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Efficacy of using NRT thresholds in cochlear implants fitting, in prelingual pediatric patients

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ABSTRACT

Objective: To evaluate the efficacy of using neural response telemetry (NRT) thresholds in predicting behavioural thresholds during programming of cochlear implant in prelingual children.
Method: Prospective study of 28 cochlear implants implanted with Nucleus 24 cochlear implant. We recorded NRT-thresholds on electrode numbers 1, 6, 11, 16 and 22 of the electrode array in each patient, the neural response thresholds were correlated with the behavioural map after six months of programming the device.
Results: The mean neural response telemetry level was significantly higher than the mean threshold level (T-level) but lower than the comfortable level (C-level) in all the electrodes tested. NRT levels could statistically significantly predict T behavioural levels and comfortable behavioural levels, $p < 0.01$. There was a strong positive correlation between comfortable thresholds and neural response telemetry level measurements and behavioural threshold level and neural response telemetry threshold measurements.
Conclusion: There is a useful role for neural response telemetry values in predicting the behavioural threshold and comfortable values in prelingual children. Combining the NRT values with behavioural observations can improve the programming of cochlear implants.

1. Introduction

A cochlear implant (CI) is a device used to restore hearing in children who are profoundly deaf. The fitting of a CI device is optimized for individual need for successful restoration of speech perception (De Vos et al., 2018).

When fitting a CI in pre-lingual children whom have never heard before, behavioural changes can account for how much current should be used to stimulate the auditory system from thresholds (T levels) up to comfortable levels that the child can tolerate without pain. Several sessions are conducted to program the device as these measurements change with time (Hughes et al., 2000).

The introduction of neural response telemetry (NRT) function in modern CIs with electrically evoked compound action potential (ECAP) was investigated for its potential as an alternative to behavioural methods (De Vos et al., 2018; Brown et al., 2000).

Our study aimed to evaluate the correlation between the (ECAP), as measured with NRT, and the behavioural T-level and C-level for prelingual paediatric cochlear implant patients.

2. Methods

2.1. Subjects

The participants included within the research project consisted of 28 children with 28 ears who had Nucleus® CI24RE Freedom cochlear implants. They comprised 10 males and 18 females, with a mean age of 4.2 years.

Children were implanted with Cochlear® model Nucleus® Freedom (CI24RE). Only patients with available NRT levels and behavioural levels were included in the study.

We choose to conduct our study on the Nucleus® CI24RE Freedom CI because this was implanted in most of the cases during the period of the study. Other models were also inserted, but were not included in this study to fix factors affecting the results. There

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was no conflict of interest.

2.2. ECAP measurement

NRT was recorded intraoperatively to measure the ECAP thresholds (NRT) on all 22 electrodes, as a routine part of the cochlear implantation surgery. ECAP measurement took place after implantation of the cochlear implant intraoperatively, using Auto-NRT software. The values were recorded and processed using Custom Sound 3.2 EP Software. The Auto-NRT stimulus and recording parameters used during the Auto-NRT measurements on all electrodes are indicated in Tables 1 and 2).

We measured NRT-thresholds on electrode numbers 1, 6, 11, 16 and 22 of the electrode array in each patient. The recording site was to be two electrodes above the stimulation electrode, for example, if a measurement was performed on electrode number 11, the recording site was electrode number 13.

The ECAP thresholds (NRT) for 140 electrodes (5 electrodes x 28 patients) were determined using Cochlear Corporation's Custom Sound 3.2 EP Software as shown in Fig. 1. Current level (CL) was used in the software for quantity description.

Table 1
Auto-NRT stimulus parameters.

Auto-NRT Stimulus Parameters	
Pulse active electrode:	Series
Probe indifferent electrode:	MP1
Probe current level (μV):	170
Probe pulse width (μs):	25
Probe stimulation rate (Hz):	80
Masker active electrode:	Probe active electrode + 0 Offset
Masker indifferent electrode:	MP1 + 0 Offset
Masker current level:	11 + 10 Offset
Masker pulse width (μs):	25 + 0 Offset
Number of maskers:	1
Masker rat e (Hz):	100

Table 2
Auto-NRT recording parameters.

Auto-NRT Recording Parameters	
Recording active electrode:	Probe active electrode +2 offset
Recording indifferent electrode:	MP2
Gain (dB):	50
Delay (μs):	122
Artefact cancellation technique:	Forward masking
Artefact reduction:	Off
Averaging number of sweeps	50
Averaging measurement window (μs):	1600
Averaging effective sampling rate (kHz):	20

2.3. Measurement of behavioural mapping levels

Switching on the device started 21 days after post-implantation using Cochlear Corporation's Custom 3.2 EP software. Behavioural levels; stimulation threshold level (T-level) and maximum comfortable level (C-level), were obtained using tone burst stimulus, where the pulses are presented to a single intracochlear electrode. This is accomplished by selecting a tone burst stimulus within the programming software. When the tone burst stimulation is selected, 500 msec bursts of biphasic current pulses are applied to a selected individual electrode in a monopolar stimulation mode.

The behavioural level, threshold level and comfortable level were recorded on electrode numbers 1, 6, 11, 16 and 22.

Behavioural levels were obtained by an experienced paediatric audiologist working with cochlear implanted children. The NRT measurements were not used and programming depended on the behavioural changes in the children. The threshold level was defined as the lowest current level needed for an observable behavioural response, such as silence or turning the head. While

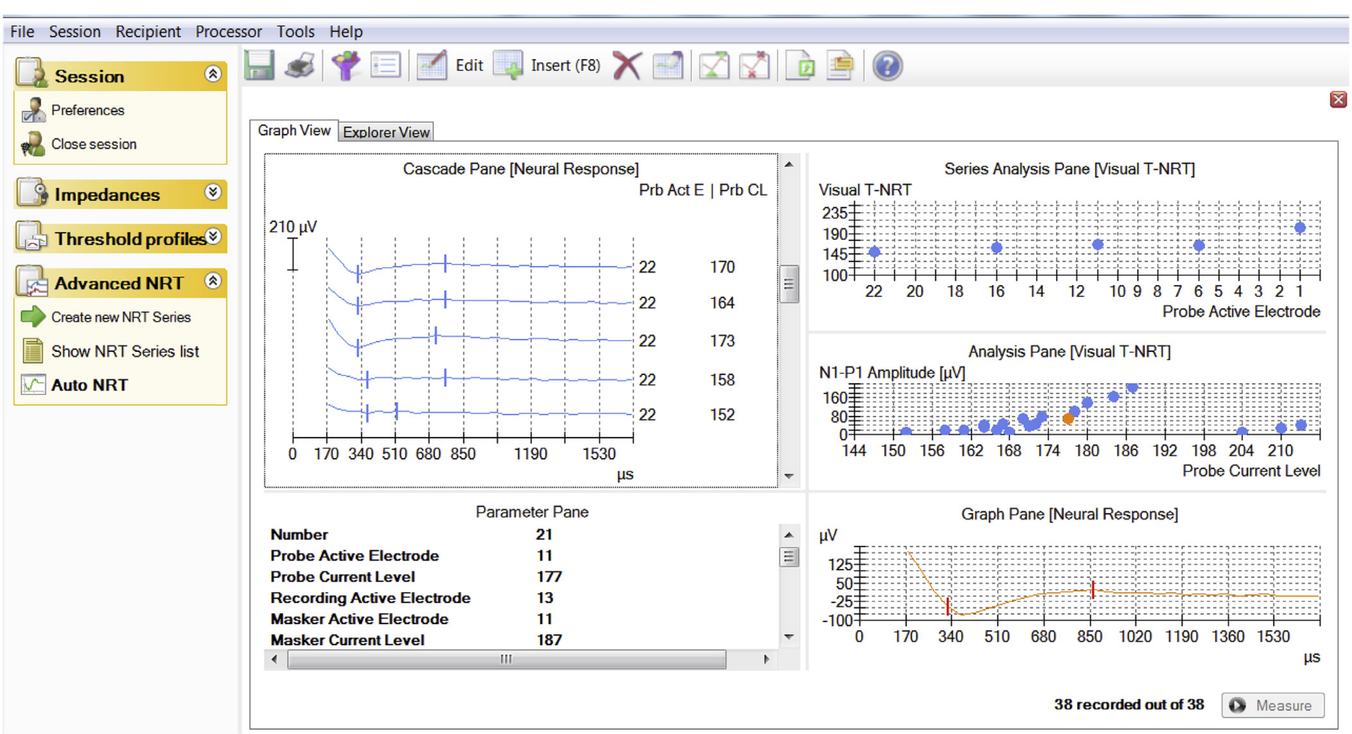

Fig. 1. Custom Sound program EP 3.2 showing Auto-NRT with parameters and curves used for recording the NRT threshold.

Table 3
Mapping details.

Sound Processor	Freedom sound processor
Implant	Nucleus® CI24RE CI
Mode	MP1+2
Strategy	ACE
Rate: pps/channel	900
Maxima	8
Pulse width: µsec/phase	37

the comfortable level was the maximum level, slightly below that level could cause behavioural discomfort, like grimacing or crying. T-levels were measured first using steps of 5 CUs. Once T-level was established, the stimulus level was systematically increased until the subject indicated that it had become uncomfortably loud (C-level).

The map that provides better performance by the patient was used in the study.

The basic details used during the mapping measurements on all electrodes are indicated in Table 3.

2.4. Statistical analysis

Data were collected from electrode numbers 1, 6, 11, 16 and 22 for NRT thresholds, as well as the behavioural threshold and comfortable levels in all patients.

The Pearson correlation coefficient was used to determine correlations and was confirmed using the Bland–Altman plot graph, mountain plot graph, one-way analysis of variance (ANOVA), and regression analysis. SPSS, Medcalc and Excel programs were used. These data were also used in another publication for assessing electrode position (Taha et al., 2015).

3. Results

All the tested electrodes recorded intraoperative NRT responses. There were variations in the amplitudes and thresholds of NRT responses across the subjects and electrodes.

NRT thresholds were found to be falling within the dynamic range, above threshold levels and below comfortable levels. There was a reduction of all levels from the basal (electrode number 1) to the apical (electrode number 22) ends of the cochlea (Figs. 2 and 3).

Table 4 shows the range and mean of neural response telemetry levels, threshold and comfortable behavioural levels at electrode numbers 1, 6, 11, 16 and 22.

At each electrode number, the differences between the mean of the threshold level, neural response telemetry level and comfortable level were statistically significant ($p < 0.01$; one-way ANOVA).

In all the electrode numbers, the mean for neural response telemetry level were higher than the mean for the threshold level

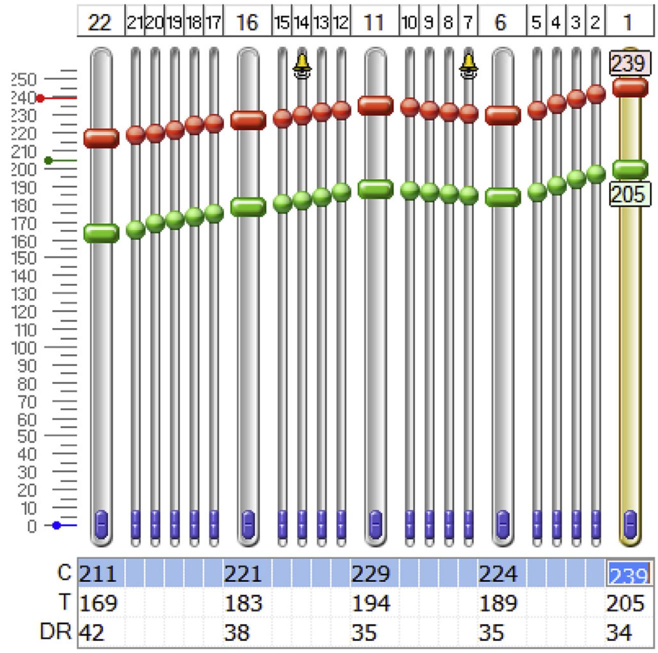

Fig. 3. A map from one of the studied cases done 6 months after implantation. Comfortable levels (C) (red marks) and threshold levels (T) (green marks) in the selected electrode numbers 22, 16, 11, 6 and 1. DR represents the dynamic range.

($p < 0.01$) and the mean for the comfortable level was considerably higher than those for the mean neural response telemetry level ($p < 0.01$) Fig. 4, 95% confidence intervals overlaps were not recorded.

Pearson correlation coefficients were used to evaluate the correlation between comfortable levels, neural response telemetry levels and threshold levels.

The correlation coefficients were all significant:

- Strong positive correlation between comfortable level and neural response telemetry level measurements ($p =< 0.01$; $r = 0.756$) (Fig. 5).
- Strong positive correlation between threshold level and neural response telemetry level measurements ($p =< 0.01$; $r = 0.787$) (Fig. 6).

The Bland–Altman plot graph is shown in Figs. 7 and 8).

A mountain plot graph was used to detect whether the NRT thresholds could be used as an equivalent of a T-level or a C-level.

As seen in Fig. 9, the two mountain plot graphs are not symmetrical in their value of zero along the X-axis, which indicates that either the C-level or T-level amount was not equivalent to the NRT

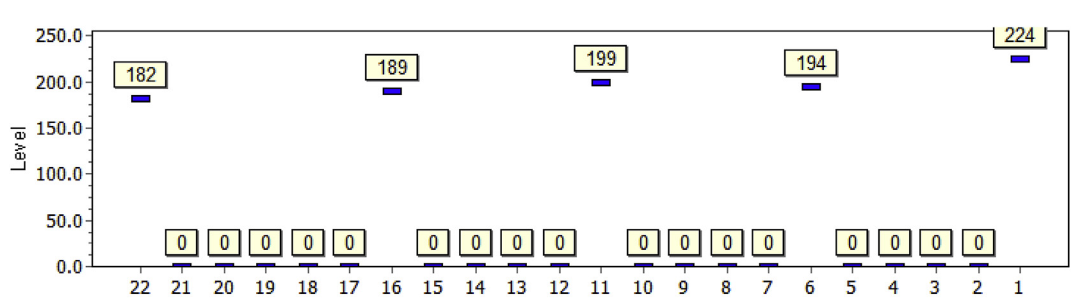

Fig. 2. The intraoperative NRT thresholds (µV) recorded on electrode numbers 22, 16, 11, 6 and 1 in one of the studied cases.

Table 4
NRT level, T-level and C-level measurements.

Electrode	No.	Threshold level (CUs)			Neural response telemetry level (CUs)			Comfortable level (CUs)		
		Range	Mean	± SD	Range	Mean	± SD	Range	Mean	± SD
1	28	151–230	191.5	19.913	180–242	214.2	17.870	200–258	227.18	15.131
6	28	143–280	177.36	19.172	163–230	194.75	16.349	163–252	215.7	17.703
11	28	129–210	169.15	20.353	129–214	189	16.689	159–244	207.9	20.977
16	28	113–202	163.5	20.532	151–211	181.56	16.327	153–242	201.3	20.741
22	28	88–199	149.9	22.569	108–109	169.3	19.222	128–229	190.2	22.324

CUs: Current Units.
No.: number of electrodes.

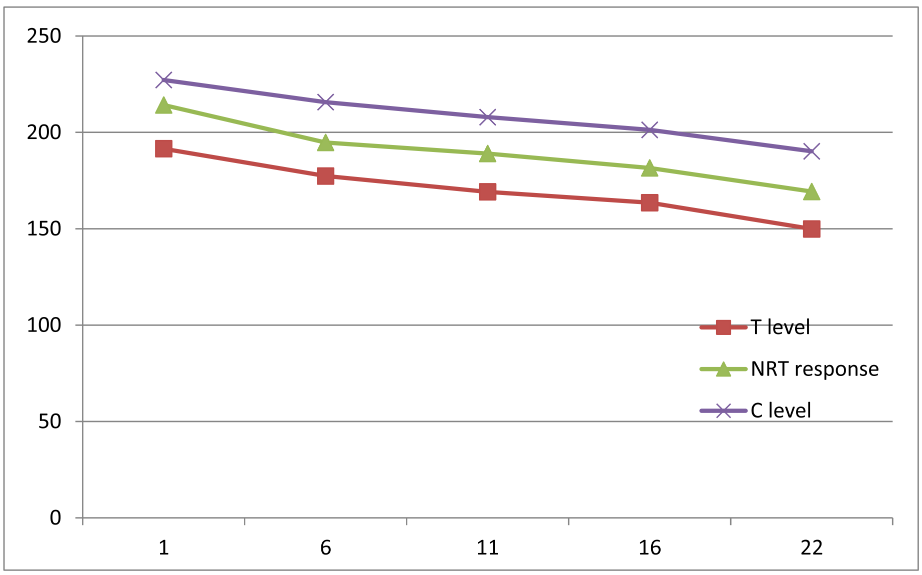

Fig. 4. The relationship between mean values of neural rResponse telemetry thresholds and threshold and comfortable levels on the different electrodes.

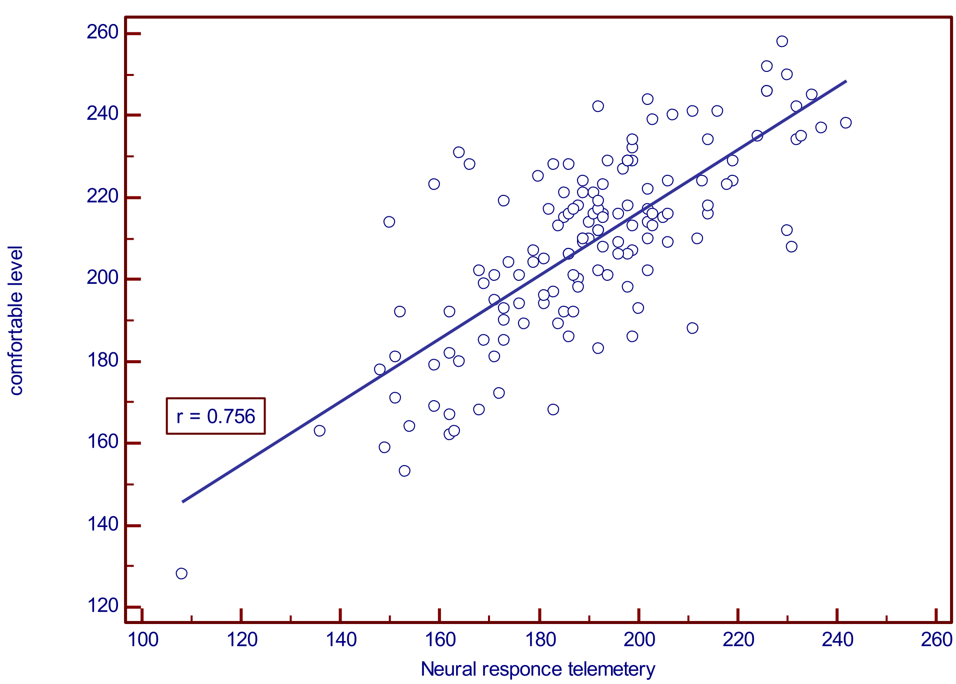

Fig. 5. Correlation between NRT level and C-level (regression).

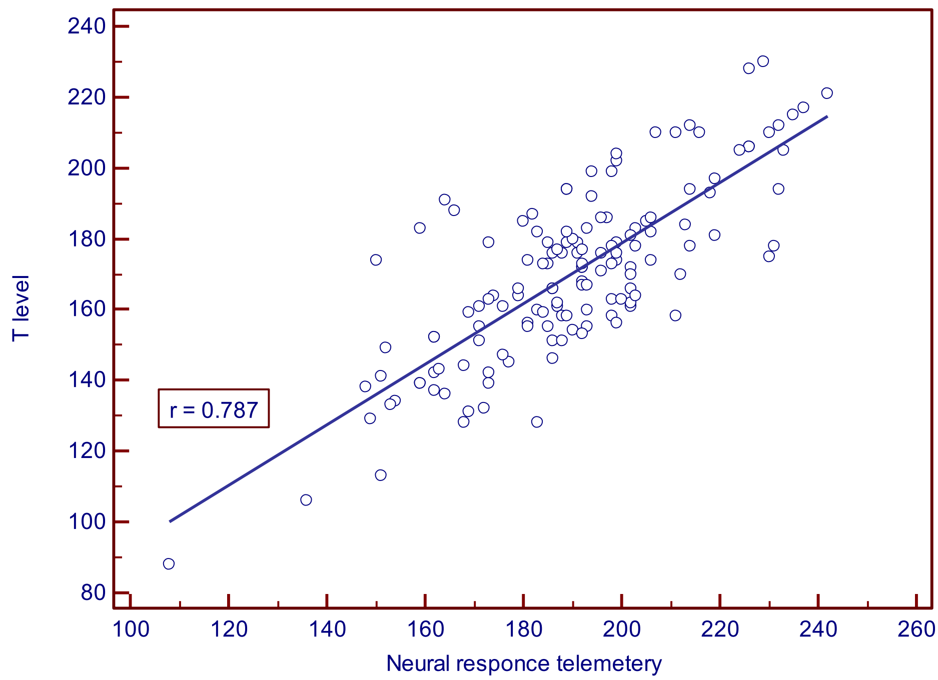

Fig. 6. Correlation between neural response telemetry level and threshold level (regression).

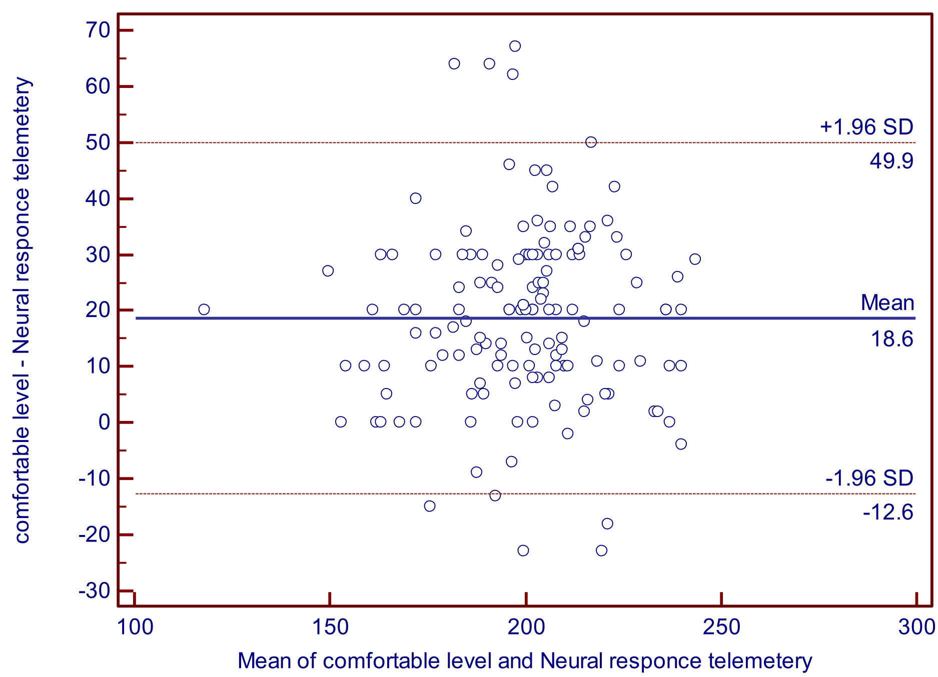

Fig. 7. Bland–Altman plot of the association between neural response telemetry level and comfortable level.

level measurement.

Regression analysis was used to calculate the equations for the prediction of estimated threshold levels and comfortable levels corresponding to NRT level measurements. A linear regression established that NRT levels were statistically significantly and could predict T behavioural levels by 62%, $p < 0.01$.

The regression equation was: threshold level = 7.7472 + 0.8552 NRT level. NRT showed 57% of predictive information for comfortable behavioural levels, $p < 0.01$ and the regression equation was: comfortable level = 62.7615 + 0.7677 NRT level. Mountain plot determined equivalence between the 2 methods.

4. Discussion

In the present study, we were interested in young children with CI who were still at an age where it is usually difficult to obtain reliable MAPs during mapping sessions, and thus, objective measures are needed to increase reliability.

The Nucleus Freedom cochlear implant used in our study was performed by the same surgeon. Full insertion according to

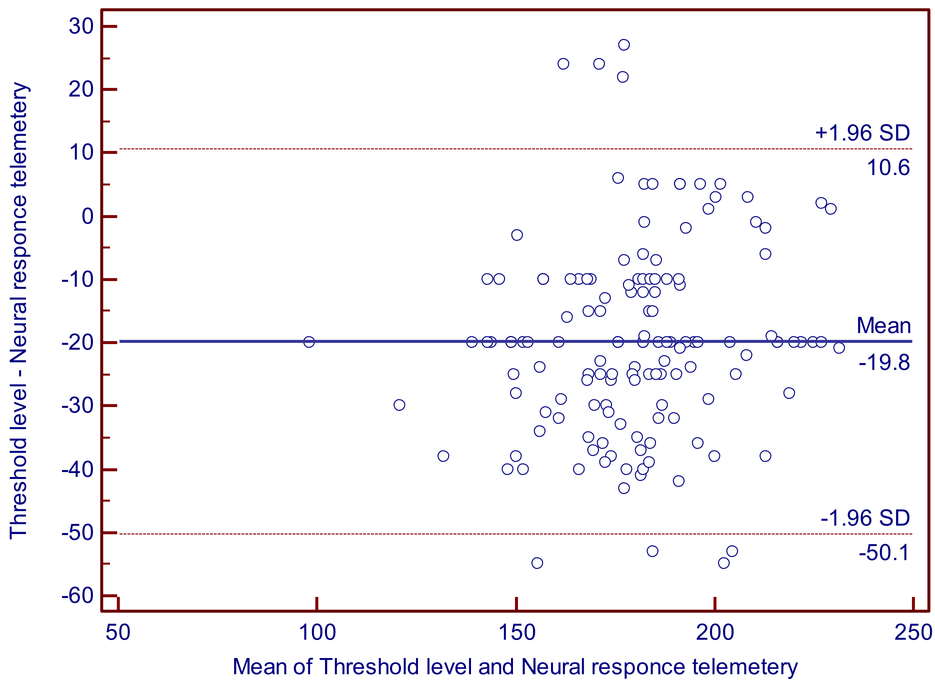

Fig. 8. Bland–Altman plot of the association between neural response telemetry level and threshold level.

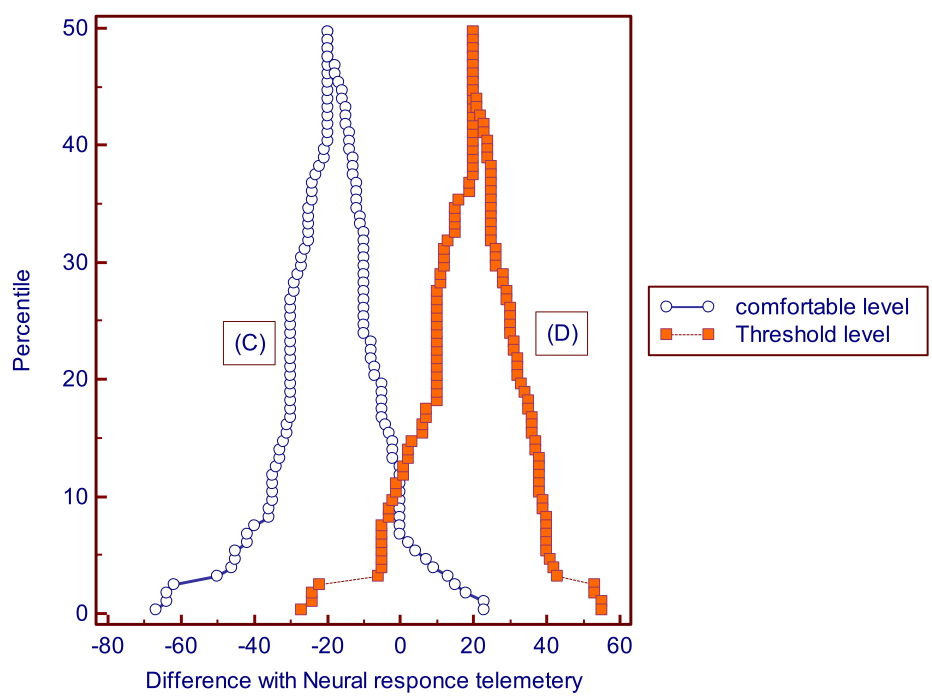

Fig. 9. Mountain plots corresponding to Fig. 7, plot C, and (Mittal and Panwar, 2009), plot D.

provided insertion depth was possible without complications in all cases. All measurements (NRT, C and T levels) were conducted on 5 selected electrodes, numbers 1, 6, 11, 16 and 22.

These chosen electrodes represented the electrode array from the cochlear base until the apex. Electrode numbers 1 and 6 represented high frequencies, number 11 and 16 represented mid-frequencies and number 22 represented the apical turn (low frequencies). Intraoperative NRT measured in our study had the advantage of being done under general anaesthesia, giving accurate results and avoiding the difficulty of obtaining accurate recordings during postoperative sessions, as well as potential bad experiences from pain during the recording (Chen et al., 2002).

We measured the threshold and comfortable behavioural levels from the selected electrodes during mapping sessions 6 months after implantation, as the behavioural standards become more stable for the final adjustment of programming the device. Henkin et al. (2003) found that during the first few months of using the implant there were significant elevations in the behavioural thresholds, which stabilised after 6 months.

Also, Thai-Van et al. (2001) concluded that the improvement of the behavioural levels was possibly because children became older and had a better response, also they became used to using the implant.

It was found in our study that the NRT thresholds were not equivalent to threshold or comfortable levels. At each electrode number, the differences between the means of the threshold level, comfortable level and NRT level were statistically significant. Besides, there was not much difference between the mean levels recorded from the selected electrodes, which suggested that there was no correlation between the electrode number and the recorded levels. This is in agreement with Brown et al. (Brown et al. (2000), who found that NRT levels were variable across adjacent electrodes.

Also, we found that the mean NRT thresholds fell between the threshold levels above and comfortable levels below. Even if there was variation in the position of neural response telemetry thresholds closer to the threshold level or comfortable level in some patients, it was always found that the NRT fell within the dynamic range across all recorded electrodes (Mittal and Panwar, 2009). Many studies (Hughes et al., 2000; Chen et al., 2002; Di Nardo et al., 2003; Gordon et al., 2002) had the same results, they concluded that NRT thresholds represented a level that should be audible but not uncomfortable. Similar results were found in adults ((Cafarelli Dees et al., 2005; Smoorenburg et al., 2002).

We observed that the contours of the Threshold and comfortable levels across all electrodes were often similar to the outlines of the NRT thresholds. These similar findings were reported by Brown et al. (Brown et al. (2000) and Hughes et al. (2001), who concluded that ECAP thresholds often followed a similar outline or shape to the map levels.

We recorded significant positive correlations between neural response telemetry levels and behavioural threshold levels, and between NRT levels and comfortable levels with P values < 0.01 and $r = 0.7$.

Moderate to strong correlations between NRT thresholds and T-levels, with correlation coefficient variations ranging between $r = 0.5$ to 0.9 across studies (Di Nardo et al., 2003; Smoorenburg et al., 2002; Cullington, 2000; Polak et al., 2005). These variations of correlation coefficients across different studies, may suggest that NRT measures alone are not reliable enough to set map levels directly.

However, other studies (Brown et al., 2000; Franck and Norton, 2001; Hughes et al., 2001) found that when combining NRT thresholds and some behavioural observations, there were stronger correlations with a more accurate map (Holstad et al., 2009).

The Bland–Altman plots indicated the presence of a positive correlation between neural response telemetry thresholds and behavioural thresholds. Visual inspection of these two plots indicated a linear relationship between the variables. We concluded that NRT levels can be used in the prediction of behavioural maps. Regression analysis, using Medcalc software, was used to calculate the equations used for the prediction of estimated comfortable and threshold levels, and corresponded to NRT level measurements.

Thai-Van et al. (2004) investigated the efficacy of using the ECAP threshold prediction of threshold and comfortable levels. They concluded that the results suggested that psychophysics had significant influence on threshold levels but not on comfortable levels. Further studies will be needed to improve the ability of NRT to accurately predict T and C levels during device fitting and to determine changes over time.

Scorpecci et al. (2016) found a significant correlation between NRT and behavioural levels in adult patients, and they practically specified C-NRT as more accurate than Auto-NRT in predicting C-levels.

4.1. Limitations

This study was conducted on small group of paediatric children, further studies on larger numbers of children and including adults could give clearer and more accurate results. Also, the use of postoperative NRT could be explored in comparison to intra-operative NRT in the prediction of behavioural levels.

5. Conclusion

NRT values can be used as an additive and a guide in the prediction of the behavioural threshold and comfortable values in cochlear implant programming, in pre-lingually deaf children whose behavioural responses are difficult to interpret.

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Ethical approval

The analysis was approved by the university medical school ethical approval committee.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.joto.2019.06.002.

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