AUDITORY STEADY-STATE RESPONSE (ASSR) AND BEHAVIORAL HEARING THRESHOLDS IN CHILDREN WITH ABSENT CLICK-AUDITORY BRAINSTEM RESPONSE.

KULKANYA WONGSANTICHON

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR
THE DEGREE OF MASTER OF SCIENCE
(COMMUNICATION DISORDERS)
FACULTY OF GRADUATE STUDIES
MAHIDOL UNIVERSITY
2010

Thesis
entitled

AUDITORY STEADY-STATE RESPONSE (ASSR) AND BEHAVIORAL HEARING THRESHOLDS IN CHILDREN WITH ABSENT CLICK-AUDITORY BRAINSTEM RESPONSE.

Kulkanya Wongsantichon.
....
Miss Kulkanya Wongsantichon
Candidate

Krisna Lertsukprasert
....
Assoc. Prof. Krisna Lertsukprasert,
M.A.
Major advisor

Montip Tiensuwan
....
Assoc. Prof. Montip Tiensuwan,
Ph.D.
Co-advisor

B. Mahai
....
Prof. Banchong Mahaisavariya, M.D.
M.D., Dip Thai Board of Orthopedics
Faculty of Graduate Studies
Mahidol University

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

Thesis
entitled

AUDITORY STEADY-STATE RESPONSE (ASSR) AND BEHAVIORAL HEARING THRESHOLDS IN CHILDREN WITH ABSENT CLICK-AUDITORY BRAINSTEM RESPONSE.

was submitted to the Faculty of Graduate Studies, Mahidol University
for the degree of Master of Science (Communication Disorders)
on
March 31, 2010

Kulkanya Wongsantichon.
....
Miss Kulkanya Wongsantichon
Candidate

Pongthep Harnchumpol
....
Assoc. Prof. Col. Pongthep Harnchumpol,
M.A.
Chair

Krisna Lertsukprasert
....
Assoc. Prof. Krisna Lertsukprasert,
M.A.
Member

Montip Tiensuwan
....
Assoc. Prof. Montip Tiensuwan,
Ph.D.
Member

....
Prof. Banchong Mahaisavariya,
M.D., Dip Thai Board of Orthopedics
Dean
Faculty of Graduate Studies
Mahidol University

....
Prof. Rajata Rajatanavin,
M.D., F.A.C.E
Dean
Faculty of medicine
Ramathibodi Hospital
Mahidol University

ACKNOWLEDGEMENTS

Foremost, I would like to express my deep and sincere gratitude to my major advisor, Assoc. Prof. Krisna Lertsukprasert who has supported me throughout my thesis with her patience and knowledge. She has spend her valuable time given me constructive comments. Her enthusiasm and encouragement helped carry me through.

I wish to offer my profound gratitude to my co-advisor, Assoc. Prof. Montip Tiensuwan for her inspiring comments and suggestions. Her statistical proficiency and directions provide good basis for the present thesis. I really appreciated the way she advises; it has helped develop my understanding of statistics. I would also like to thank Assoc. Prof. Col. Pongthep Harnchumpol for agreeing to be my thesis committee.

My special thanks are extended to all professors of Speech and Hearing Clinic, Department of Otolaryngology, Faculty of Medicine, Ramathibodi Hospital in giving their knowledge and experiences. I'm particular grateful to Mrs. Ratsuda Rajawong and Mrs. Yanitchara Thongrak of preschool rehabilitation program for their kind cooperation and invaluable technical help during the data collection, including all staffs of Speech and Hearing Clinic.

I would like to thank all the children, parents and caregivers who participated in this study. Thanks to all my friends at Communication Disorder Graduate Program for being nice colleagues, good company and friendship. I owe my loving thanks to my friends at Bible Study Fellowship in Bangkok: Miss. Melinda Burnette, Mrs. Charlene Wellings, and Miss Stephane Elena Roth for encouragement, especially for their faithful prayers, including all the members of evening women's class. Big thanks to Sapan Luang Church friends who stand side by side with me since the beginning stages of this work. Most especially, thanks to my loving and supportive parents, sisters and Mr. Sutee Jeankittimasak. And to God, who never fails His promise.

The Bangkok Christian hospital scholarship is gratefully acknowledged for partially financial support, and for allowing me to study full-time until completion.

Kulkanya Wongsantichon

AUDITORY STEADY-STATE RESPONSE (ASSR) AND BEHAVIORAL HEARING THRESHOLDS IN CHILDREN WITH ABSENT CLICK-AUDITORY BRAINSTEM RESPONSE.

KULKANYA WONGSANTICHON 4836304 RACD/M

M.Sc. (COMMUNICATION DISORDERS)

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

ABSTRACT

This current study aims to examine the distribution of behavioral hearing thresholds in children who demonstrated absent ABR waveform at maximum presentation level and to describe the relationship between behavioral hearing thresholds and ASSR threshold estimations.

Thirty-nine children, aged 2 years 4 months to 11 years, who were enrolled in a preschool aural rehabilitation program at the Speech and Hearing Clinic, Ramathibodi Hospital participated in this study. The behavioral hearing thresholds were obtained using conventional play audiometry. ASSR testing was conducted by using the SmartEP system.

The mean behavioral thresholds were 82.95, 99.07, 106.69, 110.51 and 109.15 dB HL at frequencies of 250, 500, 1000, 2000 and 4000 Hz, respectively. The mean difference between ASSR and conventional play audiometry with standard deviation were -8.20 ± 19.28, -4.69 ± 22.99, -8.20 ± 15.89, -2.98 ± 14.51 and -2.37 ± 17.36 dB HL at frequencies of 250, 500, 1000, 2000 and 4000 Hz, respectively. For overall frequencies, the difference with standard deviation was -5.26 ± 17.78 dB HL with a statistically significant difference of $p < 0.05$. The inter-rater Kappa values showed moderate agreement at 2000 Hz ($k = 0.491$) and 4000 Hz ($k = 0.409$), fair agreement at 250 Hz ($k = 0.320$) and 500 Hz ($k = 0.236$), and there was no statistically significant agreement at 1000 Hz ($k = 0.180$).

In conclusion, these findings showed that the ASSR technique is a valuable extension of the clinical audiological test battery, particularly for evaluating hearing sensitivity in children with absent ABR at maximum intensity level (99 dB nHL). The mean differences from the current study can be useful in hearing threshold estimation.

KEYWORDS: ASSR / ABSENT CLICK-ABR / CHILDREN /
CONVENTIONAL PLAY AUDIOMETRY

60 pages

การศึกษาเปรียบเทียบระดับการได้ยินจากการตรวจ ASSR และการตรวจการได้ยินแบบการตอบสนองทางพฤติกรรมในเด็กที่ไม่มีการตอบสนองจากการตรวจ click-ABR

AUDITORY STEADY-STATE RESPONSE (ASSR) AND BEHAVIORAL HEARING THRESHOLDS IN CHILDREN WITH ABSENT CLICK-AUDITORY BRAINSTEM RESPONSE.

กุลกันยา วงศ์สันติชน 4836304 RACD/M

วท.ม. (ความผิดปกติของการสื่อความหมาย)

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

บทคัดย่อ

การศึกษาในครั้งนี้ มีวัตถุประสงค์เพื่อศึกษาการกระจายของระดับการได้ยินจากการตรวจการได้ยินแบบตอบสนองทางพฤติกรรม และศึกษาเปรียบเทียบกับระดับการได้ยินจากการตรวจ ASSR ที่ความถี่ ตั้งแต่ 250, 500, 1000, 2000 และ 4000 Hz ในกลุ่มเด็กที่ไม่มีการตอบสนองจากการตรวจ click-ABR ในโครงการฟื้นฟูสมรรถภาพเด็กหูพิการก่อนวัยเรียน โรงพยาบาลรามาธิบดี จำนวน 39 คน อายุระหว่าง 2 ปี 4 เดือน ถึง 11 ปี

ผลการศึกษา พบว่าเด็กที่ไม่มีการตอบสนองจากการตรวจ click-ABR นี้ ยังคงมีระดับการได้ยินคงเหลืออยู่ที่ความถี่ต่างๆ โดยมีค่าเฉลี่ยเท่ากับ 82.95, 99.07, 106.69, 110.51 และ 109.15 dB HL ที่ความถี่ 250, 500, 1000, 2000 และ 4000 Hz ตามลำดับ ค่าความแตกต่างระหว่างระดับการได้ยินจากการตรวจ ASSR และแบบตั้งเงื่อนไขประกอบการเล่น มีค่าเท่ากับ -8.20 ± 19.28, -4.69 ± 22.99, -8.20 ± 15.89, -2.98 ± 14.51 และ -2.37 ± 17.36 dB HL ที่ความถี่ 250, 500, 1000, 2000 และ 4000 Hz ตามลำดับ และเมื่อพิจารณารวมที่ความถี่ตั้งแต่ 250 ถึง 4000 Hz พบค่าความแตกต่างเท่ากับ -5.26 ± 17.78 dB HL อย่างมีนัยสำคัญทางสถิติที่ $p < 0.05$ นอกจากนี้ พบค่าความสอดคล้องระหว่างระดับการได้ยินที่ได้จากการตรวจทั้งสองวิธีอยู่ในระดับปานกลางที่ความถี่ 2000 ($k = 0.491$) และ 4000 Hz ($k = 0.409$) ค่าความสอดคล้องพอใช้ที่ความถี่ 250 ($k = 0.320$) และ 500 Hz ($k = 0.236$) แต่ที่ความถี่ 1000 Hz ไม่พบค่าความสอดคล้องอย่างมีนัยสำคัญทางสถิติ ($k = 0.180$)

ดังนั้น จากการศึกษานี้ แสดงให้เห็นว่าในกลุ่มเด็กที่ไม่พบการตอบสนองจากการตรวจ click-ABR ที่ความดัง 99 dB nHL การตรวจ ASSR จะสามารถช่วยประมาณระดับการได้ยิน

60 หน้า

CONTENTS

CHAPTER I INTRODUCTION

CHAPTER II LITERATURE REVIEW

CONTENTS (cont.)

CHAPTER III MATERIALS AND METHODS

CHAPTER IV RESULTS

CONTENTS (cont.)

Page

CHAPTER V DISCUSSION

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ABR	auditory brainstem response
AM	amplitude modulation
AMFR	amplitude modulation following response
AP	action potential
ASSR	auditory steady-state response
AVCN	anterior ventral cochlear nucleus
BOA	behavioral observation audiometry
CF	carrier frequency
CM	cochlear microphonic
CN	cochlear nucleus
CPA	conventional play audiometry
DCN	dorsal cochlear nucleus
DNLL	dorsal lateral lemniscus
ECochG	electrocochleography
EEG	electroencephalography
EFR	envelope following response
f_c	carrier frequency
FFR	frequency following response
FFT	Fast Fourier Transform
FM	frequency modulation
f_m	modulation frequency
HL	hearing level
Hz	hertz
INLL	intermediate lateral lemniscus
LSO	lateral superior olivary complex
MASTER	Multiple Auditory STEady-state Responses
MF	modulation frequency

LIST OF ABBREVIATIONS (cont.)

MGB	medial geniculate body
MM	mixed modulation
ms	millisecond
MSO	medial superior olivary
PAMRs	postauricular muscle responses
PVCN	posterior ventral cochlear nucleus
SAM	sinusoidal amplitude modulation
SD	standard deviation
SNR	signal to noise ratio
SOC	superior olivary complex
SPL	sound pressure level
SP	summating potential
SSEP	steady-state evoke potential
SSER	steady-state evoke response
VNLL	ventral lateral lemniscus
VRA	visual reinforcement audiometry

CHAPTER I
INTRODUCTION

1.1 Background of study

Early detection of hearing loss and timely intervention in children is the important role and responsibilities of audiologists. If undetected and untreated, hearing loss in children can lead to delayed speech and language development. Delay in acquisition of these skills may impact on a child’s cognitive, as well as social and personal development. Therefore, an early, reliable diagnosis and description of hearing loss is essential in determining appropriate treatment to minimize potential developmental delays attributed to the loss.

1.2 Statement of the problem

In young infants, the audiologist uses various noisemakers to elicit startle responses and motor reflex changes in the child by observation; this is referred to behavioral observation audiometry (BOA). A factor causing trouble with this test is that the noisemakers are not standardized in frequency and intensity. Visual reinforcement audiometry (VRA) evaluates the hearing of infants from six months to two years. Sounds of varying frequency and intensity are presented to one of two calibrated loudspeakers or earphones, as the child sits on a parent's lap or in a chair. When a sound such as a tone at a specific frequency or speech is presented, the child's eye-shift or head-turn response toward the sound source is rewarded by a visual stimulus, such an animated toy or a lighted mechanical toy mounted near the loudspeaker. However, the test which performed through loudspeakers yields an audiogram for the better-hearing ear audiogram, if an ear difference in hearing occurred. In contrary, if the child tolerates wearing earphones, then the test assesses hearing in each ear separately. As the child gets older around 30 months through five years of age, conventional play audiometry (CPA) is useful. The child is conditioned to listen for a sound and to respond through play activity such as placing a ball in a cup or placing a peg in a pegboard, when the auditory stimulus is heard. Thus, subjective assessment of auditory function requires children’s cooperation. Moreover, a reliable behavioral response is difficult in young children. Electrophysiological testing is a non-behavioral method to assess hearing loss in infants and young children. However, they should never be a substitution for behavioral audiometry in children [1].

One useful and clinical used as hearing loss diagnosis procedures is click-evoked auditory brainstem response (click-ABR). The ABR is the representation of electrical activity generated by the eight cranial nerve and brainstem in response to auditory stimulation. Currently, the ABR is widely recognized as an effective evoked potential technique. However, there are some limitations for this method. The click-ABR has been shown to correlate with behavioral threshold at 2000 and 4000 Hz [2-4]. Besides to this high-frequency estimation, it is necessary to obtain low-frequency thresholds in order to estimate the shape of the audiogram and to provide a complete assessment of hearing sensitivity. Tone burst ABR in response to tone-burst stimuli result in frequency-specific responses have been displayed in pure tone behavioral thresholds (500 to 4000 Hz) estimation with reasonable accuracy [5]. However, ABR recordings are limited by restrictions on maximum presentation levels and the subjective visual inspection used to determine threshold. The upper limit for presentation level in most clinical ABR equipment (90-100 dB nHL) is too low to adequately measure all hearing losses, especially those in the severe to profound range. This limitation can make hearing losses that exceed the maximum output difficult or impossible to quantify. Even tone burst-ABR enables to estimate hearing sensitivity at low frequencies specifically, but it could not be tested both ears at the same time. Despite its appeal as a clinical procedure for hearing assessment in children, the tone burst ABR causes time consuming to achieve fully data in children.

One alternative to standard ABR recordings is the ASSR. The investigation of auditory evoked responses evoked by either frequency and/or amplitude modulation of sinusoidal stimuli began in the early 1980s. During the beginning there were many studies of auditory responses evoked with stimulus rates in the region of 40 Hz. However, the low modulation frequency was later founded to be poorly suitable as a clinical procedure for auditory assessment in infants and young children. Over the years, a variety terms were used in addition to the 40 Hz response to describe auditory steady-state responses, including amplitude modulation following response (AMFR), the envelope following response (EFR), frequency following response (FFR), steady-state evoke response (SSER), and steady-state evoke potential (SSEP). Many researchers continue up to present study for steady-state response evoked by faster rates of amplitude and frequency modulation. Each of the research group in Australia and Canada, and authors from other countries, confirmed the ASSR with higher (75-110 Hz) can be applied in electrophysiological estimation of auditory thresholds in infants and young children, even in sleep with sedation [6].

ASSR, requires the same general instrumentation with ABR for clinical recording. In comparison with ABR, ASSR use the same earphones to deliver stimuli, the same electrodes to detect the response, but use different software for stimulus generation and response analysis. ASSR is evoked with constant sinusoidal (pure-tone) stimuli modulated rapidly in amplitude and/or frequency, while ABR is evoked with transient (short duration) stimuli. There is different strategy for ASSR response analysis versus ABR. The clinician typically examines a characteristic of ABR waveform visually and manually calculates response parameters, such as latency and amplitude of specific waves or components. With ASSR measurement, in contrast, their complex waveform cannot be detected visually. Instead, it is detected by either Fast Fourier Transform (FFT), which is automated spectral analysis of stimulus in the frequency domain, or by automated analysis of the phase of the response relative to stimulus phase. There are a number of potential advantages of ASSR. First, the frequency-specific stimuli utilized for estimation of auditory sensitivity at audiometric frequencies. Second, signal intensity levels can be as high as 120 dB HL [7]. As a consequent, ASSR is useful for electrophysiological assessment of severe-to-profound hearing loss in infants and young children. In addition, ASSR analysis and detection method is based on automatic determination, experience in waveform identification is not necessary. Nevertheless, ASSR recording requires a very quiet state of arousal, the measurement in infants and young children required sedation.

Several studies reported the correlation between ASSR and behavioral thresholds improved with degree of hearing loss [8-10]. One of these studies demonstrated the ASSR reliably estimated behavioral threshold of greater than and equal 60 dB HL; showed higher correlation compared to those thresholds of less than 60 dB HL [9]. Another study results indicated a closer correlation between ASSR and profound behavioral thresholds than for severe thresholds at 0.5, 1, 2 and 4 kHz [8]. Another literature also supported that ASSR can be used as reliable hearing level predictions for ears with hearing losses in the severe to profound range [11].

This current study aims to investigate clinical usefulness of ASSR for estimation of behavioral hearing thresholds in hearing impaired children with absent click-ABR. The children who participated in this study have been enrolled a preschool rehabilitation program at the Speech and Hearing Clinic, Ramathibodi Hospital. These children have severe or severe-to-profound hearing impairment. For these two attributes conditions; degree of hearing loss and sound detection skill, would bring reliable information of the data. Therefore, this study serves for two purposes. First, to examine the distribution of behavioral hearing threshold in children who had demonstrated absent ABR waveform at maximum presentation level. Second, is to describe the relationship between behavioral hearing thresholds and ASSR thresholds estimation in severe and profound hearing loss children in the frequencies between 250 to 4000 Hz.

This study will be useful in estimation of hearing sensitivity in hearing impaired children, especially when ABR showed no response at the maximum intensity level. Results of this study provide mean differences between ASSR and behavioral thresholds which can be applied for hearing threshold estimation in children who are in the same age group and degree of hearing loss.

1.3 Purposes of the study

1. Examine the distribution of behavioral hearing threshold in children who had demonstrated absent ABR waveform at maximum presentation level.
2. Describe the relationship between behavioral hearing thresholds and ASSR thresholds estimation in severe and profound hearing loss children in the frequencies between 250 to 4000 Hz.

1.4 Research questions

1. What is the distribution of behavioral hearing threshold in children who had demonstrated absent ABR waveform at maximum presentation level?

2. What is the relationship between behavioral hearing thresholds and ASSR thresholds estimation in severe and profound hearing loss children in the frequencies between 250 to 4000 Hz?

1.5 Expected outcomes of the research

1. This study will be useful in estimation of hearing sensitivity in hearing impaired children, especially when ABR showed no response at the maximum intensity level.

2. This study will provide mean differences between ASSR and behavioral thresholds which usable to be applied in hearing threshold estimation for children in the same group of age and degree of hearing loss.

1.6 Definitions

1. Auditory steady-state response threshold is defined as the minimum intensity level where a response is present from electrophysiological method [10, 12].
2. Behavioral threshold is the lowest level at which a pure-tone stimulus is audible, involving any type of behavioral response [13].

1.7 Organization of the study

This study is organized into six chapters. An introduction is given in Chapter I. Chapter II describes a review of related literature. The methodology is presented in Chapter III. The results of this study are shown in Chapter IV. Chapter V describes the discussions. Finally, the conclusion is presented in Chapter VI.

CHAPTER II
LITERATURE REVIEW

2.1 Central Auditory Nervous System

When hair cells release the neurochemicals and picked up by the neurons of the auditory nerve. The nerve impulses flow along the auditory nerve into the brainstem and in the long run to the cortex. The central auditory nervous system is a highly complex network that the anatomical limits begin at the cochlear nucleus and end at the auditory cortex. The central auditory nervous system is assembled by its various nuclei. Nuclei are bundles of cell bodies; each serves as a relay station for nuclei information from the cochlea and auditory nerve to other nuclei in the auditory nervous system and to nuclei of others sensory and motor systems. The nuclei involved in the primary auditory pathway of the central auditory nervous system are cochlear nucleus, superior olivary complex, lateral lemniscus, inferior colliculus, and medial geniculate body. Nevertheless, the end point of the central auditory nervous system might be somewhere in the efferent system or possibly in nonauditory part of cerebrum. Moreover, literature suggested that the type of acoustic stimuli either the task would effect where the end point of the central auditory nervous system is [14].

2.1.1 The cochlear nucleus

The cochlear nucleus (CN) is the first relay station and is located in the cerebellopontine angle area, a lateral recess formed at the juncture of the pons, medulla, and cerebellum. Information is brought via the cochlear nerve to the CN. It consists of three most important sections: the anterior ventral cochlear nucleus (AVCN), the posterior ventral cochlear nucleus (PVCN), and the dorsal cochlear nucleus (DCN). Auditory nerve fibers enter at AVCN and PVCN juncture, whereas then each fiber projects into the three individual nuclei. Auditory nerve fibers entering

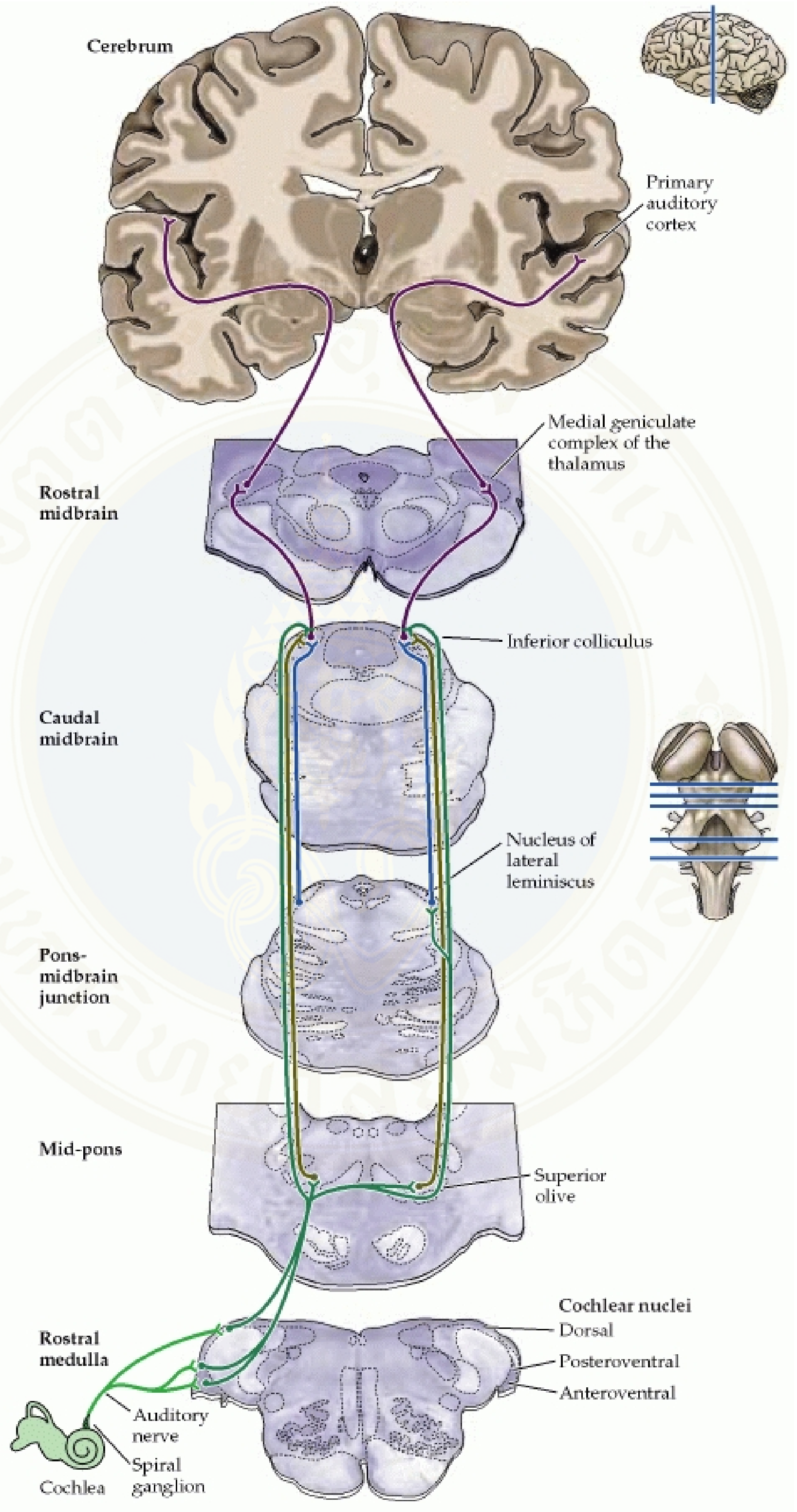


Figure 2.1 Diagram of the central auditory pathways [15].

each section in systematic fashion keep the frequency organization from the cochlea.

The cochlear nucleus contains multiple cell types: pyramidal (fusiform), octopus, stellate, spherical (bushy), globular (bushy), and multipolar cells. Characteristic manner of these cells will modify incoming neural impulse provides the basis for coding information by their type of neural activity. This correspondence between cell type and response pattern represent the meaningful relationship between structure and function of cochlear nucleus cells. This divergence of cell type related to their tuning curve.

Three fiber tracts that project out of the cochlear nucleus as follows: dorsal acoustic stria, intermediate acoustic stria and ventral acoustic stria. The dorsal acoustic stria proceeds from the dorsal cochlear nucleus and continues contralaterally to the superior olivary complex (SOC), lateral lemniscus and inferior colliculus. The intermediate acoustic stria generates in the PVCN and connects with the contralateral lemniscus (ventral nucleus) as well as the central nucleus of the contralateral inferior colliculus. The ventral acoustic stria, the largest tract, ascends from the AVCN and combines with the trapezoid body. The ventral stria extends contralaterally along the lateral lemniscus to the SOC and other nuclear groups. In addition, other fibers project ipsilaterally from each division of the cochlear nucleus, synapse at the SOC and nuclei of the lateral lemniscus. Some synapse at the inferior colliculus only and completely bypass the SOC and nuclei of the lateral lemniscus.

2.1.2 Superior olivary complex

The superior olivary complex is a small mass of gray substance situated ventral and medial to the cochlear nucleus in the caudal portion of the pons. It contains several groups of nuclei: the lateral superior olivary complex (LSO), the medial superior olivary nucleus (MSO), the nucleus of the trapezoid body and the lateral and medial preolivary nuclei. The SOC nuclei also have a tonotopic organization similar to that of cochlear nucleus. In the LSO have a unique tonotopic organization which lower frequencies are represented laterally and the higher frequencies medially following the S-shaped contour of the nucleus. While the LSO responds to a broader range of frequencies, the MSO has a primary low-frequency representation. The nucleus of the

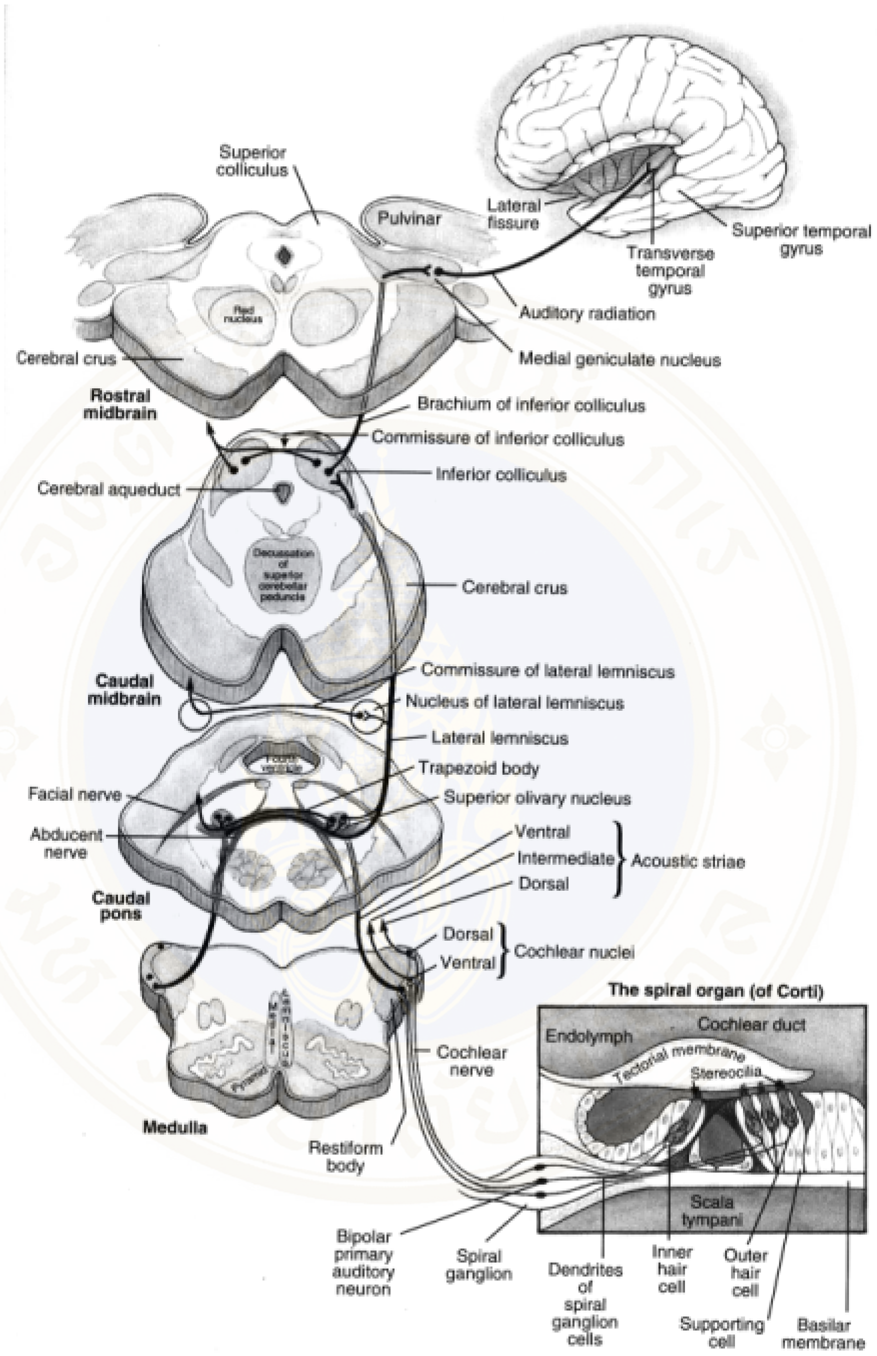


Figure 2.2 A schematic diagram of central auditory pathways showing cross-sectional representation of brainstem and transverse section through cerebrum [16].

trapezoid body has a tonotopic orientation with the low frequencies represented laterally and the high frequencies medially.

The SOC is a complex relay station which is the first place in auditory pathway where a variety of ipsilateral and contralateral inputs provide for special function in binaural listening. Interaural time and intensity variation reflected in inputs to the SOC which related to sound localization ability. Additionally the SOC has important role in integration and interpretation of directional cues for binaural listening through excitatory and inhibitory response. For example, a rapidly alternation speech perception task and the binaural fusion test are rely on binaural integration and the interaction of information in the SOC. In cases with signal degradation before the SOC would show abnormal results. Binaural integration is also necessary for the measurement of masking level differences (MLDs). Several studies supported that the SOC involve in measurement of MLDs which are a sensitive index of brainstem integrity. Moreover, the SOC also appears to serve as relay station in the acoustic stapedius muscle reflex arc [14].

2.1.3 Lateral Lemniscus

The lateral lemniscus is the primary auditory pathway in the brainstem. It composes of both ascending and descending fibers. The ascending portion extends bilaterally from the cochlear nucleus to the inferior colliculus in the midbrain and contains both crossed and uncrossed fibers of the cochlear nucleus and SOC.

The lateral lemniscus contains ventral, intermediate, and dorsal nuclei (VNLL, INLL, and DNLL, respectively). These nuclei are located posterolaterally in the upper portion of the pons, near the lateral surface of the brainstem. Most neurons of the dorsal segment of the lateral lemniscus can be activated binaurally, yet most neurons from the ventral segment can be activated only by contralateral stimulation.

The dorsal nuclei have more numerous afferent connections with lower brainstem than ventral nuclei. Through the midst of these are bilateral inputs from the LSO, ipsilateral inputs from the MSO and ventral nuclei of the lateral lemniscus, and contralateral inputs from the ventral cochlear nucleus. Besides, contralateral input is received from the other dorsal nuclei of the lateral lemniscus via the commissure of Probst. The ventral nuclei of the lateral lemniscus receive primarily contralateral input from the lower brainstem. These connections include the AVCN, PVCN, and SOC. Ipsilateral connections do exist between the medial nucleus of the trapezoid body and the ventral nuclei of the lateral lemniscus. There are no contralateral inputs between the ventral and the contralateral nuclei of the lateral lemniscus. Moreover, clinical evidence suggested that wave V component of ABR related to the neurons within the lateral lemniscus.

2.1.4 Inferior Colliculus

The inferior colliculus is located on the dorsal part of the midbrain which is largest and most recognized auditory structure of the brainstem. The inferior colliculus is obviously noticed as two spherical mounds from the dorsal aspect of the midbrain. For on the dorsal surface of the midbrain, the superior colliculi can be seen as two additional rounded projections, slightly rostral and lateral to the inferior colliculus.

Inferior colliculus contains of three primary regions; the central nucleus, lateral and dorsal nuclei. The central nucleus is the central part of the inferior colliculus. It connects with many afferent fibers arising from the lower brainstem. This central nucleus, along with its inputs and thalamic projections, is a component in the main auditory pathway. Lateral and dorsal nuclei or called as the pericentral nucleus, are less well organized than the central nucleus. These latter two nuclei surround the central nucleus like a belt and are composed of both auditory and somatosensory fibers. The inferior colliculus receives input from the dorsal and ventral cochlear nuclei, lateral and medial superior olivary nuclei, dorsal and ventral nuclei of the lateral lemniscus, and contralateral inferior colliculus.

The tonotopic organization within the inferior colliculus has a feature that high frequencies are ventral and the low frequencies are dorsally positioned. Also, their large numbers of fibers which provide sharp tuning curve bring forth high frequency resolution. For a role in sound localization, it contains many time and spatially sensitive neurons and neurons sensitive to binaural stimulation. Finally, the inferior colliculus takes part as the relay nuclear complex in transmitting auditory information to higher levels and has a commissure that permits neural communication between the left and right inferior colliculus.

2.1.5 Medial geniculate body

The medial geniculate body (MGB) is located anteriorly to the inferior dorsolateral surface of the thalamus and slightly rostral to the inferior colliculus. The MGB and the inferior colliculus are located only ~1 cm aside even though the MGB located in the thalamus and the inferior colliculus in the midbrain. The MGB divides in three parts contains ventral, dorsal and medial divisions. Cells in the ventral MGB are mainly response to acoustic stimuli whereas the other divisions contain neurons that respond to both somatosensory and acoustic stimulation. Ventral MGB is involved in transmits specific discrimination (speech) auditory information to the cerebral cortex. Dorsal MGB projects axons to association areas of the auditory cortex. They function in directing auditory attention. For Medial MGB operates as a multisensory arousal system. By the side of the MGB, there are posterior nucleus, the reticular nucleus and the pulvinar. These three areas effectively increase the amount of the thalamus that is responsive to auditory stimuli.

Afferent inputs to the MGB are arriving from the inferior colliculus through the branchium with uncrossed. However, it is possible that some input may come from contralateral inferior colliculus and that some lower nuclei may input directly on the MGB.

2.2 Overview of the auditory evoked potentials.

Electrical potentials from the scalp proceeding in the response to an auditory signal were first recorded in 1939 by Pauline Davis and colleagues [17]. There were electrical responses generated after presenting an auditory stimulus. These responses were visible because of their relatively high amplitude in comparison to unrelated background physiological noise.

In 1930, cochlear potentials were first recorded by Waver and Bray. Thereafter, it has been known as electrocochleography (ECochG) and was used clinically since early of 1960s [17]. Click and tone burst signals are used to stimulate the response, yet click is more commonly used in clinical measurement [18]. Typical ECochG waveform is shown in Figure 2.3. After the abrupt stimulation, response components are occurred within the first 2 or 3 millisecond (ms): cochlear microphonic (CM), summating potential (SP) and eight nerve action potential (AP). The amplitude ratio between the SP and the AP is used to identify Meniere's disease. However, nowadays these components are also commonly used in other applications such as enhance wave I of ABR, diagnose auditory neuropathy or in intra-operative monitoring [19].

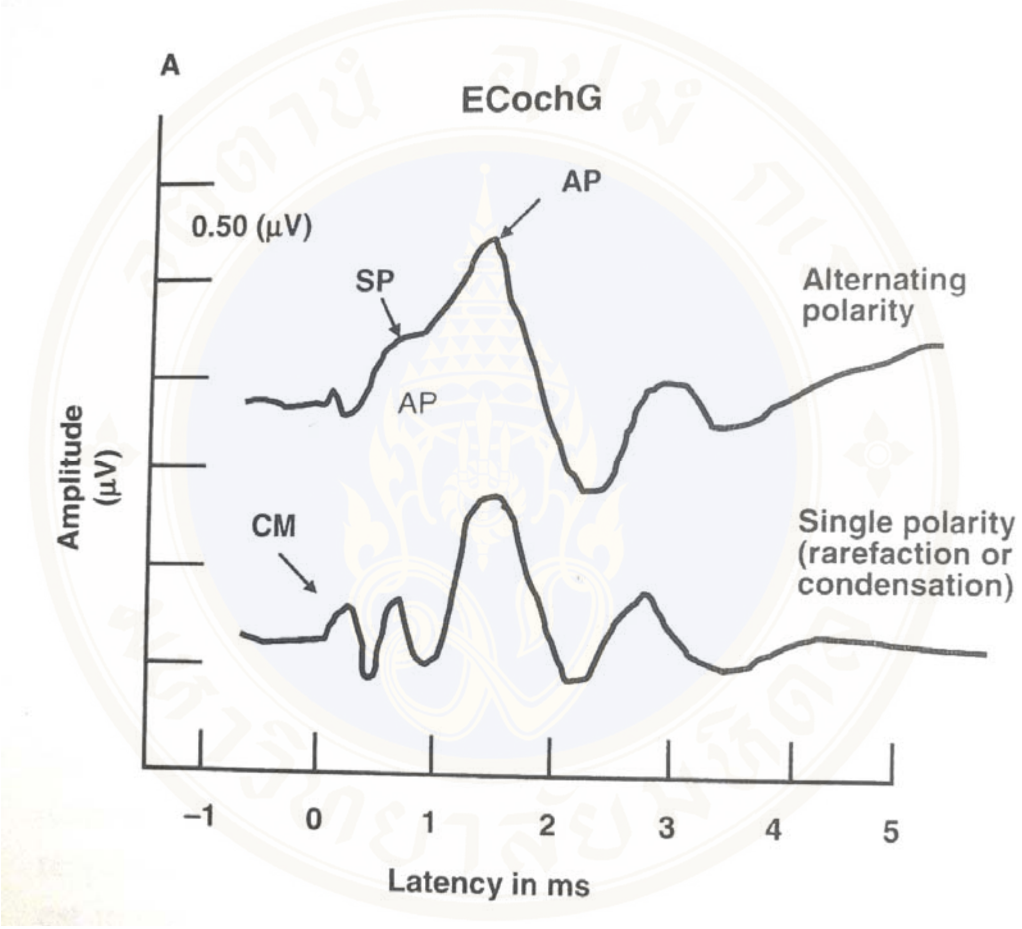


Figure 2.3 Electrocochleography (ECochG) waveforms [19].

Until the late 1960s, while Sohmer and Feinmesser were recording APs via ECochG, they observed a series of peaks with amplitudes of less than 1 microvolt occurring within 6 ms after presentation of an auditory stimulus [20]. They suggested that the peaks following the AP represented activity in auditory nuclei and tracts of the brainstem. In 1971, first description of human ABR was given by Jewett and Williston [19, 21]. The response composed of a series of up to 7 peaks designated by Roman numeral I to VII as shown in Figure 2.4. These waveforms normally occur within a 10 ms time period after a click stimulus presented.

The ABR is generated by eighth nerve or auditory nerve within the auditory brainstem pathways. Their neural generators are as follows: wave I arise from the distal portion of the auditory nerve which is similar to ECochG action potential (AP), wave II arise from the proximal portion. Wave III is generally generated in the cochlear nucleus, and IV probably arises from the superior olivary complex. The sharp positive peak of wave V generates mainly from the lateral leminiscus following with a slow negative wave represents dendritic potentials in the inferior colliculus. Wave VI and VII appear to be generated in the inferior colliculus and perhaps the medial geniculate body [21].

ABR has a wide range of clinical applications, including retrocochlear pathology, universal newborn hearing screening, hearing sensitivity estimation and intra-operative monitoring. Click stimuli have been used to elicit ABR in auditory diagnosis. However, the characteristics of its broad spectral content and rapid onset result in limitation for specific hearing threshold estimation.

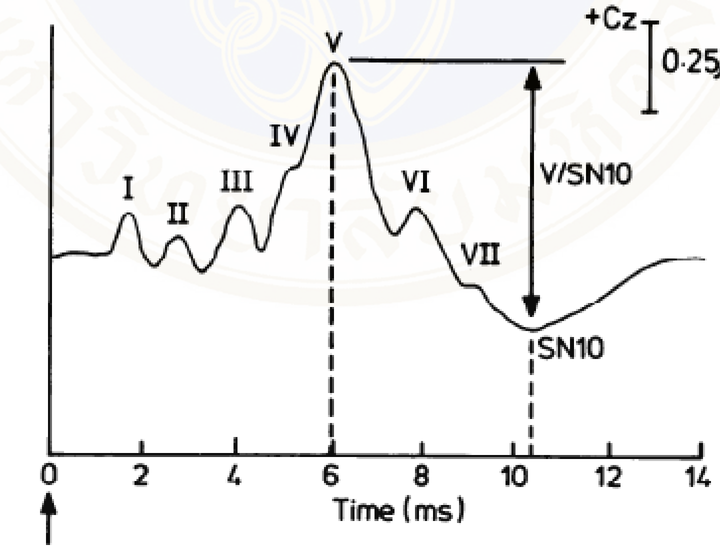


Figure 2.4 The typical ABR latencies and waveform [21].

ASSR is a new evoked potential method elicited in response to sinusoidal either amplitude and/or frequency modulated tone. In contrast to ABR, ASSR is a steady-state response arises form continuous stimulation of pure-tone carrier frequencies, such as 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz. Each tone independently modulated in amplitude and frequency. The principles behind the ASSR are time-averaging and the Fast Fourier Transform (FFT) method. The response arises from multiple neural generators and differs at different modulation frequencies. There were several opinions among studies. Kuwada suggested that generators could be in the midbrain or pons and the superior olivary complex or cochlear nucleus [22]. Neural generator for low modulation frequencies below 40 Hz is believed to be in the cortex, while higher modulation frequencies between 40 to 60 Hz are in subcortical. Besides, Cone-Wesson stated that the neural generators for ASSR of less than 20Hz is in cortical areas of the brain. For modulation frequencies between 20 Hz and 60 Hz generate responses from the thalamus, auditory midbrain and primary cortex. And high modulation frequency of more than 60 Hz generate response contributed mostly by the brainstem [23].

2.3 Historical perspective of ASSR

Since the clinical practice of click-ABR does not meet frequency-specific hearing sensitivity estimation needs in hearing impaired children, the information on speech frequency region of 500 Hz through 4000 Hz is important for audiological management. Over the years, several procedures were suggested for recording frequency-specific ABRs. Some approaches involved masking of frequency regions that were not intended to be part of the stimulus. While another approaches, presented click stimulus to the same ear as either a high-frequency noise masking signal or presented an abrupt pure-tone stimulus with masking at lower and higher frequencies. One most common clinical approach for recording frequency specific ABR is the use of tone-burst stimuli without ipsilateral masking.

However, the ASSR technique has several advantages beyond tone-burst-evoked ABR. First, ASSR takes less time consuming, since each audiometric frequency of tone-burst-evoked ABR will take the same amount of time as one click-ABR. Reasonable test time is another important criterion for any auditory evoked response to be effective in pediatric threshold estimation [24, 25]. Second, the maximum intensity for recording ASSR is more extended because of its continuous nature of the stimuli. And finally, ASSR response detection uses an objective statistical method, while ABR recordings are most often depend on the examiner subjectively reviewing of the waveforms and deciding whether a response is present.

The ASSR is an auditory evoked potential that use continuous tonal auditory stimulation. In 1981 Galambos et al described in term of "the auditory 40 Hz potential" [26]. Early investigations of 40 Hz responses have shown that they are sensitive to state of arousal which decreases under natural sleep, sedated or anesthesia state [27, 28]. Currently, recording the ASSR by using higher modulation frequencies (80-110 Hz) could overwhelm these limitations. They produced less effect on testing in infants and sleeping children, though these fast rate responses are smaller in amplitude than the 40 Hz response.

The ASSR may be elicited by amplitude modulation (AM), frequency modulation (FM), or a combination of both AM and FM (MM). Amplitude modulation is a process which varies the amplitude of carrier wave. Amplitude modulation stimulus occurs from a carrier signal, such as a pure tone and a modulated signal. The modulated signal is a direct current (DC) signal whose amplitude is varied over time and used to modulate the amplitude of the carrier signal [14].

Frequency modulation is described by variations in the frequency of a carrier wave over time which related to changes in the cochlea as a result of FM stimulation. FM has been an alternative to increase the bandwidth of signal, even though reduced frequency specificity of the response. A combination of AM and FM could enhance ASSRs in comparison to AM alone.

Groups of researcher in Australia [19] and another group in Canada [29] accredited 'mixed modulation' at a variety of modulation frequencies as high as 100 Hz effective in eliciting auditory responses. Mixed modulation combines AM and FM, evokes a response that approximates the sum of these two modulations [25]. Mixed modulation stimuli are most commonly used and preferred because they produce the largest amplitude responses [30].

2.4 Principles of ASSR Measurement

ASSR is elicited by a tone that is modulated both in amplitude and frequency. Modulating the tone restricted tone spectrum makes frequency spread narrower than a tone burst or click. While ABR is evoked with transient stimuli divided by silent period, ASSR is evoked with constant sinusoidal stimuli modulated rapidly in amplitude and/or frequency. Using of the ongoing steady-state stimulus to elicit the ASSR has advantage on higher effective intensity level. The rate of stimulus modulation affects the site of ASSR generation within the auditory system. ABR and ASSR have distinctly different strategy for response. Typically, clinician inspects a characteristic of ABR constant waveforms and manually calculates response parameter. While ASSR recording contains Electroencephalography (EEG) activity, brain activity increased within the spectral region of the amplitude modulation frequency if there is response. The ASSR complex waveform cannot be detected visually. On the contrary, it is detected by either automated spectral analysis of stimulus related brain energy in the frequency domain (Fast Fourier Transform, FFT) or by automated analysis of the phase of the response relative to stimulus phase, i.e., the similarity of the response with repeated stimulation or phase coherance. The presence of a response versus background noise is verified statistically.

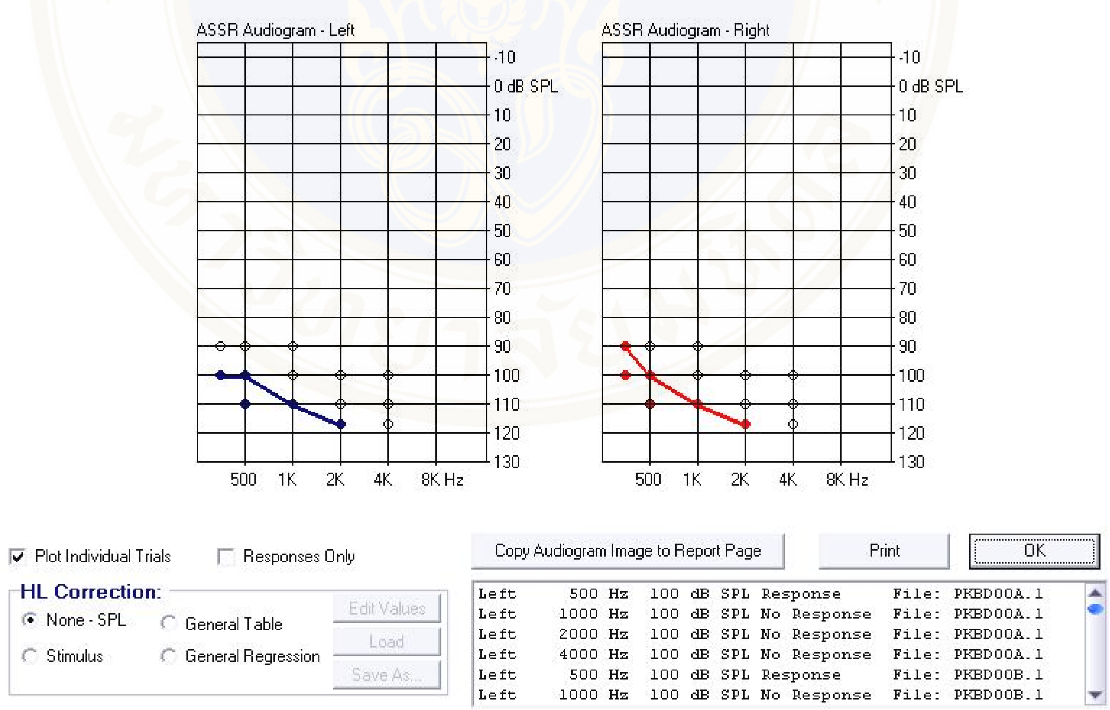
2.4.1 ASSR stimuli

ASSR can be evoked by distinct types of stimuli. Sinusoidal amplitude modulation (SAM) of a continuous tone is the most general stimulus. ASSR elicited by SAM tone is considered to be a reflection of the synchronous discharge of auditory neurons that are phase-locked to the modulation frequency (MF) of the stimulus tone. The narrow band power spectrum of the SAM tone provides ASSR reliable frequency-specific hearing information [31]. When the carrier frequency (CF) is f_c and the MF is f_m, the power spectrum of the SAM tone has three steep peaks at f_c-f_m, f_c, and f_c+f_m; the power spectrum is considerably narrower than the spectra of click and tone pips.

FM stimuli can also evoke a response. MM combining both AM and FM, evoke a response which almost the sum of both modulations. For the tonal stimuli, the responses to mixed modulation are larger than the responses to simple sinusoidal modulation [25].

When multiple stimuli simultaneously presented at a time, with each stimulus modulated at its own signature frequency. The response can then be determined separately at the frequencies in the response spectrum equivalent to the different modulation frequencies. Four stimuli in one ear or eight stimuli in two ears could be recorded with insubstantial loss of amplitude or increase in the background EEG noise. Therefore, thresholds can be detected much more rapidly than by recording each stimulus separately. Sometime it is necessary to improve the recording efficiency in order to demonstrate clearly that subthreshold responses are not present; however, it usually took two to three times rather than eight times.

The maximum intensity presentation level for test stimuli was 117 dB SPL, while the presence of a response would demonstrate in form of dB SPL and dB HL unit (Figure 2.5, 2.6). ANSI S3.6–1996 corrections for Etymotic ER-3A earphones were used to convert from dB SPL to dB HL [32].

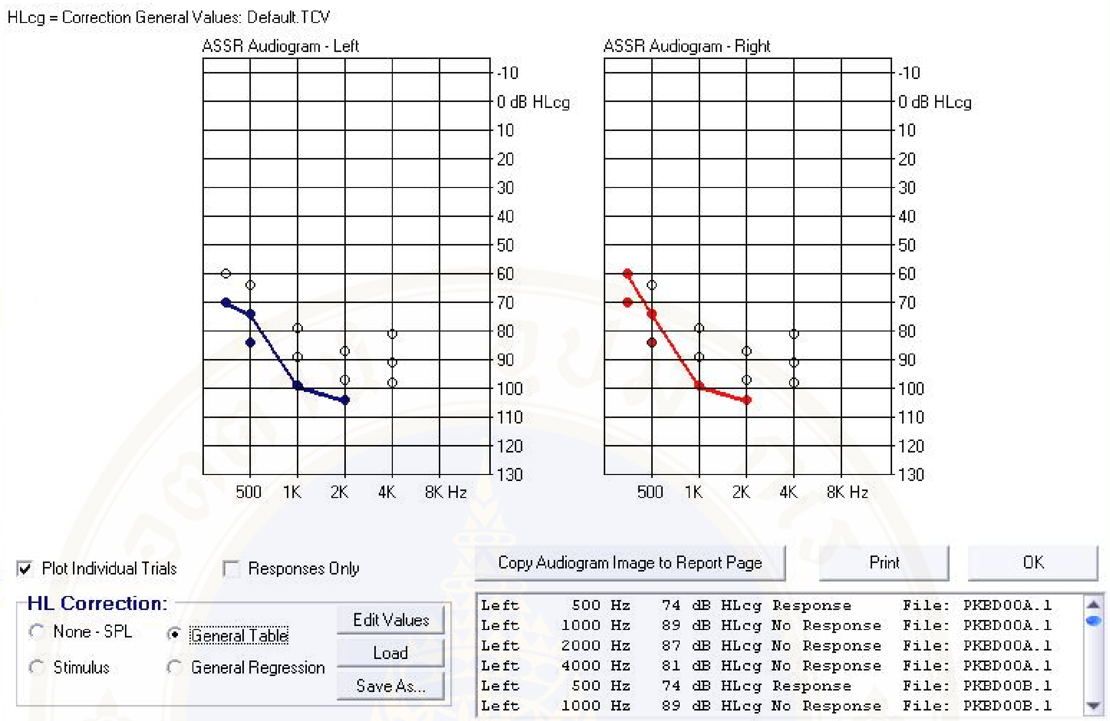


☑ Plot Individual Trials ☐ Responses Only

HL Correction:
● None - SPL ○ General Table
○ Stimulus ○ General Regression

```
Left      500 Hz  100 dB SPL Response     File: PKBD00A.1
Left     1000 Hz  100 dB SPL No Response  File: PKBD00A.1
Left     2000 Hz  100 dB SPL No Response  File: PKBD00A.1
Left     4000 Hz  100 dB SPL No Response  File: PKBD00A.1
Left      500 Hz  100 dB SPL Response     File: PKBD00B.1
Left     1000 Hz  100 dB SPL No Response  File: PKBD00B.1
```

Figure 2.5 The example of ASSR instrument displays the response results in dB SPL.



HLcg = Correction General Values: Default.TCV

☑ Plot Individual Trials ☐ Responses Only

HL Correction:

○ None - SPL ● General Table

○ Stimulus ○ General Regression

```
Left      500 Hz   74 dB HLcg Response      File: PKBD00A.1
Left     1000 Hz   89 dB HLcg No Response   File: PKBD00A.1
Left     2000 Hz   87 dB HLcg No Response   File: PKBD00A.1
Left     4000 Hz   81 dB HLcg No Response   File: PKBD00A.1
Left      500 Hz   74 dB HLcg Response      File: PKBD00B.1
Left     1000 Hz   89 dB HLcg No Response   File: PKBD00B.1
```

Figure 2.6 The example of ASSR instrument displays the response results converted from dB SPL unit to dB HL.

2.4.2 ASSR analysis

The ASSR activity can presented in a polar plot, where amplitude of vector and phase describe amplitude of activity. A common approach for calculation of phase of the ASSR is to quantify phase delay (or lag) between the onset phase of the stimulus and the onset phase of the response. The result of the phase calculation is shown in a polar plot with vector lines extending out from the center. The length of the vector in µV designates amplitude of brain activity, whereas the angle between the vector lines and 0º phase line indicates phase in degrees. There are three possible results with the vector plot: (1) Phase locked: a coherent relation between the stimulus and the phase of ASSR, represent the presence of response. (2) Random: no coherent relation is detected between the stimulus and the phase of the ASSR, show under adequate measurement conditions with low noise. (3) Excessive noise: the level of ambient electrical, EEG, or myogenic noise is excessively high precluding confident detection of an ASSR.

ASSR activity is always found with background noises which contain both physiologic and electrical sources. In general, auditory evoked potential has two important strategies for enhancing detection of desired brain activity by filtering out unwanted spectral activity for minimizing background noise, and repeat stimulation to increase signal. Moreover, artifact rejection of noise is also crucial in detection of ASSR. Therefore, F-test is used to determine the probability that a response is really present versus simply background noise, verify that the presumed response is statistically different than background noise. The probability of the presence of a response versus noise within ongoing EEG is statistically determined with both the fast Fourier transformation (FFT) and the phase coherence analysis. Fourier analysis or fast Fourier transformation (FFT) is an approach used for analyze ASSR activity during acoustic stimulation.

2.4.3 Fourier analysis, Fourier transform and fast Fourier transform

Joseph Fourier, a French mathematician who lived in the early nineteenth century showed that any complex periodic sound wave disturbance can be mathematically broken down into a series of sinusoids with specific frequencies, amplitudes, and phases. This is done using a mathematical device called the *Fourier transform.* The analysis is called *Fourier analysis* and each sinusoid is called a (Fourier) component of a complex sound [33, 34].

Periodic tone is the simplest type of complex tone to which Fourier analysis can be applied. Periodic is composed of a number of sinusoids. Each sinusoid has a frequency that is an integer multiple of the frequency of a common fundamental component. It appears that human is able to hear the harmonics of a periodic sound wave individually to a limited extent. When a complex tone is presented, we usually hear a single pitch corresponding to the repetition rate of the whole sound despite ability to hear the lower harmonics of a complex sound to some extent. When two simultaneous pure tones are presented, two separate tones often heard with its pitch rather than a single complex sound. Therefore, our perception corresponds to the analysis of the sound in terms of its Fourier components.

In theory of Fourier analysis, mathematical techniques used in calculating spectra require the waveform to last an infinite time which impossible in practical situation. Besides, it is clearly understand that the ear does not take infinite time to analyze sounds. In many situations it is useful to apply a “window” to the sound, take only a segment of a sound and assume that the waveform has zero value outside the time limits of the segment. Only the portion of the waveform falling within the window is “seen”. *The Fourier transform* of the windowed sample can then be calculated by giving what is called the short-term spectrum of the sound. The spectrum contains energy over a considerable range of frequencies. To reduce the effect of discontinuities in the waveform which introduced by applying the window, it is possible to use a window that is weighting function at the center of the window than at the edge. Typically, window lengths are between 5 and 200 milliseconds. The frequency resolution possible depends on the duration of the window, possible the frequency resolution is equal to the reciprocal of the window duration.

The use of computers to solve problem of Fourier analysis often involves an algorithm called the fast Fourier transform (FFT) [34].

2.5. ASSR in auditory threshold estimation in children

The ASSR has been an interesting topic over the past decade for hearing threshold estimation in children either normal hearing or various degrees of hearing loss.

Several studies have shown the relationship between behavioral and ASSR thresholds. The correlations between ASSR and behavioral thresholds generally increase directly with the degree of hearing loss [10, 35]. Rance compared behavioral thresholds with the ASSR thresholds obtained in normal to profound hearing level in children and adults. The relationship is demonstrated by an overall correlation coefficient of 0.97 for 250 to 4000 Hz [10]. Luts have investigated thresholds in 10 infants between 3 and 14 months of age. Frequency-specific correlations were 0.92, 0.93, 0.91 and 0.93 for 0.5, 1, 2, and 4 kHz, respectively. The overall Pearson correlation was 0.92 [36]. Similarly, high correlation was observed in other studies [6, 37-39].

Swanepol investigated a sample of 5 girls and 5 boys, with severe to profound congenital sensorineural hearing loss. The best correlation was obtained at

1000 Hz (0.74), and the worst correlation coefficient was obtained at 500 Hz (0.58) [24]. Later, Swanepol investigated the usefulness of ASSR in estimating 7 subjects (12 ears) between ages of 15 to 18 years with confirmed moderate sensorineural hearing loss. The smallest difference and least variation between behavioral and ASSR thresholds was observed at 1000 Hz with a mean difference of 2 ± 7 dB. The largest difference and variation was recorded at 500 Hz (8 ± 10 dB). The mean difference between all 500 to 4000Hz is 5 ± 8 dB [40]. Moreover, studies suggested that ASSR thresholds are closer to behavioral threshold when higher carrier frequency stimuli are used [10].

The comparison was made between ASSR and behavioral hearing thresholds. Luts reported mean difference between both measures was 0.9 ± 12.8 dB, difference scores ranged from -30 to 20 dB. Of the absolute differences 68% were within 10 dB, 94% were within 20 dB [41]. Another study reported about 55% of the estimates are within 5 dB of the behavioral hearing threshold, and 94% within 15 dB [42].

While Han found that ASSR thresholds were usually higher than behavioral thresholds with a difference of 8 to 15 dB [6]. Swanepol reported mean differences varied between 2 and 8 dB across frequencies and 69% of recordings showed threshold differences within 10 dB [24, 40]. Ahn described the relationship by the equation; PTA (pure tone average) = 1.05*mean ASSR-7.6 [38].

2.6 Factors influencing ASSR

2.6.1 Age and maturation

The ASSR with fast stimulus modulation frequencies is used clinically for hearing assessment in infants [10, 11, 36]. John [43] described the auditory steady-state responses evoked by various types of stimulus modulations in 70 full-term infants categorized into two groups. A set of fifty newborn infants with gestational ages between 37 and 42 weeks were tested within 74 hours after birth, when the other twenty infants were tested between 3 and 15 weeks after birth. The incidence of significant responses rose substantially when the infants were tested at the age of 1 to 3 months rather than within 3 days of birth. The responses showed significantly larger in the older infants though there were no differences in the EEG noise levels of the recording of these two groups. They suggested that the main cause of these larger response in the older children probably because of the maturation of the auditory system.

Rance examined the relationship between ASSR and behavioral thresholds in twenty-five children aged 10 to 58 months and thirty-five adults aged 24 to 82 year. The results clearly showed that there was no significant age effect in error prediction values at 250, 500, 1000, 2000 and 4000 Hz [10].

2.6.2 Gender

John and Picton reported that the ASSR tended to be earlier in latency and larger in amplitude for female than for male subjects. However, the ANOVA showed no significant different in effects of gender for either amplitude or latency [44]. These findings are consistent with previous study [45]. Effect of gender on the ASSRs may occur and be similar to those found in ABR [44, 45]. These differences may be presented in the newborn babies [46]. The literature also described that gender differences related with the size of head [44] and the length of the cochlea partition [47].

2.6.3 Attention, state of arousal, and sleep

Subject's state is absolutely impact successfulness and reliability of the ASSR measurement. Previous studies suggested that attention and state of arousal influenced the 40 Hz ASSR [27, 28]. Most studies indicated that ASSR amplitude was decreased during sleep. On the contrary, Pockett and Tan reported the amplitude of ASSR increased during low arousal state when obtained from a mastoid reference [48]. They also reported that about 50% of subjects did not show ASSRs when awake but during drowsiness. Later, Picton suggested that these increased responses were caused by postauricular muscle responses (PAMRs) from mastoid reference recordings [49]. Aoyagi affirmed that the 40 Hz ASSR is high reliable in an awake adult and 80 Hz provides accurate hearing information with a good frequency specificity in asleep children [31]. In addition, Rance noted the sleeping does not significantly affect the relationship between ASSR and behavioral thresholds at 90 Hz modulation frequency [10].

CHAPTER III

MATERIALS AND METHODS

This chapter deals with materials and methods used in this study. The participants characteristics of this study are described the criteria and sample size calculation. Following by the instrumentations, measuring and testing procedures, test environment and finally the statistical methods used in data analysis are described.

3.1 Participants

The subjects of this study composed of thirty-nine children (18 girls, 21 boys) age between 2 years 4 months to 11 years old who enrolled a preschool aural rehabilitation program at the Speech and Hearing Clinic, Ramathibodi Hospital. All children had been trained for listening skill especially sound detection. Twenty subjects were fitted with hearing aids both ears, and nineteen subjects had one ear with cochlear implant. Subjects who have one ear cochlear implant, the test would be performed on the opposite ear. All subjects showed no response click-ABR at maximum intensity (99 dB nHL). Normal middle ear (type A tympanogram) was a pre-requisite for inclusion criteria. None of the subjects showed any indication of middle ear dysfunction, according to tympanometric results. Children with multiple handicaps and children who can not sleep naturally during the measurement were excluded from this study. The testing started in June 2008 and lasted until January 2009.

3.2 Preliminaries

The examiner clearly explained the objective of this study to the child’s parent including the preparation before the test session, test procedures, how much time to spend on the test, how many days needed for the test, including the risks and benefits of the experimentation. Then informed consent was obtained prior to the test.

3.3 Instrumentations

The instruments used in this research:

3.3.1 Audiometer – GSI-61

3.3.2 Acoustic immittance instrument GSI - Tymstar

3.3.3 Auditory Steady-State Response instrument - Intelligence Hearing System model SmartEP version 2.21 USBez with insert earphones (ER-3A)

3.4 Procedures

3.4.1 Conventional play audiometry

3.4.1.1 Training procedure

Before performing conventional play audiometry, conditioned training procedures were needed to prepare and help the child understand the test. The procedure started with visual stimulation step; the child watched the red light flashed while holding object (mostly are toys) and placed near by the light. Whenever the light flashed on, the child was asked to response by moving the object. At the beginning, the examiner might help by grasping child's hand to response by placing a block or a piece of small toy in a toy basket. After the few trials the examiner would let the child performed by him or herself, if the task was done correctly the examiner praised as reinforcement. Later, the stimulus would be changed into tactile stimulation by following the same condition. The child was asked to response whenever he felt vibration. After child understood conditioning, the stimulus would be changed to auditory stimulation which is pure tone at different frequencies used in routine audiometry.

3.4.1.2 Conventional play audiometry

While the child sat in a chair with a parent nearby in sound proof room, the examiner put headphones gently but firmly on the child's head. The examiner went out to the equipment room whereas a trained- assistant stayed with the child in the examination room. The test session started with low frequency at 500 Hz on the basis of severe to profound hearing loss usually has residual hearing at low frequency. Tone stimulus was used to present approximately above the expected threshold; unless it was maximum intensity level of the instrument. The examiner reinforced the child for a correct action with body language and facial expression. The assistant was ready to give another piece of toy as soon as the child responded correctly. Three to four trials should be sufficient for the child to understand the task. Then the examiner descended the intensity level 10 dB steps. Thresholds were assessed at 250, 500, 1000, 2000, and 4000 Hz using 10-dB-down and 5-dB-up threshold-seeking procedure. Sometime during the test session the child forgot what to do; the examiner would recondition the child with the assistant's help. Occasionally, hearing evaluation in children takes time to complete. If the child showed the sign of boredom but the test did not yet complete, the examiner would try with another set of toy to motivate the child's enthusiasm. Even though the child did not co-operate, the task would be tried on the other day within a week.

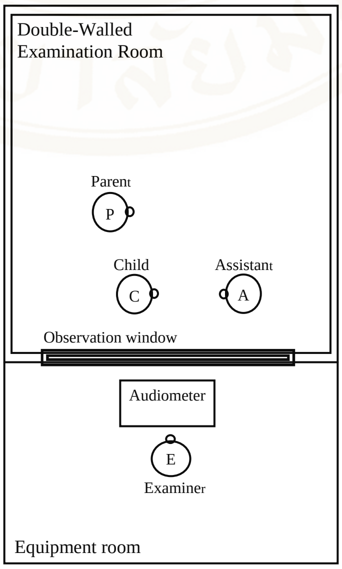


Figure 3.1 Position during pure-tone conventional play audiometry.

3.4.2 Auditory steady-state response

Test stimuli were 250, 500, 1000, 2000 and 4000 Hz tones. The modulation frequencies for 500, 1000, 2000 and 4000 Hz for left ear stimuli were 77, 85, 93 and 101 Hz and for right ear were 79, 87, 95 and 103 Hz. Since the frequency of 250 Hz testing has to be measured separately from others frequencies as default of instrument, the modulation frequencies for 250 Hz were 77 and 79 Hz for left and right ear, respectively. These modulation frequencies are default specifications of SmartEP system.

The examiner reminded the parents not to put the child to sleep before the test. After the child finished his/her meal, the parent and the child moved to a quiet air conditioned room and wait until the child felt sleepy. Then ASSR would be taken right after the child slept with parent stay beside in test room. The ASSR was performed during natural sleep. The parent or caregiver was informed what will be done during the procedure. Test time and date was set according to a nap time of each child. For older child, the explanation would be done, thus the child understood what would be expected. The child would have chance to see and touch some parts of equipment to make them less anxious, feel relax and cooperate during the test. If the child could not sleep or cooperate with the test procedure, a second attempt was made in another day; if the test could not be performed, the child would be excluded from subject group.

The test stimuli were presented through ER 3A insert earphones. Electrode placement is two channels system with corresponding two inverting electrodes at each mastoid, ground electrode on the lower forehead and two non-inverting leads with Y-adaptor on mid frontal forehead. The skin preparation gel was used to clean the sites to reduce skin impedance. All electrode impedances were less than 5 kOhm with inter-electrode impedance values below 3 kOhm. The test was performed during natural sleeping condition to exclude movement artifacts. If the child has one ear with cochlear implant, the test was performed at the opposite site.

The examiner started the test with 90 dB SPL stimulus at 500, 1000, 2000 and 4000 Hz simultaneously, while 250 Hz carrier frequency was testing separately. If there was no response or the response did not meet the standard criteria, the intensity level will be increased 10 dB until the response was reached. The maximum intensity of the instrument is 117dB SPL. If there were response, the level is then reduced by 10 dB or increased by 5 dB until the threshold level was identified. Threshold was taken as the lowest intensity whereas a response was found at that level but no response was found at a lower level. For threshold level at 250 Hz, the test was done separately but with the same procedure.

3.4.2.1 Stimulus parameters

SmartEP ASSR 2.21 USBez

Parameter	**Selection**	
Stimulus parameters		
Transducer	ER3A insert earphones	
Type	Sinusoid	
Frequencies	250, 500, 1000, 2000, 4000 Hz	
Modulation rate	Left ear:	Right ear:
	250Hz (77Hz)	250Hz (79Hz)
	500Hz (77Hz)	500Hz (79Hz)
	1000Hz (85Hz)	1000Hz (87Hz)
	2000Hz (93Hz)	2000Hz (95Hz)
	4000Hz (101Hz)	4000Hz (103H
Mode	Monaural or binaural (dichotic)	
Acquisition Parameters		
Electrodes		
Noninverting	Mid frontal forehead	
Inverting	Mastoid	
Ground	Lower forehead	
Amplifier parameters		
Gain:	100K	
High pass filter:	30 Hz	
Low pass filter:	300 Hz	
Notch line filter:	OFF	
Analysis algorithm	Fast Fourier Transform with F-Test	

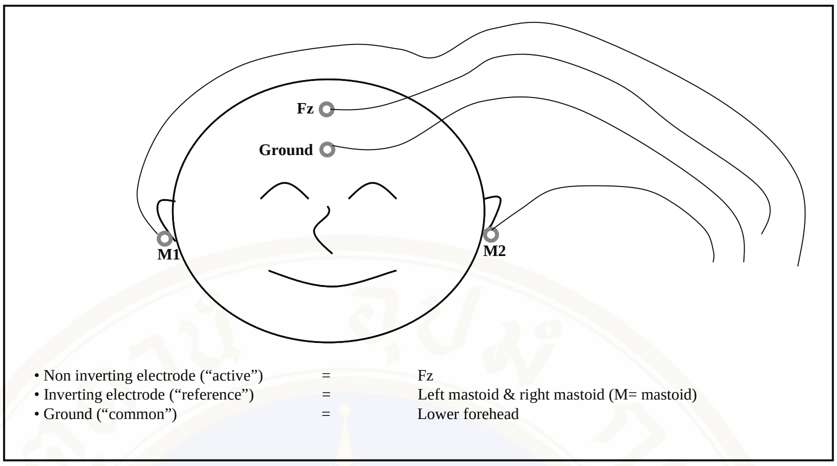


Figure 3.2 ASSR electrode placements**.**

3.4.2.2 Response criteria and interpretation of results

Threshold for each carrier frequency was determined with the use of a bracketing technique. A threshold was defined as the lowest intensity level where a significant response was obtained. Moreover, a threshold was only accepted when SNR (signal to noise ratio) of signal > 6.13 dB, SNR of sidebins > 6.13 dB, Amplitude of signal > 0.0125 µV and noise amplitude < 0.05 µV. If no significance was achieved at these criteria a false positive response was assumed.

Signal averaging was used to improve the signal to noise ratio (SNR), average the steady-state potentials in time domain and converts them into the frequency domain using the Fast Fourier Transformation technique. The amplitude of the ASSR response at each modulation frequency is compared with that of the adjacent frequencies using the F-statistic. When the significant of the F-value at a certain modulation frequency fell below 0.05, an ASSR response was indicated. The response was considered absent when the F-value was greater than or equal to 0.05.

3.5 Test environment

3.5.1 The Conventional play audiometry

The Conventional play audiometry was done in an audiometric test room satisfying standard criteria (ANSI 1969) for maximum permissible ambient noise for audiometric test rooms. The room size is sufficient to accommodate the parent, child, and audiologist comfortably and is adequately ventilated.

3.5.2 Auditory steady-state response

ASSR thresholds were measured in a quiet air conditioned room. For young children, the parent prepared the child to sleep after meal time which usually was their afternoon nap time. The room was set, all electrode wires were kept in the drawer, out of children’s sight so they would not be bullied or frightened. Until the child felt sleepy, they would be put into a proper position ready to be tested and tape the electrode wires in place. Parent would stay beside the child during the test. The older children were encouraged to sleep during the measurement. A comfortable and secure atmosphere help the child relax and fell to sleep. In some case, darkening the room helps initiating, maintaining and lengthening the sleeping period.

3.6 Data analysis

The statistical package SPSS for Windows version 17.0 is used for data analysis as follows:

1. Mean and standard deviations (SD) is performed to measure data distribution of ASSR thresholds and behavioral thresholds at 250, 500, 1000, 2000 and 4000 Hz.

2. Wilcoxon signed ranks test is performed to determine the significance of a mean difference ASSR thresholds and mean behavioral thresholds at 250, 500, 1000, 2000 and 4000 Hz.

3. Kappa statistic measures agreement between ASSR thresholds and behavioral thresholds at 250, 500, 1000, 2000 and 4000 Hz.

CHAPTER IV
RESULTS

This research aims to examine the distribution of behavioral hearing thresholds in children who had demonstrated absent ABR waveform at maximum presentation level (99 dB nHL). Secondly, is to describe the relationship between behavioral hearing thresholds and ASSR thresholds estimation in severe and profound hearing loss children across the frequencies between 250 to 4000 Hz.

The results of study consist of the following topics:

1. A summary of the subject characteristics of data collection
2. The distribution of behavioral hearing thresholds in children who had demonstrated absent ABR waveform at maximum presentation level.
3. The advantage of ASSR in estimation hearing thresholds over click-ABR.
4. The relationship between ASSR thresholds and behavioral hearing thresholds estimation in severe and profound hearing loss children across the frequencies between 250 to 4000 Hz.
5. Inter-rater reliability between two instruments.

4.1 Subject characteristics

A total of thirty-nine children (fifty-nine ears) participated in this study, which composed of 18 girls and 21 boys. The average age of the children is 6 years 5 months (range from 2 years 4 months to 11 years). All subjects showed no click-ABR response at maximum intensity level and had been training listening skill and sound detection in a preschool aural rehabilitation program at the Speech and Hearing Clinic, Ramathibodi Hospital.

4.2 The distribution of behavioral hearing thresholds

All children who participated in this study had been confirmed with absent ABR results at maximum presentation level (99 dB nHL). Figure 4.1, showed the distribution of behavioral hearing thresholds at 250 to 4000 Hz. Generally, the central rectangle spans the first quartile to the third quartile. A segment inside the rectangle refers to the median while whisker above and below the box refers to the locations of the minimum and maximum level. The unfilled circles display outliers, surprisingly high maximum or high minimum. In this study, the data distributions at high frequencies (2000 to 4000 Hz) are correspondence with absent click-ABR response [50]. The results showed residual hearing at low frequencies which was the audiometric configuration of congenital sensorineural hearing loss.

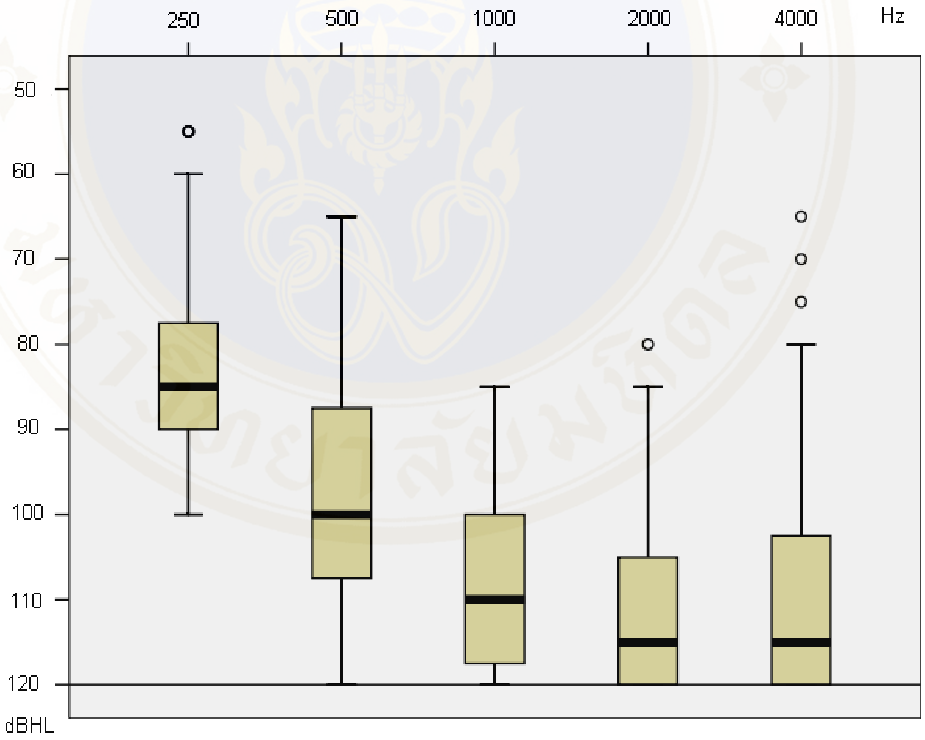


Figure 4.1 The distribution of behavioral hearing thresholds (number of ears = 59) across frequencies for children with absent ABR waveform at maximum presentation level. (X axis represents frequency at 250 to 4000 Hz while Y axis represents hearing level in dB HL)

4.3 The estimation of hearing thresholds result from ASSR

Table 4.1 The percentage of ears demonstrated the presence and absence of ASSR thresholds at 117 dB SPL.

Frequency (Hz)	**Number of tested ear**	**ASSR presence**	**ASSR absence**
		No. of ears (%)	No. of ears (%)
250	56	51 (86.44%)	5 (8.62%)
500	59	34 (57.63%)	25 (42.37%)
1000	59	44 (74.58%)	15 (25.42%)
2000	59	25 (42.37%)	34 (57.63%)
4000	59	21 (35.59%)	38 (64.41%)

Table 4.1 showed the number and the percentage of ears which demonstrated the presence and absence of ASSR in all subjects with absent click-ABR. Therefore, while ABR can not be used to estimate hearing sensitivity in the severe-to-profound range of impairment [51], ASSR are enable. Since ASSR at 250 Hz was tested separately from other frequencies as default setting of the instrument. Sensitivity estimation for 250 Hz of three ears was excluded because the child woke up before the test was completed. For this reason, only 56 ears were tested for 250 Hz and 59 ears for 500, 1000, 2000, and 4000 Hz.

While click-ABR provides hearing sensitivity information only in the 2000-4000 Hz region which is not frequency-specific but in current results showed the presence of ASSR response in frequency by frequency including low frequencies. The ASSR responses were found in 51 ears (86.44%), 34 ears (57.63%), 44 ears (74.58%), 25 ears (42.37%) and 21 ears (35.59%) at 250, 500, 1000, 2000 and 4000 Hz, respectively, when all the ABR records showed no response. When we considered in regarding to the absence of ASSR, only at 2000 and 4000 Hz showed no ASSR response over 50% of ears. Therefore, ASSR will provide useful threshold information at low frequencies. These results support the usefulness of ASSR over ABR.

Table 4.2 The number and percentage of recordable thresholds in the presence of conventional play audiometry (CPA) in the absence of ASSR.

In the absence of ASSR (n = 117)	**CPA at intensity level** (dB HL)	**no. of recordable threshold (%)**
	70-79	1 (0.8%)
	80-89	4 (3.4%)
	90-99	12 (10.3%)
	≥100	100 (85.5%)

The number and percentage of recordable threshold in the presence of CPA at intensity range of 70-79, 80-89, 90-99 and ≥100 dB HL were 1 (0.8%), 4 (3.4%), 12 (10.3%) and 100 (85.5%), respectively (Table 4.2). Mostly, the absence of ASSR response at maximum levels showed a tendency of hearing level over 100 dB HL. There were 42 (36%) from 117 recordable thresholds showed absent response both CPA and ASSR.

However, only these results were not sufficient to conclude the reliability of ASSR. At present, audiometry was accepted as a gold standard hearing threshold assessment [52-54]. Therefore, this study would explore the relationship and compare the results between ASSR and conventional play audiometry.

4.4 The mean difference between ASSR thresholds and behavioral hearing thresholds

Table 4.3 showed mean of hearing thresholds derived from ASSR and CPA, and the mean differences. Mean ASSR estimated thresholds were 74.39, 94.37, 98.49, 107.53 and 106.78 dB HL at frequency of 250, 500, 1000, 2000 and 4000 Hz, respectively, with standard deviation ranged between 14 to 23 dB. While mean of CPA thresholds were 82.95, 99.07, 106.69, 110.51 and 109.15 dB HL at 250, 500, 1000, 2000 and 4000 Hz, respectively, with standard deviation ranged between 11 to 15 dB.

Table 4.3 The mean difference between ASSR thresholds and behavioral hearing thresholds from CPA across frequencies by Wilcoxon signed ranked test.

Frequency (Hz)	Measurement	N	Mean (dB)	SD	Mean Difference ASSR-CPA threshold	SD	z	p
250	ASSR	56	74.39	17.33	-8.20	19.28	-3.056^{**}	0.002
	CPA		82.95	11.95				
500	ASSR	59	94.37	23.28	-4.69	22.99	-1.512	0.130
	CPA		99.07	14.25				
1000	ASSR	59	98.49	14.71	-8.20	15.89	-4.114^{**}	0.000
	CPA		106.69	11.36				
2000	ASSR	59	107.53	16.45	-2.98	14.51	-1.158	0.247
	CPA		110.51	11.47				
4000	ASSR	59	106.78	19.26	-2.37	17.36	-0.363	0.363
	CPA		109.15	15.03				
Total	ASSR	292	96.54	21.85	-5.26	17.78	-4.948^{**}	0.000
	CPA		101.80	16.38				

Note In case of hearing thresholds were 120 dB or more, the number of 120 was used for calculation; **significant at p-value < 0.01

For mean differences derived from CPA thresholds subtract from ASSR thresholds were -8.20, -4.69, -8.20, -2.98 and -2.37 at frequency of 250, 500, 1000, 2000 and 4000 Hz, respectively. These results demonstrated that ASSR thresholds were underestimated when compared to behavioral hearing thresholds. Wilcoxon signed ranked test demonstrated statistically significant different (p < 0.01) only at 250 and 1000 Hz, but there were slightly difference at 500, 2000 and 4000 Hz without statistically significant. The integration of hearing thresholds from 250 through 4000 Hz showed mean difference value of -5.26 dB with statistically significant difference (p < 0.01).

4.5 Inter-rater reliability

For examining the reliability between two hearing assessment instruments, ASSR and CPA, the inter-rater agreements were measured by using Cohen’s Kappa analysis. In the first trial, we categorized all estimated hearing thresholds into groups according to categories of degree of hearing impairment which is universal standard and also using in Audiology clinic, Ramathibodi hospital (Table 4.4) [55, 56]. Then each group with the same degree of hearing impairment the thresholds were calculated for the value of agreement. Nevertheless, the Kappa value could be computed only when the number of rows equals to the number of columns. For this reason, the data could be computed only at 500 and 4000 Hz. The results were 0.213 (p 0.025) and 0.319 (p 0.001) consequently (Table 4.7), which mean fair strength of agreement.

The second trial, the criteria was applied by combine two categories together. Mild hearing loss was combined with moderate hearing loss, while moderately severe was combined with severe hearing loss. The inter-rater agreement Kappa values between ASSR and CPA were able to apply from 250 to 4000 Hz as shown in Table 4.6. Overall, results revealed fair to moderate agreement between these two methods on hearing thresholds estimation. We observed a moderate agreement at the high frequencies (2000 and 4000 Hz) and a fair agreement at low frequencies (250 and 500 Hz). There was no statistically significant agreement at 1000 Hz.

Table 4.4 Categories of degrees of hearing loss.

Pure-tone average in dB HL	Degree of hearing loss [52, 53]	Combined degree of hearing loss*
$\leq$ 15	Normal hearing	Normal hearing
16-25	Slight hearing loss	Slight hearing loss
26-40	Mild hearing loss	mild to moderate hearing loss
41-55	Moderate hearing loss	
56-70	Moderately severe hearing loss	moderately severe to severe hearing loss
71-90	Severe hearing loss	
>90	Profound hearing loss	Profound hearing loss

Note *combined in order to analyze inter-rater agreement in second trial.

Table 4.5 The distribution of hearing level classification provided for assessing thresholds agreement between ASSR and CPA in first trial.

Freq.	CPA	Hearing level classification					
		ASSR					
		mild	mod	mod sev	severe	profound	total
		n	n	n	n	n	n
250 Hz	mild						
	mod	0	1	2	0	0	3
	mod sev	1	0	5	2	0	8
	severe	0	2	22	8	3	35
	profound	0	0	6	2	2	10
	total	1	3	35	12	5	56
500 Hz*	mild						
	mod						
	mod sev			2	0	1	3
	severe			3	6	4	13
	profound			4	13	26	43
	total			9	19	31	59
1000 Hz	mild						
	mod						
	mod sev						
	severe			1	7	2	10
	profound			0	23	26	49
	total			1	30	28	59
2000 Hz	mild						
	mod						
	mod sev						
	severe			1	5	1	7
	profound			1	7	44	52
	total			2	12	45	59
4000 Hz*	mild						
	mod						
	mod sev			1	2	0	3
	severe			0	2	2	4
	profound			1	7	44	52
	total			2	11	46	59
250 to 4000 Hz	mild						
	mod		1	2	0	0	3
	mod sev	1	0	8	4	1	14
	severe	0	2	27	28	11	68
	profound	0	0	12	52	143	207
	total	1	3	49	84	155	292

Table 4.6 The distribution of hearing level classification provided for assessing thresholds agreement between ASSR and CPA in second trial.

		CPA	Hearing level classification			
			ASSR			
			mild to mod	mod sev to sev	profound	total
			n	n	n	n
Frequency (Hz)	250	mild to mod	1	2	0	3
		mod sev to sev	3	37	3	43
		profound	0	8	2	10
		total	4	47	5	56
	500	mild to mod				
		mod sev to sev		11	5	16
		profound		17	26	43
		total		28	31	59
	1000	mild to mod				
		mod sev to sev		8	2	10
		profound		23	26	49
		total		31	28	59
	2000	mild to mod				
		mod sev to sev		6	1	7
		profound		8	44	52
		total		14	45	59
	4000	mild to mod				
		mod sev to sev		5	2	7
		profound		8	44	52
		total		13	46	59
	250-4000	mild to mod	1	2	0	3
		mod sev to sev	3	67	13	83
		profound	0	64	142	206
		total	3	133	155	292

Table 4.7 Inter-rater reliability and agreement between ASSR and CPA.

Methods inter-rater	Number of ears	Kappa coefficient	
		1st trial	2nd trial
ASSR -- CPA 250 Hz	56	NA	0.320**
ASSR -- CPA 500 Hz	59	0.213*	0.236*
ASSR -- CPA 1000 Hz	59	NA	0.180
ASSR -- CPA 2000 Hz	59	NA	0.491**
ASSR -- CPA 4000 Hz	59	0.319**	0.409**
ASSR -- CPA 250 to 4000 Hz	59	NA	0.451**

Note According to the Kappa coefficient, the standard for strength of agreement for the Kappa coefficient: 0.00 = poor, 0.00-0.20 = slight, 0.21-0.40 = fair, 0.41-0.60 = moderate, 0.61-0.80 = substantial and 0.81-1.00 = almost perfect [57]; *significant at p-value < 0.05, **significant at p-value < 0.01

1st trial: Kappa agreement value according to the categories of degree of hearing loss [55, 56].

2nd trial: Kappa agreement value at 250 Hz through all 4000 Hz according to combination of mild hearing loss with moderate hearing loss and moderately severe with severe hearing loss.

CHAPTER V
DISCUSSION

In this chapter, we bring together the results presented in the previous chapter and the discussion concentrating on the relationship between behavioral hearing thresholds and ASSR thresholds estimation in severe and profound hearing loss children. The discussion will be based on theoretical results and empirical evidence, as well as pointing out some areas for future research. The issues will be discussed as follows (1) the usefulness of ASSR and the comparison of hearing threshold estimation between ASSR and conventional play audiometry (2) the agreement between the two methods.

5.1 The usefulness of ASSR and the comparison of hearing threshold estimation between ASSR and conventional play audiometry

The distribution of behavioral threshold as in Figure 4.1 showed residual low-frequency hearing in children with absent click-ABR. Moreover, Table 4.1 demonstrated response of ASSR while click-ABR were absent at the maximum presentation level in all children, especially at lower frequencies. These provide important advantages in low frequency amplification to the group of subjects with retained low frequency hearing perception.

When considering on the presence of ASSR, the difference between conventional play audiometry and ASSR were -8.20 ± 19.28, -4.69 ± 22.99, -8.20 ± 15.89, -2.98 ± 14.51 and -2.37 ± 17.36 dB HL at frequency of 250, 500, 1000, 2000 and 4000 Hz, respectively. However, Wilcoxon signed ranked test demonstrated statistically significant difference ($p < 0.01$) only at 250 and 1000 Hz, but there were slightly difference at 500, 2000 and 4000 Hz without statistically significant. For overall frequencies, the difference with standard deviation was -5.26 ± 17.78 dB HL with statistically significant difference ($p < 0.01$) (see Table 4.3). Therefore, these different values can be used to estimate hearing thresholds in specific frequency. However, the results of current study differ from Rance [11]. Rance also investigated the use of ASSR for hearing assessment in a group of children with absent click-ABR. Their ASSR and behavioral hearing thresholds were obtained in 108 infants and young children. The results showed ASSR thresholds typically were obtained at close proximity to the behavioral thresholds, 99% was seen within 20 dB for the behavioral level. The difference between ASSR and behavioral threshold difference values with standard deviation were 5.4 ± 8.1, 6.3 ± 7.1, 4.1 ± 6.4, 3.1 ± 6.4 and 5.6 ± 6.6 dB HL at 250, 500, 1000, 2000 and 4000 Hz, respectively.

This is probably related to the study design and the number of sample size. Rance's study was retrospective design with larger sample size. Another possible explanation for this differing result is the method for behavioral test. Behavioral audiometric test in current study was conventional play audiometry, while Rance including either visual reinforcement audiometry or conventional play audiometry under headphones using warble tones at octave frequencies in the range 250 to 4000 Hz. Maximum presentation levels were 120 dB HL at all frequencies apart from 250 Hz, which was limited to 105 dB HL. Our behavioral data, derived entirely from conventional play audiometry procedure with pure-tone monaurally under earphones.

Later, Rance studied in a different group of subject [35]. In a group of 211 infants with normal hearing and varying degrees of sensorineural hearing loss aged between 1 to 8 months. Rance evaluated the effect of hearing level by divided data into categories based on ASSR level. The mean differences were determined by subtracting behavioral hearing threshold from ASSR. For ASSR level of 60 to 85 dB HL, the mean differences were -1.04 ± 14.20, -1.00 ± 10.64, -3.55 ± 8.29 and -3.02 ± 7.18 dB at 500, 1000, 2000, and 4000 Hz, respectively. And for ASSR level above 90 dB HL, the mean differences were 1.50 ± 7.76, -0.18 ± 6.51, -1.08 ± 6.27 and -2.02 ± 6.30 at 500, 1000, 2000, and 4000 Hz, respectively.

Furthermore, Rance [10, 35] founded that ASSR overestimated behavioral thresholds. In contrast, in the current study we founded ASSR generally underestimate hearing thresholds from behavioral audiometry. A possible hypothesis to justify this finding would be the difference of the software system used. Rance recorded the frequency-specific thresholds by a Bio-logic MASTER system, while the current study used SmartEP. Han [6] also used Smart ASSR from Intelligent Hearing Systems similar to the current study, found behavioral hearing thresholds were significantly correlated with ASSR thresholds (p = 0.000). Han noted that ASSR generally lower than behavioral thresholds. Moreover, Swanepol [8] reported 19 of 36 subjects (53%) with profound hearing loss has ASSR underestimated the behavioral thresholds on average within 1 to 4 dB, except for 4000 Hz where the ASSR underestimated behavioral thresholds by 7 dB. This different aspect perhaps is in consideration of the distinction among brand name products. Recently, the studies of the effectiveness of ASSR have been widely performed; however, there has not yet been widely studying on SmartEP of Intelligence Hearing System. In year 2005, there was a comparison between two approaches of auditory steady-state responses under a similar test condition; a monaural single-frequency technique with AUDERA of GSI, and a binaural multiple-frequency technique using MASTER. The MASTER (Multiple Auditory STEady-state Responses) is developed by and based on the research of John and Picton at the Rotman Research Institute, University of Toronto. While the single-frequency approach an AUDERA device of Grason-Stadler, manufactured by ERA Systems, Ltd., based on research at the Department of Otolaryngology, The University of Melbourne [42]. Therefore, it is very interesting to do further study including SmartEP on the investigation of their individual techniques.

In the absence of ASSR at maximum presentation level, the results showed as much as 85.5% of recordable thresholds have hearing level over 100 dB HL (Table 4.2). In accordance with Rance [11], the absence of ASSR was a reliable indicator of profound or total hearing loss.

5.2 The agreement between two methods

Since the population of the current study is non-parametric distributions, Cohen’s Kappa analysis was used to analyze the agreement between two methods. In first trial, all estimated hearing thresholds were categorized into groups according to categories of degree of hearing impairment. The results showed fair strength of agreement at 500 and 4000 Hz, while other frequencies were not applicable because of the limitation of Kappa statistics. In second trial, the inter-rater agreement Kappa values were re-calculated when two categories of hearing level were combined. Moderate agreement was observed at high frequencies (2000 and 4000 Hz), fair agreement at low frequencies (250 and 500 Hz), and there was no statistically significant agreement at 1000 Hz.

Correspondingly, Aoyagi which cited in Ahn [38] also reported the correlation coefficients between two methods. Higher correlation coefficients were founded at higher frequencies; 0.73, 0.86, 0.88, and 0.92 at 500, 1000, 2000 and 4000 Hz, respectively. Lins, Picton which cited in Ahn [38] and Luts [36] suggested that ASSR results should be interpreted with caution at 500 Hz. In addition, Rance and Cohen [10] were in consistent states that ASSR thresholds are closer to behavioral thresholds when higher carrier frequency stimuli are used. However, there is also presence of contradiction finding. Ahn [38] reported high correlation coefficients of 0.94, 0.95, 0.94, and 0.92 at 500, 1000, 2000, and 4000 Hz, respectively. Ahn discussed that the using of different modulating frequencies caused their correlation coefficient higher than other previous studies in all frequencies. Besides, Picton [44] found that the ASSR amplitudes were larger in the ear with high modulation frequency at 500 Hz than 1000 and 2000 Hz responses.

CHAPTER VI
CONCLUSIONS

The present study was carried out to investigate the clinical usefulness of ASSR for estimation of behavioral hearing thresholds in hearing impaired children with absent click-ABR. Thirty-nine children (fifty-nine ears) with no response click-ABR at maximum intensity level were participated. All children had been trained listening skill and sound detection in preschool aural rehabilitation program at the Speech and Hearing Clinic, Ramathibodi Hospital.

The results of this study indicate that while ABR can not be used in hearing sensitivity estimation in the group of severe to profound range of impairment, ASSR enable. ASSR provides additional information regarding audiometric configuration due to their higher maximum presentation level and the ability to obtain frequency specific information from low to high frequency.

In the presence of ASSR response, this study reveals that the mean different values between conventional play audiometry and ASSR will be usable in hearing threshold estimations, frequency specifically. The different values were -8.20 ± 19.28, -4.69 ± 22.99, -8.20 ± 15.89, -2.98 ± 14.51 and -2.37 ± 17.36 dB HL at frequencies of 250, 500, 1000, 2000 and 4000 Hz, respectively. However, there were statistically significant difference ($p < 0.01$) only at 250 and 1000 Hz, but there were slightly difference at 500, 2000 and 4000 Hz without statistically significant difference. For overall frequencies, the difference with standard deviation was -5.26 ± 17.78 dB HL with statistically significant difference ($p < 0.01$). Moreover, the current study showed ASSR typically underestimate behavioral hearing threshold. Additionally, when ASSR was no response at maximum levels, 85.5 percent of recordable thresholds showed predicted of hearing level over 100 dB HL.

For agreement analysis between two methods, moderate agreement was observed at high frequencies (2000 and 4000 Hz), fair agreement at low frequencies (250 and 500 Hz), and there was no statistically significant agreement at 1000 Hz.

These results reveal that at high frequencies the relationship between conventional play audiometry will be found more agreement with ASSR than at low frequencies.

In conclusion, these findings showed that ASSR technique is a valuable extension of the clinical audiological test battery, particularly for evaluating hearing sensitivity in children with absent ABR at maximum intensity level. It provides information about the configuration of hearing loss which is useful for an audiology intervention involving hearing aid fitting or cochlear implant decision-making process. However, pure-tone audiometry is described as the gold standard for assessment of a hearing loss. [58, 59] Other audiological test battery are, therefore, remain essential. ASSR can be used as a counterpart with ABR in auditory sensitivity evaluation. The mean differences from the current study can be used in estimating the hearing threshold calculation. However, short term and long term follow up in young children are important until behavioral audiogram could be obtained.

Recommendations

After a thorough analysis of data, some recommendations are as follows:

1. This study is limited by a small sample size. In the current study, we report mean different value between two methods with a high standard deviation. Future studies should attempt to increase the sample size. A larger sample size will leads to increased precision in hearing threshold estimation.

2. We recommend further research work to investigate the comparison of auditory steady-state responses among brand name products in the present under a similar test condition; AUDERA of GSI, MASTER of Bio-logic System corporation and SmartEP of Intelligent Hearing System.

REFERENCES

[1] Northern JL, Downs MP. Hearing in children. 4th ed. Baltimore, MD: Williams & Wilkins; 1991.

[2] Gorga MP, Johnson TA, Kaminski JR, Beauchaine KL, Garner CA, Neely ST. Using a combination of click- and tone burst-evoked auditory brain stem response measurements to estimate pure-tone thresholds. Ear Hear. 2006 Feb; 27(1): 60-74.

[3] Gorga MP, Worthington DW, Reiland JK, Beauchaine KA, Goldgar DE. Some comparisons between auditory brainstem response thresholds, latencies, and the pure-tone audiogram. Ear Hear. 1985 Mar-Apr; 6(2): 105-12.

[4] Hyde ML, Riko K, Malizia K. Audiometric accuracy of the click ABR in infants at risk for hearing loss. J Am Acad Audiol. 1990 Apr; 1(2): 59-66.

[5] Stapells DR, Gravel JS, Martin BA. Thresholds for auditory brain stem responses to tones in notched noise from infants and young children with normal hearing or sensorineural hearing loss. Ear Hear. 1995 Aug; 16(4): 361-71.

[6] Han D, Mo L, Liu H, Chen J, Huang L. Threshold estimation in children using auditory steady-state responses to multiple simultaneous stimuli. ORL J Otorhinolaryngol Relat Spec. 2006; 68(2): 64-8.

[7] The Hearing Review. [database on the Internet]. Allied Media. 2004 [cited Aprl, 2010]. Available from: http://www.hearingreview.com/issues/articles/2004-08_02.asp.

[8] Swanepoel D, Hugo R, Roode R. Auditory steady-state responses for children with severe to profound hearing loss. Arch Otolaryngol Head Neck Surg. 2004 May; 130(5): 531-5.

[9] Swanepoel D, Erasmus H. Auditory steady-state responses for estimating moderate hearing loss. Eur Arch Otorhinolaryngol. 2007; 264(7): 755-9.

[10] Rance G, Rickards FW, Cohen LT, De Vidi S, Clark GM. The automated prediction of hearing thresholds in sleeping subjects using auditory steady-state evoked potentials. Ear Hear. 1995 Oct; 16(5): 499-507.

[11] Rance G, Dowell RC, Rickards FW, Beer DE, Clark GM. Steady-state evoked potential and behavioral hearing thresholds in a group of children with absent click-evoked auditory brain stem response. Ear Hear. 1998 Feb; 19(1): 48-61.

[12] Herdman AT, Stapells DK. Auditory steady-state response thresholds of adults with sensorineural hearing impairments. Int J Audiol. 2003 Jul; 42(5): 237-48.

[13] Stach BA. Comprehensive Dictionary of Audiology. New York: Thomson Learning.; 2003.

[14] Ross J. Roeser MV, Holly Hosford-Dunn. Audiology. Diagnosis. 2nd ed.: Thieme Medical Publishers, Inc.; 2007.

[15] NCBI. How Information from the Cochlea Reaches Targets in the Brainstem.: Sinauer Associates, Inc.; 2010 [updated 2010; cited 2010 January 14th]; Available from: http://www.ncbi.nlm.nih.gov/bookshelf/br.fcgi?book=neurosci&part=A911.

[16] QMUL. Neuroanatomy of the Auditory and Visual systems.: Queen Mary University of London.; 2008 [updated 2008; cited 2010 January14th]; Available from: https://courses.stu.qmul.ac.uk/smd/kb/microanatomy/brain/CAL3/BaBy1CAL3.htm.

[17] Hood LJ. Clinical applications of the auditory brainstem response.: Singular Publishing Group, Inc.; 1998.

[18] R. Steven Ackley TND, Charles J. Limb. An essential guide to hearing and balance disorders.: Psychology Press; 2007 [cited. Available from: http://books.google.co.th/books?id=JRFtYiI3eWUC&lpg=PA141&ots=52RC3zpiFb&dq=EcochG%20placing%20electrode&pg=PA141#v=onepage&q=EcochG%20placing%20electrode&f=false.

[19] Hall JW. New handbook of auditory evoked responses.: Pearson educattion, Inc.; 2007.

[20] Sohmer H, Feinmesser M. Cochlear action potentials recorded from the external ear in man. Ann Otol Rhinol Laryngol. 1967 Jun; 76(2): 427-35.

[21] Mason S, McCormick B, Wood S. Auditory brainstem response in pediatric audiology. Arch Dis Child. 1988 May; 63(5): 465-7.

[22] Kuwada S AJ, Batra R, Fitzpatrick DC, Teissier N, D' Angelo WR Sources of the scalp-recorded amplitude-modulation following response. J Am Acad Audiol. 2002; 13: 188-204.

[23] Cone-Wesson B, Dowell RC, Tomlin D, Rance G, Ming WJ. The Auditory Steady-State Response: Comparisons with the Auditory Brainstem Response. J Am Acad Audiol. 2002; 13: 173-87.

[24] Swanepoel D, Schmulian D, Hugo R. Establishing normal hearing with the dichotic multiple-frequency auditory steady-state response compared to an auditory brainstem response protocol. Acta Otolaryngol. 2004 Jan; 124(1): 62-8.

[25] Robert F. Burkard, Jos J. Eggermont, Manuel Don. Auditory evoked potentials: basic principles and clinical application. Illustrated ed.: Lippincott Williams & Wilkins; 2006.

[26] Galambos R, Makeig S, Talmachoff PJ. A 40-Hz auditory potential recorded from the human scalp. Proc Natl Acad Sci U S A. 1981 Apr; 78(4): 2643-7.

[27] Linden RD, Campbell KB, Hamel G, Picton TW. Human auditory steady state evoked potentials during sleep. Ear Hear. 1985 May-Jun; 6(3): 167-74.

[28] Jerger J, Chmiel R, Frost JD, Jr., Coker N. Effect of sleep on the auditory steady state evoked potential. Ear Hear. 1986 Aug; 7(4): 240-5.

[29] Stapells DR, Linden D, Suffield JB, Hamel G, Picton TW. Human auditory steady state potentials. Ear Hear. 1984 Mar-Apr; 5(2): 105-13.

[30] Petitot C, Collett L, Durrant JD. Auditory steady-state responses (ASSR): effects of modulation and carrier frequencies. Int J Audiol. 2005 Oct; 44(10): 567-73.

[31] Aoyagi M, Watanabe T, Ito T, Abe Y. Reliability and frequency specificity of auditory steady-state response detected by phase spectral analysis. J Acoust Soc Am. 2007 Sep; 122(3): EL58.

[32] Vander Werff KR, Brown CJ. Effect of audiometric configuration on threshold and suprathreshold auditory steady-state responses. Ear Hear. 2005 Jun; 26(3): 310-26.

[33] Norman J. Lass CMW. Hearing Science Fundamental. Mosby, Inc., an affiliate of Elsevier Inc.; 2007.

[34] Yost WA. Fundamentals of Hearing: an introduction. 5th ed.: Elsevier Inc.; 2007.

[35] Rance G, Rickards F. Prediction of hearing threshold in infants using auditory steady-state evoked potentials. J Am Acad Audiol. 2002 May; 13(5): 236-45.

[36] Luts H, Desloovere C, Kumar A, Vandermeersch E, Wouters J. Objective assessment of frequency-specific hearing thresholds in babies. Int J Pediatr Otorhinolaryngol. 2004 Jul; 68(7): 915-26.

[37] Kariya S, Fukushima K, Kawasaki A, Kataoka Y, Nishizaki K. Auditory steady-state responses to multiple simultaneous stimuli in children with functional or sensorineural hearing loss. Eur Arch Otorhinolaryngol. 2008 Jul; 265(7): 769-73.

[38] Ahn JH, Lee HS, Kim YJ, Yoon TH, Chung JW. Comparing pure-tone audiometry and auditory steady state response for the measurement of hearing loss. Otolaryngol Head Neck Surg. 2007 Jun; 136(6): 966-71.

[39] Stueve MP, O'Rourke C. Estimation of hearing loss in children: comparison of auditory steady-state response, auditory brainstem response, and behavioral test methods. Am J Audiol. 2003 Dec; 12(2): 125-36.

[40] Swanepoel D, Erasmus H. Auditory steady-state responses for estimating moderate hearing loss. Eur Arch Otorhinolaryngol. 2007 Jul; 264(7): 755-9.

[41] Luts H, Wouters J. Hearing assessment by recording multiple auditory steady-state responses: the influence of test duration. Int J Audiol. 2004 Sep; 43(8): 471-8.

[42] Luts H, Wouters J. Comparison of MASTER and AUDERA for measurement of auditory steady-state responses. Int J Audiol. 2005 Apr; 44(4): 244-53.

[43] John MS, Brown DK, Muir PJ, Picton TW. Recording auditory steady-state responses in young infants. Ear Hear. 2004 Dec; 25(6): 539-53.

[44] Picton TW, van Roon P, John MS. Multiple auditory steady state responses (80-101 Hz): effects of ear, gender, handedness, intensity and modulation rate. Ear Hear. 2009 Feb; 30(1): 100-9.

[45] John MS, Picton TW. Human auditory steady-state responses to amplitude-modulated tones: phase and latency measurements. Hear Res. 2000 Mar; 141(1-2): 57-79.

[46] Sininger YS, Cone-Wesson B, Abdala C. Gender distinctions and lateral Asymmetry in the low-level auditory brainstem response of the human neonate. Hear Res. 1998 Dec; 126(1-2): 58-66.

[47] Bowman DM, Brown DK, Kimberley BP. An examination of gender differences in DPOAE phase delay measurements in normal-hearing human adults. Hear Res. 2000 Apr; 142(1-2): 1-11.

[48] Pockett S, Tan SM. The auditory steady-state response is not a suitable monitor of anesthesia. Anesth Analg. 2002 Nov; 95(5): 1318-23.

[49] Picton TW, John MS, Purcell DW, Plourde G. Human auditory steady-state responses: the effects of recording technique and state of arousal. Anesth Analg. 2003 Nov; 97(5): 1396-402.

[50] Shlomo Silman CAS. Auditory Diagnosis, Principles and applications. Sandiago, California: Academic Press, Inc.; 1991.

[51] Byron J. Bailey & Jonas T. Johnson. Head and neck surgery-otolaryngology. 4th ed. Philadelphia, USA: Lippincott williams and wilkins.; 2006.

[52] Valete-Rosalino CM, Rozenfeld S. Auditory screening in the elderly: comparison between self-report and audiometry. Braz J Otorhinolaryngol. 2005 Mar-Apr; 71(2): 193-200.

[53] Sliwinska-Kowalska M, Kotylo P. Otoacoustic emissions in industrial hearing loss assessment. Noise Health. 2001; 3(12): 75-84.

[54] Halloran DR, Hardin JM, Wall TC. Validity of pure-tone hearing screening at well-child visits. Arch Pediatr Adolesc Med. 2009 Feb; 163(2): 158-63.

[55] Clark JG. Uses and abuses of hearing loss classification. ASHA. 1981 Jul; 23(7): 493-500.

[56] Gelfand SA. Essentials of Audilogy. 2nd ed. New York: Thieme medical pubhlishers, inc.; 2001.

[57] Looney SW. Biostatistical methods.: Humana Press; 2002.

[58] Folsom RC, Widen JE, Vohr BR, Cone-Wesson B, Gorga MP, Sininger YS, et al. Identification of neonatal hearing impairment: recruitment and follow-up. Ear Hear. 2000 Oct; 21(5): 462-70.

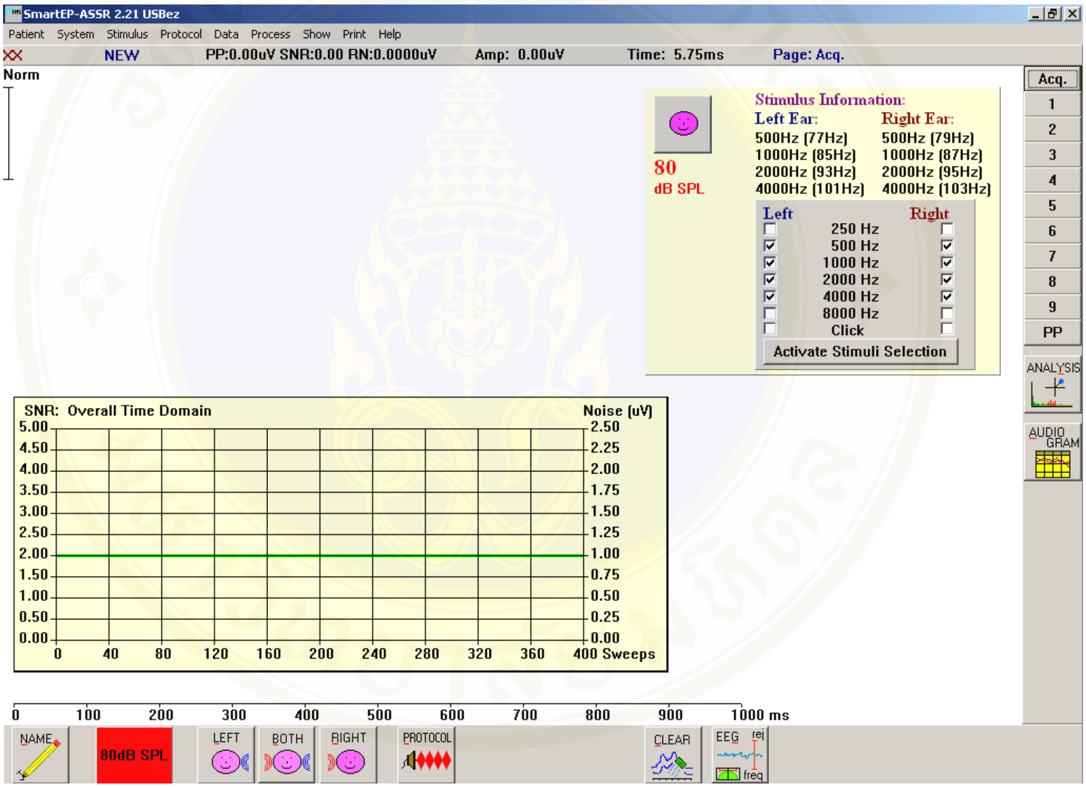
[59] Savio G, Perez-Abalo MC, Gaya J, Hernandez O, Mijares E. Test accuracy and Prognostic validity of multiple auditory steady state responses for targeted hearing screening. Int J Audiol. 2006 Feb; 45(2): 109-20.

APPENDICES

APPENDIX A

ASSR USER INTERFACE

Provides testing selection for the measurement such as ear tested (left, right, or both ears), intensity level (dB SPL), frequency of the stimuli, etc.


SmartEP-ASSR 2.21 USBez

NEW PP:0.00uV SNR:0.00 RN:0.0000uV Amp: 0.00uV Time: 5.75ms Page: Acq.

80 dB SPL

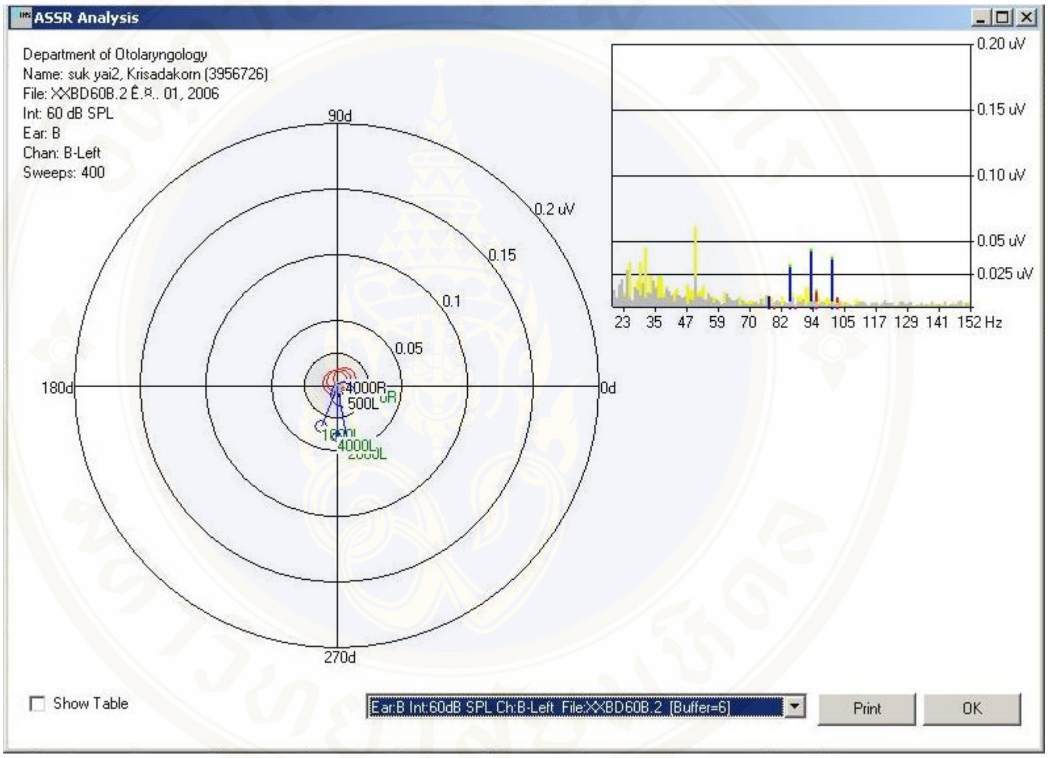
Stimulus Information:

Left Ear:	Right Ear:
500Hz (77Hz)	500Hz (79Hz)
1000Hz (85Hz)	1000Hz (87Hz)
2000Hz (93Hz)	2000Hz (95Hz)
4000Hz (101Hz)	4000Hz (103Hz)

Left		Right
☐	250 Hz	☐
☑	500 Hz	☑
☑	1000 Hz	☑
☑	2000 Hz	☑
☑	4000 Hz	☑
☐	8000 Hz	☐
☐	Click	☐

EXAMPLE OF ASSR ACTIVITY SCREEN

Presented in a polar plot, where displays the amplitude of activity, amplitude of background noise



ASSR Analysis

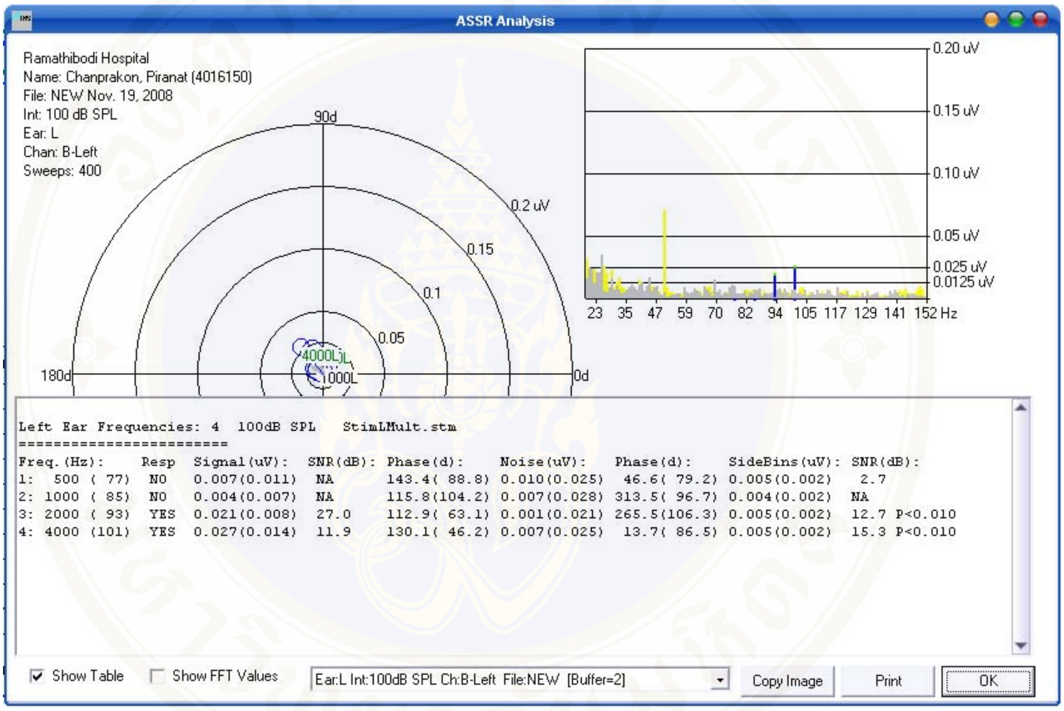
Department of Otolaryngology
Name: suk yai2, Krisadakorn (3956726)
File: XXBD60B.2 Ê.¤.. 01, 2006
Int: 60 dB SPL
Ear: B
Chan: B-Left
Sweeps: 400

☐ Show Table

Ear:B Int:60dB SPL Ch:B-Left File:XXBD60B.2 [Buffer=6]

SCREEN CAPTURE OF ASSR RESPONSE CRITERIA

Displays signal to noise ratio (SNR), SNR of side binaural, amplitude of signal and noise amplitude.



Ramathibodi Hospital
Name: Chanprakon, Piranat (4016150)
File: NEW Nov. 19, 2008
Int: 100 dB SPL
Ear: L
Chan: B-Left
Sweeps: 400

```
Left Ear Frequencies: 4  100dB SPL   StimLMult.stm
========================
Freq.(Hz):     Resp  Signal(uV):  SNR(dB): Phase(d):    Noise(uV):   Phase(d):    SideBins(uV): SNR(dB):
1:  500 ( 77)  NO    0.007(0.011)  NA      143.4( 88.8) 0.010(0.025)  46.6( 79.2) 0.005(0.002)   2.7
2: 1000 ( 85)  NO    0.004(0.007)  NA      115.8(104.2) 0.007(0.028) 313.5( 96.7) 0.004(0.002)  NA
3: 2000 ( 93)  YES   0.021(0.008)  27.0    112.9( 63.1) 0.001(0.021) 265.5(106.3) 0.005(0.002)  12.7 P<0.010
4: 4000 (101)  YES   0.027(0.014)  11.9    130.1( 46.2) 0.007(0.025)  13.7( 86.5) 0.005(0.002)  15.3 P<0.010
```

APPENDIX B

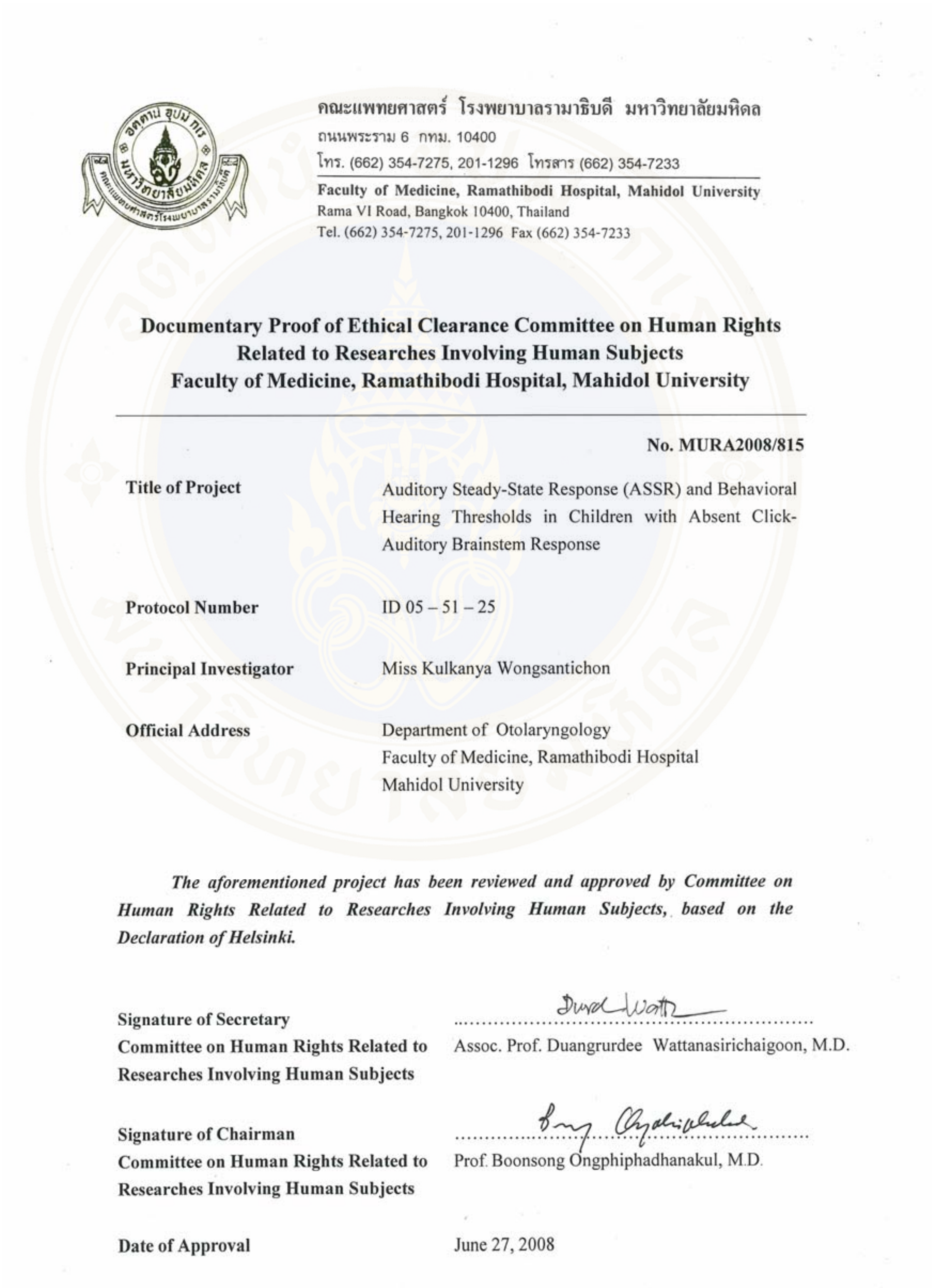
RAW DATA OF HEARING THRESHOLDS AND DIFFERNCES

	250			500			1000			2000			4000		
Ear	ASSR	CPA	ASSR-CPA	ASSR	CPA	ASSR-CPA	ASSR	CPA	ASSR-CPA	ASSR	CPA	ASSR-CPA	ASSR	CPA	ASSR-CPA
1	70	80	-10	74	85	-11	90	90	0	120	120	0	120	120	0
2	70	90	-20	74	100	-26	89	105	-16	104	120	-16	120	120	0
3	--	--	--	64	120	56	79	120	41	104	120	-16	98	120	-22
4	70	95	-25	120	105	15	89	115	-26	120	110	10	120	120	0
5	70	65	5	91	65	26	106	100	6	120	120	0	120	115	5
6	87	60	27	120	75	45	120	90	30	120	115	5	120	115	5
7	50	55	-5	64	80	-16	69	90	-21	77	80	-3	56	65	-9
8	70	85	-15	64	80	-16	79	85	-6	87	85	2	81	75	6
9	80	80	0	120	120	0	106	120	14	120	120	0	91	120	-29
10	70	80	-10	84	95	-11	120	115	5	120	120	0	98	120	-22
11	40	65	-25	74	80	-6	79	85	-6	77	90	-13	61	100	-39
12	60	60	0	64	80	-16	89	85	4	87	90	-3	98	80	18
13	120	95	25	120	110	10	120	120	0	120	120	0	120	120	0
14	50	90	-40	120	105	15	89	115	-26	87	115	-28	71	110	-39
15	70	80	-10	120	100	20	106	105	1	120	105	15	120	120	0
16	70	80	-10	91	110	-19	106	100	6	120	95	25	120	100	20
17	70	90	-20	64	95	-31	100	95	5	67	90	-23	91	95	-4
18	70	85	-15	84	95	-11	100	105	-5	67	100	-33	91	95	-4
19	70	90	-20	120	105	15	99	110	-11	120	110	10	120	115	5
20	70	75	-5	91	105	-14	89	100	-11	120	105	15	120	120	0
21	69	80	-11	91	100	-9	80	100	-20	104	100	4	120	95	25
22	88	75	13	120	85	35	88	90	-2	104	105	-1	120	100	20
23	87	80	7	120	120	0	120	110	10	120	120	0	120	120	0
24	120	80	40	74	90	-16	89	100	-11	97	95	2	81	70	11
25	80	85	-5	120	105	15	89	100	-11	120	120	0	120	115	5
26	87	95	-8	120	105	15	120	110	10	120	115	5	120	120	0
27	120	90	30	120	100	20	120	105	15	120	115	5	120	110	10
28	69	85	-16	84	95	-11	89	100	-11	120	110	10	120	120	0
29	60	90	-30	120	110	10	89	110	21	120	110	10	120	110	10
30	120	95	25	120	110	10	120	120	0	120	105	15	120	105	15
31	50	90	-40	120	120	0	120	120	0	120	120	0	120	120	0
32	70	100	-30	74	100	-26	89	115	-26	120	120	0	87	120	-33
33	80	70	10	91	100	-9	89	110	-21	87	115	-28	120	105	15
34	70	70	0	74	85	-11	89	100	-11	120	110	10	120	100	20
35	70	65	5	74	85	-11	89	95	-6	104	95	9	120	95	25

	250			500			1000			2000			4000		
Ear	ASSR	CPA	ASSR-CPA	ASSR	CPA	ASSR-CPA	ASSR	CPA	ASSR-CPA	ASSR	CPA	ASSR-CPA	ASSR	CPA	ASSR-CPA
36	70	90	-20	74	100	-26	99	120	-21	120	120	0	120	120	0
37	70	90	-20	64	115	-51	89	120	-31	120	120	0	120	120	0
38	70	100	-30	120	120	0	120	120	0	120	120	0	120	120	0
39	75	90	-15	120	100	20	89	105	-16	120	120	0	120	120	0
40	70	55	15	64	70	-6	79	90	-11	87	90	-3	91	85	6
41	70	55	15	64	65	-1	79	90	-11	77	100	-23	81	115	-34
42	60	85	-25	74	100	-26	89	110	-21	120	115	5	81	115	-34
43	70	85	-15	74	105	-31	89	120	-31	87	120	-33	120	120	0
44	60	80	-20	74	105	-31	89	115	-26	87	120	-33	71	120	-49
45	60	75	-15	74	85	-11	89	105	-16	97	120	-23	98	120	-22
46	60	95	-35	64	95	-31	89	110	-21	87	110	-23	81	110	-29
47	120	85	35	120	115	5	120	110	10	120	115	5	120	115	5
48	70	100	30	74	120	46	99	120	21	120	120	0	120	120	0
49	--	--	--	74	105	-31	99	120	21	104	120	-16	120	120	0
50	80	95	-15	120	120	0	120	120	0	120	120	0	120	120	0
51	70	100	-30	84	120	-36	106	120	14	87	120	-33	81	120	-39
52	60	85	-25	91	100	-9	99	100	-1	120	105	15	120	105	15
53	80	85	-5	120	100	20	106	110	-4	120	115	5	120	110	10
54	87	90	-3	120	95	25	120	120	0	120	120	0	120	120	0
55	87	90	-3	120	95	25	120	120	0	120	120	0	120	120	0
56	70	85	-15	120	115	5	120	120	0	104	120	-16	120	110	10
57	70	90	-20	74	105	-31	89	110	-21	97	120	-23	120	115	5
58	70	70	0	120	85	35	120	90	30	120	95	25	81	80	1
59	--	--	--	120	90	30	89	95	-6	97	90	7	71	70	1
Mean	77.47	82.59	-7.13	101.13	99.07	-1.24	113.52	106.69	-3.73	139.07	110.51	-2.98	171.67	109.15	-2.37
S.D.	17.33	11.95	19.28	23.28	14.25	22.99	14.715	11.357	15.89	16.45	11.47	14.51	19.26	15.03	17.36
min	40	55	-40	64	65	-51	69	85	-31	67	80	-33	56	65	-49
max	120	100	40	120	120	56	120	120	41	120	120	25	120	120	25

Note *In case of ASSR thresholds were absent, the number of 120
**In case of hearing thresholds from CPA were absent; the number of maximum intensity level for each frequency was used for calculation.

APPENDIX C



คณะแพทยศาสตร์ โรงพยาบาลรามาธิบดี มหาวิทยาลัยมหิดล
ถนนพระราม 6 กทม. 10400
โทร. (662) 354-7275, 201-1296 โทรสาร (662) 354-7233
Faculty of Medicine, Ramathibodi Hospital, Mahidol University
Rama VI Road, Bangkok 10400, Thailand
Tel. (662) 354-7275, 201-1296 Fax (662) 354-7233

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

---

No. MURA2008/815

Title of Project	Auditory Steady-State Response (ASSR) and Behavioral Hearing Thresholds in Children with Absent Click-Auditory Brainstem Response
Protocol Number	ID 05 – 51 – 25
Principal Investigator	Miss Kulkanya Wongsantichon
Official Address	Department of Otolaryngology Faculty of Medicine, Ramathibodi Hospital Mahidol University

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

Signature of Secretary **Committee on Human Rights Related to Researches Involving Human Subjects**	.... Assoc. Prof. Duangrurdee Wattanasirichaigoon, M.D.
Signature of Chairman **Committee on Human Rights Related to Researches Involving Human Subjects**	.... Prof. Boonsong Ongphiphadhanakul, M.D.
Date of Approval	June 27, 2008

BIOGRAPHY

NAME	Miss Kulkanya Wongsantichon
DATE OF BIRTH	27 June 1980
PLACE OF BIRTH	Chonburi, Thailand
INSTITUTIONS ATTENDED	Chulalongkorn University, 1997-2001 Bachelor of Science (Medical Technology) Mahidol University, 2005-2009 Master of Science (Communication Disorders)
HOME ADDRESS	586 Rama 4 Road, Bangrak, Bangkok, 10500 Tel. 0-2633-0093-4 E-mail : kung_kulkanya@yahoo.com