>It's worth noting that this interface also shows how much time the user has left for his license to expire. After it expires, perSONA will ask the user to answer a survey asking feedback on the software. After finishing it, he will receive a key that grants him a permanent license.

ules available in perSONA. Three of the most important points of interest are the panel labelled (a), (b) and (c) in Figure 4. The button (a) allows the user to access the functionalities present within the calibration module. By means of panel (b) the user is able to access the functionalities of the patients database and the audiologist's database. Buttons in panel (b) allow for quick access to functions such as creation of a new patient's entry, visualization, change or removal of a patient's entry. Using these quick access buttons will redirect the user to the Patient's database interface, described in Section 4.8.1. The same quick access functions are available for the audiologist's database.

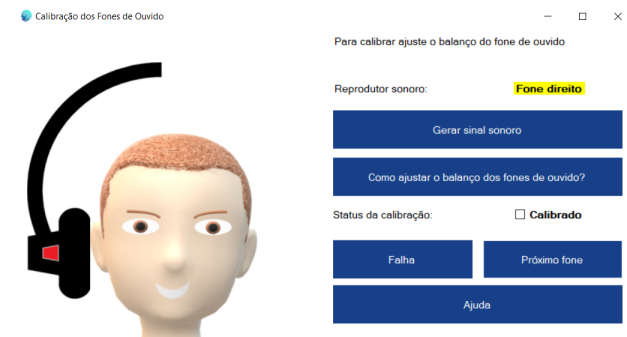
In the lower panel, labelled (c) in Figure 4, the user can choose between perSONA's two current audiometric evaluation modules: pure tone audiometry (teaching) and Speech-in-noise perception assessment.

#### 4.5 Instrumental calibration module

The (instrumental) calibration module, that can be accessed via (a) in perSONA's main interface (Figure 4), was created to help users that are inexperienced with the calibration of their sound reproduction system, as calibration is extremely important for a proper hearing evaluation. The module is able to help speech therapists with the relative calibration of both headphone and speakers set ups (2 or 8 speakers) for speech recognition assessment.<sup>2</sup>

Relative calibration will be made for the reproduction system that has been chosen when perSONA was started<sup>3</sup>. After starting the calibration module from perSONA's main interface, it will ask for some basic information about the device to be calibrated (brand, model) and equipment used for calibration. For speaker calibration different devices can be used: 1) Sound pressure level meter (SPLM), 2) iPhone with a SPLM-app and an external microphone or 3) microphone, ADC and signal processing software. For most accurate

headphone calibration an artificial ear, together with an ADC and signal processing software must be used. Then the module will provide explanations on how to use the calibration module and the main calibration module interface (Figure 5) will open.



(a) Calibration interface for relative headphone calibration



(b) Calibration interface for 8 speaker calibration



(c) Calibration interface for 2 speaker calibration

**Figure 5:** Calibration's module main interface.

Calibration works similarly for both headphone and speakers. First each sound source must be calibrated separately (left ear and right ear for headphones, one speaker at a time for speakers). To do so, perSONA will make the connected device play a 1/12-octave narrow-band noise centered at 1 kHz. The user is then required to verify, and adjust the sound pressure level to 94 dB SPL, pro-

<sup>2</sup>Actually, calibration is only relative between the two speaker's of a headphone. Future versions of the calibration module will implement absolute calibration for audiometric headphones too.

<sup>3</sup>If the user would like to calibrate another reproduction system he will need to either open perSONA twice or reopen the software after finishing the first calibration



duced by the headphone at the microphone of an artificial ear or by speakers at the microphone of a SPL-meter, using the interface's slider. After individual calibration of all sound sources, the module will need one last calibration with them all playing at the same time.

#### 4.6 Speech-in-noise perception module

The speech-in-noise perception (SINP) module allows for a wide variety of configurations to carry out speech perception tests using recorded speech materials and different spatial sound source configurations. The speech perception module is divided in 2 parts: the setup and the test window.

##### 4.6.1 Speech perception test setup

The setup window is where the applicator can choose different options to adapt the test to his research or clinical use. Figure 6 shows the main elements that are present in the setup interface for the speech perception module.

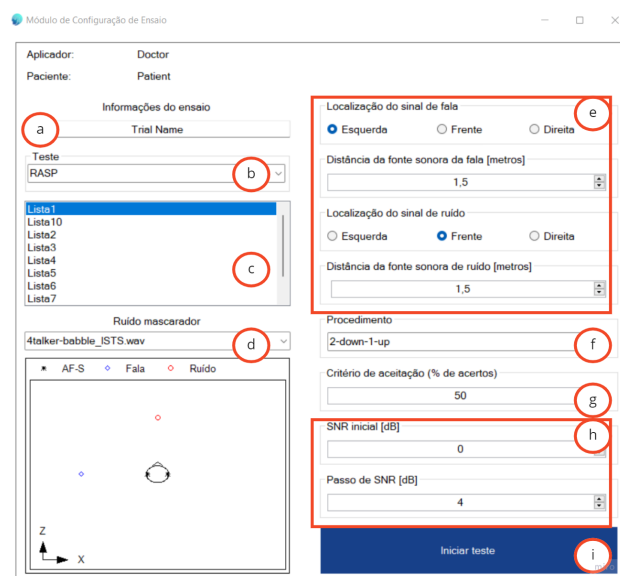


**Figure 6:** Interface for speech perception test setup.

Each trial can be named by means of item (a). The name given will be used as name for the associated .JSON data file that will contain both information on the setting used as well as the results.

The “Teste” drop-down menu (b) allows to select a specific type of speech test. In fact it defines the speech material to be used. perSONA currently have 2 different tests with their own sets

of recorded and transcribed speech materials <sup>4</sup>, including:

**Alcaim/Ynoguti:** sentences developed by Alcaim [4] and recorded by Ynoguti [5], both from a male and a female speaker, sampled with 11 KHz during the original acquisition by Ynoguti [5];

**RASP:** “Reconhecimento auditivo de sentenças no português” (RASP) [6] is a speech perception test that was adapted to assess speech recognition in portuguese speaking adults.

User’s should prefer the RASP test, as the sentence material is more modern and recordings were made with a sampling frequency of 48 kHz using high quality condenser microphones in a semi-anechoic chamber. For each test (“Teste”), recorded speech material, and corresponding transcripts, are organized in subsets (“listas”<sup>5</sup>) and can be selected (c).

The user can select the competing noise by means of the “Ruído mascarador” drop-down menu (d). Currently perSONA includes 15 noises:

**4-talker babble ISTS**, a 4-talker babble noise standardized as ISTS, sampled at 44,1 kHz; [7]

**portuguese babble**, taken from the RASP test [6], all being continuous normal unmodulated voices, sampled at 48 kHz:

- babble 4 meninas dialog: 2 simultaneous dialogues, 2 female speakers for each dialogue;
- babble 4 meninas ind: 4 female speakers speaking simultaneously;
- babble 8 meninas dialog: 4 simultaneous dialogues, 2 female speakers for each dialogue;
- babble 8 meninas ind: 8 female speakers speaking simultaneously;

<sup>4</sup>If the user wants to include any new speech material, he can do so by adding the recorded and transcribed speech material in the same style of the other existing ones to the Speech folder, the same can be done for the noises.

<sup>5</sup>Listas is the portuguese term used in audiology to describe a subset of sentences from a specific test such as RASP.

- babble 12 meninas dialog: 6 simultaneous dialogues, 2 female speakers for each dialogue,;
- babble 12 meninas ind: 12 female speakers speaking simultaneously.

Male babble noises and mixed-gender babble noises will be made available soon.

**Cafeteria babbles** described in [8]:

- cafeteria babble: babble noise sampled as 16 kHz;
- cafeteria babble 16kHz 21s: a two channel mixed-gender German babble noise, sampled as 16 kHz;

**Noises from the ICRA Noise CD** as described in [9, 10]:

- ICRA No01 16kHz 21s: Continuous normal unmodulated male voice, english, extracted from track 01 of the ICRA Noise CD;
- ICRA No06 16kHz 21s: two-speaker mixed gender conversation, english, normal vocal output, extracted from track 06 of the ICRA Noise CD;
- ICRA No07 16kHz 21s: six-speaker mixed gender babble, english, normal vocal output, extracted from track 07 of the ICRA Noise CD;

**FX Bus Engine 002 16kHz 12s** : Diesel engine idle noise, sampled at 16 kHz;

**SSN IEEE** IEEE Speech-shaped noise, sampled at 16 kHz;

**street noise Loizou 16kHz 21s** street noise described in [8], sampled at 16 kHz;

If the users wishes, any other noise signals can be added to the respective folder in C:/Program Files (x86)/LVA-UFSC/perSONA-BETA/perSONA/data/Sounds/Noise and these files will be displayed for selection in item (d).

By means of radio-buttons and drop-down menus in area (e) the localization (direction and distance) for both the source of noise and speech can be defined. The graphic display of the localization

of the noise and speech sound source in the lower left corner of Figure 6 is adjusted accordingly. Position of both speech and noise sound source will be passed to the bundled VA software that calculates the signals sent to each of the sound sources that are part of the sound reproduction setup.

The drop-down menu “Procedimento”, item (f), is used to select the testing paradigm [11]:

- 2-down-1-up: If the patient recognition score for 2 consecutive sentences is at or above the acceptance criteria (item (g)), the SNR of the next sentence will decrease by the amount chosen (SNR Step, (h)). Otherwise, the SNR of the next sentence will be increased by the same amount;
- 1-down-1-up: If the patient recognition score for 1 sentence is at or above the acceptance criteria (item (g)), the SNR of the next sentence will decrease by the amount chosen (SNR Step, item (h)). Otherwise, the SNR of the next sentence will be increased by the same amount;

By means of the drop-down menu “Critério de aceitação (% de acertos)” (g) the minimum percentage of words that the patient needs to correctly understand and repeat in each sentence in order be considered understood can be set.

Also, by means of two other drop-down menus (h) the initial SNR (“SNR inicial [dB]”) and the SNR’s step-size ( “Passo de SNR [dB]”) can be selected. The user can force no adaptation of the SNR trough the whole test by setting the step-size to 0 dB. He also might choose to suppress any competitive noise, selecting an initial SNR larger than 40 dB. Both settings can be useful to make specific tests, such as speech perception tests in quiet.

Finally, the “Iniciar teste” button (i) will save the setup to the JSON file and will open the speech perception test window shown in Figure 7.

#### 4.6.2 Speech perception test

The speech perception test window (Figure 7) allows the user to apply the test according to the configurations made before and to visualize the

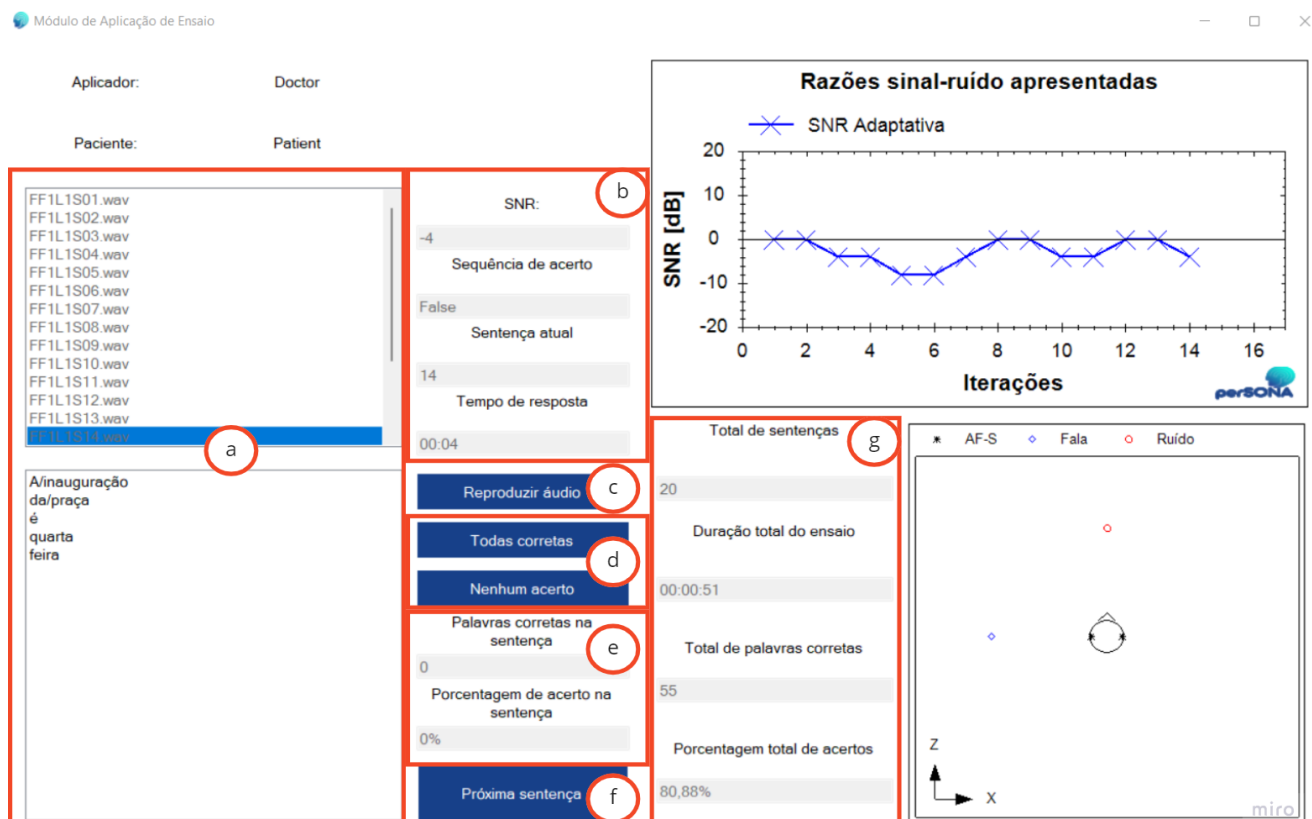


**Figure 7:** Interface for the speech perception test.

results needed to make a diagnosis. The test interface shows the name of the applicator and patient, a graph that shows the SNR of each sentence as the test progresses and the localization of both speech and noise sources.

In the left column a of the interface the speech files that are part of subset chosen for the current test are listed, being the one that is being reproduced highlighted light blue. The transcript of this sentence is being shown in the lower left panel, being each word allocated to an individual line. Definite and indefinite articles are allocated together with the corresponding substantive.

The audiologist can select the words the patient understood correctly, or can select either that all were correctly understood (“Todas corretas”) or no one was (“Nenhum acerto”) using the appropriate buttons (d). When hitting (“Todas corretas”) all words in the transcript shown are automatically highlighted. When the ‘Nenhum acerto’ button is used, all words are deselected. According to the patient’s response and the selection made by the audiologist the number and percentage of correctly understood word in each sentence is calculated and given in the lower portion of the central

column (e).

The upper part of the central column (b) shows information about the running test, such as current SNR, if the last sentence was correct or not, the current sentence number and time it took the patient to answer. It was positioned this way as to be as close as possible to the graph of the SNR.

The button “Reproduzir áudio” (c) is used to start reproduction of the sentences of the selected subset.

The button “Proxima sentença” is responsible to advance to the next sentence of the chosen subset. As a result the next sentence will be highlighted in the upper left panel, its transcript will be shown in the lower left panel and the counters in the upper and lower central panel (b) and (e) will be adjusted or reset.

In panel (g) information regarding the complete trial is given. It displays the total number of sentences already reproduced, the total elapsed time, total number and percentage of words correctly recognized by the patient.

After concluding the trial, a message will resume its results and these will be saved as data and in

the patients history.

## 4.7 Educational pure tone audiometry module

An educational pure tone audiometry module was created to provide students during remote teaching with the possibility to train pure tone audiometry (PTA) with an audiometer simulator. Its user interface seeks to imitate the most relevant functions and the general appearance of a real commercially available audiometer, such as the inter-acoustics AC40.

### 4.7.1 Functionalities of psycho-acoustic calibration

To utilize the pure tone audiometry teaching module first it's necessary to have a psycho-acoustic calibration of the sound reproduction set-up (Figure 8) so that the standard threshold can be established. To do so the first time the module is opened, a few messages will appear showing the user what he will need to do in order to calibrate properly. During the calibration, the user will save a sound power corresponding to the hearing threshold at each frequency. This will be used as baseline to the software for the audiometry to come. Without completing calibration perSONA will not allow performing audiometric tests. At any point in time this calibration can be redone if the user wishes to make a new calibration. To do so, in perSONA's main interface (Figure 4), there is a setting button (at the most up left) that has the option to re-calibrate the pure tone audiometry module.

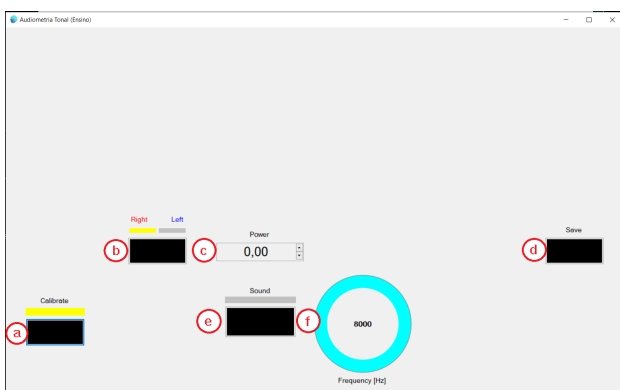


**Figure 8:** Interface for psycho-acoustic calibration required for the pure tone audiometry teaching module.

Figure 8 shows the main elements present in the psycho-acoustic calibration module. The “Calibrate” button (a) shown in Figure 8 activates the

calibration functionalities and it is only visible to the user when the system hasn't been calibrated yet.

The “Right/Left” button (b) is used to toggle the channel and with it the ear that will be stimulated by the pure tone. The channel that is currently selected is represented by a yellow light. Toggling between channel during calibration is necessary to be able to calibrate the system according to the threshold for the user's best ear, as in most cases the user might have a unilateral hearing loss.

The “Sound” button (e) plays the pure tone with the power and frequency currently selected. Power is adjusted by the user with the “Power” button (c) until the user's hearing threshold is found. The frequency bar (f) dictates the current frequency that is being calibrated. The frequency will automatically swap with each save (d). The module can reproduce every frequency utilized in pure tone audiometry (8; 6; 4; 3; 2; 1,5 and 1 kHz; 750; 500; 250 and 125 Hz, in this order<sup>6</sup>. The adjusted threshold is saved (d) and will be considered 0 dB[NA] at its respective frequency.

### 4.7.2 Functionalities of pure tone audiometry teaching module

The interface for educational pure tone audiometry (PTA) shown in Figure 9 is designed to look just like a real audiometer. It features elements to mimic it's functions, some being present also in the psycho-acoustic calibration module (Figure 8).

The use can toggle between air and bone conduction audiometry (a). Ideally, bone conduction audiometry would be performed with the aid of bone vibrators instead of headphones, but, since most (student) users do not have bone vibrators, the module in this configuration is only used to represent the exam visually, changing the symbols that will be saved in the audiogram. However, the PTA functionality reproduces the pure tones for the patient and presents the patient's thresholds to the user. The user can change between channels using the “Right/Left” toggle switch (b).

<sup>6</sup>Calibration is done with decreasing frequencies in order to help minimize confusion by the user because simple headphones struggle to reproduce low frequency sounds, which may cause the user to think it's not working. Starting at a higher frequency, helps the user to understand the procedure and finish the calibration.



“Sound detected” (c) is used to recognize and count if a stimuli was detected. “Mask on/off” (d) toggles the masking noise between on and off, visually represented the same way as elements (a) and (b). Masking noise will always be triggered for the contralateral ear that is stimulated by the pure tone.

The “Save” button (e) is responsible for plotting the threshold obtained at the current frequency and hearing level into the audiogram. The threshold will be plotted into the audiogram using standardized audiological symbols.

“Pure Tone dB[NA]” (f) and “Frequency [Hz]” (h) adjust the hearing level dB[NA] and frequency of the pure tones that will be reproduced using the “Sound” button (g).

“Masking” (i) controls the hearing level for the masking noise generated while “Frequency” (h) also controls its central frequency. “Masking” (i) will only work if masking is active.

As the module is intended for teaching and learning, the “Undo” button (j) reverts the last action performed by the “Save” button (e). The “Finish” button (k) ends the audiometry and save the exam results in a .JSON file, which can later be analyzed in another perSONA module.

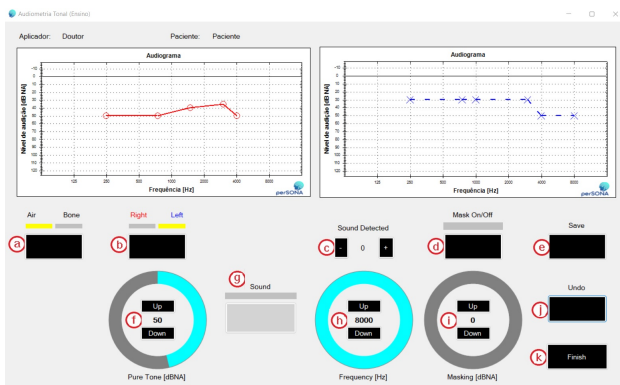


**Figure 9:** PTA interface.

Is worth noting that Trentin et. al. [12] evaluated the sound reproduction performance of the pure tone audiometry teaching module on different Windows computers and with different types of headphones and found that a 5dB increase in hearing level (HL) adjusted in the PTA teaching module results quite consistently in a nearly 5 dB increase in sound pressure level produced at the microphones of a KEMAR with proper impedance simulator. Only for sound pressure

levels above 90 dB SPL some headphones and soundcards could not deliver consistent 5 dB increments in SPL at the manikins ear for every 5 dB HL increment adjusted. Also, harmonic distortion was low, influencing only in a few select conditions the intended SPL at the manikins ear. However, to guarantee such proper sound reproduction the ASIO4ALL audio driver must be used instead of Window’s standard audio driver, that include equalizers and automatic gain controls that are great for noise reduction and music appreciation but inappropriate for the purpose of an audiometer simulator.

## 4.8 Patient data management module

Patient data management functionalities can be accessed via perSONA’s main interface. The patient data management module allows to access, insert and modify the patient’s information, including anamnesis records (Figure 10), pure tone thresholds (Figure 11) and test results obtained with speech perception test (Figure 12). Information regarding the aforementioned items is displayed in 3 different tabs, each one with it’s own set of elements.

### 4.8.1 Patient’s data

The first tab (Figure 10) shows the patient’s personal information, that can be edited at any time.

Hearing loss anamnesis records for both ears include type of loss; etiology; degree of loss; pre or post lingual; date of diagnosis; years of privation; (hearing) device name; date of evaluation; (hearing) device brand; and (hearing) device model.

### 4.8.2 Patient audiometry records

The second tab (Figure 11) shows the patient’s PTA records. This tab displays the audiogram of the selected PTA and a set of elements that are responsible for their own set of actions. Section “Audiometrias cadastradas” (a) shows a list with every single PTA completed by the patient, ordered by date. Audiograms can be selected and examined individually or by selecting multiple audiometry, pressing the “ctrl” key while selecting<sup>7</sup>.

<sup>7</sup>It should be noted that if the user chooses to select multiple PTAs options to manually setup a audiometry are unavailable

**Figure 10:** Patient's data and anamnesis records interface.

Section “Configurações da audiometria” ② shows information about the currently selected PTA and also allows the user to manually register new ones or delete old ones. To register a PTA the user needs to select date, ear and pathway (“air”, “bone(mastoid)”, “bone(forehead)” or “free field”) and must provide the specific hearing level data for each frequency using the elements of section ③. The user can also inform an absence of the patient's response<sup>8</sup> in certain frequencies. After providing the required information, the user can choose to preview ④ and save ⑤ the audiogram.

By the buttons in section ⑤ current audiogram can also be saved as .png file or printed.

### 4.8.3 Records of speech perception test

The third tab in the interface shown in Figure 12 shows the patient's speech perception test results, by means of graph that shows the test results and

<sup>8</sup>It may occur in an audiological examination when the sound reproduction chain is not able to generate a sound signal with a hearing level corresponding to the patient's threshold. This usually occurs in assessments of patients with profound deafness who need high levels of hearing to have a hearing sensation. The set of controls aims to define this peculiarity during the recording of an audiometry.



**Figure 11:** Interface for pure tone audiometry records.

a set of elements with valuable information and options for the user. Section ① shows a list with every single speech perception test done by that current patient by date and hour. The user can choose to select one or many results. All selected results will appear in the graph and a set of valuable information will be displayed for the user to see. This includes test's SRT; convergence threshold SNR; trial name and date; speech source direction; noise source direction; distance from speech source; distance from noise source; test's list of sentences; test's procedure; test's noise type; total accuracy score(%); applicator's name. Section ② buttons are to print or save the current speech perception test result.

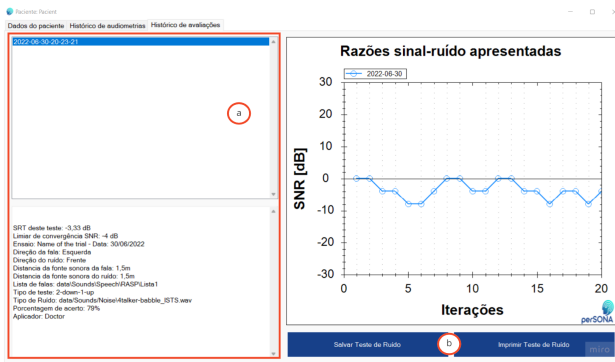


**Figure 12:** Interface for speech perception test records.

## 5. CONCLUSIONS AND OUTLOOK

Developed initially to be a free and flexible platform for speech perception tests with recorded speech material [3], the perSONA platform has evolved, through several updates, into an interesting tool to help with speech perception testing and teaching of pure tone audiometry. It can be downloaded at <https://persona.ufsc.br/> and runs on every 64-bit Windows operating system.

Updates developed in the past two years included relevant features such as modules for instrumental and psychoacoustic calibration, new speech material such as the sentences and female babble noises from the RASP test, as well as an educational pure tone audiometry module. Also, through its updates new functions were introduced in each module as well as design improvements were implemented.

Due to its modular architecture, new functionalities can be added to the perSONA platform. For educational purposes additions such as a speech audiometry training module, for teaching speech recognition threshold and speech recognition percentage index tests, and a simple bone vibrator for the pure tone audiometry training module would be relevant additions. Calibration functionalities might be further improved including dBHL-to-dBSPL correction tables for relevant headphone models. Improvements regarding functions to better manage the computer's sound cards are likely to be added to reduce difficulties naive user's have setting up their system. Also, documentation and guidance for users can be further improved, and will be available at <https://persona.ufsc.br/>. As resources are limited, turning perSONA into an open-source solution is being evaluated and contributions are warmly welcome.

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