Electrically Evoked Stapedial Reflex Threshold levels: Relationship with behavioural 'T' and 'C' levels in Cochlear Implants users

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<u>CERTIFICATE</u>

This is to certify that this dissertation entitled ***"Electrically evoked stapedial reflex threshold levels: Relationship with behavioural 'T' and 'C' levels in Cochlear Implants users"*** is the bonafide work submitted in part fulfilment for the degree of Master of Science (Audiology) of the student (Registration No. 09AUD008). This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other university for the award of any other Diploma or Degree.

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CERTIFICATE

This is to certify that the dissertation entitled ***"Electrically evoked stapedial reflex threshold levels: Relationship with behavioural 'T' and 'C' levels in Cochlear Implants users"*** has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier in any other university for the award of any Diploma or Degree.

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DECLARATION

This dissertation entitled ***"Electrically evoked stapedial reflex threshold levels: Relationship with behavioural 'T' and 'C' levels in Cochlear Implants users"*** is the result of my own study under the guidance of Prof Asha Yathiraj., Professor, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier at any other University for the award of any Diploma or Degree.

Mysore,

May, 2011. Register No: 09AUD008

"DEDICATED TO
AMMA, APPA
AND ANU"

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CHAPTER 1

INTRODUCTION

Improvement in cochlear implant (CI) technology is reported to have resulted in significant increase in user benefit. It has been found that children who are born with severe-to-profound hearing loss and receive cochlear implantation at an early age can develop speech and language skills that commensurate with their hearing peers (Yoshinaga-Itano, Sedey, Coulter, & Mehl, 1998).

Effective programming is considered necessary for maximum benefit from the cochlear implants (Jerger, Jenkins, Fifer, & Mecklenburg, 1986). Bresnihan, Norman, Scott and Viani (2001) reported that cochlear implants require programming on an individual basis to provide appropriate levels of electrical stimulation. They also reported that programming multichannel cochlear implant required the client's active participation in order to make a series of judgments regarding perception of stimuli being presented through the implant. Success of implantation was considered dependent on the adequacy of the map. The authors reported that the map could be generated by means of an electrical dynamic range for each active electrode. This range was established by ascertaining a threshold ('T') level, which served as the lower limit, and a comfort ('C') level, which formed the upper limit of electrical stimulation.

Most adult cochlear implant users are reported to perform the psychophysical tasks required to obtain the 'T' and 'C' levels with good reliability and repeatability (Spivak, Chute, Popp, & Parsier, 1994). Balkany et al. (2002) found that obtaining 'C' levels from children was extremely difficult, although most of them could be conditioned to provide reliable 'T' levels. Setting the 'T' level required the child to respond to the presence or absence of a sound. Although the same technique was used in setting the 'C' level, the child was required to make a judgment about the sound beyond its simple presence or absence. Moreover, the concept of 'most comfortable level' has been found to be often beyond young children's capabilities, even among the typically hearing population (Bresnihan et al., 2001). The use of objective measures has been reported to enable clinicians to determine optimal parameters (Jerger et al., 1986).

Objective measures of the auditory system's response to electrical stimulation were speculated to facilitate the speech processor fitting. Several objective measures have been investigated to serve this purpose. These include electrically evoked stapedius muscle reflex (eSR) (Jerger et al., 1986; Battmer, Laszig, & Lehnhardt, 1990; Spivak & Chute, 1994), electrically evoked compound action potential *(ECAP)* (Abbas & Brown, 1991) and electrically evoked auditory brain stem response *(EABR)* (Shallop, Beiter, Goin, & Mischke, 1991).

Brown, Abbas and Gantz (1990) found eSRT and ECAP useful in programming cochlear implants. The *eSRT* was defined as the minimal amount of electrical stimulation that elicits a measurable contraction of the stapedius muscle in the middle ear (Jerger, Oliver, & Chmiel, 1988). As early as 1986, clinical researchers established that electrical stimulation of the auditory system could result in measurable contraction of the stapedius muscle in the manner similar to the measurement of the acoustic stapedial reflex (Jerger et al., 1986; Jerger et al., 1988). Raine, Ajayi, Cruikshank, Khan, and Beesley (1997, as cited in Lorens, Walkowaik, Piotrowska, Skarzynski, & Anderson, 2004) noted that the eSRT could be recorded both intra-operatively and post-operatively. Intra-operative eSRT was generally recorded via visual detection of the stapedial contraction by the surgeon. The post-operative eSRT was recorded using an immittance meter in the contralateral ear (non-implanted) in response to electrical stimulation through the implant. The change in the compliance was measured and recorded.

The stapedial reflex, whether measured acoustically or electrically, is considered to be a neuromuscular reflex mediated through the brainstem. It was found that a stimulus led to the stapedius muscle contraction which resulted in increase in stiffness of the ossicular chain and reduced the compliance of the middle ear system. The change in compliance measured and recorded using an immittance meter, as a consequence of acoustic or electrically evoked stapedial reflexes were reported to be essentially identical physiologically and anatomically. Both were noted to have a threshold and demonstrated amplitude growth to a point of saturation (Hodges, Butts, & King, 2005).

ECAP, which records the compound action potential at the origin of the cochlear nerve through the implant system, has been incorporated in most implant systems. It is considered as a gross electrical potential that reflects the synchronous firing of a large number of electrically stimulated auditory nerve fibers (Abbas & Brown, 1991). It is been reported that *ECAP* is not clearly recordable in all cases, but has been found to correlate moderately well with the 'C' levels (Smoorenburg, Willeboer, & van Dijk, 2002).

EABR is another objective method which is reported to be robust but its recording is time consuming (Mason et al., 1996). EABR consists of a series of vertex positive peaks occurring within the first 6–8 ms following the electrical stimulation of the auditory nerve (Abbas & Brown, 1991). It's been reported that EABR is susceptible to contamination by both electrical noise and muscle artifact and requires a sedated subject and careful control of the electrical environment (Gordon, Papsin, & Harrison, 2004).

Need for the study

Research has shown that provision of appropriate levels of stimulation results in better outcomes in cochlear implant users (Moog & Geers, 2003). Some cochlear implant users such as infants, young children and persons with cognitive disabilities may not be able to make reliable loudness judgements necessary to determine the amount of electrical stimulation that is deemed to be most comfortable. As the age at implantation becomes increasingly younger, it has become more important to use objective methods for programming cochlear implants in very young children who cannot provide reliable behavioural responses.

Several studies have indicated that the electrically evoked stapedial reflex threshold correlates with the behaviourally obtained 'C' levels (Jerger et al., 1986; Spivak & Chute, 1994; Hodges et al., 1997). These findings suggest the usefulness of the eSRT as an objective predictor of 'C' levels in individuals who fail to give consistent behavioural responses. There is also evidence that fitting programs derived from eSRT measures can provide comparable benefit levels to those obtained by behavioural testing in cochlear implant systems. However, Stephan and Mueller (2000) found a poor correlation between the eSRT and 'C' levels.

The main advantage of eSRT over other objective measures is that they can be recorded quickly (Bresnihan et al., 2001). Also, fitting the program derived from eSRT measures is noted to provide comparable benefit to those obtained by behavioural testing

(Bresnihan et al., 2001). eSRT is found to be unaffected by electrical artifact unlike *ECAP* (Hodges et al., 1997). Also, eSRT recordings have been studied over years and several studies have reported that it correlates with the 'C' level (Jerger et al., 1988; Spivak & Chute, 1994; Hodges et al., 1997).

Fu and Shannon (2000) have demonstrated the consequences of setting up incorrect 'T' and 'C' levels on phoneme recognition in cochlear implant users. They showed that reduced electric dynamic range had a significant effect on vowel and consonant perception leading to deterioration in the performance. Hence, it is important to set correct 'T' and 'C' levels. Therefore, it is necessary to confirm the utility of eSRT in programming cochlear implants.

From the above information, it can be seen that both objective and behavioural measures play an important role in the programming of cochlear implants. However, in young children, behavioural methods alone may not offer reliable responses to provide optimal programming. eSRT is one such objective measure that provides valuable data for cochlear implant programming since it can be recorded in relatively less time. Hence, it is essential to investigate the relationship between eSRT levels and 'T' and 'C' levels so that it can aid in cochlear implant programming.

Aim of the study

The study aimed to investigate the relationship between electrically evoked stapedial reflex threshold (eSRT) and behaviourally set 'T' levels and 'C' levels in individuals using cochlear implants.

CHAPTER 2

REVIEW OF LITERATURE

Conventional programming of cochlear implants has been performed using a subjective estimation of the 'T' level and the 'C' level for the electrodes by applying short pulse trains. The 'T' and 'C' levels are determined using a psychophysical method similar to threshold and loudness discomfort level procedures in acoustic hearing. In some recipients, adults as well as children, these behavioural measurements have been found to be difficult to perform and time-consuming. In toddlers and infants it has been noted to be difficult to get reliable responses within a restricted time. Attempts have been made to reduce the time required for fitting by determining 'T' and 'C' levels for a limited number of electrodes and setting these levels for the other electrodes by interpolation. However, as it would theoretically be best to try each combination of clinical parameters to optimize speech perception with the cochlear implant, the ideal fitting procedure has been found to be time-consuming (Gordon, Papsin & Harrison, 2004)

Setting the minimal and maximal current levels/current units in cochlear implants varies across manufacturers. For Nucleus Cochlear implants, the 'T' level has been defined as the level at which the patient identifies the softest sound sensations 100% of the time. It is considered as the lowest level at which the patient hears the stimulus every time it is presented. The 'C' level sets the maximum allowable stimulation level for each electrode. It has been defined as the maximum stimulation level that does not produce an uncomfortable loudness sensation for the patient. The 'C' level is recommended to be set by increasing the current from the 'T' level until the individual indicates that the stimulus is loud but comfortable. These values have been noted to vary across electrodes as well as among patients (Allum, Greisiger & Probst, 2002)

For Med-El cochlear implants, the threshold level is denoted by ‘T’ level and comfort level is denoted by ‘MCL’ level. According to Brickley and Boyd (2000, as cited in Craddock, 2003) ‘MCL’ is defined as the highest stimulus level at which sound is loud but still comfortable. Spahr and Dorman (2005) recommended the automatic setting of the ‘T’ levels at 10 % of the MCL for several reasons including reduced audibility of low level noise, programming time and enhanced peak to valley ratio for formant perception. Also, they reported that the level of speech understanding obtained in the behavioural threshold condition did not differ significantly from that obtained in 10 % of the ‘MCL’ condition. Hence, they opined that setting programs based on ‘MCL’ could be time saving.

For Advance Bionic Corporation cochlear implants, threshold is denoted by ‘T’ level and comfort level is denoted by ‘M’ level. Adjustments of the volume control are allowed to exceed ‘M’ level to a value determined by the clinician (cited in Craddock, 2003).

Benefits of Accurate Measurement of ‘T’ and ‘C’ levels

Jerger et al. (1986) reported that the ‘C’ and the ‘T’ levels are set by means of behavioural methods. They found that for children, setting the level of minimal stimulation, the ‘T’ level, is usually successfully achieved by standard paediatric audiology techniques. These include operant conditioning tasks, conditioned play audiometry, and visual reinforcement audiometry. However, obtaining 'C' levels was found to be extremely difficult in the paediatric population (Balkany et al., 2002). Lack of auditory experience in very young children, together with limited language abilities, has been found to make the task of setting 'T' and 'C' levels a long term, ongoing process. Overstimulation or understimulation could occur leading to lack of appropriate progress (Bresnihan, Norman, Scott & Viani, 2001).

In order to overcome the difficulties faced with behaviourally setting 'T' and 'C' levels, objective procedures have been advocated (Bresnihan et al., 2001). The following section describes and highlights the importance of objective measures of programming cochlear implants.

Objective Measures for Cochlear Implant Programming

The use of objective measures for cochlear implant programming has received intensive study over the past few years. Over the course of the last two decades, a significant body of research has been published that describes the role of objective measures in the management of patients with cochlear implants (Jerger et al., 1986; Battmer, Laszig, & Lehnhardt, 1990; Abbas & Brown, 1991; Spivak & Chute, 1994). A range of objective methods to be used in individuals using cochlear implants have been reported. These include electrically evoked stapedial reflex thresholds (Jerger et al., 1986; Battmer et al., 1990; Spivak & Chute, 1994), electrically evoked compound action potential (Brown, Abbas, & Gantz, 1990), electrically evoked brainstem response (van den Honert & Stypulkowski, 1986; Abbas & Brown, 1991), electrically evoked middle latency response (Kileny & Kemink, 1987; Shallop, Beiter, Goin, & Mischke, 1990), electrically evoked mismatch negativity potential (Kraus et al., 1993; Ponton & Don, 1995; Kileny, Boerst, & Zwolan, 1997), as well as electrically evoked versions of long latency potentials (Kaga, Kodera, Hirota, & Tsuzuku, 1991; Micco et al., 1995; Kileny, Boerst, & Zwolan, 1997). There have also been a number of studies that describe potential applications for electrically evoked stapedial reflex threshold in cochlear implant recipients (Battmer et al., 1990; Stephan, Welzl-Muller, & Stiglbrunner, 1991; Spivak & Chute, 1994; Hodges et al., 1997, 2003). All these electrically evoked responses have been noted to have characteristics that are very similar to their acoustically evoked counterparts.

Electrically evoked stapedial reflex threshold (eSRT) for cochlear implant programming: Several studies have indicated a strong relationship exists between the eSRT and the comfort levels established on cochlear implant users (Spivak & Chute, 1994; Hodges et al., 1997; Gordon, Papsin, & Harrison, 2004). The use of electrically evoked stapedial reflex thresholds in implanted patients was mooted by Jerger et al. (1986). The authors showed that the stapedius reflex could be elicited by electrical stimulation using a reflex averaging technique. They obtained reflexes by activating one medial, one basal and one apical electrode pair using three different bipolar modes on two adult cochlear implant users. The results showed that currents eliciting reflex thresholds were lower, ipsilateral reflexes were stronger and the reflex was of shorter duration when compared to an ear canal stimulation stapedial reflex threshold of normal hearing individuals.

Similar results were reported with the Vienna device (Stephan et al., 1988, 1990 & 1991). The reflex was detected in 10 out of 12 adult Vienna device users in whom the uncomfortable level (UCL) could be reached and had an intact middle ear functioning. The reflex threshold was found to be located in the upper part of the dynamic range between the most comfortable level (MCL) and the uncomfortable level (UCL). In a follow-up report by Stephan et al. (1991), a good agreement between the reflex threshold and the upper portion of the comfortable listening range was obtained, although the percentage of patients displaying reflexes was much smaller.

eSRT in Adults using Nucleus cochlear implant systems: Jerger et al. (1988), based on a study of 7 experienced Nucleus 22 cochlear implant users in the age range of 25 to 60 years, found eSRT to correspond closely to their preferred listening level. The findings of the study indicated that the reflex growth function could be used as a guideline for programming, particularly in young children.

Similar results were reported by Battmer et al. (1990) on a group of 25 experienced Nucleus 22 implant users, 19 of whom had measurable eSRTs. Reflex thresholds were obtained at levels approximately 70% to 80% of the listener's dynamic range, thus being most closely related to levels of maximum stimulation. They suggested that stapedius reflex evaluation could be used as a useful tool for speech processor fitting.

Van den Borne, Mens, Snik, Spies and Broek (1994) measured stapedius reflex thresholds and evoked auditory brainstem responses (*EABR*) in 7 experienced users of the Nucleus cochlear implant. The stimulus used to record eSRT and *EABR* was biphasic 400 microseconds/phase clicks. There was no stapedius reflex (SR) seen in 3 patients, 2 of whom had a history of middle-ear disorder. *EABR* was observed in only 5 patients.

The average SR threshold was found somewhat more consistently at 66% of the dynamic range between threshold and uncomfortable level, but grossly overestimated the most comfortable level (MCL) in most cases.

Polak, Hodges and Balkany (2005) compared behavioural judgment of ‘C’ levels and ‘T’ levels for Straight and Contour electrode arrays with two objective thresholds, electrically elicited stapedial reflex thresholds (*eSRTs*) and electrically elicited compound action potential thresholds (*ECAP* thresholds), on experienced adult cochlear implant users. The authors also evaluated the predictive value of objective measures for the Straight and Contour electrode arrays, respectively. Thirty experienced adults with Nucleus 24 cochlear implant were included. Half the subjects used the Straight electrode array, and the other half used the Contour electrode array. Subjective ‘C’ levels, ‘T’ levels and eSRTs were successfully identified for each active electrode. *ECAP* thresholds were measured on 5 representative basal, medial, and apical electrodes. The results showed that there were no significant differences between the Straight and Contour electrode array with regard to stimulation requirements between ‘C’ levels, ‘T’ levels, *ECAP* thresholds and eSRTs. They concluded that both eSRTs and *ECAP* thresholds may be used equally for estimation of subjective levels for either straight electrode array or Contour electrode array.

Comparison of responses of pre-lingually and post-lingually deafened adult Nucleus cochlear implant users on two objective measures employed, to predict programming levels was also carried out by Polak, Hodges and Balkany (2005). The two measures compared were eSRT levels and neural response telemetry (NRT). Thirty experienced pre-lingually and post-lingually deafened adults underwent standard behavioural judgements of ‘C’ levels and T’ levels followed by eSRT and NRT measurements. The results showed that maximum stimulation levels estimated by both eSRT and NRT were highly correlated with the ‘C’ levels. Variablilty of NRT results was higher than for eSRT results.

eSRT in Children using Nucleus cochlear implant systems: The relationship between electrically evoked acoustic reflex thresholds (EARTs) and behavioural comfort levels in children and adult cochlear implant users was investigated by Spivak and Chute in 1994. EARTs and behavioural comfort levels were obtained in 35 Nucleus cochlear implant users (19 children and 16 adults). The results showed that EARTs differed from behavioural comfort levels by a mean of 9.6 current levels for children and 19.4 current levels for adults. While EARTs were found to be acceptably close to behavioural comfort levels in eight children and four adults, it significantly overestimated or underestimated comfort levels in the rest. Hence, the authors concluded that EARTs may provide valuable information regarding levels which should not be exceeded while programming cochlear implants.

Hodges, Butts and King (2003) who studied eSRT on 24 children and 24 adults using Nucleus devices, obtained reflexes on 84 % and 67 % of them respectively. They also observed that the relationship between the eSRT levels and the behavioural perception of maximum comfortable listening was very strong, with a strong correlation of 0.76 for the paediatric users and 0.84 for the experienced adults.

Bresnihan et al. (2001) evaluated the use of eSRT to measure comfort levels for children and to compare these results with behavioral measurements, and to report the results of a questionnaire assessing the acceptability and general performance of program before and after adjustment of comfort levels measured with eSRTs. Programming with the eSRT technique was successfully completed in 20 of a sample of 26 children. Comfort levels with the eSRT method were found to be consistently lower than those obtained with behavioural techniques. Children using programs set with eSRT, wore their implants longer and had fewer episodes of discomfort to environmental sounds. They concluded that comfort level estimation by means of eSRT was reliable and hence a valuable programming tool in the paediatric population.

eSRT in Individuals using Med El cochlear implant systems: A moderate correlation (0.48) between eSRT levels and most comfortable levels (MCLs) was reported by Clutton et al. (1998, as cited in Lorens, Walkowaik, Piotrowska, Skarzynski, & Anderson, 2004). They evaluated post-operative eSR thresholds in 12 children using a cochlear implant. Also, the authors opined that the eSRT levels were to be stable over time.

An estimation of maximum comfort loudness levels (MCL) by measurement of electrically evoked stapedius reflex was examined Stephan and Muller (2000) in 6 experienced cochlear implant users using COMBI 40 implant system. The stapedius reflex was tested and loudness scaling was performed simultaneously using an up/down stimulation protocol close to the reflex threshold with automated recording of both the test procedures. The eSRT and loudness scaling were evaluated separately. The overall correlation between eSRT and MCL was found to be high (r= 0.92), with a similar dependence of eSRT and MCL on the channel stimulated. Thus, the authors concluded that when stapedius reflex could be detected post-operatively and the eSRT levels could be applied successfully for the fitting procedure of the speech processor.

Butts et al. (2001, as cited in Hodges, Butts, & King, 2003) reported on the measurement of stapedial reflexes in both adults and paediatric cochlear implant users. Regression analysis confirmed a strong predictive relationship between eSRT and the most comfortable level (MCL) in most of the participants. All the reflex thresholds were obtained below the level of the loudness discomfort.

In order to determine the relationship between eSRT level and MCL, Allum, Greisiger and Probst (2002) studied the electrode-specific relationship between the two measures. This was estimated in 29 Med-EL Combi 40+ and 25 Nucleus CI 24 M patients after first fitting of the speech processor and 2 and 6 months later. They showed that the MCL values were mostly less than the eSRT values. However, the values increased progressively over the first 6 months, reaching 83% and 72% of the eSRT values, on an average, across all electrodes for the Med-El and Nucleus systems respectively. The population variation across electrodes decreased over the 6-month observation period and was least for the apical half of the array, for which the correlation coefficients of regressions between eSRT and MCL were around 0.65 for both systems. The authors indicated that estimates of MCL values from the eSRT could be more accurate for the apical half of the intra-cochlear array and could then be described by an offset value plus an increase of MCL by 0.62 and 0.53 of eSRT for the Med-EL and Nucleus systems, respectively.

The viability of using eSRT to create speech processor programs in children was assessed by Lorens et al. (2004), by investigating the eSRT and MCL correlation. A high correlation between MCLs ($r^2 = 0.789$) was obtained, and there was no significant difference between the programs, with the eSRT program being slightly softer than the behavioural program. Thus, their data suggested the viability of using eSRT programs safely in the paediatric and difficult-to-assess population.

The practical application of eSRT measures was investigated by Brickley et al. (2005) in a group of 22 adult Med- El COMBI 40+ users using standard clinical procedures. They examined the correlation between eSRT and a series of behavioural loudness percepts. Psychophysical measures of threshold, maximum comfort level (MCL) and maximum acceptable loudness (MAL) were recorded. It was found that eSRT was closest to the MCL using 500 ms burst. The results confirmed the ease of measuring eSRT in a clinical setting and that a high level of confidence could be placed on the use of the objective measures for setting processor maps in the absence of behavioural data.

*eSRT in individuals using Advance Bionic Corporation cochlear implant systems***:** A systematic relationship between speech-burst electrically evoked acoustic reflex threshold (EART) levels and HiResolution programming units was demonstrated by Buckler, Dawson and Overstreet (2003, as cited in Wolfe & Kasulis, 2008). The system differed from other systems in that the stimulus used for programming was not an electrical impulse but rather bursts of white noise passed through the same filters and envelope detectors that were employed for the processing of the signals during daily use. They found that the speech burst EARTs are highly correlated with speech burst ‘M’ levels (comfort levels) in participants using HiResolution sound processing.

eSRT have been used to optimize fitting in children along with Neural Response Imaging (NRI). This was studied by Caner, Olgun, Gultekin and Balaban (2007). They measured the compound action potential through NRI and eSRT and psychophysical measurements in 15 children to develop guidelines to optimize HiRes programs in patients implanted with Advanced Bionics CII-Bionic Ear or a HiRes 90K cochlear implant. The results showed that single-channel threshold NRI and eSRT values could be clinically useful for programming cochlear implants in children, although it should be done with caution as they found considerable inter subject variability.

Wolfe and Kasulis (2008) investigated speech recognition performance of 19 post-lingually deafened adults using HiResolution bionic ear system. The participants were programmed using two different methods. While one set of programs were estimated through eSRT, the other was through a conventional method. The results showed that eSRTs could be measured easily in the majority of the subjects. There were close agreements between eSRTs and M levels in the subjects' behaviourally based programs. Programs created using eSRT levels as a guide for setting levels yielded better speech recognition than programs using conventional behavioural measures of M levels. Thus, the data indicated that the individuals could obtain strong benefits from cochlear implants using programs with stimulation levels based on the objective measure.

The review of literature on eSRT as an objective measure to programme cochlear implants reveals that it could be used for setting processor maps in the absence of behavioural data. Several studies have indicated a strong relationship to exist between eSRT levels and ‘C’ levels/MCLs. Hence, maps could be created using eSRT levels which are found to be effective and easier to perform unlike behavioural tasks.

Electrically evoked compound action potentials (ECAP): The compound action potential (CAP) of the auditory nerve is noted as the first action potential to arise after supra-threshold auditory stimulation. It represents the summed response of numerous fibers firing synchronously. The CAP has been reported to be evoked with acoustical or electrical stimuli (as cited in Cullington, 2003). In the latter case, the response has been referred to as *ECAP*. According to Brown, Abbas and Gantz (1990), bidirectional telemetry system allows the recorded *ECAP* to be sent back from the implant to the speech processor, from which it can be analyzed. Using this system, *ECAP* recordings can be performed quickly intra- or post-operatively, without any additional equipment. As the recording electrode is located inside the cochlea, muscle artifacts during *ECAP* recording were found to be smaller than when using surface electrodes. Therefore, measurements could be performed without sedation, even in patients who are lively and making noises themselves.

The first direct recordings of *ECAP* in humans were made in Ineraid cochlear implant users (Brown, Abbas, & Gantz, 1990). With the Ineraid cochlear implant system, all of the implanted electrodes were accessible via the percutaneous plug and were directly connected to the external equipment. The *ECAP* was typically recorded using monopolar (one intracochlear electrode with an external reference) or bipolar (two intracochlear electrodes). An additional intracochlear electrode (reference to one of the extracochlear electrodes) was typically used to record the *ECAP*.

The *ECAP* was found to represent a synchronous response from electrically stimulated auditory nerve fibers, and is considered to be the electrical version of Wave I of the ABR. The *ECAP* is reported to be recorded as a negative peak at about 0.2-0.4 ms following stimulus onset, followed by a much smaller positive peak or plateau occurring at about 0.6-0.8 ms (Brown, Abbas & Gantz, 1998). The amplitude of the *ECAP* was found to be as large as 1-2 mV, which was roughly an order of magnitude larger than the electrically evoked auditory brainstem response (*EABR)* (Abbas & Brown, 1991). The recording of electrically evoked compound action potentials *(ECAP)* of the auditory nerve via bidirectional telemetry using the intra-cochlear electrodes of the cochlear implant is reported to be a well established method.

Alvarez et al. (2010) analyzed how electrically evoked compound action potential *(ECAP)* responses could be used to assess whether electrodes should be activated in the map and to estimate 'C' levels in the Med-El Tempo+ Cochlear Implant Speech Processor. The relationship between *ECAP* responses and the activation of electrodes was analyzed in 21 post-lingually and 28 pre-lingually deafened participants. *ECAP* measurements allowed the 'C' level profile to be predicted with a mean relative error of 6%. This enabled the prediction of the 'C' level of each electrode relative to the average 'C' level of the patient. Hence, the authors suggested that the *ECAP* could be a reliable and useful objective measurement that could assist in the fitting of the Tempo+ cochlear implant speech processor.

Electrically evoked auditory brainstem responses (EABR): The first descriptions of the *EABR* were published in the late seventies and early to mid-1980s

(Starr & Brackmann, 1979; Dobie & Kimm, 1980; van den Honert & Stypulkowski, 1986). *EABR* was noted to consist of a series of vertex positive peaks occurring within the first 6–8 ms. This was found following the electrical stimulation of the auditory nerve, recorded using a 25 μs/phase biphasic current pulse and standard filtering and recording electrode montages.

Several researchers focused on the *EABR* as a tool for fitting the speech processor of cochlear implantee (Shallop et al., 1991; Van den Borne et al., 1994; Micheyl, Truy, & Collet, 1998; Firszt, Rotz, Chamebrs, & Novak, 1999). In general, correlations between behavioural 'T' levels and *EABR* thresholds were highly significant. Further, *EABR* thresholds were obtained at approximately at the 'C' level, although occasionally they extremely exceeded the 'C' levels. A main obstacle in *EABR* recording has been found to be the stimulus artifact, which is large and could obscure the response. Non-auditory potentials, such as facial nerve stimulation and muscle artifact, could also interfere with recording the early latency potentials such as *EABR*. In small children, *EABR* could be obtained with the use of sedation. Abbas and Brown (1991) observed that *EABR* could be used as an appropriate tool in the paediatric applications. However, its small amplitude response was susceptible to contamination by both electrical noise and muscle artifact and as such required a sleeping or sedated subject and careful control of the electrical environment.

Electrically evoked middle and late potentials: The latency and morphologic characteristics of both the electrically evoked middle latency response *(EMLR)* and the long latency electrically evoked auditory responses have been reported by several authors

(Kaga, Kodera, Hirota & Tsuzuki, 1991; Kraus, et al., 1993) to be very similar to their acoustic counterparts. They found that *EMLR* is characterized by a series of slow vertex positive peaks occurring within a time window of 10–50 ms following stimulation. Electrically evoked long latency responses consist of a series of potentials occurring within a time window of approximately 50–300 ms. The *EMLR* is thought to reflect neural activity at the level of the auditory midbrain, and, while there are several different long latency cortical or pre-cortical responses that can be recorded from cochlear implant users. To date, most of the focus recently has been on the electrically evoked N1/P2 complex (Ponton & Eggermont, 2001; Sharma, Dorman, & Spahr, 2002). The possibility of recording mismatched negativity (MMN) responses as well as event-related P300 potential evoked using electrical instead of acoustic stimulation have also been reported (Kraus et al., 1993; Ponton & Don, 1995; Makhdoum, Hinderink, Snik, Groenen, & van den Broeke, 1998). These relatively centrally generated evoked potentials have been noted to have several advantages over *EABR* or *ECAP* (Ponton & Don, 1995; Makhdoum et al., 1998). Since the latency of these responses is found to be long, the problems with stimulus artifact reduction have been found to be not as severe as those typically encountered with *EABR* or *ECAP*. Consequently, recording procedures typically used for acoustic stimulation are noted to be adequate for recording the middle or late response to stimulation through the implant. Additionally, speech or speech-like stimuli rather than single electric pulses can be used. Finally, in some circumstances, the fact that these responses reflect higher-order processing within the auditory system can also be advantageous since they may reflect changes in processing within the central nervous system over time.

From the literature it is clear that objective measures could be used to enable clinicians set optimal map parameters for individuals using cochlear implants. Though electrically evoked stapedial reflexes could be used to set mapping parameters, there is considerable debate regarding the relationship between eSRT levels and comfort levels in individuals with cochlear implants. Also, there is no agreement among various authors in setting 'T' and 'C' levels from the exact eSRT levels. Jerger et al. (1988) found eSRT level to correspond closely to their preferred listening level. However, Battmer et al (1990) obtained reflex thresholds at levels approximately equal to 70% to 80% of the listener's dynamic range. Hence, there is a need to investigate the relationship between eSRT levels and behavioural 'T' and 'C' levels, to evaluate the appropriateness of using it as a programming tool in the paediatric population (often the difficult-to-test population). Keeping in mind the review of literature, the method of the study was designed.

CHAPTER 3

METHOD

The present study was undertaken to investigate the relationship between electrically evoked stapedial reflex threshold (eSRT) levels and behaviourally set threshold levels (‘T’ levels) and comfort levels (‘C’ levels) in individuals using Nucleus cochlear implants.

Participants

A total of eleven cochlear implant users, in the age range of 5 to 16; 6 years, participated in the study. It was ensured that all the individuals had congenital hearing impairment and were users of Nucleus 22/24 cochlear implant for at least three months. In addition, they had full insertion of the electrodes, as reported by the surgeon, along with stable maps. A map was considered stable if the variation between two consecutive maps was not more than 3-4 current levels. Normal middle ear functioning was confirmed with the presence of an ‘A’ type tympanogram. It was ensured that the participants had no other neurological or otological symptoms. Table 1 provides details of the age, number of years the implant was used and the type of the processor used by the participants.

Table 1: *Current age, age of implantation and speech processor used by the participants*

Participant No	Age (in years)	Age of Implantation (in years)	Speech processor
1	14	11	Sprint
2	8	6	Sprint
3	16	10	Freedom
4	10	8	Freedom

5	8	6	Freedom
6	5	3;6	Esprit 3 G
7	11	8	Sprint
8	8	7;6	Freedom
9	11	9	Sprint
10	9	6	Freedom
11	7	6;5	CP810

Test environment

The evaluations were carried out in a quiet room, free from distraction. The test room was ensured to have adequate lighting and comfortable temperature.

Procedure

Prior to measuring eSRT on the participants, the ‘T’ and ‘C’ levels of the previous two maps were noted from files of the clients. This was done to confirm the presence of stable maps. The ‘T’ and ‘C’ levels had been measured by the same two audiologists who had over 8 years of experience doing cochlear implant mapping.

Procedure for measuring eSRT

A calibrated middle ear analyzer (GSI Tympstar) was used to perform tympanometry and to record the eSRTs. All participants had to undergo tympanometry before eSRT testing to rule out any middle ear pathology. The recording was done after ensuring that the participant was quiet in order to minimize artifacts caused by body movements. The recording of eSRT was measured with the middle ear analyser set to reflex decay mode.

The test stimuli were presented using the ‘Custom Sound EP software (Version 3)’ loaded in a computer via the programming Pod to a Freedom processor. The participants either wore their own Freedom or CP810 processor or a loaner Freedom device. The loaner Freedom was used since it was not possible to carry out eSRT using Sprint or 3G processors. The speech processor, with the transmitter coil worn by the participant, was connected to the programming Pod and the recording of eSRT was obtained in the ear contralateral to the implanted ear.

The measurement was done using standard biphasic pulses presented through the speech processor at a rate of 900 pulses per second. Stimulation began at approximately 20 programming units below the previously behaviourally measured 'C' level and was raised in 5 CL until a reflex was noticed. A change in acoustic admittance for a 226-Hz probe tone, resulting from the stapedial reflex contraction, was noted. eSRTs were recorded from at least 5 electrodes (1, 7, 12, 17 and 22). If a clear reflex was present, the stimulus level was decreased by 10 CL. If no reflex was evident, stimulation was increased by 5 units until a reflex was present. Testing was terminated if the participant reported of any signs of discomfort, even if an eSRT was not determined. The threshold was considered as the lowest stimulus level that produced a repeatable deflection in baseline recording, synchronous with the stimulus presentation. Non-auditory stimulation (facial nerve stimulation) was monitored by keeping a track of the individual's facial expression as the eSRT was obtained at higher current levels.

Procedure for measuring 'T' and 'C' level

The 'T' and 'C' levels that were established for each participant prior to the measurement of eSRT, were utilized for the study. These had been measured approximately 6 to 12 months earlier, for clients using the device for over a year, and 0 to

3 months earlier for participants using the device for less than a year. Streamlined fitting had been adopted for measuring ‘T’ levels across the 5 electrodes (1, 7, 12, 17 and 22) using a stimulation rate of 900 pulses per second. The responses were obtained using conditioned play audiometry. The ‘T’ level was defined as the level at which the participant identified the softest sound sensations 100% of the times. ‘T’ level had been determined by obtaining the individual’s hearing threshold twice using an ascending-descending method. The stimuli had been increased by 2 CL and decreased by 4 CL. After obtaining the reliable ‘T” levels across 5 electrodes, it was interpolated for the rest of the electrodes.

Once thresholds were obtained across all the electrodes, ‘C’ levels had been measured. The setting of the ‘C’ level was always done in fine ascending steps to avoid over-stimulation. At lower levels, it was increased by 5 CL and at higher levels by 2 CL. Loudness growth charts were used, wherein the individual had to point to a 5-point loudness scale (‘very soft’, ‘soft’, ‘comfortable’, ‘loud but no pain/not uncomfortable’ and ‘loud but pain/uncomfortable’) as the stimulus level was increased. Multiple stimulations were given at each level to ensure consistent responses.

In two individuals, the ‘C’ levels could not be obtained with accuracy, as they could not perform the loudness growth rating task. For these two individuals, ‘C’ levels were increased globally for all the electrodes in steps of 2-5 CL. It was ensured that they had no discomfort at these levels in the live mode.

To confirm that the maps provided were accurate, aided audiograms had been obtained for all the participants. This was done one week after the ‘T’ and ‘C’ levels were established. The aided audiograms were well within the speech spectrum in all the clients.

Analyses

The obtained scores were tabulated and analysed to determine the relationship between the behaviourally set ‘T’ and ‘C’ levels with the eSRT levels for each of the electrodes that were tested. The data was subjected to statistical analyses using SPSS software (Version 18). Paired *t*-test was used to compare the eSRT levels with the ‘C’ levels for each of the electrodes. The relationship between the eSRT levels and the ‘T’ levels were also determined.   Spearman’s rank correlation test was used to determine the correlation between eSRT levels and ‘T’/’C’ levels. The findings of the statistical analyses are described in the following chapter.

CHAPTER 4

RESULTS AND DISCUSSION

The results of the data of the eleven participants that were analysed using SPSS software (Version 18) are discussed in terms of the eSRT values, the 'C' levels and a comparison of the two. In addition, the relation between eSRT levels with the 'T' and 'C' levels are also discussed. Figure 1 shows a sample eSRT from a participant demonstrating absent reflex and a present reflex.

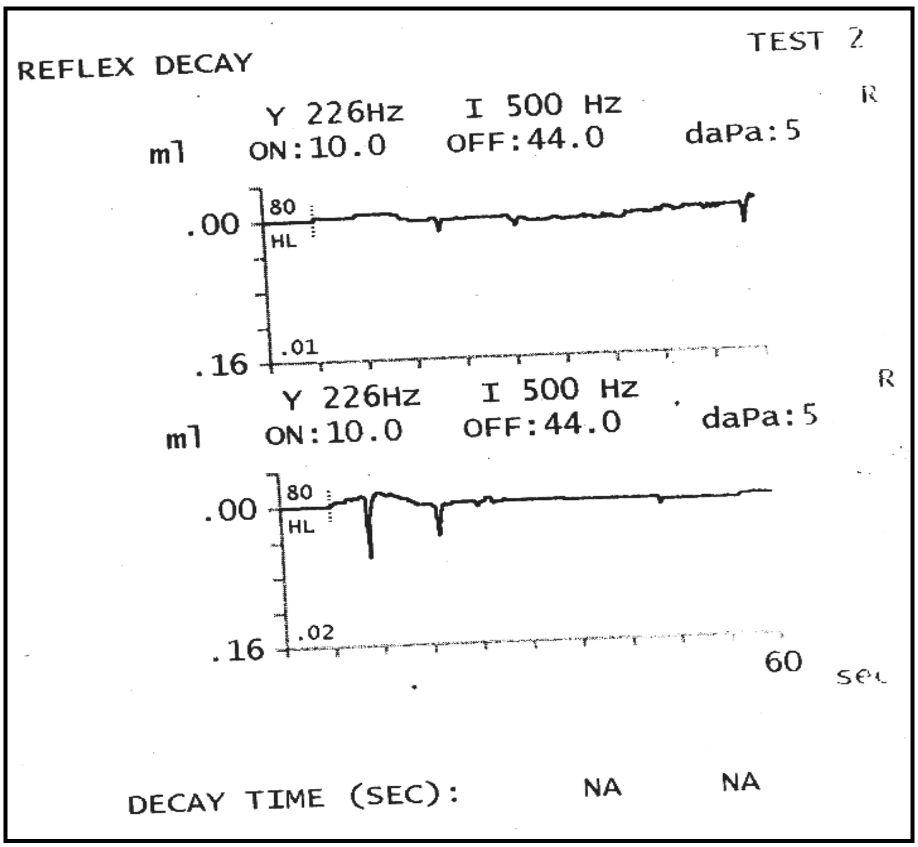

Figure 1: Sample of an eSRT obtained from a participant using Nucleus cochlear implant. Upper panel shows the absent reflex and lower panel shows the presence of a reflex.

Characteristics of eSRT responses

eSRTs were measured successfully in all the participants, in most of the electrodes. While the eSRT could be measured in all the participants on electrodes 12, 17 and 22, it was not so on electrodes 1 and 7.

Table 2: *Mean and Standard deviation for eSRT levels and 'C' levels*

Electrode	eSRT levels				'C' levels			
	Mean	**S D**	**Range**	**N**	**Mean**	**S D**	**Range**	**N**
1	217.85	23.77	250-190	7	182.28	8.59	205-171	7
7	212.50	17.67	250-195	10	184.10	15.55	212-167	10
12	212.00	11.91	235-195	11	186.72	11.81	207-175	11
17	208.63	7.77	225-200	11	187.63	13.96	216-170	11
22	205.27	7.60	215-190	11	188.63	17.24	232-167	11

Table 2 provides the mean and standard deviation (SD) for eSRT and 'C' levels for all the electrodes. From Table 2, it is clear that eSRTs could not be obtained for electrode 1 from 4 participants. In a similar way, eSRTs could not be measured from one participant from electrode 7. This occurred despite the participants having no middle ear problems. The eSRTs could not be measured on electrode 1 in three of the participants, since increase in CL resulted in the stimulation going out of compliance. In one participant, it could not be measured on electrodes 1 and 7 due to poor pressure stabilization that led to considerable fluctuation in the compliance.

The descriptive statistics revealed that mean current levels required to elicit eSRT levels increased gradually from the apical electrodes (electrode 22) to the basal electrodes (electrode 1). Similarly, the SD was less for electrode 22, and steadily increased towards electrode 1 (Table 2).

Characteristics of 'C' levels

The mean and SD of the 'C' levels calculated from the values noted from the earlier stabilized map is shown in Table 2. The mean was noted only for the electrodes where the eSRT was measurable. This was done though 'C' levels were established for all electrodes on all the participants. It is evident from Table 2 that the mean 'C' levels varied marginally across the electrodes. However, the SD was largest for electrode 22 and least for electrode 1. From Table 2, it is clear that eSRT levels were higher for all the electrodes compared to the 'C' levels in all the participants.

Comparison of eSRT levels and 'C' levels

Statistical analyses were done to compare the eSRT levels and 'C' levels obtained from the 11 participants. For the electrodes 7, 12, 17 and 22, the comparison was done using paired *t*-test, while for electrode 1, it was done using Wilcoxon's signed rank test. The latter test was used for electrode 1 due to the reduced number of participants on whom the measurement could be done on. There was a significant difference between the eSRT and 'C' levels for each of the electrodes (7 to 22) for the 11 participants (Table 3 and Figure 2).

Table 3: *Comparison of eSRT levels versus 'C' levels for of the electrodes using paired t-test*

Electrode No	T	df	Sig. (2-tailed)
7	5.600	9	.000
12	6.839	10	.000
17	4.453	10	.001
22	2.760	10	.020

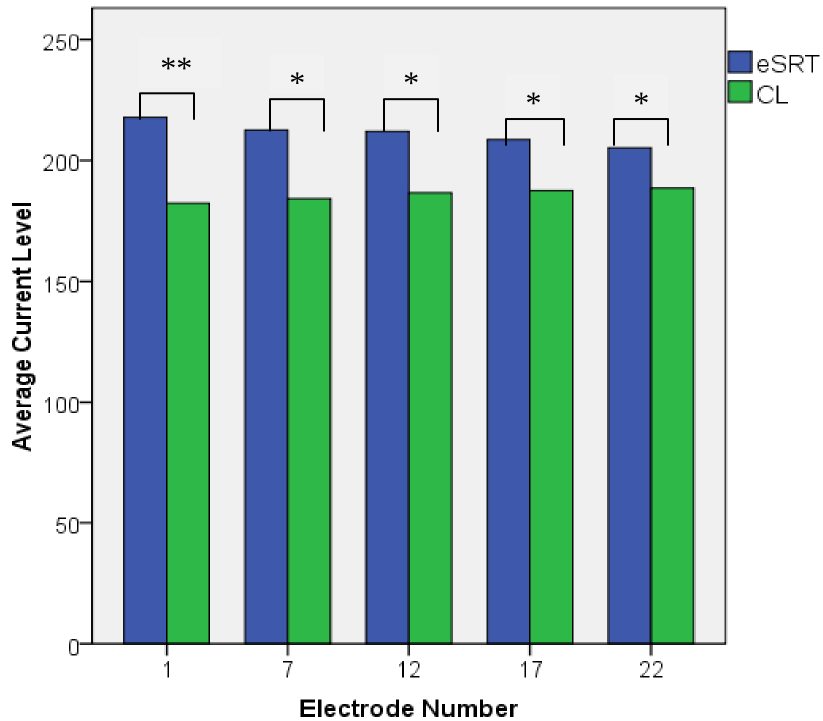

Figure 2: Graphical representation of eSRT versus 'C' level

Note: ** = $p < 0.01$; * = $p < 0.05$

On observation of the raw data, it was seen that 5 of the participants had a difference of more than 30 CL between the eSRT and 'C' levels. All these participants perceived the electrical stimulation as 'loud but not uncomfortable' at a lower level and showed saturation in loudness growth beyond that level. Hence, their 'C' levels were set at the lower level. This could have accounted for the large difference between their eSRT and 'C' levels. Further, statistical analysis was done to see if there is any significant difference between the eSRT and 'C' levels after excluding these 5 participants. Table 4 shows the values of mean, median and SD for the 6 participants whose eSRT and 'C' levels differed by less than 30 CL. Since the number of participants was small, the median values were calculated. The mean and the median for the eSRT levels as well as 'C' levels did not differ much across the 5 electrodes.

Table 4: *Mean, Median and SD for eSRT and 'C' level for 6 participants*

Electrode	**eSRT levels**				**'C' levels**			
	Mean	**Median**	**S D**	**N**	**Mean**	**Median**	**S D**	**N**
1	203.75	197.50	18.87	4	180.25	179.00	9.28	4
7	205.83	202.50	11.58	6	185.16	180.50	17.40	6
12	205.33	206.00	9.30	6	188.33	188.00	12.42	6
17	204.16	202.50	4.91	6	188.50	189.50	11.94	6
22	200.50	201.50	7.17	6	190.83	192.00	5.63	6

eSRT and 'C' levels were compared using non-parametric Wilcoxon's signed rank test. The Z value and the level of significance are shown in Table 5. From the table, it is evident that there was no significant difference between eSRT levels and 'C' levels for all the electrodes except for the electrode number 7.

Table 5: *Comparison of eSRT versus 'C' level for each electrode*

Electrode No	**Z**	**Sig. (2-tailed)**
1	-1.826	.068
7	-2.201	.010
12	-2.201	.059
17	-2.207	.076
22	-2.032	.079

Strength of correlation was investigated using Spearman's rank correlation (ρ) for the 11 participants for all the measures (eSRT levels, 'C' levels and 'T' levels). The ρ value and the level of significance (p) are shown in the Table 6. The data show that there was a positive correlation between eSRT and 'C' levels for all the electrodes though not statistically significant (varying from 0.112 to 0.627). Similarly, there was a low positive correlation ($p > 0.05$) between eSRT and 'T' levels for the electrodes 1, 7 and 13.

However, there was a negative correlation between the two measures for the electrodes 17 and 22.

Table 6: *Spearman's rank correlation cofficient (ρ) for the 11 participants*

Electrode No	**eSRT vs 'C' level**		**eSRT vs 'T' level**	
	ρ	**p**	**ρ**	**p**
1	0.6	> 0.05	0.118	> 0.05
7	0.627	> 0.05	0.28	> 0.05
12	0.26	> 0.05	0.131	> 0.05
17	0.112	> 0.05	-0.205	> 0.05
22	0.487	>0.05	-0.417	> 0.05

It was observed in the present study that the 'C' levels were lower than that of the eSRT values. This was in concurrence with the findings of Allum, Greisiger and Probst (2002). They too noticed in the majority of their participants, that the 'C' levels were lower than the eSRT levels. However, other authors (Polak, Hodges, King, Payne, & Balkany, 2006; Spivak & Chute, 1994) have reported of lower eSRT levels with respect to 'C' levels. The difference between the findings of the present study and the study by Allum, Greisiger and Probst (2002) from the others probably lies in the inclusion criteria of the participants. In the present study and in the study by Allum, Greisiger and Probst (2002), responses were obtained from pre-lingually deafened children while it was obtained from post-lingually deafened adults by Polak et al. (2006). Behavioral responses obtained from children in establishing 'C' levels might not have been accurate. Hence, this could have lead to lower 'C' levels compared to eSRT levels.

The fact that the eSRT levels obtained in the current study were found to overestimate the 'C' levels in most of the participants, indicates that the information should be applied with caution while programming cochlear implants. However, the eSRT levels did not exceed the uncomfortable level (UCL) in the present study.   This is consistent with the findings reported by Battmer et al. (1990). Hence, this information could be used as a guide to ensure that the levels of stimulation do not exceed the UCL.

The results of the present study also indicate that the possibility of obtaining reflexes were high at the mid and apically located electrodes (12 to 22) than the electrodes that are most basally located (1 and 7). This finding is in consensus with the findings reported by Allum, Greisiger and Probst (2002) who reported higher possibility of obtaining reflexes for the apical electrodes than for the basal electrodes.   The authors opined that this could be primarily due to the placement of the electrodes in relation to the modiolus. The apical electrodes were reported to be closer to the modiolus when compared to the basal electrodes. This could have lead to less focused stimulation of the auditory nerve endings in the basal region. Further, it is known fact that acoustically elicited stapedial reflexes are often absent at higher frequencies than in the lower frequencies.

The results of the present study indicate that the relation between the eSRT values and the 'C' and 'T' levels vary considerable across the participants. This is evident from the fact that the 'C' levels differed from eSRT levels by more than 30 current levels in 5 of the participants and less than 30 current levels in the rest. This finding is not in agreement with that obtained by Spivak and Chute (1994). They reported that the electrically evoked acoustic reflex thresholds (EARTs) differed from behavioural comfort levels by a mean of 9.6 current levels for a group of 19 children and by 19.4 current levels for a group of 16 adults using nucleus cochlear implants. However, EARTs noted by Spivak and Chute were also found to significantly overestimate or underestimate the ‘C’ levels in 6 adults and 4 children. The results of the present study also showed a significant difference between the two measures (eSRT and ‘C’ levels) when the findings of all the participants were considered. Only when 5 of the participants who showed considerable difference between the two measures were eliminated, did no significant difference between the two measures occur for most of the electrodes. This shows the variability of the data in the present study and in the study by Spivak and Chute (1994).

Similar findings were also reported by Hodges et al. (2000) who studied eSRT on 24 children and 24 adults using Nucleus devices. They obtained reflexes on 84 % and 67 % of them respectively. They also observed positive correlation between electrically evoked stapedius reflex threshold (eSRT) and the behavioural perception of maximum comfortable listening.

Comparison of eSRT levels with the behavioural ‘T’ and ‘C’ levels

The raw eSRT data obtained were also compared with the actual ‘T’ and ‘C’ levels for all the participants to see the relationship of eSRT with the behaviourally set ‘T’ and ‘C’ levels. Calculations were done to determine as to what percentage the ‘T’ and ‘C’ levels were of the eSRT levels for all the electrodes. It was found that ‘T’ level was 56.82%, 66.06%, 63.06%, 63.17% and 63.95% of the eSRT level for the electrodes 1, 7, 12, 17 and 22 respectively. Similarly, the ‘C’ level was found to be 86.47%, 87.6%, 88.19%, 89.26% and 90.4% of the eSRT level. The grand average for the ‘T’ level was found to be 62.61 % of the eSRT level and 88.38 %, for the ‘C’ level.

For Nucleus cochlear implants, setting of the ‘C’ and ‘T’ levels from the eSRT levels has not been investigated much in the literature. However, there is evidence regarding setting the ‘MCL’ and ‘T’ levels from the eSRT levels for Med-El cochlear implant systems. It has been reported by Spahr and Michael (2005) that the ‘T’ levels was recommended to be set at 10% of the MCL. Also, they reported that the level of speech understanding obtained from maps set using behavioural thresholds did not differ significantly from maps having 10% of the ‘MCL’. They opined that setting programs based on ‘MCL’ could be time saving. Thus, in a similar way, the results of the present study could be utilized while programming children with cochlear implants. However, eSRTs were found to overestimate comfort levels. Although, the participants in the present study could tolerate the higher levels of stimulation while measuring eSRT on individual electrodes, a map that was set with the eSRT levels was found to be not that beneficial for one of the clients. The caregiver of this child reported of poorer speech understanding as well as deterioration in speech production. Hence, the information obtained from eSRT measurements must be applied with caution.

Thus, from the findings of the present study it can be construed that there exits considerable individual variability in the relationship between eSRT levels and behaviourally set ‘C’ and ‘T’ levels. It was found that there was a significant difference between eSRT levels and ‘C’ levels for all electrodes. However, when the data of the participants in whom the difference between the eSRT and ‘C’ level was not more than 30 CL were analysed, it was found that there was no significant difference between the two measures (eSRT and ‘C’ levels) across most of the electrodes. This demonstrates the presence of individual variation in cochlear implant use.

CHAPTER 5

SUMMARY AND CONCLUSION

Jerger et al. (1986) reported that effective programming is needed to obtain maximum benefit from cochlear implants. However, Balkany et al. (2002) reported that obtaining 'C' levels from children was difficult, though they could be conditioned to provide reliable 'T' levels. Use of objective measures for programming cochlear implants in young children has become important, as they cannot provide reliable behavioural responses. Some of the objective techniques used for programming cochlear implants include electrically evoked stapedius muscle reflex (eSRT)), electrically evoked compound action potential *(ECAP)*, and electrically evoked auditory brain stem response *(EABR)*. Among the objective techniques, eSRT has been found to be time effective, resulting in it being popular. Several studies have indicated that the electrically evoked stapedial reflex threshold correlates with the behaviourally obtained 'C' levels (Jerger et al., 1986; Spivak & Chute, 1994; Hodges et al., 1997). Hence, the present study was carried out to determine the relationship between eSRT levels and 'T' and 'C' levels that have been reported in literature to enable clinicians determine optimal parameters.

A total of 11 participants were included in the study in the age range of 5 to 16; 6 years. All participants used Nucleus cochlear implants. The eSRT levels were measured from the electrodes 1, 7, 12, 17 and 22. These values were compared with their behaviourally set 'T' and 'C' levels. Paired *t*- test was used to compare eSRT levels with the 'C' levels for all the electrodes. Spearman's rank correlation was also used to investigate the relationship between the eSRT levels and behaviourally set ‘C’ and ‘T’ levels.

The results of the present study revealed

- Successful measurement of eSRT was possible for most of the electrodes for all the participants.
- The eSRT levels were higher than the ‘C’ levels.
- A Significant difference between eSRT levels and ‘C’ levels was seen when the data of all the participants were analysed.
- No significant difference between eSRT levels and ‘C’ levels were obtained for the electrodes 1, 12, 17 and 22 when 6 participants with the difference of less than 30 CL between eSRT levels and ‘C’ levels were analysed.
- There was a high possibilty of obtaining eSRT for the mid and apically located electrodes than the basally located electrodes.
- There was no statistically significant correlation between the eSRT levels and the ‘T’/’C’ levels.
- The grand average of the ‘T’ level was found to be 62.61 % of the eSRT level, while for the ‘C’ level, it was found to be 88.38 % of the eSRT level. This information could be used to set the ‘T’ and ‘C’ levels in difficult-to-test population, but with caution, as the number of participants was small.

Clinical implications

- From the findings of the present study, it is evident that eSRT can be measured in children using cochlear implants, provided they have normal middle ear function.

- It provides information regarding setting of the ‘C’ levels in children who are often found to have difficulty in providing reliable behavioural responses. Thus, eSRT measurement could act as a supplementary objective method to facilitate programming of the cochlear implants, especially in children.

- This study also demonstrates the presence of individual variability in the relationship between eSRT levels and behaviourally set ‘C’ and ‘T’ levels in cochlear implant users.

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