CLICK EVOKED OTOACOUSTIC EMISSIONS AND DISTORTION PRODUCT IN FULL TERM NEONATES

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Click evoked otoacoustic emissions (CEOAEs) and distortion product (DPOAEs) are generated within the inner ear by an active, nonlinear process underlying the sensitivity and selectivity mechanism of the cochlea. They can help assess the functional condition of the cochlea and preferable for hearing screening in neonates. The close correlation between CEOAEs and DPOAEs was found. In general when one type of OAEs is present the other would be also. The purpose of this study was to investigate the characteristics of CEOAEs and DPOAEs in full term neonates that were focused on ear side and gender difference. The correlation between CEOAEs and DPOAEs from the same ear of full term neonates was also investigated.

The CEOAEs and DPOAEs were measured in 44 full term neonates, 22 of which were males (44 ears) and 22 females (44 ears), and the mean ages were 5.68 days and 3.59 days for male and female subjects, respectively. The results indicated that the overall CEOAEs response and the SNR at 1-4 kHz did not show a significant difference between ear side and between genders. The DPOAEs SNR in the right were greater than left ears at all frequencies tested. However, a significant difference occurred at 2 and 4 kHz. These were considered as less significant for clinical application, especially, for hearing screening. In addition, the DPOAEs SNR at 1-6 kHz did not show a significant difference between genders. The results of this study confirmed the correlation between CEOAEs and DPOAEs in the same ear at 1.5-4 kHz. However, the correlation did not exist at 1 kHz, which might be due to high noise level in some subjects that obscured the CEOAEs and DPOAEs response. This study found that both CEOAEs and DPOAEs could be obtained from neonates without effect of ear side or gender, which allowed using data from all ears as a guideline for hearing screening or for clinical purposes.

However, this study showed a tendency that the CEOAEs and DPOAEs responses in the right were greater than in the left ears and in female than in male subjects. Further measurement by increasing the number of subjects and muti-variance analysis should be considered. Additionally, recording by using similar instrument, measurement parameters and criteria used to select the subjects should be considered too.

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รดา ดารา : การวัดเสียงสะท้อนจากหูชั้นในโดยใช้เสียงคลิ๊ก และ distortion product ในเด็กแรกเกิดที่ไม่มีภาวะเสี่ยงต่อการสูญเสียการได้ยิน (CLICK EVOKED OTOACOUSTIC EMISSIONS AND DISTORTION PRODUCT IN FULL TERM NEONATES) คณะกรรมการควบคุมวิทยานิพนธ์ : จันทร์ชัย เจรียงประเสริฐ, M.D.,M.Sc., ศิริพันธ์ ศรีวันยงค์, M.B.A.,M.Sc., อุไรรัตน์ สุบรรณวิลาส, M.Sc. 83 หน้า. ISBN 974-664-765-2

เสียงสะท้อนจากหูชั้นในโดยใช้เสียงคลิ๊ก (CEOAEs) และ distortion product (DPOAEs) เชื่อว่าเกิดขึ้นจากกระบวนภายในหูชั้นใน มีประโยชน์ในการช่วยประเมินสภาวะของหูชั้นใน เหมาะกับการตรวจการคัดกรองการได้ยินในเด็กแรกเกิด และพบว่า CEOAEs และ DPOAEs มีความสัมพันธ์กัน กล่าวคือ หากสามารถวัด CEOAEs ในหูข้างใด ก็จะตรวจพบ DPOAEs ด้วย วัตถุประสงค์ของการศึกษาในครั้งนี้เพื่อศึกษาลักษณะของ CEOAEs และ DPOAEs ในเด็กแรกเกิดที่ไม่มีภาวะเสี่ยงต่อการสูญเสียการได้ยิน โดยเปรียบเทียบขนาดของ CEOAEs และ DPOAES ในหูข้างซ้ายและหูข้างขวา และเปรียบเทียบในเพศชายและเพศหญิง และศึกษาความสัมพันธ์ระหว่างขนาดของ CEOAEs และ DPOAEs ในหูคนคนเดียวกัน ในการตรวจวัดเสียงสะท้อนจากหูชั้นใน ในเด็กแรกเกิดที่ไม่มีภาวะเสี่ยงต่อการสูญเสียการได้ยิน 44 คน แบ่งเป็นเพศชาย 22 คน (44 หู) อายุเฉลี่ย 5.68 วัน เพศหญิง 22 คน (44 หู) อายุเฉลี่ย 3.95 วัน ผลการศึกษาพบว่าระดับการตอบสนองของ CEOAEs และขนาดของ CEOAEs ที่ความถี่ 1- 4 kHz ในหูข้างซ้ายและหูข้างขวาและในเพศชายและเพศหญิงไม่มีความแตกต่างกันอย่างมีนัยสำคัญทางสถิติ ผลการศึกษาพบแนวโน้มว่าขนาดของ DPOAEs ในหูข้างขวามีขนาดใหญ่กว่าในหูข้างซ้าย แต่พบว่ามีความแตกต่างกันอย่างมีนัยสำคัญทางสถิติเฉพาะที่ความถี่ 2 และ 4 kHz และไม่พบว่ามีความแตกต่างที่ความถี่อื่น ซึ่งความแตกต่างที่พบนี้มีความสำคัญน้อยในการนำไปใช้ทางคลินิก และโดยเฉพาะเมื่อนำไปใช้ในการตรวจคัดกรองการได้ยิน ส่วนขนาดของ DPOAEs ที่ความถี่ 1- 6 kHz ในเพศชายและเพศหญิงพบว่าไม่มีความแตกต่างอย่างมีนัยสำคัญทางสถิติ ผลการศึกษาครั้งนี้พบว่าขนาดของ CEOAEs และ DPOAEs ในหูคนคนเดียวกันมีความสัมพันธ์กันที่ความถี่ 1.5 - 4 kHz ส่วนที่ความถี่ 1 kHz ไม่พบว่ามีความสัมพันธ์กัน อาจเนื่องมาจากเสียงที่เกิดขึ้นจากภายในตัวเด็กบดบังการตอบสนองของ CEOAEs และ DPOAEs การศึกษาครั้งนี้ไม่พบว่าความแตกต่างของหูและเพศมีผลต่อการตอบสนองของCEOAEs และ DPOAEs ในเด็กแรกเกิด ซึ่งผลการศึกษาครั้งนี้อาจนำไปใช้เป็นแนวทางในการตรวจคัดกรองการได้ยินหรือการนำไปใช้ทางคลินิก อย่างไรก็ตามผลการศึกษาครั้งนี้แสดงแนวโน้มว่า การตอบสนองของ CEOAEs และ DPOAEs ในหูข้างขวามีขนาดใหญ่กว่าหูข้างซ้ายและในเพศหญิงมีขนาดใหญ่กว่าเพศชาย การศึกษาครั้งต่อไปจึงควรพิจารณาถึง การเพิ่มจำนวนกลุ่มตัวอย่าง ใช้การวิเคราะห์ความแปรปรวนในการวิเคราะห์ข้อมูล นอกจากนี้เครื่องมือและตัวแปรที่ใช้ในการตรวจ รวมถึงเกณฑ์ในการคัดเลือกกลุ่มตัวอย่างควรมีการนำมาพิจารณาด้วย

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CHAPTER I

INTRODUCTION

Otoacoustic emissions (OAEs) are sounds that originate from the cochlea. They are believed to be produced by the active contraction of the outer hair cells in the organ of Corti (1). As a result of this motile activity, a pressure wave travels backward through the middle ear and can be recorded with a sensitive microphone in the auditory meatus. The otoacoustic emissions can be separated into spontaneous and evoked otoacoustic emissions (EOAEs). Spontaneous otoacoustic emissions (SOAEs) are sounds continuously emitted by the ear without external stimulation. They can be detected in about 50% of all ears with normal hearing (2). Evoked otoacoustic emissions occur in response to the presentation of acoustic stimuli to the ear. They can be usefully categorized into three different subtypes. Transient evoked otoacoustic emissions (TEOAEs) are evoked by acoustic transients such as click or tone burst. Stimulus frequency otoacoustic emissions (SFOAEs) are evoked by a single, continuous pure tone. Distortion product otoacoustic emissions (DPOAEs) are evoked by two simultaneous primary pure tones separated in frequency at f1 and f2 over a wide frequencies range between 0.5-8 kHz (3). These three types of evoked otoacoustic emissions are found in essentially all normal hearing ears (4).

Click evoked otoacoustic emissions (CEOAEs) measurement are considered as objective, noninvasive and easy to perform. With a click stimulus, CEOAEs can be evoked over a wide frequency range. Therefore, CEOAEs were used in hearing screening in neonates and infants by many researchers (4,5,6,7,8,9). They found that CEOAEs could be recorded in almost all ears of full term neonates and infants. The incidence of CEOAEs in neonates without any risk of hearing impairment was reported to be 90-100%. The typical frequency spectrum of the CEOAEs response in neonate is 0.5 to 5 kHz (5). The presence or absence of CEOAEs in this range may be indicative of the level of hearing (10).

The comparison of the CEOAEs and the auditory brainstem response (ABR) results in infants revealed that the CEOAEs were always present when the ABR wave V threshold is equal to or below 30 dBHL and always absent when the ABR wave V threshold has higher than 40 dBHL (7). CEOAEs in neonates using the Standard mode and the QuickScreen mode performed in hospital environment was reported (6). The QuickScreen mode increased the overall signal to noise ratio in frequencies above 1 kHz than the Standard mode. The CEOAEs recording could be performed easily prior to discharge. This suggested the ability of the QuickScreen mode to collect data quickly in noisy conditions for hospital based neonatal screening.

The effects of ear and gender for CEOAEs in full term neonates and infants were reported in previous studies (11,12,13). The CEOAEs amplitude, the reproducibility and the signal to noise ratio values in female were greater than male subjects, and similar results had been observed in the right than in left ears, respectively. The differences in CEOAEs measurements with regard to ear and gender were reflected in respective failure rates of infant ears (12) and possibly reflected the differences in efferent cochlear inhibition (13).

Although most of the OAEs data in neonates were click evoked otoacoustic emissions, distortion product otoacoustic emissions (DPOAEs) are considered as a clinical routine for the detection of hearing loss in neonates (3,9,14,15,16). The DPOAEs in neonates and adults were comparable in amplitude. However, the DPOAEs audiogram in neonates did not show a dip between 1 and 3 kHz and had higher amplitude than adults (9). The characteristics of DPOAEs audiogram in neonates were quite similar to those in adults. With two sharp peaks of maxima amplitude at f2 frequencies of 2 kHz and 5-6 kHz and a decline in DPOAEs amplitude in midfrequencies. This confirmed the limitations of DPOAEs recording for testing parts of the basilar membrane where the lower frequencies were coded (14).

Few comparative studies between CEOAEs and DPOAEs in neonates have been reported (17,18,19). The correlation existed between the half octave RMS of CEOAEs level and RMS DPOAEs levels in the same ear. An ear which exhibited high DPOAEs level also exhibited high CEOAEs level (19). All normal neonate ears had detectable CEOAEs and DPOAEs (17,18).

Because OAEs are noninvasive, easy to perform, objectively, and sensitive to cochlear status, the application of OAEs to pediatric populations have been proved to be an efficient test for screening hearing impairment; separating peripheral hearing loss and central auditory dysfunction and monitoring cochlear status in patient receiving ototoxic drugs (5,6,15,16,20). Both CEOAEs and DPOAEs are considered as frequency specific test of cochlear function (21) and are part of clinical routine (15,16). When combined both of these tests for the detection of auditory dysfunction in neonates, they will give additional information about the status of the cochlea (15).

This research was to study the overall CEOAEs amplitude, the CEOAEs signal to noise ratio , the DPOAEs signal to noise ratio and the correlation between CEOAEs amplitude and DPOAEs amplitude in full term neonates by using the ILO92 OAEs system.

1. Purpose of This Study

1. To compare the overall CEOAEs amplitude between the left and right ears of full term neonates.

2. To compare the overall CEOAEs amplitude between male and female full term neonates.

3. To compare the CEOAEs signal to noise ratio at half octave frequency bands between the left and right ears of full term neonates.

4. To compare the CEOAEs signal to noise ratio at half octave frequency bands between male and female full term neonates.

5. To compare the DPOAEs signal to noise ratio at different f2 (DP-gram) between the left and right ears of full term neonates.

6. To compare the DPOAEs signal to noise ratio at different f2 (DP-gram) between male and female full term neonates.

7. To study the correlation between the CEOAEs amplitude and the DPOAEs amplitude at half octave frequency bands in the same ear of full term neonates.

2. Research Questions of This study

This study intends to answer these following questions:

1. Was there any difference between the overall CEOAEs amplitude in the left and right ears of full term neonates?

2. Was there any difference between the overall CEOAEs amplitude in male and female full term neonates?

3. Was there any difference between the CEOAEs signal to noise ratio at half octave frequency bands in the left and right ears of full term neonates?

4. Was there any difference between the CEOAEs signal to noise ratio at half octave frequency bands in male and female full term neonates?

5. Was there any difference between the DPOAEs signal to noise ratio at different f2 (DP-gram) in the left and right ears of full term neonates?

6. Was there any difference between the DPOAEs signal to noise ratio at different f2 (DP-gram) in male and female full term neonates?

7. Was there any correlation existing between individual CEOAEs amplitude and DPOAEs amplitude at half octave frequency bands in the same ear of full term neonates?

3. The Advantages of This Research

1. This study will test the validity of CEOAEs and DPOAEs as an objective, noninvasive and frequency specific test of cochlear function that can be applied to neonates prior to discharge from the hospital.

2. This study will provide information of the overall CEOAEs amplitude, the CEOAEs signal to noise ratio, the DPOAEs signal to noise ratio and the correlation between CEOAEs amplitude and DPOAEs amplitude in full term neonates that may be used as a guideline for hearing screening or for clinical diagnosis.

List of Abbreviations

CEOAE(s)	click evoked otoacoustic emissions
dB	decibel
DP	distortion product
DPOAE(s)	distortion product otoacoustic emissions
EOAE(s)	evoked otoacoustic emissions
GM	geometric mean
Hz	Hertz (cycle per second)
ILO	Institute of Laryngology and Otology
min	minute
msec	millisecond
OAEs	otoacoustic emissions
RMS	root mean square
SD	standard deviation
SNR	signal to noise ratio
SOAE(s)	spontaneous otoacoustic emissions
SFOAE(s)	stimulus frequency otoacoustic emissions
SPL	sound pressure level
TEOAE(s)	transiently evoked otoacoustic emissions
FFT	fast Fourier transformations
OHC(s)	outer hair cell
IHC(s)	inner hair cell

CHAPTER II

LITERATURE REVIEW

This chapter presented some of the basic anatomy and physiology of the cochlea. The basic characteristics of click evoked otoacoustic emissions (CEOAEs), distortion product otoacoustic emissions (DPOAEs) and the correlation between CEOAEs and DPOAEs in neonates were focused. The use of CEOAEs and DPOAEs for the detection of auditory dysfunction in this population has also been reviewed.

1. The anatomy and physiology of the cochlea

1.1 The cochlea

The cochlea consists of a bony tube that spirals around to form a snail-like structure. The tube is subdivided into three parallel fluid filled chambers, scala vestibuli, scala media and scala tympani. The apical end of scala vestibuli is connected to scala tympani via a small opening called helicotrema. The scala vestibuli and scala tympani are filled with a fluid called perilymph, containing high concentration of sodium and low concentration of potassium. The middle chamber is scala media and is filled with endolymph, high in potassium and a low in sodium. The scala media is separated from scala vestibuli by Reissner's membrane and from scala tympani by the basilar membrane (Figure 1).

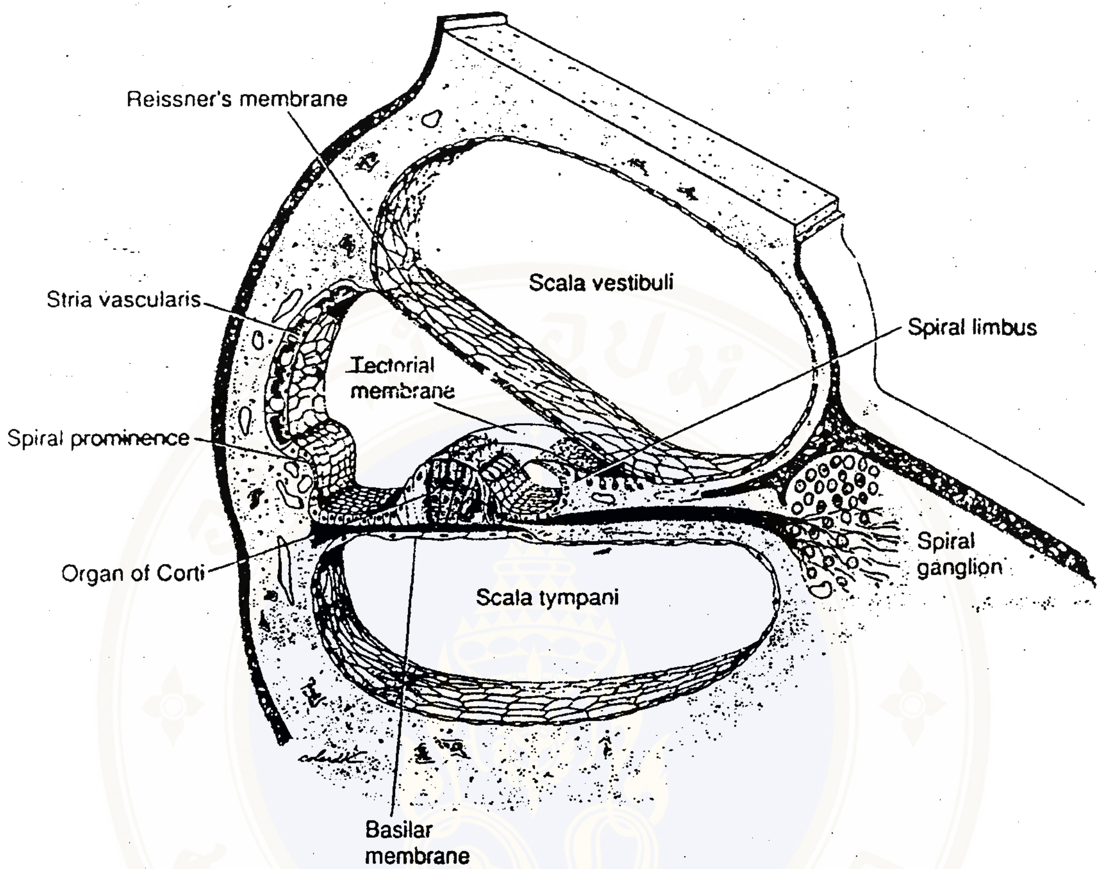

Figure 1. Cross-section of the cochlea showing the three scalae and associated structures (22)

1.2 The organ of Corti

The sense organ responsive to acoustic energy is located on the basilar membrane and is called the organ of Corti. The organ of Corti attaches to the osseous spiral lamina medially and to the spiral ligament laterally. The organ of Corti is covered by a gelatinous flap called the tectorial membrane. It attaches only on its inner edge to the spiral limbus. The sensory cells are hair cells consisting several stereocilia on their top surface. There are approximately 3500 inner hair cells (IHCs) and 12000 outer hair cells (OHCs). The IHCs are flask shaped and contain a centrally located nucleus. They are aligned in a single row just medial to the inner pillar cells. While the OHCs are cylindrically shaped with a nucleus near the base and are aligned in three rows lateral to the outer pillar cells and are supported from beneath by Deiters' cell (22,40,41,42,43). The stereocilia of the OHCs are firmly embedded within the tectorial membrane. While the stereocilia of the IHCs are not embedded but rest in a groove on the undersurface of the tectorial membrane called Hensen's stripe (Figure 2).

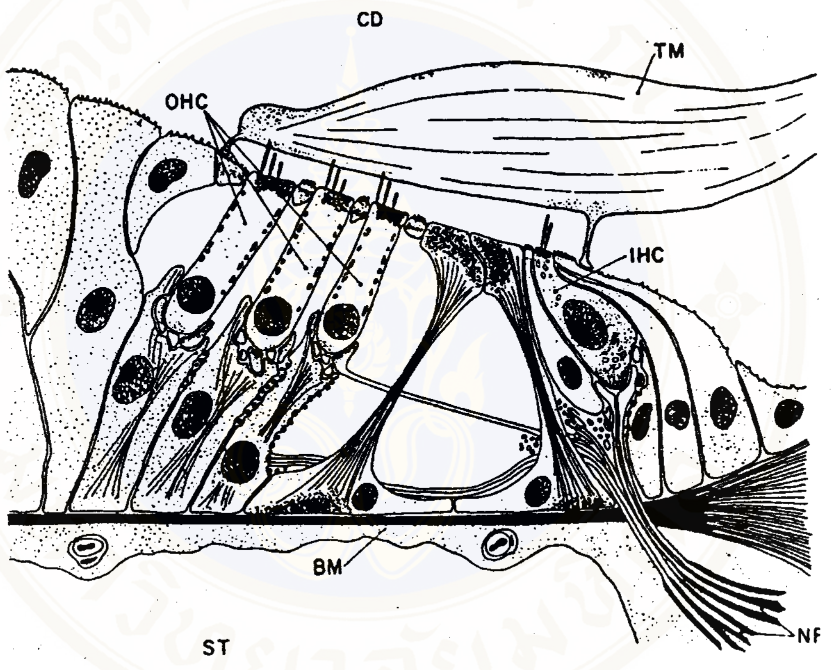

Figure 2. Cross section of the organ of Corti, showing the tectorial membrane (TM), the inner hair cell (IHC), the outer hair cells (OHC). The stereocilia of the outer hair cells are firmly embedded within the tectorial membrane ,while the stereocilia of the IHCs are not embedded (From Ryan and Dallos) (23)

Auditory neurons synapse with the basal portions of both inner and outer hair cells. Approximately 90 to 95 % of the afferent fibers (Type I fibers) connect directly with IHCs, each inner hair cell receiving about 20 fibers. The remaining afferent fibers (Type II fibers) 5-10 % synapse with the outer hair cells, each fiber synapsing with about 10 hair cells. (Figure 3). Auditory efferent fibers synapse with OHCs directly and terminate on the dendrites of afferent fibers innervating the IHCs (24,25,26).

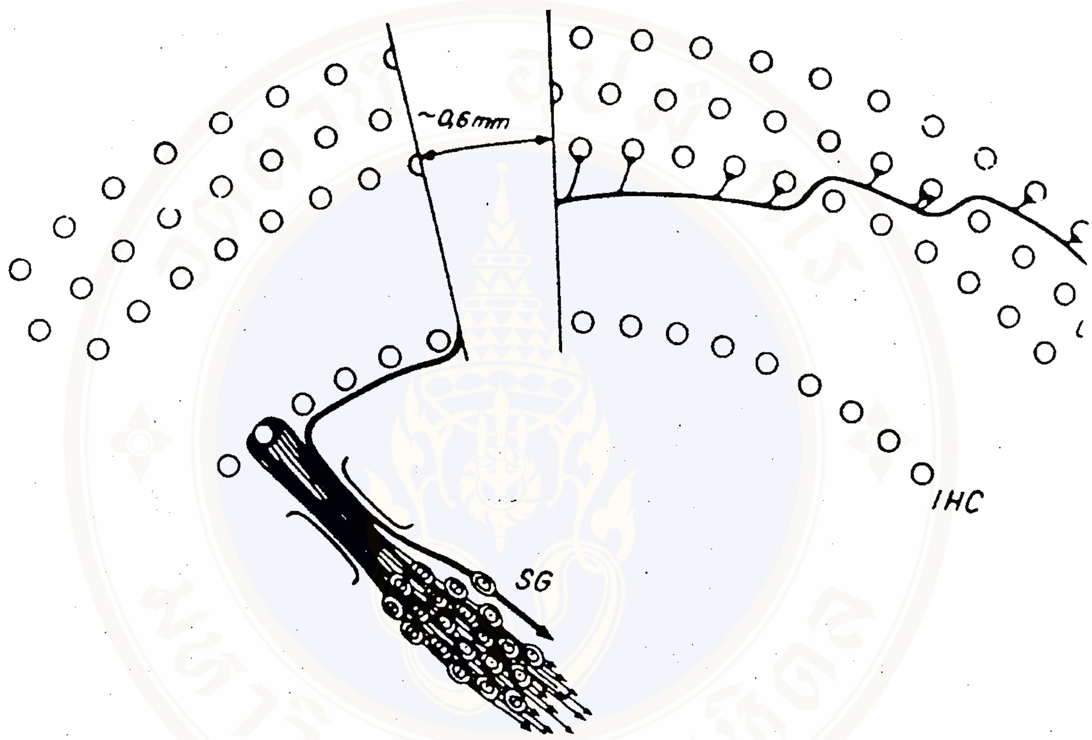

Figure 3. Afferent innervation of the organ of Corti. Approximately 90-95 % of the afferent fibers (Type I fibers) connect with inner hair cells, the remaining (Type II fibers) connect with outer hair cells (22)

A displacement of the basilar membrane will result in a shearing movement between the hair cells and the tectorial membrane, resulting in lateral or medial deflection of the stereocilia . This bending movement of the stereocilia initiates the transduction of acoustic energy into neural signals (Figure 4).

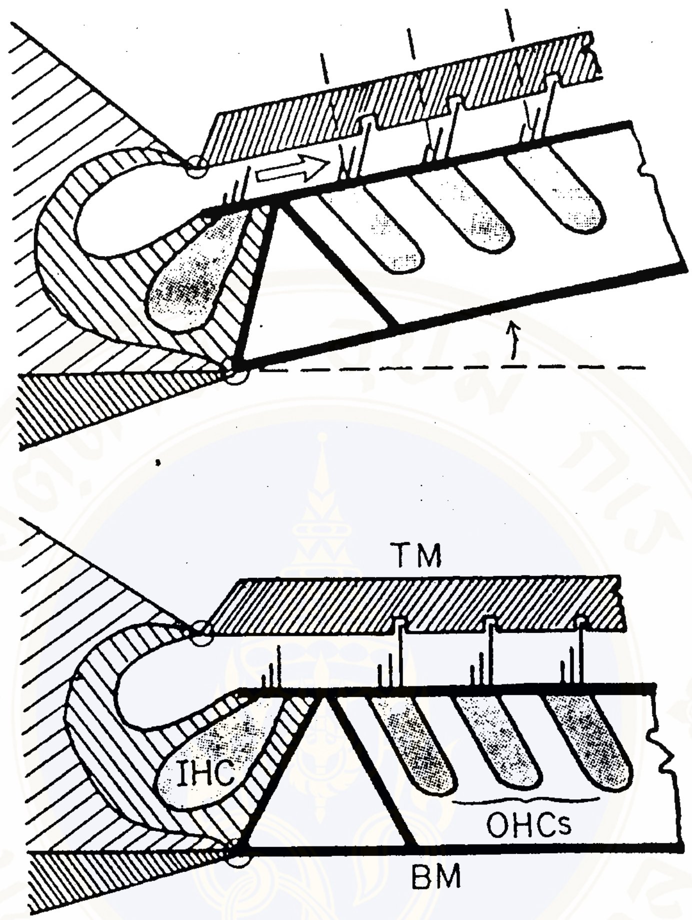

Figure 4. Displacement of the basilar membrane, causing a shearing movement between the stereocilia and the tectorial membrane (26)

1.3 Cochlear mechanics and the traveling wave

When the acoustic stimulus causes the stapes to vibrate, its movement is opposed by the inertia of the inner ear fluid mass as well as by the frictional resistance generated by fluid motion, causing the pressure change within the scalae. The stiffness of the basilar membrane decrease form base to apex, while the mass increase. This produces a delay between basilar membrane displacement and the pressure gradient across the cochlear partition. This delay displacement increases from base to apex of the cochlea. Thus, basilar membrane motion begins at the base and propagates toward the apex, giving the appearance of a traveling wave (23,24,25). Each of the solid lines in figure 5 represents the basilar membrane motion at four successive instants in time. The dotted line represents the maximum peak through excursion of the basilar membrane along the length of the cochlea. The amplitude gradually increases with distance from the base, reaching a maximum value and then the amplitude drops off rapidly.

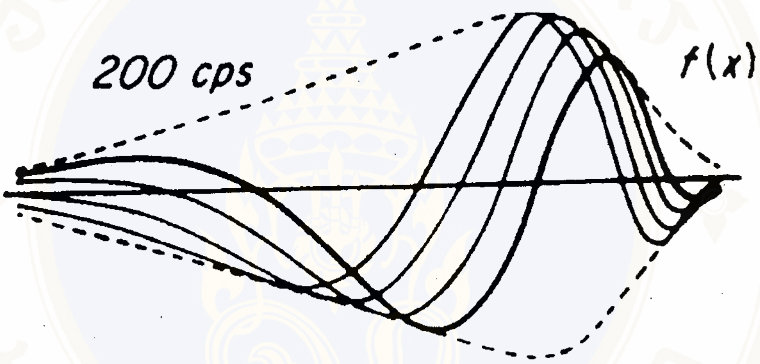

Figure 5. Amplitude of basilar membrane motion as a function of distance from the base of the cochlea to a 200 Hz tone, showing the instantaneous displacement of basilar membrane at successive time interval (solid lines) and the displacement envelope (dotted lines). (24)

Recent measurements of basilar membrane motion have shown that it response to sound is very sharply tuned (24,25). The frequency that is most effective (lowest sound level) in exciting the particular place in the cochlea is called the characteristic frequency (CF). To produce the displacement at a frequency above or below the CF, the sound level has to be increased significantly. This type of iso-response curve is referred to a tuning curve (Figure 6). In normal ears, the tuning curves typically consist of a low threshold narrowly tuned tip and a high threshold broadly tuned tail (23,24,25,26)

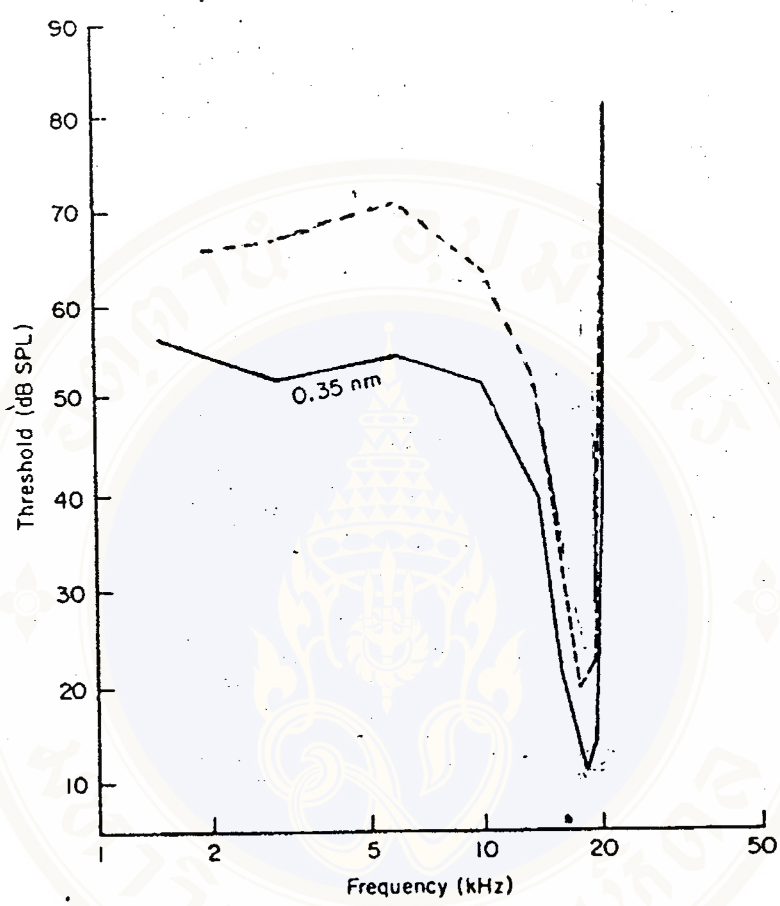

Figure 6. Tuning curve for the 18-kHz point on the basilar membrane (solid lines), made for vibration criteria of 0.35 nm. Dotted line: tuning curve of an auditory nerve fiber. (22)

1.4 Hair cell physiology

1.4.1 Transduction

The transduction channels are located near the tips of the stereocilia bundles (Hudspeth,1982) and are connected to the next tallest row of stereocilia by a flexible link. When the stereocilia bundle is deflected toward the tallest stereocilia, tension is created in the transduction link, which increases the influx of K^+ leading to depolarization. The tension alters the intracellular potential of the hair cell and causes the neurotransmitter releases from the presynaptic area at the lower end of the hair cell to stimulate the afferent ending of auditory nerve fibers. When the bundle is deflected in the opposite direction, the channel is closed, reducing the influx of K^+ leading to hyperpolarization (23,24,25).

1.4.2 Outer hair cells motility

The sensory receptors in the inner ear have traditionally been considered passive structures. However recent studies on isolated OHCs have shown that these cells were capable of moving along their long axis (23,24,25). Two classes of movements have been observed in OHCs. Type I movement elicited by electrical stimulation consists of cycle by cycle changes in cell length around some mean value. OHCs contract when the cell is depolarized and elongate when the cell is hyperpolarized. This length change is distributed between the nucleus and the cuticular plate region, suggesting that the motor underlying the motile response is distributed over the length of the cell. Electromotile responses have been observed at frequencies as high as 8 kHz (24).

Type II movement consist of a slow increase in cell length, which in some cases can be superimposed upon the faster type I movements.The slow type II movements can be elicited by electrical stimulation and various pharmacological agents such as K,$^+$ acetylcoline, cholinomimetic analogues, caffeine (23,24).

Some insights into the functional significance of the mechanical response can be gleaned from the schematic shown in figure 7. The base of each OHC is supported by a cuplike structure formed by the Deiter'cells. The phalangeal process of the Deiters' cell projects toward the cuticular plate of adjacent hair cell. The triangular structure is formed by cuticular plate. The OHC and the phalangeal process of the Deiter'cell would be rigid as the OHC lengthened and conversely more compliant if it shortened. This would influence the compliance of the cochlear partition, thereby altering its vibration characteristics to acoustic stimuli. In addition, a change in OHC length could alter the position of the overlying tectorial membrane, since the tallest stereocilia on the OHCs appear to be embedded in the tectorial membrane. Finally, the rapid type I movement could conceivably provide cycle by cycle feedback about cochlear partition motion.

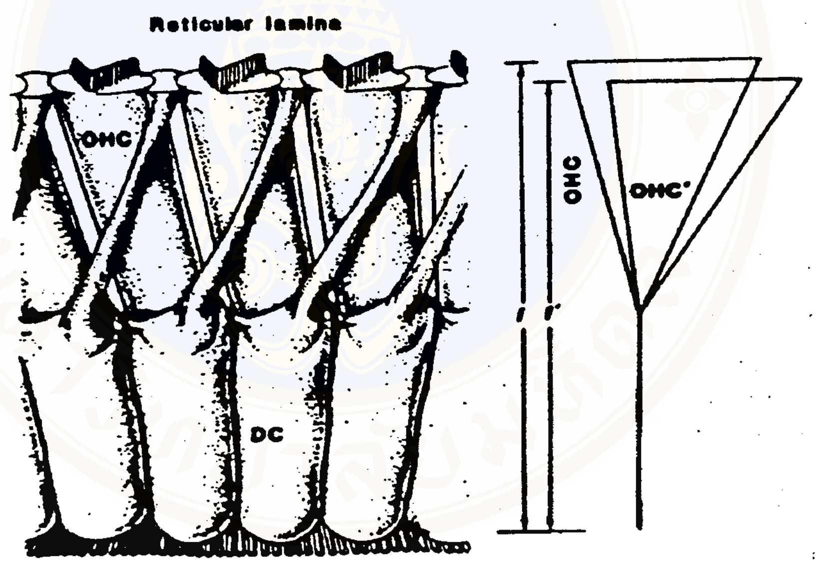

Figure 7. Left panel: Cochlear partition showing the base of each OHCs resting in the depression of a Deiter's cell (DC). Phalangeal processes of the Deiter's cell project upward at an angle of toward the reticular lamina and terminate between OHCs. Right panel: An OHC at rest (OHC) and during contraction (OHC'). Distance between the basilar membrane and reticular lamina is shown before (1) and during (1') contraction. (24)

1.5 Cochlea electrical potentials

When an acoustic stimulus sets the basilar membrane into motion. The stereocilia bundles on the hair cells are deflected, resulting in a complex series of electrophysiological events in the cochlea. The three gross potential are the endocochlear potential, the cochlear microphonic potential and the summating potential.

1.5.1 The endocochlear potential (EP)

The endocochlear potential is +80 mv DC, can be recorded with an electrode in the scala media without any acoustic stimulus. The stria vascularis is believed to be the generator of the EP when the stria vascular is damaged or becomes anoxia the EP significantly decrease (24,25,26).

1.5.2 The cochlear microphonic (CM)

The cochlear microphonic is the extracellular correlate of the alternate current (AC) flowing through hair cells. It is generated predominately by outer hair cells (23,24,25). If the OHCs are destroyed, the complete loss of OHCs, the CM input/output function shows roughly a 30-40 dB loss in sensitivity and a significant drop in a maximum CM voltage,while the IHCs remain intacted. By contrast, the CM is only slightly reduced when the IHCs are destroyed but the OHCs are intacted (24).

1.5.3 The summating potential (SP)

The summating potential is the DC potential that occurs during the presentation of a stimulus. It can be either recorded as positive or negative shift in scala media depending on circumstances such as the stimulus frequency, level and duration. The SP probably receives contribution from both IHCs and OHCs, and possibly form other sources (25,26)

2. Otoacoustic Emissions (OAEs)

The otoacoustic emissions (OAEs) are low level acoustic signals generated within the cochlea, transmitted through the middle ear and can be measured in the ear canal with a sensitive microphone. They are thought to be by products of an active cochlear mechanisms or cochlear amplifier that works to enhance low level sensitivity and frequency selectivity of the basilar membrane (11,23,27,28,29). More specifically, the emissions most probably reflect the underlying nonlinear activity of the cochlea outer hair cells (4,13,17,30,31).

Classification of otoacoustic emissions

They are two broad classes of OAEs, spontaneous otoacoustic emissions and evoked otoacoustic emissions. According to the stimulus used to elicit them, evoked OAEs can be separated into three subtypes, transient evoked otoacoustic emissions (TEOAEs), stimulus frequency otoacoustic emissions (SFOAEs) and distortion products otoacoustic emissions (DPOAEs).

1. Spontaneous otoacoustic emissions (SOAEs)

SOAEs are narrow band acoustic signals usually less than 20 dBSPL generated within the cochlea without acoustic stimulation and can be detected in about 50% of normally hearing ear (2,4)

2. Evoked otoacoustic emissions (EOAEs)

2.1 Transient evoked otoacoustic emissions (TEOAEs)

TEOAEs are elicited by acoustic transients such as clicks or tonebursts presented to the ear. They can be detected in essentially all of normal hearing ears (2,4,5).

2.2 Stimulus frequency otoacoustic emissions (SFOAEs)

SFOAEs are low level sounds from the ear at the stimulus frequency following the continuous tonal stimulation.

2.3 Distortion product otoacoustic emissions (DPOAEs)

DPOAEs are elicited by two simultaneous primary pure tones separated in frequency at f1 and f2 (f2 frequency higher than f1). The strongest emissions distortion components are usually measured at the frequency of 2f1-f2.

3. Transient Evoked Otoacoustic Emissions (TEOAEs)

TEOAEs can be evoked by any brief transient stimuli. Click stimuli is the most commonly and widely used, which can be stimulated nearly the whole cochlea over a wide frequency range up to 5 kHz.

3.1 Click evoked otoacoustic emissions (CEOAEs)

According to the standard default mode of the ILO 88 and ILO 92, the stimuli are 80μs rectangular pulses presented in a group of four stimuli. Each group is called nonlinear clicks. Three clicks are presented at equal amplitude and the fourth is presented at three time greater in amplitude but is inverted in polarity. With a differential in stimulus set, all linear responses such as from the external meatus and middle ear at this level are canceled. The remaining nonlinear response is a result of the cochlear emissions and is analyzed in a time window from 2.5-20 msec after the stimulus onset.

3.2 QuickScreen technique

The QuickScreen technique is developed to minimize the effects of low frequency noise interference on the detection of an emission. This technique will cut off low frequency response to 12.5 msec since the latency of 500 Hz is 15 to 20 msec. However, the shorter window also nearly halves the noise added to high frequency component, emitted within 5 msec and the time window of 12.5 msec in QuickScreen is long enough to capture 1 kHz OAEs. In neonates and infants, this technique reduces the total test time and decreases the effects of low frequency noise (10,32,33). Figure 8 shows typical CEOAEs measurements from the same ear of one neonate using standard mode and QuickScreen mode.

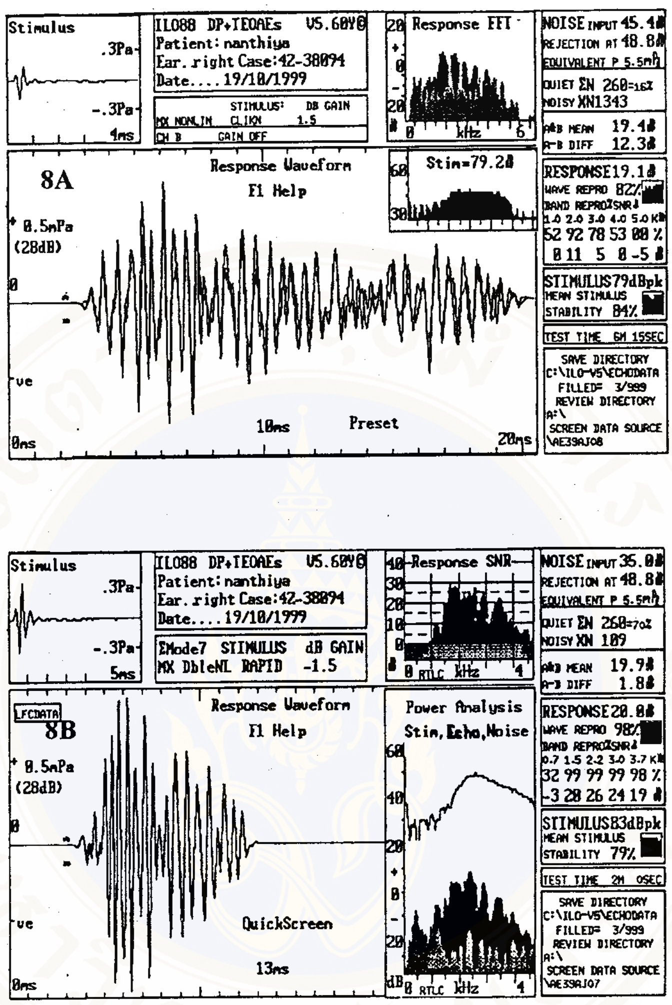

Figure 8. Showing the CEOAEs response waveforms and fast Fourier transformations (FFT) of the response and the stimulus waveforms from the same ear of one neonate ear. The standard mode and QuickScreen mode are used for the recording. Figure 8A and 8B shows the difference in the result for the standard mode and the QuickScreen mode . As seen in figure 8B, the QuickScreen mode has less noise in high frequency region, which makes the emission more visible. Less noise during the QuickScreen measurement resulted in fewer data points rejection (109 versus 1343) and shortens the test time than the standard mode (2 min versus 6 min 15 sec).

3.3 Characteristic of CEOAEs

3.3.1 Waveform

The CEOAEs waveform varies greatly across ears. However, the response energy typically occurs within 20 msec post stimulus. The earlier parts of the response are the higher frequency components, and the later parts are dominated by lower frequency components. In normal ears, the spectrum of CEOAEs mimics the stimulus spectrum and the response are broadband, usually containing frequency components between 0.5 and 4.5 kHz with a maximum amplitude occurring between 1 to 2 kHz (28,33).

3.3.2 Amplitude

The clinical useful characteristic of CEOAEs is the nonlinear response as a function of stimulus level. In normal hearing ears, when the stimulus levels are less than 10 dBSPL, the amplitude increases linear as the stimulus level increases (4,28). As the stimulus is approximately 50 to 60 dBSPL, the amplitude increases more slowly and are saturated (16).

3.3.3 Latency

The physiological characteristic of OAEs, which is not readily mimicked by instrumental or middle ear defects is latency. Latency is referred to the time between presentation of the stimulus and detection of the response, and is typically 5-20 msec in humans and tends to decrease as the frequency of the OAEs component increases. In the time domain the response is frequency dispersion, that is the frequency of the response increases the latency of the response will be shorten (4,34).

3.4 CEOAEs obtained from neonates

3.4.1 CEOAEs amplitude

Although the differences of the measurements and the criterion have been applied to determine the presence of emissions, most investigators (8,16,28,33,35,36) have found that the CEOAEs response amplitude in neonates are more robust than that in adults. Most data indicated that the CEOAEs amplitudes in neonates are greater than those responses obtained from adults 10 dB or more and the differences are maintained over a wide range of intensities as seen in figure 9 (16,35). Possible explanation includes differences in the volume of the external ear canal, differences in the middle ear transfer function, differences in cochlear function or a combination of all three (16).

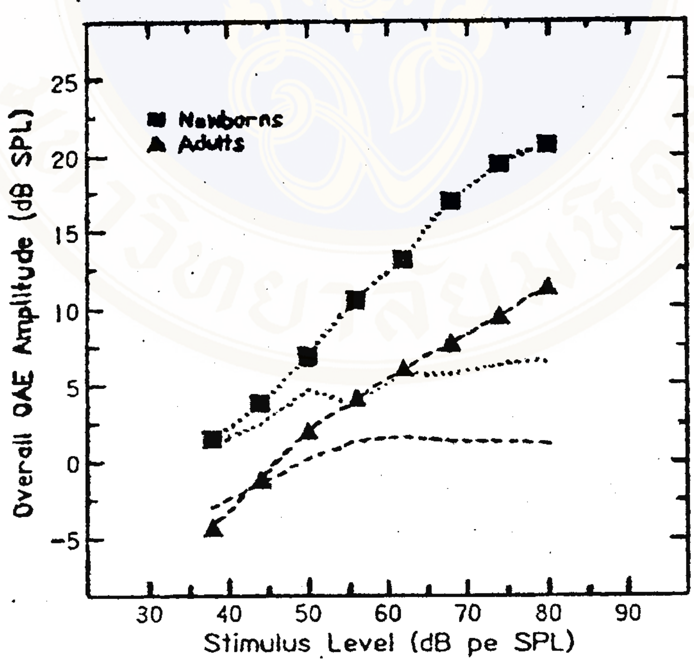

Figure 9. Mean amplitude of CEOAEs as a function of stimulus level form 27 normal full-term neonates and 31 normal hearing adults. Dotted line and dashed line indicated the estimated noise levels for neonates and adults. (16)

3.4.2 CEOAEs spectrum

The spectrum of CEOAEs in neonates typically shows higher energy in high frequency regions than adults (19,35,37,38) . The differences are probably associated with first, in neonates the low frequency emissions may be obscured by the higher noise level than in adults. Second, the spectrum of click in neonate ear canal at low frequency has less energy than in adult (16,17,35,38,39). Third, the lower level in the low frequency bands may be due to energy leak out of the ear canal in neonates (36,40). Figure 10 shows the mean stimulus spectra (figure 10A) and their response spectra (figure 10B) of CEOAEs from neonates and adults. The stimulus spectra are different between two groups. Although there is less power energy in the stimulus at the lower frequencies, the response spectrum is essentially flat in neonates. The stimulus is fairly flat in the adult ear canal but the response spectrum has a distinct high frequency roll-off.

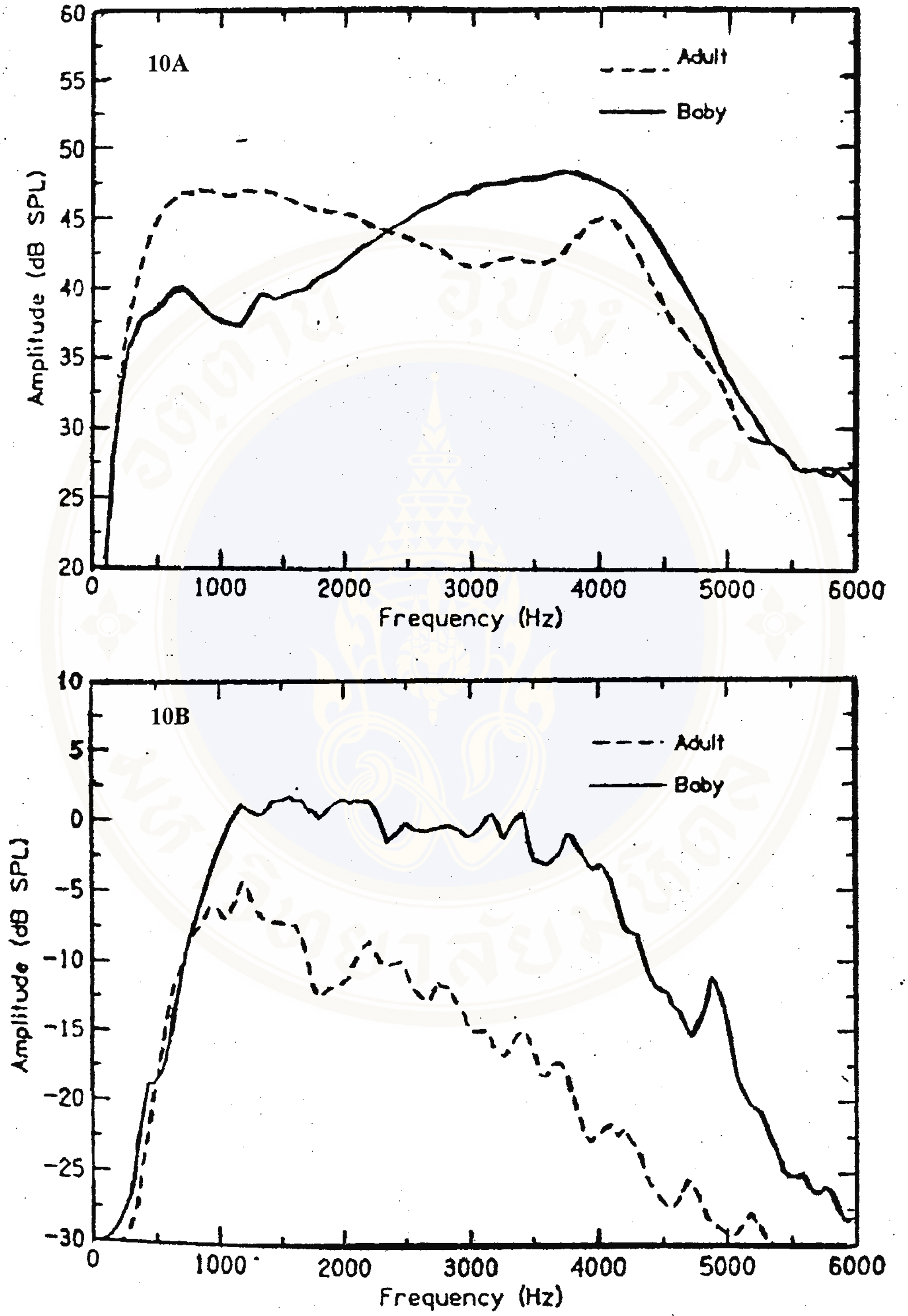

Figure 10. Mean stimulus (figure 10A) and response spectra (10B) for normal full-term neonates and normal hearing adults. The stimulus is an 80 dBSPL click (16).

A study by Smurzynski et al (19) also found the similar results for this observation as discussed previously. The CEOAEs response in neonates was higher than that in adults for the frequency above 1.5 kHz. However, for the frequency below 1.5 kHz the CEOAEs response was higher in adults than that in neonates. The differences between the CEOAEs spectrum could be due to the difference of stimulus spectrum observed in the two age groups. The spectrum of click stimulus in neonate ears showed a band passed shape with a decline below about 2 kHz and 4.5 kHz, whereas adults showed a low band passed shape with a flat spectrum in low frequency range and a decline above 4 kHz.

3.4.3 Noise

The greater noise level, particularly for the lower frequency in neonates is a confounding factor effecting CEOAEs recording when compared with adults (10,11,16,17,33,37,41). The differences are due to the higher of physiological noise in neonates such as breathing, sucking, swallowing and sniffing or due to the environmental noise (11,13,16,27,33).

David et al (10) obtained CEOAEs from 351 ears of neonatal subjects. Recording was performed in the mother 's hospital room while they were asleep. They concluded that, in neonates, the ambient noise levels were clearly higher in the 1 kHz frequency band and the CEOAEs response was also lower when compared with other frequencies.

3.5 The effects of ear side, gender, and age on CEOAEs amplitudes

3.5.1 Ear side

Few studies reported the effects of ear side on CEOAEs amplitude. Newmark et al (13) found a significant difference between the right and the left ears of CEOAEs amplitude obtained from 120 healthy full term neonates. The overall CEOAEs response and the CEOAEs amplitude for the frequency bands of 2, 3 and 4 kHz in the right ears were greater than in the left ears for both male and female subjects. However, a significant difference of CEOAEs SNR between ear side occurred only at 2 kHz in male subjects. Similar findings were also found in infants and adults (12,42)

3.5.2 Gender

The differences of CEOAEs amplitude in male and female subjects were presented in previous studies (11,13). Aidan et al (11) obtained CEOAEs from 552 and 600 ears of male and female neonates without any risk of hearing loss. The mean amplitude of CEOAEs was 22.11 dBSPL in female and was 21.36 dBSPL in male subjects. They found a significantly stronger of CEOAEs amplitude in female than those of male subjects. ($P< 0.0001$)

3.5.3 Age

The CEOAEs amplitude obtained from neonates at the time post partum were studied. Kok et al (8) found that the CEOAEs amplitude grow stronger during the first few day of life. They reported data obtained from 1036 ears of healthy neonates as a function of hours aged. The mean amplitude of CEOAEs were 16 dBSPL, 20 dBSPL and 22 dBSPL at the ages of 24, 48 and 72 hours, respectively.

Several investigators found that in neonates the CEOAEs were more prevalence and had greater amplitude if CEOAEs were obtained until the second to the fourth days after birth (6,8,11,40,42).

Norton et al (39) found a significant decreases in CEOAEs amplitude related with ages. They obtained CEOAEs evoked by 80 dBSPL clicks in 60 subjects at the age from 17 days to 30 years, who were divided into three subgroups (each subgroup, n= 20) base of age 17 days to 9.9 years, 10.0-19.9 and 20.0-29.9 years. The CEOAEs amplitude in neonates, infants, children and adolescent were more robust than that of adults.

3.6 Clinical applications

It is well established that CEOAEs can be detected in almost of normal hearing ears (3,11,16, 27, 32,33). The presence of CEOAEs implied a normal working conditions of the cochlea and also indicated normal mechanically active functioning of the outer hair cells (28,31). When the cochlear mechanism is impaired, OAEs are diminished and hearing threshold is raised. Typically CEOAEs are absent in ears with hearing threshold greater than 25-30 dBHL at the associated frequency (7,13,42,43,44,45,46). Therefore, CEOAEs can be used as a specific and sensitive non-invasive tool for the detection of hearing impairment, particularly in pediatric populations.

Several investigators have suggested that CEOAEs is an appropriate test for hearing screening in neonates, infants and difficult to test patients (9,11,13,16,37, 38,40). They also concluded the main interesting of CEOAEs measurements as an non-invasive, objectively and easy to perform with all neonates prior to discharge from a hospital, and this test can be used as a clinical tool for mass hearing screening.

Another potential clinical applications of CEOAEs are used for separating peripheral hearing loss and central auditory dysfunction, monitoring cochlear status in-patients who receiving ototoxic drugs, or in noise exposure.

4. Distortion Product Otoacoustic Emissions (DPOAEs)

DPOAEs are elicited by two simultaneous primary pure tones at frequency f1 and f2, in which f1 represents the lower frequency stimulus or primary tone and f2 represents the higher frequency primary. Although many distortion components arise from bitonal stimulation of the cochlea, the DPOAEs at 2f1-f2 is the highest in amplitude and has been the most frequency measured (29,47,48,49,50,51). The reference frequency typically used have been either f2 or the geometric mean frequency of the two primary $(f1Xf2)^{0.5}$ (48,49).

4.1 Characteristics of DPOAEs

4.1.1 Amplitude

In human ears, DPOAEs amplitudes are approximately 60 dB smaller than the primary tones (2,4,47,50,52). Several investigators have shown that the amplitude of DPOAEs depends on the level of the primary tone (L1 or L2), the level differences (L1 minus L2), the primary frequencies and their ratio (f2/f1) (2,4,47,52,53,54).

For measuring DPOAEs, the primaries frequency ratio of approximately 1.2:1 to 1.3:1 is the most widely used because these ratio elicited the most robust DPOAEs at most frequencies (2,53,54,55). The relative levels of the primary tone also have a significant effect on the DPOAEs response. The level of f1 may be equal (i.e. L1=L2=70 dBSPL) or greater than the level of f2 (i.e. L1=65 dBSPL and L2=65,55 or 50 dBSPL). When DPOAEs are being tested in neonates, the frequency separation ratio of 1.22 and the primary tones at intensity levels of 65 dBSPL and 50 dBSPL for f1 and f2, respectively are recommended (32).

The DPOAEs amplitudes are commonly measured in two basic forms. First, the DP-gram or DPOAEs frequency level function, is typically plotted as a function of frequency of the primary tones across a range of frequencies between 0.5-8 kHz. The DPOAEs amplitude are measured when the primary tones are maintained at a constant level (i.e. L1=l2=55,65 or 75 dBSPL), and the stimulus frequency are increased. Figure 11 shows the DP-gram obtained from neonate.

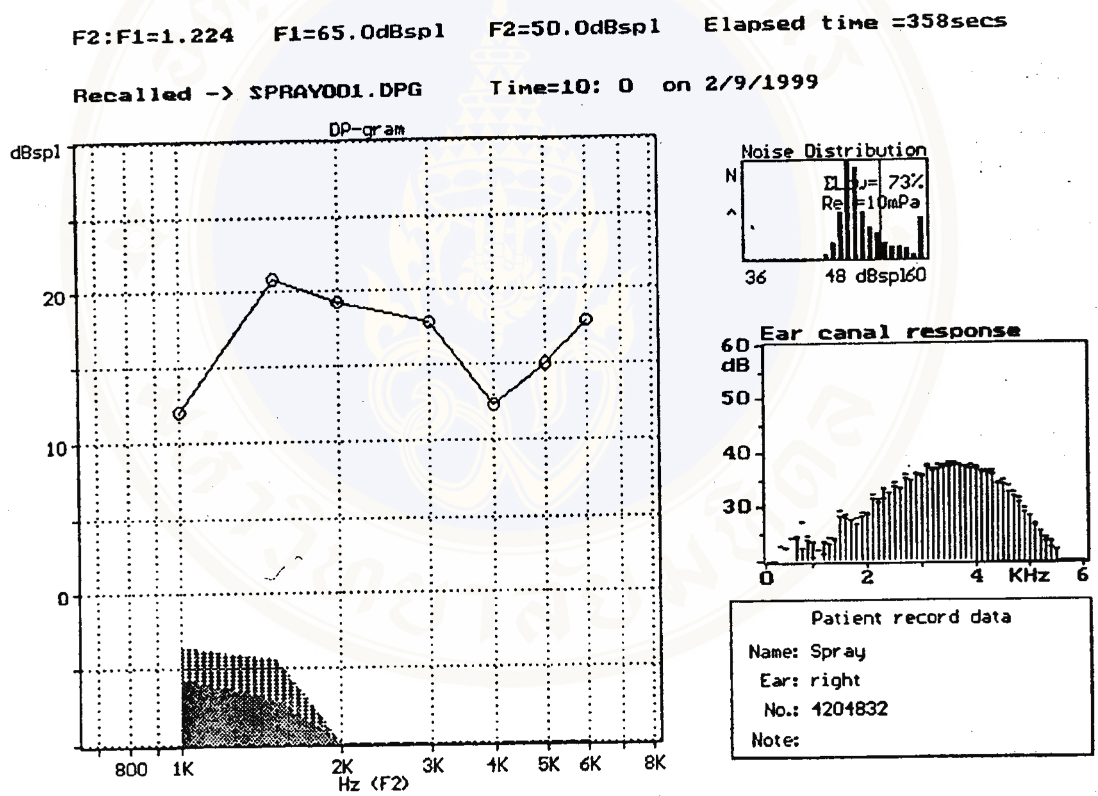

Figure 11. An example of DP-gram obtained from a neonate, recording two points per octave. The 2f1-f2 was elicited using f2/f1=1.2, L1= 65 dBSPL, L2= 50 dBSPL. Shaded area are noise level of +1SD and +2SD.

Another response form of DPOAEs is the response/growth or input/output function. A series of I/O functions are determined as a geometric mean frequencies that are related to the conventional audiogram (i.e. at 0.5,1,2,3,4,6 and 8 kHz) by varying the primary tone levels in 5 dB steps (i.e. from 25 to 75 dBSPL)

4.2 DPOAEs obtained from neonates

4.2.1 DPOAEs amplitude

A number of investigators studied the DPOAEs in neonates (9,14,17,19,56). They found a difference between neonatal DPOAEs amplitude and those obtained from adults.

Lasky et al (9) measured DPOAEs from 10 neonatal and 10 adult subjects. The primary levels were presented at equal level at 65 dBSPL. The f2/f1 ratio was 1.2 and f2 varied in 20 dB steps (in equally frequency range) from 537-10009 Hz. The DPOAEs amplitudes were plotted relative to f2 frequency. They concluded that DPOAEs in neonatal and adult subjects were comparable in amplitudes, except at f2 frequency at 2783 and 2393 Hz; the DPOAEs amplitudes in neonatal subjects were significantly higher than that adult subjects.

Lafreniere et al (17) and Smurzynski et al (19) measured DPOAEs using constant of primary tones. The DPOAEs amplitude was plotted as a function of the geometric frequency of the primaries. Both studies reported that the DP-gram from neonates were qualitatively similar to those from adults. However, mean DPOAEs amplitudes from neonates were higher than those measured from adults for primary frequencies at 3000 Hz and lower. For primary frequencies 3400 Hz and higher the DPOAEs amplitudes in neonates were lower than in adults.

Lafreniere et al (56) analyzed the DPOAEs from 31 ears of healthy neonates at the age of 2 to 4 days. All neonate ears had detectable DPOAEs. The mean amplitude of DPOAEs ranged from 7-11 dBSPL below 2 kHz with a peak at 12 dBSPL in 1.1 kHz region. In neonates the DP-gram showed a dip in the median at 3.4-4 kHz range and the DPOAEs amplitude were 2 and 3 dBSPL, respectively. The second peak of the DP-gram was in the 4.8-8 kHz region, the DPOAEs amplitude was approximately 7 dBSPL.

Marco et al (14) obtained DPOAEs from 24 ears of healthy neonates. The DP-gram obtained from neonates were quite similar to those from adults, with two sharp peaks of maximum amplitude at f2 frequencies of 2 kHz and 5-6 kHz and a decline in mid frequencies. The highest amplitude of DPOAEs at f2 frequency of 2 kHz and 6 kHz were 17.8 and 22.4 dBSPL, respectively.

4.2.2 Noise

In neonates physiological noise and environmental noise can effect the DPOAEs measurement, particullary in the low frequency components.

Smurzynski et al (19) measured DPOAEs from preterm and full term neonates. They reported that the noise produced by the subjects during breathing, swallowing and muscle and joint movement or by vascular pulsation was usually highest at the low frequencies below 1.5 kHz. For some subjects, DPOAEs could not be recorded for frequencies below 2000 Hz.

In other studies of DPOAES from neonates (14,18,20,57,58), the investigators also reported high noise levels in the frequencies below 2000 Hz although they were in naturally sleep and the DPOAEs measurements were obtained in a quiet room.

4.2 The effects of ear side, gender and, age on DPOAEs amplitudes

4.2.1 Ear side

The effects of ear side on DPOAEs measurement in neonates has not been reported. In children, Spektor et al (59) found the difference between ears of the same subject. The study also suggested collecting the normative data between ears of the same subject due to the variability of DPOAEs.

4.2.2 Gender

In adult subjects, the effects of gender on DPOAEs measurements were reported in a few studies. Gender was found to have significant effects on DPOAEs amplitude. DPOAEs amplitude tended to be greater in female than that of male subjects (48,55,56)

Gaskill et al (60) obtained DPOAEs from 12 adult subjects (6 females, 6 males). Analysis of variance showed that the variation in DPOAEs levels across frequency were significant [(F7,70)=2.792, P=0.013]. They reported that DPOAEs were larger in female than male subjects for the frequency test in 1000-5000 Hz range. Similar result was also reported by Cacace et al (58).

4.2.3 Age

Prieve et al (61) studied the characteristic of DPOAEs in infants, toddlers, children and adults and defined the differences among age groups. DPOAEs were measured from one ear of 196 subjects at the age of 4 weeks to 29 years. They were divided into 7 subgroups based on age, less than 1 yr (n=28), 1-3 yr (n=28), 4-5 yr (n= 24), 6-8 yr (n=30), 9-11 yr (n=23), 12-17 yr (n=28) and 18-29 (n=35). The main finding of this study found that there were different in the mean DPOAEs amplitude among age groups. The differences were frequency dependent, but independent of stimulus level.

Infants showed higher mean DPOAEs amplitudes for f2 frequency ranging from 1500 Hz to 5000 Hz than teen aged 12-17 yr and adults. At 2000 Hz and 3000 Hz, infants mean DPOAEs amplitudes were higher than those obtained from all others age groups. Children aged 1-3 yr had higher mean DPOAEs amplitudes than young adults at 3000,5000 Hz and 6000 Hz. At 6000 Hz, children aged less than 8 yr had higher mean DPOAEs amplitudes than adults. Children aged 6-8 yr showed higher DPOAEs amplitudes than adults at 3000 Hz, and those aged 9-11 yr showed higher mean DPOAEs amplitudes than adults did at 4000 Hz.

4.4 Clinical applications

Distortion product otoacoustic emissions are a property of all normally hearing ears. DPOAEs are quite recently introduced as a new objective auditory assessment test to elicit the cochlear responses at specific frequency (20,21,47,54). The benefit of DPOAEs are, first, DPOAEs can be elicited over a wide frequency range which extends to higher frequencies (0.5-8 kHz). Second, the DPOAEs have an extensive dynamic range regarding hearing loss which permits both threshold and supra threshold to be made for hearing loss up to 45-55 dBHL (20). Third, DPOAEs can be measured noninvasively, are highly repeatable, under test retest conditions (2,21,47,54).

Several investigators also suggested to using DPOAEs as a screening method for auditory function and could be very useful for young children, especially in neonatal subjects. (19,20,47,54,58,61)

According to their sensitivity to high frequency functions especially for the frequency between 4 - 8 kHz, the DPOAEs can be used for the early detection of subtle dynamic changes of OHCs function, e.g., in presbycusis persons, noise exposed persons and in patients receiving ototoxic drugs prior to their detection by clinical audiometric tests (21,27,49,52,6,63).

5. Correlation between CEOAEs and DPOAEs

The two types of OAEs that show the greatest potential for clinical utility are the CEOAEs and the DPOAEs. Both CEOAEs and DPOAEs are generated within the inner ear by an active, nonlinear process underlying the sensitivity and selectivity mechanisms of the cochlea (64). The close correlation between CEOAEs and DPOAEs in the same ears has been reported because CEOAEs and DPOAEs are related to hearing threshold level, (17,18,19,31). In general when one type of OAEs is present, the other will be also. When only one type of OAEs is to be chosen for a clinical evaluation, then the purpose of the testing should be a major factor in determining the selection.

For a screening purpose in a short period of time, CEOAEs is preferred over a series of DPOAEs. In addition, CEOAEs can be use as a potential clinical testing for hearing screening in neonates because of their excellent test/retest reliability over a mid frequency ranges from 1-3 kHz that is important for speech and language acquisitions (31,64). If the goal is to monitor changes in a specific frequency region, then DPOAEs should be considered. In conclusion, when combine CEOAEs and DPOAEs for the detection of hearing impairment. Both of them will give additional information concerning the cochlear status, and to precisely evaluate the peripheral auditory function in subjects of all ages (17,18,31,56,59).

CEOAEs and DPOAEs obtained from neonates

The preliminary study of CEOAEs and DPOAEs from neonates was first reported by Lafrenier et al (17). The measurements were obtained from 35 ears of healthy neonates ranging in age from 2-6 days. They reported that all normal neonate ears had detectable CEOAEs and DPOAEs.

Bonfils et al (18) showed the correlation of CEOAEs and DPOAEs obtained from neonates. Neonates that had normal CEOAEs response amplitudes, also showed large DPOAEs amplitudes. In contrast, neonates who had atypical CEOAEs frequency spectrum in low frequency component, the DPOAEs amplitudes were decreased at those frequencies.

Smurzynski et al (19) studied the correlation of CEOAEs and DPOAEs from 25 ears of full term neonates. The CEOAEs and DPOAEs from the same ears were analyzed in four half-octave bands centered at approximately 1.4, 2.0, 2.8 and 4 kHz. The statistical analysis showed a correlation between the half octave RMS values of CEOAEs and DPOAEs in the 2 and 4 kHz regions at the 0.005 level of significance. The level of significance were 0.05 and 0.01 for the 2.8 and 1.4 kHz, respectively. These data suggested that some common mechanisms underlie the generation of CEOAEs and DPOAEs in human cochlea at different states of development. Even though the two types of OAEs exhibit some differences, they were both believed to reflect active biomechanical properties of OHCs. Subtle differences in middle ear transmission characteristics might be another element that could potentially influence the correlation between CEOAEs and DPOAEs. This possibility was reflected, for example, by the fact that some ears that passed the CEOAEs test failed the DPOAEs test.

CHAPTER III

MATERIALS AND METHODS

1. Subjects

Forty-four full term neonates in the nursery ward of Methapracharak hospital served as the subjects for this research. Recording were performed in both ears of full term neonates of which 22 were males (44 ears) and 22 were females (44 ears), at an age ranged from 1 day to 28 days after birth. They were selected from full term neonates with full consent from the parents.

Exclusion criteria were;

1.1. Neonates who had current upper respiratory tract disease.

1.2. Neonates who were considered to be at risk of hearing impairment e.g., anoxia, fetal or neonatal infection, ototoxic treatment during gestation or after birth, hyperbilirubinemia, family history of hereditary hearing impairment or ear, nose and throat malformation.

2. Instruments

The instruments used in this study were:

2.1. Otoscope

2.2. The ILO292 DP Echoport version 5, Otodynamic OAEs analyzer

3. Method

3.1. CEOAEs recordings

CEOAEs recording were performed in a quiet room at Hearing Center Methapracharak hospital. The ILO292 DP Echoport version 5. The QuickScreen mode was used in response analysis within a time window form 2.5 to 12.5 msec after the stimulus onset. The stimulus was a click with an electrical duration of 80 μs. The gain of the ILO292 OAE system were adjusted to present stimuli at a peak level of 80±3 dBSPL. The neonate probe (No.HPC60913B) with an appropriate size of a rubber probe tip was sealed into the ear canal without external support.

The acoustic stimulus waveform was recorded in the ear canal and displayed in a check probe fit routine first. A good fit has been achieved when there was minimal noise leakage into the meatus as indicated by a noise bar. When the probe tip was judged to be good enough, the stimulus spectrum should be a smooth, rounded curve extending across 1 to 4 kHz. The artifact rejection level was adapted to the recording conditions for each ear. This level vary between 43 and 52 dBSPL (37). During the measurement the stability of the stimulus and the probe fit was indicated on the screen by a green light. If the light turns red the probe should be refitted or the measurement restarted. Two hundred and sixty sweeps were averaged for each recordings.

3.2. DPOAEs recordings

The DP Echoport ILO292 was used to obtain the DP-gram. Two pure tones at the primary frequencies of f1 and f2 , with a frequency ratio f2/f1 fixed at 1.22 were mixed acoustically and presented to a probe (No.HPC60913B) which was sealed into the ear canal without external support. The level of primary tones are at 65 dBSPL and 50 dBSPL for f1 and f2 (32).

The DP-gram were recorded using 7 pair of stimuli at two points per octave, the f2 frequency coincided with the frequency analyzed were varying form 1.001 to 6006 kHz. The averaging was done manually at each frequency until the signal was clearly distinguished from the noise floor at +2 standard deviations (SD).

The noise level at +1 SD and +2 SD, the signal to noise ratio (SNR) at each frequency are also assessed. The frequencies f1 and f2 and coincident DPOAEs 2f1-f2 and geometric mean frequencies were listed in Table 1.

Table 1. Frequencies for stimulation (f1 and f2), DPOAEs (2f1-f2) and the geometric frequency of f1 and f2.

Frequency (Hz)			
GM	F1	f2	2f1-f2
1	0.818	1.001	0.635
1.5	1.233	1.501	0.965
2	1.636	2.002	1.270
3	2.454	3.003	1.905
4	3.284	4.004	2.564
5	4.102	5.005	3.199
6	4.919	6.006	3.832

GM = Geometric means of f1 and f2

4. Procedures

CEOAEs and DPOAEs recording were performed in a quiet room at Hearing Center Methapracharak hospital. In each recording all neonates were swaddled and placed in the crib or being held by the parent while they were naturally asleep after feeding or in a quiet state. The first recording was performed on the available ear. When the probe was fitted in place, the noise in the ear canal could be monitored to the satisfaction level below 52 dBSPL (37). The CEOAEs from each ear was recorded first, then a complete DPOAEs audiogram was recorded before beginning on the second ear.

5. Criteria Used to Ensure a Valid Recording

CEOAEs : The criteria include

5.1. the CEOAEs response level was at least 3 dB above the noise floor (27)

5.2. the reproducibility was greater than 50 % (8,19,27,34,65)

5.3. stimulus stability measurement of 75% or greater (32).

5.4. peak stimulus target at 80 dBSPL, acceptable range 77-83 dBSPL (32).

DPOAEs : The DPOAEs amplitude was 3 dB above the noise floor (+2SD) at that frequency (27,48).

6. Data Analysis Plan

1. Mean and standard deviation were used to analyzed the overall CEOAEs amplitude, the CEOAEs signal to noise ratio and the DPOAEs signal to noise ratio.

2. Independent t-test was used to study the different of the overall CEOAEs amplitude, the CEOAEs signal to noise ratio and the DPOAEs signal to noise ratio between ear and between genders.

3. Pearson's product moment correlation was used to study the correlation between the CEOAEs amplitude and the DPOAEs amplitude in the same ear of full term neonates.

CHAPTER IV

RESULTS

The purpose of this study was to investigate the difference of the overall CEOAEs amplitude, the CEOAEs SNR, the DPOAEs SNR between ear and between genders. The correlation between the CEOAEs and DPOAEs amplitude from the same ear of full term normal neonates was also investigated.

The OAEs measurements were performed in both ears of 44 full term normal neonates of which 22 were males (44 ears) and 22 were females (44 ears). The overall age ranged from 1 day to 28 days, the means age were 5.68 days (SD = 6.67) and 3.95 (SD = 4.31) days for male and female subjects, respectively.

1. The overall CEOAEs amplitude in the left and right ears of full term neonates

Table 2 showed the mean and SD of the overall CEOAEs amplitude in the left and right ears of full term neonates. The mean and SD of the overall CEOAEs amplitude in the left and right ears were 20.95 (SD = 4.08) and 22.39 (SD = 4.31) dB, respectively. The t-test showed no significant difference of the overall CEOAEs amplitude between the left and right ears of full term neonates.

Table 2. Mean and SD of the overall CEOAEs amplitude (dB) in the left and right ears of full term neonates.

CEOAEs	Left ear (n = 44) $\overline{X}$±SD	Right ear (n = 44) $\overline{X}$±SD	p- value
Overall amplitude (dB)	20.95±4.08	22.39±4.31	0.112 ^{ns}

ns = non significant at p-value > 0.05

2. The overall CEOAEs amplitude in male and female full term neonates

Table 3 showed the mean and SD of the overall CEOAEs amplitude in male and female full term neonates. The mean and SD of the overall CEOAEs amplitude in male and female full term neonates were 21.27 (SD = 3.99) and 22.07 (SD = 4.47) dB, respectively. The t-test showed no significant difference of the overall CEOAEs amplitude between male and female full term neonates.

Table 3. Mean and SD of the overall CEOAEs amplitude (dB) in male and female full term neonates.

CEOAEs	Male (n = 44 ears) $\overline{X}$±SD	Female (n = 44ears) $\overline{X}$±SD	p- value
Overall amplitude(dB)	21.28±3.99	22.07±4.47	0.385 ^{ns}

ns = non significant at p-value > 0.05

3. The CEOAEs SNR for half-octave frequency band at 1, 1.5, 2, 3 and 4 kHz in the left and right ears of full term neonates

The mean and SD of CEOAEs SNR in the left and right ears of full term neonates were listed in table 4 and illustrated in figure 12. In addition the level of noise floor in dBSPL (mean +2SD) at half-octave frequency bands were illustrated in figure 12. From table 4 the mean and SD of CEOAEs SNR at 1, 1.5, 2, 3 and 4 kHz in the left ears were 12.14 (8.16), 21.95 (7.13), 23.86 (7.47), 25.24 (7.38) and 21.70 (7.32) dB, respectively. In the right ears the mean and SD of the CEOAEs SNR at 1, 1.5, 2, 3 and 4 kHz were 14.33 (5.89), 23.89 (8.28), 24.17 (7.32), 26.44 (6.72) and 24.15 (7.71) dB, respectively. The t-test showed no significant difference of CEOAEs SNR at all frequencies tested between the left and right ears of full term neonates.

Table 4. Mean and SD of CEOAEs SNR (dB) for half-octave frequency band at 1, 1.5, 2, 3 and 4 kHz in the left and right ears of full term neonates.

Frequency (kHz)	Left ear $\bar{X}$±SD (dB)	Number of ears	Right ear $\bar{X}$±SD (dB)	Number of ears	p-value
1	12.48±8.16	42	14.33±5.89	38	0.171 ^{ns}
1.5	21.95±7.13	44	23.89±8.28	44	0.241 ^{ns}
2	23.86±7.47	44	24.17±7.32	44	0.844 ^{ns}
3	25.24±7.38	44	26.44±6.72	44	0.426 ^{ns}
4	21.70±7.32	44	24.15±7.71	44	0.131 ^{ns}

ns = non significant at p-value > 0.05

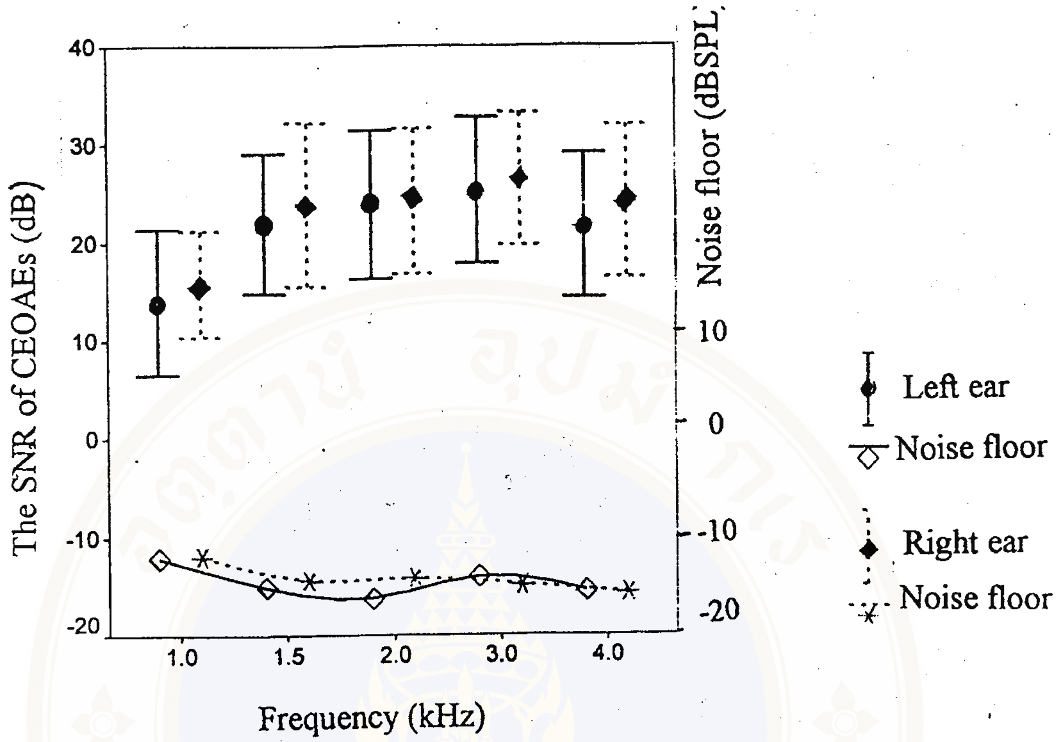

Figure 12. Mean and SD of CEOAEs SNR at 1, 1.5, 2, 3 and 4 kHz in the left and right ears of full term neonates. Error bar represented ± 1 SD of the mean. The solid line with open squares and asterisks represented the level of noise floor in dBSPL (mean +2SD) in the left and right ears, respectively.

4. The CEOAEs SNR for half octave frequency band at 1, 1.5, 2, 3 and 4 kHz in male and female full term neonates

The mean and SD of CEOAEs SNR in male and female full term neonates were listed in table 5 and illustrated in figure 13. In addition the level of noise floor in dBSPL (mean +2SD) at half-octave frequency bands were illustrated in figure 13. From table 5 the mean and SD of CEOAEs SNR at 1, 1.5, 2, 3 and 4 kHz in male subjects were 13.79 (6.37), 22.91 (7.420), 23.33 (7.38), 25.83 (6.32) and 22.13 (6.93) dB, respectively. In female subjects the mean and SD of CEOAEs SNR at 1, 1.5, 2, 3 and 4 kHz in female subjects were 12.85 (7.77), 22.92 (8.15), 24.70 (7.35), 25.85 (7.78) and 23.72(8.17) dB, respectively. The t-test showed no significant difference of CEOAEs SNR at all frequencies tested between male and female full term neonates.

Table 5. Mean and SD of CEOAEs SNR (dB) for half-octave frequency bands at 1, 1.5, 2, 3 and 4 kHz in male and female full term neonates.

Frequency (kHz)	Male $\bar{X}$±SD (dB)	Number of ears	Female $\bar{X}$±SD (dB)	Number of ears	p-value
1	13.79±6.37	37	12.86±7.72	43	0.560 ns
1.5	22.91±7.42	44	22.92±8.15	44	0.996 ns
2	23.33±7.38	44	24.70±7.35	44	0.385 ns
3	25.83±6.32	44	25.85±7.78	44	0.988 ns
4	22.13±6.93	44	23.72±8.17	44	0.328 ns

ns = non significant at p-value > 0.05

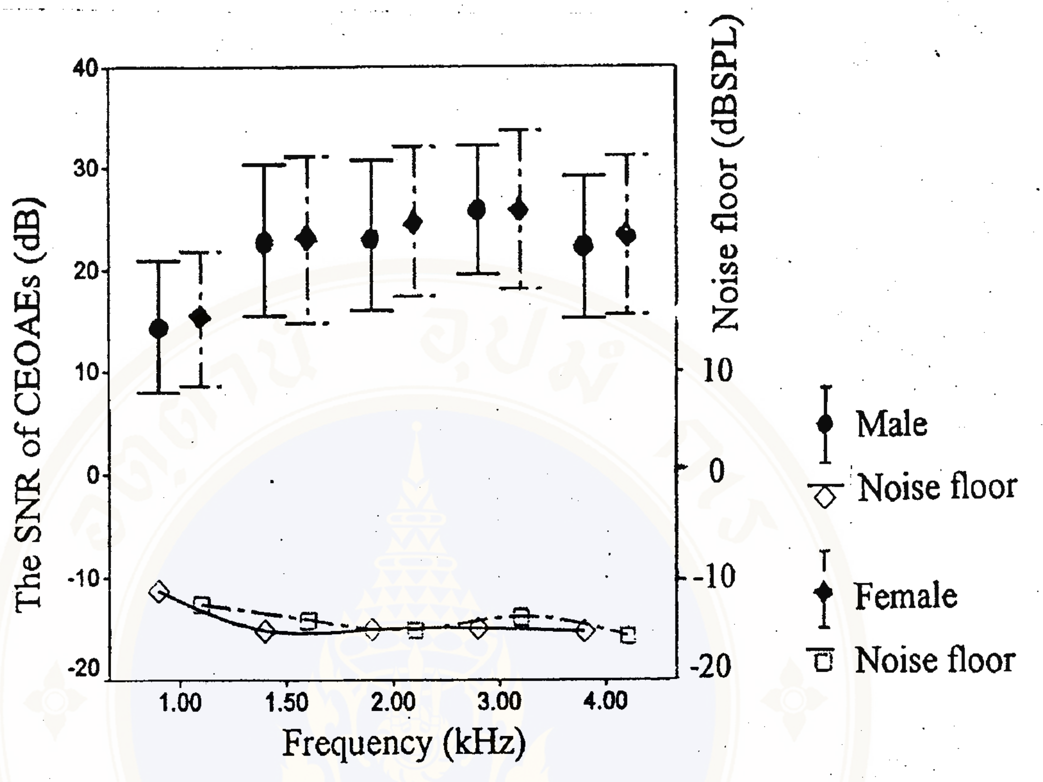

Figure 13. Mean and SD of CEOAEs SNR at 1, 1.5, 2, 3 and 4 kHz in male and female full term neonates. Error bar represented ± 1 SD of the mean. The solid line and dashed line with open squares represented the level of noise floor in dBSPL (mean +2SD) in male and female full term neonates, respectively.

5. The DPOAEs SNR at 1, 1.5, 2, 3, 4, 5 and 6 kHz in the left and right ears of full term neonates

The mean and SD of DPOAEs SNR in the left and right ears of full term neonates were listed in table 6 and were illustrated in figure 14. In addition the level of noise floor in dBSPL (mean +2SD) at half-octave frequency bands were illustrated in figure 14. From table 6, the mean and SD of DPOAEs SNR at 1, 1.5, 2, 3, 4, 5 and 6 kHz in the left ears were 12.52 (6.21), 20.98 (6.89), 23.41 (7.12), 20.59 (7.15), 19.62 (7.81), 24.03 (8.25) and 20.81 (7.96) dB, respectively. In the right ears the mean and SD of DPOAEs SNR at 1, 1.5, 2, 3, 4, 5 and 6 kHz were 13.78 (6.01), 21.61 (5.95), 26.62 (6.33), 23.02 (5.89), 24.07 (6.63), 26.55 (7.45) and 23.29 (8.40) dB, respectively. The t-test showed a significant difference of DPOAEs SNR at 2 and 4 kHz between the left and right ears of full term neonates at p-value < 0.05. There was no significant difference of the DPOAEs SNR at 1, 1.5, 3, 5 and 6 kHz between the left and right ears of full term neonates.

Table 6. Mean and SD of the DPOAEs SNR (dB) at 1, 1.5, 2, 3, 4, 5 and 6 kHz in the left and right ears of full term neonates.

Frequency (kHz)	Left ear $\bar{X}$±SD (dB)	Number of ears	Right ear $\bar{X}$±SD (dB)	Number of ears	p-value
1	12.52±6.21	36	13.73±6.01	36	0.383 ns
1.5	20.98±6.89	44	21.61±5.95	44	0.648 ns
2	23.41±7.12	44	26.62±6.33	44	0.028*
3	20.59±7.15	44	23.02±5.89	44	0.085 ns
4	19.62±7.81	44	24.07±6.63	44	0.005**
5	24.03±8.25	44	26.55±7.43	44	0.137 ns
6	20.80±7.96	41	24.02±8.20	41	0.076 ns

** significant at p-value < 0.01,* significant at p-value < 0.05,

ns = non significant at p-value > 0.05

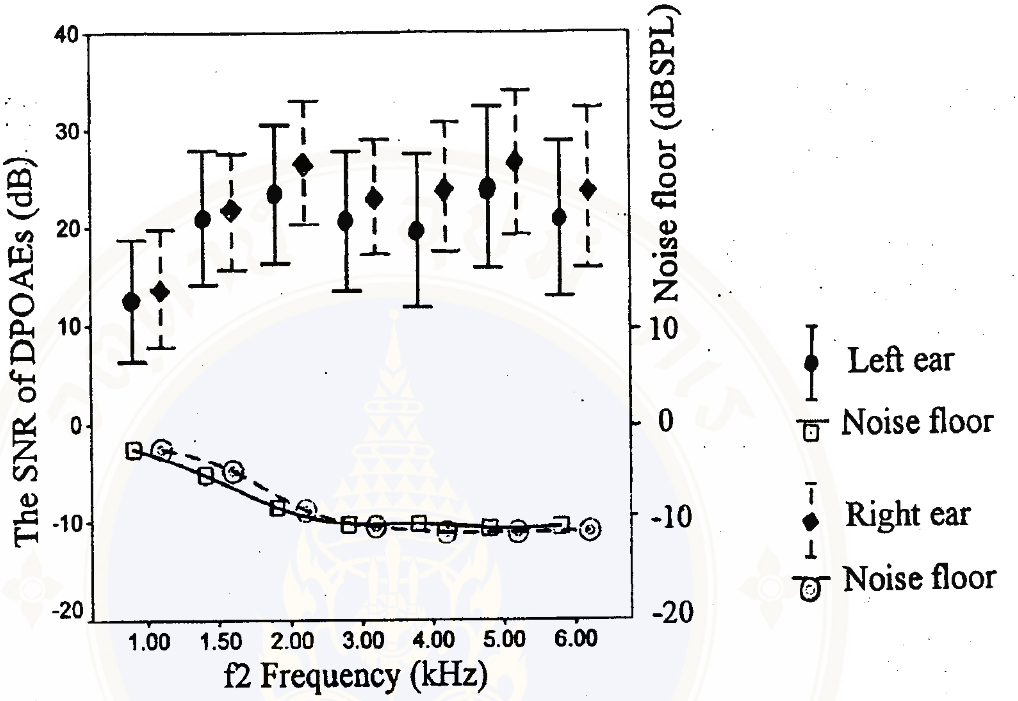

Figure 14. Mean and SD of DPOAEs SNR at 1, 1.5, 2, 3, 4, 5 and 6 kHz in the left and right ears of full term neonates. Error bar represented ± 1 SD of the mean. The solid line with open squares and the dashed line with open circles represented the level of noise floor in dBSPL (mean +2SD) in the left and right ears, respectively.

6. The DPOAEs SNR at 1, 1.5, 2, 3, 4, 5 and 6 kHz in male and female full term neonates

The mean and SD of DPOAEs SNR in the male and female full term neonates were listed in table 7 and were illustrated in figure 15. In addition the noise floor (+2SD) at half-octave frequency bands were illustrated in figure 15. From table 6, the mean and SD of DPOAEs SNR at 1, 1.5, 2, 3, 4, 5 and 6 kHz in male subjects were 12.85 (6.09), 21.00 (5.89), 24.11 (6.86), 20.52 (6.33), 20.35 (7.18), 24.39 (8.92) and 22.85 (8.05) dB, respectively. In female subjects the mean and SD of DPOAEs SNR at 1, 1.5, 2, 3, 4, 5 and 6 kHz were 13.53 (6.19), 21.59 (6.94), 25.93 (6.87), 23.10 (6.74), 23.34 (7.68), 26.18 (6.72) and 22.00 (8.40) dB, respectively. The t-test showed no significant difference of DPOAEs SNR at all frequencies tested between male and female full term neonates.

Table 7. Mean and SD of the DPOAEs SNR (dB) at 1, 1.5, 2, 3, 4, 5 and 6 kHz in male and female full term neonates.

Frequency (kHz)	Male $\bar{X}$±SD (dB)	Number of ears	Female $\bar{X}$±SD (dB)	Number of ears	p-value
1	12.85±6.09	40	13.53±6.19	32	0.645 ^{ns}
1.5	21.00±5.89	44	21.59±6.94	44	0.667 ^{ns}
2	24.11±6.86	44	25.93±6.87	44	0.217 ^{ns}
3	20.52±6.33	44	23.10±6.74	44	0.068 ^{ns}
4	20.35±8.19	44	23.34±7.68	44	0.063 ^{ns}
5	24.39±8.92	44	26.18±6.72	44	0.291 ^{ns}
6	22.85±8.05	41	22.00±8.40	41	0.642 ^{ns}

ns = non significant at p-value . 0.05

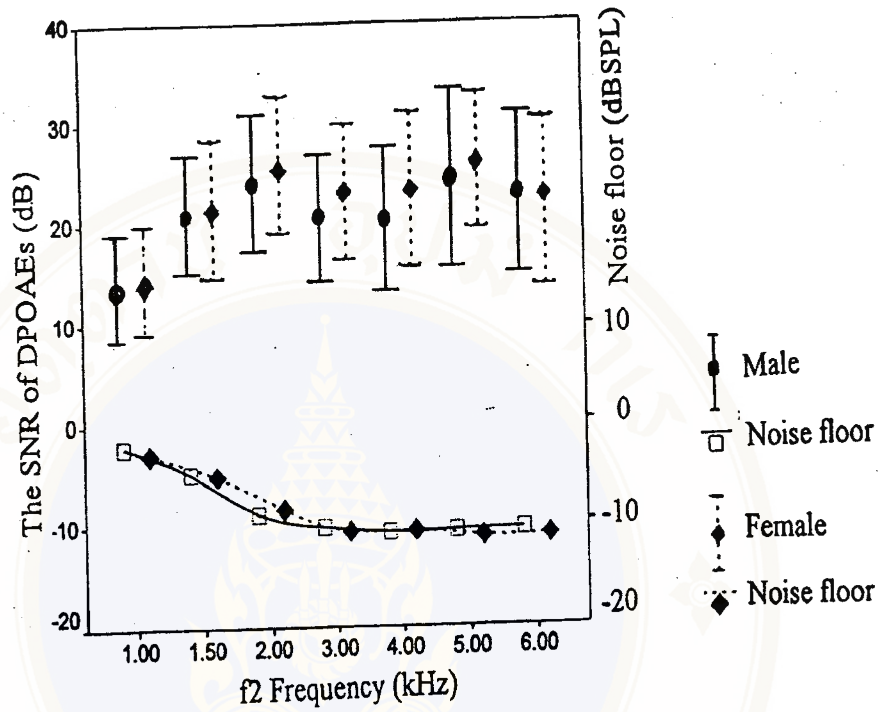

Figure 15. Mean and SD of DPOAEs SNR (dB) at 1, 1.5, 2, 3, 4, 5 and 6 kHz in male and female full term neonates. Error bar represented ± 1 SD of the mean. The solid line with open squares and the dashed line with filled squares represented the level of noise floor in dBSPL (mean +2SD) in male and female full term neonates, respectively.

7. The CEOAEs and DPOAEs amplitude (dB) in the same ear of full term neonates for half-octave frequency band at 1, 1.5, 2, 3 and 4 kHz

From table 8, the correlation coefficient (r) between the CEOAEs and DPOAEs amplitude in the same ear of full term neonates at 1, 1.5, 2, 3 and 4 kHz were 0.085, 0.301, 0.267, 0.246 and 0.245, respectively. The Pearson's product moment correlation showed a significant positive correlation between the CEOAEs and DPOAEs amplitude in the same ear of full term neonates at 1.5, 4 kHz at p-value < 0.01 and 2, 3 kHz at p-value < 0.05. There was no significant correlation between the CEOAEs and DPOAEs amplitude in the same ear of full term neonates at 1 kHz. The correlation between CEOAEs and DPOAEs amplitude from the same ear of full term neonates for half-octave frequency bands was illustrated in figure 16A-16E.

Table 8. The correlation coefficient (r) of CEOAEs and DPOAEs amplitude (dB) in the same ear of full term neonates for half-octave frequency band at 1, 1.5, 2, 3 and 4 kHz.

Frequency (kHz)	Number of ears	r	p-value
1	66	0.085	0.502 ns
1.5	88	0.301	0.004**
2	88	0.267	0.011*
3	88	0.246	0.021*
4	88	0.405	0.000**

* significant at p-value < 0.05; ** significant at p-value < 0.01

ns = non significant at p-value > 0.05

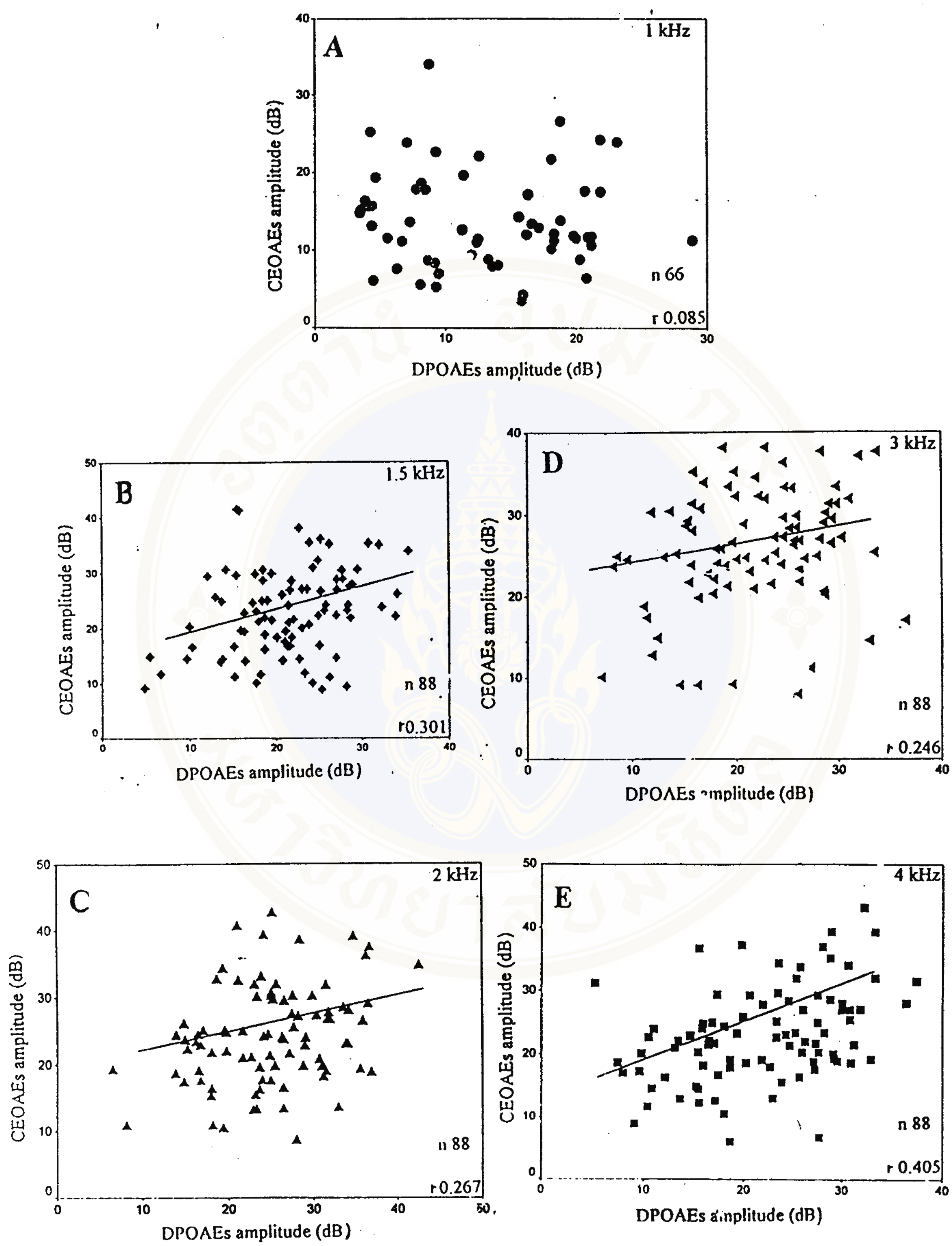

Figure 16. Scatter plotted showing the correlation (r) between CEOAEs and DPOAEs amplitude (dB) at 1 kHz (16A), 1.5 kHz (16B), 2 kHz (16C), 3 kHz (16D), and 4 kHz (16E).

CHAPTER V

DISCUSSION AND CONCLUSION

This study was conducted to investigate the characteristics of CEOAEs and DPOAEs in 44 full term neonates, which 22 were males and 22 were females, at the age ranged from 1 day to 28 days. The characteristics of CEOAEs and DPOAEs were focused on ear side, gender difference. The correlation between CEOAEs and DPOAEs amplitude from the same ear was also investigated.

1. The overall CEOAEs amplitude in the left and right ears of full term neonates

The results in table 2, showed no significant difference of the overall CEOAEs amplitude between the left and right ears of normal full term neonates. These findings agreed with Qui et al (65). They obtained CEOAEs in 20 newborn babies who had normal hearing, but the numbers of male and female subjects were not reported in that study. In normal subjects, these findings implied that when considering the normal variance and substantial effects of other factors in generation of OAEs, such as hearing threshold, middle ear status and subjects age, the clinical significant of ear difference may be negligible in an interpretation of CEOAEs.

Newmark et al (13) reported the effect of ear asymmetry on CEOAEs amplitude. They found that the overall CEOAEs amplitude in the right ears were significantly greater than left ears for both male and female neonates (male 118 ears, female 120 ears). In this study, the mean overall CEOAEs amplitude in the right and left ears included the CEOAEs data from both males and females, respectively. However, in the study of Newmark et al (13), the statistical analysis in the right and left ears were analyzed separately from each group of males and females. Therefore, the results of this study were different from those of Newmark et al (13). It was possibly due to the difference in statistical analysis.

2.The overall CEOAEs amplitude in male and female full term neonates

The results in table 3, showed no significant difference of the overall CEOAEs amplitude between male and female subjects. Although the overall CEOAEs amplitude in female slightly greater than those of male subjects, the difference failed to reach statistical significance. The results of this study were different from those of Adian et al (11), who obtained CEOAEs from a large group of full term neonates (male 552 ears, female 600 ears). They found that the overall CEOAEs amplitude in female were greater than those of male subjects. The reasons why the present study was different from Adian 's study were postulated. First, it was possibly due to difference in number of ears tested, which was less than Adian's study. Second, for CEOAEs measurement, the time window influenced the amplitude values because of the different latencies and duration of the specific frequency components (16,66). In this study the time window was 2.5 to 12.5 msec, whereas in the study of Adian et al (11) the time window was 2.5 to 17.5 msec. Third, it was possibly due to difference in testing criteria used to determine the presence of emissions. In this study, testing criteria included a reproducibility greater than 50 %, stimulus stability 75% or greater, peak stimulus target at 80±3 dBSPL and 260 sweeps averaged. However, in Adian 's study the presence of emissions was based on reproducibility greater than 60% and 64-256 sweeps averaged.

In this study showed a tendency that the overall CEOAEs amplitude in female were greater than those of male subjects. However, statistical analysis failed to reveal any significant difference of the overall CEOAEs amplitude between genders. Further study by increasing the number of subjects more than the present study should be determined.

3. The CEOAEs SNR for half octave frequency band at 1, 1.5, 2, 3 and 4 kHz in the left and right ears of full term neonates

In this study the CEOAEs SNR in the right ears were greater than in the left ears at all the tested frequencies, but failed to reveal any significant difference as showed in table 4. There was little information regarding ear differences of CEOAEs SNR in neonatal subjects. The results of this study were similar to Newmark et al (13) in some aspects. They obtained CEOAEs from 118 and 120 ears of male and female subjects, respectively. They found no significant difference of CEOAEs SNR between ear side for female subjects at all frequencies tested and for male subjects at 1, 3, 4, and 5 kHz. However, a significant difference of CEOAEs SNR between ear side occurred only at 2 kHz in male subjects, that might be due to the greater mean differences of CEOAEs SNR at this frequency than the remaining frequencies. They pointed out that the inter-aural emissions differences in these findings might be associated with the efferent auditory activity, which was primarily associated with auditory inhibition. There were some reasons that might account for the varying results. First, Newmark et al obtained CEOAEs from a large group of neonatal subjects for both genders. Second, they analyzed the CEOAEs SNR between ear side across the tested frequencies from each group of male and female subjects separately. However, in this study the CEOAEs SNR in the left and right ears were analyzed from both genders and did not found any significant difference between ear side. Third, non-auditory factors such as head size and body weight were considered in Newmark's study that was difference from this study.

This study showed a tendency that the CEOAEs SNR in the right were greater than in left ears. However, no significant difference of CEOAEs SNR between ear side was found. Further study by increasing the number of subjects for both genders and multi-variance analysis should be considered.

4. The CEOAEs SNR for half octave frequency band at 1, 1.5, 2, 3 and 4 kHz in male and female full term neonates

In this study the CEOAEs SNR in female were greater than those of male full term neonates at almost the tested frequencies, but failed to reveal any significant at all test frequencies showed in table 5.

The effect of gender on CEOAEs measurement in infants was reported by Driscoll et al (67). They obtained CEOAEs from 96 males and 113 females in a quiet state at the age ranged form 1.5 to 2.5 months (mean age = 2 months). The CEOAEs were analyzed between ear side separately for both genders. Their results showed a significant difference for CEOAEs SNR across gender that females had greater CEOAEs SNR at 2.4, 3.2 and 4 kHz than those of male subjects for the left and the right ears. Discrepancy of the results from this study and those from Driscoll et al might be due to difference in the number of ears tested, difference in subjects age, and difference in statistical analysis.

Fuse et al (66), obtained CEOAEs from 42 normal hearing adult subjects, the CEOAEs amplitudes from the left and right ears from both genders were analyzed at the frequencies 0.5, 1, 2 and 4 kHz that were different from this study. However, similar finding in some aspects between studies was found. They found that the CEOAEs SNR for the left and right ears in both male and female subjects did not showed any significant difference across frequencies tested.

As discussed above the results of this study showed a tendency that the overall CEOAEs amplitude and the CEOAEs SNR were greater in the right than in left ears and in female than in male subjects. However, no significant difference of the overall CEOAEs amplitude and CEOAEs SNR between ear and between genders occurred. Further study about some factors that might effected the CEOAEs measurements are suggested. First, the CEOAEs measurement should be obtained from a large group of neonatal subjects for both genders and multi-variance analysis should be determined. Second, criteria used to select the subjects such as head size and body weight that were differences from the present study need to be considered.

5. The DPOAEs SNR at 1, 1.5, 2, 3, 4, 5 and 6 kHz in the left and right ears of full term neonates

In this study the DPOAEs SNR in the right were greater than in the left ears at all tested frequencies, however, a significant difference of DPOAEs SNR occurred at 2 and 4 kHz (P< 0.05 and < 0.01). No comparison data of DPOAEs SNR across the tested frequencies between ear side in neonatal subjects was reported.

In adult subjects, there were some evidences showed that the DPOAEs responses from both ears of the same individual were correlated (57, 68). Lonsbury-Martin et al (68) obtained DPOAEs from normal hearing adults. They found that the DPOAEs amplitude were similar between ears of the same subjects. Statistical analysis (Pearson 's product correlation coefficient) was also supported this notion that there was a strong relationship between the emission amplitude from both ears of each subject regardless of the test frequencies. In this manner, the correlation of DPOAEs responses between ears of the same subject could be described that when the DPOAEs response in the left ear was high the right ear would be also. These findings implied that both ears of adult subjects were equally capable of generation a considerable amount of biomechanical activity across the frequency range.

Because of the criteria used or methods to measure DPOAEs such as primary levels, frequency ratios were different across study, the effect of ear side on DPOAEs measurements was controversial and needed more comprehensive studies from different age groups (59, 70). In this study there was considerable variability of DPOAEs SNR between subjects and within subjects, across the test frequencies. Some ears demonstrated peaks and troughs unique to the individual. These variabilities of DPOAEs SNR might be caused by the differences in the outer ear and middle ear resonances of individual subjects that had an influence on DPOAEs measurements. Although a significant difference between ear side of DPOAEs SNR occurred at 2 and 4 kHz, there was less significant for average ear side differences in DPOAEs measurement, or to be of clinical significance.

6. The DPOAEs SNR at 1, 1.5, 2, 3, 4, 5 and 6 kHz in male and female full term neonates

In this study, there was no significant difference of DPOAEs signal between male and female full term neonates as showed in table 7. No comparison data of DPOAEs SNR across the test frequencies between genders was reported in neonatal subjects. However, the effect of gender on DPOAEs measurement was reported in adult subjects (58, 60, 69). Cacace et al (58) and Gaskill et al (60) found that DPOAEs amplitudes in female subjects were greater than those of male subjects, that might be due to better auditory thresholds in female than those of male subjects. Although Kimberly 's study (69) suggested that anatomical difference in cochlear length between male and female adult subjects might influence the DPOAEs responses, however, no anatomical studies between gender in neonatal subjects has been reported.

Because of the criteria used or methods to measure DPOAEs such as primary levels, frequency ratios were different across study, the effect of gender on DPOAEs measurements was controversial and needed more comprehensive studies from difference age groups (60, 70). Inaddition, there was inadequate information or standard criteria to explain all aspects about gender difference in DPOAEs measurements. Therefore, normative data for male and female subjects especially in neonate separately have received little attention in the literature.

7. The correlation coefficient (r) between CEOAEs and DPOAEs amplitude in the same ear of full term neonates for half octave frequency at 1, 1.5, 2, 3 and 4 kHz

The results in table 8 and the illustrated in figure 16B – 16E, showed the significant positive correlation between CEOAEs and DPOAEs amplitude at 1.5, 2, 3 and 4 kHz, which the strongest correlation existed at 4 kHz (p-value 0.000). These findings implied that when one type of OAEs was increased, the other would be also. For low frequency at 1 kHz there was no correlation between both types of OAEs, which might probably be caused by high noise level that obscured the amplitude of CEOAEs and DPOAEs in some subjects. In the present study the correlation between two types of OAEs in the same ear of full term neonates supported the notion that both CEOAEs and DPOAEs were derived from similar mechanisms in the cochlea (49, 71).

These findings were similar to previous study by Smurzynski et al (19), who showed a significant correlation between the CEOAEs and DPOAEs RMS levels in each half octave frequency bands at 1.4, 2, 2.8 and 4 kHz obtained from full term neonates. They suggested that some common mechanisms were involved in the generation of CEOAEs and DPOAEs in the human cochlea. Even though the two types of OAEs exhibited some differences, they were both believed to arise from nonlinear active biomechanical properties of OHCs (24, 29, 59).

CONCLUSION

The purpose of this study was to investigate the difference of the overall amplitude of CEOAEs the SNR of CEOAEs, the SNR of DPOAEs between ear and between genders. The correlation between the CEOAEs and DPOAEs amplitude from the same ears of full term neonates was also investigated. The findings of this study were discussed according to data reported in the literature. The results from this study suggested the following conclusions:

1. No significant difference was found between the left and right ears or between male and female full term neonates with regard to the overall CEOAEs amplitude or the CEOAEs SNR at 1-4 kHz.

2. This study showed a tendency that the DPOAEs SNR were greater in the right than left ears at all frequencies tested. However, significant difference was found at 2 and 4 kHz.

3. No significant difference was found between male and female full term neonates with regard to the DPOAEs SNR at 1-6 kHz.

4. Positive correlation between the CEOAEs and DPOAEs amplitudes was found in the same ear of full term neonates at 1.5 - 4 kHz.

Recommendation

1. This study showed a tendency that the overall CEOAEs amplitude and the CEOAEs SNR were greater in the right than left ears and in female than in male

subjects. However, statistical analysis failed to reveal any significant difference between ear side and between genders. Further study by increasing the number of subject for both genders and multi-variance analysis should be considered.

2. This study showed a tendency that the DPOAEs SNR were greater in the right than left ears and in female than in male subjects. A significant difference between ear side occurred at 2 and 4 kHz that the DPOAEs SNR were greater in the right than left ears. However, no significant difference of DPOAEs SNR between genders was found. These findings suggested that further measurement of DPOAEs by using similar instrument, measurement parameter and criteria used to select the subjects should be considered among studies.

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APPENDIX

Table A-1 Raw data of the overall CEOAEs amplitude and CEOAEs SNR at 1-4 kHz in the right ears of male subjects

No	Age	overall	1 kHz			1.5 kHz			2kHz			3 kHz			4 kHz		
		res.	S	N	SNR	S	N	SNR	S	N	SNR	S	N	SNR	S	N	SNR
1	14	22.2	-2.6	-20.1	17.5	7.6	-21.3	28.9	13.8	-15.5	29.3	10.9	-14	24.9	18.8	-15.5	34.3
2	2	24.1	-5.7	-12.7	7	19	-22.5	41.5	4.4	-13	17.4	16.5	-14.8		3.2	-18.7	21.9
3	2	33.2	11.6	-15	26.6	15.5	-15	30.5	20.8	-21.7	42.5	25.4	-6.8	32.2	14.1	-14.4	28.5
4	2	22.6	4.8	-8.6	13.4	7.5	-13.7	21.2	15.1	-23.8	38.9	9	-19.3	28.3	6.7	-13.5	20.2
5	2	23.5	-5.4	-19.7	14.3	13	-13.7	26.7	16.5	-13.5	30	14.4	-12.6	27	10.7	-14.4	25.1
6	5	15.3	-2.5	-6.8	4.3	2.4	-13.8	16.2	6.8	-15	21.8	5.6	-16.1	21.7	-11.2	-17.2	6
7	1	23.4				9.4	-13.8	23.2	13.1	-15.2	28.3	16.4	-16.9	33.3	15.1	-14.2	29.3
8	15	30.5	7.6	-16.2	23.8	16.3	-16	32.3	12.4	-14.2	26.6	16.6	-16.6	33.2	27	-16.2	43.2
9	2	25.1	15.7	-8.5	24.2	13.1	-14	27.1	10.2	-16.9	27.1	7.3	-17.3	24.6	8.9	-19	27.9
10	4	20.9	0	7.6	7.6	15	-7.8	22.8	9.9	-13.3	23.2	11.8	-14.8	26.6	6.6	-13.3	19.9
11	3	21.8	4.4	-7.6	12	12	-10.1	22.1	1.1	-12.3	13.4	6.6	-15.5	22.1	-1.3	-19.7	18.5
12	14	19.8	-4.4	-13.1	8.7	12.5	-18.5	31	11.4	-10	21.4	12.8	-14.4	27.2	2.7	-15.2	17.9
13	3	19.8	0.9	-16.3	17.2	10.8	-19	29.8	5	-14.5	19.5	9.9	-28.2	38.1	5.3	-17.9	23.2
14	2	26.9	7.9	-11.7	19.6	-1	-17.6	16.6	7.5	-11	18.5	12.9	-10.1	23	23.1	-8.9	32
15	1	19.1	-1.6	-17.9	16.3	1.9	-25	26.9	3.7	-20.9	24.6	12.4	-12.3	24.7	3.6	-17.9	21.6
16	3	25.4	3	-8.4	11.4	13.4	-15.2	28.6	12	-13.3	25.3	15.8	-12.2	28	15.3	-18.4	33.7
17	10	16.3	0.1	-13.7	13.8	-2.2	-16.7	14.5	-0.6	-11.3	10.7	0.9	-9.2	10.1	-0.5	-16.7	16.2
18	1	18.8	-2.2	-14.8	12.6	7.3	-9.4	16.7	5.2	-12	17.2	7	-17.8	24.8	4.5	-12.5	17
19	3	20.1	0.5	-10.1	10.6	0.5	-9.6	10.1	8.3	-14.6	22.9	12.2	-16.8	29	12.9	-14	26.9
20	6	17.8				7.1	-16	23.1	5.7	-7.5	13.2	9.1	-16.1	25.2	11.9	-13.5	25.4
21	2	17.1	-5.3	-18.4	13.1	7	-11.4	18.4	5.2	-14.4	19.6	9.1	-20.7	29.8	-6.3	-21.1	14.8
22	28	21.9	1.3	-9.2	10.5	14.5	-5	19.5	13.2	-9.4	22.6	6.8	-4.4	11.2	6.3	-12.5	18.8

Table A-2 Raw data of the overall CEOAEs amplitude and CEOAEs SNR at 1-4 kHz in the left ears of male subjects

No	Age	overall	1 kHz			1.5 kHz			2 kHz			3 kHz			4 kHz		
		res	S	N	SNR	S	N	SNR	S	N	SNR	S	N	SNR	S	N	SNR
1	14	21.7	-4.6	-16.1	11.5	-0.1	-22	21.9	4.5	-22.5	27	12.9	-19	31.9	11.4	-17.8	29.2
2	2	23	2.5	-9	11.5	15.1	-23	38.1	12.2	-20.3	32.5	10	-20.4	30.4	7.8	-16.9	24.7
3	2	24.2	0	-17.8	17.8	0	-18.9	18.9	7.6	-16.7	24.3	13.7	-16.6	30.3	9.7	-17.2	26.9
4	2	21.6				1.9	-8.2	11.1	13.2	-9.7	22.9	7.6	-14.2	21.8	16.8	-5.2	22
5	2	18.2	-4.9	-13.3	8.4	13.3	-19.9	35.2	2.6	-16.2	18.8	10	-13.3	23.3	3.8	-12.8	16.6
6	5	14.6				-3.8	-22.2	18.4	-2.3	-12.6	10.3	9.3	-17.5	26.8	-4.4	-16.9	12.5
7	1	19.1	-9.7	-15	5.3	1.7	-15.2	16.9	8.4	-15.2	23.6	12.6	-13.2	25.8	7.8	-16.2	24
8	15	29.9	-3.2	-14.8	11.6	1.9	-25.7	27.6	17.8	-21.3	39.1	23.9	-14.2	38.1	11.6	-11.2	22.8
9	2	21.2	3.1	-19	22.1	11.5	-17.2	28.7	11	-13	24	-1.6	-10.8	9.2	7.6	-11.4	19
10	4	20.6	5	-6.3	11.3	11.5	-9.6	21.1	13.3	-9.4	22.7	2.7	-11.9	14.6	13.5	-11.4	24.9
11	3	21.9	6.4	-3	9.4	14.7	-9.4	24.1	5.1	-18.7	23.8	7.8	-12	19.8	0.3	-17.5	17.8
12	14	20.3	-5.1	-11.2	6.1	7.2	-9.6	16.8	5.7	-19.2	24.9	9.6	-15.7	25.3	10.4	-19.2	29.6
13	3	20.1	-0.5	-9.3	8.8	2.9	-22.7	25.6	10.8	-18.7	29.5	11.4	-22.5	33.9	6.2	-16.4	22.6
14	2	19.6				-3.9	-13	9.1	2.9	-16.2	19.1	13.7	-7.2	20.9	10.9	-7.8	18.7
15	1	21.1	-4.9	-13.7	8.8	8.5	-15.7	24.2	12.8	-21.3	34.1	8	-16	24	2.2	-18.7	20.9
16	3	24.8	0	-15.2	15.2	8.2	-13.3	21.5	7.4	-5.7	13.1	19.9	-11.4	31.3	7.3	-16.6	23.9
17	10	21.3	9.6	-24.4	34	9.3	-20.3	29.6	3.2	-18.4	21.6	12.8	-14	26.8	-3.4	-18.9	15.5
18	1	14.9				2.6	-14.2	16.8	9.4	-15.5	24.9	6.2	-17.5	23.7	-5.3	-16.9	11.6
19	3	18.1				5.5	-3.4	8.9	4.9	-11.4	16.3	11.6	-13.3	24.9	3.4	-15.2	18.6
20	6	16	4.8	-6.3	11.1	6.1	-8.8	14.9	-3	-13.7	10.7	8.1	-16.4	24.5	-2.6	-13	10.4
21	2	16.4	-1.9	-21.5	19.6	4.2	-21.9	26.1	1.3	-17.6	18.9	9.5	-19.7	29.2	-5.4	-22.6	17.2
22	28	22	3	-10.4	13.4	14.6	-10.4	25	12.1	-18.4	30.5	8.5	-15.2	23.7	6.8	-15.2	22

Table A-3 Raw data of DPOAEs SNR at 1-6 kHz in the right ears of male subjects

No	Age	1 kHz			1.5 kHz			2 kHz			3 kHz			4 kHz			5 kHz			6 kHz		
		S	N	SNR	S	N	SNR	S	N	SNR	S	N	SNR	S	N	SNR	S	N	SNR	S	N	SNR
1	14	16.1	-5.8	21.9	20.7	-7.1	27.8	14.2	-12.4	26.6	17.3	-10.7	28	11.8	-11.7	23.5	17.3	-11.7	29	22.4	-13.5	35.9
2	2	9.5	-0	9.5	14.1	-1.4	15.5	18.1	-6.9	25	18.6	-10.6	29.2	12.9	13.3	26.2	4.7	-12.2	16.9	17.2	-12	29.2
3	2	12.3	-6.5	18.8	19.9	-7.8	27.7	15.2	-10	25.2	13	-9.3	22.3	17.8	-11	28.8	-1.8	-11.5	9.7	14.9	-12.1	27
4	2	18.1	1.5	16.6	17.7	-0.3	18	25.7	-9.1	34.8	14.6	-10.7	25.3	6	-9.4	15.4	15.1	-11	26.1	11.2	-9.2	20.4
5	2	12	-3.6	15.6	20.8	-4.4	25.2	19.3	-10.6	29.9	17.9	-10.4	28.3	12.3	-11	23.3	15	-11.6	26.6	17.9	-11.1	29
6	5	14.9	-1	16	17.7	-1	18.7	9.5	-10.3	19.8	5.8	-9.7	15.5	8.1	-10.5	18.6	15.4	-10.3	25.7	2.2	-11.9	14.1
7	1	12.1	-2.5	14.6	20.4	-7.9	28.3	23.8	-9.8	33.6	13.5	-11.3	24.8	6.5	-10.8	17.3	21.8	-11.8	33.6	20.3	-10.1	30.4
8	15	4.6	-2.5	7.1	17.6	-7.3	24.9	23	-8.7	31.7	13.4	-12.1	25.5	22.6	-9.6	32.2	29.1	-10.9	40	32.8	-9.9	42.7
9	2	20.5	-1.4	21.9	21.9	-1.7	23.6	19.2	-11.2	30.4	15.1	-11.7	26.8	13.5	-16.5	30	10.3	-12	22.3	14.8	-11.7	26.5
10	4	3.9	-2.4	6.3	6.3	-1.9	16.3	14.9	-1.4	16.3	11.8	-7.9	19.7	17.9	-11.2	29.1	18.4	-8.4	26.8	19.7	-9.5	29.2
11	3	14.3	-1.9	16.2	16.2	-9.8	33.9	23.4	-9.6	33	7.9	-10	17.9	8.6	-11.6	20.2	4.7	-11.4	16.1	2.8	-10.7	13.5
12	14	6.7	-2	8.7	19.6	-4.7	24.3	19.3	-7.9	27.2	13.8	-10.9	24.7	12	-10.6	22.6	16	-11.4	27.4	16.3	-10.1	26.4
13	3	13.1	-3.2	16.3	14.4	-3.2	17.6	21.8	-9.4	31.2	13.1	-9.8	22.9	8.5	-10.8	19.3	22.3	-11.1	33.4	16.9	-12.2	29.1
14	2	11.9	0.5	11.4	11.9	1.6	10.3	4.4	-9.5	13.9	14.3	-7.1	21.4	22.5	-10.8	33.3	24.4	-9.7	34.1	24.7	-7.5	32.2
15	1	2.6	-1.3	3.9	19.1	-2.5	21.6	10	-9.8	19.8	8.1	-12.9	21	6.6	-10.4	17	12.7	-11.3	24	4	-12.3	16.3
16	3	16.9	4.4	12.5	19.9	-1.9	21.8	18.5	-9.2	27.7	5.5	-10.3	15.8	15.5	-10.2	25.7	13.3	-10.9	24.2	13.2	-10.1	23.3
17	10	8.4	-10.4	18.8	12.2	-10.5	22.7	8	-10.2	18.2	-3.1	-10.3	7.2	-3.3	-15.4	12.1	-6.6	-13.7	7.1	0.8	-13.6	14.4
18	1	4.7	-6.6	11.3	9	-6.1	15.1	5.5	-9.4	14.9	4.5	-8.6	13.1	-0.8	-8.8	8	15.8	-9.3	25.1	-2.1	-9.4	7.3
19	3	15.9	-5.3	21.2	12.3	-5.4	17.7	23.2	-10.9	34.1	17.7	-11	28.7	13.8	-12.2	26	25.6	-10.5	36.1	16.9	-10.2	27.1
20	6	3	2.2	5.2	11.6	-6.1	17.7	15.7	-10.8	26.5	5.1	-9.2	14.3	16.4	-14.4	30.8	17.7	-11.8	29.5	11.2	-11.9	23.1
21	2	2.9	-1.5	4.4	13.8	-6.3	20.1	17.4	-11.4	28.8	13.1	-12.9	26	3.6	-11.6	15.2	10.7	-10	20.7	1.8	-10.5	12.3
22	28				16.1	-5	21.1	24	-5	29	20.7	-6.7	27.4	21.7	7.8	29.5	19.1	'-7.7	26.8	10.2	-7	17.2

Table A-4 Raw data of DPOAEs SNR at 1-6 kHz in the left ears of male subjects

No	Age		1 kHz			1.5 kHz			2 kHz			3 kHz			4 kHz			5 kHz		6 kHz		
		S	N	SNR	S	N	SNR	S	N	SNR	S	N	SNR	S	N	SNR	S	N	SNR	S	N	SNR
1	14	15.4	-4.6	20	21.1	-7.6	28.7	16.1	-12.1	28.2	12.5	-10.4	22.9	14.8	-12.7	27.5	24.8	-12.1	36.9	21.4	-12.1	33.5
2	2	8.1	2.5	5.6	18.4	-4.3	22.7	12.6	-6.1	18.7	4	-9.7	13.7	3.5'	-12.4	15.9	15.8	-9.7	25.5	'11.8	-13.2	25
3	2	2.2	-5.6	7.8	12.2	-6.5	18.7	14.6	-10.1	24.7	1.8	-10.1	11.9	20.5	-10.3	30.8	13.7	-9.5	23.2	14.4	-10	24.4
4	2	13	4.5	8.5	21.4	-4.8	26.2	23	-10.9	33.9	16.8	-9.5	26.3	9.1	-7.4	16.5	5.9	-10	15.9	6.2	-11.5	17.7
5	2	8.3	-0.9	9.2	19.3	-6.9	26.2	20.5	-11	31.5	14.8	-11.5	26.3	6.2	-11.2	17.4	10.9	-10.3	21.2	15	-9.8	24.8
6	5	18.7	1.9	16.8	21.4	0.4	21	14.8	-4.6	19.4	15.4	-10.4	25.8	7	-10.1	17.1	16.5	-11.6	28.1	6.8	-9.8	16.6
7	1	6.6	-2.7	9.3'	17.5	-7.5	25	15.8	-10.7	26.5	7.2	-10.9	18.1	4.3	-11.5	15.8	5.4	-10.1	15.5	11.3	-14.9	26.2
8	15	16.6	-4.3	20.9	19.2	-9.4	28.6	14.6	-9.6	24.2	8.2	-10.6	18.8	3.3	-11.3	14.6	38.8	-8.8	47.6	3	-9.8	12.8
9	2	9.5	-3.1	12.6	16.7	-1.8	18.5	14.1	-10.1	24.2	10.3	-9.4	19.7	12.7	-9.1	21.8	9.6	-12.7	22.3	15.9	-9.6	25.5
10	4	17.7	-11.7	28.9	10.6	-10.9	21.5	6.5	-10.3	16.8	23.4	-9.7	33.1	23.3	-4.2	27.5	22.1	-3.3	25.4	15.5	3.2	12.3
11	3	10.3	-1.7	12	18.4	-.3	21.4	22.3	-6.8	29.1	6.1	-10.3	16.4	8.7	-9.9	18.6	11.7	-11.2	22.9	15.8	-11.2	27
12	14	3.3	-1.2	4.5	17.4	-3.9	21.3	14.6	-5	19.6	14.4	-9.5	23.9	13.3	-10.1	23.4	18.5	-10.3	28.8	9.7	-9.9	19.6
13	3	9.5	-3.8	13.3	9.8	-3.2	13	15.4	-9.9	25.3	6.6	-10.3	16.9	-0.4	-10.9	10.5	15.2	-10.5	25.7	14.3	-11	25.3
14	2	11	5.7	5.3	5.8	0.9	4.9	0	-6.6	6.6	10.8	-11	21.8	16.8	-10.3	27.1	21.1	-11.6	32.7	23.6	-10	33.6
15	1	16.2	-4.1	20.3	17.9	-10.5'	28.4	8.2	-11.2	19.4	7.3	-10.9	18.2	-0.7	-13.8	13.1	5.4	-11.4	16.8	0.4	-11.1	11.5
16	3	10.8	7.2	3.6	23.7	4.2	19.5	19.6	-3.7	23.3	6.5	-9.3	15.8	1	-10	11	4.2	-10.3	14.5	5.9	-9.5	15.4
17	10	3.4	-5.4	8.8	9.2	-6.2	15.4'	7.9	-10.2	18.1	14	-12.3	26.3	13	-10.5	-23.8	7.4	-10.7	18.1	3.8	-13	16.8
18	1	11.7	-2.6	14.3	17.2	-4.4	21.6	11.2	-5.9	17.1	-2.6	-10.9	8.3	2.1	-8.3	10.4	1.9	-8.9	10.8	-2.3	-9.4	7.1
19	3	5	-7	12	15.2	-10.1	25.3	15.7	-10.8	26.5	-3.3	-12	8.7	-3.7	-11.2	7.5	13.1	-15.9	29	14.3	-10.5	24.4
20	6	6.3	-0.4	6.7	3	-2.5	5.5	2.2	-6.	8.2	0.2	-9.4	9.6	8.6	-9.4	18	19.9	-9.7	29.6	7.8	-9.4	17.2
21	2				9.7	-11	20.7	5.6	-11	16.6'	5.1	-10.3	15.4	-0.1	-9.7	9.6	-6.2	-11.3	5.1			
22	28				15.4	-3.6	19	19	-6.1	25.1	12.8	-6.2	19	6.5	-6.5	13.4	5.1	-6.4	11.5			

Table A-5 Raw data of the overall CEOAEs amplitude and CEOAEs SNR at 1-4 kHz in the right ears of female subjects

No	Age	overall		1 kHz		1.5 kHz			2kHz			3 kHz			4 kHz		
		res.	S	N	SNR	S	N	SNR	S	N	SNR	S	N	SNR	S	N	SNR
1	3	20.1	-0.1	-11.3	11.2	7.4	-16.4	19.6	7.3	-12.2	19.5	10.6	-16.7	27.3	10.8	-23.2	34
2	2	16.8	4.7	-13.1	17.8	9.1	-15.5	29.4	4	-17.1	21.1	5.8	-15.4	21.2	5.1	-14	19
3	7	30.4	4.4	-14.2	18.6	23.1	-11.9	30.6	21.8	-15.5	37.3	15.9	-21.7	37.6	20.3	-19	39.3
4	4	28.1	1.6	-11.3	12.9	7.6	-10	27.1	13.7	-16.3	30	24.9	-12.7	37.6	17.5	-17.6	35.1
5	1	18.5	5	-12.6	17.6	-1	-10.4	19.4	5.	-18.7	23.9	10.6	-13.2	23.8	-7.5	-19.7	12.2
6	1	26.1	12.2	-11.7	23.9	20.5	-14.8	13.9	3.8	-22.7	26.5	13.7	-19.7	33.4	-0.6	-22.2	21.6
7	1	24	6.9	1.3	5.6	4.1	-7.3	36.1	6.8	-16.7	23.5	18.2	-15.2	33.4	4.6	-16.7	21.3
8	1	25.5	-2	-8.4	6.4	10.2	-14	26.2	11.7	-7.4	19.1	17.5	0.1	17.4	16.7	-14.8	31.5
9	16	21.9	6	-7.6	13.6	9.9	-15	41.3	11.3	-16	27.3	13.1	-10.8	23.9	10.1	-13.2	23.3
10	18	19	-7	-12.8	5.8	-1.4	-15.5	14.2	4	-15.6	19.6	4.1	-16.2	20.3	14	-13.8	27.8
11	2	17.6	-0.6	-8.6	8	0.7	-9.4	23.8	3.3	-5.2	8.5	3.1	-4.9	8	8	-8.3	16.3
12	2	24.3	2.4	-9.4	11.8	17	-18.5	24.6	10.4	-18.5	28.9	9.7	-16.6	13.1	13.1	-24.1	37.2
13	12	27.8	4.8	-10	14.8	9.3	-10.3	35	8.4	-12.2	20.6	9.4	'-15	24.4	11.6	-11.7	23.3
14	2	23.7	-6.3	-21.9	15.6	10.2	-19.2	17.6	10.3	-13.9	24.2	17.4	-17.1	34.5	5.1	-14	19.1
15	2	23.2	-4.1	-20.4	16.3	9.7	-20.9	9.4	10.2	-21.5	31.7	12.9	-16.7	29.6	9.9	-17	26.9
16	2	25.8	1.4	-20.3	21.7	8.4	-18.7	35.3	12.6	-19.7	32.3	15.2	-16.1	31.3	19	-5.9	24.9
17	3	14.3	-4.1	-16.2	12.1	3.4	-16	11.2	2.5	-15.5	18	4.6	-15.6	20.2	0.9	-17.6	18.5
18	2	18.9	7.6	-9.9	17.5	2.5	-11.4	24.2	10	-7.4	17.4	9.2	-11.4	20.6	3.3	-22.5	25.8
19	2	24.9	6.5	-18.7	25.2	20.1	-16	24.9	12.6	-19	31.6	10.6	-18	28.6	18.4	-5.9	24.3
20	3	25.6	-0.6	-4.1	3.5	10.7	-15.5	14.1	17	-19	36	14	-14.4	28.4	4.2	-13.3	17.5
21	3	25.9	8	-11.3	19.3	17.5	-23.8	10.1	16.5	-15.2	31.7	12	-15.2	27.2	8.6	-19.7	28.3
22	3	17.1	-2.8	-20.9	18.1	-3.3	-17.5	35.5	1	-19.9	20.9	10.7	-21.5	32.2	-1.7	-14.6	12.9

Table A-6 Raw data of the overall CEOAEs amplitude and CEOAEs SNR at 1-4 kHz in the left ears of female subjects

No	Age	overall	1 kHz			1.5 kHz			2kHz			3 kHz			4 kHz		
		res.	S	N	SNR	S	N	SNR	S	N	SNR	S	N	SNR	S	N	SNR
1	3	17	7.4	-15.2	22.6	10	-10.5	20.5	6.3	-9.7	16	0.7	-14.2	14.9	1.5	-12.9	14.4
2	2	15.3	-10.4	-26.1	15.7	-2.6	-17.1	14.5	3.2	-22.7	25.9	8.5	-14.2	22.7	0.5	-14	14.5
3	7	29.5	-3.2	-16.7	13.5	8.4	-13.5	21.9	10.9	-19	29.9	22.7	-14.4	37.1	19.7	-16.9	36.6
4	4	23.4	2.7	-9	11.7	9.3	-13	22.3	15	-17.9	32.9	16.9	-11.9	28.8	15	-16.9	31.9
5	1	16.3	-4.9	-13	'8.1	5.7	-15.9	21.6	-1	-18.5	17.5	8.8	-18.4	27.2	-3.9	-24.1	20.2
6	1	23.3	4.5	-5.7	10.2	9.5	-18.4	27.9	16.6	-11.3	27.9	15.7	-16.2	31.9	8.3	-15	23.3
7	1	21.5				4.4	-7.5	11.9	7.8	-10.9	18.7	10.9	-6.2	17.1	11.8	-16.2	28
8	1	25	'3.2	-7.8	11	12.4	-14.6	27	14.1	-12.2	26.3	17.6	-7.8	25.4	15.2	-14	29.2
9	16	19.4				4	-10.4	14.4	5.6	-15.2	20.8	9.9	-14.6	24.5	10.8	-7.3	18.1
10	18	17.5				-4	-15.7	11.7	3.1	-21.7	24.8	10.6	-15.2	25.8	5.4	-17.2	22.6
11	2	16				2.7	-8.9	11.6	3.7	-11.4	15.1	3.7	-5.4	9.1	8.6	-11.4	20
12	2	21.4	-7	-12.6	5.6	7.9	-16.9	24.8	5.4	-14	19.4	8.5	-8	26.5	20	-19.3	39.3
13	12	22.5	-2	-12	10	12.6	-17.3	29.9	6.5	-8.8	15.3	13.4	-16.1	29.5	12.4	-14.6	27
14	2	18.5	-9.7	-17.1	7.4	-0.5	-15.2	14.7	9.6	-14.7	24.3	7.3	-18	25.3	3.5	-16.7	20.2
15	2	23	-1	-17.2	16.2	7.1	-21.7	28.8	6.9	-20.7	27.6	18	-17.2	35.2	10	-13	23
16	2	21.5	4.1	-19.7	23.8	5.7	-15	20.7	16.7	-13.4	30.1	-0.1	-12.9	12.8	-3.4	-16.2	12.8
17	3	15	-4.3	-26.1	21.8	4.3	-18.9	23.2	-6.2	-19.2	13	4.3	-17.2	21.5	4.1	-17.3	21.4
18	2	20.8	-0.8	-8.8	8	13.4	-8.9	22.3	9.8	-12.3	22.1	-1.3	-20.1	18.8	-2.8	-11.7	8.9
19	2	28.9	1.4	-10.8	12.2	15.2	-15.4	30.6	15.9	-22.5	38.4	26.6	-8.6	35.2	12.2	-19	31.2
20	3	28				14.7	-16.2	30.9	12.9	-21.7	34.6	17.3	-19	36.3	20.3	-16.6	36.9
21	3	29.8	25	-9.7	34.7	20.8	-9.8	30.6	15.8	-24.7	40.5	11.8	-18.4	30.2	10.2	-19	29.2
22	3	17.8	-9.2	-12.3	3.1	-3.4	-16.9	13.5	-1	-17.2	16.2	14	-16.7	30.7	8.1	-13.3	21.4

Table A-7 Raw data of DPOAEs SNR at 1-6 kHz in the right ears of female subjects

No	Age	1 kHz			1.5 kHz			2 kHz			3 kHz			4 kHz			5 kHz			6 kHz	
		S	N	SNR	S	N	SNR	S	N	SNR	S	N	SNR	S	N	SNR	S	N	SNR	S	N
1	3	14.2	-4.1	18.3	22.7	-9.6	32.3	21.1	-9.9	31	15	-9.7	24.7	18.5	-12.1	30.6	16.4	-12.6	29	16.6	-12.9
2	2	7.7	0.8	8.5	14.6	-2.7	17.3	18.3	-6.6	24.9	4.4	-14.8	19.2	5.7	-12.9	18.6	4.4	-12.4	16.8	7.2	-13.3
3	7	2.8	-5.4	8.2	23.9	-8.1	32	21.7	-9	30.7	23.8	-10	33.8	21.6	-11.7	33.3	29.1	-10.1	39.2	18.9	-10.3
4	4	13.6	-3.5	17.1	18.3	-2.7	21	16.4	-11.1	27.5	18	-12.4	30.4	17	-11.8	28.8	23.9	-11.7	35.6	10.3	-10
5	1	16.5	-4.2	20.7	20.3	-7.9	28.2	16.7	-9.7	26.4	4	-11.7	15.7	'4.1	-11.4	15.5	10.9	-11	21.9	-1.7	-12.1
6	1	20.7	-2.5	23.2	27.9	-2.9	30.8	24.1	-7.9	32	6	-13.3	19.3	17.6	-9.7	27.3	23.3	-13.1	36.4	25.7	-11.2
7	1	14.5	6.4	8.1	11.7	3.5	8.2	16.9	1.9	15	20.4	-9.5	29.9	24.5	-10.1	34.6	20.7	-10	30.7	7	-11.8
8	1	19.3	-1.5	20.8	21.2	-4.6	25.8	25.3	-10.3	35.6	-0.5	-12	11.5	15.5	-11.9	27.4	20.6	-12	32.6	23.6	-13.4
9	16	6.3	-1	7.3	17.1	-1.3	18.4	21.4	-6.1	27.5	14.5	-10	24.5	17.1	-11.1	28.2	15.3	-10	25.3	12.9	-9.6
10	18				15	-1.4	16.4	16.9	-8.6	25.5	7.3	-10.5	17.8	10.6	-11.3	21.9	6.1	-11.3	17.4	15.5	-9.7
11	2	11.7	-1.9	13.6	18.7	-5.5	24.2	20	-8	28	16.1	-10	26.1	15.3	-10.3	25.6	18.5	-10.8	29.3	18.3	-9.3
12	2	16.6	-3.2	-19.8	20.6	-3.3	23.9	27.1	-9.4	36.5	15.8	-9.9	25.7	9.7	-10.1	19.8	24.2	-10.8	35.2	17.7	-11.3
13	12	-0.6	-4.1	3.5	7	-8.9	15.9	20.9	-9.8	30.7	13.5	-9.4	22.9	16.2	-9	25.2	5.8	-10.1	15.9	-4.9	-10.4
14	2	-2.1	-6	3.9	6.6	-5.5	12.1	6.3	-7.7	14	13.9	-8.1	22	22.8	-10.1	32.9	9.3	-10.7	20	4.2	-9.9
15	2				15.9	-2.6	18.5	12.9	-10.2	23.1	12.8	-11.9	24.7	20.1	-9.9	30	19.4	-10.1	29.5	16.8	-10.7
16	2	10.6	-7.5	18.1	19.4	-3.6	23	15.7	-5.5	21.2	7.3	-12.6	19.9	6.2	-10.6	16.8	18.3	-11.2	29.5	17.5	-12.5
17	3	10.8	-7.5	18.3	9.1	-7.2	16.3	21.6	-9.6	31.1	16.3	-12.5	28.8	18.8	-12.1	30.9	23.4	-9.6	33	13.3	-13.1
18	2				6.5	-7.1	13.6	6.7	-10.1	16.8	8.8	-9.9	18.7	9.2	-10.7	19.9	8.3	-18.7	27	0.6	-14
19	2	1.7	-2.6	4.3	16.2	-9	25.2	19.3	-12.5	31.8	5.1	-10.1	16.2	2.5	-10.5	13	12.9	-10.5	23.4	5.9	-11.3
20	3	13.5	-2.3	15.8	23.6	-10.5	34.1	25.9	-10.4	36.3	15	-11	26	16.7	-10.5	27.2	11.4	-11.6	23	14.4	-10.2
21	3	2.4	-2.3	4.7	10.7	-5.1	15.8	16.5	-9.2	25.7	19.6	-10.8	30.4	15	-9.9	24.5	24.4	-9.7	34.1	20.2	10
22	3				16.6	-4.2	20.8	15.8	-6.9	22.7	9.9	-10.1	20	12.8	-10.1	22.9	11.2	-10.8	22	-0.7	11.7

Table A-8 Raw data of DPOAEs SNR at 1-6 kHz in the left ears of female subjects

No	Age	1 kHz			1.5 kHz			2 kHz			3 kHz			4 kHz			5 kHz			6 kHz		
		S	N	SNR	S	N	SNR	S	N	SNR	S	N	SNR	S	N	SNR	S	N	SNR	S	N	SNR
1	3	12	2.7	9.3	24.3	1.3	23	15.2	-8.5	23.7	2.9	-9.6	12.5	4.9	-10.5	15.4	16.5	-9.5	26	7	-10	17
2	2	-2.9	-7.3	4.4	6.5	-3.2	9.7	7.6	-7.3	14.9	6.4	-10.9	17.3	2.8	-8	10.8	9.1	-12	21.1	7.7	-13.6	21.3
3	7				10.5	-8.2	18.7	15.9	-7.5	23.4	21.5	-10.6	32.1	8.6	-6.9	15.5	14.9	-8.5	23.4	10.5	-7.8	18.3
4	4	14	-7.2	21.2	15.5	-11.5	27	13.3	-10.6	23.9	8.6	-12.2	20.8	12.9	12.4	25.3	17	-13.4	30.4	18.3	-10.1	28.4
5	1	13.3	-0.7	14.	20.4	-1.6	22	14.6	-9.4	24	13.4	-10..4	23.8	17.2	-10.4	27.6	9.3	-10.3	19.6			
6	1	16.2	-1.9	18.1	25.2	-3.7	28.9	25.3	-8.9	34.2	18.3	-12.8	31.1	19.4	-10.3	29.7	19.9	-11.6	31.5	12.9	-9.9	22.8
7	1	15	-0.2	15.2	19.3	-4	23.3	26.5	-10.4	36.9	26.2	-10.4	36.6	26.6	-9.8	36.4	18.4	-10.7	29.1	12.1	-11.2	23.3
8	1	14.8	2.4	12.4	22.8	-4.3	27.1	23.6	-12.3	35.9	21.7	-11.9	33.6	18.2	-11	29.2	23.8	-10.1	33.9	30.2	-11.5	41.7
9	16	8.7	-0.2	8.9	9.5	-4.3	13.8	17.1	-4.6	21.7	9.9	-10.2	20.1	5.9	-10	15.9	9.9	-10.1	20	7.4	-11.6	19
10	18					-6.1	6.7	11.2	-10.5	21.7	7	-11.6	18.6	10	-13.3	23.3	8.5	-10	18.5	11.5	-12.3	23.8
11	2	3.2	-1.8	5	16.6	-1.6	18.2	13.9	-4.1	18	8.3	-6.3	14.6	2.4	-7.4	9.8	13.5	-5.4	18.9	1	-7.5	8.5
12	2	2.5	-1.2	3.7	12.5	-1.2	13.7	15.4	-8.3	23.7	19.7	-9.7	29.4	17	-11.9	28.9	18.3	-13.7	32	17.4	-10.8	28.2
13	12				11.3	-8.2	19.5	14.8	-8.4	23.2	20.9	-8.6	29.5	21.7	-10.1	31.8	23.3	-10.1	33.4	21	-10.4	31.4
14	2	12.5	-7.8	20.3	20	-7	27	8.5	-8	16.5	6.8	-9.5	16.3	15.3	-10.6	25.9	14.3	-10.4	24.7	3.4	-9.5	12.9
15	2	9.8	-2.6	12.4	18.5	-8.6	27.1	21.4	-10.4	31.8	5.1	-9.8	15.9	13.1	-11.1	24.2	21	10	31	10.8	-10.6	21.4
16	2	5.5	-6.7	12.2	18.4	-5.4	23.8	16.4	-8.7	25.1	1.7	-10.3	12	-0.7	-14.3	13.6	-8	-18.8	10.8	10.5	-11.3	21.8
17	3	9	-10.2	19.2	15.8	-9.8	25.6	13.2	-9.7	22.9	13.4	-10.1	23.5	20.5	-10.7	31.2	21.8	-12.4	34.2	16	-15.9	31.9
18	2	9.5	-1.3	10.8	20.2	-4.7	24.9	7.4	-7.9	15.3	0.2	-11	11.2	-1.3	-10.4	9.1	4.9	-11.5	16.4	-6.3	-10.6	4.3
19	2	11.9	-5.6	17.5	7.4	-6.8	14.2	18.4	-10	28.4	9.1	-10.8	19.9	-4.7	-10	5.3	9.2	-12.9	22.1	9.4	-12.3	21.7
20	3	16.3	-2.9	19.2	25.4	-10	35.4	30.8	-11.8	42.6	13.7	-11	24.7	16.6	-11.4	28	23.6	-10.8	34.4	7	-10.3	17.3
21	3	8	-1.7	9.7	25.3	-4.2	29.5	17.3	-3.8	21.1	17.1	-11.5	28.6	11	-9.6	20.6	16.4	-10.2	26.6	2.5	-10.1	12.6
22	3				6.8	-3.2	10	11.9	-6.2	18.1	7.1	-9.5	16.6	6	-10.4	16.4	7.2	-12.5	19.7	-1.1	-9.8	8.7

BIOGRAPHY

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