A STUDY OF NORMATIVE CHARACTERISTICS OF AUDITORY BRAINSTEM RESPONSE TO BONE - CONDUCTION IN NORMAL NEWBORNS

THITIMA HANCHOKCHAISKUL

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THITIMA HANCHOKCHAISKUL: A STUDY OF NORMATIVE CHARACTERISTICS OF AUDITORY BRAINSTEM RESPONSE TO BONE-CONDUCTION IN NORMAL NEWBORNS. THESIS ADVISORS: CHEAMCHIT THAWIL, B.Sc., M.A., SIRIPARN SRIWANYONG, M.B.A., M.Sc., URAIRAT SUBARNVILAS, M.Sc., 101 P. ISBN 974-664-598-6

The purpose of this research was to study the normative characteristics of Auditory Brainstem Response to bone-conduction (BC- ABR) obtained from normal newborns, aged 48-72 hours, who were not in high risk register by using fifteen males and fifteen females. The birth weight for the male group was 3, 162 grams and for the female group was 3, 214 grams. All of the subjects passed the screening using TEOAEs test in both ears. The instrumentation used in this study was SMART EP. The clicks stimuli were presented at the rate of 7.1 per second. The intensity was attenuated at 50, 40, and 30 dBnHL and down to threshold. The filter setting was 30-3000 Hz with alternation polarity.

The results of this study revealed that the morphology of BC- ABR in the higher intensity was clearer than the morphology of BC- ABR in the lower intensity. Wave I and wave V could be identified when the higher intensity (≥ 30 dBnHL) was used. The mean BC- ABR threshold was 26.92 (± 3.46) dBnHL. Also, there was no significant difference in BC- ABR threshold between gender and ear differences. The mean latencies of wave I at 50, 40, and 30 dBnHL were 2.6815 (± .3031), 3.2895 (±.3098), and 4.2785 (± .3152) milliseconds, respectively. The mean latencies of wave V at 50, 40, and 30 dBnHL were 7.9705 (± .3047), 8.8187 (± .3239), and 9.9762 (± .3294) milliseconds, respectively. The signal intensity had significant effects on the latency of BC- ABR and the effect of intensity on latency change was larger for low intensity than for high intensity. In addition, the relationships of wave I and wave V latency- intensity functions were non-linear. The results of the mean latencies of wave I and wave V at 50, 40, and 30 dBnHL in male and female subjects and ear differences were not significant difference.

The findings of this study can be used as a guideline for appropriate BC stimulus levels for screening or assessment of newborns.

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ฐิติมา หาญโชคชัยสกุล : การศึกษาค่ามาตรฐานของการทดสอบการได้ยินระดับก้านสมองโดยการนำเสียงผ่านทางกระดูกในเด็กแรกเกิดปกติที่ไม่มีภาวะเสี่ยงต่อการสูญเสียการได้ยิน (A STUDY OF NORMATIVE CHARACTERISTICS OF AUDITORY BRAINSTEM RESPONSE TO BONE-CONDUCTION IN NORMAL NEWBORNS) คณะกรรมการควบคุมวิทยานิพนธ์ : เจียมจิต ถวิล, B.SC., M.A., ศิริพันธ์ ศรีวันยงค์, M.B.A., M.Sc., อุไรรัตน์ สุบรรณวิลาส, M.Sc. 101 หน้า. ISBN 974-664-598-6

การศึกษาครั้งนี้มีวัตถุประสงค์เพื่อหาเกณฑ์มาตรฐานของการตอบสนองการได้ยินระดับก้านสมองโดยการนำเสียงผ่านทางกระดูกในเด็กแรกเกิดปกติที่ไม่มีภาวะเสี่ยงต่อการสูญเสียการได้ยิน กลุ่มตัวอย่างที่ศึกษาเป็นเด็กแรกเกิดที่คลอดครบกำหนด อายุ 48-72 ชั่วโมง แบ่งเป็นเด็กเพศชายจำนวน 15 คนมีน้ำหนักเฉลี่ยเท่ากับ 3, 162 กรัม และเด็กเพศหญิงจำนวน 15 คนมีน้ำหนักเฉลี่ยเท่ากับ 3,214 กรัม ได้รับการตรวจร่างกายจากกุมารแพทย์ว่ามีสุขภาพแข็งแรง ผ่านการตรวจคัดกรองการได้ยินโดยวิธี TEOAEs ทั้งสองหู ทดสอบการตอบสนองโดยใช้เครื่องทดสอบการได้ยินระดับก้านสมองผ่านทางกระดูกรุ่น SMART EP กระตุ้นด้วยเสียงคลิกในอัตรา 7.1 คลิกต่อวินาที ที่ระดับความดัง 50, 40, และ 30 dBnHL ช่วงความถี่ 30 –3000 Hz และ Polarity เป็น Alternation

ผลการศึกษาพบว่าลักษณะรูปร่างของคลื่นการได้ยินระดับก้านสมองของการนำเสียงทางกระดูกมีความชัดเจนในระดับความดังสูงมากกว่าระดับความดังต่ำโดยเมื่อใช้ระดับเสียงตั้งแต่ 30 dBnHL ขึ้นไป คลื่นที่ I และ คลื่นที่ V จะปรากฏชัดเจนและเมื่อใช้ความดังต่ำกว่า 30 dBnHL คลื่นที่ I จะหายไปและไม่ปรากฏคลื่นที่ V เมื่อลดความดังถึงระดับ Threshold ค่าเฉลี่ยของ BC-ABR Threshold เท่ากับ 26.92 (±3.46) dBnHL. ไม่พบความแตกต่างอย่างมีนัยสำคัญทางสถิติของ BC- ABR threshold ระหว่างเพศและระหว่างหูที่แตกต่างกัน ค่าเฉลี่ยของระยะเวลาการเกิดคลื่นที่ I ที่ระดับความดัง 50, 40 และ 30 dBnHL เท่ากับ 2.6815 (± .3031), 3.2895 (±.3098), 4.285 (±.3152) มิลลิวินาที ตามลำดับ และ ค่าเฉลี่ยของระยะเวลาการเกิดคลื่นที่ V ที่ระดับความดัง 50, 40 และ 30 dBnHL เท่ากับ 7.9705 (± .3047), 8.8187 (± .3239), 9.9762 (± .3294) มิลลิวินาทีตามลำดับ ที่ระดับความดังต่างกันระยะเวลาการเกิดคลื่นที่ I และ คลื่นที่ V มีความแตกต่างอย่างมีนัยสำคัญทางสถิติ ระยะเวลาการเกิดคลื่นที่ I และ คลื่นที่ V ระหว่างเพศและหูไม่มีความแตกต่างกันอย่างมีนัยสำคัญทางสถิติผลการศึกษาในครั้งนี้จึงเป็นประโยชน์ต่อการประเมินระดับการได้ยินระดับก้านสมองโดยการนำเสียงผ่านทางกระดูกในทารกแรกเกิด

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CHAPTER I

INTRODUCTION

Statement of the problem

Early detection of hearing loss is considered one of the most important factors in the habilitation of the deaf child. Because an infant learns important auditory skills that play a role in subsequent language acquisition, there is general agreement that the interval from birth to the discovery of the hearing impairment may represent significant time lost in auditory development. Late detection of hearing loss may cause a child to become more educationally retarded than warranted on the basis of hearing loss alone (1, 3, 4, 5, 6, 7). In general, hearing impaired children demonstrate limited speech production skills (8), significantly delayed receptive and expressive language skills and reduced academic achievement, especially in language–related areas (8).

In the past, early detection of hearing loss, although desirable, has not been achieved. In the U.S.A. and Canada, the average age of detection varies from 15 to 60 months (9, 10, 11) and habilitation starts at an average age of 24 months (12). So, early detection and management of hearing loss are recommended primarily because of its potentially adverse effects on language acquisition. Here, the first months are crucial because normal language development is rapid (14, 15, 16). Before language expression, the child has experienced over a year of language reception, during which complex intellectual events have occurred (15). Compromise of language acquisition is not restricted to severe hearing impairment; even mild conductive losses may have deleterious effects (17, 18, 19, 20, 21). Hearing impairment; bilateral conductive and / or sensorineural deficit in the frequency region important for speech recognition (8).

Early detection and habilitation of hearing loss is widely endured because delay is believed to compromise the development of speech and language skills (10, 22, 23, 24, 25). Recent studies have indicated that the quality of auditory stimulation can effect anatomical, physiological, and behavioral changes associated with the developing auditory system (27, 28). Early identification of hearing impairment in infants allows for more successful intervention and rehabilitation of communication skill (3, 20, 25). The Joint Committee on Infant Hearing of the American Academy of Pediatrics recommended that, if possible, infants with specific high- risk factors should have habilitation begun by 6 month of age (3, 24, 29).

Regarding to pediatric hearing evaluation, Behavioral Observation Audiometry (BOA) has been the most commonly used screening test. It is quick, simple but insensitive: high false- negative rates of 40 % to 74 % have been reported (4, 15, 19, 30, 31). Tympanometric assessment of middle ear function is interest in neonatal screening because of the high incidence of middle ear fluid (32, 33). However, false–negative results are common (15, 17, 21). One of the more effective strategies for early detection of hearing impairments in infants is the use of the auditory brainstem response (ABR) test with high- risk neonate (15, 35, 36, 37, 38, 39). Two methods are currently available for stimulus delivery: air conduction (AC) and bone conduction (BC) Since the mid- 1970 S, brainstem electric response audiometry (BERA) has become an important clinical tool, especially for neonates and infants or adults who cannot be tested reliably with conventional audiometric techniques (1, 15, 21, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49). Several investigators have suggested that click ABR thresholds correlate best with hearing sensitivity in the 2,000 – 4,000 Hz. region (3, 41, 46, 50, 51).

The Otoacoustic emission tests, the most recent available objective test, are used for the initial screening test too but both AC- ABR test and Otoacoustic emission tests given in the first 36 hours postpartum may yield "false- positive" results. Owing to unresolved mesenchyme or amniotic fluid in the middle ear, or external ears occluded with vernix, creating transient, conductive hearing losses (52). Middle ear pathology is often difficult to detect in newborns because vernix and other debris obscuring the tympanic membrane can complicate otoscopic examination (7, 53, 54, 55). If the goal of early screening is to identify permanent sensorineural loss, rather than resolving middle ear disorder, then the sensitivity of both OAEs. and conventional AC- ABR to middle ear status constitutes a potentially major source of false- positive responses (55, 56, 57). Of these factors, transient middle ear disorders have received considerable attention. The high incidence of middle ear effusion among neonate intensive care unit infant (21) and the presence of residual substance and fluid in the middle ear cavity of newborn infants have been suggested as potential contributors to the so called "inaccuracy" in ABR newborn auditory screening (24, 57).

In an effort to differentiate sensorineural from conductive hearing impairments and thereby improving the efficiency of ABR screening methods, the use of ABR to bone-conducted stimuli has been suggested (44, 53, 58, 59, 60, 61, 62, 63, 64, 65, 66). The bone conduction auditory brainstem response (BC–ABR) test were first reported in the 1970s with the inception of ABR as a clinical tool and have received considerable attention during the past 15 years, with a flurry of papers published on the topic since 1987 (52, 53). In the past, BC-ABR was recorded essentially to assess cochlear reserve in subject with congenital atresia or microtia of the external ear. Later, investigators suggested the BC-ABR measurement be included in the early identification of hearing loss in high-risk infants who failed the AC-ABR procedure (44, 58, 67). Although BC-ABR tests has not been widespread but it is important for the accurate determination in infant and other populations who are unable to participate in audiometric tasks of cochlear sensitivity and the difficult diagnosis of conductive versus sensorineural hearing loss (53, 60, 66, 68). ASHA (1991) recommended BC-ABR tests for assessment of newborns, infants and toddler (4). Hall suggested that BC-ABR is not only feasible, it is an essential component of state-of-the art pediatric ABR assessment (58).

The ABR to air- and bone- conducted clicks are the most widely employed evoked potential audiometric techniques (40, 47, 68). Clicks are broad spectrum stimuli that stimulates many nerve fibers. It provided an excellent stimulus for eliciting the short latency potentials. Its abrupt onset and brief duration contribute to good synchronization, and minimize stimulus artifact (69). The morphology of the ABR to bone-conducted clicks is similar to that obtained by air conduction (21, 47, 48, 62, 79). Several investigators compared air- and bone-conducted stimuli in infants and adult. They found that latency of wave V for bone-conducted stimuli was longer than the latency for air-conducted stimuli delivered at the same sensation level (21, 33, 40, 47, 48, 57, 62, 70, 79).

AC-ABR has played an important role in the Speech and Hearing Clinic since 1985 to estimate hearing threshold sensitivity and to evaluate auditory pathway in neonate, infants, uncooperative children, pseudohypacusis and adult. AC-ABR normative data were established and were widely used for clinical purposes. However

BC-ABR has received less attention as the normative data have not been established yet. As a results, it is necessary for the audiology unit to have its own normative data for determining cochlear reserve in newborns, infants, children with congenital atresia or other aural deformities and for whom conventional psychometric tests methods may not be possible. From the above mentioned reasons, the researcher aims to study of normative characteristics of hearing in normal newborns by using the auditory brainstem response to bone-conduction.

The purposes of this research

1. To study the characteristics of morphology of BC- ABR in normal newborns.
2. To establish normative data of BC- ABR thresholds, wave I and wave V latencies in normal newborns.
3. To compare normative data of BC- ABR thresholds between normal male and female newborns.
4. To compare normative data of BC- ABR threshold between right and left ears of normal newborns.
5. To compare normative data of wave I and wave V latencies of BC- ABR at 50, 40, 30 dBnHL between normal male and female newborns.
6. To compare normative data of wave I and wave V latencies of BC- ABR at 50, 40, 30 dBnHL between right and left ears of normal newborns.
7. To study wave I and wave V Latency- Intensity Function of BC- ABR in normal newborns.

The hypothesis of this research

1. The mean BC- ABR thresholds are significant difference between normal male and female newborns.

2. The mean BC- ABR thresholds are significant difference between the right and left ears of normal newborns.

3. The mean BC- ABR wave I latencies at 50, 40, 30 dBnHL are significant difference between normal male and female newborns.

4. The mean BC- ABR wave V latencies at 50, 40, 30 dBnHL are significant difference between normal male and female newborns.

5. The mean BC- ABR wave I latencies at 50, 40, 30 dBnHL are significant difference between the right and left ears of normal newborns.

6. The mean BC- ABR wave V latencies at 50, 40, 30 dBnHL are significant difference between the right and left ears of normal newborns.

The expected outcomes of this research

1. The result of this study can be used to determine cochlear reserve and to estimate hearing threshold in newborns, infants, children and person whom conventional psychometric test methods may not be possible.

2. The timing of identification of substantial sensorineural deficits can be advanced to the earliest stage of life, thus allowing clinicians a precious period for preparing and administering early intervention.

3. It can be useful for the audiologist provide objective counseling to relieve psychologically stress from the parents who have hearing impaired newborns.

4. The result of this study can be used as normative data to assess hearing threshold in newborns by bone-conduction ABR in the speech and hearing clinic.

CHAPTER II

REVIEW OF THE LITERATURE

The Auditory Brainstem Response (ABR), a noninvasive electrophysiological technique, is the most popular and essential procedure in clinical audiology (4, 5, 24, 36, 37, 39, 72). ABR was first reported a series of four wave components in human subjects by Sohmer and Feinmesser and later described by Jewett et al. The labelling convention for the waves that used Roman numerals I through VII to identify the peaks was suggested by Jewett and Williston.

The ABR technique can be used to determine the magnitude and type of hearing defect. Additionally, it is suitable for infant hearing screening and has been recommended as the test choice by the Joint Committee on Infant Hearing (24, 72). Two methods are currently available for delivery of stimulation. First, ABR using air conducted stimulation has been widely used in testing pediatric populations, especially in audiological screening for at-risk infants (15, 36, 37, 42). Second, ABR using bone conducted stimulation has also been used to evaluate the cochlear status of newborns, infants or at-risk infants with abnormal ABR to air-conducted stimuli (53, 60, 63, 65, 68). Thus, congenitally deaf newborns or those infants identified with lesser degrees of hearing impairment by ABR can benefit from early auditory intervention, habilitative management, and longitudinal objective monitoring.

The purpose of this chapter is to review some basic knowledge related to ABR testing:- neurodevelopment of human auditory system, ABR measurement parameters, ABR threshold and affecting factors. These factors are described as follows:

1. Neurodevelopment of human auditory system

A rudimentary nervous system is apparent early in human embryogenesis. Neurulation, the process whereby the nervous system is formed, is evident by the third week of gestation. Cell proliferation proceeds at a phenomenal rate averaging up to 250,000 new neurons. At birth virtually all the neurons of the mature central nervous system (CNS) are present and the brain approximates 25 percent (350 grams) of the adult volume. Growth and development of the neuropil and supportive infrastructure, particularly in the-neocortex, however, extends well into postnatal life with most of the mass added by the fourth year (72). Active movement of cells into the brainstem is completed by the second month of gestation, whereas migration into the cerebral cortex and other structures continues for several months after birth in the term infant (72, 73).

Once in the appropriate place, the nerve cell begins the intricate process of differentiation. Axonal out growth commences almost immediately. Following some delay, dendrites project from the opposite pole of the neuron branching from terminal segments (72). The appearance of dendritic spines and the formation of synaptic contacts takes place relatively late in gestation.

In the fetal human cortex, exodendritic synapses evince by the onset of the second trimester, progress from superficial to deep layers and are typically excitatory in nature. Axosomatic synapses as well as exodendritic spine synapses occur primarily during the third trimester and early postnatal period and are generally inhibitory (72). Myelination also respects a definite chronological order. Starting early in the second trimester, after cell multiplication and migration have ended, the deposition of a lipidprotein material, arranged in concentric layers around nerve axons, persists well into adulthood (72). Myelination essentially abides by an ontogenetic and phylogenetic succession according to the origin and type of neuron. The onset and termination of myelination in the auditory pathway including the acoustic nerve, trapezoid body, lateral lemniscus and brachium of the inferior colliculi is most active between 22-24 weeks gestation (72). The roots of the eight nerve, both divisions, are among the earliest of the sensory tracts to show myelin lamellae ordinarily completing their cycle by the end of the fifth fetal month. The cortical auditory system, however, does not conclude its cycle until beyond the first year postpartum. Using birth weight as the criterion for prematurity, Rourke and Riggs found the secondary acoustic pathway to be poorly sheathed in infants below 1500 grams (72).

Although a primary physiologic province of myelin is to accelerate neural conduction, impulse traffic nevertheless takes place in pre- and unmyelinated fibers. Indeed, the development of electrical potential and excitability of nerve cell membranes proceeds synaptic formation and axonal transmission. Several studies of preterm infants describe a long latency surface negative wave as the most salient feature of evoked activity seen at or before 25 weeks post-conception (26, 72, 80, 108).

The late third-trimester fetus has long been known to respond to sound (74). The end points used for testing hearing antenally have been a change in overall fetal activity or heart rate acceleration (75, 76). Birnholz and Benacerraf found that blink-startle responses to vibroacoustic stimulation were monitored ultrasonically in human fetuses of known gestational age. Responses were first elicited between 24 and 25 weeks of gestational age and were present consistently after 28 weeks (76). Initially described over two decades age as a series of minute, positive deflections or "far-field potentials" occurring within 10 ms of and abrupt acoustic stimulus, these submicrovolt signals comprise the early components of the acoustic EP which new define the auditory brainstem response or ABR (72).

While the gross anatomical structures responsible for the generation of the ABR are fairly well understood, the molecular substrate and complex interactions that produce the successive waves remain obscure (72). Studies on the origins of ABR waveform were investigated by numerous researchers so, the exact generator for each ABR wave was not clear. However, Goldstein et al. and Moller and Moller summarized the origin of the various ABR components that wave I of the ABR originates exclusively from the distal portion of the eight nerve; peak II originates mainly from the proximal portion of the auditory nerve, although there may be some small contribution from other, more distal portions of the auditory nerve; and peak III are mainly generated by the neurons in the cochlear nucleus and trapezoid body or superior olivary complex and trapezoid body. The neural generators of peak IV are lateral lemniscus, ventral lemniscus, cells or superior olivary complex or ascending auditory fibers in the pons. Other studies of the neural generators of ABRs in human that have been based on intracranial recordings have essentially obtained results similar to those just summarized (72).

Nevertheless, this interpretation, particularly regarding peaks III and IV, is only a generalization of the findings. There is no doubt that sources other than the cochlear nucleus and superior olivaly complex also contribute to peaks III and IV of the ABR. The neural generators of peak V are complex; ventral inferior colliculus and ventral lateral lemniscus. Peak VI and VII seem to be mainly generated by somaspikes of the inferior colliculus or higher brainstem structure (72).

Thus the ABR can provide a wealth of information concerning the function capacity and development of the caudal auditory pathway. The ABR is currently accepted as the method of choice for assessing cochlear sensitivity in the neonate, young infant and otherwise "hard to test" populations.

Over the years, maturational trends for the various parameters of the ABR have been amply documented in the literature (49, 75, 93). Much emphasis has been placed on response latency and interwave intervals because of their high within and between subject reliability. Typically the latency of wave I is taken as and index of peripheral conduction and the wave V-I interwave interval as and estimate of central (brainstem) conduction time (72).

2. ABR measurement parameters

ABR measurement is not restricted to ideal environment. As a result, testing is often conducted in settings that are hostile to eletrophysiologic evaluations. For example, testing newborns in the neonatal intensive care unit (NICU) can involve excessive noise, competing electrical monitoring equipment and infant developmental status, as well as medical and nursing interruption. Despite the best of intentions and quality control, there will always be some ABR records that are compromised by electrical and myogenic artifact.

Since a wide variety of pathologic and stimulus recording factors directly affect ABR interpretation, a through understanding of normative response variability is required. In the estimation of normal auditory sensitivity and confirmation of neurotologic integrity, analysis of the ABR involves three response properties. They include the waveform morphology, peak latency, and peak amplitude.

2.1 Waveform morphology

Morphology refers to the visual appearance of the waveform. Unlike the five to seven wave peaks that are characteristic of an adult recording, only three prominent wave components are typically discernable in the term newborn (37, 75, 83, 84, 85). Analysis of waveform morphology rarely permits confident differentiation of normal versus abnormal findings (72). In the Figure 1 illustrates the ABR differences for a normal hearing newborn and an adult.

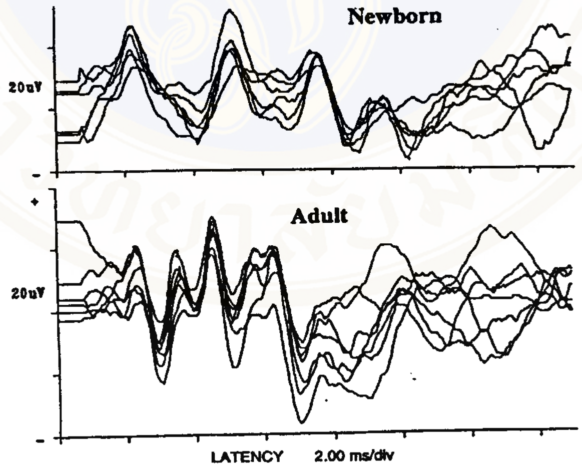


Figure 1 A series of 6 ABR waveforms, each obtained from the same ear of a term newborn (top) and of an adult (bottom). Each trace represents the sum of 2000 click stimuli at 60 dBnHL (72).

Even the most cursory comparison illustrates the distinctive morphologic differences between the two. The emergence of the ABR is commonly reported between the 26th and 30th week of the gestational period, but only at high click intensity presentation levels (75, 86, 87, 88). Between three and four month of age, wave II is readily identifiable and waves IV and V begin to show signs of progressive peak separation (89). By the end of the first year of life, the morphology of the infant response approximates that of the adult. Figure 2 ABR waveform recorded at various ages from a normal infant and from adult.

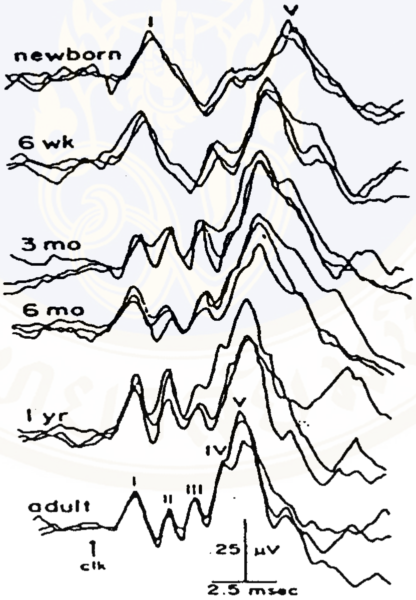


Figure 2 ABR waveforms recorded at various ages from a normal infant and from an adult (83).

The figure 3 showed averaged auditory brainstem potentials derived from a normal term infant (40 weeks gestation) measured six separate times over a two hour period. The components were remarkably consistent in both form and amplitude except for wave II and IV. The latencies of the most reproducible and easily defined components (wave I, III, the IV-V complex, or V) were definded at their peak. Waves II, VI, and VII were too variable in appearance to allow systematic study. The recording accuracy on repeated measures of the same waves was ± 0.1 msec. Wave IV and V were often fused into a single component designated as the "IV-V complex".

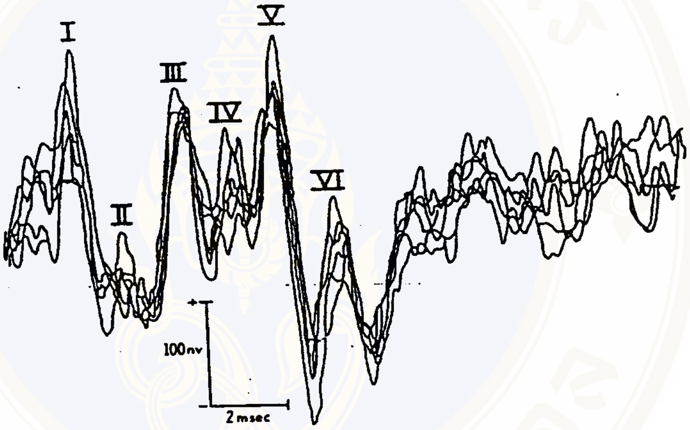


Figure 3 ABR waveform from normal term infant at 40 weeks gestation and measured six separate times over two hours period. Six distinct components designated I through VI can be identified. Click rate was 10/sec; click intensity, 65 dBSL (75).

Bone conduction and air conduction ABR thresholds can be compared. Several studies have compared with ABRs elicited by AC clicks at the same intensity levels. BC- ABRs have essentially the same waveform morphology, but have approximately 0.5 msec longer latencies in adults and older children (21, 47, 48, 62,79). This is likely due to increased travel time along the cochlear partition for the lower frequency BC stimulus. Due to maturation differences, this prolongation in BC ABR latencies appears to be less pronounced in young infants (53). Air and Bone conduction ABRs from a newborn infant are shown in Figure 4.

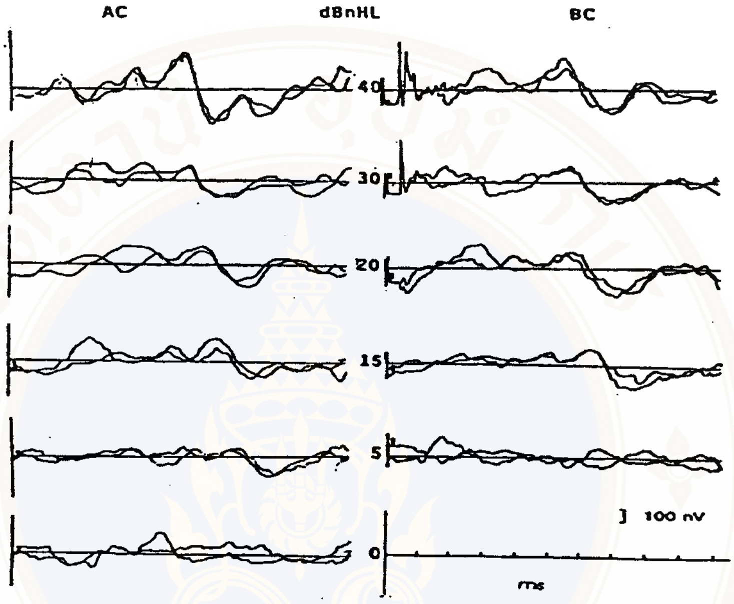


Figure 4 AC- and BC-ABR response to clicks from 40 dBnHL down to the thresholds (57).

In addition, in the previous studies, Tucci et al. studied in 12 normal hearing adults by using the Auditory brainstem response to bone conducted and found that in the higher intensity stimulation, the morphology was clearer than the lower intensity. The percentage of all subjects demonstrated an identifiable wave I and wave V. Wave I was present in all subjects at 50 and 40 dBnHL, in 83 percent at 30 dBnHL and 33 percent at 20 dBnHL. While, wave V was present in all subjects at 50, 40 and 30 dBnHL and 92 percent at 20 dBnHL (67). However, Kramer studied the percent of subjects in whom a detectable only wave V. The results showed that all subjects had detectable wave V of BC-ABRs to clicks at 40, 30, and 20 dBnHL and only 67 percent at 10 dBnHL (138).

The morphology of an ABR is subject to changes due to maturation, pathology, stimulus and recording variables (37, 77). As a result, ABR waveform components are not precise indicators of auditory pathology. However, certain characteristics such as the presence or absence of wave peaks provide gross indications of auditory pathology (72).

2.2 Peak latency

The ABR wave peak components are most often described in term of their latency characteristics. Absolute wave latency is the duration in milliseconds (ms) between signal presentation and the measured peak. The relative period between two waves is most commonly called the interwave interval (IWI) or the interpeak latency (IPL). Absolute and relative ABR latencies typically calculated from a newborn are displayed in Figure 5.

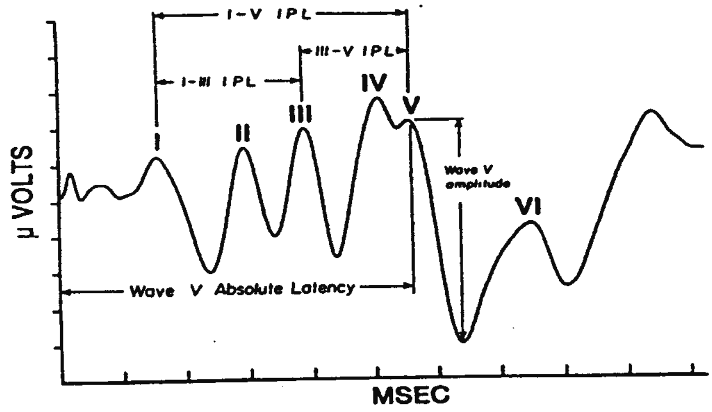


Figure 5 Method for labeling (Roman numerals) and calculating absolute and interpeak latency and peak-to-through amplitude (72).

Latency of the ABR is affected by a number of variables, most notably, development of the auditory system and stimulus intensity. The absolute latencies of all waves increase with decreasing stimulus intensity. In a healthy term infant, wave I and V latencies are about 2.0 and 7.0 ms respectively, for a 60 dBnHL click stimulus (72) These latency values are extremely variable and change as a function of maturation until about 18 to 24 months of age. In general, latencies reduce with increasing age although the rate of decrease is dependent on both the specific wave (e.g.,peripheral or central site of generation) and physiologic condition (e.g., synaptic efficiency, myelination, dipole orientation). Generally, the more rostal the wave generator site, the longer the developmental time course (90). That is, wave I latency reaches adult levels earlier than more centrally generated wave peak components (wave III, IV, and V).

In comparison, relative latency offers insight into functional integrity of the auditory brainstem pathways. The adventage of IWIs is that they are less variable and more sensitive than absolute peak latency to CNS pathologies (91). Both conductive and sensory hearing loss will generally prolong the absolute latency of all wave peak components. In contrast, lesions of the acoustic nerve and brainstem pathway tend to prolong wave peaks generated beyond wave I (at the distal segment of the acoustic nerve). Therefore, increases in interwave latency values (I-III, III-V, I-V) tend to distinguish between peripheral and central abnormalities. Although greater variability in ABR measures have been reported for younger rather than older infants (92), a high correlation between ears is found in all age groups (93, 94). Finally, Cone-Wesson, Kurtzberg, and Vaughan reported that about 15% of high risk infants present with prolonged interwave intervals on evaluation (110). Infants with this manifestation include those suffering from post-infectious and post-anoxic encephalopathy, myelinopathy, and other neurologic insult (95).

Infant and adult ABRs to bone and air conduction clicks have previously been compared. Many studies shown that wave V latencies for bone conducted stimuli were longer than air (21, 33, 40, 47, 48). Cornacchia , Martini, and Morra studied air and bone conduction ABR in 20 adults and 20 infants with normal hearing. The results in both groups shown that the latency function of wave V evoked by bone stimulation gives longer latencies and that in the infant group the air and bone conduction are farther apart (on average 0.88msec) than in the adult group (on average 0.56msec) (40). The mean latencies of wave V by Auditory brainstem response to bone conduction clicks in infants and reported that the mean latencies were 7.24 (± 0.36), 7.51 (± 0.50), 7.84 (± 0.50), 8.36 (± 0.53), and 9.16 (± 0.66) at 60, 50, 40, 30, and 20 dBnHL, respectively (40). In the other studies, Yang, Stuart, Stenstrom, and Green studied the latency function of wave V evoked by bone conducted stimuli. They showed that the mean latencies were 8.67 (± 0.43), and 9.36 (± 0.51) at 30, and 15 dBnHL, respectively (44).

Cone- Wesson and Ramirez compared BC- ABR latencies between gender and ear differences. They found that there were no significant differences in latency attributable to gender or ear differences at all levels of stimulation (13).

2.3 Peak amplitude

Response amplitude is usually described in microvolts (μV) and is a vertical measure from either the voltage baseline having a zero reference to the wave peak or more commonly, as the difference between the peak of a wave and its following trough (Figure 6).

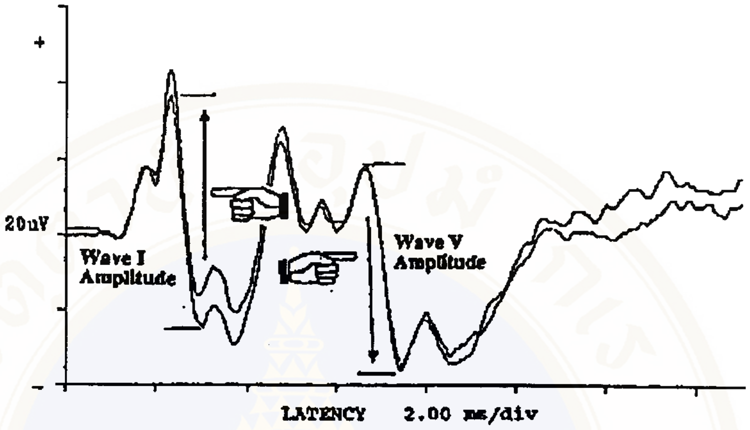


Figure 6 Amplitude measurement criteria from a three year old male. Each trace represents the sum of 2000 click stimuli at 85 dBnHL (72).

Amplitude will tend to decrease as stimulus intensity decreases, although the degree of wave peak amplitude reduction varies (49, 97, 98). At or near term, the newborn wave V amplitude approximates the wave I amplitude (75, 83, 99, 100). Decreases in wave amplitude are usually consistent with hearing loss or neurotologic disease. In extreame cases of neurodegenerative disorders or severe-to-profound hearing loss, wave peaks may be unmeasurable. A typical amplitude recording from a newborn using a 70 dBnHL click stimulus at a rate of 10/sec is about 0.35 and 0.40μV for waves I and V, respectively (97)

Although amplitude measures have been used as a supplementary response parameter in ABR analysis, they have not gained clinical acceptance due to their inherent variability. As an alternative, Starr and Achor were first to suggest the use of the amplitude ratio as a clinical alternative to absolute amplitude measures. The wave V/I amplitude ratio is most often used clinically because waves I and V are prominent at an early age, are easily identifiable and represent two distinct anatomical generator sources; that is, peripheral versus central. The ratio compares activity in the auditory nerve and more rostal regions of the brainstem (90).

The amplitude ratio is affected by stimulus intensity, presentation rate, electrode type, scalp location and age (95, 101, 102, 103). For example, as age increases, the amplitude ratio increases until about the first year of life when it reaches adult value (104). In an early study, Salamy, Fenn, and Bronshvag contended that the amplitude ratio was capable of distinguishing high-risk infants from healthy infants especially at about 1 year of age. However, Eggermont and Salamy found large standard deviations in their earlier data and conceded that the use of V/I ratio as a parameter to differentiate term from preterm infants was no longer applicable. Variations in response amplitude have been attributed to a number of biologic factors including dipole wave orientation, volume conduction, impedance properties, and neural synchrony (90, 95).

Infant and adult ABRs to bone and air conduction clicks have been compared. Cornacchia, Martini, and Morra found that the amplitude of wave V, evoked by air- and bone-conduction stimuli in both groups, bone-conducted clicks give a larger amplitude than air-conducted signals (40).

3. ABR threshold

When the ABR is used to estimate the hearing status of children it is not essential that all major component waves (I, III, and V) be identifiable. It is necessary only to determine that the test stimulus elicited a detectable response and then measure the absolute latency (the time interval from stimulus onset to the point of peak amplitude) of a dominant ABR component wave. In latency measurements, wave V is routinely used because it is consistently the most robust and stable component of the ABR. As stimulus intensity is decreased, wave V is usually the last wave to disappear (6, 72, 79).

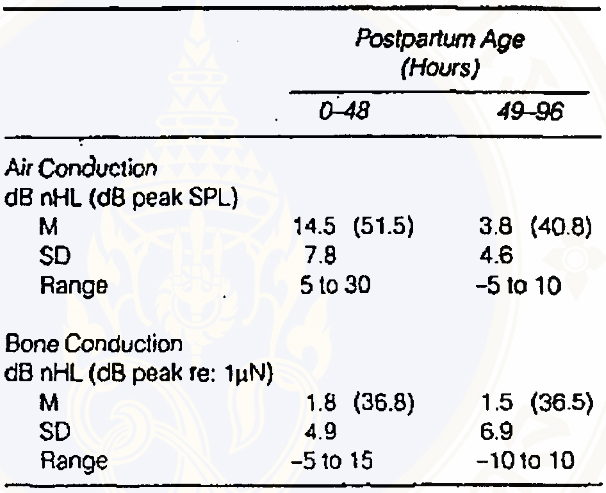
Neonate and infant ABR thresholds to air-conducted click stimuli have been reported by several authors (40, 105, 106, 108, 109) Relative to adult ABR thresholds to click stimuli, infant thresholds have been generally reported to be elevated and to converge with age. The transient threshold elevation of the neonatal ABR to air-conducted stimuli has been attributed to middle ear residuals and/ or fluid attenuating air- conducted signals to the cochlea (108, 109).

Recently, Stuart et al. reported data contrary to the previous trend of evaluated ABR thresholds to air- conducted clicks among neonates relative to adults. Identical mean ABR thresholds of 3.75 dBnHL (40.75 dB peak SPL) were found between 20 full-term neonates, tested between 48 and 72 hours postpartum, and 20 normal-hearing young adults. The authors suggested that a number of test paradigm disparities between this and earlier studies may have contributed to the dissimilar findings. At any rate, the authors questioned the notion that air-conducted stimuli are attenuated by fluid and residuals in the middle ear cavity before reaching the cochlea (62). The authors did offer a caveat in suggesting that middle ear dynamics may play a role in infants less than 2 days of age postpartum and that resolution of fluids and residuals is greatest in the first 50 hours following birth and that neonatal ABR thresholds to air-conducted stimuli may approximate those of adults after that time. Support for this speculation can be based on the following: their subjects were tested 48 to 72 hours postpartum; ABR thresholds to air-conducted stimuli have been reported to improve in the first 2 days following birth (109). In Thailand, Bunyarakyothin studied AC- ABR in 44 newborn subjects with age rage 24- 72 hours and found that the mean AC- ABR threshold was 33.86 dBnHL (34).

Based on previous studies, it was speculated that if the resolution of fluids are residuals in the middle ear occurs prior to 48 hours postpartum, neonates who are assessed during this time should exhibit poorer hearing sensitivity than neonates who are assessed after 48 hours postpartum (i.e. one would predict that subjects tested less than 48 hours postpartum should display higher ABR thresholds to air-conducted clicks than older subjects). As such, one would not expect to find group differences between ABR thresholds to bone-conducted clicks, recognizing that the ABR to bone-conducted stimuli is a feasible method to assess the cochlear reserve in neonates (53, 59, 60, 65, 68).

So that, Stuart, Yang, and Green (47) investigated the above speculation by comparing ABR thresholds to air- and bone- conducted clicks among neonates less than 48 hours and those greater than 48 hours postpartum and found that mean ABR threshold were differences between air- and bone- conducted stimulus conditions for the group of neonates less than 48 hours of age. For neonates between 49 and 96 hours of age, a non significant difference between mean ABR thresholds to air- and bone-conducted stimuli was found. Means, standard deviations and ranges of conducted clicks for both groups of subjects are presented in Table 1.

Table 1 Mean, Standard Deviations and Ranges of ABR thresholds to air- and bone-conducted clicks for both neonate groups (52).



	Postpartum Age (Hours)	
	0–48	*49–96*
Air Conduction dB nHL (dB peak SPL)		
M	14.5 (51.5)	3.8 (40.8)
SD	7.8	4.6
Range	5 to 30	-5 to 10
Bone Conduction dB nHL (dB peak re: 1μN)		
M	1.8 (36.8)	1.5 (36.5)
SD	4.9	6.9
Range	-5 to 15	-10 to 10

A number of investigators have reported comparisons of ABR to air and bone conducted stimuli. Cornacchia, Matini and Morra reported ABR responses from 20 adults and 20 infants with normal hearing to air and bone conducted clicks. The results showed that both groups have similar ABR threshold; ≤ 15 dBnHL to air conducted stimuli and ≤ 20 dBnHL to bone conducted stimuli (40). Stuart et al studied ABR threshold to air and bone conducted clicks in 20 full term neonates and found that the mean ABR threshold to air and bone conducted clicks for neonate to be 3.75 and 1.25 dBnHL, respectively (62). In the others study about ABR thresholds, Gorga et al. compared ABR thresholds for AC versus BC click and tonal stimuli in adults. They showed that BC-ABR thresholds for low-frequency stimuli were at a higher dBnHL level than for AC stimuli, but in the high frequencies and for clicks there were no significant differences. Figure 7 shows ABR thresholds in dBnHL as a function of frequency, with responses for clicks representation (33).

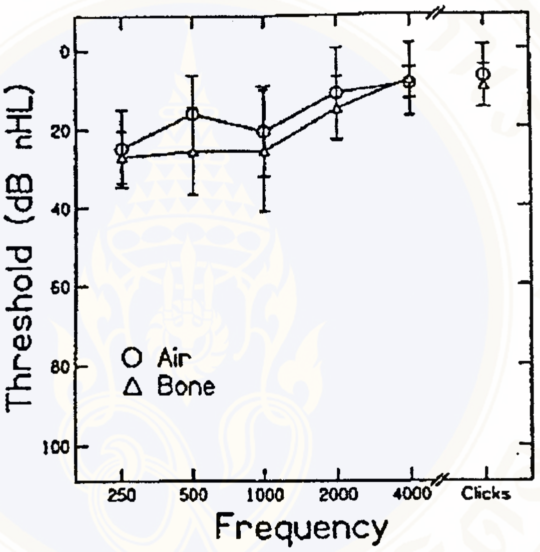


Figure 7 ABR thresholds (in dBnHL) as a function of frequency. Air conduction thresholds are shown as O. Bone conduction thresholds are shown as Δ. Error bars represent ±1 SD (33).

There is a tendency for ABR thresholds to decrease as frequency increases for both air- and bone- conducted stimuli. This pattern is similar to previously reported descriptions of the effect of frequency on ABR thresholds under roughly similar conditions (51, 60, 94).

Stuart et al. reported ABR threshold to bone conducted clicks, specifically neonates and demonstrated that the mean BC- ABR threshold for neonate less than 48 hours postpartum was 1.8 dBnHL, while for the neonate between 49- 96 hours the mean BC- ABR threshold was 1.5 dBnHL (47).

Cone- Wesson and Ramirez studied and focused on the problem of estimating hearing sensitivity in newborns from auditory brainstem responses evoked by clicks and 500 Hz and 4000 Hz tonebursts presented by a bone- conduction oscillator. The effects of acoustic energy transmitted to the ear canal, gender, and ear differences were also investigated. They found that BC- ABR thresholds for BC stimuli were 56, 52, and 53 dB (re 1 μN) or –5, -14, and 0 dBnHL (re adult psychophysical threshold) for click and 500 Hz and 4000 HZ tonebursts, respectively. Gender- related threshold were differences, with female infants having lower thresholds than males; however, these different were not significant. In addition, ear differences were not significant (13).

4 Affecting factors

4.1 Subject factors

4.1.1 Age

Although changes in the ABR have been reported in older adults (111), the effects of age is the primary subject variable in infants. Latency differences are so pronounced that establishing age–specific normative data is recommended on a weekly basis during the preterm period, biweekly between term and about three months, and monthly thereafter until 18 to 24 months of age. The effects of maturational change on infant ABR measures are well documented (47, 62, 91, 94, 99, 105, 109, 113). As summarized in Figure 8, response latency decreases with age whereas wave amplitude increases, particularly those waves generated from more rostral neural generator sites.

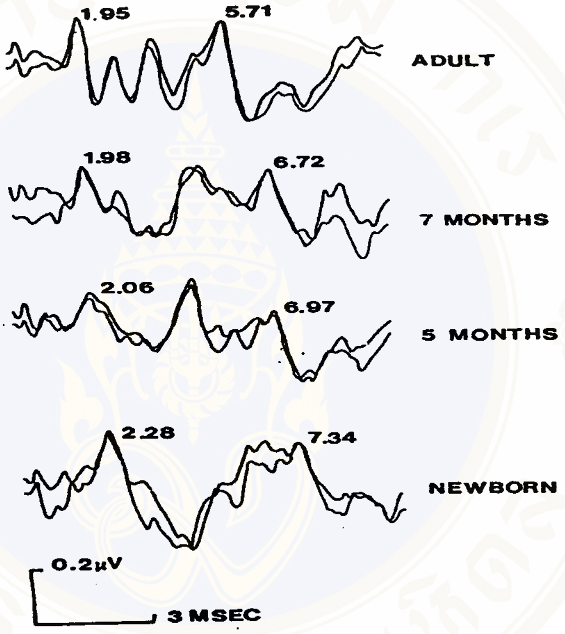


Figure 8 ABR traces representing the maturation of the auditory system (72).

The ABR has been identified in premature infants as early as the 26th gestational week at high stimulus intensities (75), although typically, the response may only consist of a wave I peak component. Galambos and associates observed the presence of replicable ABR traces in one or both ears in 83 percent of a group of premature newborns tested at 30 weeks gestational age (GA). This percent increased proportionally and by term (40th wk GA), 91 percent failure rate was attributed to either transient or permanent hearing lose or neurologic sequelae (36).

The recognition that the various wave peaks are differentially affected by maturation has led to the establishment of age-specific norms for the newborn and infant population. Wave V latency decreases nonlinearly from term ultimately reaching adults equivalency between 12 and 24 months (33, 49, 83). Despite conflicting reports (112), wave I latency approximates adult value by the third month of age although the specific time course varies among studies (62, 83, 99, 106, 113). For example, Schwartz et al. found, in a group of 20 preterm infants aged 35 to 38 weeks post-conceptional age (PCA), no significant difference in wave I latency compared to adult values. They support the concept of peripheral auditory maturity and central auditory immaturity as reflected by latency prolongation of wave III and V relative to the adult response.

In a comprehensive study of age-related ABR measures, Gorga and colleagues investigated 585 stable infants with normal hearing who ranged from 33 to 44 post-conceptional age (PCA) in weeks. ABR data were divided into six two-week age groups (94). Generally, these authors found orderly decreases in latency with increasing age. The latency of waves I and V and the interwave intervals (IWIs) all produced systematic statistically significant decreases. Additionally, they reported that 89 percent of their sample (1,249 ears) demonstrated ABR thresholds of at least 30 dBnHL and that 84 percent of 585 babies had ABR 30 dBnHL thresholds in both ears.

Gorga et al. reported non significant wave I latency changes in 535 children ranging from 3 months to 3 years of age suggesting early maturation of the response. However, consistent with previous data, they observed a systematic decrease in mean wave V latency during the first 24 month period. They reported mean wave V latencies that were about 0.6 ms shorter for the 33 to 36 month group (5.63 ms at 80 dBnHL) compared to the 3 to 6 month group (6.25 ms) (134).

Fria and Doyle calculated wave slope ratios as a function of age. They found that all ratios were independent of age during the first stage suggesting that both peripheral and central changes contribute to latency maturation. However, Eggermont and Salamy, and Gorga et al. refuted the two exponential model description of wave V latency in full term infants. Eggermont and Salamy studied 465 full term and 178 pre-term infants, and found no difference in brainstem maturation as reported by the I-V latency between infant groups but did find differences in absolute latencies. They attributed these differences to possible mild conductive hearing loss and damage to the cochlea due to the administration of ototoxic medications in the pre-term population (91, 134).

Healthy and premature high risk infants differ significantly, adding to the complexity of normative data collection (93). For example, in premature infants, the rate of latency reduction for wave V is about 0.2 to 0.3 ms/w as GA increases from 30 to 40 weeks and about 0.1 to 0.2 ms/wk for wave I (84, 90). To avoid maturational effects that may further complicate newborn assessment. It is recommended that ABR testing should be deferred until the infant is medically stable, off ototoxic medications, breathing unassisted and can be tested in an open crib.

4.1.2 Gender

In the newborn, gender is not a significant factor in ABR response measure (72). Stockard et al. tested 77 normal term babies and found no statistical gender differences in IWIs (77). These finding were confirmed by Jacobson et al. who reported ABR results for 124 newborns between term and two months of age. They found no significant latency changes attributable to gender and suggested that for this age category, response measurement could be merged for clinical assessment without statistical variance (99). Other clinical support comes from a larger study by Durieux-Smith and colleagues who tested 434 newborns ranging in age from 32 to 56 weeks GA and found no difference in ABR latency or amplitude between gender (97). Conflicting data have been reported (35, 114), although differences in peripheral hearing and neurologic status, transducers and correct GA estimates may contribute to these apparent gender differences.

4.1.3 Temperature

The effects of decreasing body temperature will tend to prolong absolute and relative latency and decrease response amplitude. Typically, temperature is not a concern for most practical applications of newborn and infant ABR. However, for the premature infant where hypothermia may be encountered, core temperature must be closely monitored. Stockard et al. reported that a reduction in mean esophageal temperature less than 35° C produced IWI prolongation and associated amplitude decreases. This findings have been confirmed by others (115) and are similar to those demonstrated in the rat (116).

Therefore, a knowledge of core body temperature is recommended when testing newborns and infants who may be monitored during surgery, on life support systems, or are generally physically compromised (e.g. shock) (72).

4.1.4 Hearing status

A prime clinical feature in pediatric ABR analysis is the identification of wave I because of its stability under most diverse conditions. This component latency serves as a benchmark of peripheral integrity. The absolute latency values of wave I and V provide information about the function status (i.e., hearing sensitivity, auditory pathology) of the auditory pathway. The relationship between electrophysiologic and behavioral threshold has been established. Lary et al. and van Zanten, Brocaar, Fetter et al. have shown that mildly elevated ABR click threshold levels decrease with increasing PCA in infants born prematurely (107). Galambos et al. reported that ABR click thresholds reach maturity by the first year of life, whereas Kaga and Tanaka found threshold differences in children up to 3 years of age (106).

The relationship between ABR and perceptual hearing threshold was examined by Sasama in a total of 115 infants and children ranging in age from less than 6 months to 3.5 years. All infants were suspected to have hearing impairment. A total of 103 were confirmed as hearing-impaired. Sasama observed an 86 percent agreement between ABR and behavioral thresholds in the hearing-impaired group whereas normal hearing children showed threshold distribution patterns that corresponded to that of normal hearing adults (96).

In a comprehensive comparison of click ABR and audiometric measures, Hyde, Riko, and Malizia examined the results of 1,367 ears in 713 children at risk for hearing loss. ABR measurement was conducted when infants ranged between 3 to 12 months whereas behavioral pure tone follow-up audiometry was content ABR accuracy for detecting average sensory hearing loss at 2000 and 4000 Hz in excess of 30 dB.

4.1.5 Middle ear pathology

The exact incidence of middle ear pathology in neonates is not known, but effusion and other forms of pathology are not uncommon in the intensive and special care nursery population. Depending on criteria and population studied, reported rates of middle ear abnormalities have ranged from 10 to over 30 percent (32). Predisposing factors include sepsis, prolonged supine position, mechanical ventilation, reduction in swallowing activity and the normal anatomic features of neonates that influence eustachian tube function. Transient or permanent middle ear abnormalities are often cited as a factor of hearing screening outcome (5, 6, 39) and probably do contribute in some degree to the differences in failure rate among studies.

Unrecognized middle ear pathology that resolves spontaneously between the time of newborn hearing screening in the hospital and the first follow-up audiologic assessment, for example at 3 to 6 months, contributes to over-referrals or false-positive ABR screening outcomes; that is, initial screening failures in infants without permanent hearing impairment. Mauldin and Jerger studied bone- versus air-conduction ABRs in 4 normal hearing adults and 11 patients with conductive hearing impairment. Notably, air-conduction stimuli were presented binaurally with TDH-39 earphones, and forehead placement was used for bone-conduction stimulation (with a B-70A vibrator and no masking). In normal subjects, the latency to wave V for bone-conducted signals was approximately 0.5 ms longer than the latency for air-conducted signals delivered at the same sensation level. In conductive hearing loss, the separation of the latency intensity functions for air conduction and bone conduction (corrected for the 0.5 ms delay) provided a valid estimate of the behavioral air- bone gab in the 1,000 to 4,000 Hz region.

4.1.6 Activity level

A critical assessment for the accurate evaluation of the newborn is the activity level at the time of testing. Clinical experience has shown that significantly different outcomes can be predicted from the same newborn when asleep or quietly resting versus in an active state (117). Although sleep has little effect on the ABR in adults (118, 119), the level of conciousness likely increases the false-positive rate observed in the newborn. Artifacts introduced into the record due to movement may contaminate and even obscure the morphology of the wave configuration, making proper wave peak identification challenging (63).

In an attempt to determine the influence of movement artifact on the newborn ABR, McCall and Ferraro reported the results of 52 stable neonates at risk for hearing loss. They divided neonates into three activity levels and found significantly different pass-fail findings. Using a 30 dB click intensity, they reported failure rates of 37 and 10 percent for the active versus asleep groups, respectively. In addition, they recommend that test failure under active conditions should be repeated under quite conditions to eliminate the question of movement artifact (81).

4.2 Stimulus factors

4.2.1 Intensity

Any change in stimulus intensity will directly affect response latency and amplitude. Generally, as intensity is increased, wave component latency decreases whereas amplitude increases. Figure 9 illustrates typical changes in latency and amplitude as intensity is attenuated. The wave V latency shifts with intensity at a rate of about 0.035 ms/dB (37, 49, 105). In a healthy term infant, wave V latency is observed at about 6.8 to 7.0 ms for a 60 dBnHL click stimulus.

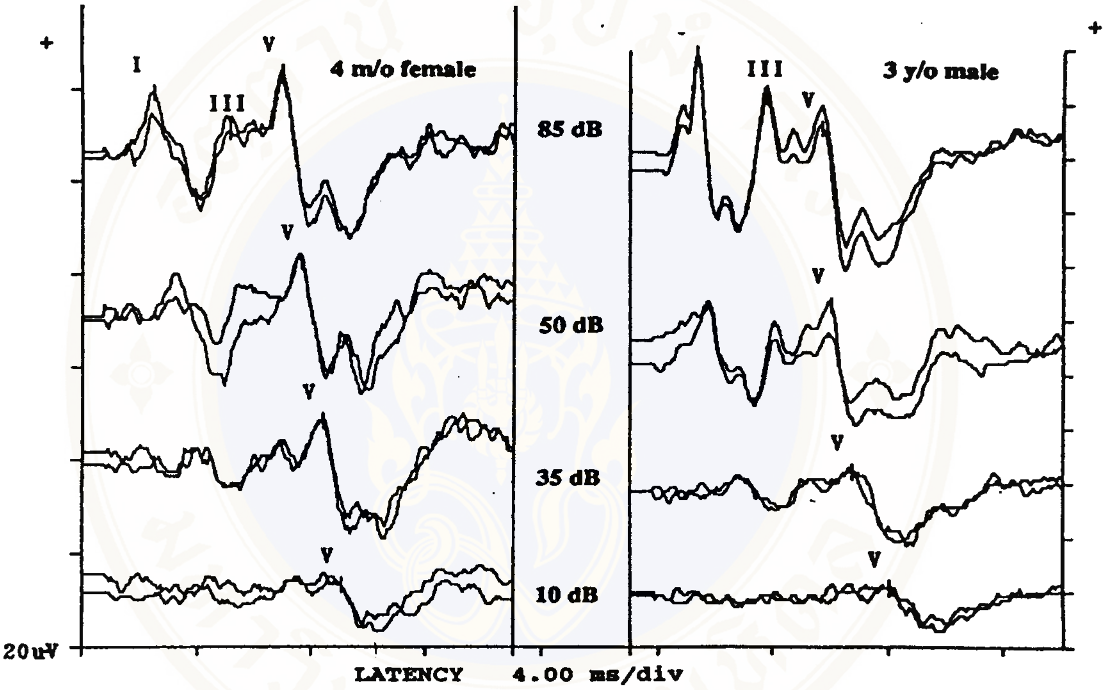


Figure 9 The effects of intensity on the ABR obtained from a four-month-old infant (left) and a three-year-old child (right) (72).

The rate of wave I latency change with intensity has been more controversial. Stockard et al. imply two transitional zones for infant wave I measurement. Between 70 and 60 dB and 40 to 30 dBnHL, the magnitude of wave I latency shift is greater than that of wave V. Due to this differential effect between peripheral and central transmission, they reported a reduction in IWI as intensity is decreased. In contrast, other investigators (93, 99) reported similar latency shifts for waves I and V resulting in a constant IWI as a function of intensity. The differences reported in IWI latency may be explained by the measurement of wave I. At higher intensities, wave I will often exhibit a bifid peak separation differing by as much as 0.4 ms (99). If peak selection is not consistent at varying intensity levels, calculation of the IWI may remain problematic.

4.2.2 Rate

A change in the stimulus repetition rate will affect the latency, amplitude, and morphology of individual wave components. For infants, an increase in rate will shift wave latency while reducing amplitude (77, 103, 113). Despland and Galambos have reported that infants as young as 32 weeks GA will respond to click stimuli at rates as high as 80/sec (84).

The effects of rate are displayed in Figure 10. An infant of less than eight months would be expected to produce a wave V shift of about 0.8 to 1.0 ms for a 70/sec rate shift whereas wave I will increase by 0.4 ms (98). Durieux-Smith and associates observed latency shift of 1.3 ms between 11 and 61/sec for 30 week GA premature newborns and shifts of 0.6 ms for a group of 4 month old infants generating a mean slope of 38 μsec/wk (97). Zimmerman et al. studied 22 full term normal newborns with GA of 39, 40, and 41 weeks for the first 6 months of life. These authors used three rates of click stimuli (11, 33, and 66/sec) to monitor ABR latency (113). They showed statistically significant increases in latency for wave I and wave V latency differences on the same order as reported by Picton et al. As a consequence, increasing repetition rate will result in an increase in the IWI latency and it likely that the differences will be more pronounced for premature infants (98, 113).

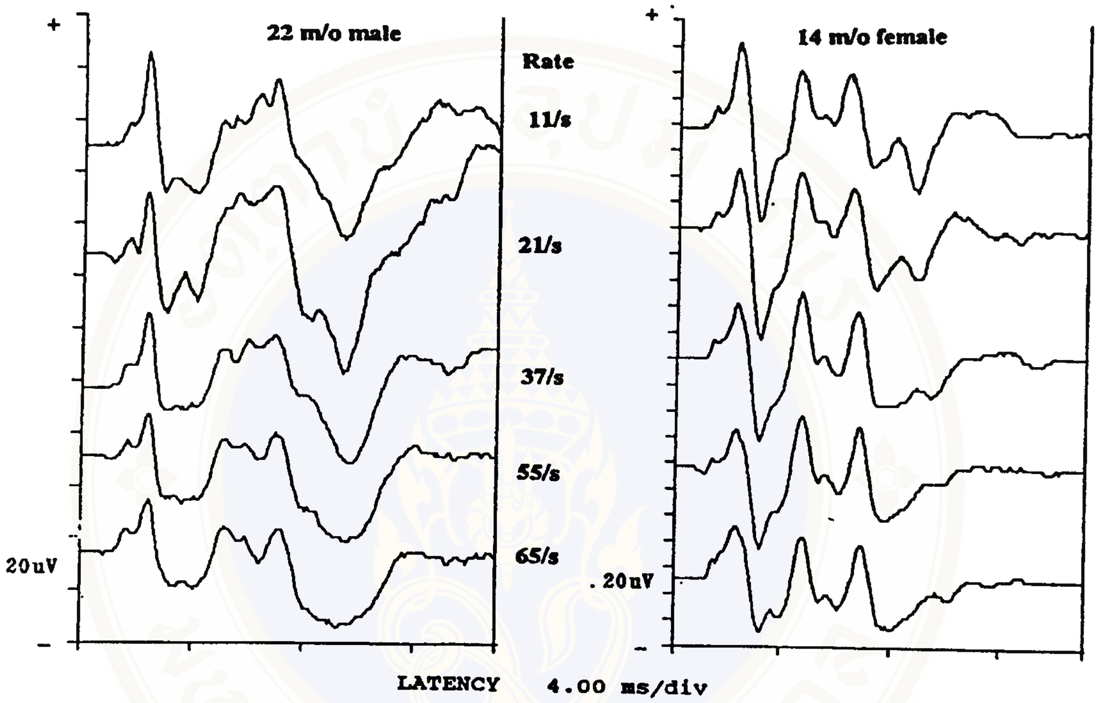


Figure 10 ABR rate study. Traces were obtained from a 22-month-old infant (left) and a 14-month-old infant (right) at 11, 21, 37, 55 and 65/sec (72).

Wave amplitude is also affected by changes in repetition rate. Wave V shows the least change, maintaining approximately 85 % of its original amplitude at rates up to 80/sec (120). In comparison, wave I amplitude is dramatically diminished by rate increase (120). This difference in wave amplitude reduction results in an increase V/I amplitude ratio. To date, studies of increased rate in newborns have not produced any indications of habituation (83), fatigue (105), or refractoriness (93).

Clinically, rate plays and important role in the assessment of the pediatric population. As rate increases, the required time to record an equivalent number of averaged traces is reduced. Time is obviously a critical factor in the evaluation of an unsedated or uncooperative infant. For example, at a rate of 10/sec, it requires approximately 13 minutes to average 2000 responses for two ears, replicating trails. However, at 37/sec, a common rate for newborn screening threshold measures, about four minutes is necessary to perform the same task. Rates of 20 to 40/sec have been reported most efficient for wave I and V identification (120).

4.2.3 Polarity

During response averaging, stimuli may be presented with either constant initial polarity (i.e., condensation or rarefaction) or alternating polarity. In the absence of clinical standards and problems observed in earphone polarity from various manufacturers (121). It is advantageous to determine the acoustic profile of the stimulus at the tympanic membrane rather than the electrical drive to the transducer. Initial positive pressure or inward movement of the eardrum is caused by condensation stimulus polarity. A rarefaction stimulus will initially move the eardrum outward by a negative pressure. Only the corresponding basilar membrane movement associated with rarefaction polarity is reported to excite primary auditory neurons (72).

There is general agreement concerning the effects of stimulus polarity on wave morphology in neonates (77, 98, 123). For the most part, when using conventional (e.g., TDH-39) earphones, alternating polarity tends to reduce electric artifact that affects wave I measurement, although almost exclusively at high intensity stimulus levels. There is less consensus about polarity influence on wave latency. The more rostral the generation of the wave component, the less sensitive the effects of stimulus polarity (124, 125).

4.2.4 Transducers

4.2.4.1 Earphone

Until recently, conventional audiometric earphones were used routinely in AEP measurement. For neonates and infants, testing was usually accomplished by removing the earphone cushion and either supporting the TDH-39/49 within the crib or bassinet. This technique introduces a number of problems including potential ear canal collapse, unpredictable oscillations in the frequency spectrum, intensity variation of the click signal and no effective ambient noise attenuation. These variables lead to both measurement and interpretation errors and likely contribute to a high false-positive rate in newborn hearing screening studies (115, 117, 127). Gorga et al. have estimated that as many as half of all newborn hearing screening failures may be attributed to ear canal collapse secondary to conventional earphone placement (127).

To compensate for these technical problems, insert earphones have been used successfully in the neonate population. With the commercial introduction of the Etymotic insert foam plugs and other methods of insert probe tip modification, the problem of ear canal collapse appears alleviated (128). Previous findings in adults have shown that when the duration of signal transmission due to tube length is compensated, an insert and a circumaural earphone produced similar ABR latency measures (129).

Due to differences in transducers, it is essential to establish new normative data when insertion transducers are employed. Clinical experience (130) in newborns and infants have shown that a simple correction factor does not always compensate for latency differences as similarly demonstrated in adults. Increase in sound pressure levels obtained in smaller canal enclosures likely increase SPL resulting in shortened latency expectations.

4.2.4.2 Bone Vibrators

Bone conduction stimulation has been recommended during follow-up ABR evaluation of auditory sensitivity when air conduction stimulation produces a response consistent with conductive hearing impairment (e.g. delayed absolute latencies). Although adequate bone conduction stimulation can be presented anywhere on the head, the two most common vibrator placements are the mastoid bone and the frontal bone (forehead). Frontal placement produces more reliable threshold results but mastoid placement is traditionally used, probably because it permits a higher effective intensity level to reach the cochlea.

In the study by Yang et al., bone conduction ABRs were recorded from three sets of patients: adults, one year old children, and healthy neonates tested between 24 and 72 hours after birth. Stimuli (0.1 ms rarefaction clicks at 30/sec) were delivered with a Radioear B-70A bone vibrator at intensity levels of 15, 25, and 35 dBnHL ABR results for three vibrator surface placements were analyzed: 1) on the frontal bone (midline forehead), 2) on the occipital bone (1 cm lateral the ipsilateral occipital protuberance), and 3) on the temporal bone (superior postauricular area). Spectra for the bone vibrator versus the TDH-39 earphone were described, and other pertinent measurement data were provided (64).

A remarkable finding of this study was the very unique latency versus placement pattern observed for the neonates. For temporal bone placement, wave V latency was markedly shorter than for the other two bone vibrator locations and was slightly shorter than even the air conduction latency values. Even the specific site of bone vibrator placement on the temporal bone is an important factor (61).

There are several commercially available bone conduction vibrators, including the Radioear models B-70A, B-71 and B-72. Among these, the B-72 produces significantly greater acoustic radiation than the B-71. Recent clinical reports have also described the Pracitronic model KH 70, a German bone vibrator with a relatively smoother and wider frequency response (131, 132). Numerous authors note that bone vibrator output declines in the high-frequency region which is important for click stimulation (44, 63, 64, 126, 133). Output levels from three commercially available bone vibrators were compared with those of two air conduction earphones (TDH-49 and a hearing aid transducer plus insert plug) by Schwartz, Larson, and De Chiccicca .

The air conduction transducers producer produced a relatively flat frequency response, whereas each of the bone conduction vibrators had energy predominantly in the 2000 Hz region, with maximum output not exceeding 35 dBHL. Of the three bone vibrators, the B-70 permitted greater output. The preceding information on bone vibrators may not accurately reflect their potential for ABR measurement (134). The reduction of bone vibrator output for higher frequencies, when expressed in units of force, may not necessarily correspond to reduced effective intensity level in this audiometric region. That is, effective output of the bone vibrator is actually in the higher frequency region.

Other problems shared by bone vibrators are excessive distortion and inter-subject variability. The distortion, which is more pronounced with higher frequencies, reduces or may even eliminate frequency specific ABR stimulation (135). The static force of bone vibrator placement is another often overlooked factor in the effectiveness of bone conduction stimulation. Variability in bone vibrator force is due to inconsistencies in placement site. The pressure with which the vibrator is held to the skull, and skull impedance (135).

In a recent study, Stuart, Yang, and Stenstrom demonstrated that changes in bone vibrator placement within the temporal bone region of newborn infants produced significantly different effects on ABR wave V latency. In comparison to air-conduction stimulation, the bone-conduction stimulation mode results in a decrease in effective intensity of approximately 40 to 45 dB. That is, if a bone vibrator is plugged into the earphone stimulus jack of an evoked response system, the actual output even at a maximum attenuator dial or instrument intensity reading of 95 dB may be only 55 dBnHL or less (61).

Yang, Stuart, Stenstrom, and Hollett found that the results of their studied indicated that ABR wave V latencies to bone conducted clicks in newborn infants were affected significantly when the vibrator to head coupling force shift exceed 200 grams. It is recommended that the coupling force be controlled and remain consistent when implementing ABR to bone conducted stimuli in newborn infants (79).

There is convincing evidence that bone conduction ABR is a clinically feasible technique in infants (6, 53, 61, 64, 65, 68). Contrary to expectations for adult subjects, latencies for ABR waves I, III and V are shorter in infants' bone-conduction than air-conduction stimuli (64). A possible explanation for this finding relates to the pattern of cochlea development in the newborn. In the immature cochlea, responsiveness to low frequency stimuli develops initially in the basal regions, the location for high frequency responsiveness in the adult cochlea (136).

Cornacchia, Martini, and Morra studied bone conduction ABR in infants (16 to 20 months) and young adults. Alternating clicks were presented to the forehead via bone-conduction with a Radioear B-70A vibrator. As expected, ABR latencies in general were greater for adults than infants. Interestingly, the study showed the convergence of wave V latency values for adults versus children with decreasing intensity of the air-conduction, but not bone-conduction stimuli. That is, bone-conduction latency-intensity functions were parallel for adults and infants. However, for air-conduction stimuli, there was an adult versus infant wave V latency difference of 0.58 ms at high-intensity levels, but a difference of only 0.08 ms at 20 dBnHL (37). In contrast, however, Gorga et al. found parallel wave V latency-intensity functions for adults (N=20) versus infants (N=1,120) over the range from 20 to 80 dBHL (134).

There is clinical evidence that bone conduction ABR assessment can be useful in circumventing the masking dilemma associated with behavioral pure tone hearing assessment (6, 43, 137). The main premise underlying this clinical application is that a wave I component observed from an electrode located on or near the ear ipsilateral to the stimulus confirms contribution of the stimulated ear to the response, whether or not masking is presented to the non-test ear.

Analysis of the waveform simultaneously recorded with an electrode on the ear contralateral to the stimulus is also helpful. If in the contralateral waveform there is no peak corresponding to the ipsilateral wave I (in the same latency region), one has further assurance that the presumed ipsilateral component is indeed wave I (Figure 11)

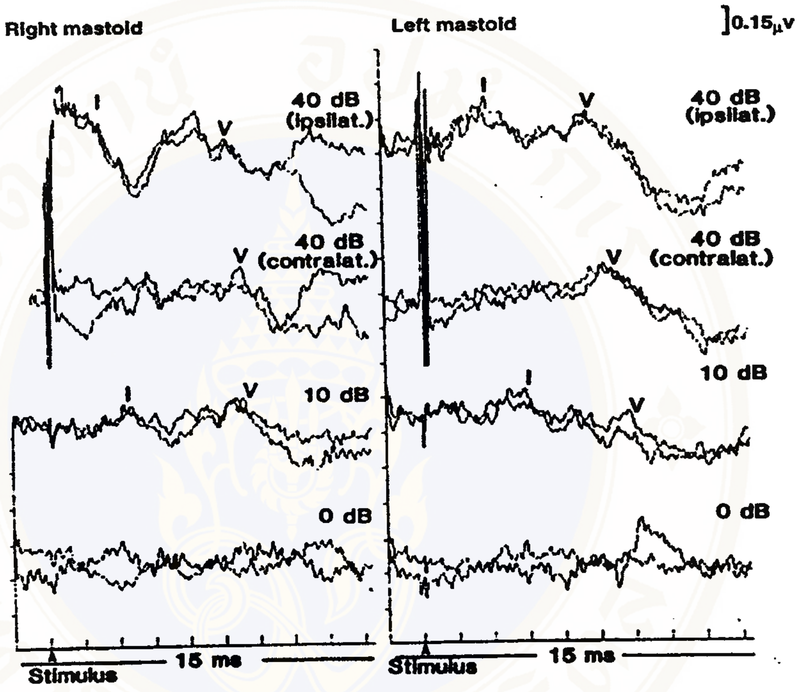


Figure 11 ABR waveforms recorded with bone conduction stimulation from a two-month-old infant with congenital aural atresia on the right and normal-appearing external ear on the left (72).

In summary, bone-conduction stimulation in clinical ABR measurement is underutilized, particularly in infant and children. There are probably a variety of reasons for this trend. The first is the limitation in maximum effective intensity level (about 50 to 55 dBnHL) for bone-conduction stimulation. Second, problems encountered in recording a clear bone-conduction ABR in adult subjects may have led to the assumption that bone-conduction ABRs are not clinically feasible or useful for assessing sensory hearing sensitivity in infants and young children. In fact, in normal-hearing infants and young children who tend to have better than average sensory hearing sensitivity in the 1000 to 4000 Hz region compared to adults, the dynamic intensity range for bone-conduction ABR stimuli may be substantially larger. Further, a distinct wave I component can often be consistently recorded with a bone-conducted stimulus in these younger subjects.

Another possible limitation has to do with the electromagnetic energy radiating from bone vibrators and the resultant stimulus artifact in ABR recordings. This is intensified when the mastoid is used for bone vibrator placement and as a site for the inverting electrode in combination with a single polarity (i.e., rarefaction or condensation) versus alternating polarity click stimulus. Two simple technical modifications can minimize these problems. Stimulus artifact can be reduced by use of earlobe or ear canal electrodes and an alternating polarity click (6).

Finally, the masking dilemma and the need for contralateral masking is cited in discussions of problems associated with bone conduction ABR measurement (63). The head offers little or no attenuation (10 dB or less) for bone-conduction stimulation, at least in adult subjects. As a result, stimuli presented via bone conduction to one mastoid may equally activate each cochlea. Some authors have stated rather categorically that the nontest ear must be rountinely masked in ABR assessment by air conduction or bone conduction. In order to rule out a contribution to the response from unintended stimulation of the better hearing, nontest ear.

However, the presence of a clear wave I component within the normal latency region from the electrode array ipsilateral to the stimulus, or a wave V of normal latency is strong evidence that the ABR is not due to stimulation of the nontest ear. Thus, the likelihood of obtaining ear specific bone conduction ABR data is enhanced in infants and may contribute importantly to audiologic and medical management.

4.2.6 Masking the non test ear

The application of masking in the non test ear to eliminate crossover of the test stimulus is standard protocol in clinical audiometry. Certainly there would be good reason to believe that the same potential for crossover exists in ABR neurodiagnostic testing, particularly since the stimuli are presented monaurally at moderately high intensity levels. Yet, the question of whether masking is routinely needed has remained open to controversy for many years.

The need for masking was first questioned by Finitzo-Hieber et al. when two adults with unilateral congenital atresia failed to show repeatable ABRs when the impaired ear was stimulated at signal levels between 100-117 dB peak equivalent (pe) SPL. Opposite findings with adults were later reached by Chiappa, et al. and Ozdamar and Stein, and more recently in infants by Hatanaka et al. In each case series, recognizable, albeit temporally delayed, ABRs were recorded initially without masking but were subsequently ablated with the introduction of masking to the normal ear of patients with unilateral deafness.

Interaural attenuation (IA) is influenced by factors such as the test stimulus and transducer type. For a click transduced either through a conventional earphone or ER-3 Tubephone, estimates of IA range from about 50 to 80 dB (39) with the ER-3 offering no significant IA advantage over the circumaural earphone as it does with long duration pure tone stimuli (39).

From a conservative audiologic perspective, it would appear that the application of contralateral masking in ABR testing should follow the same principals as in behavioral audiometry using a minimum estimate of 50 dB IA; that is, you need to mask whenever the intensity of the stimulus exceeds sensory sensitivity in the non-test ear by more than about 50 dB.

An alternative method of determining when to mask is based on the interaural latency difference of corresponding peak components. The ABR produced by transcranial stimulation is significantly longer in latency and reduced in amplitude owing to the lower signal intensity reaching the contralateral cochlea. Such a crossover response would be so delayed relative to the better ear that the need for masking would be apparent. The advantage of this approach to determining when to mask is that it does not assume knowledge of cochlear sensitivity in the non-test ear (72).

Given the broad frequency response of a click and since the masking-noise intensity dial of evoked response instrumentation is not calibrated in effective levels, one might consider constructing an effective masking table as described originally by Sanders and Rintelmann and reviewed more recently by Sanders. Unlike pure tone audiometry where effective masking is computed for each pure tone center frequency, it needs only be determined at the resonant frequency of the transducer for a click stimulus. This can be obtained from the spectral analysis during routine calibration. If this is not available, 3000 Hz would serve as a good approximation. Although effective masking level can also be derived through direct measurement of ABR threshold in normal listeners, this method is inordinately time consuming (72).

In contrast to AC receivers, no study has evaluated IA for a click transduced through a BC oscillator. One would suppose that IA is probably no greater than 10 dB as in pure tone audiometry, thereby necessitating the need for masking whenever a BC ABR is recorded. To circumvent the need for masking with infants and young children, Stapells recommends using the ipsilateral to contralateral latency and amplitude asymmetry seen with a two channel ABR recording, where wave V is smaller in amplitude and prolonged in latency in the contralateral versus ipsilateral channel (60). According to Stapells, at about 40 dB HL, the latency and amplitudes between the two channels are equivalent, suggesting probable crossover to the non test ear. At lower signal levels, however, the ipsilateral (stimulated ear) shows the expected earlier wave V latency with larger voltage than its contralateral counterpart. The presumption here is that the ipsilateral response reflects no contribution from the opposite cochlea (60). However, Yang et al. found higher interaural attenuation (lower likelihood of cross-over) for newborns whose cranial sutures remain flexible and open and they showed that infants have a higher interaural attenuation for BC clicks than do adults so, masking of the nontest ear is needed for infants older than 1 year or for younger infants when BC test levels exceed 30 dBnHL (64)

4.3 Recording factors

4.3.1 Filters

The recording of ABR activity is affected by both physiologic and electrodynamic events. One major stumbling block in most electrophysiologic recordings is that subcortical synchronized neural discharge patterns are several magnitudes smaller than random EEG, thus obscuring the activity of interesting. In order to compensate for this voltage mismatch, bandpass filtering has been introduced as one method of improving the signal-to-noise ratio during routine measurement. The degree of improvement is dependent on the spectra of the signal and the noise component (51). During adult ABR neurodiagnostic evaluation using click stimuli, band-pass setting of 100 to 1500 or 3000 Hz are usually adequate for definitive results. However, high-pass filter settings of 20 to 30 Hz are required for audiologic applications of low-frequency, low-intensity stimuli (139). Although a narrowing of band-pass filter settings (e.g. high-pass filter cutoff > 150 Hz) may be used in cases of severe myogenetic artifact and electrical interference, there is a concomitant distortion of ABR latency and amplitude (126) and a major reduction of the wave V spectral energy content (122). Using suggested reduced high-pass cut off filter setting, wave V amplitude may increase by as much as 20 %.

Compared to the adult ABR, the spectral content of an infant ABR response, particularly at high intensities, has greater low-frequency energy (72). Therefore it is common practice to extend the high-pass filter setting downward from 100 to 20 or 30 Hz during infant recording to enhance wave V amplitude (5, 51, 122). On the average, click ABR thresholds for normal infants can improve by 3 dB using a 30 Hz filter setting (60).

4.3.2 Scalp distribution

Differential pre-amplifiers are most commonly used in ABR measurement as a method of improving the signal-to-noise ratio. A differential recording requires input at a minimum of three electrodes, the non-inverting, the inverting and the common. Since ABR activity is generated at subcortical levels, volume conducted and monitored at the scalp as far-field potentials, the frequently used terms active and reference are not applicable in this context and are discouraged (72).

It is reasonable to assume that correct electrode placement would maximize the largest amplitude and most reliable ABR peak measurement. With newborns and infants, a single channel recording using a vertical electrode montage is most common, although 2-channel recordings have also been advocated (78). The wave V response is characteristically recorded between the vertex (Cz) or forehead (Fz) and either the mastoid or earlobe ipsilateral to the stimuli, although a noncephalic site may produce greater amplitude wave V recordings. Wave I in contrast is most robust when measured in a horizontal (i.e., earlobe to earlobe) configuration (78).

Hecox and Burkard have shown that a horizontal montage will produce a larger wave V amplitude 40 percent more often than a vertical montage for infants less than eight months old, whereas wave I amplitude is larger in 70 percent of the cases. Multi-channel evoked potential systems allow greater flexibility with regard to electrode placement and recording sites and under certain circumstances, provide additional information not demonstrated using conventional single channel recordings (90).

4.3.3 Test environment

The location for ABR recording is predicted on the rationale for testing (screening, threshold assessment, or neurotologic evaluation), infant status and the facility. Most often, the ideal site (an eletrically shielded audiologic test suite) is not feasible since practical considerations usually dictate less than optimum settings. Ambient noise levels are typically in excess of 60 dBA and may be higher when infants are confined to isolates (72, 85). When using intensity levels less than ambient noise level, latency prolongations and thresholds elevations should be anticipated (72).

Another primary environmental concern is electrical interference frequently found in NICU facilities caused by line noise (60 Hz) and other electric monitoring devices. Typically, high-risk infants are in isolates with respiratory monitors and cardiac catheters. Temperature is controlled with either lights or warming blankets. All electrical devices are potential hazards for electrophysiologic assessment. If testing is critical and cannot be postponed until the infant can be moved to a more favorable setting, recommendations include technical alterations (e.g., insert earphones) to minimize the effects of noise and the use of an isolation transformer to compensate for electrical interference. Under such conditions, a cautious approach to interpretation is recommended (72).

4.3.4 Analysis window

The recording of ABR activity in normal adult is usually limited to the first 10 ms post-stimulus onset. However, there are several intervening factors that must be taken into account when threshold sensitivity is required. For example, the use of low frequency tone bursts which excite apical regions of the cochlea tend to produce wave V response latency in excess of 10 ms. Auditory pathology, especially conductive hearing loss which prolongs absolute wave peak latencies, may obscure peak detection since measurable wave components can exceed the 10 ms analysis window. Additionally, when premature infants are tested prior to full-term adjusted age, incomplete maturation of the auditory system will introduce significantly delayed peak latency responses (72).

The consensus of the clinical community recommends the use of 15 or 20 ms analysis latency epochs for routine newborn and infant application (37, 115). Schwartz and Schwartz have recommended this latency expansion because: 1) the interval beyond 10 ms represents a means of estimating background noise levels, and 2) there is a greater likelihood of observing wave III and V to low intensity stimulus levels with the extended window (78).

4.3.5 Contralateral recording

As stated earlier, conventional infant ABR recording minimally requires the use of three electrodes. The most commonly used electrode placement for infants is a vertical montage with recording electrodes attached between either the vertex or forehead and the earlobe or mastoid of the stimulated ear. In the newborn and infant. This montage typically allows the on-line collection of three primary wave peaks; however, on occasion, ipsilateral recordings may be obscured and peak identification limited. Under these conditions, the use of simultaneous contralateral recordings have been recommended. Figure 12 illustrates the differences demonstrated in ipsilateral versus contralateral recordings from an infant ABR trace. As correctly pointed out by Stapells and Mosseri, the terms ipsilateral and contralateral do not refer to the generators of the response but rather the site of the inverting electrode to the stimulated ear (77).

The maturation of the contralateral response does not follow the same time course as that of the ipsilateral recording (120). Typically, as age increases, contralateral wave recordings decrease in latency and although amplitudes increase with age, responses are of such small magnitude they are more difficult to identify than their ipsilateral counterparts. Recently, Stapells and Mosseri recorded ipsilateral and contralateral responses from 37 infants aged 2 weeks to 20 months. Although contralateral response measures were consistent with previous reports, these investigators felt that due to smaller amplitudes, contralateral recordings were limited in their contribution to threshold measures, particularly prior to 9 months of age. Contralateral response measures were encouraged (77). However, when wave V peak latency was ambiguous. Stapells and Mosseri concluded that the observed differences of the ipsilateral and contralateral responses were likely due to dipole orientation of similar generators.

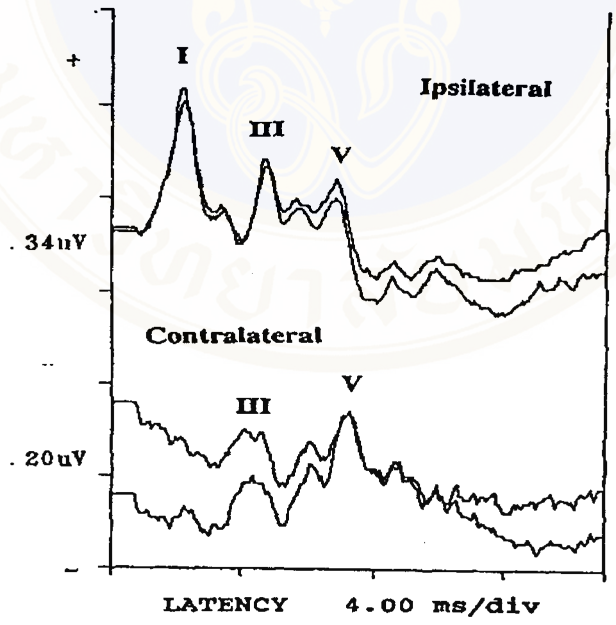


Figure 12 Ipsilateral versus contralateral ABR recordings. Traces were obtained from a seven-month-old infant (72).

4.3.6 Electrode types

There are several different types of EEG electrodes used in infant evoked potential recording. Among the many varieties, a simple method of classification is either disposable or nondisposable. Within depending on subject status, recording conditions and evoked potential of interest. The nondisposable type usually consists of either a cup, flat disk, or needle electrode. Common to the cup (usually having a hold in the center for injection of conductive cream) or disk is an outer diameter of 4 to 10 mm that is attached to the scalp. These reusable electrodes are connected by an insulated lead wire to a connector plug. A useful modification of the cup is the clip electrode. Either one or two cup electrodes are connected in a fashion similar to a clothes pin and clipped on the earlobe. Depending on hospital policy, needle electrodes, which by their nature are invasive, are either immediately disposed of after use or gas sterilized and used repeatedly. In infant auditory monitoring, needle electrodes are least used and generally restricted for special applications (e.g., intraoperative or intensive care unit monitoring, or with burn victims). It is important to remember that needle electrodes always carry the added risk of infection. The proper handling and discarding (follow hospital policy) of such materials cannot be stressed sufficiently. In contrast, disposable electrodes may be metal, cloth, or plastic. They usually contain a self-adhesive surface and may contain a conductive gel. Cloth or plastic electrodes are usually attached to an insulated lead wire via an alligator clip (72).

CHAPTER III

METHODOLOGY

1.Subjects

Thirty normal hearing newborns in the nursery ward of Vajira Hospital (male15, female15) served as the subjects for this research. The range in postnatal age from 48-72 hours. The selection criteria are as follows:

1.) Gestational age between 38-42 weeks.

2.) No risk for hearing loss. (The Joint Committee on Infant Hearing , 1994)

3.) Apgar scores of 8 or higher at 1 and 5 minutes.

4.) Birth weight no less than 2,500 grams.

5.) Physically and neurologically normal as judged by pediatric house staff.

6.) TEOAEs test pass both ears.

In 1994, The US Joint Committee on Infant Hearing made recommendations for the identification, diagnosis and management of hearing loss in early infancy (24, 29). The recommendations included a list of risk criteria in neonates (birth -28 days) include the following:

1.) Family history of hereditary childhood sensorineural hearing loss.

2.) In utero infection such as cytomegalovirus, rubella, syphillis, herpes and toxoplasmosis.

3.) Craniofacial anomalies including those with morphological abnormalities of the pinna and ear canal.

4.) Birth weight less than 1,500 grams (3.3 lbs).

5.) Hyperbilirubinemia at a serum level requiring exchange transfusion.

6.) Ototoxic medications, including but not limited to the aminoglycosides, used in multiple courses or in combination with loop diuretics.

7.) Bacterial meningitis.

8.) Apgar scores of 0-4 at 1 minutes or 0 to 6 at 5 minutes

9.) Mechanical ventilation lasting 5 days or longer.

10) Stigmata or other findings associated with a syndrome known to include a sensorineural and / or conductive hearing loss.

2. Instrumentations

The instrumentations used in this research are the following:

1. Otoscope
2. Auditory brainstem response Instrument- Smart EP with bone vibrator (B-71) and insert earphone (ER-3A).
3. Electrode cup (Approximately 0.6 cm.in diameter).
4. Elastic band
5. Spring – scale
6. The OAEs ILO 292 DP Echoport version 5 Otodynamic

3. Procedures

All subjects were tested in the quite room while they were in natural sleep. Three electrodes consisted of one (noninverting) attached to the high forehead (Fz); one (inverting) was attached to the stimulus earlobe (Ai); one (common) was attached to the opposite earlobe (Gnd). The electrodes were placed in the electrode plugs located on the top cover of the Opti-Amp transmitter box. The sites at which the electrodes were to be placed must be cleaned and prepared for placement using alcohol 70% or other solution for reducing skin impedance. An electrolyte cement was applied to improve the conductivity of the skin, to give contact stability, and to effectively increase the electrodes surface area. The electrodes were hold in place with medical tape. The bone vibrator was placed in a superoposterior auricular area . The one held in place with an elastic band (2.5x40 cm.). The elastic band was adjusted to apply a vibrator to head coupling force 425±25 grams. The coupling force was measured with a hand-held spring scale. The interelectrode impedance for any pair of electrodes checking was done and maintained below 7 kohm. The recorded electroencephalograph (EEG) samples that exceeded ±25 μV were rejected.

The Smart EP was used to record the subjects's ABR responses. The clicks stimuli were presented at a rate of 7.1 per second. The filter setting was 30 to 3,000 Hz. The polarity of the clicks was alternating. The parameter was set according to BC-ABR protocol in the Audiologist's desk reference (71). The test started at the intensity of 50 dBnHL and continuing down to threshold. The level was decreased in 10 dB steps until a response was no longer evident, at which time it was increased by 5 dB and one final measurement was taken. BC-ABR in normal hearing was tested. During recordings of ABRs to bone conduction, contralateral air-conducted broad band noise masking at 50 dB was employed via insert earphone. Threshold was arbitrarily defined as the lowest level at which a response replicated in both runs of 2,048 sweeps and wave V latency was measured for each condition at which a response was evident. The responses were stored on disk and printed on paper for later analysis. Wave I and wave

V latencies were identified by two advisors and the researcher. The final agreement was based on the decision made by two examiners.

However, all subjects were tested in the quite room while they were in natural sleep. Therefore, the testing time for each subject was average at 1-2 hours.

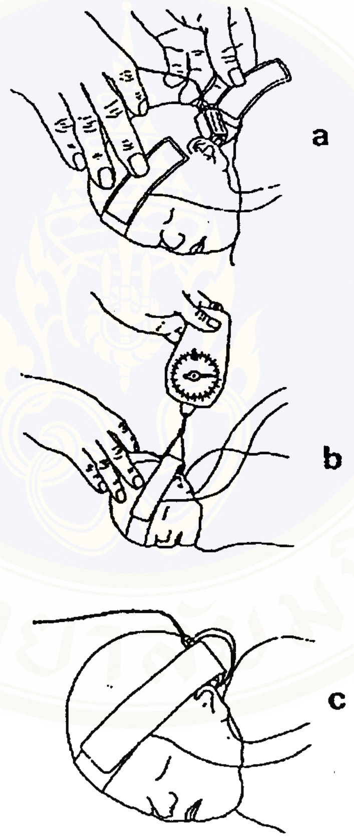


Figure 13 Procedures for bone-conduction oscillator placement in neonates. Step a, placement of oscillator, held in place with an elastic band; step b, measurement of coupling force with a spring-scale; step c, close-up of oscillator placement and headband (65).

4. Measurement

The measurement of ABR response were as followed:

4.1 Thresholds to bone-conducted clicks.

4.2 Wave I and wave V latencies to bone-conducted clicks were obtained by measuring the peak of each waveform.

5. Data analysis

The following statistical methods were employed to analyze the obtained data:

1. Means and Standard deviations (SD) of ABR thresholds, wave I and wave V latencies were used.
2. Anova (Analysis of varience) was used to compare differences in BC-ABR thresholds, wave I and wave V latencies. The analysis was based on these factors
    - Groups (male and female).
    - Intensity (30, 40, 50 dBnHL).
3. The t-test was used to determine the differences of the mean between female and male newborns, and between right and left ears of newborn subjects.
4. The Sheffe's test was used to calculate the means of wave I and wave V latencies in each intensity.

CHAPTER IV

RESULTS

The purpose of this research was to study the normative characteristics of Auditory Brainstem Response to bone- conduction in normal newborns. The experiment was conducted in both ears of 30 full term newborn subjects. There were 15 males and 15 females. The gestational age for the male group was 38.60 weeks and the standard deviation was 0.62, and for the female group was 38.67 weeks and standard deviation was 0.71. The birth weight for the male group was 3,162.00 grams and standard deviation was 201.35, and for the female group was 3,214.67 grams and standard deviation was 235.24. The Smart-EP was used to record the subject's ABR responses. The clicks stimuli were presented at the rate of 7.1 per second. The filter setting of the clicks was 30 to 3,000 Hz. The polarity was alternating. The test started at the intensity of 50 dBnHL and attenuated at 10 dB step until the ABR threshold was reached. The time window was 10 milliseconds. The raw data of latencies of various waves were shown in the Appendix (Table A-1 to A-3).

1. The waveform morphology when ABR to bone- conduction was used.

From this study, the morphology of BC- ABR, wave I and wave V were illustrated in Figure 14.

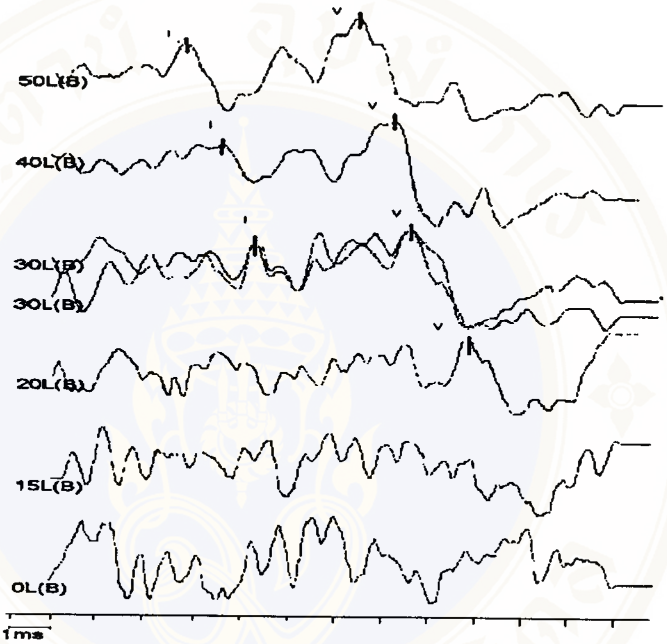


Figure 14 The example of one newborn subject recording of Bone-conduction ABR to clicks from 50 dBnHL down to thresholds.

From this study, the results showed that the signal intensity had the effects on the latency of Bone- conduction ABR. A decrease in signal intensity was accompanied by a lengthening of latency of brainstem potential for all subjects.

The percentage of all normal newborn subjects demonstrating an identifiable wave I and wave V at various presentation levels were shown in Table 2.

Table 2 Percentage of wave I and wave V of all subjects demonstrating identifiable waveform components of the BC-ABR

Intensity	Wave I		Wave V	
(dBnHL)	N (ears)	Percent (%)	N (ears)	Percent (%)
50	60	100	60	100
40	60	100	60	100
30	60	100	60	100
25	0	0	24	40
20	0	0	9	15

The results showed that wave I and wave V were presented in all subjects at the three intensity levels (50, 40, 30 dBnHL). However, wave I was absent when the intensity at 25 dBnHL was used, while wave V was still presented in 40 percent at 25 dBnHL, and in only 15 percent at 20 dBnHL.

2. BC-ABR threshold

The percentage of BC-ABR threshold in newborn subject groups were presented in Table 3

Table 3 The distribution of percentage of BC-ABR threshold by different intensity.

ABR threshold (dBnHL)	N (ears)	Percent(%)
30	27	45
25	24	40
20	9	15
Total	60	100

The results showed that 45 percents of newborn subjects exhibited BC- ABR threshold at 30 dBnHL, 40 percents at 25 dBnHL and 15 percents at 20 dBnHL, respectively. In addition, the mean BC- ABR threshold in this study were 26.92 (± 3.46) dBnHL.

The comparison of mean BC-ABR threshold of female and male newborn subject groups were presented in Table 4.

Table 4 The comparison of mean BC-ABR threshold in dBnHL between female and male subject groups.

N(ears)	Gender				t	P-value
	Female		Male			
	Mean	SD	Mean	SD		
60	25.67	3.65	27.33	3.41	-1.828	.073

In female group, the mean of BC-ABR threshold was lesser than that of the male group (25.67 dBnHL and 27.33 dBnHL, respectively). However, this difference was not statistically significant ($p > 0.05$)

Table 5 The comparison of BC-ABR threshold between right and left ears.

N (ears)	Ears				t	P-value
	Right		Left			
	Mean	SD	Mean	SD		
60	26.17	3.87	26.83	3.34	.714	.478

$p > 0.05$

The statistical analysis, a t-test for independent samples was used when a comparison between right and left ears. The results showed no statistically significant difference in BC-ABR threshold attributable to ear difference.

3. Absolute latencies

The mean values of wave I and wave V latencies at 50, 40 and 30 dBnHL and standard deviation were summarized in Table 6.

Table 6 Showed Mean and standard deviation of wave I and wave V latencies (msec) at 50, 40 and 30 dBnHL.

Wave	Intensity (dBnHL)	Absolute latency (msec)	
		Mean	SD
I	50	2.6815	.3031
	40	3.2895	.3098
	30	4.2785	.3152
V	50	7.9705	.3047
	40	8.8187	.3239
	30	9.9762	.3294

The mean latency of both wave I and wave V at 50 dBnHL were the shortest when comparing with the mean latencies of wave I and wave V at 40 and 30 dBnHL, respectively. Therefore, the results showed that when the intensity decreased the latency increased.

4. The absolute latencies of wave I and wave V at 50, 40, 30 dBnHL of female and male subjects.

The analysis of variance was used to compare BC-ABR latencies of wave I, intensity and gender as showed in Table 7.

Table 7 Analysis of variance for wave I latency

Source of Variation	Sum of Squares	DF	Mean Square	F	Sig of F
Main Effects	80.720	3	26.907	288.443	.000*
Intensity (50,40,30 dBnHL)	80.224	2	40.112	430.006	.000***
Gender	.496	1	.496	.915	.339
2-way Interactions	.001	2	.001	.008	.992
(Intensity-Sex)	.001	2	.001	.008	.992
Explained	80.721	5	16.144	173.069	.000***
Residual	16.231	174	.093		
Total	96.953	179	.542		

* Significant at the 0.05 level

*** Significant at the 0.001 level

The analysis revealed that wave I latencies from each pair of intensity differed significantly (F=430.006, DF=2, $p \leq 0.001$). Therefore, to determined which specific means contributed to the significant difference, the Sheffe's test was used to calculate the means of wave I latency in each intensity. The results were shown in Table 8.

Table 8 The mean difference of wave I latency in each intensity (50, 40, 30 dBnHL).

Intensity level (dBnHL)	Mean difference of wave I		
	50	40	30
50	-	.6080	1.6187
40		-	1.0107
30			-

$P \leq 0.05$

The results showed that the BC- ABR latency of wave I in each intensity were statistical significant difference ($p \leq 0.05$).

However, similar of wave I, analysis of variance for BC- ABR latency of wave V, intensity and gender were also calculated. The results were shown in Table 9 and the mean latencies difference of wave V were shown in Table 10.

Table 9 Analysis of variance for wave V latency

Source of Variation	Sum of Squares	DF	Mean Square	F	Sig of F
Main Effects	122.094	3	40.698	387.405	.000*
Intensity (50,40,30 dBnHL)	121.638	2	60.819	575.941	.000***
Gender	.456	1	.456	0.579	.447
2-way Interactions	.031	2	.061	.148	.863
(Intensity-Sex)	.031	2	.061	.148	.863
Explained	122.125	5	24.425	231.301	.000*
Residual	18.374	174	.106		
Total	140.499	179	.785		

* Significant at the 0.05 level

*** Significant at the 0.001 level

The results showed a significantly different effect of wave V for each pair of intensity (F=575.949, DF=2, p≤0.001). Therefore, to determined which specific means contributed to the significant difference, the Sheffe's test was used to calculate the means of wave V latency in each intensity. The results were shown in Table 10.

Table 10 The mean difference of wave V latency in each intensity (50, 40, 30 dBnHL).

Intensity level (dBnHL)	Mean difference of wave V 50	 40	 30
50	-	.8482	2.0057
40		-	1.1575
30			-

$P \leq 0.05$

In the Table 10, the results showed that the latency of wave V at intensity, 50 dBnHL was significantly different from those at 40 and 30 dBnHL.

Figure 15 showed the relationship between the absolute latency and the intensity of both wave I and wave V (Latency-Intensity Function).

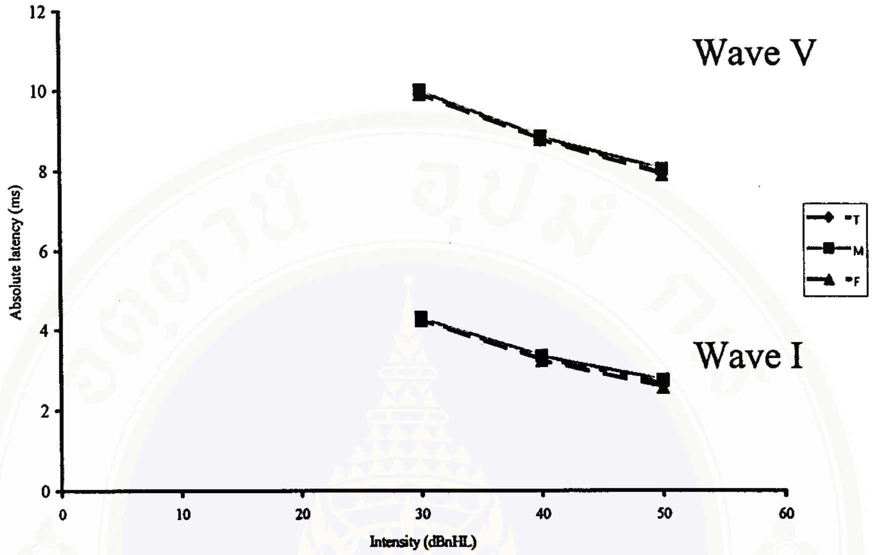


Figure 15 The relationship between the absolute latency and the intensity of wave I and wave V (Latency-Intensity Function).

Based on the 3 intensity levels (50, 40, and 30 dBnHL), the effect of intensity on latency change is larger for low intensity than for high intensity. For example, in the Table 8, when the intensity decreased from 50 dBnHL to 40 dBnHL, the latency level of wave I increased to .6080 ms; while the intensity decreased from 40 to 30 dBnHL, the latency level of wave I increased to 1.0107 ms. In addition, when the intensity decreased from 50 dBnHL to 40 dBnHL, the latency level of wave V increased to .8482 ms, and when the intensity decreased from 40 to 30 dBnHL, the latency increased to 1.1575 ms. From this study, the relationship of wave I and wave V latency- intensity functions were non-linearity.

5. The comparison of absolute latencies of wave I and Wave V at 50, 40, 30 dBnHL between female and male groups.

The results were showed in Table 11.

Table 11 The comparison of absolute latency of wave I and V at 50, 40, 30 dBnHL between female and male newborns subject groups.

Intensity (dBnHL)	Wave	Gender	N (ears)	Mean	SD	t	P-value
50	I	Female	30	2.2623	.2979	-1.422	.160
		Male	30	2.7367	.3031		
	V	Female	30	7.9047	.2983	-1.700	.094
		Male	30	8.0363	.3201		
40	I	Female	30	3.2357	.2899	-1.490	.142
		Male	30	3.3433	.3149		
	V	Female	30	8.7850	.3427	-0.755	.453
		Male	30	8.8523	.3477		
30	I	Female	30	4.2517	.3255	-0.656	.514
		Male	30	4.3053	.3608		
	V	Female	30	9.9247	.3127	-1.216	.229
		Male	30	10.0277	.3428		

$P > 0.05$

The results showed that there were no significant difference of both wave I and wave V latency in each intensity between female and male subjects ($P > 0.05$).

6. The comparison of absolute latencies of wave I and Wave V at 50, 40, 30 dBnHL between right and left ears.

The results were shown in Figure 12.

Table 12 The comparison of absolute latency of wave I and V at 50, 40, 30 dBnHL between right and left ears.

Intensity (dBnHL)	Wave	Ear	N (ears)	Mean	SD	t	P-value
50	I	Right	30	2.6787	.3118	-.072	.943
		Left	30	2.6843	.3094		
	V	Right	30	7.9530	.3010	-.442	.660
		Left	30	7.9880	.3167		
40	I	Right	30	3.3237	.3053	-.875	.354
		Left	30	3.2553	.3209		
	V	Right	30	8.7827	.3424	-.808	.422
		Left	30	8.8547	.3374		
30	I	Right	30	4.3237	.3405	-.223	.371
		Left	30	4.2333	.3041		
	V	Right	30	9.9343	.3093	-.983	.330
		Left	30	10.0180	.3573		

$P > 0.05$

The results showed that there were no significant difference of both wave I and wave V latency in each intensity between right and left ears ($P > 0.05$).

CHAPTER V

DISCUSSION

The study was conducted to establish the normative characteristics of hearing in 30 normal newborn subjects by using the Auditory Brainstem Response to bone-conducted clicks (BC-ABR). The hypotheses in this study were emphasized on the morphology, BC- ABR threshold and the absolute latencies of wave I and wave V.

1. The waveform morphology

An example of BC- ABR waveform in this study was illustrated in Figure 14 (Page 60). Both of wave I and wave V were presented in all subjects at 50, 40, and 30 dBnHL. However, wave I was absent when the lower intensity was used (≤ 25 dBnHL), while wave V was still present in 40 percent at 25 dBnHL and in only 15 percent at 20 dBnHL.

From this study, the morphology of BC- ABR was similar to other studies Yang EY, Stuart A, Mencher GT, Mencher LS, and Vincer MJ (21), Stuart A, Yang EY, and Green WB (47), Stuart A and Yang EY (48), Stuart A, Yang EY Stenstrom R and Reindorp AG (62), Tucci DL, Ruth RA, Lambert PR (67), Kramer SJ (138). In the higher intensity stimulation, the morphology was clearer than the lower intensity. Generally, changes in ABR morphology were directly affected by subject characteristics such as; physical status, age, maturation, pathology (47, 62, 91, 94, 99, 105, 109, 113), stimulus and recording parameters used in testing (37, 49, 93, 99, 105).

However, the difference of the percentage of presentation of wave I and wave V were possibly due to different subjects, instrumentation, and the testing method such as; filter setting or other (67, 138). In addition, the findings of this study indicated that the waveform morphology of BC- ABR was effected by changes in the stimulus intensity, and wave I was among the first components to disappear as stimulus intensity was reduced, whereas wave V persists the longest. Also, wave V was usually the last wave to disappear when the stimulus intensity was decreased (37, 53, 77).

Accurate clinical decisions must be based on a knowledge and understanding of normal response variability. As the results, it is necessary for the audiology unit to have its own normative data for determining cochlear reserve.

2. BC- ABR threshold

The results in this study showed that 85 percent of subjects exhibited BC- ABR threshold at 25 – 30 dBnHL, and only 15 percent exhibited BC- ABR threshold at 20 dBnHL. In addition, the mean BC- ABR threshold in this study were 26.92 (± 3.46) dBnHL.

The finding in this study was similar to others. A number of investigators have been reported the threshold of ABR to bone conducted stimuli (44, 57, 59, 63, 64, 65, 66, 67, 68, 133, 138). However, the difference of the percentage of BC-ABR threshold was possible due to; age difference (47, 62, 82, 91, 94, 99, 105, 106, 111), differences of the stimulus factors (44, 49, 68, 93, 99), bone vibrator placement (61, 63, 64, 126, 133), and test environment (72, 85).

The comparison of BC- ABR threshold between female and male were studied. The results in this study showed that the mean of BC- ABR threshold in female was lesser than male (25.67 and 27.33 dBnHL, respectively). However, this difference was not statistically significant ($p > 0.05$).

There was very little information regarding gender in early infancy or childhood. In BC- ABR testing, Sininger et al. studied hearing threshold in human neonates. The results showed better BC- ABR thresholds for male newborns (2). In contrast, Cone- Wesson and Ramirez reported that there were no significant difference in BC- ABR threshold between gender and ear differences (13). In adult, some researchers reported that there were differences in the central conduction time, growth rate of central nervous system, actual brain size between male and female (35, 114) or may be because of temperature (115) or hormonal effect (72). On the other hand, there were several studies showed that gender was not a significant factor in ABR measurement in newborn (72, 75, 92, 99). It was possible due to; the same age group of subject, or the neonatal brainstem is not completely myelinated (2, 44, 47, 61, 62, 63, 64, 113, 126, 132, 133). In addition, they still have no head size different and/ or they may not have the effects from hormones (5, 6)

The comparison of right and left ears were studied. A significant difference was not observed in mean ABR threshold to bone conducted between ears difference in this study.

Ear differences for sensitivity have received little attention in the literature, even though the brain has definite structural and functional asymmetries (72, 111). There have been no anatomic studies of right ear and left ear differences for either the conductive or sensorineural mechanism that could help account for ear asymmetries in sensitivity. Burns et al. suggests that such anatomic asymmetries exist. The effect of such anatomic or functional differences on ABR threshold estimates is unknown (13, 72, 111).

3. Absolute latencies

The mean latency of wave I at 50, 40, and 30 dBnHL were 2.6815 (± .3031), 3.2895 (± .3098), and 4.2785 (± .3152), respectively. In addition, the mean latency of wave V at 50, 40, and 30 dBnHL were 7.9705 (± .3047), 8.8187 (± .3239), and 9.9762 (± .3294), respectively. As expected, both wave I and wave V latencies decreased as intensity increased.

The results in this study were similar to those of other studies (40, 44, 47, 48). The pattern of the finding indicated that in lower intensity, BC- ABR gave longer latencies than in higher intensity. However, the mean latency in each intensity were different from other's. Latency of the ABR is effected by a number of variables, most notably, development of the auditory system and stimulus intensity. The latency of wave V represents the sum of a peripheral transmission time (from stimulus onset to cochlear nerve) and a central transmission time (from the cochlear nerve to higher brainstem) which is mature at different rates in the infant (72, 75). The peripheral time is determined by middle ear function, cochlear mechanics (travelling wave time), cochlear transduction, synaptic and cochlear nerve fiber conduction velocity. The central time is associated with fiber conduction velocity and synaptic transmission of brainstem tracts and nuclei. The fact that, in neonates and infants the latency of wave V was longer than in adults has been thought to be related to the incomplete development of the infant's auditory apparatus (46, 86, 103). The neonatal brainstem is not completely myelinated until 1 year (2, 72). This immaturity would depend on a relative inefficiency in the energy transmission of the middle ear, an inefficient cochlear transduction, a low nerve conduction velocity associated with incomplete myelination and/ or poor synaptic efficiency of the cochlear nerve and brainstem tracts and nuclei (75). The absolute latencies of all waves increase with decreasing stimulus intensity (72). Picton et al. (45) found that at the high intensity, ABR waveforms were definable, but at low intensity wave I and wave III tended to disappear while wave V remain with reduced amplitude and prolonged latencies. In addition, they suggested when stimulus intensity is decreased, the neurons were less responsive (72).

Therefore, the latency of the BC- ABR is affected by a number of variables, most notably, development of the auditory system and stimulus intensity. These latency values are extremely variable and change as a function until about 18 to 24 months of age (47, 62, 72, 91, 94, 99, 105, 113). In general, latencies reduce with increasing age although the rate of decrease is dependent on both the specific wave (e.g., peripheral or central site of generation) and physiologic condition (e.g., synaptic efficiency, myelination, dipole orientation). Behavior of mean latencies as a function of signal frequency and intensity is similar to previous reported on the whole nerve action potential. Technical aspects will also affect the ABR recording. Factors include bone vibrators placement (61, 131, 132, 133, 134), hearing status (96, 106, 107), stimulus polarity (72, 77, 98, 123), rate (77, 98, 103, 113), filtering characteristics (5, 51, 122, 126, 139) and stimuli (37, 49, 105), all of which may influence the latency of the brainstem response.

As the results, it is necessary for the audiology unit to have its own normative data for determining cochlear reserve.

Latency- Intensity Function

As showed in Table 7 and 9 (Page 65 and 67, respectively), the absolute latencies of wave I and wave V at 50, 40, and 30 dBnHL were significant difference ($p \leq 0.001$). Therefore, signal intensity had significant effects on the latency of BC-ABR.

From this study, the results showed that when the intensity decreased, the latencies of both wave I and wave V were increased. Based on the three intensity levels (50, 40, and 30 dBnHL), the effect of intensity on latency change was larger for low intensity than for high intensity. The intensity decreased from 50 dBnHL to 40 dBnHL, the latency level of wave I increased to .6080 ms; while the intensity decreased from 40 to 30 dBnHL, the latency level of wave I increased to 1.0107 ms. In addition, when the intensity decreased from 50 dBnHL to 40 dBnHL, the latency of wave V increased to .8482 ms, and when the intensity decreased from 40 to 30 dBnHL, the latency increased to 1.1575 ms. From this relationship, as showed in Figure 15 (Page 69), wave I and wave V latency- intensity functions were non-linear.

As with all sensory evoked responses, both amplitude and latency of the ABR are influenced by changes in signal intensity. This concomitant decrease in response voltage and increase in absolute latency in proportion to intensity reduction forms the basis of the latency-intensity series. On the average in the normal ear, wave I and wave V latencies increase, owing to the more apical spread of cochlear excitation and thus increased traveling wave time as intensity decreases (72).

4. The comparison of absolute latencies of wave I and wave V at 50, 40, and 30 dBnHL between female and male subjects.

The results showed that there were no significant difference of both wave I and wave V latencies in each intensity between female and male newborn subjects (P > 0.05).

There were very little information regarding wave I and wave V latencies between female and male in early infancy or childhood. However, Cone- Wesson and Ramirez reported that there were no significant differences in wave V latency attributable to gender at all levels of stimulation (13).

In adult, females have larger ABR amplitudes and shorter latencies compared to males (81, 82, 100). The shorter latencies and higher amplitudes are thought to be due to shorter cochlear length in females compared to males (83). That is, males have larger heads and, therefore, perhaps inherently longer neural pathways (causing longer conduction times) (13). In addition, in adults, the gender difference may be related to the hormonal difference but the exact mechanism of this effect is not clear. The issue of ABR gender differences in infancy and childhood, however, remains unresolved. The result of this studied found that gender did not affect BC- ABR latency. It was possible due to; age group of subject, or the neonatal brainstem is not completely myelinated (2, 44, 47, 61, 62, 63, 64, 113, 126, 132, 133). In addition, they still have no head size different and, they may not have the effects from hormones (5, 6). Other investigators found shorter latency in female versus male preterm infant but the differences were small and inconsistent in comparison to the striking gender effect for adults (6).

5. The comparison of absolute latencies of wave I and wave V at 50, 40, and 30 dBnHL between right and left ears.

From this study, the results showed that there were no significant difference of both wave I and wave V latencies in each intensity between right and left ears of newborn subjects ($P > 0.05$).

There was no information regarding wave I latency between right and left ears in newborn subjects. In addition, there was very little information regarding wave V latency between right and left ears. However, the finding in this study was similar to those of Cone-Wesson and Ramirez studied. They reported that there were no significant differences in wave V latency attributable to ear differences at all levels of stimulation (13). There have been no anatomic studies of right ear versus left ear that could help account for ear asymmetries in sensitivity (80). In addition, ear differences for sensitivity have received little attention in the literature, even though the brain has definite structural and functional asymmetries (13, 80).

CHAPTER VI

CONCLUSION

Audiological evaluation by BC- ABR is one of the most important method for hearing evaluation. In this study, the experiment was conducted in both ears of 30 normal newborn subjects whose the age ranged from 48-72 hours. The birth weight was 3,188 (± 218.70) grams. The clicks stimuli were presented at the rate of 7.1 per second. The bandpass of the clicks was 30 to 3,000 Hz with alternating polarity. Three electrodes consisted of one (noninverting) attached to the high forehead (Fz); one (inverting) was attached to the stimulus earlobe (Ai); and one (common) was attached to the opposite earlobe (Gnd). The bone vibrator was placed in a superoposterior auricular area . The one held in place with an elastic band (2.5x40 cm.). The elastic band was adjusted to apply a vibrator to head coupling force 425±25 grams. The coupling force was measured with a hand-held spring scale. Normative data was obtained with statistical analysis. Results were concluded as follow:

1. The waveform morphology of BC- ABR was similar to AC- ABR (as showed in Figure 14 (Page 60). In the higher intensity stimulation, the morphology was clearer than the lower intensity.
2. The mean BC- ABR threshold in newborns were 26.92 (± 3.46) dBnHL.
3. The comparison of BC- ABR threshold between female and male newborn subjects were not significant difference ($p > 0.05$).

4. The comparison of BC- ABR threshold between right and left ears of newborn subjects were not significant difference ($p > 0.05$).
5. The mean latencies of wave I at 50, 40, and 30 dBnHL were 2.6815 (± .3031), 3.2895 (± .3098), and 4.2785 (± .3152), respectively.
6. The mean latencies of wave V at 50, 40, and 30 dBnHL were 7.9705 (± .3047), 8.8187 (± .3239), and 9.9762 (± .3294), respectively.
7. The comparison of the mean latencies of wave I and wave V between female and male newborn subjects in each intensity were not significant difference ($p > 0.05$).
8. The comparison of the mean latencies of wave I and wave V between right and left ears of newborn subjects in each intensity were not significant difference ($p > 0.05$).
9. The signal intensity had significant effects on the latency of BC- ABR and the effect of intensity on latency change was larger for low intensity than for high intensity. In addition, the relationship of wave I and wave V latency- intensity functions were non- linear.

Recommendations

From the results of this study, some recommendations and future research are suggested as follow:

1. Further BC- ABR studies are recommended in subjects with congenital atresia, or other aural deformities and in subjects with different age groups.
2. There are still limitations in the use of BC- ABR. It is recommended that BC oscillator output should not exceed 55 dBnHL, limiting accurate assessment to patients with no more than a moderate cochlear loss.

3. The presence of a stimulus artifact as a result of electromagnetic energy radiating from bone vibrator, which may obscure definition of ABR peak, particularly wave I. To minimize this problem, it is recommended that (a) used earlobe electrodes instead of mastoid placement, and (b) alternating polarity BC clicks as recommended by Hall (1992).
4. Masking the ear contralateral to the test ear is recommended.
5. It is recommended that the coupling force (approximately 400- 450 grams) be controlled and remain consistent when implementing ABR to bone conducted stimuli in newborn infants.

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APPENDIX

Table A- 1

Female	Absolute Latency					
	50 dBnHL		40 dBnHL		30 dBnHL	
	Wave I	Wave V	Wave I	Wave V	Wave I	Wave V
F1R	2.4	7.82	3.22	8.22	3.86	9.57
F1L	2.33	7.68	3.47	8.62	3.95	10.25
F2R	2.36	8.07	3.2	9	4.65	10.05
F2L	2.4	7.53	3.08	8.42	4.2	9.48
F3R	2.4	7.4	3.3	8.83	4.57	9.95
F3L	2.5	7.87	3.05	9.2	4.4	10.2
F4R	3.3	8.18	3.7	9.2	4.18	10
F4L	3.1	7.95	3.45	9	4.42	10
F5R	2.9	8.05	3.5	9.23	3.82	10.03
F5L	3.25	8.27	3.45	9.3	4.18	10.18
F6R	2.95	7.82	3.33	8.93	4.68	9.96
F6L	2.5	8.03	2.95	9.05	3.96	9.64
F7R	2.75	7.62	3.15	8.07	4.48	9.53
F7L	2.2	7.47	3.65	8.52	4.2	9.53
F8R	2.6	7.97	3.16	8.63	4.28	9.32
F8L	2.48	7.68	2.97	8.8	4.45	9.62
F9R	2.38	8.4	2.92	9	4.38	10.48
F9L	2.43	8.04	3.02	8.52	4.07	10.73
F10R	2.75	7.62	3.17	8.48	4.22	9.57
F10L	2.4	7.45	2.84	8.02	4.46	9.62
F11R	3.06	8.03	3.68	9.02	4.18	10
F11L	2.92	7.95	2.98	8.86	3.95	9.8
F12R	2.32	7.42	3.12	8.32	4.25	10.05
F12L	2.22	8.05	3.06	8.85	4.85	10.25
F13R	2.6	7.97	3	8.83	4.65	10
F13L	2.7	8.02	3.08	9.1	4.03	9.98
F14R	2.47	8.25	3.27	9.08	4.02	10.1
F14L	2.68	8.18	3.4	8.85	4.18	10
F15R	2.8	8.2	3.37	8.97	4.03	9.85
F15L	2.64	8.15	3.53	8.63	4	10
TOTAL	78.79	237.14	97.07	263.55	127.55	297.74

Table A- 2

Male	Absolute Latency					
	50 dBnHL		40 dBnHL		30 dBnHL	
	Wave I	Wave V	Wave I	Wave V	Wave I	Wave V
M1R	2.6	7.97	2.95	8.42	4.22	9.8
M1L	2.8	8.2	2.98	9.02	3.88	10.2
M2R	3.45	8.43	3.75	9.4	4.32	10.15
M2L	3.1	8.57	3.8	9.55	4.1	10.3
M3R	2.38	7.85	3.15	8.47	4.06	9.37
M3L	2.6	7.88	2.88	8.42	4.18	9.43
M4R	2.78	8.13	3.5	8.95	4.78	9.9
M4L	2.43	7.92	3.32	9.15	4.07	10.12
M5R	3.2	8.02	3.7	8.68	4.82	10.02
M5L	2.75	7.32	3.2	8.57	3.98	10.27
M6R	2.4	7.65	3.55	8.68	4	9.8
M6L	2.62	7.58	3.2	8.23	4.08	9.6
M7R	2.65	7.57	3.35	8.38	4.52	10
M7L	2.8	7.45	3.24	9	3.95	10.15
M8R	2.37	8.13	2.78	8.52	3.65	9.83
M8L	2.88	8.2	3.24	8.73	4.28	9.4
M9R	3.03	8.15	4	8.83	4.7	9.95
M9L	3.1	8.57	3.7	9.03	4.33	10.17
M10R	2.38	8.02	3.02	9	4.78	9.8
M10L	2.53	8.52	3.08	9.1	4.75	10.25
M11R	2.8	8.03	3.75	9.4	4.32	10.12
M11L	3.4	8.18	3.7	9.05	4.13	10.48
M12R	2.55	7.88	3.2	8.68	5.07	10.15
M12L	2.42	8.43	3.04	8.85	4.98	10.05
M13R	2.92	7.98	3.4	8.43	3.65	9.68
M13L	2.7	8.37	3.25	8.9	4.52	9.92
M14R	2.48	8.2	3.2	9.29	4.48	10.8
M14L	2.85	8.08	3.8	9.3	4.97	10.77
M15R	2.33	7.76	3.32	8.54	4.69	10.2
M15L	2.8	8.05	3.25	9	4.2	10.15
Total	82.1	241.09	100.3	265.57	130.46	300.83

Table A- 3

Female					Male				
No.	Day	Week	Weight	Thx	No.	Day	Week	Weight	Thx
F1R	2	38	2900	20	M1R	2	39	3480	30
F1L	2	38	2900	25	M1L	2	39	3480	25
F2R	2	39	3200	25	M2R	2	38	3300	25
F2L	2	39	3200	30	M2L	2	38	3300	30
F3R	2	40	3250	25	M3R	2	39	2780	30
F3L	2	40	3250	20	M3L	2	39	2780	30
F4R	2	38	2750	25	M4R	2	38	3150	25
F4L	2	38	2750	25	M4L	2	38	3150	25
F5R	2	38	3350	25	M5R	2	38	3200	30
F5L	2	38	3350	30	M5L	2	38	3200	30
F6R	2	38	3500	25	M6R	2	38	2850	30
F6L	2	38	3500	30	M6L	2	38	2850	30
F7R	2	39	3180	30	M7R	2	39	3450	30
F7L	2	39	3180	30	M7L	2	39	3450	30
F8R	2	38	3100	30	M8R	2	39	3000	25
F8L	2	38	3100	25	M8L	2	39	3000	20
F9R	2	39	3400	20	M9R	2	38	3150	30
F9L	2	39	3400	25	M9L	2	38	3150	25
F10R	2	39	3480	30	M10R	2	39	3100	30
F10L	2	39	3480	30	M10L	2	39	3100	30
F11R	2	38	3300	20	M11R	2	38	3210	20
F11L	2	38	3300	25	M11L	2	38	3210	25
F12R	2	40	3580	25	M12R	2	39	3200	25
F12L	2	40	3580	20	M12L	2	39	3200	30
F13R	2	38	3100	30	M13R	2	38	3060	25
F13L	2	38	3100	30	M13L	2	38	3060	20
F14R	2	39	3250	25	M14R	2	40	3450	30
F14L	2	39	3250	25	M14L	2	40	3450	30
F15R	2	39	2880	20	M15R	2	39	3050	25
F15L	2	39	2880	25	M15L	2	39	3050	30
Total	60	1160	96440	770	Total	60	1158	94860	845

BIOGRAPHY

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