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Final stage of cochlear implant fitting – method SHCHUP

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Abstract

To accurately set the most comfortable loudness (MCL) levels we must determine the upper tolerance levels of electrical stimuli at each electrode. An upper tolerance level is the threshold of discomfort. The adjustment of MCL levels based on subjective estimates of the loudness of electrical stimuli is not too reliable. Audiologist trains the child to evaluate the loudness of electrical stimuli of different amplitudes on different channels using the categorical loudness scaling (CLS) method. It should be noted that CLS uses sequences of electrical stimuli presented over single channels.

Objective methods used in the fitting play a small role as an indication of the global MAP profile. Parents and speech therapists choose a working everyday program on the base of perception of the audio signal in the entire frequency range of the implant. Hence, since CI-patients rate sounds, we have to use sounds for fitting too. Discomfort level estimate of loudness discomfort is an effective and valid clinical measure for characterizing the "threshold of discomfort". So, for optimal fitting we need to find the threshold of auditory discomfort.

Speech therapists use sound sources (toys, musical instruments, drums, phonemes, speech and so on). All of them have wide (sometimes comb) spectrum with irregularities of amplitudes in different parts of their spectrum. Sound pressure levels (SPL) of such sound sources are uncontrolled ones. So, speech therapists can't give any instructions on how to adjust maximal electrical levels (MEL) in everyday program.

It is necessary to create special sound stimuli. Experienced adult CI patients evaluated the perception of audio signals sent simultaneously to three channels. SPLs of every single-channel band signal were the same. Comfortable SPLs of all sums of 3 single-channel bands were in a range 103-105 dB SPL. Good coincidence with the upper SPL limit of an implant (106 dB SPL). It means that the step noises can be used for setting the maximal electrical levels (MEL).

Based on the results of this investigation we created our SHCHUP method in which we used 4-channel step noises stimuli for the fitting of 12-channel implant. After some modification, the SHCHUP method can be used to fit implants with any number of electrodes. A few hundreds of CI-patients were fitted using the SHCHUP.

Introduction

The speech signal is converted in a result of processing in the cochlear implant (CI) and some of the original information is lost. According to Shannon (1993), implanted patients perceive this altered audio signal with a new sensory system [1]. Since every bit is expensive for the CI patient, in order to achieve the maximum possible result of a speech perception (understanding of speech) by the implanted patient, the processor program needs to be configured as precisely as possible. Only in this case, the CI patient will receive the maximum possible information through the CI system. Shapiro and Bradham (2012) correctly stated that device programming is not a goal per se but the absolute goal is to provide the patient with a comfortable program which ensures maximum performance [2] and so the foundation on which all rehabilitation is built is the optimal fitting of the speech processor, which determines the quality of rehabilitation.

The programming of a CI speech processor involves setting many parameters of processor's work that are written to the processor program when it is first turned on. Combination of values of these parameters together is commonly called the MAP. Correct and precise setting of these parameters is significant for the patient. Among other things the programming involves setting the frequency range, current threshold levels, and most comfortable loudness (MCL) levels in channels of the implant. We discussed the issues of setting a current threshold levels and frequency range limits for Med-El implants earlier [3,4]. In this article, we will only discuss the issue of installing the maximum electrical levels (MEL) in channels of the implant to achieve MCL levels. MCL levels are the threshold levels of discomfort, i.e upper tolerance limits that are critical for processor programming [5].

Implant fitting of small children represents the most difficult task for an audiologist since the child cannot reliably estimate the loudness of electrical stimuli used in fitting, so the focus of this article will be on working with children. In addition to the goal of achieving the maximum outcome of the patient's rehabilitation, optimal fitting is also necessary in terms of developing new coding strategies. Only in case of fine (optimal) fitting it is possible to reliably evaluate existing strategies and rely on these results when developing new ones.

To accurately set the MCL levels, we must determine the upper tolerance levels of electrical stimuli at each electrode. An upper tolerance level is the threshold of discomfort.

Let's look at how the stimulation is done, and the loudness of electrical stimuli is evaluated during fitting of CI patients.

The fitting starts with telemetry and then stimulation by short current bursts in SWEEP mode, i.e with sequential stimulation of all

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channels. The first session is continuing until the clear child's response to the stimulation [6]. In this case, the child realizes that as a result of the audiologist's manipulations, some new sensation has appeared in his head. The audiologist naturally understands that this is the sensation of sound caused by electrical stimuli. During fitting in the following days, we use short current bursts or sequences of them through different channels at different levels of stimulation, monitor the response, and try to get the child to make subjective assessments of the loudness of electrical stimuli. When creating new programs, we rely as much as possible on these subjective estimates. It should be noted that evaluating the loudness of stimuli of different frequency bands (from different electrodes) is not an easy task, even for adult patients. When the MAP derived from psychoacoustical data is activated the resultant percept is often too loud or too soft [5]. Therefore, the adjustment of MELs based on subjective estimates of the loudness of electrical stimuli is not too reliable.

During the fitting, parents and speech therapists consistently switch the implant from quiet to louder programs and monitor the child's reactions to these programs. The children display their total(!) assessment of the loudness of programs of increasing intensity by their behavior and reactions, and thus the parents choose the optimal – working program.

In addition to subjective assessments, objective methods are used in the fitting, but they play a small role as an indication of the global MAP profile [7,8]. For example electrical levels equal to the threshold levels of the stapedial reflex may be lower than the MCL levels of the optimal program for a different number of steps (step-0.2-0.3 dB) in different patients [9-11]. Therefore, the high correlation between MCL levels and reflex thresholds, sometimes obtained, is not a reason to use the threshold levels of the stapedial reflex as the final MCL levels.

The results of reflexometry cannot be used for the final setup, but they are necessary for CLS [12]. After performing reflexometry, the audiologist gets information about the levels of electrical stimuli that the child hears loudly and about the ratio of current values and loudness levels on the scale of quiet-good-loud. This allows audiologist to train the child to evaluate the loudness of electrical stimuli of different amplitudes on different channels using the CLS method. It should be noted that CLS uses sequences of electrical stimuli presented over single channels. Children are successfully trained to evaluate the loudness of such stimuli — this is an interesting game for them. Some children, passing by our laboratory, themselves pull their parents to us for the fitting. After mastering CLS, the child gets an experience in evaluating the loudness of electrical stimuli, which will be used in the future - namely, during the method SHCHUP.

So, What do we have at this stage? Estimating the loudness of single electrical stimuli is a difficult task even for adults. A derived program based on subjective evaluations can be both loud and quiet after activation [5]. Objective methods do not give the global MAP profile, i.e MCL levels [7,8]. CLS works successfully, but on single channels on a sequence of electrical stimuli [12]. Therefore, we do not yet have clear indications of MCL levels. Based on the results of CLS, reflexometry and, if possible, a child's subjective assessments, we create a program with a certain configuration of MELs in all channels. From this program, we create three more and from these 4 programs the parents and speech therapists choose a working everyday program on the base of perception of the audio signal in the entire frequency range of the implant. Hence, since CI-patients rate sounds, we have to use sounds for fitting too.

As shown in study of Sherlock LP, Formby C [13] a simple loudness discomfort level estimate of loudness discomfort is an effective and valid clinical measure for characterizing the "threshold of discomfort". And for optimal fitting, we need to find the threshold of auditory discomfort. How?

Speech therapists use sound sources (toys, musical instruments, drums, phonemes, speech and so on). They have wide (sometimes comb) spectra with irregularities of amplitude in different parts of their spectrum. SPLs of such sound sources are uncontrolled ones. As an example, we will give the spectrum of the handbell (Figure 1).

Let the patient feel discomfort at the sounding of the handbell. How can this result be used in the fitting? In which channels should we reduce MELs and by how much? Unclear. This example also applies

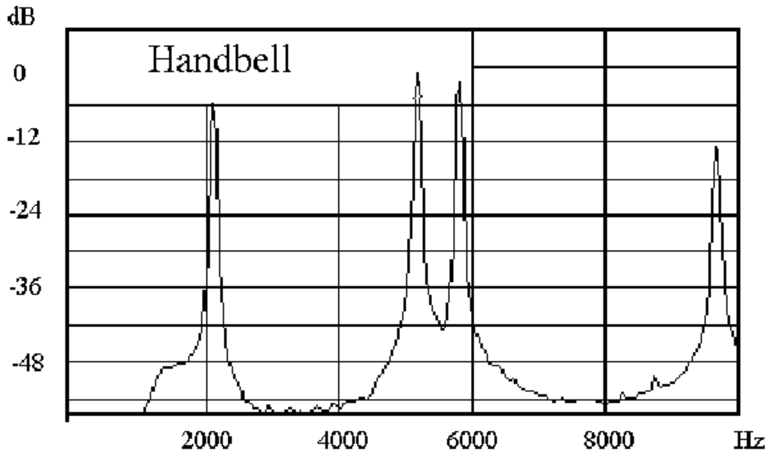

Figure 1. Spectrum of a handbell. The abscissa axis is the frequency, Hz. The ordinate axis is the sound pressure level, dB SPL

to other sound sources used by speech therapists. Therefore, speech therapists can't give any instructions on how to change the MELs in the program.

As you know, the CI processes the input sound signal in a certain intensity range from lower to upper level. All implants have an upper processing limit, for example upper limit of Med-El is 106 dB SPL. Therefore, for optimal fitting it is necessary that the electrical pulse generated in each channel for an input signal with an SPL of 106 dB evoked a sense of the upper tolerance level.

Obviously, it doesn't make sense to use audio single-channel stimuli for this purpose. As we have shown earlier, the use of white noise provides little information for correcting MELs across the channels [14]. So, it is necessary to create special audio stimuli. Which ones?

We decided to investigate how experienced adult CI patients evaluate the perception of audio signals sent simultaneously to three channels. SPLs of every single-channel band signal were the same. The purpose of the study was to determine which SPL of sum signals the patients set as the threshold of auditory discomfort at working program.

Seven experienced adult CI patients participated in this study. They used 8-channel implant «Tempo» for more than 5 years. They were reliably fitted and their optimal programs were second programs. MELs of these programs were MCL levels.

We cut off 8 bands from white noise. Width of every band was equal to width of every single-channel band. We equalized sound pressure levels of all these bands using amplifier "Azur 640A" and summed 3 equal SPL bands of adjacent channels. A result was eight 3-channel step noises of summed bands of channels 1-2-3, 2-3-4, 3-4-5, 4-5-6, 5-6-7, 6-7-8, 7-8-1, 8-1-2-3. The task of a participant was to set SPL of every sum of bands at threshold level of sound discomfort. Participants used most comfortable program of their implant.

So: Most comfortable SPLs of all sums of 3 single-channel bands are at Figure 2.

Most comfortable SPLs of all sums of 3 single-channel bands were in a range 103-105 dBs. Good coincidence with the upper SPL limit of an Med-El implant (106 dB SPL). It means that the step noises can be used for setting the electrical MCL levels. The results of our study were confirmed vootiue (at the patient's own ear). At first quieter program patients did not feel the discomfort at intensity level of any sum of 3 single-channel bands more than 106 dB SPL. At third louder program, the patients felt the discomfort at intensity levels of any sum of 3 single-channel bands less than 106 dB SPL.

Especially it should be noted that all of these experienced patients themselves said that the estimation of comfortable loudness of one-channel electrical stimuli is much more difficult task for them than an estimation of most comfortable sound pressure levels of sum of 3 single-channel bands. Participants themselves gave such comments during our experiment without additional questions.

Based on the results of this investigation we created our SHCHUP method in which we used 4-channel step noises stimuli for the fitting of 12-channel implant. After some modification, the SHCHUP method can be used to fit implants with any number of electrodes.

Methods

Preparing a sound stimuli for the SHCHUP procedure

Using the "Adobe Audition" program" we create white noise. Using our comb filtering program [14], we cut out the frequency bands from it. The boundaries of each band are equal to the boundaries of each single-channel band. We transmit every band to the input of the amplifier AZUR and from it to the TDH3 located on the plate of artificial ear 4153. With the same position of the loudness control of the amplifier, we change the amplitude of the band in the Audition program so that the SPLs of single-channel audio bands were the same (lets 96 dB SPL), i.e we align all single-channel bands to the 96 dB SPL. After equalizing the SPLs of all single-channel bands we summed up 4 bands of neighboring channels -1-4, 5-8 and 9-12 channels.

As an illustration, the full spectrum of 12 channels step noise is presented at the Figure 3 schematically.

During the previous days of fitting, the child gains an experience on a perception of speech and of surrounding sounds of full spectrum. It should also be noted that patients have some experience with categorical loudness scaling of electrical stimulus sequences over single channels. Before performing the SHCHUP, we demonstrate to the child a step

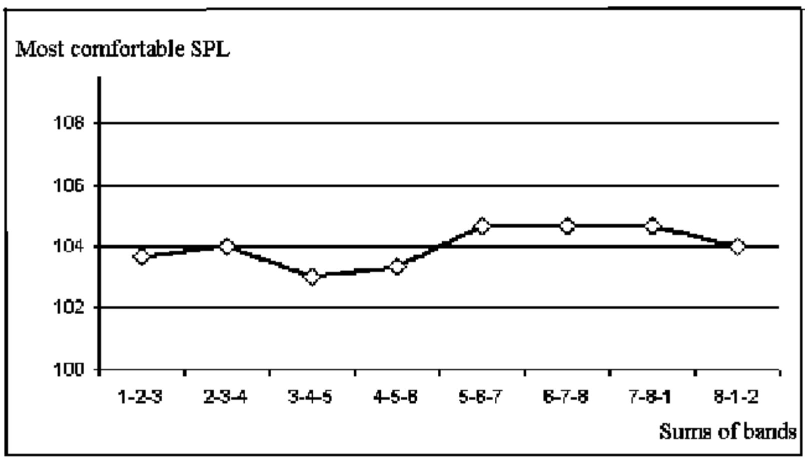

Figure 2. Most comfortable SPLs of sums of 3 single-channel bands. The abscissa axis is sums of 3 single-channel bands. The ordinate axis is the sound pressure level, dB SPL

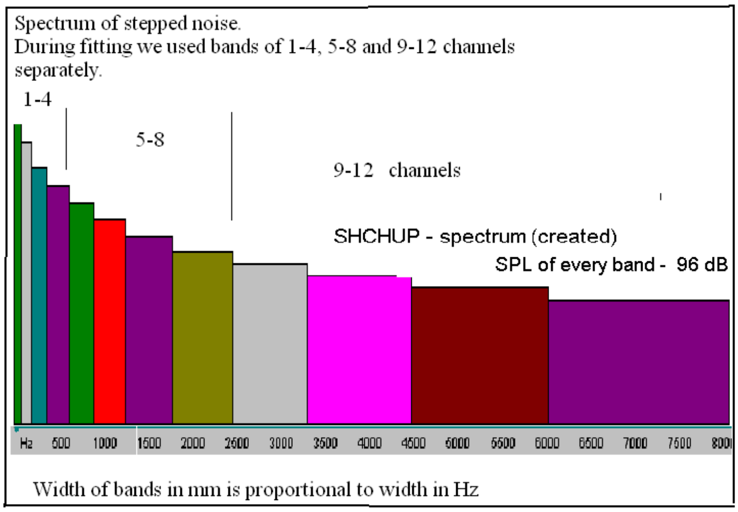

Figure 3. Schematic presentation of step noise. The abscissa axis is a frequency, Hz. The ordinate axis is the amplitude of the stimulus (schematically) - mV

noises of low, medium and high frequencies of different intensity. After such an introduction, we ask him to scale the loudness of sounds using the CLS method (using fingers or pictures), which he has previously gained experience with.

The purpose of this research is to determine the level of electrical stimuli at which 106 dB SPL of step noises cause the sensation of loud but comfortable on the CLS scale?

Procedure

The SHCHUP is conducted at the everyday program selected by parents and speech therapists. The MELs configuration was created on the base of results of reflex registration and CLS of each child. If possible, we take into account subjective estimates of the loudness of single electrical pulses used in the fitting.

Antenna of an implant is connected to a long wire and is placed on the patient's head. We switch on the speech processor and place an implant under the circumaural embouchure of headphone TDH-3 through which we will present a step noise stimuli. The installation and the child are ready for the study. Turn on the AZUR amplifier at the minimum gain.

Practical execution of SHCHUP

We are slowly increasing SPL of step noise and observing the child's behavior. Child shows own estimation of the loudness using fingers or CLS drawings. We register a most comfortable SPL (loud but comfortable) of each of the three 4-channel step stimuli. In accordance with the results of our registration of patient's reaction (in dB SPL) we change electrical MELs in appropriate channels of a patient's MAP. We increase MELs in channels at which a patient did not feel a discomfort at intensity level more than 106 dB SPL. We decrease MELs in channels at which a patient felt discomfort at level less than 106 dB SPL. We do not change MELs in channels at which a patient adjusted sound MCL at level around 106 dB SPL.

The study continues until the amplitude of electrical stimuli is determined, at which the child displays a slight negative reaction at the intensity of step sounds in the 106 dB SPL zone. It should be noted that most children are interested in participating in this survey. A few hundreds of CI-patients were fitted using the SHCHUP.

We would like to emphasize that a SHCHUP method of loudness estimation is very comfortable method for fitting of small prelingual children in low, middle and high frequency ranges of spectrum separately. And especially for patients with two implants! Reactions of a child are similar at equal loudness of step sounds of different frequency bands. At SPL near discomfort threshold the child begins to hide face, frowns, conceals himself, turns head to mother with question in eyes, stretches his arm to antenna and so on. There is an evident feedback. And reactions are the same at the same loudness level in right and left ears. We remind that our adult experienced patients themselves (without additional questions) said that the estimate of comfortable loudness of one-channel electrical stimuli is much more difficult task for them than an estimate of most comfortable sound pressure levels of sums of three single-channel bands.

We want to emphasize the convenience of practical use: If we are slowly increasing SPL of sound we can slightly touch threshold of discomfort at any SPL (90, or 97, or 102 dB SPL, or…) and immediately decrease the intensity of sound. To touch, to notice beginning of negative reaction and quickly to decrease SPL of step noise. Or we cannot achieve (touch) discomfort at 106 and more dB SPL. It should be especially noted that such smooth and rapid changes in stimulation levels are not possible when testing with electrical stimuli. Child's reaction is carefully observed.

N.B. As stimuli of high SPLs are used in the SHCHUP so there is no need to use a very soundproof chamber. We successfully used headphone with circumaural embouchure in our practical work.

At the end of fitting we create a program (MAP2) using the results of SHCHUP and relying on the MELs of the everyday program selected by parents. We also evaluate the perception of full-spectrum step noise (Figure 3) on the program we received. If necessary, we simultaneously increase or decrease the MELs of the new program. Relative to it, we create a new configuration (combination of 4 MAPs). First program is 3 step lower. Third and forth programs are 3 and 6 steps higher than second program accordingly. For selection of comfortable program we give instruction-explanation to the parents of CI patients. "During our life we all use always the same program. Sometimes we hear loud sounds. But we do not always use earplugs. Why cannot your CI-child hear loud sounds? Sometimes. Can. And must. Sometimes!!! Program is optimal one if your child sometimes hears loud sounds" [15].

After learning the CLS and SHCHUP, it will be easier for the child to evaluate the loudness of single-channel stimuli further.

It is possible to create "Device for cochlear implant fitting" with 3,5 or more 4-channel bands for any implants of any Firm.

This SHCHUP method of fitting is patented [16] and successfully used in our practice.

Conclusions

1. Experienced adult CI patients set most comfortable SPLs of all sums of 3 single-channel bands in a range 103-105 dB SPL.

2. Estimation of comfortable loudness of step noise stimuli is a simpler task than estimation of loudness of single-channel electrical stimuli.

3. Step noises are adequate and appropriate stimuli for the fitting of a cochlear implanted patients. Especially of small children. Especially of patients with two implants.

4. The experience of evaluating the loudness of stimuli in CLS and SHCHUP will be useful in further fine-tuning.

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