Efficacy of Auditory Processing Training in Cochlear Implant Children: A New Approach

Thesis submitted for

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Introduction and Rationale

Hearing impairment has a high prevalence affecting approximately 5 in 1000 newborn children **(Frei et al., 2005).** Childhood hearing loss is a widespread problem with significant impact on communication, language production, learning, social development and quality of life **(Peggy, 1997).**

The identification, assessment and management of hearing impairment in the pediatric population can be a challenging endeavor. Nevertheless, newer technology improved techniques and the cooperative efforts of various professional organizations and their constituencies have made significant strides towards achieving this goal. As more precise objective technologies are introduced, there will be a tendency to rely more heavily on their application **(Jacobson & Jacobson, 2004).**

Early in life, evidence suggests that, auditory input and communication are essential for the normal development of language, cognition, and behavior. Thus, deaf children who experience significant disruptions in auditory input are likely to show delays not only in the production of oral language but also in other important aspects of development such as visual attention and behavioral control **(Quittner et al., 2004).**

Cochlear implants (CIs) have shown tremendous promise in restoring auditory information to deaf children and concomitant improvements in speech recognition and production **(Quittner et al., 2004).** CI is not just a technique, but a driving force behind an elaborate care-programme for the severely hearing impaired patient **(Van de Heyning et al., 2004).**

Individual speech and language outcomes of deaf children with cochlear implants (CIs) are quite variable. Individual differences in underlying auditory cognitive functions may explain some of this variance **(Horn et al., 2005).** It is not yet clear whether cochlear implants enable children to reduce or overcome cognitive deficits associated with hearing impairment **(Khan et al., 2005).**

Auditory evoked potentials provide objective evidence of central auditory processing differences across experienced CI users. **Singh et al. (2004)** reported that mismatch negativity (MMN) was recorded in 80-85% of star performers but in only 15-20% of poor performers. These results indicate that MMN may be used to assess the functional status of the auditory cortex in terms of auditory memory and discrimination in young children with cochlear implants and may provide an objective mechanism for differentiating good from poor performers.

Rehabilitation of CI children is mandatory to develop their ability to recognize speech using the auditory signal and to interpret auditory experiences. Moreover, most of the training programs and rehabilitation for CI focuses on verbal communication. Unfortunately, the temporal aspects of the auditory stimuli and the phonemic abilities were not much included in the classic training program of the CI children.

Recently, auditory training for central auditory processing disorders have been applied to improve the auditory ability and cognition including attention and memory. During the last few years the area of using computer-based program training for remediation showed promising results and marvelous outcomes **(Miller et al., 2001& Tallal et al., 2001).** This program involved adaptive training exercises applied in the form of CD-ROM mounted games. Direct skills remediation, or auditory training, consists of bottom-up treatment approaches designed to reduce or resolve the central auditory processing disorder **(ASHA, 2005).**

However, review of literature revealed that the role of such program in improving the auditory and auditory cognitive abilities in hearing impaired particularly cochlear implanted children has not been explored in other studies. This program might be of great help in hearing impaired children to improve their auditory cognitive abilities. Accordingly, this study is designed to explore the value of application of computer-based training program for training of some underlying auditory processing abilities and addressing auditory cognition and its effect on speech and language for cochlear implanted children.

Aims of the work

1- To assess the efficacy, if any, of the training program for central auditory abilities on the speech perception test results of cochlear implanted children.

2- To study the electrophysiological test in cochlear implant children pre and post-training.

3- To study central auditory abilities in cochlear implant children pre and post-training.

Chapter 1

Cochlear Implant, Histopathological Considerations & Long term effects of Electric Stimulation

The cochlear implant is the most successful neural prosthesis developed to date. Approximately 60,000 people have received cochlear implants **(Wilson, 2004).** Cochlear implantation is an established treatment for selected individuals with bilateral severe to profound sensoirneural hearing loss (SNHL) who derive limited benefits from conventional hearing aids. The Italian scientist Alessandro Volta (1800) is credited with being the first to demonstrate that electric stimulation could directly evoke auditory sensations in humans. It was not till 1960 where the first cochlear implant was developed which comprised single electrode that was surgically placed within the scala tympani. The House-3M single-electrode implant became the first ***Food and Drug Administration (FDA)*** - approved device in 1980 and had several hundred users. The introduction of multi-channel devices, development of advanced speech coding strategies, and refinement of candidacy criteria have led to substantial improvements in postimplant performance, evidenced by improved open-set speech understanding in both children and adults **(Toh and Luxford, 2002).**

Engineering Design of Cochlear Implant

The function of a cochlear implant is to bypass the hair cells via direct electrical stimulation of surviving neurons in the auditory nerve. In general at least some neurons survive even in cases of prolonged deafness and even virulent etiologies such as meningitis **(Leake and Rebscher, 2004).**

Commercially-available cochlear implant devices share some common biomedical engineering characteristics. Each manufacturer's device consists of two basic parts: an implantable device consisting of an electrode array and electronic circuitry, and an external device that transforms acoustic information and transmits it in a suitable form for stimulation of auditory nerve via the electrodes **(James et al., 2003).**

**Components of Implant System:

Most cochlear implant systems consist of similar internal and external components. These systems are best conceptualized as consisting of four major components:

A- Microphone:

A microphone is typically housed within a component of the external portion of the implant system or may be used in isolation. Through refined methods of gathering sound, microphones offer the capability of narrowing the spectrum of input in order to reduce interference with salient signals (for example, speech in noise). An important design consideration of an implant system is the specification of a microphone that is an efficient receiver and at the same time isolates the external vibration that occurs with head movement and walking. The microphone's design should allow for sensitivity to a broad spectrum of frequencies with minimal distortion **(Wilson, 2000).**

B- Speech Processor:

An externally worn speech processor converts microphone inputs into a code of electrical stimuli that conveys the information contents of speech and environmental sounds to be delivered to the auditory pathway by the implant ***(Fig. 1).*** An external antenna, held in place by the magnet of the implanted receiver/ stimulator, enables radio-frequency transmission. The external processor and antenna are fitted 3-4 weeks after implantation of the internal device. This permits incision healing, resolution of skin flap swelling, and stabilization of the interface between the surface of the implanted electrodes and target neurons. Batteries housed within the processor drive the system. Current systems maintain power requirements that allow for battery life beyond waking periods of 12 – 16 hours **(Wilson, 2000).**

Signal-processing parameters are determined during fitting sessions by an audiologist and are stored in the memory of the processor. Memory locations for different programs provide processing options to accommodate different listening conditions. Volume, sensitivity, and strategy selection controls on the process provide substantial control to the user to adjust process or inputs to the implant. External signal input ports provide the ability to directly connect to telephone, TV, FM systems, as in a 'looped' environment, and other personal listening equipment **(Wilson, 2000).**

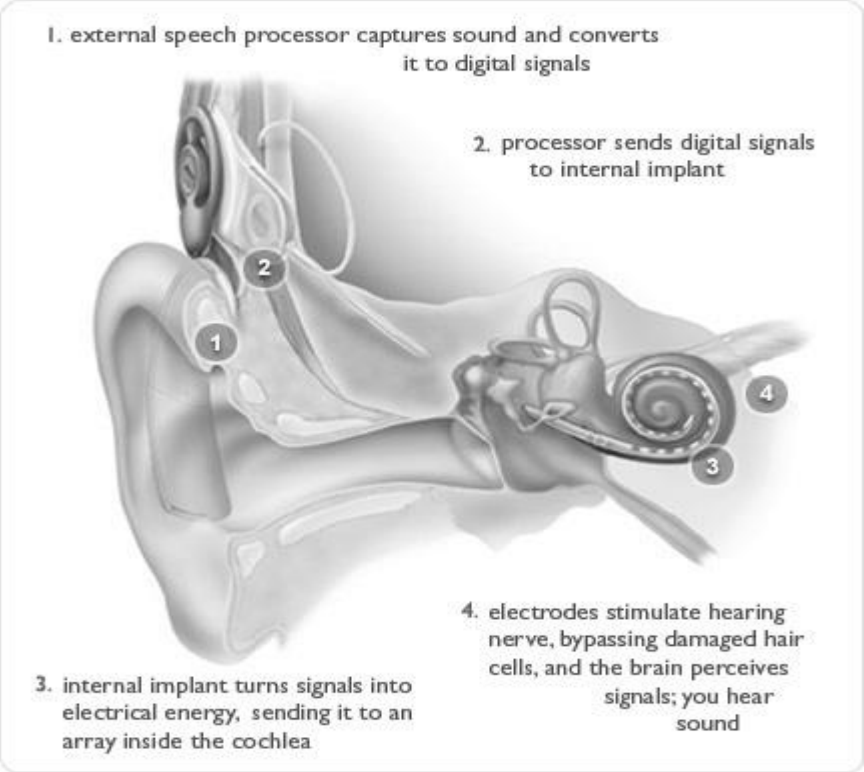

Figure 1: *Cochlear Implant Components (Wilson, 2004)*

C- Transmission Link:

A percutaneous connector or transcutaneous link is used to convey stimuli or stimuli information from the external speech processor to the implanted electrodes. All commercially available implant systems use a transcutaneous link. In some cases the link is bidirectional, allowing transmission of data from the implanted components out to the external coil and speech processor or speech processor interface, as well as transmission of data from speech processor to the implanted receiver/ stimulator and electrode array **(Wilson, 2004).**

D- Internal (implanted) components: receiver/stimulator and electrode array:

The internal, implantable portion of the cochlear implant system provides the direct biologic interface that imparts processed signals to the auditory nervous system. A receiver/stimulator accepts, decodes, and transmits signals. A magnet within the hermetically sealed casing of the receiver/stimulator aligns and retains the external antenna for transcutaneous transmission. Stimulation codes generated by the speech processor are transmitted to the implanted receiver/stimulator via an inductive link that exists across the skin and subcutaneous tissue **(Wilson, 2004).**

Once the signals are conveyed to the receiver/stimulator, signals via a connecting lead to an array of electrodes implanted within the scala tympani. The scala tympani offers an immobile, protected site for electrode placement. Electrodes in this position lie close to the target peripheral dendritic endings and cell bodies of auditory nerve afferent fibers. The design of the electrode array must be biocompatible and mechanically stable. It must allow for practical fabrication and facilitate atraumatic insertion **(Wilson, 2004).**

Monopolar electrode designs place one or more active electrodes adjacent to the neural target and a ground electrode external to the cochlea. Current is passed between the active (monopole) and the ground electrode. Stimulation with a monopole typically saturates a nerve with the stimulating current and requires less power to excite a population of neurons. Enhanced processor efficiency can prolong battery life. ***Bipolar electrode*** designs, in contrast, place both active and ground electrodes within the cochlea. Bipoles provide a more restricted field of current and the potential for more discrete stimulation of neurons. Because smaller populations of neurons are stimulated there is less likely to be channel interaction relative to the use of monopolar designs. Bipolar stimulation entails greater electrical resistance and higher power requirements **(Cochlear Corporation, 1994).**

Multi-channel arrays are typically placed within scala tympani along the first and a variable portion of the second turn of the cochlea. The depth of insertion is a function of surgical technique, obstructing tissue within the cochlea, and electrode design, but often reflects the longitudinal stiffness imparted by the carrier and connectors housed within the core of the implanted array. Electrode design, particularly the longitudinal (curved versus straight) and cross-sectional shape and the stiffness of the carrier, influence bending and the trajectory of the array tip during insertion. These properties likely influence depth of insertion and position of electrode contacts relative to neuronal fibers housed within the modiolar core of the cochlea **(Wilson, 2000).**

Current electrode carriers are typically inserted over distance of up to 30 mm. Insertion along this length of the cochlea places electrodes of the array adjacent to fibers of the auditory nerve that normally subserve the entire range of speech frequencies. The aim is to simulate frequency analysis normally provided by basilar membrane mechanics and the tonotopy of fiber activation within the cochlea. Insertion beyond the first portion of the basal (first) turn of the cochlea seems necessary intuitively to approach low-frequency neurons. However, the need for insertion beyond 20 mm into the cochlea is as yet uncertain **(Wilson, 2004).**

*****How cochlear implant works:***

A microphone picks up sounds and converts it into an electrical signal for input to speech processor through a cord. The speech processor, which is a powerful miniaturized computer that filters, analyzes and digitizes sounds into a set of stimuli for an implanted electrode or array of electrodes. The stimuli are sent to the electrodes through a transcutaneous link or through a percutaneous connector. A typical transcutaneous link includes encoding of the stimulus information for efficient radiofrequency transmission from an external transmitting coil to an internal (implanted) receiving coil. The signal received by the internal coil is decoded to specify stimuli for the electrodes. A cable connects the internal receiver/stimulator package to the implanted electrodes. In the case of a percutaneous connector, a cable connects pins in the connector to the electrodes **(Wilson, 2004).**

Assessment of implant candidacy

The success of this technology in enhancing communication abilities in a large number of patients has encouraged the expansion of candidacy criteria to include patients for whom, in the early years of cochlear implantation, implants were deemed to be contraindicated. Children have now been implanted in large numbers, and much recent work has focused on the special considerations required in caring for this population. In experienced hands, serious complications secondary to cochlear implant surgery are rare; the vast majority of ears can be safely implanted **(Niparko, 2000).**

Full assessment of candidacy for cochlear implantation requires consideration of a range of factors that will likely affect use and performance of the device and, ultimately, an individual's level of satisfaction with an implant. A multidisciplinary team brings together professionals offering different perspectives on a candidate's needs and the capabilities of the implant to meet them. The importance of comprehensive assessment is underscored by several factors:

- The cochlear implant is a communication tool, and is not a curative intervention for the hair cell dysfunction that prevents normal hearing,
- Preoperative expectations will largely shape postoperative satisfaction with any form of auditory rehabilitation,
- The multifaceted nature of communication disorders often necessitates more than one rehabilitative strategy, particularly in children in whom deficits in auditory processing, speech production, cognitive ability, and attention may need to be addressed, and
- Candidates should have the psychological makeup, motivation and motivated support system to learn to use and maintain the device to optimize performance.

*****Hearing assessment:***

Originally, candidacy for a cochlear implant requires total or near-total sensorineural hearing losses as characterized by pure-tone average *(PTA) (at 0.5, 1, and 2 kHz)* of 100 dB or greater, amplified thresholds that failed to reach 60 dB, and an absence of open-set speech recognition despite the use of powerful, best-fit hearing aids. As clinical experience has indicated that mean speech reception scores of these individuals generally exceed those aided results of individuals with lesser impairments, the audiologic criteria have been relaxed to include those with PTAs > 70 dB and range and speech understanding of up to 50% on sentence testing. Although thresholds as reflected by the PTA provide a convenient indicator of impairment level, more important to implant candidacy is the individual's experience with amplification.

FDA guidelines suggest that candidates should have at least 6 months' experience with high-powered binaural amplification and undergo aided-speech audiometry. Length of profound hearing loss and residual hearing appear to be critical factors in determining implant success **(Rubinstein et al., 1999).** Duration of deafness and preoperative scores on tests of sentence recognition are both significant predictors of word recognition with a cochlear implant and account for 80% of the variance in word recognition achieved with a cochlear implant.

Although audiologic criteria to be met for a particular device will depend upon **FDA**-approved labeling, candidacy for current devices requires that word discrimination scores do not exceed 30 % in best-aided conditions **(Cochlear Corporation, 1992)**. Mean speech recognition scores following implantation exceed these levels, and individuals with some preserved speech recognition ability preoperatively often score substantially higher than in their preoperative condition **(Waltzman et al., 1995).**

Audiologic criteria for childhood candidacy follow similar guidelines. Children should demonstrate PTAs of 70 dB or greater to be considered for implantation. Acquiescence in hearing aid use can be important to patient preparation for wearing the external portion of an implant system. The development of aided communication abilities as reflected in cognitive and language acquisition over a period of observation constitutes the critical criterion for determining candidacy in young children **(Mecklenburg, 1990).** In very young children who cannot be assessed with behavioral techniques, candidacy determination is increasingly dependent upon threshold determination; extreme elevations in thresholds *(consistent with profound deafness and lack of potential for speech understanding with amplification)* can provide an indication for early implantation **(Arts et al., 2002).**

Kileny et al. (2001) demonstrated that children implanted between the age of 12 and 36 months outperform children implanted between the age of 37 and 60 months. This, together with earlier identification of childhood deafness, is pushing the age at implantation lower. For many years, the lower limit for age at implantation was 2 years. As of year 2000, the FDA has approved a device for implantation for those patients aged 12 months and older. Further reductions in age at implantation are currently limited by the nature of audiologic testing in very young children **(Arts et al., 2002).** In general, with the use of modern techniques for neonatal screening and early diagnosis, confident assessment of severe to profound hearing loss can be made in a child by the time they are 12 months old. In cases of hereditary hearing loss or meningitis, a confident assessment can sometimes be made at younger than this **(Arts et al., 2002).**

The integrity of the auditory nerve may be verified with transtympanic stimulation with behavioral responses in adults *(promontory testing)*, or averaged, far-field auditory potentials in children **(Kileny et al., 1994).** In preoperative assessment of the severe of profoundly deaf cochlear implant candidate, electrical stimulation of the inner ear may be helpful in verifying responsiveness and choosing the ear to be implanted. Although the strict prognostic value of preoperative promontory testing is probably limited, the test is useful when asymmetries in the appearance of the cochlea are noted on computed tomography *(CT)* scanning, and because of concerns about the responsiveness of their ear to a novel stimulus **(Blamey et al., 1992).**

*****Otologic and medical assessment:***

Candidates for implantation often wonder if the etiology of their deafness will predict success or failure. However, linkages between etiology and the degree of survival of neural elements **(Nadol, 1984)** in profound deafness have demonstrated prognostic value in only selected pathologies. Nonetheless, establishing the precise etiology of deafness can provide useful information in guiding the implantation process. For example, cochlear implants are often quite beneficial in cases of slowly progressive losses in which adaptive abilities such as lip reading have developed. Cochlear otosclerosis and temporal bone fractures may be more likely to manifest adventitial facial nerve stimulation with activation of the implant **(Niparko et al., 1991)**, thereby necessitating modifications of the processing program.

Etiology alone is rarely a contraindication to implantation. Prior meningitis *(with associated cochlear ossification)* and chronic ear disease may necessitate adaptation of the implantation procedure. Profound sensorineural hearing loss associated with congenital absence of neural foramina **(Jackler et al., 1987)** and profound losses due to acoustic tumors are rare disorders in which the etiology often obviates the option for cochlear implantation on the basis of inadequate auditory innervation.

*****Radiological assessment:***

Preoperative high-resolution CT of the temporal bones provides the best means of determining cochlear patency. Although the radiographic appearance is not always predictive of scalar patency, results that are falsely negative or falsely positive are relatively infrequent. The radiographic appearance of the cochlea should be considered in light of clinical information, particularly when there is a history of meningitis or otosclerosis, and particularly when considering the likelihood of complete