A Psychophysics experimental software to evaluate electrical pitch discrimination in Nucleus cochlear implanted patients

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Abstract. Multichannel electrode array design in cochlear implants has evolved into two major categories: straight and perimodiolar electrodes. When implanted, the former lies along the outer wall of the *scala tympani*, while the later are located closer to the *modiolus*, where the neural ends are. Therefore, a perimodiolar position of the electrode array could be expected to result in reduced stimulus thresholds and stimulating currents, increased dynamic range, and more localized stimulation of the neural elements. However, their advantage for pitch discrimination has not been conclusively stated. Therefore, in order to study electrode independence, a psychophysical software has been developed, making use of Nucleus Implant Communicator tools provided by Cochlear company under a research agreement. The application comprises a graphical interface to facilitate its use, since previous software has always required some type of computer language skills. It allows for customization of electrical pulse parameters, measurement of threshold and comfort levels, loudness balancing and alternative forced choice experiments to determine electrode discrimination in Nucleus© users.

1. Introduction

The level of hearing rehabilitation obtained through cochlear implants has increased dramatically since its introduction. This is the result of developments that include advanced signal processing, higher stimulation rates, greater numbers of channels, and the development of more efficient electrode arrays [1].

The results of several experiments in which electric field patterns for different electrode configurations have been investigated within the cochlea, reveal that the spatial gradient increases as the distance between the stimulating electrodes and neuronal tissue decreases. Therefore, an electrode that is closer to the neuronal endings would be expected to reach the hearing threshold current at lower levels due to the steeper slope of the electric field [2,3]. The result would be higher for sets of electrodes placed laterally. In addition, electric fields steeper slopes are less spread to adjacent neuronal populations, which decreases the probability of interaction between channels. This can result in a better discrimination between the electrodes [4-6].

However, the selectivity of the electric fields about the neural stimulation depends on a number of factors apart from the electrode-nerve proximity. These include: patterns of neuronal survival population, stochastic variability characteristics of individual nerve fibers, cochlear anatomy, signal characteristics and design features of the electrode [7]. Many of these factors may be interdependent and may affect the threshold as well as the selectivity. For example, an individual with a poor nerve survival will have poorer selectivity and higher thresholds than one with good nerve survival, regardless of the type of electrode array, as the subject requires higher values to achieve optimal neural excitation.

Several research groups have designed psychophysical platforms to reduce the amount of programming needed to build experiments. Although these are very comprehensive and adaptable tools that allow the researcher to design virtually any experiment on psychoacoustics, they lack the necessary tools to perform electrical stimulation experiments [8-11].

An exception to the limitations of these platforms is APEX, a software application built and distributed under contract by the Experimental Audiology Department in Leuven [12]. This platform supports psychoacoustic experiment design both for acoustical and electrical stimuli by means of a cochlear implant, and even the combination of both. In APEX, the actual experiments are designed in XML format. Even though this is a great advantage and requires much less learning time, it still requires some degree of computer language knowledge, since XML is not as straightforward as a visual interface.

This paper describes a visual interface-based psychophysical software to conduct electrode discrimination tests to work towards better understanding of the psychophysics of electrical hearing. The platform is controlled exclusively through a graphical interface, where pulse parameters are entered in purpose-designed cells and loudness balance and alternative-forced-choice experiments are already built in.

2. Platform design

The present Psycoachoustic Research Platform was designed using the Nucleus Implant Communicator (NIC) library for Python (Python Software Foundation, v2.3). NIC is a research tool developed by Cochlear LTD and allows researchers to build applications to control the electrical stimuli delivered by the intracochlear electrodes of Nucleus Cochlear implants.

The researcher and subject interfaces were designed using Visual Studio (Microsoft Corp. Visual Studio Community 2013). It was also used to collect information about the connection state of the implant. Since the NIC library is in Python, scripts in the same language were built to control the implant receiver/transmitter by sending instructions to a supplied cochlear implant research sound processor. The supplied processor was connected to a computer via a USB port. Thus, a file-based communication system was established. Finally, the data is arranged so that a patient can be assigned to a range of psychoacoustic tests nested within the type of stimulus and further dependent on intensity. For each patient, the user can define multiple tests.

3. Platform Description

Insert Patient

The option *Insert Patient* on the Start page opens the window in Fig. 1, where demographic and clinical data can be inserted. The Comfort (C) and Threshold (T) level values from the patient's standard map can also be inserted. Finally, the location of the electrodes with respect to the modiolus can also be inserted as perimodiolar, mid-modiolar and lateral wall.

On this window, and all subsequent ones, there is an indicator of the communication state between the application and the processor (connected/not connected) for safety reasons. It will show whether the computer correctly detects the processor or not.

Figure 1. Insert Patient. Here demographic, clinical data and electrode position with respect to the *modiolus* can be registered.

Stimulus Definition

Once the patient has been saved, the Existent Patient window replaces the New Patient, where the same information is displayed, but now the user can select the different tests to perform the study.

A stimulus must be defined before the experiment can proceed. The Define Stimulus button opens a window (Fig. 2) that allows customization of the following parameters: stimulation mode, stimulus duration, inter-stimulus interval, pulse phase and gap durations and pulse frequency. The stimulus consists of a train of electrical biphasic pulses at a frequency specified by the pulse rate option. Stimulation mode refers to the type of ground electrode used: the reference electrode located in the mastoid region (1), the internal processor case (2) or a combination of the two (1+2). The inter-stimulus interval refers to the resting time between two stimuli. These settings will remain fixed for all tests of the study.

Figure 2 Stimulus definition window. PPS: pulses per second; Stimulation mode: ground electrode location (1 for ground electrode in the mastoid, 2 for internal processor case and 1+2 for a combination of both); # PPS: number of pulses per second (defines stimulus duration); silence: defines time lapse between pulse trains.
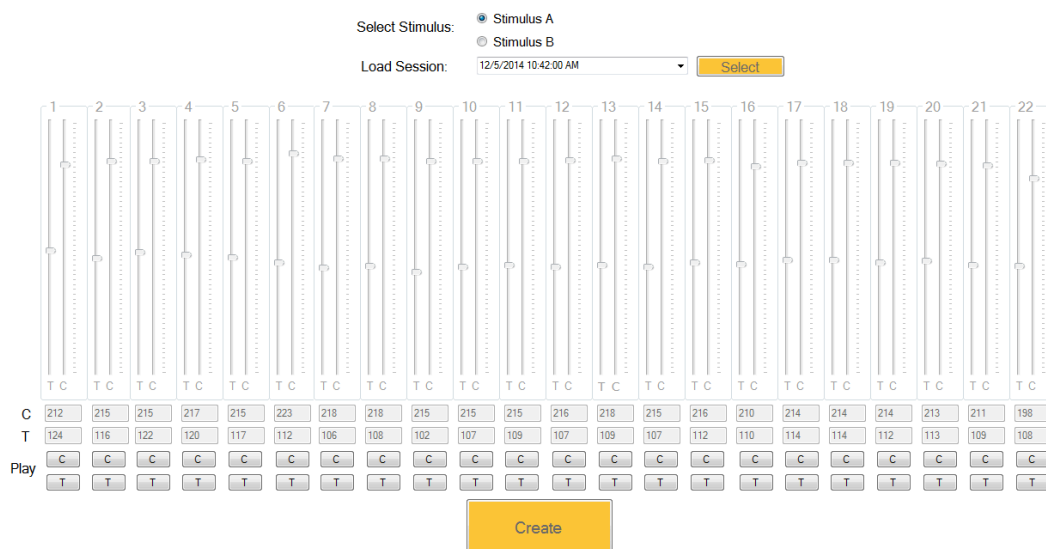
Dynamic Range Map

The Dynamic Range (DR) of an electrode defines the current intensity span that produces auditory sensation and is determined by the T and C levels of each electrode. The window can be seen in Fig. 3. The T level is calculated using the *up-down* method: a stimulus is presented at progressively increasing intensity until the patient reports hearing sensation and then it is lowered down again using smaller intensity steps until it is no longer heard. To find the C level, the stimulus is presented in progressively smaller steps as the intensity rises until the patient reports that the sound is no longer comfortable because it is too loud, but never painful.

In this part of the test, a new map can be created or a previous session can be loaded by selecting one from the *Load Session* scroll. When two different stimuli are used in an experiment, two independent maps must be created using one stimulus at a time.

Loudness Balance

The second step is to loudness balance all electrodes so that the stimuli delivered to all electrodes are perceived as equally loud. In the *Loudness Balance* window shown in Fig. 4, the user can compare an electrode with 21 other electrodes. In addition, one can select the stimulus to be used (A or B). The user must select the percentage of DR intensity that the initial reference electrode will have. This will be the electrode that will be objectively fixed at the desired percentage, and all others will be perceptually balanced with respect to it. The number of times one electrode will be compared to another (repetitions) can also be selected.

The method used is the confluence method. The patient is presented with two stimuli, the first corresponding to a reference electrode, and the second to a test electrode. The latter begins randomly above or below 10% of the DR percentage selected prior to test commencement. The patient selects which one of the two stimuli sounds louder using the window in Fig. 5 and the intensity of the test electrode will be lowered or raised until confluence is achieved. Then the patient has to state that they sound equal using the appropriate button. The stimuli will be repeated with the same settings to confirm that the patient perceives them as equal and then the system will automatically start again but with the test electrode being 10% different in the opposite sense. The test electrode final value is the average of the two approaches.

Figure 3. Dynamic Range Map. C and T levels for each electrode are determined using the up-down method.

Figure 4. Patient view for electrode loudness balance. The patient has to select which stimulus sounds louder.

Figure 5. Loudness Balance Window.

Alternative Forced Choice Experiment for Electrode Discrimination

The chosen method for electrode discrimination is a three-interval, forced-choice procedure (3FC) (Fig. 6). Two of the stimuli come from a selected reference electrode and a third one from a signal electrode. They are presented in random order and each test electrode is presented the number of times stated in the *Number of Repetitions* scroll. The patient has a user interface with three buttons (stimuli 1 to 3) and has to select the one that sounds different. The researcher will select a reference electrode and a number of electrodes to compare it with. Results are given as percentage correct scores.

Figure 6. Alternative forced choice experiment for electrode discrimination.

4. Conclusion

The experimental software developed in this paper allows for conducting psychoacoustic experiments on electrode discrimination. The stimulus variables and psychophysical procedures can be adjusted and the three basic steps necessary to conduct electrical stimulation experiments are easy to implement. The side benefits are to relieve psychoacoustic researchers of the burden of programming language skills, which would otherwise be necessary to generate and analyse stimulus signals. However, the application is experimental and can only be used by professionals who are trained on the application and have signed a NIC agreement. A NIC agreement requires a signed contract with the company to allow the researcher to access the Python library that can control the processor.

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