CHAPTER 3: THE RESEARCH WORK

3.1. Aims and Objectives of the Study

The aims were,

(a) to study the trends in multi-modal electrophysiological tests & behavioural responses, sequentially over the first year of implant use, from the time of ‘Switch-On’ till the completion of Auditory Verbal Habilitation program,

(b) to generate normative data for electrophysiological tests & behavioural responses based on the trends,

(c) to correlate the multi-modal electrophysiological thresholds levels with behavioural comfort levels, and

(d) to create predictive formulae for deriving optimal behavioural comfort levels (if unknown) based on their electrophysiological correlations, using linear & multiple regression statistical methods.

The study objective was to develop a statistical method as above and test its clinical reliability in cohorts of comparable Cochlear Implants, using the various types of devices of the three cochlear implant companies. The fulfillment of this objective would help to prove the study hypothesis and establish the multi-modal test-based statistical prediction method for unknown behavioural levels, as a useful technique which can be clinically applied for programming ‘Difficult to MAP’ Cochlear Implants in future.

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3.2. Materials and Methods

3.2.1. (a) The Study Design: A non-interventional / observational and analytical, prospective cohort study correlating the standardized clinically available diagnostic multi-modal electrophysiological tests with psychophysical behavioural responses among cohorts of comparable cochlear implantees.

- **Inclusion criteria** – Pre-lingual implantees diagnosed with congenital bilateral severe to profound sensorineural hearing loss (Age Range: 2 – 12 years) with normal inner ear anatomy, normal mental status, age appropriate milestones & no other handicaps.

- **Exclusion criteria** – Candidates with multiple handicaps, syndromes, inner ear and eighth cranial nerve anomalies, auditory neuropathy, dyslexia, Mental Retardation, neurological & psychological disabilities and children below 2 years of age (who were difficult to test candidates).

**Study Period:** October 2007 – September 2013 (six years).

**Study Centers:** This multi-centric clinical study was performed at:

- Cochlear Implant Program Centre of Sri Ramachandra University (CLIPS), Chennai and,
- Cochlear Implant Electrophysiology Lab & Habilitation Clinic, Madras ENT Research Foundation (MERF), Chennai
**Professionals Involved:** The Principal Investigator Dr. S. Raghunandhan, Consultant ENT Surgeon, MERF-Chennai performed the study under the guidance and supervision of the Research Advisory Board which comprised of Prof. Lt. Col. A. Ravikumar, Prof & Head, Dept of ENT- Head & Neck Surgery, Sri Ramachandra University, Chennai (Guide), Prof. Mohan Kameswaran, Chief Consultant ENT Surgeon, Madras ENT Research Foundation, Chennai (Co-Guide) and Dr. Kalyani Mandke, Senior Audiologist, Mandke Hearing Services, Pune (RAC Member). The study required assistance from the Cochlear Implant Surgical Teams, Implant Audiologists, Auditory Verbal Habilitationists, Clinical Psychologists and Pediatricians at both centers of the study. Dr. Porchelvan, Professor of Biostatistics, performed the data analysis for this study.

**Financial Disclosure:** The study required no funding / financial assistance. The electrophysiological testing equipment and programming software required for the study were provided by Madras ENT Research Foundation and the Cochlear Implant Program of SRU, with no additional cost incurred by the candidates for participating in the study.

**Risk Disclosure:** This was a non-interventional, observational and analytical study which involved NO RISK to the participants of the study group.
3.2.1. (b) The Study Method: All cochlear implantees in the study group underwent multi-modal electrophysiological tests namely - Impedance Telemetry (IT), Electrically Evoked Compound Action Potentials (ECAP) - Neural Response Imaging (NRI in AB implants) / Auditory Response Telemetry (ART in MedEl Pulsar / Sonata implants) / Neural Response Telemetry (NRT in Cochlear Nucleus implants) , Electrically Evoked Stapedial Response Telemetry (ESRT) and Electrically Evoked Auditory Brainstem Responses (EABR), at periodic intervals after ‘Switch-On’ at 1, 4, 8 & 12 months respectively, in conjunction with sequential Behavioural Mapping, as per standard habilitation protocols. In the MedEl Combi40+ implant group, the ECAP (ART) module was unavailable and hence these implantees underwent rest of the electrophysiological tests as per the above protocol.

The electrode array was divided for data collection, into three offsets (apical array, mid-array & basal array), depending on the number of electrodes available in the array. Hence, the MedEl Implants had offsets of 4 electrodes each (apical array El 1 to 4, mid-array El 5 to 8 and basal array El 9 to 12); Advanced Bionics Implants had offsets of a minimum of 5 electrodes each (apical array El 1 to 5, mid-array El 6 to 11 and basal array El 12 to 16) and Cochlear-Nucleus Implants had offsets of a minimum of 7 electrodes each (apical array El 22 to 16, mid-array El 15 to 9 and basal array El 8 to 1) – named in the same reverse order as per the Cochlear-Nucleus companies’
nomenclature given for the electrode array. One representative electrode from each of this offset was chosen for ESRT & EABR testing.

At each schedule, conventional psychophysical behavioural Mapping was performed, prior to conducting electrophysiological tests, in order to record the actual comfort levels, while the children were fully alert and cooperative. Electrophysiological tests were performed on the same day or on the subsequent day, when the child was cooperative or when sedated with Pedichloryl (Trichlofos) / or while sleeping naturally. Prior to the electrophysiological tests, Impedance Telemetry was checked mandatorily at each schedule in order to confirm if all electrodes were conditioned for electrical stimulation (Henkin Y, 2003). The testing sequence was staged as follows – EABR (for three electrodes from three offsets across the array – apical, mid array and basal array), NRI / ART / NRT (electrode-wise) and ESRT (for a minimum of three electrodes from three offsets across the array – apical, mid array and basal array). EABR was tested first when the child was asleep or sedated since, it required a tedious set up, was time consuming and EEG disturbances / muscle artifacts needed to be minimal during the test. ECAP testing was performed following EABR and ESRT was tested last, since most children were averse to the loudness of stimuli and would otherwise not cooperate for further testing. In between tests, adequate rest time was allowed, in order to obtain maximum cooperation from the child and to avoid the fatigue factor. No child required sedation more than once at
each schedule and with experience these tests could be performed faster, while the children were asleep after an afternoon meal. In about 10% of cases where satisfactory recordings were not obtained, due to technical issues or patient incompliance, tests were repeated on the next day. Thus, the research team could successfully acquire all required data within two days for each child at each test schedule.

The threshold for all objective measures, was defined as the lowest stimulation level at which a response was identified as present. Visual inspection of characteristic peaks was performed by the experienced audiologist for each objective measure, in order to identify and confirm the thresholds of stimulation. The learning curve was difficult in the initial period of the study, due to various issues like technical and software snags, stimulus artifacts and electrical interferences (especially with EABR), patient compliance (especially with ESRT) and other logistic reasons. Hence, data was collected for a few cases in each cohort under General Anesthesia in the operating room, in order to precisely identify the parameters which need to be set for electrophysiological stimulation and also to obtain normative values in these cases, which were once again compared with the electrophysiological responses recorded among them when under sedation at the CI clinic. By this method, the research team could define the standard settings for all tests, variations could be obviated and eventually the multi-modal testing task became easier with growing experience over the six years of study.
3.2.1. (c) The Study Principle: The study aimed to analyze the correlations of behavioural comfort levels with various electrophysiological threshold levels, since the MAP law & principle of programming in MedEl & Advanced Bionics implants were based on comfort level based fitting by identifying the most comfortable levels (MCL and M-Levels respectively) for optimal stimulation via the implant, while the Threshold levels were auto-set at approximately 10% of these comfort levels. This helps to maintain an optimal Dynamic Range throughout the period of habilitation. Majority of the study group, belonged to the above implant companies, where comfort level based fitting by identifying most comfortable levels was the main focus while creating optimal MAPs for these Implantees.

As a variation, behavioural programming in Cochlear Nucleus implants was based on threshold level based fitting wherein, individual Comfort & Threshold (C & T) levels, both of which needed to be set for each electrode in the MAPs. During the course of data analysis for Cochlear Nucleus implants, it was observed that electrophysiological correlations were positive & comparable with both C-levels and T-levels, with stronger correlates obtained for all three electrophysiological tests with the C-levels. Hence, it was decided to correlate only C-levels with the various electrophysiological (EP) tests, since this helped maintain similarity in the study design with the other implant groups, and it avoided the problem of generating two sets of correlations (EP Vs T-level & EP Vs C-level) only for the Cochlear Nucleus implant group.
3.2.2. The Study Samples & Groups: The study included 58 non-syndromic, congenital, pre-lingual, profoundly hearing impaired children aged between 2 to 12 years with normal inner ear anatomy and no additional handicaps. Since most children who were diagnosed with profound cochlear hearing loss and received cochlear implants, fell into the age range between 2 to 12 years at both centers of the study (as was observed in the Indian scenario at the time of the commencement of research work), this age range was chosen after due discussion and consensus from the research advisory board of this study, in order to acquire adequate samples of comparable age-matched, implant device-matched cohorts for analysis.

Finally, among the 58 candidates sequentially selected over the six years of research work, 44 children were aged between 2 to 6 years, while 14 children were aged between 7 to 12 years of age, by the time they received their cochlear implants (their demographic details are appended in the Observations & Results chapter). All these candidates were selected for cochlear implantation as per the standard guidelines formulated in the Consensus Document of the Cochlear Implant Group of India, 2004 which is available online at www.cigi.in. Prior to inclusion in the study, a written and informed consent was obtained from the parents of the candidates in English / their mother tongue, after counseling regarding the test protocols and the anticipated outcomes of the study.
The Institutional Ethics Committee of Sri Ramachandra University provided full approval for this study on 14\textsuperscript{th} March, 2008. The 58 candidates were divided into three study groups based on the three Implant companies, whose devices were included in the study. Depending on the type of implant used, further sub-divisions were made into ‘Device-matched’ cohorts, according to the variations in the internal device and the speech processor used. Such divisions were necessary, since data analysis for each of these cohorts needed to be done independently and results could not be compared, since there was a chance of bias induced by variable electrode design or speech processing technology influencing the results (Ref: Miller CA et al, 2003; Polak M et al, 2005).

The study groups were classified as follows;

1. The Advanced Bionics implant group had a single cohort of 10 implantees who received the HiRes 90K Implant with Harmony speech processor

2. The MedEl implant group had 30 implantees in two cohorts,
   - Cohort-1: 20 implantees who received the Combi40+ device with Tempo Plus speech processor
   - Cohort-2: 10 implantees who received the Pulsar / Sonata device with Opus 2 speech processor

3. The Cochlear Nucleus implant group had 18 implantees in three cohorts,
   - Cohort-1: 6 implantees who received the CI24ST (Straight Array) with ESPrit 3G speech processor
   - Cohort-2: 6 implantees who received the CI24CA (Contour Advanced Array) with Freedom speech processor
   - Cohort-3: 6 implantees who received the CI512CA (Version 5) with CP810 speech processor
During the course of this research work, more candidates received the MedEl Combi40+ implant, at both centers of the study, which provided a larger sample for inclusion in the study group, while smaller cohorts were possible with the MedEl Pulsar/Sonata, Advanced Bionics and Cochlear Nucleus implants. A rapid upgrade occurred in the Cochlear Nucleus implant technology during the last five years, which lead to introduction of new designs in electrode array and speech processor. This influenced the availability of candidates during the study period and lead to the formation of three 3 smaller cohorts (each with a variable electrode design and speech processor). Data analysis was done individually in these 3 cohorts, and their outcomes were not compared, since the variables of advanced implant technology and speech processing strategy, may bias the results in favour of the Cohort-3 (as per Hughes LM & Abbas PJ, 2006).

Although each of the three Cochlear Nucleus implant cohorts comprised of only six candidates (which was the minimum sample required, as per the power calculations done by the bio-statistician for obtaining an in-depth electrode-wise / offset-wise analysis with statistical significance), due to the availability of 22 electrodes in each of these implantees, there was the opportunity for generating larger electrode-wise data for electrophysiological and behavioural levels in the Cochlear Nucleus implant group, than in the other implant types which had larger samples but with fewer electrodes in their array.
The only difference between the MedEl Pulsar and Sonata variants was in the Receiver Stimulator Coil - Pulsar had a Ceramic casing while Sonata had a Titanium casing. The testing and programming parameters were the same in both variants and hence these were clubbed into a single comparable cohort.

The research team believed that analysis of results done among such smaller cohorts was necessary in the practical sense, since these results would reflect upon actual clinical scenarios, wherein an audiologist would eventually need to refer to his / her own recent age-matched, device-matched implant groups for trouble-shooting while facing a ‘Difficult to MAP’ situation. Successful application of this study method in small cohorts would enhance its acceptance for clinical use among future implantees, not only at well established CI clinics, but even in smaller and evolving CI clinics, which may not possess the facilities of access to a CI database for reference or the clinical expertise of having worked with a large number of cochlear implantees.
3.2.3. **Study Materials & Techniques:** Electrophysiological testing and Mapping were conducted with the following basic setup;

- Advanced Bionics HiRes 90K Cochlear Implant system was connected to the Soundwave (Version 2.0.33) software via a Platinum Speech Processor (PSP), during the various tests.

- MedEl Combi40+ Cochlear Implant system was connected to the CI Studio+ (Version 2.0) software via a Diagnostic Interface Box (DIB version 4.0), during the various tests, and the MedEl Pulsar / Sonata Cochlear Implant system was connected to the Maestro (Version 4.0) software via a Diagnostic Interface Box (DIB version 4.0) during the various tests.

- Cochlear Nucleus Implant system was connected to the Custom Sound & Custom Sound EP (Version 3.0 & 3.2) software via a PPS / Pod interface, during the various tests.

3.2.3.1. **The Mapping Protocol:** Using the conventional Behavioural Mapping technique at each schedule of programming, psychophysical behavioural comfort levels were sequentially obtained across the array in a step-wise manner and these were incorporated into the speech processor as the most stable and preferred MAP for the child. Most comfortable levels were determined by increasing stimulus intensity until the child indicated that the sound was loud but tolerable. Younger children, whose ability to judge the loudness was limited, were monitored for eye blinking, changes in facial expression or activity level during and shortly after stimulus presentation, in
order to identify their comfort levels. The Mapping Team of two professional CI Audiologists at both centers of study, the principal investigator and an in-house child psychologist along with the mother of the child, were involved in monitoring the child’s subjective response to psychophysical sound perception at each test schedule. A standardized observation technique was used for appropriately identifying the most comfortable levels among all the candidates at the various test schedules as shown in the Table 3.1 below (Aaron RJ et al, 2006).

<table>
<thead>
<tr>
<th>Age at Implantation</th>
<th>Duration of Implant Use</th>
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<tbody>
<tr>
<td>1 Month</td>
<td>4 Months</td>
</tr>
<tr>
<td>2 - 4 yrs</td>
<td>Cry</td>
</tr>
<tr>
<td>4 - 8 yrs</td>
<td>Cry / Smile</td>
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<tr>
<td>8 - 12 yrs</td>
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3.2.3.2. EABR Testing: EABR stimulus was delivered by the SCLIN2000 software (Version 1.08) in Advanced Bionics Implants, MedEl Zebra DOS software (Version 3.0) in MedEl Combi40+ implants, Maestro software (Version 4.0) in MedEl Pulsar / Sonata implants and by Custom Sound EP
(Version 3.0 & 3.2) for Cochlear Nucleus implants. For recording EABR, the non-inverting electrode was placed at center mid-line of the head (CZ), inverting electrodes were placed on each mastoid, and a ground electrode was placed on the forehead of the child. Recordings from the channel using the ipsilateral mastoid electrode were used for statistical analysis. Electrodes passed through an analogue low pass filter (~32 KHz) to essentially eliminate artifacts from the transmitting coil signal before entering a pre-amplifier. The signal was filtered at 10 to 3000 Hz, and the amplifier was set at 150,000. The stimulus was given with electrical pulses of 25 microseconds of alternating polarity presented at a repetition rate of 11 - 31 Hz. These pulses was carried onto the implant by the trigger cable via the PSP (in AB implant) / DIB (in MedEl implant) / PPS – Pod (in Cochlear Nucleus implant) and the responses were received by a pre-amplifier and sent to the Intelligent Hearing Systems (IHS) SmartEP (Evoked Potential) software (Version 3.91USBez), in a paired computer to synchronize the recording window with the stimulus presentation. Recordings on the IHS-SmartEP module (common recording software for all the implant types) were made between 5 and 80 ms, relative to stimulus onset and a time window of 10 milliseconds, was used for visual inspection of the EABR waveforms.

Three representative electrodes were chosen from the three offsets created across the array (apical array, mid-array and basal array) as defined by Gordon et al, 2004 and the single representative electrode chosen from
each of the offsets, was used for EABR testing through all the schedules for data collection. Large intensity level steps of 10 CU / CL were used for EABR to minimize test time, in an effort to complete testing for all three electrodes across the array at one sitting, while the children were asleep or sedated. In a few cases, EABR waveforms were interspersed with non-auditory waveforms or artifacts and in these cases, a polarity reversal with adjustments in high / low pass filter settings needed to be done, in order to overcome any ambiguity and clearly identify EABR responses. If the EEG activity was grossly interfering with identification of EABR responses, the child was rescheduled for another test under sedation on the subsequent day. While recording EABR, it was observed that waves, eIII and eV were clearly recordable between 2 to 7 milliseconds, with their amplitudes being more prominent at higher intensity levels. The EABR threshold level, was identified as the lowest intensity of stimulus which evoked a consistent, clearly recognizable wave eV and this was considered as the confirmation of a brainstem response to electrical stimulation via the cochlear implant.

3.2.3.3. ECAP Testing: ECAP (NRI / ART / NRT) thresholds were serially obtained for all electrodes along the array, using the in-built EP modules of the programming software provided by the three implant companies, with automated settings for all electrodes across the array. The default stimulation range was maintained for acquiring ECAP recordings from all electrodes. In case of no ECAP response from an electrode, the test was repeated once again under sedation or on the next day. In a rare occasion, ECAP data was
extrapolated from adjacent electrodes for analysis. Amplitude Growth Function (AGF) was sequentially monitored at various stimulation levels, by the typical appearance of N1–P2 waveform morphology and the ECAP threshold for each electrode was identified as the lowest intensity of stimulus, which evoked a clearly recognizable ECAP waveform on the recording software.

3.2.3.4. ESRT Testing: Electrically evoked stapedius reflex measurement was performed in the implanted ear, after confirming normal middle ear function with Tympanometry. In cases where middle ear function was altered due to Eustachian Cattarh / effusion, this test was postponed by a few days, until normal middle ear function was completely restored with adequate treatment. Stimulus for ESRT was given from the various programming software, with tone-burst pulse trains of approximately 18 microseconds, using automated pulse width parameters and default channel rates of around 3712 pps with 500ms intervals. This stimuli triggered ESRT responses which were recorded on the Reflexometer of an Interacoustics AZ 26 Impedance Bridge (common recording equipment for all the implant types). Three representative electrodes chosen from the three offsets created across the array (apical, mid array and basal array) as per Gordon’s method, 2004 were used for measuring ESRT responses at all test schedules.
For the MedEl implant groups alone, due to the lesser number of electrodes along the array, electrode-wise ESRT testing was feasible. Hence, data was acquired for all electrodes & multi-modal analysis was then done, using three representative electrodes along the three offsets along the array, in a similar way as was performed in the other implant groups. ESRT thresholds were identified to be that minimal stimulus level, which evoked a recognizable deflection on the reflexometer (when measured in the manual reflex decay mode). If a response was determined to be present, the stimulus level was decreased in steps of 5 CU / CL / qu, until the response was absent in the recording. ESRT thresholds were accepted as present, if three immittance deflections were clearly observed on the reflexometry for a particular stimulus level.

3.2.3.5. **Measurement Units:** The common standard measurement unit, which represents the basic unit of stimulus intensity used in the testing and programming Software for electrical stimulation via the cochlear implants followed in the various study groups, was the Clinical Unit (CU) in AB Implants / Current Level (CL) in Cochlear Nucleus Implants / Current Unit (cu) in MedEl Combi40+ Implants and Charge Unit (qu) in MedEl Pulsar / Sonata Implants. This basic measurement unit was standard & comparable between all electrophysiological parameters and the programming levels set in the Maps.
Uniquely, the MedEl Pulsar / Sonata implants had two measurement units in the Maestro 4.0 software, namely the charge unit (qu) which was the unit used for charge based programming of the implant and also for ESRT measurements, and the Current Unit (cu) which was used for ART and EABR measurements in the software. Both these units could be automatically displayed by the software, for the various measurements done on an electrode. Current units accurately reflect upon the thresholds of the auditory nerve, to evoked electrical stimuli and hence cu is accepted as the default unit of measurement for ART & EABR analysis in the software. Current units are not suitable for analyzing the fitting of MAPs in the speech processor, but charge units (qu) are valid to do this, due to the following Mapping principle. Maestro software uses a ‘charge-based’ fitting approach, where charges get adjusted on each channel during a fitting session. Based on compliance limits, given by the channel impedances (IFT) & implant supply voltage, stimulation currents (cu) and pulse phase durations (PR) are auto-calculated. Since smallest possible pulse variations are the norm in this software, mostly the current unit (cu) is equal to the compliance limit, depending only on implant supply voltage / channel impedance (Vanpoucke F, 2004).

Hence, in the MedEl Pulsar / Sonata implant group, data was collected using both the cu & qu units for the various objective measures and in qu units for the Behavioural responses, as provided in the software. In order to achieve precise & statistically significant results, the correlation and
regression analysis was performed by using the actual electrophysiological current thresholds recorded in the software, while their appropriate Mapping levels were statistically predicted in current units and then converted into the charge units, by applying the conversion formula between cu and qu as provided by the MedEl literature (1 cu = 1 microAmpere and 1 qu = 1 nanoCoulomb and charge (qu) = amplitude (cu) x phase duration (microsec) / 1000). This conversion was possible when the pulse width was not altered while testing the electrode channel for electrophysiological measurements and behavioural responses at each test schedule. This method was successful in providing statistically predicted behavioural comfort levels in charge units, which could be compared with the actual behavioural comfort levels of the implantees, and these predicted behavioural levels, could thus be incorporated into the Subjects’ speech processor for clinical trial.

3.2.3.6. Overcoming Variables during tests: The Stimulation Rate (SR) and Pulse Width / Pulse Duration (PW) needed to be considered while recording electrophysiological responses across the array at all test schedules. These parameters are pre-defined in the stimulating software and generally would be maintained at the same value, while testing across all the electrodes. Literature has shown that any change in these parameters, would influence a bias in the values measured between various electrodes across the array and at subsequent test schedules (Craddock et al, 2004; Kreft HA et al, 2004; Davids T et al, 2008). Hence, every effort was made to maintain default stimulus parameters during most electrophysiological measurements.
It was logistically and practically impossible to maintain the same pulse width across all the electrodes at all times of testing. Hence, while sequential data was collected across the electrode channels, care was taken to avoid the bias which can occur due to pulse phase duration changes. In some cases, where the pulse duration was variable in an electrode over time, the data collection was deferred and the electrode was re-tested or omitted from analysis. If a representative electrode showed no response during testing, the test was repeated on the subsequent day. Sometimes these variables needed to be re-adjusted, while testing certain electrodes, which were not responding to the normative pre-set levels as was applied for other adjacent electrodes (in order to elicit a response). This was more so with EABR wherein a higher pulse width was often required to elicit a recognizable auditory nerve response.

The electrophysiological threshold recorded with a variable SR / PW, was statistically corrected to suit the normative levels for other adjacent electrodes recorded using the standard SR / PW levels. In a few cases a correction factor could be statistically set to overcome the pulse width variations and these values were taken for analysis. On rare occasions, when an electrode was found to be persistently unresponsive / refractory to stimulation (as noted in 3% cases), values from an adjacent electrode were extrapolated to that electrode for completion of data.
3.2.3.7. **Statistical Methods for Data Analysis:** Data was analyzed by the Bio-statistician using the SPSS 17.0 software. Trends in electrophysiological and behavioural responses of the auditory nerve recorded at each test schedule, was analyzed using the paired t-test and normatives were obtained for the various cohorts of the study group. Using the Karl Pearson’s correlation method, electrode-wise one-to-one correlations were derived for ECAP (NRI / ART / NRT) versus Most Comfortable Levels (M-Level / MCL / C-Level) and offset based correlations with representative electrodes (apical, mid-array & basal array) for ESRT and EABR versus Most Comfortable Levels were calculated sequentially over time. The reference range used for correlation was – ‘r’< 0.001 = No significant correlation, 0.001 to 0.300 = Poor correlation, 0.301 to 0.700 = Moderate correlation and 0.701 to 0.999 = Good correlation.

The correlations were used to derive predictive formulae by linear & multiple regression analysis. Using this method ECAP, ESRT & EABR values recorded for a representative electrode across the array, could be applied individually into the linear regression formulae, and can also be combined together into a multi-modal matrix in a multiple regression formula for deriving an optimal Comfort Level for that electrode (if unknown). Thus optimal comfort levels can be statistically predicted using all the three EP tests or by using any of them independently. Prior to combining the three electrophysiological parameters for multiple regression analysis, it was
necessary to perform a cross-correlation analysis in-between these three objective measures, in order to ascertain that they do not exert any undue influences upon each other, thus reducing the accuracy of multi-modal comfort level predictions.

As per bio-statistical norms, cross-correlations between independant variables combined into a multiple regression matrix, should not have values equal to or above those linear correlations which were derived between them and the dependant variable, which needs to be predicted by applying them together. Hence, in the study it was mandatory to confirm that cross-correlations between the various objective measures (independent variables) were moderate and they were much lesser in value, than their individual linear correlations with the comfort levels. Once this was confirmed, a successful multi-modal matrix combining the three objective measures could be generated, with no undue influence of one on another measure, while predicting the comfort levels (dependant variable). This statistically predicted value for an unknown comfort level can be used as a reference to program that electrode in ‘Difficult to MAP’ situations, wherein no behavioural inputs are available to program that electrode.

The statistically predicted comfort levels which were derived using linear and multiple regression models were compared with the actual (behaviourally recorded) comfort levels among members of various cohorts of
the study group, using Cronbach’s Alpha Reliability test method, for confirming the efficacy of the study method. The reference range used for reliability test was – ‘R’ < 0.001 = No reliability, 0.001 to 0.400 = Poor reliability, 0.401 to 0.700 = Moderate reliability and 0.701 to 0.999 = Good reliability.

In clinical practice, performing such a reliability analysis becomes paramount, since it often lies upon the implant audiologist’s discretion to choose a multi-modal or single best linear correlation method for predicting unknown comfort levels. Based on the results of statistical reliability of the linear and multiple regression methods, the implant audiologist can thus make a judicious decision. It is the research team’s belief that, in general it is best to pursue a multi-modal prediction method, if all three / more than one electrophysiological measurement, is available for analysis. Otherwise a linear correlation / prediction method using a single electrophysiological measurement needs to be performed.

The cumulative data of the actual behavioural comfort levels of the various study cohorts, recorded at 1 month & 12 months of implant use, were compared with their linear and multiple regression based statistically predicted comfort levels generated at 1 month (first schedule) and 12 months (last schedule) respectively using scatter plots, in order to analyze the frequency distribution of the data points, which will confirm the efficacy of the
study method at various test schedules and to get an insight into the longitudinal trends in the compared parameters, over a time of implant use. The statistically predicted comfort levels were incorporated into the programs of the speech processors of randomly selected subjects of each cohort, at the first & fourth test schedules, in order to assess the clinical efficacy of this method, at various periods of implant use.

The success of this clinical trial was assessed by the auditory & behavioural feedback obtained from these children, with CI aided audiometry and auditory verbal skill tests, while using the MAPs based on the predicted comfort levels, as compared with the responses recorded from their behaviourally set MAPs.