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Calibrated Ling Sounds Test for Cochlear Implant fitting in children

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***Abstract*— The Implanted children audiometric evaluation inaccuracies may lead to an extended period of the time to achieve proper cochlear implant (CI) electric stimulation. In this work we hypothesized that the relationship between implanted patient hearing thresholds estimation based on the Electrical Cochlear Response (ECR) and detection thresholds to Ling Sounds intensity calibrated according to higher energy spectral component allow electrical current stimulation adjustment of intracochlear electrodes. ECR is an objective test which is performed while patient is asleep and using the CI in everyday operation mode. Stimulus are variable intensity pip tones whose frequency is coincident with the central frequency of the band frequencies in which incoming sound is divided. The ECR Hearing Threshold is determinate by initial ECR detection and is defined as the minimum intensity level which auditory nerve portion involved with test electrode responds to electric stimulation hence producing an auditive experience to subject. Correlation observed between ECR Hearing Thresholds and Calibrated Ling Sounds detection thresholds is high enough (r^2= 0.99) for electrodes electric current adjustment based on patient detection thresholds obtained in a Calibrated Ling Sound Test.**

***Clinical Relevance*— Generally, CI programing according to patient individual requirements means electrical current level modification in one or more electrodes of the array based on patient auditory behavior, rehabilitation therapy performance and audiometry. Because of time necessary patient become used to CI stimulation early audiometry results are questionable, however. Considering Calibrated Ling Sounds detection thresholds are high correlated with objective estimation of ECR Hearing Thresholds, the electrode electric current dynamic range adjustment based on a Calibrated Ling Sound Test may reduce the period of time to achieve a proper CI electric stimulation, hence improving patient rehabilitation expectations.**

I. Introduction

For Cochlear Implant (CI) fitting is necessary to establish T and M/C level of the electric current dynamic range in the electrode array, among other functioning parameters [1]. Nowadays to know about success of initial CI fitting or the result of any readjustment made to electric current dynamic range in an electrode or electrodes it is necessary attend to patient acceptation device degree and auditory behavior developing for several weeks, along with audiometry application for monitoring any hearing thresholds change. This procedure is repeated up to get normal hearing thresholds and useful and safe hearing in the implanted patient. However, in pediatric patients factors such as short age, lack of communication resources, additional health problems and insufficient training make audiometry result doubtful [2]. In the other hand, audiometry test frequencies are not related to frequency bands in which CI divided the spectral contents of the incoming sound, leading to electric current dynamic range inaccuracies when this adjustment is made based solely on audiometry.

Usually, in a rehabilitation therapy session by using Sounds Ling Test [3] patient ability for detection, identification and discrimination of speech sound is evaluated. This is a live voice test performed at a conversational intensity level, approximately 60 dB_{HL} one meter away from patient, using six speech sounds distributed across audiometry frequency axis. Result contrast of this test and audiometry may lead to modify current dynamic range in the electrode array. Previously Ling sounds have been used for obtaining speech sound detection thresholds in Hearing Aid users [4], however to date there is no report of its use in implanted patients.

In an Electrical Cochlear Response (ECR) test by using a pip tone of variable intensity in sound field a scalp potential is picked up when pip tone intensity maps on to a stimulation electric current level high enough to evoke auditory nerve electric response [5,6]. ECR Hearing Threshold corresponds to the minimum intensity level for which ECR is detected in an electrode selected by means of its central frequency. In this way correspondence to frequency bands incoming sound is divided by CI is achieved and at the same time the number of data points for plotting audiometry graph is increased. ECR Hearing Thresholds do not depend on conscient patient response and can be obtained any time after CI initial fitting

In a previous work in a group of children with doubtful audiometry a significative difference up to 22 dB_{HL} was found ($p<0.05$) when Hearing Thresholds and ECR Hearing Thresholds were compared [7]. However, when audiometry is good enough a non-significative difference of ≤ 5 dB_{HL} was found [6,8]. Concluding that Hearing Thresholds can be estimated by means of an ECR test.

Of easy application Ling Sounds Test usually is part of a regular rehabilitation therapy session for a fast subject auditory evaluation. An intensity calibration of these sounds based on higher energy spectral component is added. The result of this version of Ling Sounds Test application to implanted children

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and its probable use for intracochlear electrodes electric current adjustment is exposed.

II. PROCEDURE

A. Population

Eleven children in a range of 2.3 to 9 years old (5±2.4). All of them with a profound neurosensorial hearing loss diagnosis. Hearing aid use for at least 6 months before implant surgery. Advanced Bionics CI users, six using Harmony sound processor and five using PSP, and electrode array complete insertion. Hearing level equivalent to a middle hearing loss PTA= 47 dB_{HL}, at the time of the study. The study complied with all applicable research and ethical standards and laws followed by the Declaration of Helsinki principles.

B. Instrumentation

Digital stimulus generator *Neuroscan STIM*, *Interacoustics* Clinical Audiometer AC-40 and 2.5 x 2.5 x 3.0 m audiometric test booth. Sound field calibration inside test boot according to ISO 389-7 for a distance of one meter between sound source and sound processor microphone localization. Intensity level for nonstandard frequencies were calibrated according to a third order polynomial approximation of values mentioned in the standard. Calibration equipment consisted of B&K 2235 sonometer, B&K 1625 filter y B&K 4230 sound calibrator. A *Neuroscan Synamp* was used for ECR acquisition.

B. Tests

CI was previously programmed by audiologist and everyday operation mode was selected for all tests. ECR Test, Audiometry and Calibrated Ling Sound Test were applied sequentially in a single study session. During test performing patient was accompanied by one of the parents.

ECR: EEG electrodes in A1 (–), A2 (–), Cz (+) and FPz (GND) positions for two recording channels, impedance electrode-skin less than 5 kΩ. Tone pips stimulus of 20 ms for 333, 455, 540, 642, 762, 906, 1076, 1278, 1518, 1803, 2142, 2544, 3022, 3590, 4265 and 6665 Hz frequencies and intensity level in the range of 20 a 70 dB_{HL} ECR was obtained by averaging 100 EEG epochs of 50 ms acquired time locked to pip tone presentation and organized according to stimulus frequency and intensity, for details see [6].

Audiometry: Sound field audiometry applied by audiologist.

Calibrated Ling Sounds: Ling sounds were previously recorded inside audiometric test booth using female voice and Audacity® software. Sounds spectral analysis was done using Matlab® and each sound intensity was calibrated for 40 and 60 dB_{HL} one meter away from patient according to its higher energy spectral component, /*m*/-229 Hz, /*u*/-449 Hz, /*a*/-879 Hz, /*i*/-2731 Hz, /*sh*/-3888 Hz and /*s*/-4880 Hz. During test one second duration Ling sounds were presented in aleatory way up to three nonconsecutive times along with a color card allusive to test sound. Two of three times sound detection was considered a right answer expressing result test as a percentage per intensity test.

C. Data Analysis

Hearing Thresholds PTA, and ECR Hearing Thresholds PTA_{ECR}, were analyzed by using a t-Student test for independent samples. Relationship between Calibrated Ling Sound threshold detection and ECR Hearing Thresholds was done by means of Pearson Correlation Analysis using SPSS® statistics software with $p<0.05$. For comparison purposes average Hearing Thresholds, ECR Hearing Thresholds and Calibrated Ling Sound threshold detection were plotted in the same graph.

III. RESULTS

TABLE I. PATIENT DEMOGRAPHICS AND CALIBRATED LING SOUND TEST SCORES.

Patient	Gender	Chronological age [years]	*Auditory age [years]	PTA		PTA_{RCE}		Score [%] Calibrated Ling Sounds	
				dB_{HL}	Hearing loss	dB_{HL}	Hearing loss	40 dB_{HL}	60 dB_{HL}
1	M	1.4	0.5	42	moderate	44	moderate	67	100
2	F	2.8	0.1	58	moderate	43	moderate	0	50
3	M	2.3	0.3	80	profound	44	moderate	0	100
4	F	1.6	0.2	47	moderate	39	mild	67	100
5	M	3.0	0.2	47	moderate	37	mild	83	83
6	M	3.4	0.3	62	severe	50	moderate	33	83
7	F	5.7	2.9	33	mild	36	mild	100	100
8	F	4.9	3.0	37	mild	38	mild	83	100
9	F	8.7	4.9	37	mild	39	mild	67	100
10	F	9.0	5.0	35	mild	42	moderate	100	100
11	M	6.7	3.8	40	mild	42	moderate	50	100

*Auditory age: CI use time elapsed from CI activation.

Hearing loss classification for some patients change depending on PTA value selected despite t-Student test did not show any statistical significative difference between PTA and PTA_{RCE} values.

In Calibrated Ling Sound scores are better for 60 dB_{HL} than 40 dB_{HL}, however patients 5, 6, 7 and 10 achieved same score for both intensity levels. All patients detected /m/, /a/ and /sh/ phonemes two of them do not detect /u/ and /i/ phonemes and just one did not detect /s/ phoneme.

Figure 1 shows Hearing Thresholds, ECR Hearing Thresholds and Calibrated Ling Sound threshold detection average profile.

Clearly is observed the no coincidence between audiometry test frequencies and intracochlear electrode central frequency.

Also is noticeable that Hearing Threshold average intensity, 49 ± 14 dB, is greater than ECR Hearing Threshold average intensity, 43 ± 8 dB. Additionally, all profiles have same tendency and that ECR Hearing Threshold profile offers better frequency resolution.

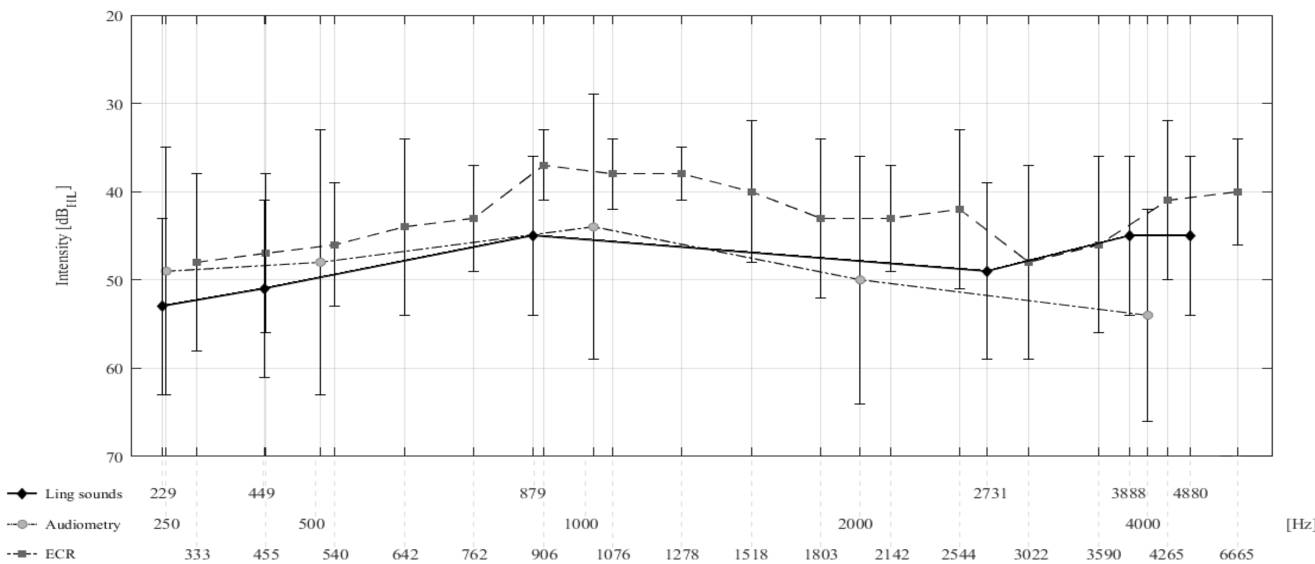

Figure 1. Audiometry (-·●-·), ECR Hearing Thresholds (--■--) and Calibrated Ling Sounds Detection Thresholds (–♦–) average profiles. Notice that ECR Hearing Thresholds offers a more detail information about patient audition and at the same time shows close relationship to Calibrated Ling Sounds Thresholds.

IV. Conclusion

The Table 1 shows that after more than a year of cochlear implant use some participants have not reach normal hearing thresholds. Reasons of this might be additional health problems, unsuitable habilitation strategy to individual patient necessities, besides inaccuracies in hearing thresholds obtention using audiometry.

Because of Calibrate Ling Sounds detection thresholds are close correlated to ECR Hearing Thresholds which in turn are a valid estimation of patient hearing thresholds suggests the possibility of using a Calibrate Ling Sounds Test for monitoring and/or readjustment of electric current dynamic range in the electrode array.

The use of this version of the traditional Ling Sounds test might reduce the period of time necessary to achieve proper CI electric stimulation despite pediatric implanted communication limitations. So, increasing patient expectation of an opportune rehabilitation.

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References

[1] Martins K.V.C. and Goffi-Gomez M.V.S., “The influence of stimulation levels on auditory thresholds and speechrecognition in adult cochlear implant users,” *Cochlear Implants International*, vol. 22(1), pp. 42-48, Jun 2021.

[2] Brown F.R., Hullar T.E., Cadieux J.H. and Chole R.A., “Residual Hearing Preservation After Pediatric Cochlear Implantation,” *PhD tol Neurotol*, vol. 31(8), pp. 1221–1226, Oct 2010.

[3] Yu-Chen H., and Ying-Chuan MaJ., “Effective Use of the Six Sound Test,” *The Hearing Journal*, vol. 69(7), pp. 16,17, Jul 2016.

[4] Glista, D., Scollie, S., Moodie, S., and Easwar, V, “The Ling 6 (HL) test: Typical pediatric performance data and clinical use evaluation,” *J Am Acad Audiol*, vol. 25(10), pp. 1008–1021, Nov-Dec 2014.

[5] Cornejo J.M., Quintana A.K., Beltran N.E. and Granados P, “Measuring implanted patient response to tone pips,” *BioMedical Engineering OnLine*, vol. 20(1), pp. 10, Jan 2021.

[6] Quintana A.K., Beltran N.E., Granados P., and Cornejo J.M., “Electrical Cochlear Response as an Objective Measure of Hearing Threshold,” *Revista Mexicana de Ingeniería Biomédica*, vol. 41(3), pp. 72-86, Dec 2020.

[7] A. Quintana, N. Beltran, M.P. Granados, E. Chamlati, Ma. Mena and J.M. Cornejo, “Objective Approach to Audiometry in the Pediatric Implanted Patient,” in *IFMBE Proceedings, Parana,* Argentina, 2015, vol. 49, pp. 707-10.

[8] A.K. Quintana, Ma.P. Granados and J.M. Cornejo, “Case Study: Audiometry and ECR profile time convergence,” in *IFMBE Proceedings*, Bucaramanga, Colombia, 2017, vol. 60, pp. 694-97.