ELECTRICAL STAPEDIUS REFLEX THRESHOLD IN PEDIATRIC COCHLEAR IMPLANT USERS

PANUPHOL VIBOONCHAICHEEP

**A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR
THE DEGREE OF MASTER OF SCIENCE
(COMMUNICATION DISORDERS)
FACULTY OF GRADUATE STUDIES
MAHIDOL UNIVERSITY
2015**

Thesis
entitled

ELECTRICAL STAPEDIUS REFLEX THRESHOLD IN PEDIATRIC COCHLEAR IMPLANT USERS

.....
Mr. Panuphol Viboonchaicheep
Candidate

.....
Assoc. Prof. Krisna Lertsukprasert,
M.A. (Communication Disorders)
Major advisor

.....
Assoc. Prof. Montip Tiensuwan,
Ph.D. (Applied Statistics)
Co-advisor

.....
Prof. Patcharee Lertrit,
M.D., Ph.D. (Biochemistry)
Dean
Faculty of Graduate Studies
Mahidol University

.....
Assoc. Prof. Krisna Lertsukprasert,
M.A. (Communication Disorders)
Program Director
Master of Science Program
In Communication Disorders
Faculty of Medicine
Ramathibodi Hospital
Mahidol University

Thesis
entitled

ELECTRICAL STAPEDIUS REFLEX THRESHOLD IN PEDIATRIC COCHLEAR IMPLANT USERS

was submitted to the Faculty of Graduate Studies, Mahidol University
for the degree of Master of Science (Communication Disorders)
on
May 26, 2015

.....
Mr. Panuphol Viboonchaicheep
Candidate

.....
Maj. Gen. Assoc. Prof. Pongthep Harnchumpol,
M.A. (Communication Disorders)
Chair

.....	.....
Assoc. Prof. Montip Tiensuwan, Ph.D. (Applied Statistics) Member	Assoc. Prof. Krisna Lertsukprasert, M.A. (Communication Disorders) Member
.....	.....
Prof. Patcharee Lertrit, M.D., Ph.D. (Biochemistry) Dean Faculty of Graduate Studies Mahidol University	Prof. Winit Phuapradit, M.D., M.P.H. (Maternal and Child Health) Dean Faculty of Medicine Ramathibodi Hospital Mahidol University

ACKNOWLEDGEMENTS

This thesis could not have been succeeded without the assistance from Assoc. Prof. Krisna Lertsukprasert who served as my advisor. I wish to thank for her kindness in providing suggestion and support which enabled me to complete this thesis successfully. I am equally grateful to Assoc. Prof. Montip Tiensuwan, my co-advisor, for her guidance in the field of statistics.

I would like to thank Maj. Gen. Assoc. Prof. Pongthep Harnchumpol, for his kindness in providing suggestions for improvement, and who was an external examiner and the chair of the thesis defense committee.

I wish to thanks Mr. Sunil Kapoor, Director of Southeast Asia and Business Development at Advanced Bionics Asia Pacific Ltd., who helped in editing the thesis. I would like to express my special thanks for the willingness of Mr. Khalid Mohamed Ajimsha, Clinical Manager at Advanced Bionics India Pvt Ltd., in providing advice in this research.

I am very grateful to all staff of the Speech and Hearing Clinic, Ramathibodi Hospital, for their cheerfulness and kind support and I would like to thank my graduate friends, especially Miss Tipwaree Aueworakhunanan, for the support, help, caring, and love.

I wish to thanks Audimed Co., Ltd. for their financial support in my graduate education. Finally, I am grateful to my family for their kind support, care, and love.

Panuphol Viboonchaicheep

ELECTRICAL STAPEDIUS REFLEX THRESHOLD IN PEDIATRIC COCHLEAR IMPLANT USERS

PANUPHOL VIBOONCHAICHEEP 5536261 RACD/M

M.Sc. (COMMUNICATION DISORDERS)

THESIS ADVISORY COMMITTEE: KRISNA LERTSUKPRASERT, M.A., MONTIP TIENSUWAN, Ph.D.

ABSTRACT

The purposes of this study were to examine the electrical stapedius reflex threshold (ESRT) in pediatric cochlear implant users. The study aimed at a comparison of electric current between behavioral M-level and ESRT. Also, speech discrimination scores between a program based on the behavioral method and a program based on ESRT were compared.

The subjects consisted of 19 pediatric cochlear implant users. They comprised 8 males and 11 females with a mean age of 11.16 years. Eleven subjects used an Advanced Bionics implant and another eight used a MED-EL implant. The most comfortable levels (M-level) of subjects were measured by the behavioral method, and ESRT levels also were measured. The M-levels values were obtained for all subjects, but the ESRT were obtained for only 15 subjects (79%). Two programs were made for these subjects, one based on behavioral M-level and one based on ESRT. The speech discrimination scores were measured for each program.

The results showed that there were no significant differences in the means of behavioral M-level and ESRT and also no significant difference in the means of speech discrimination scores between the ESRT program and behavioral program. The findings demonstrate the advantage of using ESRT to set M-level for young cochlear implant users. The application of ESRT may increase the efficiency to predict M-levels at the initial fitting process and enhance listening performance for appropriate speech and language development in pediatric cochlear implant users.

KEY WORDS: COCHLEAR IMPLANT/ ELECTRICAL STAPEDIUS REFLEX THRESHOLD

63 pages

การตอบสนองต่อกระแสไฟฟ้าของกล้ามเนื้อ Stapedius ในผู้ป่วยเด็กที่ใช้อุปกรณ์รับเสียงฝังหูชั้นใน
ELECTRICAL STAPEDIUS REFLEX THRESHOLD IN PEDIATRIC COCHLEAR IMPLANT USERS

ภาณุพล วิบูลชัยชีพ 5536261 RACD/M

วท.ม. (ความผิดปกติของการสื่อความหมาย)

คณะกรรมการที่ปรึกษาวิทยานิพนธ์: กฤษณา เลิศสุขประเสริฐ, M.A., มนต์ทิพย์ เทียนสุวรรณ, Ph.D.

บทคัดย่อ

วัตถุประสงค์ของการศึกษานี้ เพื่อศึกษา electrical stapedius reflex threshold (ESRT) ในเด็กที่ใช้อุปกรณ์รับเสียงฝังหูชั้นใน โดยการเปรียบเทียบปริมาณกระแสไฟฟ้าที่กระตุ้นในระดับฟังสบายที่สุด (M-level) จาก behavioral method และปริมาณกระแสไฟฟ้าที่กระตุ้นให้เกิด ESRT และศึกษาเปรียบเทียบความสามารถในการจำแนกเสียงพูดระหว่างการใช้โปรแกรมที่ปรับปริมาณกระแสไฟฟ้าตามค่า M-level จาก behavioral method และ โปรแกรมที่ปรับปริมาณกระแสไฟฟ้าตามค่า ESRT

กลุ่มตัวอย่างประกอบด้วย เด็กที่ใช้อุปกรณ์รับเสียงฝังหูชั้นใน จำนวน 19 คน เพศชาย 8 คน และเพศหญิง 11 คน อายุเฉลี่ย 11.16 ปี กลุ่มตัวอย่างจำนวน 11 คนใช้อุปกรณ์รับเสียงฝังหูชั้นในยี่ห้อ Advanced Bionics และอีก 8 คนใช้ยี่ห้อ MED-EL ทำการวัดค่าปริมาณกระแสไฟฟ้าที่กระตุ้นให้รับฟังเสียงสบายที่สุดจาก behavioral method และปริมาณกระแสไฟฟ้าที่กระตุ้นให้เกิด ESRT กลุ่มตัวอย่างทั้งหมดสามารถวัดค่าปริมาณกระแสไฟฟ้าที่กระตุ้นให้รับฟังเสียงสบายที่สุดได้ มีเพียง 15 คน คิดเป็น 79% ที่สามารถวัดค่า ESRT ได้ เปรียบเทียบการใช้งาน 2 โปรแกรมในกลุ่มตัวอย่างที่มี ESRT โดยตั้งโปรแกรมตามปริมาณกระแสไฟฟ้าที่กระตุ้นให้รับฟังเสียงสบายที่สุดจากbehavioral method และโปรแกรมที่ตั้งปริมาณกระแสไฟฟ้าตามค่า ESRT ทดสอบความสามารถในการจำแนกเสียงพูดของทั้งสองโปรแกรม

ผลการศึกษาพบว่า ปริมาณกระแสไฟฟ้าที่กระตุ้นให้รับฟังเสียงสบายที่สุดจาก behavioral method และปริมาณกระแสไฟฟ้าที่กระตุ้นให้เกิด ESRT ไม่มีความแตกต่างกันอย่างมีนัยสำคัญทางสถิติ และค่าความสามารถในการจำแนกเสียงพูด (speech discrimination scores) ของทั้ง 2 โปรแกรม ไม่มีความแตกต่างกันอย่างมีนัยสำคัญทางสถิติ ผลการศึกษานี้แสดงให้เห็นถึงประโยชน์ของการนำค่าการตอบสนองที่ได้จาก ESRT มาใช้เป็นแนวทางในการกำหนดปริมาณกระแสไฟฟ้าให้เด็กที่ใช้อุปกรณ์รับเสียงฝังหูชั้นใน การนำค่า ESRT มาประยุกต์ใช้ อาจช่วยเพิ่มประสิทธิภาพในการกำหนดปริมาณกระแสไฟฟ้าในเด็กที่ไม่ให้ความร่วมมือในการทำ behavioral method โดยเฉพาะในช่วงเริ่มต้นของการใช้อุปกรณ์ เพื่อเพิ่มประสิทธิภาพของการฟัง อันจะเป็นประโยชน์ในการพัฒนาภาษาและการพูดต่อไป

63 หน้า

CONTENTS

CONTENTS (cont.)

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ENT	ear, nose, and throat
dB	decibel
T-level	threshold level
M-level	most comfortable level
C-level	comfortable level
ECAP	electrical evoked compound action potential
EABR	electrical evoked auditory brainstem response
ESRT	electrical stapedius reflex threshold
cm	centimeter
mm	millimeter
Hz	hertz
US FDA	United States Food and Drug Administration
ABR	auditory brainstem responses
ASSR	auditory steady-state responses

CHAPTER I
INTRODUCTION

1.1 Background and rationale

In the normal hearing process, sound travels from the environment through the outer ear to the tympanic membrane that makes the vibration of the membrane and three small bones (malleus, incus and stapes) in the middle ear. This vibration generates the mechanical energy which is transmitted through the stapedial footplate into the small area in the cochlea; called the oval window [1]. Then the energy causes the movement of fluid in the inner ear that is called mechanical fluid motion. The mechanical fluid motion stimulates hair cells in the cochlea to generate electrical signals and send them to the auditory nerve [2, 3]. The brain interprets this signal as sound [4]. If a problem occurs in the hearing process, it causes hearing loss. Hearing loss or hearing impairment is caused by abnormalities of the structure and/or function of the auditory system [1]. Generally, hearing loss can be classified according to which part of the auditory system is damaged. There are two basic types of hearing loss, conductive hearing loss and sensorineural hearing loss. In addition, a combination of both is called mixed hearing loss.

Conductive hearing loss is caused by any disorder or condition that impairs the transmission of sound from the environment to the cochlea, so that the energy reaching the cochlea is less than it should be. The possible causes of conductive hearing loss include: impaction of ear wax in the ear canal, the presence of a foreign body in the ear canal, presence of otitis externa, perforation of tympanic membrane, ossicular chain disruption or discontinuity, etc. This type of hearing loss can often be treated with medicine or surgery.

The second type, sensorineural hearing loss occurs when there is damage to the cochlea and/or auditory nerve. The function of hair cells in the cochlea is transforming mechanical information to neural information. If the cells are damaged, the sound travels through the outer ear, middle ear and inner ear but cannot travel to

the brain for interpretation. There are many causes of sensorineural hearing loss such as ototoxic drugs, exposure of loud sound, congenital disorders, and so forth. Unlike conductive hearing loss, most of sensorineural hearing loss cannot be medically or surgically treated.

The severity of hearing impairment is defined by the degree of hearing loss. It is categorized into five degrees [5] that consists of mild hearing loss (26-40 dB), moderate hearing loss (41-55 dB), moderately severe hearing loss (56-70), severe hearing loss (71-90 dB) and profound hearing loss (91 dB or more). The severity of hearing loss influences the capability of hearing differently [6, 7]. For example, patients with mild hearing loss may have difficulty in hearing soft sounds or listening in a noisy environment, but still hear clearly in a quiet environment. Patients with moderate hearing loss often have difficulty in conversation. They misunderstand speech signals even in quiet environment. In noisy environment, they have more difficulty in understanding speech. For the cases with moderately severe hearing loss, they cannot understand even loud speech. In cases of severe hearing loss, they hardly hear speech. They can hear loud environmental sounds and only the most intense speech sound when speaker is close to the ear. People with profound hearing loss cannot hear any speech sounds. They may perceive some sound as a vibration and use lip-reading to recognize speech. When, hearing loss cannot be medically or surgically treated, ENT doctor and audiologist recommend the patient to use hearing aids. This instrument amplifies sound and makes it loud enough for patient’s hearing level. Patients with mild, moderate and moderately severe hearing loss often receive benefit from using hearing aids, but patients with severe or profound hearing loss receive little or no advantage from hearing aids [8]. Because most of hair cells in the cochlea are damaged and unable to produce a sufficient neural signal to interpret in the brain. With the hearing aids, they can hear better but still cannot hear speech clearly. The cochlear implant is a considerable choice for these patients.

Cochlear implantation has been approved for more than 30 years to help deaf people hear speech again. While hearing aids amplify sound and deliver it to the damaged cochlea, the cochlear implant is designed to bypass the damaged cochlea by means of transforming sounds into electrical signals and sends it directly to stimulate the survival auditory nerve fibers. With this process, deaf people can hear and

understand speech sounds [9]. Most of postligually deafened people who use a cochlear implant can communicate with other people, thus they can return to their work[10]. In cases of prelingually deafened people such as congenital deaf child, who are good candidates cochlear implants and receive proper aural rehabilitation, they have limitations in speech perception than the postlingually deafened group, but still develop speech and language like normal children [11, 12].

Cochlear implant consists of two components; the internal and external parts. The internal part is called implant package that is surgically placed in the skull by the surgeon. This part includes the receiver that is placed under the scalp behind the ear and electrode array that is surgically inserted through the mastoid and middle ear into the cochlea. Actually, there are number of electrode contacts along the cochlea that aided tonotopic arrangement perception [13]. The external part includes a microphone, sound processor (or speech processor) and transmitting coil. This part is placed behind the ear or in a pocket. The microphone collects the sound and sends to the sound processor component. The acoustic signals are analyzed and converted to electrical signal codes by the processor. The codes contain critical information and characteristics of the acoustic signals. These codes are delivered through the transmitting coil to the receiver that decrypts the electrical signal codes from the speech processor. Then, the receiver transmits the corresponding electrical signal data to the appropriate electrodes to stimulate the auditory nerve fibers.

In general, the audiologist starts initial fitting appointment after the device has been implanted to the patients for approximately 4 weeks [14]. In this procedure, the audiologist creates an individualized set of parameters that determine the characteristics of the electric current used to stimulate the electrode array. The fitting procedure of cochlear implant is called programming or mapping. At present, the mapping process has become more sophisticated because of advance cochlear implant technology provides a variety of complex parameters to improve sound quality. However, every cochlear implant requires two levels of electrical stimulation that are the important parameters.

The first level is called threshold level (T-level) that is defined as the minimum electric current required for the cochlear implant users to perceive the sound. The second level is called most comfortable level (M or C-level) that is

referred to as the upper limit of electric current at which a sound is most comfortable or loud but comfortable[15]. Typically, the T-level and M-level are set by the behavioral method. Both levels are measured using verbal feedback from the device users. The stimulation is presented at a low level and slowly increased until the cochlear implant user detects the sound, then up and down procedure, which like an audiometry procedure is used to find T-level. When the T-level is determined, the level of current is gradually increased until the user reports that the perception meets comfortable level. This level is defined as M-level. However, the T-level has less impact on speech perception performance. Smoorenburg et al. found that M-level has a greater effect on patient performance than T-level [16]. Therefore, the primary emphasis of mapping session is the M-level. Some of the cochlear implant brands recommend that the T-level may be set equal to 10 percent of the M-level in each electrode [17].

Most of adult cochlear implant users find the fitting procedure to be difficult because of the fact that the patients need a period to learn about the sound from their devices. Moreover, an auditory sensation is different for each stimulation channel. For this reason, most of the patients feel fatigue and strain to identify the loudness level in each electrode. For pediatric users, who lack the auditory experience, language and cognitive abilities to cooperate with fitting tasks, the challenge is much greater [18, 19]. Because of their skills, young children often provide questionable behavioral responses. The audiologists have to determine the response based on observation of the child's reactions to stimulus, such as sudden quieting, decrease in activity level, searching for the sound or crying. The appropriate setting of M-levels are important to accomplish a reasonable performance of the cochlear implant[20]. An inaccurate measurement of M-level settings may result in poor speech perception and may cause the delay in speech and language development [21]. Therefore, objective methods are necessary for the improvement of precise M-levels in young children. There are many researches shown that objective methods are efficient for the M-levels settings [22-25].

Objective methods provide not only useful information for mapping procedure, but also reduce the time for mapping in children who have limited attention span. There are varieties of objective method available to obtain information that help

establishing M-levels; include the electrical evoked compound action potential (ECAP) [26-29], electrical evoked auditory brainstem response (EABR) [30-33] and electrical stapedius reflex threshold (ESRT) [34-37]. Even though the results of three measurements have been shown that there were correlations with M-levels from behavioral method [38], but the ESRT seems to be the most useful method because EABR and ECAP provide not enough accuracy and sufficient data to mapping [39]. Moreover, the advantage of ESRT compared to EABR and ECAP is less electrical artifacts [40].

1.2 Statement of the problem

At present, the minimal age of implantation has continued to decrease. So, the need for objective measurements to program the cochlear implant has become more important. The ESRT has been reported as an effective tool for mapping; however, there are a few researches about this topic in pediatric cochlear implant users, especially in Thailand. The majority of subjects used in previous studies were adults. The good performance with maps based on ESRT has been demonstrated in adults should also be demonstrated in children. The purpose of this research is to compare ESRT and M-levels values from behavioral method. In addition, speech discrimination ability with maps based on ESRT measurement and behavioral method in pediatric cochlear implant users were compared.

1.3 Purposes of the research

1. To compare electric currents between behavioral M-level and ESRT in pediatric cochlear implant users.

2. To compare speech discrimination scores between program based on behavioral method and program based on ESRT in pediatric cochlear implant users.

1.4 Research questions

1. Is there any difference in electric current between behavioral M-level and ESRT in pediatric cochlear implant users?

2. Is there any difference in speech discrimination scores between program based on behavioral method and program based on ESRT in pediatric cochlear implant users?

1.5 Expected outcomes of the research

The results of this research can describe about the ESRT in pediatric cochlear implant users. The outcomes may provide the advantages of ESRT. These data may be helpful for audiologist or clinician in accurately predict M-levels in children at the initial fitting process, reduce mapping time and enhance listening performance for appropriate speech and language development.

CHAPTER II
LITERATURE REVIEW

The content in this chapter consists of the anatomy and physiology of the auditory system, the principles of cochlear implant, and programming cochlear implant in pediatric users.

2.1 Anatomy and physiology of auditory system

The auditory system is comprised of the outer ear, middle ear, inner ear (Figure 2.1), and central auditory nervous system.

The outer ear includes the pinna, the ear canal and ending at the tympanic membrane. The pinna made of cartilage covered by skin. It is indented structure, which collect the sound and deliver it into the ear canal. Moreover, it still helps in localizing sound. The ear canal is approximately 2.5 cm to 3.5 cm long and 6.5 mm wide [1]. Normally, the canal has a pipe S shape. The inner two-third of the canal is bony portion and another outer one-third is cartilaginous portion. The outer portion has the tiny hairs and the glands, which produce cerumen (ear wax) [41]. These secretions provide antimicrobacterial functions and also help to keep the canal free of debris and some foreign bodies and insects[1]. The ear canal directs airborne sound waves towards the tympanic membrane and acts as a resonating tube and actually amplifies sounds at between 3,000 and 4,000 Hz. The tympanic membrane divides the outer ear from the middle ear. It transmits the sound vibration from outer ear to middle ear. An average thickness of membrane is about 0.074 mm. The shape of membrane likes a cone which is an ideal shape for transmitting sound.

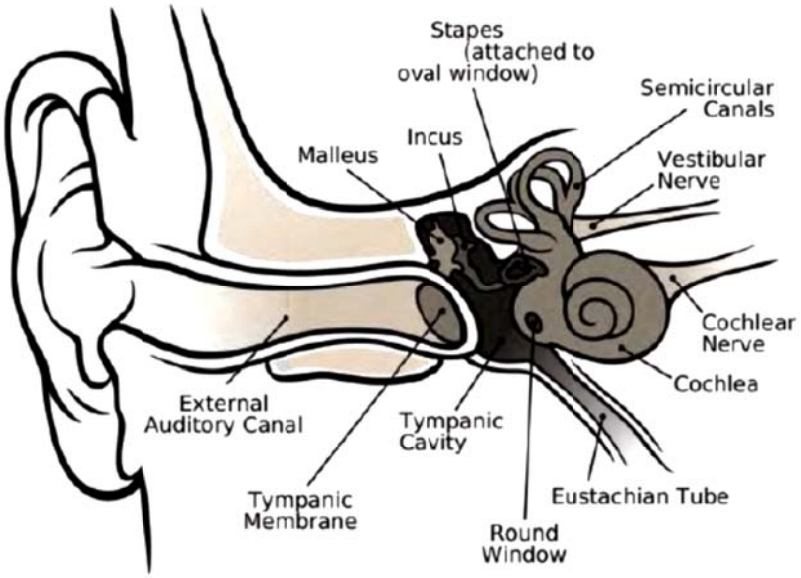

Figure 2.1 The human peripheral auditory system showing the outer ear, middle ear and inner ear [42].

The middle ear is a cavity that locate in the mastoid process of the temporal bone[41]. It consists of ossicular chain, Eustachian tube, which opens and allows the air pressure on both sides of the tympanic membrane to equalize, and two small muscles called 1) stapedius muscle and, 2) tensor tympani muscle. The middle ear transmits the sound vibration to the inner ear via the ossicular chain. The ossicular chain includes three tiny bones: the malleus, incus, and stapes. The stapes connects to inner ear by an oval window of the cochlea. When the tympanic membrane has vibrations that make the malleus move and send the vibration to incus, then the incus receives the vibration and passes it to stapes. The stapes transmits the vibration to the inner ear via the oval window of the cochlea.

The inner ear is composed of 2 functional systems. The systems are separate, yet both are encased in the same bony capsule and share the same fluid systems as shown in Figure 2.2. The hearing system is known as the cochlea. This system has the sensory organs for hearing, which transform sound to nerve signals. The vestibular system plays an important role in maintaining balance of the body. This system consists of urticle, saccule and three semicircular canals.

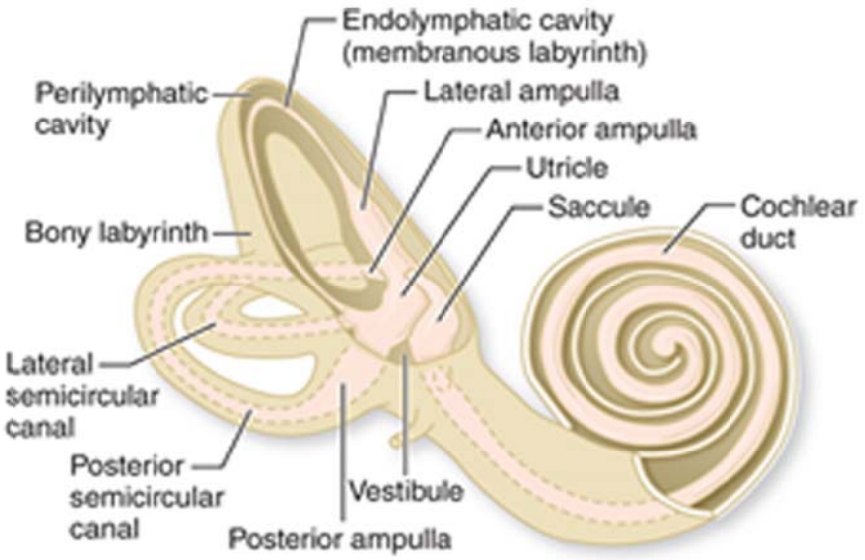

Figure 2.2 The right inner ear, view from front [43].

The cochlea has a shape like a spiral of two and a half turns. It coils around a bony pillar called modiolus. The cochlea is set up like a duct within a duct. The outside duct is called bony labyrinth and the inside duct is called membranous labyrinth. The cochlea is separated into three chambers (Figure 2.3). From above down, these are the scala vestibuli, the scala media and the scala tympani. All chambers are filled with fluid. The fluid in scala vestibuli and scala tympani is called perilymph. There is linkage between the perilymph of the scala vestibuli and the scala tympani at the cochlea's apex at a point known as the helicotrema. The fluid in scala media is called endolymph.

The scala vestibuli extends from oval window to helicotrema and the scala tympani extends from the helicotrema to terminate at a round window. The scala media is a closed, triangular cavity bounded above by Reissner's membrane and below by the basilar membrane upon which lies the organ of Corti (Figure 2.4). The organ of Corti is sensory organ for hearing. It comprises the tectorial membrane, supporting cells, and hearing receptor cells called hair cells. The hair cells are divided into four rows. There are one row of inner hair cells(about 3500 cells) and three rows of outer hair cell(about 12000 cells) [1]. Each hair cell has many hairs called stereocilia that extend into the endolymph. The neural impluses are produced when stereocilia are

bending back and forth in relationship with fluid movement in the inner ear[44]. Approximately 90% of the afferent fibers come from inner hair cells and the remaining 10% come from outer hair cells. These fibers are joined to form the cochlear nerve and, integrated with the vestibular nerve, become the vestibulocochlear nerve. This nerve runs through the internal auditory meatus to the central auditory system[2].

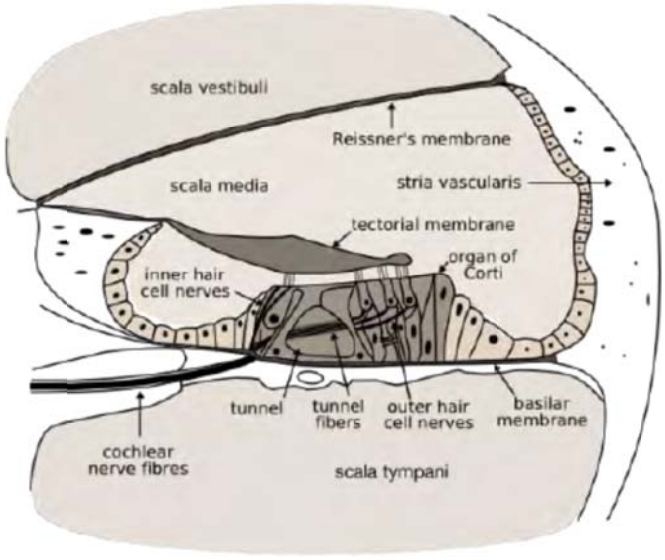

Figure 2.3 Cross section of the cochlea, showing the basilar membrane, Reissner's membrane, the three scala and the organ of Corti [42].

The transduction of sound to neural signals is occurred when the stapes transmits the vibration into the cochlea at the oval window. Then the perilymph moves along the scala vestibuli through Reissner's membrane that causes simultaneous movement of endolymph in scala media, resulting in vibration of the barsilar membrane. The movement of basilar membrane makes the stereocilia deflect, which produce neural signals.

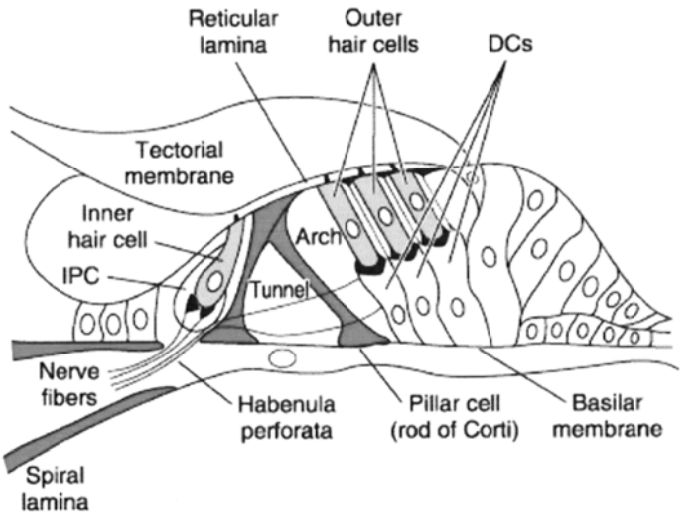

Figure 2.4 Structure of the organ of Corti [45].

2.2 Hearing mechanism

2.2.1 Normal hearing mechanism

Sound is the pressure waves generated by vibrating medium molecules. So, hearing is the ability to perceive sound by detecting vibrations through the auditory system [46]. Sound waves are collected by the pinna and travel through the ear canal toward the tympanic membrane. Sound waves are converted to vibrations by the ossicular chains in the middle ear. Then, the ossicular chains vibrate the oval window, causing fluid movement in the cochlea. The fluid movement leads to moving of basilar membrane that stimulates the hearing receptor cells in the organ of Corti to fire electrical impulses. These impulses are delivered to the brain, where it is interpreted as sound [47].

2.2.2 Hearing loss

Hearing loss or hearing impairment is a partial or total inability to hear. It is caused by many different etiologies. Typically, there are two main types of hearing loss depending on which part of the auditory system is damaged: conductive hearing loss and sensorineural hearing loss.

Conductive hearing loss occurs when sound is not sent through the outer ear and the middle ear, causing the acoustic signals reaching the inner ear is less than it should be. Because conductive hearing loss involves sound energy transmission to the cochlea but not the sensory process in the cochlea, the patients complain about sound too soft but not a loss of clarity [1]. Conductive hearing loss is caused by any disorder or condition that impairs the transmission of sound in the outer ear or the middle ear such as malformation of the outer ear or middle ear, the presence of foreign body in the ear canal, impaction of cerumen, perforation of tympanic membrane, fluid in the middle ear from cold or allergies, ear infection (otitis externa, otitis media), poor eustachian tube function, ossicular chain disruption or discontinuity, the presence of benign tumor, etc. This type of hearing loss can often be treated with medication or surgery.

Sensorineural hearing loss is defined as damage to the cochlea or damage to the auditory nerves. The cochlea contains sensory receptor cells that transform mechanical information into neural information. If these cells are damaged, the auditory system cannot transform sound to neural signals, cause hearing loss. Sensorineural hearing loss reduces the ability to hear speech sounds. Most people with sensorineural hearing loss complain that they can hear speech sounds, but it is unclear or difficult to understand. The impairment of auditory functioning is caused by the acoustic signals cannot travel to the brain for interpreting due to the damaged hair cells cannot produce a sufficient neural signal. The hair cells can be destroyed by the diseases (e.g., meningitis, diabetes, Meniere's disease), ototoxic drugs, exposure of loud sound, congenital disorders, and so forth. Unlike many conductive disorders, medicine and surgery cannot treat sensorineural hearing loss.

The hearing impairment is defined by the degree of hearing loss. According to Roeser [48], the degree of hearing loss is classified by the severity of the loss as shown in Table 2.1.

Table 2.1 Communication difficulty as a function of hearing loss cited in Roeser [48]

Level of Hearing Loss (Pure Tone Average 500-1000-2000 Hz)	**Degree of Hearing Loss**	**Communication difficulty**
25-40 decibel	Mild	Demonstrates difficulty understanding soft speech; good candidate for a hearing aid. Children will needs preferential seating and resource help in school
41-55 decibel	Moderate	Demonstrates an understanding of speech at 3-5 feet; requires the use of hearing aid. Children will needs preferential seating, resource help and speech therapy
56-70 decibel	Moderately Severe	Speech must be loud for auditory reception; difficulty in group discussion, requires the use of hearing aid. Children will require special class for hearing impaired, plus all of the above.
71-90 decibel	Severe	Loud speech may be understood at 1 foot distance; may distinguish vowels but not consonants; requires the use of hearing aid. Children will require special class for hearing impaired, plus all of the above.
90 + decibel	Profound	Does not rely on audition as primary modality for communication; may benefit from hearing aid and cochlear implant; may work well with total communication approach.

When, hearing loss cannot be medically or surgically treated, ENT doctor and audiologist recommend the patient to use the hearing devices. People with mild, moderate and moderately severe hearing loss often receive great benefit from wearing appropriate hearing aids. Unfortunately, hearing aids often perform little benefit for patients with severe and profound hearing loss. Hearing aids which act as a sound amplifier do not cure the damaged organ in auditory system. Hence, patients with severe and profound hearing loss who have a lot of destroyed hair cells and unable to produce an appropriate neural signal to interpret in the brain, do not receive benefit from hearing aids. For patients who receive little or no advantages from hearing aids, the cochlear implant is recommended.

The hearing aids amplify sound and deliver it to the damaged cochlea, while the cochlear implant is designed based on the idea of bypassing the normal hearing mechanism and electrically stimulating of the residual auditory neurons directly. From the research of Hinojosa and Marion indicated that the most common cause of deafness is the loss of hearing receptor cells in cochlea rather than the loss of auditory neurons [49]. Therefore, healthcare professionals encourage the use of cochlear implant in deaf people because their remaining auditory neurons are still stimulate to excite neural signals [47]. With the cochlear implant and appropriate rehabilitation, patients with severe and profound hearing loss can communicate like a normal people.

2.3 Principles of cochlear implant

2.3.1 History of cochlear implant

The first person who interest in using electricity to stimulate the hearing process is Alessandro Volta. In 1800, he experimented by discharging electricity into the metal rod that was inserted in his ear. He reported that electrical stimulation produced an auditory sensation. He explained this sensation as “a boom within the head”. In 1855, Duchenne reported data about the use of alternating current to stimulate the ear. He received a sound similar to the beating of a fly’s wing. In 1939, Stevens and Jones published the theory of electrical stimulation of the ear. They

suggested that the electricity could be transformed into sound by the middle ear that acts as a transducer, before it reached the inner ear. This hearing was called the electrophonic effect. In 1940's, most researchers focused on electrophonic hearing until in 1950, electrical stimulation of auditory nerve was found by neurosurgeon named Lundberg. He stimulated the auditory nerve with sinusoidal current during the operation. The patient heard only noise. However, a more detail research followed in 1957 by Djourno and Eyries. They placed a wire on the auditory nerve of deaf people who was undergoing surgery. Their patient reported that a sound resembled as "a roulette wheel of the casino"[50]. This observation inspired the doctor to search for treatment of deafness. In 1963, American otologist William House and the neurosurgeon John Doyle stimulated the auditory nerve of patients with total deafness by electric current via the electrode array that was inserted through the round window into the scala tympani of the cochlea. The patients reported that they had auditory perception. They found that loudness changed with level of electric current and pitch changed with variation in the rate of stimulation [51]. In 1966, Simmons provided more data about position of electrode that involve to sound perception. He placed six electrode array through the promontory and vestibule directly into the modiolus of the cochlea. The subjects were tested to assess the effect of variation in the frequency and intensity of the signal. He reported that these subjects could detect the change of signal duration and perceive tonality of sound[52]. In 1972, House 3M which a first cochlear implant was developed by William House and Jack Urban[53](Figure 2.5). The House 3M was single channel device and was approved by United States Food and Drug Administration (US FDA) in 1984. At the same time, the Australian otologist Graeme Clark evolved the multi-channel cochlear implant. He successfully developed in 1978[54]. In 1982, the first commercial multi-channel device was introduced under the name of Cochlear Nucleus22 and was approved by FDA in 1985. This device enhanced the speech perception and speech recognition abilities compared to the single channel device[55]. Since the 1990's, clinical researches have resulted in improving in cochlear implant technology and clinical approaches to cochlear implant. Average performance has improved significantly over the course of the past decade. So, cochlear implant was accepted in helping deaf people to hear speech again.

Figure 2.5 The House 3M single channel cochlear implant: the body worn speech processor unit with transmitting coil and microphone cable[42].

Currently, there are four major cochlear implant manufacturers have commercially available systems on the market (Figure 2.6). These include the Advanced Bionics Corporation, Med-EL Hearing Technologies and Cochlear Ltd. that were approved by FDA for use in the United States, and the Neurelec complied with international standards ISO 9001 and ISO 13485.

Figure 2.6 The speech processors of the 4 cochlear implant manufacturers: from left to right: Cochlear Ltd., Med-EL Hearing Technologies, Advanced Bionics Corporation and Neurelec [42].

2.3.2 Components of cochlear implant

The components of cochlear implant are divided into internal and external parts as shown in Figure 2.7. The internal parts are surgically placed in the skull by the surgeon, including a receiver and an electrode array. The receiver is referred as the implant package which surgically positioned beneath the muscle tissue and skin at behind the ear. The implant package is usually made from titanium or ceramic. The implant package does not have its own battery, but is powered by the speech processor via electromagnetic induction. The electrode array, which reaches from implant package, is surgically inserted through the mastoid and middle ear into the cochlea. The array is usually inserted into the Scala tympani through the round window. Because of placing the electrode array closer to the modiolus or the inner wall of the scala tympani can reduce the electric current needed for stimulation of the nerve endings [56, 57]. The wire in the array is made out of platinum-iridium alloy and covered in silicon. There are a number of electrode contacts along the electrode array that imitate the function of 10000 hair cells in the cochlea. Different electrodes are stimulated according to the frequency of the signal. Electrodes at the base of cochlea are stimulated with high frequency signals, while electrodes at the apex are stimulated with low frequency signal.

The external parts consist of a microphone, speech processor and transmitting coil. This part is placed behind the ear or in a pocket. The microphone is responsible for picks up the sound in environment and sends it to speech processor. The microphone for a cochlear implant system is designed to have broad frequency response that does not extend to very low frequencies in order to reduce picking up low frequency that occurred by walking and head movements [56]. The speech processor is like a computer that uses different processing strategies to analyze and transforms acoustic signals from microphone into patterns of electrical signal codes. This signal is sent to the transmitting coil which encodes the stimulus information into a radio frequency signal and sends across the skin to the receiver in implant package. The transmitting coil is kept in place over the receiver with a pair of external and internal magnets.

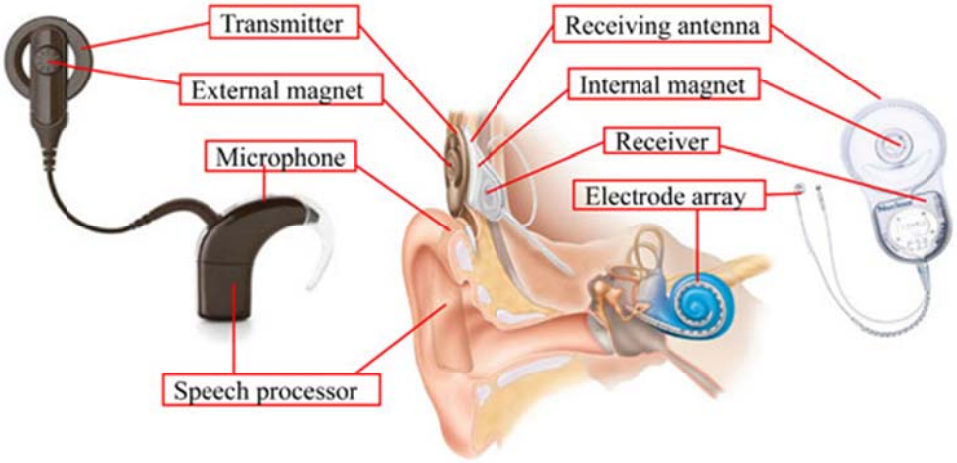

Figure 2.7 The components of cochlear implant (external and internal parts)

2.3.3 Mechanism of cochlear implant

The function of the ear is to transform physical vibration into encoding nervous impulse. The normal hearing process starts from sound travels through the outer ear to middle ear which transforms sounds into mechanical energy and sends it to cochlea. This energy stimulates mechanical fluid motion in the cochlea. The hair cells in cochlea are stimulated by mechanical fluid motion to generate electrical signals and transmit it to the auditory nerve.

Cochlear implant is designed to help in bypassing this process, by transforming sounds into electrical signals and sends it directly to stimulate the auditory nerve. The functionality of cochlear implant relies on joint capabilities of the external and internal parts. Sound waves are picked up by the microphone. The microphone output is conveyed to the speech processor which filters, analyzes and rectifies the acoustic signals into digital signal codes. These codes contain information about how to activate each electrode. The speech processor sends encoded signals to the transmitting coil that change digital signals to radio frequency signal and deliver to the receiver. The receiver decodes the signals and transmits a synchronous pattern of stimulation signals to the individual electrodes on the electrode array to stimulate the cochlea which lead the signals along the auditory nerve to the brain for interpretation [13]. Figure 2.8 shows the mechanism of cochlear implant.

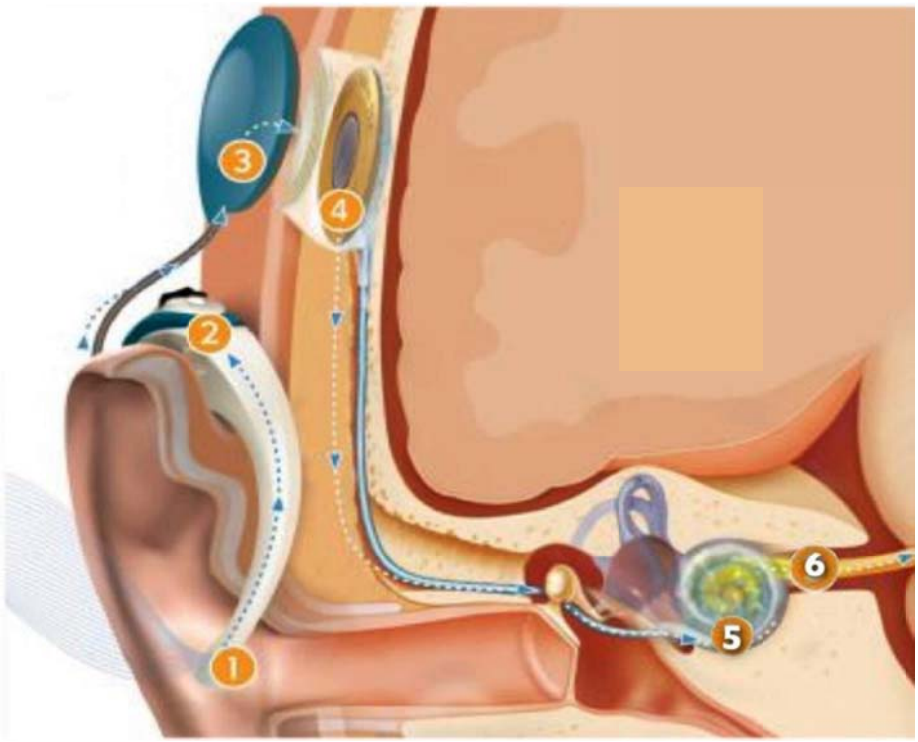

Figure 2.8 Mechanism of cochlear implant. (1) Sounds are received by the microphone. (2) The speech processor analyzes and codes the sounds to digital signal. (3) The coded signals are sent from the transmitting coil by means of radio frequency signals to the receiver under the skin. (4) The receiver decodes the signal transmitted into electrical signal pattern. (5) The electrical signals are sent to the electrode array in the cochlea. (6) The cochlear nerve fibers are stimulated and transfer neural signal to the brain where sound is interpreted [42].

2.3.4 Evaluation for candidacy

During the past decade, the indication for cochlear implantation evolved significantly due to improvement in cochlear implant technology, positive outcomes with cochlear implant and safer surgery. For instance, in 1980, cochlear implants were recommended for deafened adults while at present, the minimum age of implantation has decreased down to 12 months [58]. However, the basic requirement for cochlear implant candidate is still a presence of bilateral deaf or bilateral severe hearing loss

and no benefits from using hearing aids. Generally, the selection of candidate requires an audiological, medical and psychological evaluation.

The primary method of determining cochlear implant candidate is the audiological evaluation. The purpose of the evaluation is to identify current candidate's hearing under both unaided and aided conditions, and to guide rehabilitation after implantation. The evaluations include a pure tone audiometry, an evaluation of current hearing aids and speech perception test. In case of children, subjective and objective tests (e.g. ABR, ASSR) are used together to find hearing thresholds. Before consideration for cochlear implantation, pediatric candidates usually undergo a trial period with a hearing aid. In General, if a result indicates bilateral severe or profound hearing loss with no benefit from hearing aids then the patient is a candidate for cochlear implant.

The medical evaluation is required to examine the patient's general health, ability to undergo anesthesia and physical condition of the cochlea and auditory nerve. These investigations aim to verifying whether the patient is healthy enough to undergo surgical procedure [58]. Furthermore, a history and etiology of patient's hearing loss should be identified. It helps cochlear implantation team to create realistic expectations for patients, and to design appropriate rehabilitation protocol [59].

The psychological evaluation is also important, as well as audiological and medical assessment. The concerns in cochlear implant surgery and the hope for positive performance outcomes lead stress to patients and their family. This evaluation is done to ensure that the expectation of candidates and family are realistic and that they understand the implantation and following process. Moreover, the evaluation may help the candidates to accept the negative results after implantation if the post-implant performance is not as expected. In children, the evaluation is more extensive that include developmental and educational evaluations. The choice of using cochlear implant is usually associated with the choice of spoken language as the primary communication mode of the child's family. Planning a rehabilitation and education before implantation makes the progress of child's performance faster [59]. Current cochlear implant indication are summarized in Table 2.2

Table 2.2 Current indications for cochlear implantation [60, 61]

	Indications
Adults :	– Severe to profound bilateral sensorineural hearing loss. – Little or no useful benefit from appropriate binaural hearing aids: o Open set speech discrimination scores in quiet in the better ear < 45%. – No radiological or medical contraindications (e.g. deformity of cochlea, absence of cochlear nerve, cardiac abnormalities). – Patient has appropriate expectations and motivation.
Children :	– Age ≥ 12 months. (In case of meningitis may be considered earlier) – Bilateral severe to profound sensorineural hearing loss. – Little or no benefit from appropriate binaural hearing aids (minimum of 3 months trial period): o Lack of progress in development of simple auditory skills. – No radiological or medical contraindications (e.g. deformity of cochlea, absence of cochlear nerve, cardiac abnormalities). – The family has appropriate expectations and motivation. – Family commits to support the rehabilitation for development of hearing and speaking.

2.4 Programming cochlear implant in pediatric users

Approximately 3-4 weeks following surgical implantation, the speech processor must be individually programmed, which is usually called programming, fitting or mapping. The aim of programming is to create a set of parameters to ensure that the electrical pattern generated by the internal part of cochlear implant in response

to sound, yields an appropriately auditory perception for individual users[62]. The programming should be performed by healthcare professionals (e.g. audiologists) with specialized training in the field of cochlear implants. The professionals use proprietary fitting software, which are provided by the cochlear implant manufacturer, to create individualized patient programs and download to the memory of patient's speech processor. There are several available tuning parameters that can be manipulated to improve speech perception performance. However, the important parameter that needs to be adjusted is the level of electric current which use to stimulate on each electrode. The level of electric current consists of threshold level and most comfortable level.

The threshold level (abbreviated as THR or T-level) is minimum electric current that required for the cochlear implant users to detect sound. The most comfortable level (abbreviated as MCL, M-level or C-level) defined as the upper limit of electric current that make the cochlear implant users perceive the sound as comfortable level. T-level and M-level are psychophysical judgments of loudness in response to electrical stimulation. Normally, T-level and M-level are behaviorally measured by means of using verbal feedback from the users. The users must indicate when sound is first perceived and when it is comfortably loud. The electric current is presented at a low level and slowly increases until the user experiences sensation of hearing, then up and down procedure, like audiometry procedure. Actually, T-level is first considers. When the T-level is determined, the currents are gradually increased until the user reports that the sound meets comfortable level. This level is defined as M-level. However, the methods used and the degree of difficulty in obtaining these measures varies depending on several factors (e.g. patient's chronologic age, other handicap conditions, and so forth). In pediatric users, both behavioral and objective methods are especially important because they are limited to provide response due to lack of listening experiences, attention span and cognitive abilities. The preferred method differs based on the age and abilities of the individual child.

2.4.1 Behavioral method

Behavioral method requires the patient's cooperation to indicate when they have heard a stimulus. For children, they are able to indicate in a variety of ways, according to age, auditory experience, and cognitive abilities. It is important to engage

the children in a suitable method. The method selected should be appropriate to their age and developmental levels. For older children who have prior auditory experience, the similar behavioral method utilized with adult patient can often be used. In process of setting T-level, the children are asked to indicate whenever they detect the stimulus. They may respond by saying or raising their hands. Nevertheless, obtaining accurate M-level can be much more difficult, because most children do not have enough listening experience to understand the concept soft versus loud. A graphic representations may be used with the child who are able to understand the symbolic transfer [17]. The pictures should illustrate various levels of loudness, ranging from soft, comfortable to uncomfortably loud (Figure 2.9).

For young children, behavioral observation is the considerable choice to be used. The clinician has to observe the child for any behavioral change that is time-locked to the stimulus. Two clinicians are usually involved in programming the cochlear implant in young children. One operates the computer that delivers the stimulation and the other interacts with the child. The child's responses are turning to search for the sound, touching the ear or head, sudden quieting, increased vocalization, blinking or crying. The children respond to sound differently, based on whether the stimulus is soft or loud.

For T-level setting, some children can provide reliable response because they only determine that presence or absence of sound, but setting the M-level, obtaining data with good reliability is extremely difficult due to lacking of the auditory experience that necessary for considering about the loudness of sound [20]. Most children often respond to supra-threshold levels of stimulation. Thus, T-level may be set higher than the child's true threshold, and M-level may exceed comfortable level.

2.4.2 Objective methods

In pediatric cochlear implant users, the use of behavioral methods to determine stimulation levels may be obtained with questionable data due to the limited cooperation of the children [63]. Objective methods do not require active participation from the patient. Thus, using objective methods may be useful for programming in children. These methods have been suggested as method of more effectively setting electrical stimulation levels in pediatric cochlear implant users [23, 25].

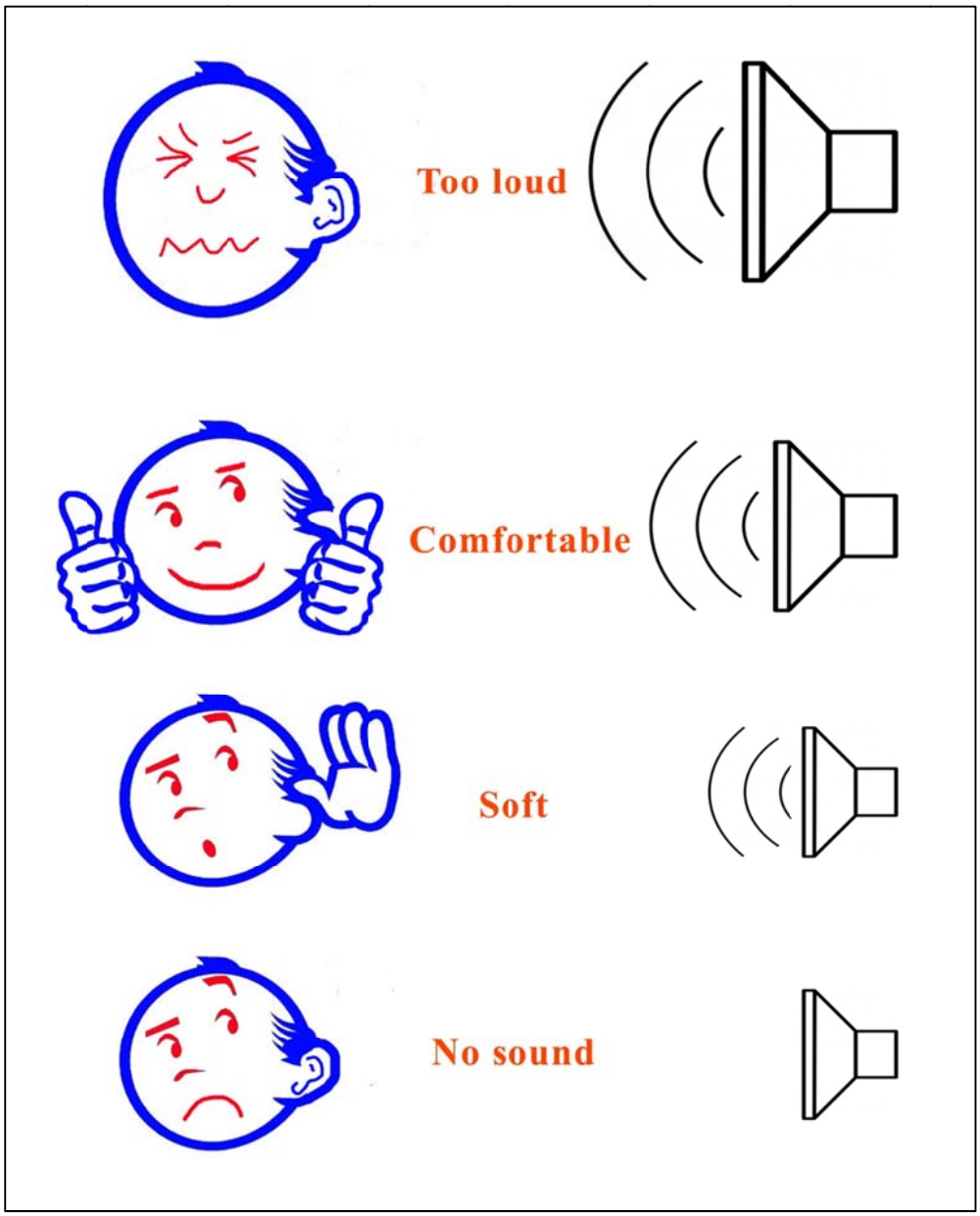

Figure 2.9 The graphic representations demonstrate different loudness level

There are various techniques that have been studied for the purposes of programming cochlear implant, including the use of the electrical evoked compound action potential (ECAP)[26-29], electrical evoked auditory brainstem response (EABR)[30-33] and electrical stapedius reflex threshold (ESRT) [34-37]. The relationship between three objective methods with behavioral measures of T-level and M-level in the same subjects has been reported by Gordon et al. They described that behavioral T-level best correlated with the ECAP and behavioral M-level best

correlated with the ESRT [38]. The EABR and ECAP did not correlate well with M-level probably because of difference in stimulus that is used to evoked response [64, 65]. While the stimulus used to program the cochlear implant is high pulse rate, the stimulus that results in optimal EABR and ECAP response is a slower pulse rate. The EABR and ECAP responses tend to present within the dynamic range that above T-level not exceed M-level [24, 39, 66]. Other advantage of ESRT compared to EABR and ECAP is less electrical artifacts during testing [40].

Since, M-level has greater influence on speech perception performance than T-level [16], the ESRT that well match with M-level becomes an ideal tool for programming cochlear implant in children.

2.4.2.1 Electrical stapedius reflex threshold (ESRT)

The stapedius reflex or acoustic reflex is referred as a contraction of the stapedius muscle induced by intense sounds. In normal ear, the reflex is elicited bilaterally in response to stimulation that is presented to either ear. The ipsilateral and contralateral pathways of the stapedius reflex are shown in Figure 2.10. The reflex is normally elicited by acoustic stimulation, and can also be elicited by electrical stimulation that is defined as electrical stapedius reflex. Thus, electrical stapedius reflex threshold is defined as the lowest level of electrical stimulus that elicits a contraction of stapedius muscle. In cochlear implant users, the electrical stapedius reflex can be measured in contralateral ear in response to electrical stimulation through the cochlear implant. In addition, electrical stapedius reflex can be recorded in intra-operative procedure. It is applied to assessing the function of cochlear implant, as well as confirming that the auditory pathway responds to the stimulation, at the time of surgery [67].

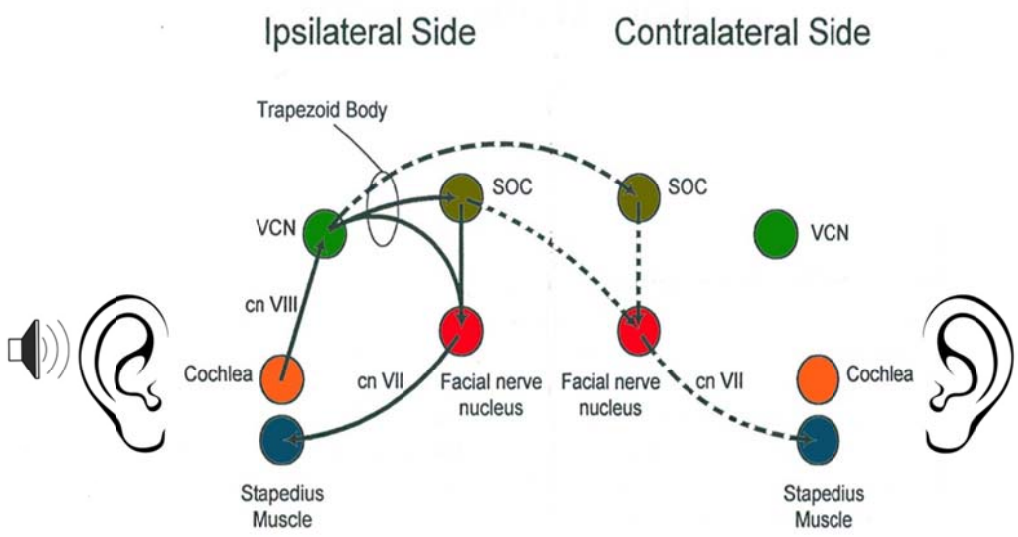

Figure 2.10 Schematic diagram of the ipsilateral and contralateral stapedius reflex pathways; cn VIII : auditory nerve; cn VII : motor branch of facial nerve; VCN : ventral cochlear nucleus; SOC : superior olivary complex (adapted from Gelfand [68])

The possibility of electrical stapedius reflex was first described by using electrical stimulation through an intracochlear electrode array in monkeys[69]. The use of electrical stapedius reflex in cochlear implant patients was demonstrated by Jerger et al. [70]. They found that characteristics of the electrically reflex were similar to characteristics of the acoustically reflex. Early studies investigated the relationship between electrically reflex amplitude growth function and dynamic range of loudness perception. In a study of 7 adults cochlear implant patients by Jerger et al., they reported that comfortable loudness levels were located between the ESRT and reflex saturation levels [34]. These findings were confirmed by studies of Stephan et al. Their studies showed that ESRT were located in the upper portion of the dynamic range between the comfortable level and the uncomfortable level [40, 71, 72]. Similar results were found by Battmer et al. [73]. Whereas, Bresnihan et al. reported that the ESRT were found to be consistently lower than M-levels [74].

Further research tends to focus in using ESRT for programming cochlear implant. Spivak and Chute [75] investigated the relationship between ESRT and behavioral M-level in 35 cochlear implant patients (16 adults and 19 children). The results showed good agreement between ESRT and M-level.

Moreover, the ESRT rarely reach the uncomfortable level. They suggested that the ESRT may be useful in fitting cochlear implant of adults and children. The comparison between ESRT and behavioral M-level was also studied by Spivak et al. [76]. They found that there was no significant difference between ESRT and M-level in 7 adults cochlear implant patients. Similar results were demonstrated by Lorens et al. who studied in 7 pediatric cohlear implant patients [77]. Many studies have shown that the correlation between ESRT and behavioral M-level was high. Hodges et al. studied with 25 adults cochlear implant users, and reported a correlation coefficient of 0.91[78]. Similarly, Stephan and Welzl-Muller found a correlation of 0.92 with 6 adults cochlear implant patients [36].

There were many researchers who reported about the patient's speech perception when using program based on ESRT. Spivak et al. [76] demonstrated that no significant differences between scores obtained with the program based on ESRT versus program based on behavioral M-level for the test of NU-6 word, NU-6 phoneme and CUNY sentence. They also reported that 4 of 7 subjects preferred the sound quality from program based on ESRT than program based on behavioral M-level. Similar findings were reported by other researchers. Hodges et al. [78] studied with 5 adult cochlear implant users, and found that speech discrimination scores obtained with behaviorally developed program were similar to those obtained with ESRT program. In addition, Kosaner et al.[21] investigated the performance of children using ESRT generated program. Their studies consisted of sound field measurement and speech perception test with closed-set monosyllabic word test. The results showed that mean of sound field thresholds were 37 dBHL at 250 Hz, 37 dBHL at 500 Hz, 33 dBHL at 1000 Hz, 34 dBHL at 2000 Hz, 35 dBHL at 4000 Hz and 33 dBHL at 6000 Hz, and mean closed-set monosyllable scores were 81%. They suggested that ESRT generated program provide performances which are similar to behavioral method.

CHAPTER III
MATERIALS AND METHODS

The purposes of this research were to study ESRT in pediatric cochlear implant users and compare electric current between M-level from behavioral method and ESRT. Then, compare speech discrimination scores between program based on behavioral method and program based on ESRT values in pediatric cochlear implant users. The materials and methods were described as follows:

3.1 Subjects

The subjects were selected from 62 pediatric cochlear implant patients who were implanted at Ramathibodi Hospital in January 2005-December 2013. Subjects were selected based on following criteria:

- Age less than 15 years.
- Previously performed the speech discrimination scores.
- Presence of Type A tympanogram both ears.

Nineteen of them who met the inclusion criteria were selected. Their parents were willing to participate in the study. All subjects in this study were evaluated after their parents had completed informed consent form.

3.2 Research materials and instrumentations

The instruments used in this research were the followings:

3.2.1 Computer with cochlear implant programming software and interface system

3.2.2 Tympanometer, GSI Tympstar^{TM} which has been calibrated based on ANSI S3.39-1987.

3.2.3 Audiometer, GSI 61 which has been calibrated based on ANSI S3.6-1996.

3.2.4 Computer for play the video cartoon that makes the child to remains motionless during procedure.

3.2.5 Speech material: RAMA SD I & II that consisted of 8 phonetically balanced word lists. Each list includes 25 monosyllabic words.

3.3 Procedures

The procedure in this research was divided into 3 stages as follows:

1) The subject's program was created by the behavioral method. The M-levels were identified for all active electrodes using an ascending procedure. The electric current was presented and gradually increased until the subject reported that the loudness was comfortable level. The T-levels were set at 10% of M-levels.

2) The ESRT were recorded by using the standard tympanometer. Before testing, the probe of tympanometer has been calibrated with test cavity box. The ESRT recording procedure was shown in Figure 3.1. To minimize the artifacts caused by movement, subjects were allowed to watch an age-appropriate video (e.g. no sound cartoon, movie). The recording of ESRT was attempted in the ear contralateral to the cochlear implant side. The tympanometer was set to reflex decay testing mode, providing a longer recording window. A 226 Hz probe tone was used. The presence of electrical stapedius reflex was represented as deflections in the pre-stimulus baseline (Figure 3.2). The ESRT were determined using an ascending-descending approach. The stimulus level was presented at M-level of behavioral response. If a stapedius reflex was observed, the stimulus level was decreased by 5 cu. If no reflex was observed, the stimulus level was increased by 2 cu until a reflex was seen. The lowest stimulus level that produced detectable deflections in the baseline was recorded as the ESRT. The ESRT were measured for all active electrodes. The test will be stopped when the subjects reported that the sound was too loud or they felt discomfort. The subject's program was created. M-levels were set based on ESRT measurement and T-levels were set at 10% of M-levels.

3) All two experimental programs were loaded into subjects's cochlear implant speech processor. Speech discrimination ability was performed for both programs. Subjects were seated in a sound-proof room. All live-voice speech material was presented from a loudspeaker that located directly in front of (0 degree azimuth) and 1 meter away from the subject at the level of 60 dBHL. The speech signal was adjusted and calibrated through the volume unit (VU) meter. The materials for speech discrimination test were Rama SD I&II. Each program was tested by two lists that are randomized. Subjects were instructed to repeat each of the words and were encouraged to guess if necessary. The speech discrimination scores were recorded.

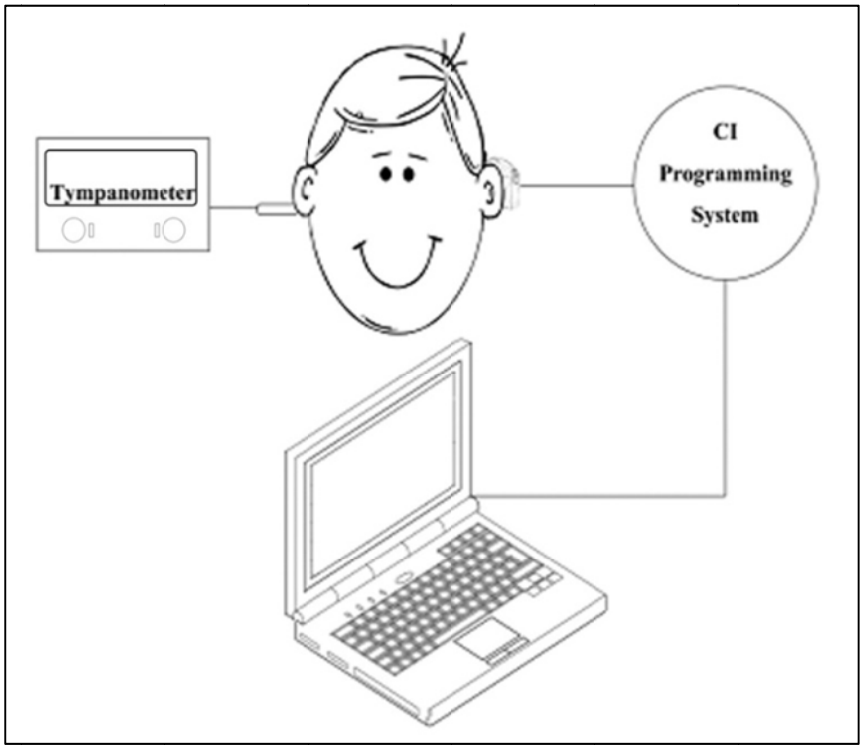

Figure 3.1 Schematic diagram of instrument set up for recording electrical stapedius reflex thresholds.

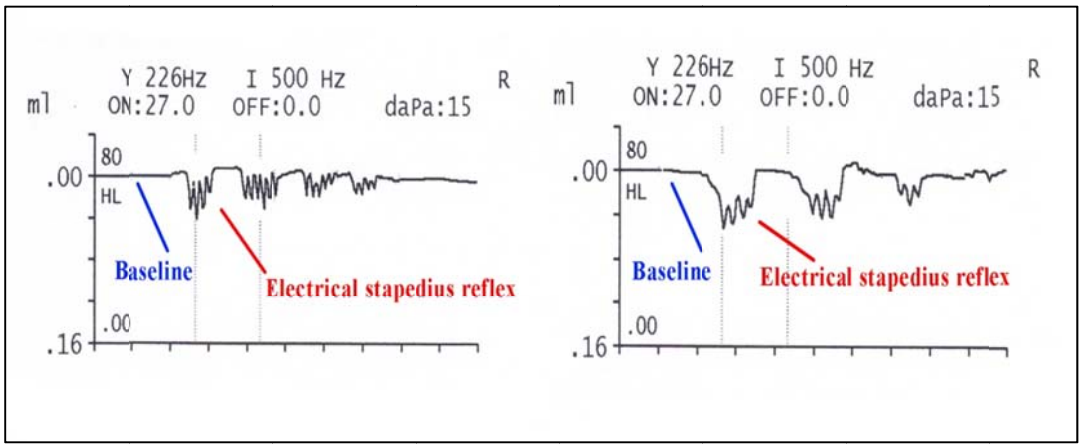

Figure 3.2 Examples of electrical stapedius reflex from 2 pediatric cochlear implant users.

3.4 Data analysis

The research data were analyzed according to the purpose of the research as follows:

3.4.1 Paired t test was used to compare electric current between behavioral M-level and ESRT in pediatric cochlear implant users. The difference was considered to be significant when $p < 0.05$.

3.4.2 Paired t test was used to compare speech discrimination scores between program based on behavioral method and program based on ESRT in pediatric cochlear implant users. The difference was considered to be significant when $p < 0.05$.

All data were analyzed by using predictive analysis software statistics version 18 (PASW 18.0).

CHAPTER IV
RESULTS

The major goals of this research were to compare electric current between M-level from behavioral method and ESRT, and to compare speech discrimination scores which were performed under the program based on behavioral method and program based on ESRT in pediatric cochlear implant users.

A total of 19 pediatric cochlear implant users participated in this study. All children had unilateral cochlear implant. The children comprised 8 males and 11 females. The mean age of them was 11.16 years, with a range of 6-14 years. Eleven of them used Advanced Bionics implant and another eight used Med-EL implant. Mean age at implantation was 5.34 years. The mean duration of implant usage of the subjects was 5.82 years. The characteristics of the subjects were shown in Table 4.1.

The research data were analyzed according to the following parts:

4.1 The comparison of electric current level between behavioral M-level and ESRT in pediatric cochlear implant users.

4.2 The comparison of speech discrimination scores which were performed under the program based on behavioral method and the program based on ESRT in pediatric cochlear implant users.

Table 4.1 Characteristics of the subjects.

	n	**Percentage**
Gender		
Male	8	42.1
Female	11	57.9
Brands of CI		
Advanced Bionics	11	57.9
Med-EL	8	42.1
	Mean ± SD	
Subject's age (years)	11.16 ± 2.90	
Age at implantation (years)	5.34 ± 2.46	
Duration of cochlear implant usage (years)	5.82 ± 1.53	

4.1 The comparison of electrical current between behavioral M-level and ESRT in pediatric cochlear implant users.

In the behavioral method, M-level values were obtained in all subjects. The ESRT were obtained only in 15 subjects (79%), whereas in 4 subjects reported loudness discomfort before reaching the stimulus level for eliciting stapedius reflex. 2 subjects showed no reflex response only a few channels that situated in the basal portion of the cochlea, another 2 subjects did not demonstrate ESRT at every channel. In this research, the mean of behavioral M-level and ESRT were calculated from 15 cases who exhibited ESRT. The mean and standard deviations of behavioral M-level and ESRT in Advanced Bionics subjects were presented in Table 4.2 and Med-EL were presented in Table 4.3. The results of both brands showed no statistically significant difference between electric current of behavioral M- level and ESRT in every channel.

Table 4.2 Mean, standard deviation, t and p-value of ESRT and behavioral M-level in Advanced Bionics pediatric cochlear implant users (n = 8).

	M-level of Behavioral Method		ESRT		t	p-value
	Mean	**SD**	**Mean**	**SD**		
Channel 1	288.75	147.82	284.00	147.06	1.715	.130
Channel 2	296.13	147.11	295.63	146.38	.160	.877
Channel 3	306.63	158.31	308.88	155.42	-.798	.451
Channel 4	322.25	165.63	325.00	163.15	-.479	.646
Channel 5	334.38	166.32	339.88	163.13	-.720	.495
Channel 6	333.88	154.14	340.25	148.57	-.933	.382
Channel 7	332.00	149.63	340.75	142.77	-.981	.359
Channel 8	322.86	130.01	333.00	125.46	-1.246	.253
Channel 9	313.13	111.55	321.75	105.41	-.846	.425
Channel 10	312.63	105.00	324.63	97.31	-1.089	.312
Channel 11	304.00	95.18	318.25	86.72	-1.141	.291
Channel 12	303.38	89.31	309.38	86.69	-.906	.395
Channel 13	301.50	83.29	305.38	79.63	-.582	.579
Channel 14	298.50	75.91	306.25	71.01	-1.230	.258
Channel 15	294.63	72.21	301.88	66.74	-.740	.484
Channel 16	212.00	148.26	222.13	151.31	-.804	.448

Table 4.3 Mean, standard deviation, t and p-value of ESRT and behavioral M-level in Med-EL pediatric cochlear implant users (n = 7)

	M-level of Behavioral Method		ESRT		t	p-value
	Mean	**SD**	**Mean**	**SD**		
Channel 1	25.43	9.31	24.25	7.37	1.334	.231
Channel 2	27.10	10.76	25.79	9.63	2.180	.072
Channel 3	26.88	11.87	27.58	11.57	-1.241	.261
Channel 4	29.16	12.71	29.21	13.28	-.037	.972
Channel 5	31.17	14.28	31.44	15.01	-.175	.867
Channel 6	30.74	14.89	31.84	16.44	-.750	.482
Channel 7	31.39	15.08	33.32	16.90	-.971	.369
Channel 8	25.50	18.88	27.02	20.20	-.913	.396
Channel 9	18.30	22.16	20.30	23.84	-1.691	.142
Channel 10	30.23	15.35	31.71	16.39	-.808	.450
Channel 11	21.46	19.14	23.68	21.61	-1.590	.163
Channel 12	26.29	15.78	27.17	16.97	-.611	.564

4.2 The comparison of speech discrimination scores which were performed under the program based on behavioral method and program based on ESRT in 15 subjects.

The results of Advanced Bionics users showd that the mean of speech discrimination scores which were performed under the program based on ESRT was 62.25%. Mean of speech discrimination scores when using program based on behavioral method was 65.25%. For Med-El users, the results showed that mean of speech discrimination scores when using program based on behavioral method was 55.71%. Mean of speech discrimination scores which were performed under the program based on ESRT was 57.14%. The analysis of both results showed that no statistically significant difference in speech discrimination scores of the two programs. The results were presented in Table 4.4 and Table 4.5

Table 4.4 Mean, standard deviation, t and p-value of speech discrimination scores of program based on behavioral method and program based on ESRT in Advanced Bionics cochlear implant users (n = 8).

	Behavioral method		**ESRT method**		**t**	**p-value**
	Mean	**SD**	**Mean**	**SD**		
Speech Discrimination Score (%)	65.25	11.11	62.25	11.34	1.655	.142

Table 4.5 Mean, standard deviation, t and p-value of speech discrimination scores of program based on behavioral method and program based on ESRT in Med-EL cochlear implant users (n = 7).

	Behavioral method		**ESRT method**		**t**	**p-value**
	Mean	**SD**	**Mean**	**SD**		
Speech Discrimination Score (%)	55.71	20.21	57.14	21.90	0.956	.376

CHAPTER V
DISCUSSION

The purpose of this study was investigated the ESRT in pediatric cochlear implant users. The ESRT were compared with behavioral M-level. The speech discrimination scores were also compared between program based on behavioral method and program based on ESRT.

The ESRT were measured in 19 pediatric unilateral cochlear implant users: 11 using the Advanced Bionics implant and 8 using the Med-El implant. Discussion was focused on the purposes that were:

5.1 The comparison of electrical current between M-level of behavioral method and ESRT in pediatric cochlear implant users.

5.1.1 Incidence of ESRT

In present study, ESRT were successfully measured in 15 of 19 subjects (79%). This finding was similar to other studies such as the study done by Battmer et al. (76%) [73], Shallop (76%) [22], Bresnihan et al. (77%) [74] and Han et al. (78%) [79]. Previous studies have reported that the ESRT were obtained in approximately 60-80% of cochlear implant users. The study of Hodges et al. [35] showed the lowest success rate in obtaining ESRT only 65%. While the highest success rate was presented in the study of Kosaner et al [21]. They found a success rate of 83%.

However, 4 of 19 children (21%) in this study did not have measurable ESRT. Because, they could not tolerate high electric current until ESRT were identified. There were 2 children who demonstrated no reflex response only a few channels that situated at the basal portion of the cochlea, another 2 children did not demonstrate ESRT at every channel. The possible reasons of absent ESRT are middle ear problems and reduction of neural fibers in the cochlea or auditory nerve due to

deafness [71, 73, 75, 80]. The middle ear dysfunction is a particular problem that affect on elicitation of the stapedius reflex. Like a normal hearing individuals, stapedius reflex cannot be acquired in implant users with abnormal middle ear function [35]. However, subjects in this study had been screen for middle ear dysfunction. All subject showed typa A tympanogram both ears. Thus, It is possible that absence of ESRT may be linked to reduction of neural fibers. Shallop suggested that the absence of ESRT may be the result of the surviving neural fibers not enough for stimulate to elicite the reflex [22]. However, some abnormality such as acute otitis media, tympanosclerosis, and absence of stapedius tendon may be present type A tympanogram. The 10 percent of type A tympanogram have no stapedius reflex [81].

Another 2 children could not be elicited ESRT only the channels that situated in the basal portion of the cochlea. The possibly reasons were clarified by Allum et al. Becasuse of the placement of electrode at the basal portion is further from modiolus than compared to the apical portion. This would presumably cause a less focused stimulation of auditory nerve ending in the basal portion. The higher electrical level is needed to elicit the ESRT in this region. So, absence of ESRT occasionally found in this region [37]. This assumption also corresponds with the acoustically elicited reflex that can be obtained better with low frequency sounds [82].

5.1.2 The comparison of electrical current between M-level of behavioral method and ESRT

From Table 4.2 and Table 4.3, the mean of ESRT were not statistically significant different from behavioral M-level. The findings were similar to the study of Lorens et al. and Walkowiak et al. [77, 83]. Lorens et al. reported that ESRT was higher than behavioral M-level but the differences were not large [77]. In contrast, Walkowiak et al. found that ESRT tend to lower than behavioral M-level [83]. However, both differences are not significant.

The results of the present study were shown in Figure 5.1 and 5.2. The figures demonstrate that ESRT were higher than behavioral M-level, same as the results of Lorens et al. These findings were consistent with Stephan et al. [40] who reported that ESRT were always located in dynamic range of loudness perception between the M-level and uncomfortable level. Similarly, Spivak and Chute found that

ESRT might exceed M-level but not reached uncomfortable level [75]. However, contrary results were reported by Bresnihan et al. [74]. They found that ESRT consistently slightly lower than behavioral M-level.

Although a variety of relationships between ESRT and behavioral M-level are found, but the same in all studies that ESRT are located close to behavioral M-level and not exceed the uncomfortable level. Thus, ESRT measurement should be useful in estimation of proper electric current, without an overstimulation for pediatric cochlear implant users, particularly in initial session.

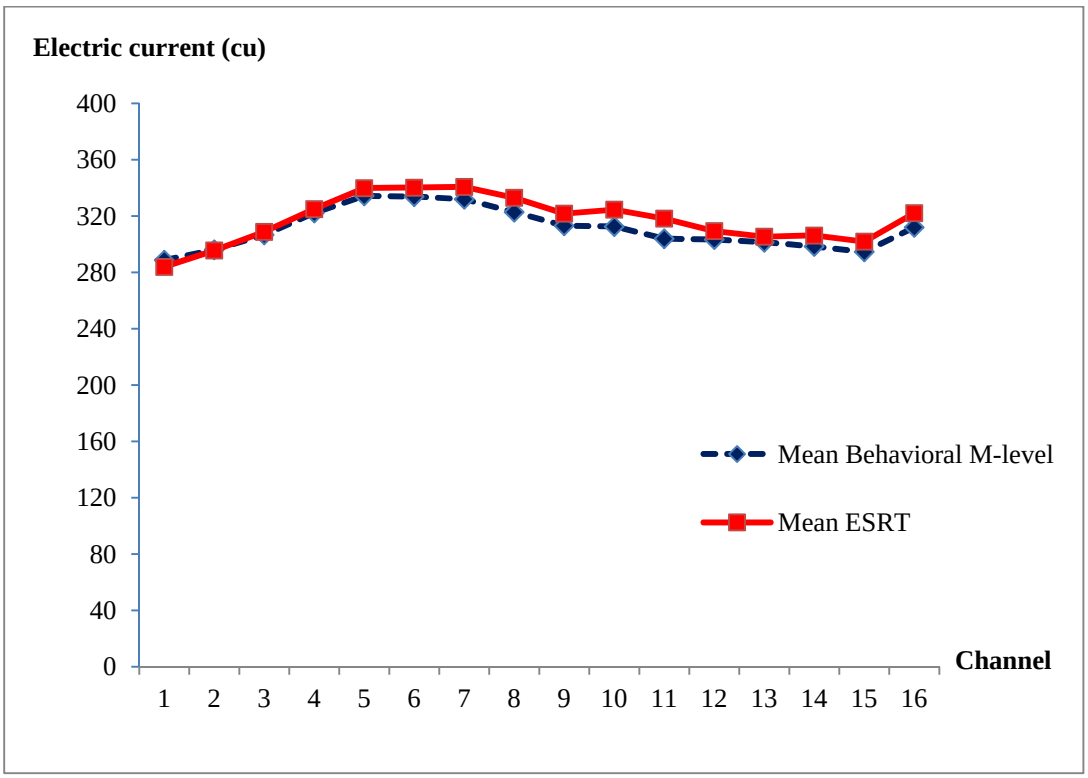

Figure 5.1 A graph demonstrating the mean behavioral M-level and mean ESRT of Advanced Bionics cochlear implant.

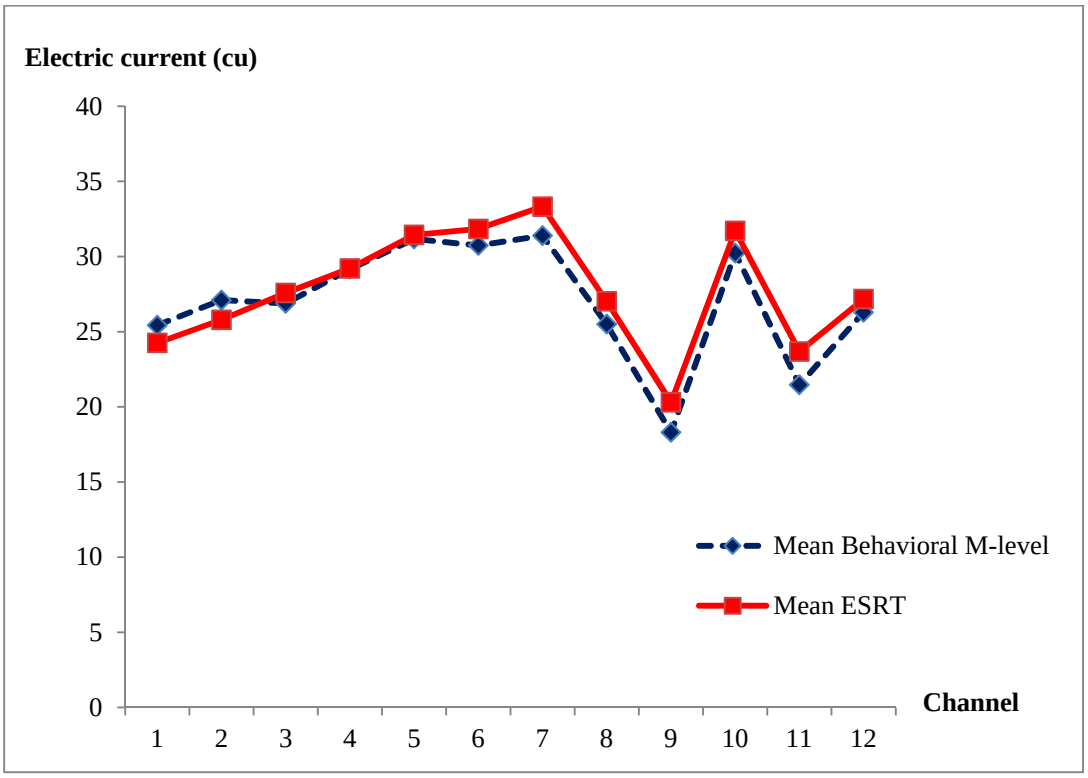

Figure 5.2 A graph demonstrating the mean behavioral M-level and mean ESRT of Med-EL cochlear implant.

5.2 The comparison of speech discrimination scores which were performed under the program based on behavioral method and the program based on ESRT in pediatric cochlear implant users.

The mean speech discrimination scores were shown in Table 4.4 and Table 4.5. For Advanced Bionic users, the mean speech discrimination scores when using the program based on behavioral method seemed to be higher than program based on ESRT. While, Med-El users showed that the mean speech discrimination scores for using the program based on behavioral method was lower than the program based on ESRT. However, there were no statistically significant differences in speech discrimination scores of both programs within both brands and the results were correlated with other studies. Spivak et al. [76] investigated the speech discrimination scores with program based on ESRT and compared with program based on behavioral method in 7 adults patients. Their results showed no significant difference between

scores obtained with ESRT program versus the behavioral program. Most of participants preferred the sound of ESRT program over the behavioral program. The results of present study were also similar with those of Hodges et al. [78] who investigated 5 adult subjects. Their findings showed no significant difference in speech discrimination scores between program based on ESRT and program based on behavioral method. The explanation of these present findings might be because the current level that induced ESRT were slightly above the current of the behavioral M-level which was not significant different. So, the outcomes of speech perception were similar to the program based on behavioral method.

However, to author's review literature, there were no researchers focused on the comparison of speech discrimination scores which were performed under the program based on ESRT and program based on behavioral method in children. There were many studies in other ways that investigated the sound perception performance of pediatric cochlear implant users when using ESRT generated program. Bresnihan et al. [74] asked the parent of 16 children to complete a questionnaire relating to the sound perception performance of children from both ESRT and behavioral program. Across all the questions, the program based on ESRT was rated as better perception than program based on behavioral method. Additionally, Kosaner et al. [21] reported that soundfield measurement of 53 pediatric cochlear implant users, who used ESRT generated program, were within the speech range. Their children also provided the good mean speech discrimination scores (81%). They suggested that using ESRT was useful technique. It may be a method of choice for programming cochlear implant in children, if the behavioral method was not available.

The results in this present study indicated that ESRT measurement seems to be the effective method in estimation of M-level for pediatric cochlear implant users who are too young, lack auditory experience, or have other handicap which interfere them to participate a behavioral method. Because, ESRT is slightly differ with behavioral M-level. Moreover, ESRT may help the audiologist to avoid overstimulation which might lead to rejection of the cochlear implant in children. Finally, pediatric implant users who use program based on ESRT should acquire speech discrimination scores comparable to behavioral method program, which will facilitate the speech and hearing development.

CHAPTER VI
CONCLUSIONS

This research focused on the study of ESRT in pediatric cochlear implant users. There were 19 children with cochlear implant who met the inclusion criteria. The ESRT could be measured for only 15 children (79%). The mean and standard deviations of behavioral M-level and ESRT in Advanced Bionics subjects were presented in Table 4.2 and Med-EL were presented in Table 4.3. The results of this study showed that mean of ESRT tend to be higher than mean of behavioral M-level. However, there were no statistically significant differences ($p > 0.05$).

In addition, the results of Advanced Bionics users showed that the mean of speech discrimination scores which were performed under the program based on ESRT was 62.25%. Mean of speech discrimination scores when using program based on behavioral method was 65.25%. For Med-El users, the results showed that mean of speech discrimination scores when using program based on behavioral method was 55.71%. Mean of speech discrimination scores which were performed under the program based on ESRT was 57.14%. The analysis of both results showed that no statistically significant difference in speech discrimination scores of the two programs ($p > 0.05$).

Recommendations from this study

The recommendations from this study regarding application and further research are as follows:

1. The findings suggested that the ESRT measurement may be applied for determination of cochlear implant stimulation levels during initial session in case of young children who are not available to perform the behavioral response.

2. The authors recommend that the ESRT measurement should be used as the battery test to avoid overstimulation in pediatric cochlear implant users.

3. It should be addressed that subjects in this study were experienced pediatric cochlear implant users, by having a minimum of 1 year's experience, this indicates that the child has stable M-level. Generally, M-level tend to increase during the first few months of implant use due to acclimatization to electrical stimulation and increased tolerance to louder sounds [84]. Thus, a further study should be focused on the ESRT in first fitting session.

REFERENCES

1.Gelfand SA. Essentials of Audiology. Second ed. New York: Thieme Medical Publishers, Inc.; 2001.

2.Sherwood L. The peripheral nervous system: Afferent division; Special senses. In: Adams P, editor. Human physiology from cells to systems sixth ed. Belmont, CA: Thomson Brooks/Cole; 2007. p. 208-17.

3.Marieb E, Hoehn K. The peripheral nervous system and reflex activity. Anatomy & Physiology. Third ed. San Francisco: Pearson Benjamin Cummings; 2008. p. 469-80.

4.Loizou PC. Introduction to cochlear implants. IEEE Eng Med Biol Mag. 1999;18(1):32-42.

5.Roeser RJ, Valente M, Hosford-Dunn H. Audiology: Diagnosis. Second ed. New York: Thieme; 2000.

6.Katz J, White TP. Introduction to the handicap of hearing impairment. In: Hull RH, editor. Aural rehabilitation: serving children and adults. Forth ed. San Diego: Singular; 2001. p. 21-30.

7.Tye-Murray N. Foundations of Aural Rehabilitation: Children, Adults, and Their Family Members. Second ed. New York: Thompson Delmar Learning; 2004.

8.Ricketts TA, DeChicchis AR, Bess FH. Hearing aids and assistive listening devices. In: Bailey BJ, Johnson JT, Newlands SD, editors. Head and Neck surgery-otolaryngology. Philadelphia: Lippincott William & Wilkins; 2006. p. 2279-93.

9.Koch DB, Staller S, Jaax K, Martin E. Bioengineering solutions for hearing loss and related disorders. Otolaryngol Clin North Am. 2005;38(2):255-72.

10.Hamzavi J, Baumgartner WD, Pok SM, Franz P, Gstoettner W. Variables affecting speech perception in postlingually deaf adults following cochlear implantation. Acta Otolaryngol. 2003;123(4):493-8.

11.Bassim MK, Buss E, Clark MS, Kolln KA, Pillsbury CH, Pillsbury HC, 3rd, et al. MED-EL Combi40+ cochlear implantation in adults. Laryngoscope. 2005;115(9):1568-73.

12.Santarelli R, De Filippi R, Genovese E, Arslan E. Cochlear implantation outcome in prelingually deafened young adults. A speech perception study. Audiol Neurootol. 2008;13(4):257-65.

13.Connell SS, Balkany TJ. Cochlear Implants. Clin Geriatr Med. 2006;22(3):677-86.

14.Mertes J, Chinnici J. Cochlear implants – Considerations in programming for the pediatric population 2006 [cited 2006 February 13]. Available from: http://www.audiologyonline.com/articles/cochlear-implants-considerations-in-programming-1011.

15.Vaerenberg B, Smits C, De Ceulaer G, Zir E, Harman S, Jaspers N, et al. Cochlear Implant Programming: A Global Survey on the State of the Art. Sci World J. 2014;2014:12.

16.Smoorenburg GF, Willeboer C, van Dijk JE. Speech perception in nucleus CI24M cochlear implant users with processor settings based on electrically evoked compound action potential thresholds. Audiol Neurootol. 2002;7(6):335-47.

17.Gross A. Fitting Techniques for the Pediatric Cochlear Implant Patient 2003 [cited 2003 May 12]. Available from: http://www.audiologyonline.com/articles/fitting-techniques-for-pediatric-cochlear-1128.

18.Langman AW, Quigley SM, Souliere CR, Jr. Cochlear implants in children. Pediatr Clin North Am. 1996;43(6):1217-31.

19.Gordon KA, Papsin BC, Harrison RV. Programming cochlear implant stimulation levels in infants and children with a combination of objective measures. Int J Audiol. 2004;43 Suppl 1:S28-32.

20.Dawson PW, Skok M, Clark GM. The Effect of Loudness Imbalance between Electrodes in Cochlear Implant Users. Ear Hear. 1997;18(2):156-65.

21.Kosaner J, Anderson I, Turan Z, Deibl M. The use of ESRT in fitting children with cochlear implants. Int Adv Otol. 2009;5(1):70-9.

22.Shallop JK. Objective electrophysiological measures from cochlear implant patients. Ear Hear. 1993;14(1):58-63.

23.Shallop JK. Objective measurements and the audiological management of cochlear implant patients. Adv Otorhinolaryngol. 1997;53:85-111.

24.Kileny PR, Zwolan TA, Boerst A, Telian SA. Electrically evoked auditory potentials: current clinical applications in children with cochlear implants. Am J Otol. 1997;18(6 Suppl):S90-2.

25.Mason S. Keynote lecture: objective measures. Am J Otol. 1997; 18 (6 Suppl):S84-7.

26.Hughes ML, Brown CJ, Abbas PJ, Wolaver AA, Gervais JP. Comparison of EAP thresholds with MAP levels in the nucleus 24 cochlear implant: data from children. Ear Hear. 2000;21(2):164-74.

27.Franck KH, Norton SJ. Estimation of psychophysical levels using the electrically evoked compound action potential measured with the neural response telemetry capabilities of Cochlear Corporation's CI24M device. Ear Hear. 2001;22(4):289-99.

28.Franck KH. A model of a nucleus 24 cochlear implant fitting protocol based on the electrically evoked whole nerve action potential. Ear Hear. 2002;23(1 Suppl):67s-71s.

29.Seyle K, Brown CJ. Speech perception using maps based on neural response telemetry measures. Ear Hear. 2002;23(1 Suppl):72s-9s.

30.Hodges AV, Ruth RA, Lambert PR, Balkany TJ. Electric auditory brain-stem responses in nucleus multichannel cochlear implant users. Arch Otolaryngol Head Neck Surg. 1994;120(10):1093-9.

31.Truy E, Gallego S, Chanal JM, Collet L, Morgon A. Correlation between electrical auditory brainstem response and perceptual thresholds in Digisonic cochlear implant users. Laryngoscope. 1998;108(4 Pt 1):554-9.

32.Brown CJ, Hughes ML, Lopez SM, Abbas PJ. Relationship between EABR thresholds and levels used to program the CLARION speech processor. Ann Otol Rhinol Laryngol Suppl. 1999;177:50-7.

33.Brown CJ, Hughes ML, Luk B, Abbas PJ, Wolaver A, Gervais J. The relationship between EAP and EABR thresholds and levels used to program the nucleus 24 speech processor: data from adults. Ear Hear. 2000;21(2):151-63.

34.Jerger J, Oliver TA, Chmiel RA. Prediction of dynamic range from stapedius reflex in cochlear implant patients. Ear Hear. 1988;9(1):4-8.

35.Hodges AV, Dolan-Ash S, Butts S, Balkany TJ. Using electrically evoked auditory reflex thresholds to fit the Clarion Cochlear Implant. Ann Otol Rhinol Laryngol. 1999;108(4):64-8.

36.Stephan K, Welzl-Muller K. Post-operative stapedius reflex tests with simultaneous loudness scaling in patients supplied with cochlear implants. Audiology. 2000;39(1):13-8.

37.Allum JH, Greisiger R, Probst R. Relationship of intraoperative electrically evoked stapedius reflex thresholds to maximum comfortable loudness levels of children with cochlear implants. Int J Audiol. 2002;41(2):93-9.

38.Gordon KA, Papsin BC, Harrison RV. Toward a Battery of Behavioral and Objective Measures to Achieve Optimal Cochlear Implant Stimulation Levels in Children. Ear Hear. 2004;25(5):447-63.

39.Miller CA, Brown CJ, Abbas PJ, Chi SL. The clinical application of potentials evoked from the peripheral auditory system. Hear Res. 2008;242(1-2):184-97.

40.Stephan K, Welzl-Muller K, Stiglbrunner H. Acoustic reflex in patients with cochlear implants (analog stimulation). Am J Otol. 1991;12 Suppl:48-51.

41.Mill JH, Khariwala SS, Weber PC. Anatomy and Physiology of Hearing. In: Bailey BJ, Johnson JT, S.D. N, editors. Head and neck surgery-otolaryngology. forth ed. Philadelphia: Lippincott Williams & Wilkins; 2006. p. 1883-903.

42.Vaerenberg B. Programming Cochlear Implants for Auditory Performance. Antwerp: University of Antwerp; 2014.

43.Ropper A, Samuels M, Klein J. Deafness, Dizziness, and Disorders of Equilibrium. Adams and Victor's Principles of Neurology. tenth ed: McGraw-Hill Education; 2014.

44.Shier D, Butler J, Lewis R. Nervous system III : Senses. Hole' s human anatomy & physiology. Eleventh ed. New York: McGraw-Hill; 2007. p. 454-64.

45.Barrett KE, Barman SM, Boitano S, Brooks H. Hearing & Equilibrium. Ganong's Review of Medical Physiology. twentyfouth ed: The McGraw-Hill Companies, Inc; 2012.

46.Nelken I, Bizley JK, Nodal FR, Ahmed B, King AJ, Schnupp JW. Responses of auditory cortex to complex stimuli: functional organization revealed using intrinsic optical signals. J Neurophysiol. 2008;99(4):1928-41.

47.Loizou PC. Mimicking the human ear. Signal Processing Magazine, IEEE. 1998;15(5):101-30.

48.Roeser RJ. Roeser's Audiology Desk Reference. Second ed. New York: Thieme; 2013.

49.Hinojosa R, Marion M. Histopathology of profound sensorineural deafness. Ann N Y Acad Sci. 1983;405:459-84.

50.Djourno A, Eyries C. [Auditory prosthesis by means of a distant electrical stimulation of the sensory nerve with the use of an indwelt coiling]. Presse Med. 1957;65(63):1417.

51.House LR. Cochlear implant: the beginning. Laryngoscope. 1987;97(8 Pt 1):996-7.

52.Simmons FB. Electrical stimulation of the auditory nerve in man. Arch Otolaryngol. 1966;84(1):2-54.

53.House WF, Urban J. Long term results of electrode implantation and electronic stimulation of the cochlea in man. Ann Otol Rhinol Laryngol. 1973;82(4):504-17.

54.Clark GM, Pyman BC, Bailey QR. The surgery for multiple-electrode cochlear implantations. J Laryngol Otol. 1979;93(3):215-23.

55.Clark GM, Tong YC, Martin LF, Busby PA. A multiple-channel cochlear implant. An evaluation using an open-set word test. Acta Otolaryngol. 1981;91(3-4):173-5.

56.Wilson BS. Engineering Design of Cochlear Implants. In: Zeng FG, Popper AN, Fay RR, editors. Cochlear Implants: Auditory Prostheses and Electric Hearing. New York: Springer; 2004. p. 14-52.

57.Frijns JH, Briaire JJ, Grote JJ. The importance of human cochlear anatomy for the results of modiolus-hugging multichannel cochlear implants. Otol Neurotol. 2001;22(3):340-9.

58.Balkany TJ, Hodges AV, Eshraghi AA, Butts S, Bricker K, Lingvai J, et al. Cochlear implants in children--a review. Acta Otolaryngol. 2002;122(4):356-62.

59.Heman-Ackah SE, Roland JT, Jr., Haynes DS, Waltzman SB. Pediatric cochlear implantation: candidacy evaluation, medical and surgical considerations, and expanding criteria. Otolaryngol Clin North Am. 2012;45(1):41-67.

60.Dowell RC, Hollow R, Winton E. Outcomes for cochlear implant users with significant residual hearing: implications for selection criteria in children. Arch Otolaryngol Head Neck Surg. 2004;130(5):575-81.

61.Cochlear implant referral criteria London: Guy’s and St Thomas’ NHS Foundation Trust [cited 2010 July]. Available from: http://www.guysandstthomas.nhs.uk/resources/our-services/surgery/audiology/cochlear-implant-referral-criteria.pdf.

62.Shapiro WH, Bradham TS. Cochlear implant programming. Otolaryngol Clin North Am. 2012;45(1):111-27.

63.Opie JM, Allum JH, Probst R. Evaluation of electrically elicited stapedius reflex threshold measured through three different cochlear implant systems. Am J Otol. 1997;18(6 Suppl):S107-8.

64.Abbas PJ, Brown CJ. Electrically evoked auditory brainstem response: refractory properties and strength-duration functions. Hear Res. 1991;51(1):139-47.

65.Abbas PJ, Brown CJ, Shallop JK, Firszt JB, Hughes ML, Hong SH, et al. Summary of results using the nucleus CI24M implant to record the electrically evoked compound action potential. Ear Hear. 1999;20(1):45-59.

66.Zimmerling MJ, Hochmair ES. EAP recordings in ineraid patients--correlations with psychophysical measures and possible implications for patient fitting. Ear Hear. 2002;23(2):81-91.

67.Baysal E, Karatas E, Deniz M, Baglam T, Durucu C, Karatas ZA, et al. Intra- and postoperative electrically evoked stapedius reflex thresholds in children with cochlear implants. Int J Pediatr Otorhinolaryngol. 2012;76(5):649-52.

68.Gelfand SA. The Acoustic Reflex. In: Katz J, editor. Handbook of clinical audiology Fifth ed. Baltimore: Lippincott Williams & Wilkins; 2002. p. 205-32.

69.Burnett PA, Miller JM, Mangham CA. Intra-aural reflexes elicited by a cochlear prosthesis in monkeys. Hear Res. 1984;16(2):175-80.

70.Jerger J, Jenkins H, Fifer R, Mecklenburg D. Stapedius reflex to electrical stimulation in a patient with a cochlear implant. Ann Otol Rhinol Laryngol. 1986;95(2 Pt 1):151-7.

71.Stephan K, Welzl-Muller K, Stiglbrunner H. Stapedius reflex threshold in cochlear implant patients. Audiology. 1988;27(4):227-33.

72.Stephan K, Welzl-Muller K, Stiglbrunner H. Dynamic range of the contralateral stapedius reflex in cochlear implant patients. Scand Audiol. 1990;19(2):111-5.

73.Battmer RD, Laszig R, Lehnhardt E. Electrically elicited stapedius reflex in cochlear implant patients. Ear Hear. 1990;11(5):370-4.

74.Bresnihan M, Norman G, Scott F, Viani L. Measurement of comfort levels by means of electrical stapedial reflex in children. Arch Otolaryngol Head Neck Surg. 2001;127(8):963-6.

75.Spivak LG, Chute PM. The relationship between electrical acoustic reflex thresholds and behavioral comfort levels in children and adult cochlear implant patients. Ear Hear. 1994;15(2):184-92.

76.Spivak LG, Chute PM, Popp AL, Parisier SC. Programming the cochlear implant based on electrical acoustic reflex thresholds: patient performance. Laryngoscope. 1994;104(10):1225-30.

77.Lorens A, Walkowiak A, Piotrowska A, Skarzynski H, Anderson I. ESRT and MCL correlations in experienced paediatric cochlear implant users. Cochlear Implants Int. 2004;5(1):28-37.

78.Hodges AV, Balkany TJ, Ruth RA, Lambert PR, Dolan-Ash S, Schloffman JJ. Electrical middle ear muscle reflex: use in cochlear implant programming. Otolaryngol Head Neck Surg. 1997;117(3 Pt 1):255-61.

79.Han DM, Chen XQ, Zhao XT, Kong Y, Li YX, Liu S, et al. Comparisons between neural response imaging thresholds, electrically evoked auditory reflex thresholds and most comfortable loudness levels in CII bionic ear users with HiResolution sound processing strategies. Acta Otolaryngol. 2005;125(7):732-5.

80.Stephan K, Welzl-Muller K. Stapedius reflex in patients with an inner ear prosthesis. Int J Artif Organs. 1992;15(7):436-9.

81.Hall J, Mueller HG. Audiologists Desk Reference vol 1: Diagnostic Audiology Principles, Procedures and Practices. London: Singular Publishing Group; 1997.

82.Djupesland G, Flottorp G, Winther FO. Size and duration of acoustically elicited impedance changes in man. Acta Otolaryngol. 1966:Suppl 224:0+.

83.Walkowiak A, Lorens A, Polak M, Kostek B, Skarzynski H, Szkielkowska A, et al. Evoked stapedius reflex and compound action potential thresholds versus most comfortable loudness level: assessment of their relation for charge-based fitting strategies in implant users. ORL J Otorhinolaryngol Relat Spec. 2011;73(4):189-95.

84.Henkin Y, Kaplan-Neeman R, Kronenberg J, Migirov L, Hildesheimer M, Muchnik C. A longitudinal study of electrical stimulation levels and electrode impedance in children using the Clarion cochlear implant. Acta Otolaryngol. 2006;126(6):581-6.

APPENDICES

APPENDIX A

RAMA SD WORD LIST FOR SPEECH DISCRIMINATION SCORES TEST

1	2	3	4	5	6	7	8	9
อ่าน	รถ	ซื้อ	ปาก	อ้วน	แม่	ว่า	เก็บ	คน
เป็ด	ตาย	เคาะ	อุ้ม	ยอด	อ่าน	แก้ว	แล้ว	จับ
เต่า	จริง	ลาด	ญาติ	ตาม	ขวา	ไม้	น้อย	เก้า
ไกล	ถ้วย	ฉาย	เร็ว	ร้อน	ไว้	บ้าน	ตา	มาก
ผ้า	เสื้อ	แว่น	ผม	ปู่	ตัว	กวาด	วัด	ฟัง
ถุง	ว่าว	ขาด	ฝ้าย	คน	เล่า	ให้	ใจ	ล้ม
เสื้อ	พัด	บ่อ	วัด	แก้ม	จะ	คว่ำ	ออก	ไม่
บ้าน	ทำ	อิ่ม	ไม้	ชั้น	ม้า	ไป	เลี้ยง	ง่าย
ม้า	ชัด	ต้ม	หก	ผัด	ชาย	สั้น	คอ	แก่
พาน	ซ่อม	ดิน	กล้วย	ดำ	กับ	โจร	ใช้	นั่ง
ลิง	แม่	จบ	ดื่ม	แถว	ไฟ	ลุง	ยัง	หมอ
ฉิ่ง	ผึ้ง	คือ	ขุ่น	ห้าม	หนัง	ข้าว	หน้า	ตาย
แหวน	ขวด	ผ่าน	งอ	สาย	กิน	เรือ	วัน	ลูก
จาน	ปืน	สร้อย	ช้าง	จันทร์	โดย	ค้า	ปิด	เสีย
ฝน	อุ่น	ไทย	โต๊ะ	บุญ	ปล่อย	เธอ	ดำ	เปล่า
หนู	บัว	ง่าม	เบ็ด	ฝูง	ใต้	การ	มั่น	หู
ช้อน	ฉาบ	ยิง	เคย	มาก	เสียง	สอง	สั่ง	ดัง
เรือ	ไฝ	ราก	ซ้ำ	น้อย	เช้า	ลูก	ความ	กรรม
ยุง	ยาม	ชีพ	หลับ	พบ	เป็น	หมู	บน	ลับ
ควาย	เงาะ	ฟ้า	นิด	ง่าย	ห้า	ชั้น	แก้	ไทย
เด็ก	ดาว	หอม	สิบ	ลุง	อ่อน	นาย	ใส่	ก่อน
หอย	เก้า	พระ	แท้	ทอง	ล้าน	กล่อง	นำ	เสร็จ
งู	เล่น	ฝั่น	พูด	ฉัน	พี่	ทั่ว	ตี	คุณ
ฟัน	ห่าน	กรรม	ฟอง	ฟัง	งาน	มอง	ทัน	เนื้อ
ธง	ค่ำ	ปลา	จอบ	ว่าว	ดู	ปี	คืน	จำ

APPENDIX B

RAW DATA OF 19 PEDIATRIC COCHLEAR IMPLANT USERS

Subject (No.)	Sex	Brand of cochlear implant	Age (years)	Age at implantation (years)	Duration of CI use (years)
1	M	Advanced Bionics	14.00	9.75	4.25
2	F	Med-EL	11.75	5.67	6.08
3	F	Advanced Bionics	14.67	8.33	6.33
4	F	Advanced Bionics	13.42	7.42	6.00
5	M	Med-EL	11.50	2.75	8.75
6	M	Med-EL	7.67	2.58	5.08
7	F	Advanced Bionics	11.50	4.00	7.50
8	F	Advanced Bionics	14.50	7.50	7.00
9	M	Med-EL	13.67	7.75	5.92
10	F	Advanced Bionics	14.67	9.17	5.50
11	F	Med-EL	11.08	5.83	5.25
12	F	Med-EL	9.08	2.92	6.17
13	F	Advanced Bionics	11.67	3.92	7.75
14	F	Advanced Bionics	6.17	4.33	1.83
15	M	Advanced Bionics	12.50	5.67	6.83
16	M	Med-EL	7.17	2.42	4.75
17	F	Med-EL	7.42	2.75	4.67
18	M	Advanced Bionics	12.92	6.42	6.50
19	M	Advanced Bionics	6.75	2.25	4.50
Mean			11.16	5.34	5.82
SD			2.90	2.46	1.33
Range		Min	6.17	2.25	1.83
		Max	14.67	9.75	8.75

Note: F = Female, M = Male

APPENDIX C

RAW DATA OF BEHAVIORAL M-LEVEL IN ADVANCED BIONICS COCHLEAR IMPLANT USERS

Subject (No.)	Channel Number															
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
1	243	249	246	246	24	249	239	238	241	245	251	268	286	311	333	316
3	237	238	246	248	240	234	222	224	216	223	209	217	207	207	204	181
4	305	318	326	312	305	300	290	287	273	272	264	256	233	207	191	191
7	128	125	124	123	125	126	128	128	128	128	130	128	127	128	125	126
8	614	618	655	687	701	661	639	566	488	458	421	424	423	405	368	327
10	229	224	228	229	245	261	266	288	297	304	312	313	320	325	328	310
13	193	200	199	214	235	241	244	241	235	236	242	244	252	267	263	***
14	263	283	318	345	371	390	409	410	417	422	413	400	366	329	312	***
15	252	273	281	295	321	333	334	339	339	347	348	349	371	378	388	390
18	374	374	374	393	393	393	393	393	391	392	370	347	319	303	301	294
19	134	134	134	150	168	170	176	172	178	178	178	178	188	188	188	188

Note: *** = Inactive electrode

APPENDIX D
RAW DATA OF ESRT IN ADVANCED BIONICS COCHLEAR IMPLANT USERS

Subject (No.)	Channel Number															
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
1	222	238	253	276	287	286	287	276	284	306	330	286	287	324	329	327
3	238	256	265	273	277	271	270	274	278	278	265	253	255	255	277	275
4	301	324	308	321	314	315	299	293	289	296	NR	NR	NR	NR	NR	NR
7	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
8	609	613	650	682	696	656	634	561	483	453	416	419	418	400	363	319
10	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
13	192	197	198	208	224	231	228	225	211	214	219	223	243	265	270	***
14	256	279	312	341	364	383	401	410	410	403	398	388	363	329	309	***
15	257	278	280	300	317	331	342	346	339	354	354	364	374	381	389	391
18	366	375	377	384	400	397	395	407	397	409	382	364	326	315	308	302
19	132	129	136	136	154	167	169	165	172	180	182	178	177	181	170	163

Note: *** = Inactive electrode, NR = No response

APPENDIX E
RAW DATA OF BEHAVIORAL M-LEVEL IN Med-EL COCHLEAR IMPLANT USERS

Subject (No.)	Channel Number											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
2	17.31	15.38	18.36	17.31	20.04	21.29	23.26	28.61	32.20	34.16	36.24	36.24
5	25.52	30.52	33.28	36.90	42.49	44.42	43.41	***	***	41.87	30.84	27.40
6	11.60	15.27	13.61	13.68	14.38	14.30	15.78	16.83	15.20	15.19	14.64	15.53
9	19.71	18.96	19.29	19.86	21.32	21.79	22.45	19.94	21.79	22.45	23.12	26.30
11	37.42	33.46	29.10	36.47	39.37	32.11	30.64	34.28	30.92	29.01	26.81	29.83
12	22.75	21.53	21.06	24.41	25.22	26.15	31.65	32.89	***	33.76	***	33.86
16	23.65	23.14	22.34	22.21	21.43	20.08	17.74	15.21	***	13.04	***	***
17	37.34	46.83	49.49	50.59	53.95	56.35	58.04	59.33	60.15	56.33	54.78	51.12

Note: *** = Inactive electrode

APPENDIX F

RAW DATA OF ESRT IN Med-EL COCHLEAR IMPLANT USERS

Subject (No.)	Channel Number											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
2	14.93	17.31	18.91	18.91	20.64	26.18	29.46	33.16	NR	NR	NR	NR
5	26.29	28.77	32.31	32.78	43.76	44.42	44.42	***	***	43.13	32.72	26.60
6	11.95	13.98	13.61	14.95	17.17	19.80	22.49	21.32	21.67	18.14	20.26	19.67
9	20.30	19.53	22.36	22.36	24.71	20.80	25.26	23.12	25.26	27.61	24.53	27.90
11	32.60	31.85	31.18	32.72	32.33	30.56	27.49	31.68	29.44	25.27	24.78	30.12
12	22.09	19.70	20.44	21.69	21.76	22.56	25.73	27.55	***	27.45	***	28.35
16	23.37	23.84	23.70	24.27	21.43	21.30	20.56	18.70	***	17.02	***	***
17	33.17	42.86	49.49	55.70	58.95	63.43	67.29	66.77	65.73	63.40	63.50	57.54

Note: *** = Inactive electrode, NR = No response

APPENDIX G

คณะแพทยศาสตร์โรงพยาบาลรามาธิบดี มหาวิทยาลัยมหิดล
๒๗๐ ถนนพระราม ๖ แขวงทุ่งพญาไท เขตราชเทวี กทม. ๑๐๔๐๐
โทร. (๐๒) ๒๐๑-๑๐๐๐

Faculty of Medicine Ramathibodi Hospital, Mahidol University.
270 Rama VI Road, Ratchathewi, Bangkok 10400, Thailand
Tel. (662) 201-1000

Documentary Proof of Ethical Clearance
Committee on Human Rights Related to Research Involving Human Subjects
Faculty of Medicine Ramathibodi Hospital, Mahidol University

No MURA2014/96

Title of Project	Electrical Stapedius Reflex Threshold in Pediatric Cochlear Implant Users
Protocol Number	ID 02 – 57 – 30
Principal Investigator	Mr.Panuphol Viboonchaicheep
Official Address	Communication Sciences and Disorders Faculty of Medicine Ramathibodi Hospital Mahidol University

The aforementioned project has been reviewed and approved by the Committee on Human Rights Related to Research Involving Human Subjects, based on the Declaration of Helsinki.

Signature of Secretary Committee on Human Rights Related to Research Involving Human Subjects	..... Prof. Duangrurdee Wattanasirichaigoon, M.D.
Signature of Chairman Committee on Human Rights Related to Research Involving Human Subjects	..... Prof. Pratak O-Prasertsawat, M.D.
Date of Approval	February 19, 2014
Duration of Study	9 Months

APPENDIX H


บัณฑิตวิทยาลัย มหาวิทยาลัยขอนแก่น
มอบเกียรติบัตรนี้ไว้เพื่อแสดงว่า
นายภาณุพล จิบูลชัยชีพ
ได้นำเสนอผลงานวิจัยระดับบัณฑิตศึกษา แบบโปสเตอร์
ปริญญาโท กลุ่มวิทยาศาสตร์สุขภาพ
ในการประชุมวิชาการเสนอผลงานวิจัยระดับบัณฑิตศึกษาแห่งชาติ ครั้งที่ ๓๔
ณ มหาวิทยาลัยขอนแก่น
วันที่ ๒๗ มีนาคม ๒๕๕๘
(รองศาสตราจารย์ ดร. สุรศักดิ์ วงศ์รัตนชีวิน)
คณบดีบัณฑิตวิทยาลัย มหาวิทยาลัยขอนแก่น
34th National Graduate Research Conference

BIOGRAPHY

NAME	Mr. Panuphol Viboonchaicheep
DATE OF BIRTH	8 February 1987
PLACE OF BIRTH	Bangkok, Thailand
INSTITUTIONS ATTENDED	Mahidol University, 2005-2008 Bachelor of Science (Communication Disorders) Mahidol University, 2012-2015 Master of Science (Communication Disorders)
HOME ADDRESS	580/15-16 Soi Mangkon 1 Mangkon Road Pomprapsattruphai Bangkok, 10100 Tel. 08-5220-2678 Email: topdsmu@hotmail.com
PRESENTATION	The 34th National Graduate Research Conference, Khonkaen University