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Evaluation of temporal difference limen in preoperative non-invasive ear canal audiometry as a predictive factor for speech perception after cochlear implantation

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Abstract

The temporal difference limen (TDL) can be measured with noninvasive electrical ear canal stimulation. The objective of the study wa to determine the role of preoperative TDL measurements in predicting patients' speech perception after cochlear implantation. We carried out a retrospective chart analysis of fifty-four cochlear implant (CI) patients with preoperative TDL and postoperative bisyllabic word recognition measurements in Helsinki University Central Hospital between March 1994 and March 2011. Our results show that there is no correlation between TDL and postoperative speech perception. However, patient's advancing age correlates with longer TDL but notdirectly with poorer speech perception. The results are in line with previous results concerning the lack of predictive value of preoperativ TDL measurements in CI patients.

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Introduction

Cochlear implant (CI) offers an effective treatment for most cases of severe sensorineural hearing loss, and with growing evidence of its safety and cost-efficacy both in adult and children, its indications have been constantly extended. With increasing experience in cochlear implantation the number of patients who undergo a preoperative promontorial stimulation test (PST[1]) or a measurement of cochlear microphonics decreases. The gain coming from those assessment tools is more and more replaced by clinical experience and evidence from auditory evoked responses or subjective audiologic tests (pure tone audiometry, speech audiometry in quiet and noise).

In PST a stimulation needle is inserted on the promontory, through the tympanic membrane under local anesthesia. PST can be employed before cochlear implantation to ascertain the intactness of the auditory pathway.[2] Applicability of PST responses in predicting CI outcome has been questionable, as there seems not to be a solid correlation between these two.[3,4] However, interpretation of those studies is difficult due to a relatively short follow-up period. Lee and colleagues[5] performed a thorough analysis about different aspects of PST responses in relation to long term CI outcome with 2 years follow-up. The researchers showed that a person's ability to detect a gap between two signals correlated with CI performance as measured by open set one- and two-syllable word recognition and sentence tests. PST is an invasive test and requires patient compliance, and is thus unfeasible in young children and persons with intellectual or multiple disabilities without general anesthesia.

Another approach for direct electrical stimulation of spiral ganglion neurons is to use electrical ear canal stimulation (EECS), where a ball-shaped electrode is placed in the intact outer ear canal.[6] While this method is noninvasive and can be used with children, its predictive value has thus far been insufficiently documented. In EECS measurements of CI candidates Neumann *et al.*[7] found postoperative speech recognition to correlate with frequency differentation but not with other measured variables [sensations, threshold level, temporal difference limen (TDL), dynamic range]. Takanami *et al.*[8] used EECS successfully in awake child patients with inner ear anomaly to demonstrate electroneural hearing before cochlear implantation.

Temporal processing ability is important in speech recognition.[9] Gap detection in PST has been shown to correlate with speech comprehension of CI patients in behavioral tests.[5] TDL is another measure of discriminatory processing. In positron emission tomography (PET) scans TDL has been shown to raise blood flow in brain regions important for speech comprehension.[10] In some earlier reports a short TDL in pre-operative invasive round window electrical stimulation has been shown to have some predictive value of CI outcome,[11,12] but it's role as a preoperative assessment tool has remained modest. In our department, we have used EECS to ascertain intactness of auditory pathway before cochlear implantation from 1994. The EECS equipment used in our department allows measurement of TDL but it does not allow gap detection. The purpose of this retrospective chart analysis was to evaluate the possible correlation between preoperative noninvasive EECS TDL measurements and postoperative speech perception and thus evaluate the clinical usefulness of the EECS test. Speech perception in this study was defined as bisyllabic word recognition in quiet, since it is currently the only validated speech comprehension test in Finnish langue.

Materials and Methods

Participants

This study was a retrospective chart analysis. Participants consisted of all 54 CI patients treated in the Department of Otorhinolaryngology of the Helsinki University Central Hospital between March 1994 and March 2011 who had preoperative EECS measurements performed with at least 6 months follow-up available for review. EECS measurements were usually performed in cases where one ear had been deaf for a long period of time while a hearing aid had been used in the opposite ear. EECS was performed in order to compare the ears and ascertain that the ear with prolonged deafness was suitable for implantation. All the participants in the study were postlingually deafened. The total number of patients receiving CI in Helsinki University Central Hospital between March 1994 and March 2011 was 215. Demographic data of patients is provided in Table 1.

Electrical ear canal stimulation

The TDL tests were conducted with MEDEL Electro Audiometer consisting of a control-display box (transmitter) and a two channel Receiver-Stimulator. Two ball shaped stimulation electrodes placed in the ear canals were connected to the receiver-stimulator via flexible, insulated lead and a connection plug. A standard adhesive electroencephalography-electrode was used as a reference electrode and was placed on the skin of the high forehead of the patient. This area of the skin was carefully cleaned with alcohol and fine sand paper in order to obtain contact impedances under 5 kΩ. The TDL test measures the smallest difference in duration of tone bursts that a patient can detect. The stimuli used were 125 Hz rectangular biphasic pulses. Each test consists of a number of test trials in which three tone bursts are presented. One of the tone bursts is a little longer than the other two. The patient was asked to indicate by voice which burst was the longer one. In the beginning of each test the stimulation level was set to the optimal subjective loudness level for the patient, *i.e.*, to the level at which a patient felt the tone bursts were the most comfortable to listen to. This was done in the demo mode of the electroaudiometry equipment by presenting series of three test tones where the TD (time difference of the long and short tone bursts) was 400 ms. The stimulation level was adjusted according to the patient's feedback. In the demo mode it was also confirmed that the patient had understood the instructions for the TDL test. The TD value in the beginning of the actual test was 208 ms. The durations of the gaps between bursts were always 450 ms. The durations of the short bursts remained the same (350 ms), while the duration of the long burst was varied (558 ms in the beginning). Depending on the performance of the patient the test was made harder or easier between trials, *i.e.*, the TD was decreased or increased, respectively. The TDL was measured using an adaptive Three-Alternative-Forced-Choice (3 up/1 down) algorithm determining the 79%-correct threshold.[13] The test was completed after seven reversals.

Speech perception test after cochlear implantation

Patients were seated in a quiet room for programming of the implant processor. The soundfield threshold and speech recognition testing according to ISO standards were completed with the patient seated in a double-walled sound-treated booth. Soundfield thresholds were obtained from 250 to 6000 Hz. Word recognition was obtained from all patients by using recorded bisyllabic, phonetically balanced words in Finnish language validated for adults (50 words, open-set test in quiet[14]). This test is currently the only validated speech perception test in Finnish language.

Ethics

The study protocol was approved by the ethics committee of the Helsinki University Central Hospital (permission number 371/E9/06).

Data analysis

All the data analysis was performed with Prism 5 software (GraphPad Software, San Diego, CA, USA). Statistical analyses were performed with unpaired *t*-test or linear regression fit, depending on the analysis (indicated in the text). $P<0.05$ was considered statistically significant.

Results

Patients

Fifty-four patients consisted of 24 males and 30 females (Table 1). Mean age at implantation was 52.0±1.6 years (mean±SEM) and there was no gender difference in implantation age. Thirty-two of the patients were implanted on the right side and 22 on the left, and implantation side distribution in males and females was equal. No differences between sides were detected in post CI speech perception (SP) scores (78.4±2.1 *vs* 70.6±4.7% for right and left sides, respectively, mean±SEM). SP in this study corresponds to the best SP measured from the patient during control visits after at least 6 months' follow-up. Overall SP was 75.2±2.3%. In males SP after CI was significantly higher, 81.9±2.7%, than in females (69.9±3.3, $P=0.0081$, unpaired *t*-test).

Temporal difference limen as predictive factor for speech perception

Individual patients' preoperative TDLs and SPs after CI are shown in Figure 1. Linear regression fit of speech perception scores after CI and preoperative TDL of the implanted ear gave a trend of shorter TDL cor-

Table 1. Patient demographics.

	All	Male	Female
No.	54	24	30
Age at implantation: mean±SEM (range), year	52.0±1.6 (21-73)	53.8±2.1 (27-68)	50.6±2.4 (21-73)
Side of CI (right:left)	32:22	14:10	18:12
Best SP: mean±SEM, %	75.2±2.3	81.9±2.7*	69.9±3.3
Follow-up for best SP: mean±SEM (range), mo	39.8±4.6 (6-151)	36.5±6.0 (6-115)	42.5±6.8 (6-151)
TDL: mean±SEM, ms	152.1±9.4	148.4±14.2	155.0±12.7

SEM, standard error mean; CI, cochlear implant; SP, speech perception, %; TDL, temporal difference limen. *P=0.0081 for the statistical significance of difference between males and females (unpaired *t*-test).

responding to better SP (Figure 1), but the trend was not statistically significant. This led us to look at the correlation between TDL and age, which is shown in Figure 2. This linear regression fit reveals that there is a statistically significant correlation between age and TDL. When looking at patient age and SP, there is a trend of worse SP with advancing age, but the correlation is not statistically significant (Figure 3).

Discussion

Earlier, preoperative tests based on electric stimulation inside or close to the middle ear were commonly used before cochlear implantation. Because studies have usually shown no or weak[11,12] correlations to postoperative outcomes, these tests are nowadays rarely used. In addition, extended indications for CI have further limited the purpose of such tests, because today most CI candidates have residual hearing. Many patients are implanted bilaterally nowadays, in particular children with bilateral profound hearing loss, but also adults.

Although the speech recognition performance of CI patients has steadily improved in recent years, considerable variability remains in implant patient outcomes.[9] There seems to be a correlation between CI patients' auditory temporal processing and speech recognition abilities.[9] Time and duration are very important dimensions in hearing, since almost all sounds change over time.[15] For speech, much of the information appears to be carried in the changes themselves, rather than in the parts of the sounds which are relatively stable.[16] In characterizing temporal analysis, it is essential to take account of the filtering that takes place in the peripheral auditory system. However, temporal resolution is not just a peripheral phenomenon. It is modulated through the auditory system.[15] Several researchers have measured thresholds for detecting gaps in narrowband sounds, either noises[17,18] or sinusoids.[19] Effects of duration has also been studied.[20] Behavioural studies show that processing of temporal cues is important for speech understanding.

TDL is a measure of discriminatory processing of sound duration. Using pre-operative invasive round window electrical stimulation it has been demonstrated to somehow predict CI outcome.[11,12] Electrical stimulation with a transtympanic electrode on the promontory of the middle ear allows the tasks of gap detection and TDL to be carried out by both normally hearing and deaf subjects. Cortical responses to promontorial stimulation in patients with postlingual deafness and control subjects has been studied with PET.[10,21] Only TDL raised blood flow in both posterior middle temporal gyri (MTG) and the right prefrontal cortex.[10] Recruitment of the right posterior MTG is important to the comprehension of speech containing mostly temporal cues. In our study linear regression analysis showed no significant relationship between TDL and postoperative speech recognition (Figure 1). This is in line with earlier results.[5,7] A possible limitation in the current study is the use of open-set bisyllabic word recognition test in quiet as a marker for speech perception and CI outcome in general. Other audiological tests, such as nonsense syllable, word, phrase or sentence tests, might de more appropriate in judging speech perception after cochlear implantation, but the open-set bisyllabic word recognition test is currently the only validated speech perception test in Finnish language, and thus used in this retrospective chart analysis. Anyhow, the results of this and previous studies suggest that preoperative TDL test predicts poorly patient's performance with CI.

The speech perception generally declines with advancing age. This

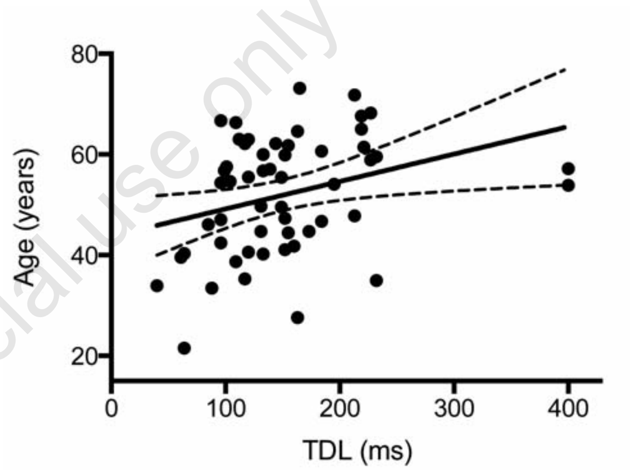

Figure 2. Effect of patient age on temporal difference limen (TDL). Linear regression fit (solid line; 95% confidence bands, dashed lines) shows correlation between age and TDL (P=0.0187).

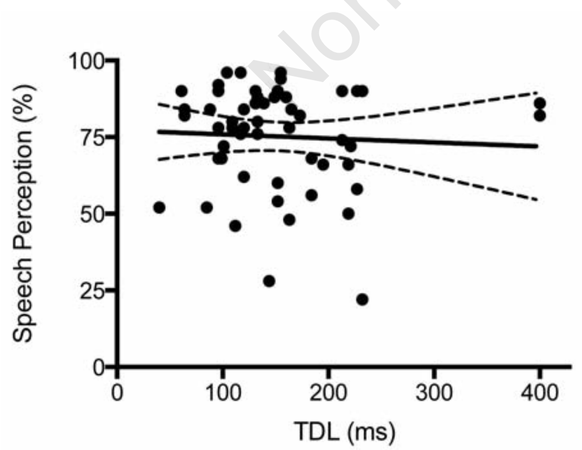

Figure 1. Speech perception after cochlear implant and preoperative temporal difference limen (TDL) of the implanted ear. Individual patient values (dots) and linear regression fit (solid line) with its 95% confidence bands (dashed lines). No statistical correlation between speech perception and TDL was found (P=0.70).

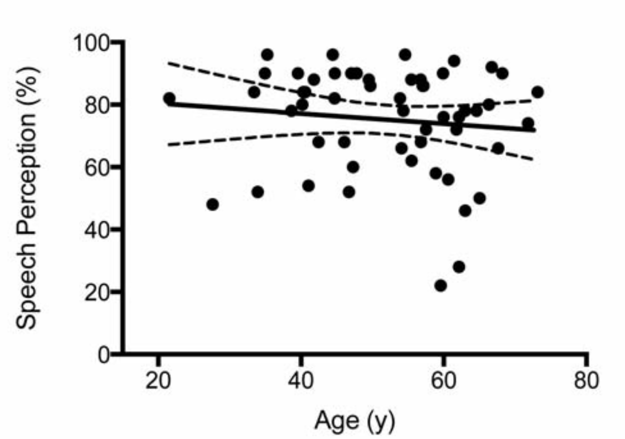

Figure 3. Effect of patient age on speech perception after cochlear implant. Linear regression fit (solid line; 95% confidence bands, dashed lines) shows no correlation between age and speech perception (P=0.42).

is true even in patients with relative mild hearing loss in pure tones.[22] In addition to reduced peripheral function due to decreased number of auditory hair cells also central auditory processing is impaired.[23] Reduced temporal precision in elderly has been reported.[24] This was confirmed in our study, since TDL correlated with age (Figure 2). Also generally decreased cognitive resources have an effect on impaired speech perception in elderly.[25] However, in our material, there was no clear correlation between age and speech perception (Figure 3).

We are continuously developing EECS method to meet our clinical needs. Currently there are limitations that need to be solved. The reliability of the method used in this study has not been determined. We are lacking normal-hearing data and our EECS test is not validated. The test-retest reliability between ears and between people needs to be studied in detail in the future. However, we find the interpretation of test results useful for specific clinical purposes on an individual basis.

We find that there is a need for EECS test within certain groups of patients in today's clinical practice. Special cases such as persons with intellectual disability, decreased cognitive abilities due to aging and associated neurodegenerative conditions including a reduced central auditory processing, or psychiatric, or additional conditions require an objective assessment of the auditory pathway performance with the use of electrical stimulation. At this point our method requires good cooperation, but Gräbel *et al.*[26] have used transtympanic electrical stimulation to evaluate auditory nerve function in an objective way. They have noticed that electrically evoked amplitude modulation following response (EAMFR) thresholds correlate with intraoperative evoked action potential thresholds. However, they did not find a correlation between EAMFR thresholds and postoperative speech perception.[27]

In conclusion we suggest that preoperative determination of TDL is not a reliable method for predicting CI performance, and thus should not be used in this context. However, with certain groups of patients, this test can produce valuable clinical data of the integrity of the whole auditory system.

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