Comparison Between Behavioural-Based Mapping And ESRT-Based Mapping In Cochlear Implantees

Original Article

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ABSTRACT

Introduction and Objectives: Programming of cochlear implant's (CI) map is performed by behavioural testing in most patients. A good map is needed to give access to hearing and speech perception, which enables better speech understanding and development. Programming based on behavioural responses may be difficult in young children because they cannot provide adequate feedback. Objective measures, such as Electrical Stapedius Reflex Threshold (ESRT), have become paramount to predict optimal current levels. This study is designed to compare the results of ESRT-based maps to behaviourally-based maps in terms of audiometric and speech performances for users.

Materials and Methods: The study was a prospective study which was performed on 34 CI users. ESRT was recorded for each electrode for every user. Behavioural-based map was compared with ESRT-based map regarding outcome measures. Aided pure tone average (PTA) and aided speech discrimination scores (SDS) were performed for each user. Both tests were done for each implantee twice, once for each different map used.

Results: Although ESRT-based maps produced satisfactory outcome measures, aided PTA and aided SDS were statistically significantly worse compared with behavioural maps in all the studied group. There was a high statistically significant positive correlation between ESRT and behavioural C-levels at every electrode number. This signifies that ESRT is a statistically significant predictor for behavioural C-levels.

Conclusion: Although ESRT-based mapping produced satisfactory results for most users, behavioural-based mapping is superior regarding outcome measures. ESRT is a particularly good predictor for behavioural C-levels and a reliable mapping alternative in challenging cases.

Key Words: Cochlear implants, ESRT, programming.

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INTRODUCTION

Cochlear implant (CI) is a device that converts sound energy into electrical impulses, thereby partially replacing the functions of the cochlea. It is accepted as the preferred course of treatment for profound and severe sensorineural hearing loss. For each stimulation channel and each user, a different quantity of electric current is required to produce an aural sense. Because of this, each user's speech processor needs to be customized on a per-user basis through a procedure known as programming or mapping.

For many patients, behavioural testing is used to program the map. To improve speech and language development in pre-lingual young CI users as well as speech understanding in post-lingually deafened adults, an accurate map is necessary to allow access to hearing and speech perception with the implant. Map parameters may occasionally be overestimated or underestimated because of the behavioural measurements of map levels[1].

The list of patients who can benefit from cochlear implantation has grown to include very young children as well as people with syndromes or multiple disabilities. For audiologists, programming the implant based on behavioural reactions can be a tedious and challenging task in these situations since they are unable to provide sufficient feedback. The importance of objective measurements, like the Electrical Stapedius Reflex Threshold (ESRT), in predicting ideal current levels has grown[3].

The most comfortable levels (C levels or MCLs) among individuals using continuous electrical stimulation (CI) have been positively correlated with the ESRT, which is defined as the lowest level of electrical stimulation which leads to a contraction of the stapedius muscle[4-6].

ESRT is readily obtained in the clinic using standard instruments for immittance measurement, or intraoperatively through direct observation or immittance measurements. It is also recordable in numerous patients[7].

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When it comes to electrophysiological measurements that can aid in mapping, ESRT has demonstrated great promise. It usually elicits at an extremely high degree of stimulation, considerably closer to levels of behavioural stimulation. It is arousal-insensitive and needs minimal cooperation, which is beneficial when working with groups that are challenging to communicate with[8].

This study is designed to compare the results of ESRT-based maps to behaviourally-based maps in terms of audiometric and speech performances for users. Additionally, it is designed to explore the possibility of establishing ESRT-based maps as a tool for appropriate mapping in cases where a behavioural-based map is difficult to obtain.

MATERIAL AND METHODS

Subjects

This study was conducted on 34 recipients of unilateral cochlear implants who regularly attend the Audio-Vestibular Medicine unit, Otorhinolaryngology Department, Alexandria Main University Hospital during the study period. Their age ranged from 7 to 62 years. 28 were prelingual and 6 were post-lingual. The study included 28 MED-EL users, 3 Advanced Bionics users and 3 Cochlear users. All subjects were cochlear implantees (At least 6 months post-operatively, after initial mapping) with normal middle ear pressure and compliance (type "A" tympanogram). Their aided PTA thresholds were 40 dB or better across frequencies 250 Hz up to 4K Hz with the CI. Ten extra participants were excluded for several reasons including abnormal middle ear function, inability to detect ESRT across some/all electrodes and inconsistent behavioural responses.

Methods

An informed consent was obtained from all participants. All patients were subjected to a complete history taking to identify the cause of hearing loss, age and duration of implantation, duration of CI usage, and risk factors for hearing loss. Middle ear function was assessed by otoscopic examination and then tympanometry using Clarinet-Inventis (clinical middle ear analyzer manufactured by Inventis, Italy) to exclude problems that may affect outcome measures.

Each subject used their device coupled to the diagnostic programming system through the dual processor interface. The subject's own processor was used. C and T levels were behaviorally determined. Adults and cooperative children should be able to provide good subjective responses. The lowest level at which the participant responded reliably indicated T levels. Levels were increased gradually until the patient determined that the sound was loud, but comfortable (C level).

Measurements of ESRT were made in the reflex decay mode of the impedancemetry device (Clarinet-Inventis, clinical middle ear analyzer). The compliance changes were monitored in the contralateral ear using the sound probe. Subjects were seated on a chair and were encouraged to stay still and keep quiet during the ESRT recording.

A 226 Hz probe tone was used. The signal was presented through the CI. The sound probe was placed to the side of the head by being fitted inside the contralateral ear. Biphasic electric pulses used in programming procedures were presented through the speech processor at levels beginning at the behavioural C levels for the stimulated electrode by using the keyboard. Default recording stimulus parameters including pulse rate, burst length, and pulse duration were set to the standard of the CI device suggested by each company. Maestro software (Version 9.0.3) was used for MED-EL users, Custom Sound Pro (Version 7.0) for Cochlear users, and Sound Wave (Version 3.2.12) for Advanced Bionics users.

Stimulus levels were raised systematically by 5 qu, recording the response if present, until the uncomfortable level (UCL) reported by users was reached. The recording window was set to the default of the impedancemetry device which is 10 seconds. The ESRT was taken as the lowest stimulus level that produced a definite, repeatable deflection in the baseline recording of at least 0.05 ml synchronous with the stimulus presentation. ESRT was considered 'absent' when current levels exceeding the participant's tolerance failed to produce changes in admittance that are time-locked with the stimulus. This was done across all active electrodes. All inactive, extra-cochlear, short circuit or no auditory percept electrodes were excluded from the recording.

An ESRT-based map was set according to the ESRT thresholds obtained. An objective program was generated by setting MCLs at ESRT levels and by setting threshold levels at 10% of MCL in MED-EL and Advanced Bionics users. Cochlear users T-levels were set similarly as the behavioural T-levels. Electrodes with ESRTs that could not be obtained or elicited pain at any level had their MCLs extrapolated from adjacent electrode MCLs. Users who found the set 10% T-level uncomfortable or painful had their T-levels assigned as the closest value to the set 10% without eliciting pain. The equation used to change ESRT values from current unit (cu) to charge unit (qu) to unify the procedure was: qu = (cu x pulse width)/1000[6].

An aided audiometric test was done to determine the implantee's hearing thresholds using the CI. Free field warble tone thresholds were obtained with both maps at frequencies 250 Hz up to 4000 Hz with a pure tone average calculated for each map using the average response from 500Hz up to 4000Hz. These pure tones were generated by an AD629 audiometer (manufactured by Interacoustics, Denmark) that was calibrated to accepted standards (ANSI 1969).

Thresholds were obtained in 5-dB increments by routine clinical modified method of limits where the subjects were asked to raise their hand to indicate a response. Thresholds were set as the lowest sound intensity that elicited a response at least 50% of the time. Thresholds were obtained just after initiation of the map.

The speech discrimination test of Arabic mono-syllabic phonetically balanced words was done for each implantee with their CI according to their age. Stimuli were presented at conversational level in the free field through the loudspeaker (around 30-40 dBSL). Phonetically balanced word discrimination lists were used for users aged 18 or older and phonetically balanced kindergarten word lists (PBKG) for users chronologically less than 18 years old. Each list consisted of 25 mono-syllabic words. Scores were provided for the number of correctly identified words, expressed as percentage scores.

Subjects were seated in a soundproof room one meter away from a loudspeaker situated in the 0-degree azimuth for both tests. Both tests were done for each implantee twice, once for each different map used.

RESULTS

This study was a prospective study which included 34 recipients of unilateral cochlear implants who regularly attended the Audio-Vestibular Medicine Unit, Otorhinolaryngology Department, Alexandria Main University Hospital during the study period.

The subjects' age ranged from 7.42–62.67 years with a mean of 18.01±10.68 years and a median of 16.71 years. There were 21 males and 13 females. There were 23 subjects aged from 7-18 years and 11 subjects aged 18+ years.

Aided Pure Tone Average (PTA)

(Table 1) shows the comparison between aided PTA with both the behavioural-based maps and the ESRT-based maps in users across the study group.

Aided PTA of ESRT-based maps was statistically significantly higher compared with aided PTA of behavioural maps in all studied group (p=.002).

There was no statistically significant difference between aided PTA of ESRT-based maps compared with aided PTA of behavioural maps in the 7-18 years age group (p=.0.73).

Aided PTA of ESRT-based maps was statistically significantly higher compared with aided PTA of behavioural maps in the 18+ years age group (p=.003) as shown in Figure.(1).

Table (1): Aided PTA across age groups:

Aided PTA	All patients (n=34)	Age groups (7-18 years) (n=23) (67.65%)	(18+ years) (n=11) (32.35%)
Aided PTA Behavioural-based			
- Min – Max	17.50 – 38.75	17.50 – 38.75	17.50 – 38.75
- Mean ± Std. Deviation	30.74 ± 5.97	30.76 ± 5.93	30.68 ± 6.33
- SEM	1.02	1.24	1.91
- Median	31.88	32.50	31.25
- 25th Percentile – 75th Percentile	27.50 – 35.00	26.25 – 36.25	28.75 – 35.00
Aided PTA ESRT-based			
- Min – Max	20.00 – 45.00	20.00 – 45.00	21.25 – 42.50
- Mean ± Std. Deviation	32.76 ± 6.15	32.28 ± 6.01	33.75 ± 6.61
- SEM	1.06	1.25	1.99
- Median	33.75	32.50	36.25
25th Percentile – 75th Percentile	28.75 – 37.50	27.50 – 36.25	28.75 – 37.50
Test of Significance *p-value*	$t_{(df=33)}$=3.322 p=.002*	$t_{(df=22)}$=1.881 p=.073 NS	$t_{(df=10)}$=3.938 p=.003*

n: Number of patients; Min-Max: Minimum – Maximum; SEM: Standard Error of Mean; df=degree of freedom; t: Paired Samples Test *Statistically significant (p<.05)

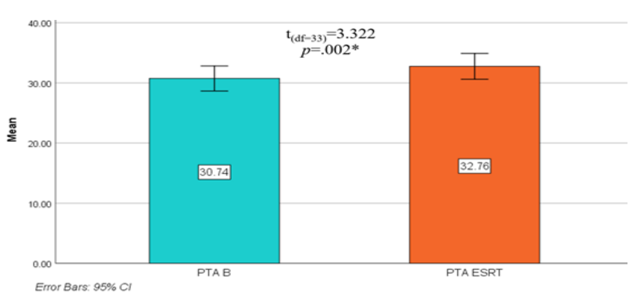

Fig. 1: Simple Bar of Mean of behaviourally-based aided PTA and ESRT-based aided PTA Index (± 95% CI) in all studied patients (n=34).

Aided Speech Discrimination Scores (SDS)

Table (2) shows the comparison between aided SDS with both the behavioural-based maps and the ESRT-based maps in users across the study group.\

Aided SDS in behaviourally-based maps were statistically significantly higher compared with aided SDS in ESRT-based maps in all studied groups and in both age groups individually as shown in Figure (2).

From the previous graph we deducted that Electrical Stapedial Reflex Threshold is a statistically significant predictor for C-level (t=42.134, p<.001).

Equation for prediction

C Level = 3.479+0.936x (Electrical Stapedial Reflex Threshold) ± e

e: Minimum to maximum = -17.77 to 21.600

Mean ± SD (0.000 ± 5.600)

Standardized Residual:

Minimum to maximum = -3.168 to 3.849

Mean ± SD (0.000 ± 0.999)

e: Residual error

Table (2): Comparison of the aided SDS in the studied groups:

Aided SDS	All patients (n=34)	Age groups (7-18 years) (n=23) (67.65%)	Age groups (18+ years) (n=11) (32.35%)
Aided SDS Behavioural-based			
- Min – Max	32.00 – 88.00	32.00 – 88.00	64.00 – 84.00
- Mean ± Std. Deviation	67.41 ± 13.40	65.04 ± 15.27	72.36 ± 6.31
- SEM	2.30	3.18	1.90
- Median	72.00	68.00	72.00
- 25th Percentile – 75th Percentile	64.00 – 76.00	52.00 – 76.00	68.00 – 76.00
Aided SDS ESRT-based			
- Min – Max	28.00 – 80.00	28.00 – 80.00	56.00 – 80.00
- Mean ± Std. Deviation	63.41 ± 13.25	61.04 ± 14.83	68.36 ± 7.47
- SEM	2.27	3.09	2.25
- Median	66.00	64.00	68.00
25th Percentile – 75th Percentile	60.00 – 72.00	52.00 – 72.00	64.00 – 76.00
Test of Significance	$t_{(df=33)}$=5.745	$t_{(df=22)}$=4.796	$t_{(df=10)}$=3.028
p-value	p<.001*	p<.001*	p=.013*

n: Number of patients; Min-Max: Minimum – Maximum; SEM: Standard Error of Mean; df=degree of freedom; t: Paired Samples Test, *Statistically significant (p<.05)

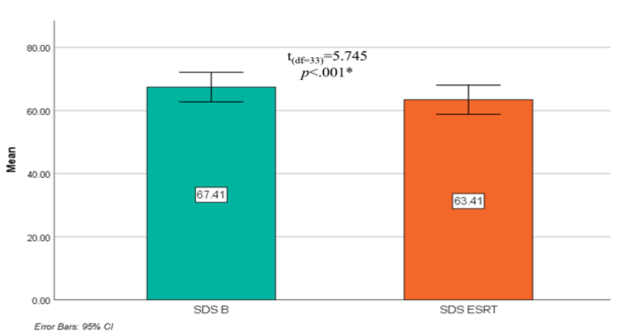

Fig. 2: Simple Bar of Mean of behaviourally-based aided SDS and ESRT-based aided SDS Index (± 95% CI) in all the studied patient group (n=34).

Correlation between ESRT and behavioural C-levels

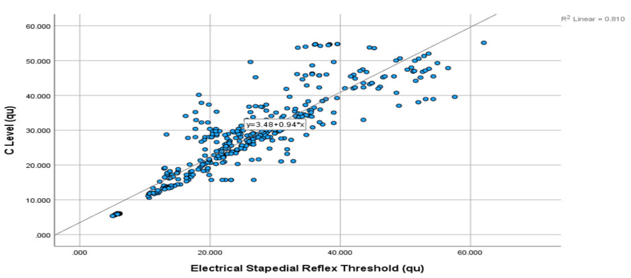

Fig. 3: Showing a statistically significant (accepted) regression model for Electrical Stapedial Reflex Threshold to predict C-level (F=1775.236, p<001). In the 419 paired observation, 81% of the variation in the data can be explained the regression model (R^2 = 0.810). There is a very high statistically significant positive correlation between Electrical Stapedial Reflex Threshold and C-level (r=0.900, p<.001).

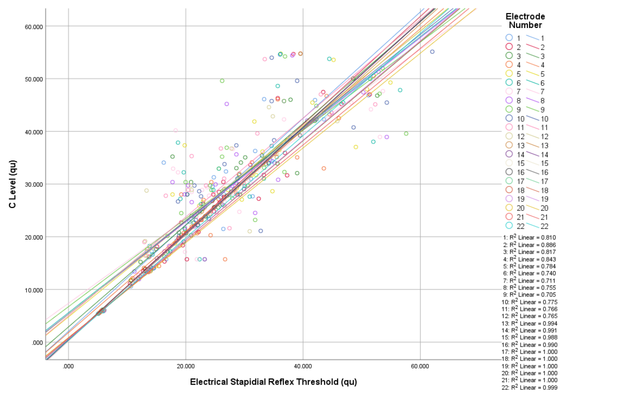

Fig. 4: Showing an exceedingly high statistically significant positive correlation between Electrical Stapedial Reflex Threshold and *C*-level (r=0.900, p<.001) at every electrode number.

From the previous graph we deducted that Electrical Stapedial Reflex Threshold is a statistically significant predictor for C-level (t=42.134, p<.001).

Equation for prediction:

C Level=3.479+0.936 x (Electrical Stapedial Reflex Threshold) ± e

e: Minimum to maximum =-17.77 to 21.600

Mean±SD (0.000±5.600)

Standardized Residual:

Minimum to maximum =-3.168 to 3.849

Mean ± SD (0.000±0.999)

e:

Residual error

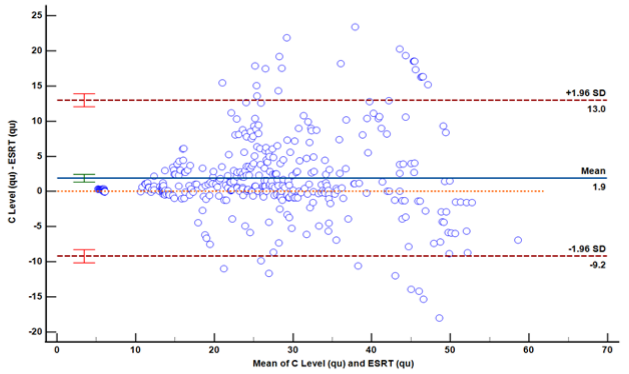

Fig. 5: Bland-Altman graph showing the relationship between the mean values of ESRT and *C*-levels against the difference between them and calculating the mean of their differences (Bias). The mean difference between *C*-levels and ESRTs is 1.9 *qu*. ESRT levels on average are lower than *C*-levels by 1.9 *qu*.

In the present study, it was deduced that there was a very high statistically significant positive correlation between ESRT and C-levels (r=0.900, p<.001) which signifies that ESRT is a statistically significant predictor for C-levels. There was also a significant correlation between ESRT and *C*-levels at each electrode number (Figures 4 and 5). Bias analysis in the present study confirms what was mentioned earlier, that ESRT values were on average lower than behavioural *C*-levels. Analysis also showed that most data points were scattered closely around the mean without any specific trend. This indicates that both methods give consistent readings that are quite close to each other (Figure 5). Having a constant to predict *C*-levels from through ESRT values is crucial for many challenging cases where behavioural mapping can be difficult to obtain.

DISCUSSION

Outcome measures in cochlear implantees usually depend on their map parameters. The generated map is based on behaviourally-determined threshold and comfort levels obtained for every active electrode. Obtaining an accurate behavioural response from younger children can be challenging for many physicians. Therefore, an objective measure for obtaining comfort levels such as ESRT would be of massive help and improve the reliability of mapping in younger children[9-11].

This study was designed to compare behavioural-based maps and ESRT-based maps regarding outcome measures to determine if ESRT can be used as a reliable objective method of mapping in challenging cases.

ESRT is measured by electrical stimulation through the CI device, and it was reported to be elicited across all CI manufacturers[2]. In this study, most cases used MED-EL cochlear implants. However, around 20% of cases used cochlear implants from the other two manufacturers (Cochlear and Advanced Bionics).

The first point to discuss regarding ESRT is whether if it can be consistently obtained in most of the cochlear implantees. This is important for determining the reliability and validity of the test. The reported occurrence rates of ESRT varies from 77% up to 83%.[11, 12]

In this study, a total of 34 cochlear implant users were tested. All 34 tested participants had ESRT elicited across all electrodes. Five more participants were initially excluded because ESRT could not be elicited across all electrodes despite normal middle ear function. This constitutes an ESRT occurrence percentage of 87% in normal middle ears (34 out of 39 cases).

Measuring ESRTs can be challenging, particularly in young children. During the ESRT measurements at each electrode recording, they ought to remain silent and cooperative. Talking, excessive swallowing, and moving your head too much could also interfere with the measurement. As stated before, the ESRT cannot be elicited unless the patient has a healthy middle ear. For many CI users, the inability to record an ESRT in middle ears that are typically functioning has no known cause[13,14].

Pitt *et al* reported that ESRTs remain consistent for individual subjects over time with the user's implant experience being the only variable correlated with ESRT stability[15].

Subsequently, with an occurrence rate of more than 85% and consistent stability over time, ESRT is considered a reliable and stable test.

Each participant had two maps evaluated. The initial map is based on their behavioural responses where the C-level is set as their behavioural most comfortable level in each electrode. The other map based on their ESRT recorded in each electrode with the C-level set as the value of the ESRT elicited in each electrode. Aided PTA and aided SDS were compared for both maps for each participant.

In the present study, aided PTA of ESRT-based maps was statistically significantly worse compared with aided PTA of behavioural maps in the whole of the studied group. This could be attributed to (Figure 5) where it shows that ESRT values were lower than C-level values across all electrodes by an average of 1.9 *qu*. Also, behavioural-based mapping is more individualized to each user so it's more likely to be more comfortable for them[2].

Another reason may be the familiarity of the behavioural-based map to the users in contrast to the ESRT-based map in which they do not have the time to get familiar with. This is one of the limitations of this present study, as users did not have enough time to familiarize themselves to the new map parameters of the ESRT-based map.

There was no statistically significant difference between aided PTA of ESRT-based maps compared with aided PTA of behavioural maps in the 7-18 years age group (p=.0.73) while it was statistically significantly higher compared with aided PTA of behavioural maps in the 18+ years age group (p=.003) (Table 1).

A plausible explanation for these findings could be that adults tend to provide more precise behavioural thresholds than children do because they are more sensitive to changes in sound, so even slight changes in map parameters can cause significant variances in responses.

As per McGregor *et al*., younger children who receive CIs typically experience better outcomes in speech and language development because the auditory cortex has the highest neural plasticity at birth, which gradually declines with age[16].

These findings agree with the results of our present study as age group 7-18 who had an average age of implantation of 4.53 years produced better aided PTA results with ESRT-based maps compared to 18+ age group.

Aided SDS in behaviourally-based maps were statistically significantly better compared with aided SDS in ESRT-based maps in the whole studied group and in both age groups in the present study (Table 2).

These findings could be attributed to the same reasons as the aided PTA results regarding map familiarity, individualized programs and lower ESRT values compared to behavioural C-level values.

The present study results agree with Çiprut *et al.,* where behavioural maps produced better speech results than ESRT-based maps[2]. Significant declines in speech comprehension tests have also been noticed by Wasowski *et al*., even with small adjustments to electrical stimulation intensities[17].

According to study results by Hodges *et al*., adult CI users' speech perception performance was the same whether they were tested using behaviourally based or ESRT-based maps[14] In the same context, Yiannos *et al* found no statistically significant difference between speech recognition in quiet with ESRT-based maps and speech recognition in quiet with behaviourally-based maps[8].

Spivak *et al* tested performance on open set tests of speech recognition with behavioural-based maps compared with ESRT-based maps for each user. Mean data suggest that speech perception was similar with both maps[18].

The similar outcomes between both maps in these studies may be attributed to behavioural C-level values and ESRT values being typically close together, although ESRTs can be either over- or under-estimated for some CI users regardless of their age or duration of implantation according to Spivak *et al*[19].

Some of the variability in outcome measures could likely be caused by different methodological approaches in ESRT recording[20]. These previous results solidify ESRT as an objective and reliable method for mapping.

Another objective of this study was to analyze the relationship between ESRT and C-levels to determine if C-levels can be successfully estimated from ESRT levels obtained.

In the present study, it was deduced that there was a remarkably high statistically significant positive correlation between ESRT and C-levels which signifies that ESRT is a statistically significant predictor for C-levels. There was also a significant correlation between ESRT and C-levels at each electrode number (Figures 3 and 4).

These results were in agreement with Spivak *et al.,* who stated that there was a fairly good agreement between ESRT and C-levels across the electrode array[19]. According to Stephan and Muller, there was a strong overall connection (r=0.92) between ESRT and C-levels. Consequently, ESRT can be effectively used for the CI processor's mapping procedure[13].

Perez-Rodriguez *et al.,* found similar MCL thresholds in both ESRT and behavioural testing in 20 pediatric patients with post-lingual deafness and unilateral CIs, establishing that both methods are reliable for use in pediatric patients[21].

In a study by Bresnihan *et al.,* on 26 children who had their ESRT and behavioural *C*-levels measures. It was deducted that the ESRT levels were consistently lower than *C*-levels obtained with behavioural techniques. However, children using programs set with ESRT wore their implants longer and had fewer episodes of discomfort to environmental sounds[11].

In a different study, Lorens *et al*., examined the most comfortable levels (MCL) of seven children, as determined by either ESRT or behavioral assessment. The parents reported that there was little variation between the programs and that there was a strong link between the MCLs[22].

Another study by Asal *et al*., on 26 pre-lingual CI users showed a positive correlation between ESRT and C levels across all electrodes. It was suggested that ESRT values can predict behavioural C levels in CI patients accurately[6]. Hodges *et al.,* compared ESRT levels with C-levels in each electrode in 25 post-lingual CI users. The analysis data resulted in an r value of 0.91 which shows a positive correlation[14].

Stephan *et al* found that the ESRT value was in the upper part of the dynamic range between the most comfortable loudness (MCL) and the uncomfortable loudness level[23]. In a study by Buckler *et al*, they compared ESRT levels to C-levels in six adults and two children. They found that ESRT levels were very close to C-levels in adults while they were above C-levels in children[24].

Bergeron and Hotton compared ESRTs and C-levels at 2 weeks and at 1-year post-fitting in a group of 11 adults. They found a linear relation between ESRTs and C-levels at both 2 weeks and 1-year post-fitting[25].

From the previous studies discussed in addition to the current study results, we can assume that behavioural-based mapping is the go-to method in conventional CI Q3 mapping when available. Behavioural-based mapping usually produces better outcome measures as it is more individualized for each user. However, ESRT-based mapping is a reliable and a stable alternative as it also produces satisfying results. Specifically, ESRT-based mapping could be a particularly useful mapping method in challenging cases who cannot give behavioural responses accurately.

There is also a very strong positive correlation between ESRT values and behavioural C-level values in the current study which makes ESRT a good predictor for behavioural C-levels using an equation with a constant value obtained.

CONCLUSION

Although ESRT-based mapping produced satisfactory results for most users, behavioural-based mapping is superior to ESRT-based mapping regarding outcome measures. There is a significant correlation between ESRT values and behavioural C-level values which makes ESRT an incredibly good predictor for behavioural C-levels and a reliable mapping alternative in challenging cases.

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