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Comparison among Steady State Evoked Potential, Tone Burst Auditory Brainstem Response and Pure Tone Audiometry in Hearing Evaluation of Adults with Normal Hearing

Dissertation submitted in partial fulfillment for the Degree of Bachelor of Health Science (Audiology)

MOHD IKHWAN MUSLIMIN BIN MOHD ZAINUDIN

School of Health Science
Universiti Sains Malaysia
Health Campus
16150, Kubang Kerian, Kelantan
Malaysia

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CERTIFICATE

This is to certify that the dissertation entitled

"Comparison among Steady State Evoked Potential, Tone Burst Auditory Brainstem Response and Pure Tone Audiometry in Hearing Evaluation of Adults with Normal Hearing"

Is the confidential record of research work done by

Mr Mohd Ikhwan Muslimin bin Mohd Zainudin

During the period 2 July 2008 to 17 May 2009

Under my supervision.

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ABSTRACT

Hearing level can be obtained using subjective or objective tests. An objective test is always preferred if the subjective test cannot be performed appropriately or if its outcomes are questionable. Auditory Brainstem Response (ABR) is a common objective test conducted to predict behavioral hearing thresholds. However, it requires a 'subjective' interpretation of the outcomes by a tester. Steady State Evoked Potential (SSEP) is the latest electrophysiological test invented to serve a similar purpose. SSEP has gained a lot of attention lately because the hearing thresholds are determined objectively. The aim of this study was to make comparison between SSEP and tone burst ABR in relation to Pure Tone Audiometry (PTA) in hearing evaluation of adults with normal hearing. Fifthteen students of USM Health Campus (30 ears, mean age of 23 ± 2.85 years) participated in this study. All subjects had normal hearing in both ears (hearing level of 20 dBHL or below between 250-4000 Hz range), as indicated by PTA. In the main testing, ABR and SSEP thresholds were obtained at frequencies of 500, 1000, 2000 and 4000Hz bilaterally from each subject. Tone bursts used in the ABR employed 2-0-2 cycle configuration, presented at rate of 21/s. The presence of wave V at particular levels was determined by testers. SSEP recording was obtained using Sinusoidally Amplitude Modulated (SAM) tones, presented at specific modulation rate (more than 80 Hz) for each frequency. SSEP thresholds were determined using F-statistical analysis. Initial analysis revealed that ABR and SSEP thresholds were significantly different from PTA thresholds, at all frequencies ($p<0.05$). Further analysis found that SSEP thresholds showed a higher correlation with behavioral thresholds at all frequencies tested, as compared to ABR. These findings are consistent with previous studies. The clinical usefulness of SSEP over ABR in predicting hearing thresholds of normal subjects is evident, at least in this study.

ABSTRAK

Tahap pendengaran seseorang individu dapat ditentukan melalui ujian pendengaran secara subjektif dan objektif. Ujian objektif sering dijalankan apabila ujian subjektif tidak dapat dilakukan atau keputusan yang diperolehi tidak memuaskan. Ujian *Auditory Brainstem Response* (ABR) adalah contoh ujian objektif yang digunakan untuk menganggar tahap ambang pendengaran. Namun, keputusan yang diperolehi memerlukan pengtakrifan secara subjektif oleh penguji. *Steady State Evoked Potential* (SSEP) merupakan teknologi terkini ujian objektif. SSEP semakin mendapat perhatian umum kerana tahap ambang pendengaran ditentukan secara objektif. Matlamat kajian ini ialah untuk membuat perbandingan di antara ujian SSEP dan ABR dengan *Pure Tone Audiometry* (PTA) dalam menilai tahap ambang pendengaran golongan dewasa yang mempunyai pendengaran normal. 15 subjek yang terdiri daripada pelajar Universiti Sains Malaysia, Kampus Kesihatan (30 telinga, purata umur 23 ± 2.85 tahun) menyertai kajian ini. Kesemua subjek mempunyai tahap pendengaran normal di kedua-belah telinga (20dBHL atau kurang di antara julat frekuensi 250Hz hingga 4000Hz), daripada ujian PTA. Semasa ujian dijalankan, tahap pendengaran ambang ABR dan SSEP pada frekuensi 500, 1000, 2000 dan 4000Hz untuk kedua-dua belah telinga diperolehi. Stimulus ABR menggunakan konfigurasi kitaran 2-0-2 dengan kadar stimulasi 21/s. Kewujudan gelombang V pada tahap tertentu ditentukan oleh penguji. SSEP menggunakan stimulus *Sinusoidally Amplitude Modulated* (SAM) yang diuji pada kadar modulasi tertentu (melebihi 80Hz) untuk setiap frekuensi. Tahap ambang pendengaran ditentukan melalui analisis F-statistik. Analisis awal mendapati keputusan ABR dan SSEP adalah berbeza daripada keputusan PTA pada semua frekuensi ($p < 0.05$). Analisis lanjut menunjukkan keputusan SSEP mempunyai hubungan yang paling hampir dengan keputusan PTA pada

semua frekuensi, berbanding ABR. Keputusan yang diperolehi daripada kajian ini adalah bertepatan dengan kajian lepas. Kelebihan secara klinikal ujian SSEP berbanding ABR bagi tujuan menganggar tahap ambang pendengaran golongan normal telah terbukti, sekurang-kurangnya dalam kajian ini.

CHAPTER 1

INTRODUCTION

Since 1980, Auditory Brainstem Response (ABR) has test been a famous for differential diagnosis purposes among difficult-to-test patients. The Steady State Evoked Potential (SSEP), a new diagnostic tool used for the same purposes but provides results in a different format. Both auditory evoked potential (AEP) tests can provide objective threshold estimation without the need of behavioral response from the subject. It has been suggested that SSEP is better for predicting thresholds for subject with moderate to profound hearing loss rather than normal hearing or mild hearing loss. ABR, on the other hand, shows the opposite outcomes, it is better to give accurate prediction of subjects with normal hearing and mild hearing loss. In this regard, it was of interest of this study to determine the outcomes of these electrophysiological (ABR and SSEP) in comparison to the Pure Tone Audiometry (PTA), as an attempt to answer which objective test is more closely related to behavioral threshold in subjects with normal hearing.

Hearing loss is simply defined as abnormal or reduced hearing sensitivity. It is measured as the number of decibels that the intensity of a tone must be raised beyond the normal threshold value, so that the tone can be detected. Hearing loss can be classified as organic or non-organic. Non-organic hearing loss is a variety of hearing deficits in which there is no apparent anatomic or physiological explanation. Organic hearing loss occurs due to some disruptions affecting external, middle and inner ears. In this respect, organic hearing losses may include conductive, sensory and neural part. For instance, a patient with cochlear damage is said to have sensorineural hearing loss. Hearing loss can also be described in terms of its severity: mild loss (30-45dBHL), moderate loss (46-65dBHL), severe loss (66-95dBHL) and profound loss (>95dB).

To determine hearing status, there are two types of test can be performed: subjective and objective tests. Subjective test requires full cooperation from a subject and the outcomes will be questionable if the subject does not give reliable responses. For example, the subject is required to push a handheld button or raise his/her hand whenever he/she hears tones. In contrast, an objective test does not require the subject to indicate his/her response and the hearing levels are determined automatically. For instance, subject's electrical brain activities are measured while he/she is sleeping and the hearing levels can be derived by analyzing the brain waveforms. Pure Tone Audiometry (PTA) is one of the famous subjective tests and has been used widely to determine hearing thresholds. PTA, however, has some limitations, since it is a subjective test. Performing PTA on patients who are difficult to test, such as 'moody' children, mental or physically disabled patients and so on can be very challenging and the outcomes can be unreliable.

The objective test is commonly performed if the subjective test cannot be conducted accordingly or if the hearing results are questionable. The objective test that has been used commonly for clinical or research purposes is ABR. ABR has been acknowledged as one of the best electrophysiological tests to estimate the auditory sensitivity. ABR can be evoked using clicks and tone burst stimuli. ABR evoked by clicks shows high correlation with average pure tone threshold in 1000-4000Hz range (Eggermont, 1982; Stapells, 1989). For frequency specific purposes, ABR can be evoked by tone bursts and it has been shown that ABR can estimate pure tone behavioral thresholds (500-4000 Hz) with reasonable accuracy (Stapells, Gravel & Martin, 1995; Durieux-Smith et al., 1990).

ABR, however, does have some limitations. If clicks are used, it can only estimate hearing threshold for high frequency region (2000Hz-4000Hz). The maximum intensity level of ABR is only about 90dBnHL and this seems too low to adequately measure all hearing losses, especially those in the severe-to-profound range (Brookhouser, Gorga, & Kelly, 1990; Rance et al., 1998). Tone burst ABR, on the other hand, can provide better hearing threshold estimation because hearing levels for different frequencies can be determined. However, compared to clicks ABR, using tone bursts to evoke ABR is often more challenging because the ABR waveform is less distinctive and sometimes difficult to interpret.

SSEP is the latest commercially available tool to predict behavioral auditory threshold levels. It was invented to measure frequency specific responses in the background electroencephalogram (EEG) to auditory stimuli presented across a broad range of frequency and sound pressure level (Tonini et al., 2005). Its prominent advantage is that it can assess multiple frequency regions of the auditory system and the hearing levels are determined through an objective interpretation (i.e. using a specific statistical analysis). It employs Sinusoidally Amplitude Modulated (SAM) tones (instead of clicks or tone bursts) to generate the required responses, as well as to preserve frequency specificity. Since the maximum intensity of signal level to evoke SSEP is about 120 dBnHL, it is useful to differentiate persons with profound hearing losses. The agreement between SSEP threshold and PTA threshold varies a lot and this study aimed to investigate this issue and to compare SSEP and ABR findings in relation to PTA thresholds at different frequencies.

CHAPTER 2

LITERATURE REVIEW

2.1 Auditory System

Hearing is one of the major sensory organs of human and is important for communication. Mainly, the function of the ear is to convert physical vibration into an encoded nervous impulse. The ear is stimulated by the vibration and it is transduced into the nerve impulse which in turn is then processed by the central auditory pathways of the brains. The ears are paired organs and located on each side of the head. The sense organ itself is known as cochlea is deeply buried within the temporal bones. The ears are composed of three parts termed the external ear, middle ear and the inner ear (Figure 1).

The function of the outer ear is to transmit the sound to the tympanic membrane. The external ear includes the auricle (pinna) and external auditory meatus. The auricle which protrudes from the side of the skull composed of elastic fibro cartilage covered by connective tissue and skin. The auricle will collects sounds and channels it into the ear canal. Blood supply to the auricle is from the external carotid system mainly by way of the posterior auricular artery and superficial temporal artery. The external auditory meatus starts from the concha and extend inside as a slightly curved canal with length of about 55mm. The meatus consists of two parts which is the outer cartilaginous part and the inner body part (Peter W. Alberti, 2000).

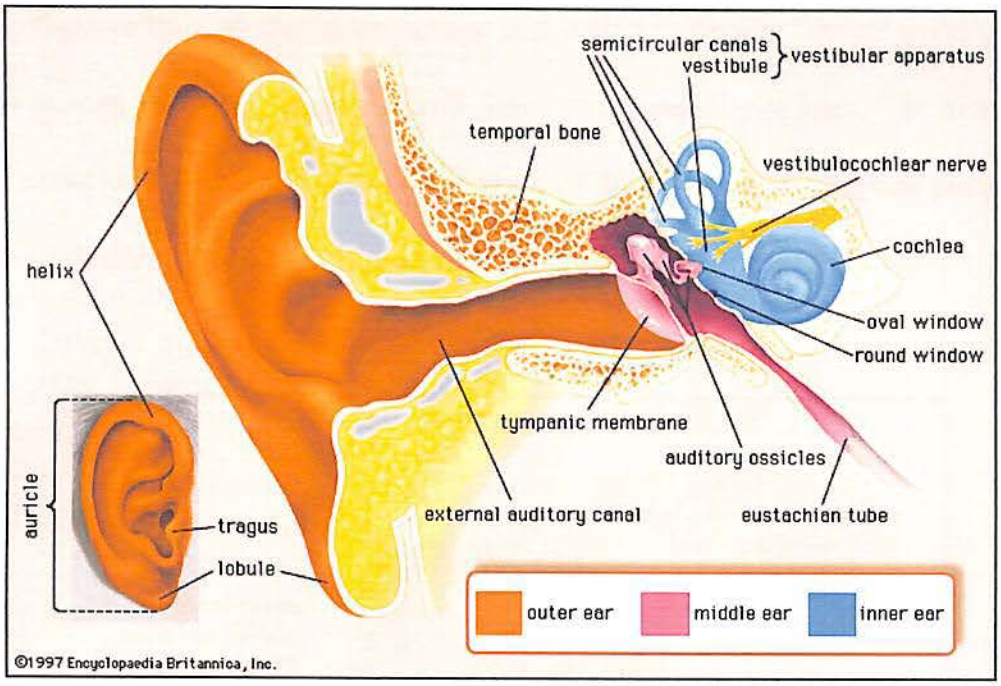

Figure 1: The pinna and external auditory canal form the outer ear, which is separated from the middle ear by the tympanic membrane. The middle ear houses three ossicles, the malleus, incus and stapes and connected to the back of the nose by the Eustachian tube. The inner ear consists of the cochlea which transduces vibration to a nervous impulse and the vestibular labyrinth which houses the organ of balance (Encyclopedia Britannica, Inc 1997).

The outer cartilaginous part is the initial part of external auditory meatus and is made up of cartilage. It is covered by thick skin which contains stiff hairs. These hairs will prevent the entry of foreign particles. Large sebaceous glands and cereminous glands are also present in the skin covering this portion. The secretion of these glands together with the desquamated epithelial cell will form the earwax. The inner part of the external auditory meatus is also covered by skin which adheres closely to the periosteum. Only the sebaceous glands area present here and small fine hairs are present on the superior wall of the canal.

The middle ear is composed of the tympanic membrane, tympanic cavity, ossicles and the Eustachian tube. The tympanic membrane separates the ear canal from the middle ear and it is the first part of the sound transducing mechanism. It is a simple membrane covered by a very thin layer of the skin on the outside, a thin lining membrane of the respiratory epithelium tract on the inner surface and with a stiffening fibrous middle layer (Figure 2). It is oval in shape, approximately 8mm wide and 10mm high. The tympanic membrane is about 0.1mm thick and lies at an angle of 40 degree in the sagittal plane with the lower aspect displaced medially (Simon K. Chiu, 1998).

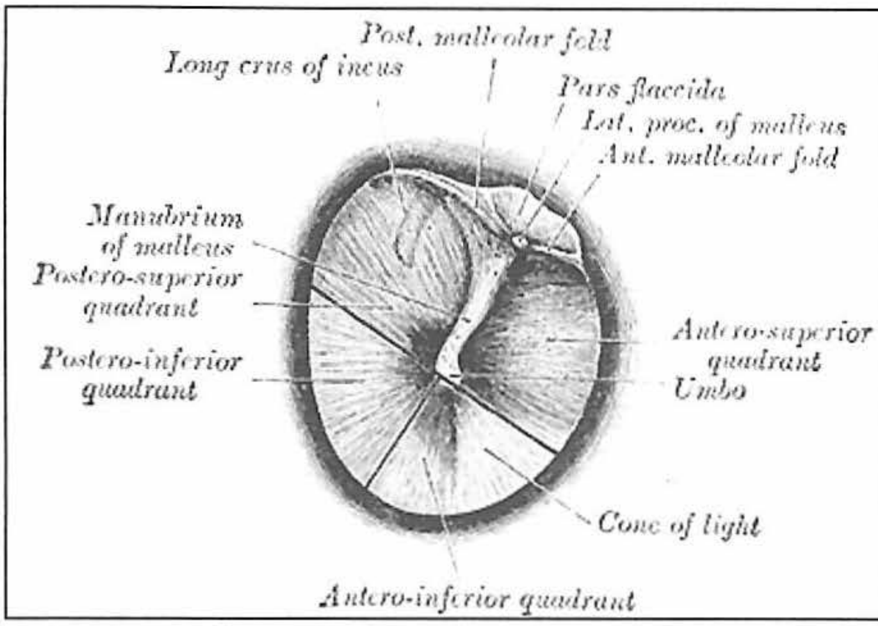

Figure 2: The right tympanic membrane as seen through a speculum.

The tympanic cavity or tympanum is the space or cleft within the temporal bone located between the tympanic membrane laterally and the inner ear medially. It communicates with the mastoid air cells anterior-inferiorly with the Eustachian tube orifice. The tympanic cavity is separated from external auditory meatus by tympanic membrane (K. Sembulingam, 2005). The ear ossicles are also known as the auditory ossicles, tiny bones which connect the eardrum to the inner ear. They transmit vibrations of the eardrum caused by the sound waves in the air to the fluid of the inner ear via the oval window. There are three ossicles: the malleus (hammer), incus (anvil) and stapes (stirrup) (Figure 3).

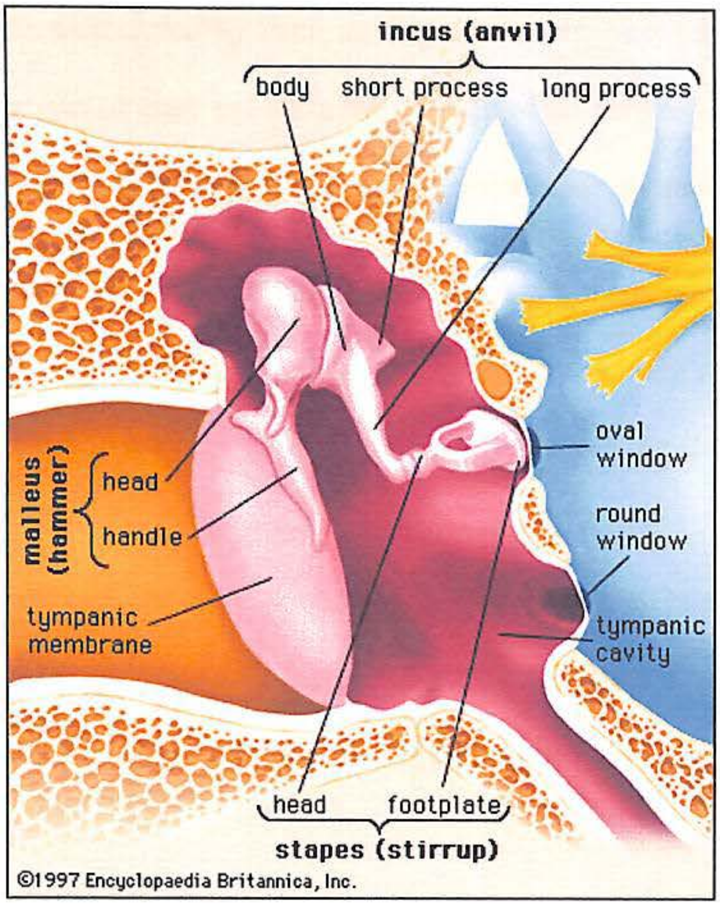

Figure 3: The structure of ear ossicles includes malleus, incus and stapes.

The malleus has the head, neck and handle. The handle or manubrium is attached to the tympanic membrane. The head or capitullum articulates with the body next to incus. Incus has a body, one long process and one short process. Anterior surface of the body articulates with the head of malleus. The short process is attached to the ligament and the long process runs parallel to handle of malleus. Stapes is the smallest ossicle and the smallest bone present in the body. It has a head, neck, anterior crus, posterior crus and a footplate. Head articulates with incus and footplate fits into the oval window (Snell, Richard S, 1986).

The auditory tube or Eustachian tube is the flattened canal leading from the anterior wall of the middle ear to the nasopharynx. Its upper part is surrounded by bony wall and the lower part is surrounded by fibro cartilaginous plate. This tube connects the middle ear with posterior part of nose and form the passage of air between middle ear and atmosphere. Thus, the pressure on both sides of tympanic membrane is equalized.

The inner ear consists of two important organs that is the semicircular canal which serve the body's balance organ and the cochlea which serves as the body's microphone in which it converts the sound pressure impulses from the outer ear into the electrical impulse which are passed to the brain through the auditory nerve (Snell, Richard S, 1986). In the inner ear, there are series of membranous sacs (termed labyrinths) which houses the sensory epithelium (Figure 4). The membranous labyrinths are filled with a fluid known as endolymph and it was surrounded within the bony labyrinth by a fluid known as perilymph (K. Sembulingam, 2005).

The cochlea is a canal that form a spirals around itself similar to a snail and it makes about 2 ½ to 2 ¾ turns. The canal of the cochlea can be divided into an upper chamber, the scala vestibule and the lower chamber known as scala tympani by the membranous labyrinth also known as cochlear duct. The scala vestibule and scala tympani contain the perilymph but the scala media contain the endolymph. The floor of scala media is formed by the basilar membrane and the roof is formed by Reissner's membrane.

There are single row of inner hair cells medially and three rows of outer hair cells laterally situated on the basilar membrane. The cells have specialized stereocilia on the apical surfaces. There are fibrous structure called the tectorial membrane that is attached to the medial aspects of the scala media. It is located above the inner and outer hair cells and come into contact with the stereocilia. Dendrites from the auditory nerve will synapse with the base of the hair cells and the nerve leaves the cochlear through the internal auditory canal and travels to the brainstem (Snell, Richard S, 1986).

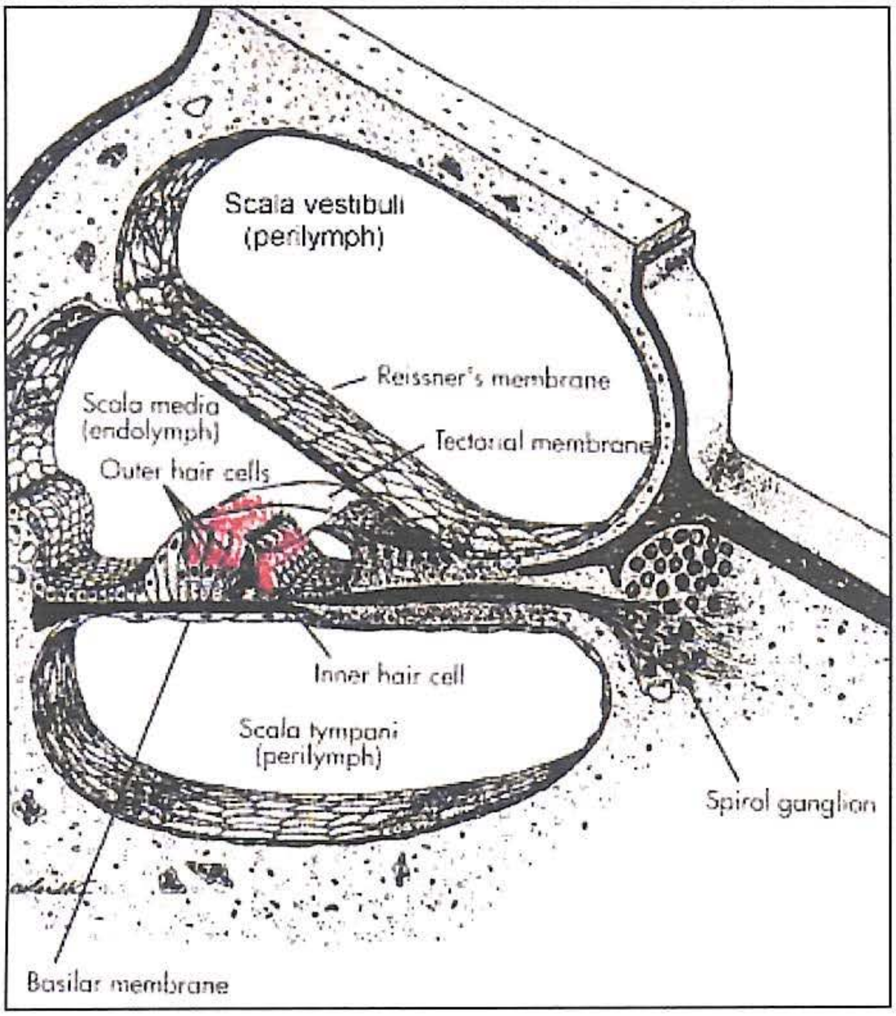

Figure 4: The cross section through one turn of the cochlear shows the endolymph and perilymph spaces and the inner and outer hair cells.

2.2 Physiology of Hearing

The physiology of hearing starts when the sound waves travel through the external auditory meatus and vibrations is produced in the tympanic membrane. These vibrations will travel through malleus and incus and reach the stapes which result in the movements of stapes. The movement of stapes will produce vibrations in the fluid of cochlea. The vibrations stimulate the hair cells in the organ of Corti and cause the generation of action potential (auditory impulse) in the auditory nerve fibers. When the auditory impulse reaches the cerebral cortex, the perception of hearing occurs (Hallowell and Silverman, 1970).

The external ear directs the sound waves towards the tympanic membrane. The ear canal acts as a resonating tube and amplifies sounds at between 3000 and 4000Hz adding to the sensitivity (and susceptibility to damage) of the ear at these frequencies. It is very sensitive and can response to the sounds of very low intensity and also the vibrations. The Eustachian tube provides the pressure equalization on either side of tympanic membrane and it is not concerned with hearing directly.

The middle ear is quite small and the mastoid air cells acts as an air reservoir cushioning the effects of pressure change. If the negative pressure lasts too long, fluid will be secreted by the middle ear and producing a conductive hearing loss. The main function of the middle ear is to amplify the sound signal. Due to pressure changes produced by the sound waves, the tympanic membrane vibrates and it moves in and out of middle ear. Thus, the tympanic membrane acts as a resonator that reproduces the vibrations of sound (Hallowell and Silverman, 1970).

The vibrations set up in tympanic membrane are transmitted through the malleus and incus and reaches the stapes, causing the movements of stapes against oval window and against the perilymph present in scala vestibule of cochlea. The ossicles functions as a lever system and effectively reduce the sound impedance. Impedance is the obstruction or opposition to the passages of sound waves. When sound waves reach the inner ear, the fluid (perilymph) present in the cochlea offers impedance.

However, the sound waves are conducted by the auditory ossicles from external ear to inner ear. So, the impedance is only 40%. The remaining 60% of sound energy developed in tympanic membrane is transmitted to the cochlear fluid by ossicles. This is because the ossicles acts like the lever system and they increase the sound pressure that arrives at oval window so that the vibrations are set up in the fluid within the cochlea. The entire process by which the tympanic membrane and the lever system of ossicles convert the sound energy into the mechanical vibrations in the fluid of internal ear is called impedance matching (Hallowell and Silverman, 1970).

The function of the inner ear is to transduce vibration into nervous impulses. They also produce a frequency (pitch) and intensity (loudness) analysis of the sound. The cochlea consists of a fluid filled bony canal within which lies the cochlear ducts containing the sensory epithelium. Energy will enter the cochlea via the stapes bone at the oval window and is dissipated through the second opening of round window. Vibrations of the stapes footplate cause perilymph to form a wave that travels along the length of the cochlea and it will take about five milliseconds. When it passes the basilar membrane of the cochlear duct, the fluid will cause the basilar membrane to move in a wave-like fashion (i.e. up and down).