AIDED THRESHOLD EQUALIZING NOISE TEST

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A Dissertation Submitted in Part Fulfillment of

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ALL INDIA INSTITUTE OF SPEECH AND HEARING
MANASAGANGOTHRI
MYSORE-570006

Dedicated to

The Almighty

Supreme Soul

&

My Parents

CERTIFICATE

This is to certify that this dissertation entitled ***'Aided Threshold Equalizing Noise Test'*** is the bonafide work submitted in part fulfillment for the degree of Master of Science (Audiology) of the student (Registration No. 07AUD014). This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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DECLARATION

This is to certify that this dissertation entitled ***'Aided Threshold Equalizing Noise Test'*** is the result of my own study under the guidance of Dr. Vinay S. N., Lecturer in Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted in any other university for the award of any diploma or degree.

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Chapter 1

INTRODUCTION

The anatomical and physiological mechanisms have established that hair cells (outer & inner) play a crucial role in the hearing mechanism. Each cochlea contains one row of approximately 3,000 inner hair cells and three to five rows of about 12,000 outer hair cells (Roeser, Valente & Hosford-Dunn, 2000). Sound hitting the tympanic membrane results in a travelling wave of fluid motion inside the cochlea, causing a ripple along the basilar membrane. The stereocilia of the inner hair cells bend or become sheared where the wave peaks. This stimulates the hair cells at the cochlea's base (responsible for high frequency) or apex (responsible for low frequency) or at some unique place in between base and apex. The wave's peak is the result of the action of the outer hair cells. The stretching or shrinking action of the outer hair cells temporarily alters the basilar membrane on either side of the peak. This mechanically forces the peak into a sharper point that in turn, increases the audibility to distinguish between frequencies that are close together.

While most cochlear hearing losses are associated with impaired function of outer hair cells (OHCs), in some cases loss of inner hair cells (IHCs) may occur (Engstrom, 1983; Schuknecht, 1993; Borg, Canlon & Engstrom, 1995). Healthy IHCs act as transducers to transform basilar membrane (BM) vibrations into action potentials in the neurons of the auditory nerve. The loss of IHCs leads to reduced efficiency of transduction, which results in elevated absolute thresholds and degraded transmission of information in the auditory nerve (Miller, Schilling, Franck & Young, 1997; Moore, 1998).

It has been known for many years that cochlear hearing loss is sometimes associated with complete destruction of the inner hair cells (IHCs) within the cochlea (Engstrom, 1983; Borg et al., 1995). Sometimes the IHCs may still be present, but may be sufficiently abnormal that they no longer function. The IHCs are the transducers of the cochlea, responsible for converting the vibration patterns on the basilar membrane (BM) into action potentials in the auditory nerve (Yates, 1995). Sometimes, the IHCs and/or neurons at certain places along the BM may be missing or functioning so poorly that a tone producing peak vibration in that region is detected by off-place (off frequency), those regions are called “dead regions” (DR) (Moore & Glasberg, 1997; Moore, 2001, 2004a). However, a tone with a frequency falling into a DR may be detected via upward or downward spread of excitation to places where there are functioning IHCs and neurons, i.e., such a tone may be detected at a place where the amount of BM vibration is lower than at the characteristic frequency (CF) place, but the IHCs and neurons are functioning more effectively (Thornton & Abbas, 1980; Florentine & Houtsma, 1983; Turner, Burns & Nelson, 1983; Moore, 1998, 2001, 2004a; Moore & Alcántara, 2001).

Moore, Huss, Vickers, Glasberg and Alcantara (2000) and Moore (2001, 2004) defined the extent of a DR in terms of its edge frequency (*fe*), which corresponds to the CF of the area of functioning IHCs and/or neurons immediately adjacent to the DR. The concept of spread of excitation and off-frequency listening forms the basis of most psychoacoustic methods for detecting DRs. Moore (2001) reported that, a DR cannot be identified from the pure tone audiogram, although a potential indication of a DR may be given by the configuration of the hearing loss. This needs to be taken with caution, as the audiometric threshold can be misleading (Halpin, Thornton & Hasso, 1994; Mackersie, Crocker & Davis, 2004; Moore, 2001, 2004a; Kluk & Moore, 2006). For the diagnosis of a DR the most applicable tests developed over the years are Psychophysical tuning curve (PTC) and Threshold Equalizing Noise (TEN) test.

Psychophysical tuning curve (PTC) is a curve showing the level of a narrow-band masker required to mask a fixed sinusoidal signal, plotted as a function of masker frequency. For normally hearing subjects, the tip of the PTC occurs close to the signal frequency, the masker is more effective when its frequency coincides with the signal frequency (Vogten, 1974; Moore, 1978). If the frequency of the signal falls within a dead region, then the tip of the PTC is shifted away from the signal frequency (Florentine & Houtsma, 1983; Turner et al., 1983; Moore & Alcantara, 2001). However, measurement of PTCs is time consuming. Moreover, PTCs can be difficult to interpret (Kluk & Moore, 2005). A method called as the ‘fast-track PTCs’ developed by Sek, Alcantara, Moore, Kluk and Wicher (2005) was designed based on Bekesy procedure of threshold tracking. This test was time economical; however, the test is not used for the diagnosis of dead regions because of limited clinical availability.

Moore et al. (2000) developed a more time economical and an effective test called as the Threshold Equalizing Noise (TEN) test. This test is intended to be more suitable for the diagnosis of cochlear dead regions in individuals with sensorineural hearing loss. The basic principle of this test involves the detection of a sinusoidal tone in the presence of a spectrally shaped broadband masking noise termed as the Threshold Equalizing Noise (TEN). The characteristic of TEN test is that the masked threshold obtained in the presence of TEN will be equal in value compared to the TEN level used in subjects with normal IHCs functioning. However, if the masked threshold is higher than the TEN level used then it may indicate damaged IHCs.

The identification of dead regions is important for people with severe or profound sensorineural hearing loss. Studies have shown that the prevalence of cochlear dead regions is more in subjects with sensorineural hearing loss with greater than moderately severe degree (Preminger, Carpenter & Zeigler, 2005; Markessis, Kapadia, Munro & Moore, 2006; Aazh & Moore, 2007; Vinay & Moore, 2007). However, as with other masking procedures, the detection of a tone in noise is affected by the amount of loudness reaching the cochlea. It is well known that subjects with cochlear hearing loss demonstrate the phenomenon of recruitment (Florentine & Houtsma, 1983; Glasberg & Moore, 1986) and also the difficulty of understanding speech in noisy environment (Moore, 1998).

Hence the above factors may be responsible to limit the level of TEN test that may be administered in individuals with sensorineural hearing loss. Care should be taken in terms of the level of the TEN that should be used in individuals with sensorineural hearing loss combined with the physiological effects of recruitment and speech understanding difficulty in the presence of background noise.

Need for the study

The diagnosis of dead regions may be useful clinically for several purposes, including (1) counseling about the likely benefit from hearing aids; (2) to help in the choice of hearing aid type or in deciding whether a person is a candidate for a cochlear implant; (3) to help in fitting and providing appropriate gain using hearing aids.

As reported by Moore et al. (2000), a TEN level of 10 dB SL above the absolute threshold of the individual may be appropriate for the administration and diagnosis of cochlear dead regions in individuals with sensorineural hearing loss. This level of TEN applies to individuals having varying degree of sensorineural hearing loss, however, there may be a problem associated with loudness recruitment and distortion in subjects with severe or profound degree of hearing loss. Moreover, previous studies have shown that the prevalence of cochlear dead regions is more than 50% when the absolute threshold of the individual increases above 70 dB HL (Vinay & Moore, 2007a). In order to test individuals with this higher degree of hearing loss, it becomes necessary that the loudness recruitment should not be a factor affecting the diagnosis of cochlear dead regions in these individuals. This is complicated by the fact that the audiometers also have a restriction incorporated in the maximum intensity levels that can be presented during the administration of the TEN test.

Previous studies reporting the prevalence of cochlear dead regions have found inconclusive results administering the TEN test because of the limitation in the level of the TEN that can be presented (Aazh & Moore, 2007; Vinay & Moore, 2007a). This can be rectified based on the priciples of obtaining aided thresholds by using a hearing aid. Since an appropriate hearing aid should provide a lower threshold around the speech spectrum compared to the unaided threshold, the TEN test may be administered at lower levels thereby increasing the possibility of varying the levels during the administration of the TEN test and obtaining the masked thresholds in the presence of TEN.

Although the TEN (HL) test is easier to administer and the noise gives rise to less loudness than for the TEN (SPL) test, it is still the case that, when assessing the presence of DRs in subjects with severe and profound hearing loss, the level of the TEN (HL) that can be generated via the audiometer may be insufficient to produce 10 dB of masking, leading to an inconclusive result (Simpson, McDermott & Dowell, 2005; Aazh & Moore, 2007; Vinay & Moore, 2007a). Also some subjects may find the TEN (HL) to be too loud, even if the TEN (HL) level is only slightly above their pure tone threshold at the test frequency. This typically happens when the hearing loss is much greater at some frequencies than at others, the loudness produced by the TEN (HL) in regions of less severe loss makes it difficult to apply the test in regions of more severe loss. For example, a person with near-normal hearing at low frequencies and a severe loss at high frequencies might find the TEN (HL) too loud when being assessed for the presence of a DR at high frequencies (Simpson, McDermott & Dowell, 2005). The identification of DRs is important for people with severe or profound hearing loss, as the presence of a

DR can inform decisions on the likely effectiveness of hearing aid amplification (Baer, Moore & Kluk, 2002; Preminger, Carpenter & Ziegler, 2005; Vickers, Moore & Baer, 2001) and on whether cochlear implantation might be more effective than use of acoustic hearing aids. People with severe or profound hearing loss are usually hearing aid wearers, often with high levels of gain in their hearing aids.

The aided version of the TEN (HL) test is referred here as the ATEN test. The TEN test is based on the fact that when a sinusoidal signal is detected at the "wrong" place in the cochlea (because of a DR corresponding to the signal frequency), a higher signal to noise ratio is needed than when there is no DR and the signal is detected at the "correct" place. When the signal is detected via off-place listening, the threshold for detecting the signal will depend on the effective level of the noise in the frequency region where the signal is detected. To obtain valid results for the ATEN, it is important that the gain of the hearing aid should not change too rapidly with frequency. If the hearing aid alters the relative level of the signal and of the noise in the frequency region where the signal is detected, the test might lead to an inappropriate diagnosis. This can happen in principle, because most hearing aids have a non-flat frequency response and many hearing aids incorporate multichannel compression. Whether this is important in practice will depend on how rapidly the gain of the hearing aid changes as a function of frequency. Typically, though such changes are smooth and gradual and they should not greatly affect the "local" signal to noise ratio. A second consideration for the ATEN test is that, when measuring aided detection thresholds in a sound field, it is necessary to use warble tones to reduce the effects of variations in sound level arising from standing waves in a room, such standing waves can have strong effects if pure tones are used. An advantage of using warble tones is that such tones are less likely than steady tones to activate the feedback reduction system in hearing aids with adaptive feedback cancellation, because the adaptive function is activated when the hearing aid detects a steady tone (Kates, 1999). It may be mentioned that, all previous studies with the TEN (HL) test have used pure tones presented through headphones. However, studies assessing the use of warble tones, as an alternative to pure-tone signals for standard audiometric testing through headphones, have not typically demonstrated significant differences in results for the two types of stimuli (Byrne & Dillon, 1981).

Thus, the present study was designed to provide an insight about the benefits of accurate identification of dead region in the individuals with severe to profound sensorineural hearing loss hearing loss in the aided condition. Apart from this, the study also aims to measure the effectiveness of the ATEN test in terms of the frequency, since most sensorineural hearing loss have a sloping pattern. This may provide sufficient information about the modifications needed for administration of the ATEN test and for programming the hearing aids. The details of the TEN and the ATEN test administration procedure and diagnosis is discussed in detail in the method section. Further rehabilitative approaches can be considered based on the accurate diagnosis of these individuals with sensorineural hearing loss.

Thus, the objectives of the present study were:

- To assess the presence or absence of cochlear dead regions in subjects with severe or profound hearing loss using unaided TEN (HL) test at various frequencies.
- To assess the presence or absence of cochlear dead regions in subjects with severe or profound hearing loss using aided TEN (HL) test at various frequencies.
- To assess the effectiveness of aided TEN test in diagnosis of dead regions.

Chapter 2

REVIEW OF LITERATURE

2.1 Overview of Cochlear hearing loss

Cochlear hearing loss is often associated with loss of function of the hair cells within the cochlea (Engstrom, 1983; Schuknecht, 1993; Borg et al., 1995). Sometimes the inner hair cells (IHCs) at certain places along the basilar membrane may be completely nonfunctioning or even missing, which means there is no transduction of basilar membrane vibration at those places. It has been known for many years that cochlear hearing loss is sometimes associated with complete destruction of the inner hair cells (IHCs) within the cochlea (Engstrom, 1983). Sometimes the IHCs may still be present, but may be sufficiently abnormal that they no longer function.

2.2. Concept of Cochlear dead region

The IHCs are the transducers of the cochlea, responsible for converting the vibration patterns on the basilar membrane into action potentials in the auditory nerve. When the IHCs are non-functioning over a certain region of the cochlea, no transduction will occur in that region. This region is called as a 'cochlear dead region'. Moore (2004) defined the extent of a dead region in terms of "place" or distance along the basilar membrane. Since IHC damage is often associated with outer hair cells (OHC) damage, the tuning of the basilar membrane, IHCs and neurons may be abnormal in an ear with a dead region, even over regions which are not dead (Moore, 2001). Dead regions appear to be relatively common in cases with severe to profound sensorineural hearing loss, with a prevalence greater than 50% when the hearing loss exceeds 70 dB HL (Aazh & Moore, 2007; Vinay & Moore, 2007a).

2.2.1. Classification of Cochlear Dead Regions:

Cochlear dead regions can be classified into three types:

- Low frequency dead regions
- Mid frequency dead regions
- High frequency dead regions

2.2.1. a. Effects of Low-Frequency Dead Regions

The etiology for low-frequency dead regions are associated with Mondini dysplasia (Parving, 1984), vascular disruption (Muziek, Guerkink, & Spiegel, 1987) and the advanced stages of Meniere's disease (Halpin, Thornton & Hasso, 1994). The figure 1 depicts the excitation pattern evoked on the basilar membrane by a low frequency signal of 250 Hz, in an ear with low frequency DR.

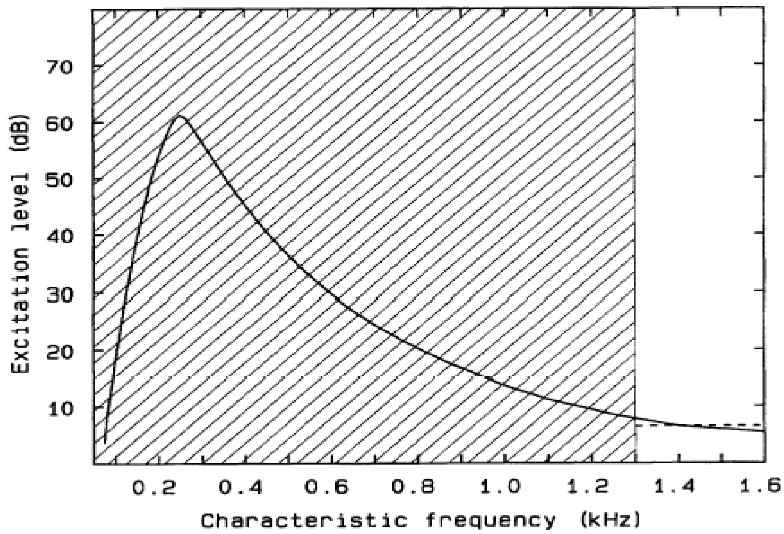

Figure 1. Dead region is indicated in shaded area. The solid curve shows the excitation pattern that might be evoked by a low-frequency (250 Hz) tone in an ear with a low-frequency dead region.

In figure 1, the low-frequency tone was not detected via neurons innervating the apical region of the cochlea, as the IHCs in that region were dead. However, the tone was audible when it produced sufficient excitation in the region of normal hearing. Spread of excitation was probably responsible for the detection of low-frequency tones falling in a dead region (Thornton & Abbas, 1980; Florentine & Houtsma, 1983; Turner et al., 1983; Humes, Tharpe & Bratt, 1984; Halpin, Thornton & Hasso, 1994).

Halpin, Thornton & Hasso, (1994) described two patients with very similar audiograms, both having a low-frequency hearing loss with nearly normal mid-frequency hearing. Many researchers have used masking sounds as a way of diagnosing the presence of DR. Maskers used have included high pass noise (Parving & Elberling, 1982), band pass noise (Humes et al. 1984) or a pure tone with a frequency just inside the region of normal hearing (Thornton & Abbas, 1980; Halpin, Thornton & Hasso, 1994). The masker has been chosen to produce its greatest effect in the region of near normal hearing. Results indicated that if a high pass noise produces a marked threshold elevation for a low-frequency signal, this indicates a low-frequency dead region.

According to Terkildsen, (1980) and Thornton and Abbas, (1980), hearing losses of 40-50 dB at low frequencies, combined with near normal hearing at high frequencies, may be associated with a low-frequency dead region. Moore et al. (2000b) found that a low-frequency dead region can be associated with a hearing loss which is relatively flat, or which decreases only slowly with increasing frequency. A study by Vinay and Moore (2007b) has reported that low frequency dead regions affect speech recognition abilities in individuals with sensorineural hearing loss and that selective amplification may benefit them in terms of the speech recognition abilities.

2.2.1. b. Effects of High-Frequency Dead Regions

Some hearing-impaired ears show marked downward spread of excitation as well as upward spread of excitation (Glasberg & Moore, 1986). Because the excitation pattern usually has a steep low-frequency side, a DR at high frequencies is usually associated with a severe or profound hearing loss at high frequencies, and the audiogram is often steeply sloping. Figure 2 depicts the excitation patterns calculated for a hypothetical ear with a 40-dB hearing loss at low frequencies (threshold excitation level indicated by the horizontal dashed line), and a dead region extending from 1000 Hz upwards (indicated by the shaded area)

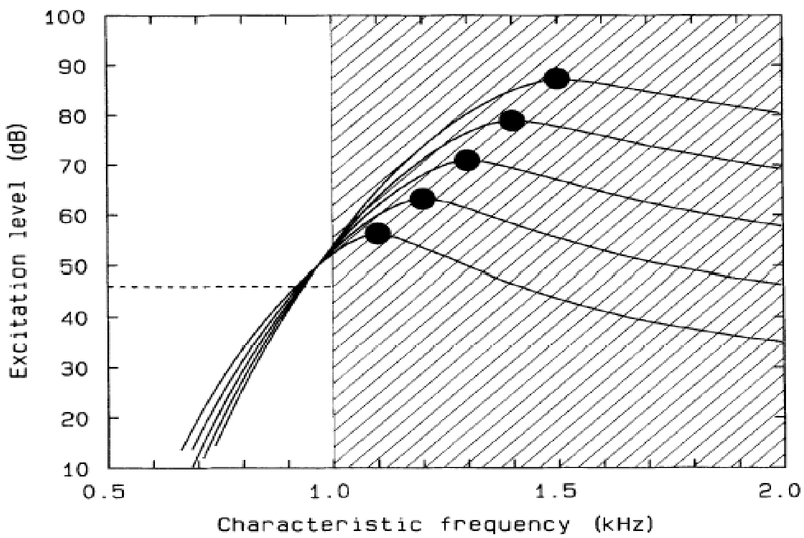

Figure 2. Excitation patterns calculated for a hypothetical ear with a 40-dB hearing loss at low frequencies (threshold excitation level indicated by the horizontal dashed line), and a dead region extending from 1000 Hz upwards (indicated by the shaded area).

In figure 2, each of the curves represents the excitation pattern for a tone with frequency falling in the dead region; the frequencies used are 1.1, 1.2, 1.3, 1.4 and 1.5 kHz. It is assumed that this tone is detected because of the downward spread of excitation. The solid circles represent the frequency and level at the peak of each excitation pattern. Whenever the audiogram has a very steep slope, the threshold worsening rapidly with increasing frequency, this should be taken as preliminary evidence for a dead region. Based on Moore et al. (2000) DR does occur when the audiogram is not steeply sloping, so the slope of the audiogram cannot be taken as a reliable way of assessing the presence or absence of dead region.

2.2.1.c. Effects of Mid-Frequency Dead Regions

There is also occurrence of mid-frequency dead regions, with good hearing at low and high frequencies (Moore, 1998; Moore & Alcantara, 2001). They may be associated with a mid-frequency notch in the audiogram. Moore and Alcantara, (2001) described one patient diagnosed as having a dead region extending from 1300 to 2800 Hz. He reported no serious problems in understanding speech because residual hearing at low and high frequencies was sufficient to allow good speech comprehension.

2.3. Phenomenon of off-frequency listening in individuals with cochlear dead regions

Basilar membrane vibration in a dead region is not detected via the neurons directly innervating that region. Detection of a tone of a particular frequency via IHCs and neurons with CFs different from that of the tone, termed as "off-frequency listening" (Johnson-Davies & Patterson, 1979; Patterson & Nimmo-Smith, 1980; O'Loughlin & Moore, 1981; Patterson & Moore, 1986).

2.4. Tests to identify cochlear dead regions

Damage to the hair cells give rise to elevated absolute thresholds in two ways. Firstly, dysfunction of the OHCs impairs the active mechanism in the cochlea, resulting in reduced basilar membrane vibration for a given low sound level (Yates, 1995; Moore, 1998). Secondly, dysfunction of the IHCs can result in reduced efficiency of the transduction, so the amount of basilar membrane vibration needed to reach the threshold is larger than normal (Moore, 2001).

2.4. a. Diagnosis of dead regions by audiogram

It has been recognized for many years that, when a DR is present, the audiogram will give a misleading impression of the amount of hearing loss, for a tone whose frequency falls in the DR (Gravendeel & Plomp, 1960; Halpin, Thornton & Hasso, 1994). The diagnosis of DRs with reference to audiogram was always termed as misleading (Moore, 2001).

Halpin, Thornton & Hasso, (1994) described two patients with very similar audiograms, both having low frequency hearing loss with near normal mid frequency hearing. Post-mortem examination showed that one had no survival of organ of corti in the apical region, while the other had an organ of corti which was present and of normal appearance. However, Moore (2001) had included certain aspects of audiogram to be taken in to consideration while assessing a dead region. They are: a) a hearing loss more than 90 dB at high frequencies or 75-80 dB at low frequencies, b) a hearing loss of 40-50 dB at low frequencies with near normal hearing at mid and high frequencies, c) a hearing loss greater than 50 dB at low frequencies with somewhat less hearing loss at higher frequencies, d) a hearing loss increasing rapidly (more than 50 dB/octave) with increasing frequency. However, previous studies have shown that audiogram is not a reliable tool to detect the presence or absence of DRs (Aazh & Moore, 2007; Vinay & Moore, 2007a).

Because of the difficulty in using the audiogram to diagnose DRs accurately, many researchers have advocated the use of masking noise as a way of diagnosing the presence of dead region. There are two different types of test available for the diagnosis of dead region using the masking method. They are: a) psychophysical tuning curve (PTC) and b) masking with threshold equalizing noise (TEN).

2.4. b. Diagnosis of dead regions by psychophysical tuning curves

The psychophysical tuning curves (PTCs) is a curve showing the level of a narrow-band masker required to mask a fixed sinusoidal signal, plotted as a function of masker frequency (Figure 3). For normally hearing subjects, the tip of the PTC occurs close to the signal frequency; the masker is more effective when its frequency coincides with the signal frequency (Vogten, 1974; Moore, 1978). If the frequency of the signal falls within a dead region, then the tip of the PTC is shifted away from the signal frequency (Florentine & Houtsma, 1983; Turner et al., 1983; Moore & Alcantara, 2001).

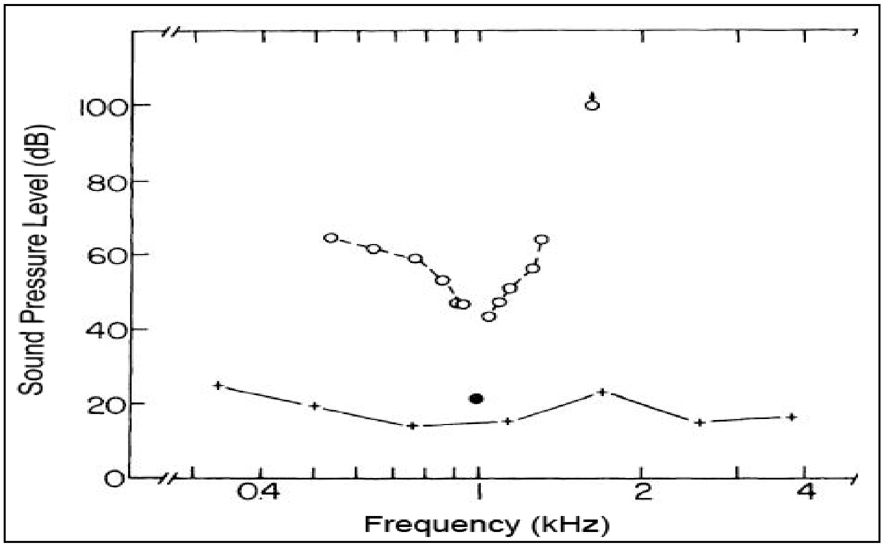

Figure 3. Psychophysical tuning curve (PTC) obtained from a normal hearing individual. The PTC was measured using a 1 kHz signal at 7 dB SL. '+' indicates the absolute threshold and 'o' indicates the PTC. Filled 'o' indicates the tip of the tuning curve.

The measurement of psychophysical tuning curves (PTCs) (Small, 1959) involves a procedure which is analogous to the physiological determination of a tuning curve on the basilar membrane (Sellick, Patuzzi & Johnstone, 1982). The masker can be either a sinusoid or a narrow band of noise. When hearing-impaired listeners are tested, PTCs have sometimes been found whose tips are shifted well away from the signal frequency (Thornton & Abbas, 1980; Florentine & Houtsma, 1983; Turner et al., 1983; Moore et al., 2000; Moore & Alcantara, 2001). This can happen when the signal frequency falls in a DR. Figure 4 depicts the PTC obtained from a subject with an extensive low frequency dead region.

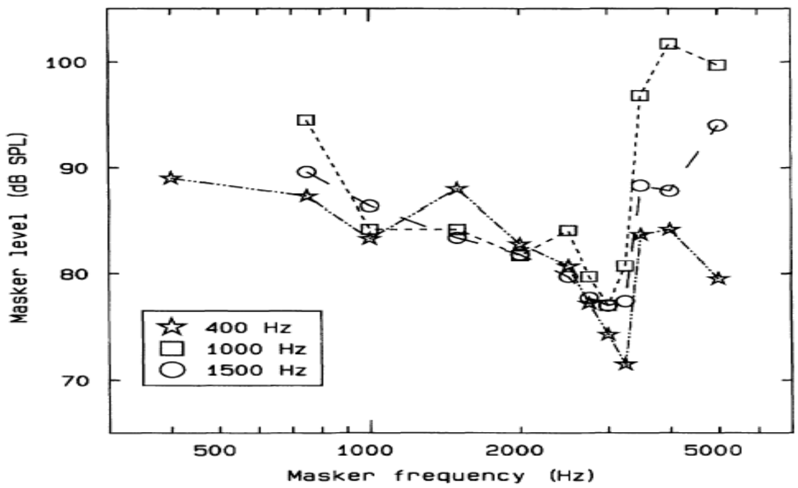

Figure 4. Psychophysical tuning curve (PTC) obtained from a subject with an extensive low frequency dead region. PTCs are shown for signal frequencies of 400, 1000 and 1500 Hz (Moore & Alcantara, 2001).

Florentine and Houtsma (1983) had taken a subject with unilateral hearing loss which was most severe at low frequencies. The masker was a sinusoid. For the normal ear, a PTC was measured using a 1 kHz signal at 7dB SL. The impaired ear was tested using a 1 kHz signal at 4.5, 7 or 13 dB SL. The resulting PTCs show tips which lie well above the signal frequency, which is consistent with a low frequency dead region. Florentine and Houtsma (1983) observed that the frequency at the tip of the PTC should decrease with increasing signal level. PTC was shifted to the signal frequency for higher levels, even when the signal level was as high as 21 dB SL. Hence, when the tip of the PTC is markedly shifted, there is a “true” dead region around the signal frequency, where the IHCs are completely non-functional.

However, measurement of PTCs is time consuming and is not currently feasible in the clinic. Moreover, PTCs can be difficult to interpret (Kluk & Moore, 2005). A more time economical test called as ‘fast-track PTCs’ can be used, however, its availability is limited for clinical use (Sek et al., 2005).

2.4. c. Diagnosis of dead regions by Threshold Equalizing Noise test

Moore et al. (2000) developed a quick test for the identification of DRs in the cochlea, which is similar to the method of 'above threshold audiometry', developed by Langenbeck (1965). The test is called Threshold Equalizing Noise (TEN) test. The test uses "Threshold Equalizing Noise (TEN)" to detect the DRs. The test requires the subject to detect a sinusoidal tone in the presence of TEN.

The spectral shape of the noise (P_s) is measured by using the formula

$$\mathbf{P_s = N_o. K.ERB}$$

where N_o indicates noise spectral density, ERB is defined as the equivalent rectangular bandwidth of the auditory filter (Patterson & Moore, 1986) and K is the signal-to-noise ratio at the output of the auditory filter required to reach the threshold. Moore and Glasberg (1997) have estimated the value of K as a function of frequency. The value of K decreases as frequency increases. The value of K at 1 kHz is about -3 dB, and it remains almost constant above 1 kHz. The ERB of a given filter is equal to the bandwidth of a perfect rectangular filter which has a transmission in its band pass equal to the maximum transmission of the specified filter and transmits the same power of white noise as the specified filter (Moore, 1998). Glasberg and Moore (1990) showed that the value of the ERB could be estimated by the formula-

$$\mathbf{ERB= 24.7\ (4.37F + 1)}$$

Where the ERB is in Hertz and F is center frequency in kHz.

The signal in the TEN test is calibrated in terms of hearing level (HL) and noise in sound pressure level (SPL) units. Moore, Glasberg and Stone (2004) devised a newer version of the TEN test called the TEN (HL), in which; both the signal and the noise are calibrated in HL units. Figure 5 depicts the spectrum of TEN for a level/ ERB of 70 dB.

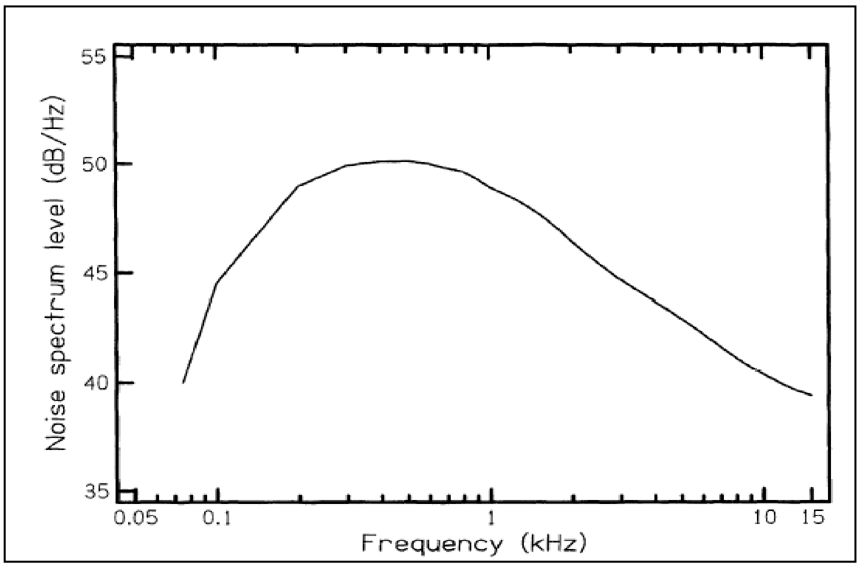

Figure 5. Spectrum of TEN for a level/ ERB of 70 dB.

Threshold Equalizing Noise (TEN) test is a simple test to detect the presence of one or more dead regions, and to delimit the frequency range of any dead region. According to Moore et al. (2000) the test is based upon the detection of sinusoids in the presence of a broadband noise, designed to produce almost equal masked thresholds (in dB SPL) over a wide frequency range, for normally hearing listeners and for listeners with hearing impairment but without DRs. This noise is called threshold equalizing noise (TEN).

For people without DRs, the TEN leads to approximately equal masked detection thresholds in dB SPL for pure tones over a wide frequency range. This version of the test is called the TEN (SPL) test. If off-frequency listening is used to detect a tone, the TEN becomes an especially effective masker, giving rise to an elevated masked threshold. To facilitate the use of the TEN test in clinical assessments, a second version of the TEN test was developed, using a wideband noise with spectral shape designed to give equal masked thresholds for pure tones in dB HL (Moore et al., 2004). In this version, called the TEN (HL) test, the bandwidth of the TEN is limited, allowing assessment of thresholds for the audiometric frequencies of most interest (500 - 4000 Hz), and the levels of the pure-tone signals from the TEN (HL) test compact disk (CD) are designed to match those generated by the audiometer, so that absolute thresholds can be derived from the audiogram and therefore need to be measured only once. The loudness of the TEN (HL) is less than the original TEN (SPL) because of the reduced bandwidth.

Zwicker and Fastl (1990) reported that the TEN produces an equal amount of masking at all frequencies (i.e. to raise thresholds a constant amount above the absolute threshold). According to Moore et al. (2000) TEN produce a constant amount of excitation at each CF, and the effects of transmission of the noise through the outer and middle ear. The TEN does not produce equal excitation at all CFs, although it does this approximately for mid-range frequencies, from about 500 to 5000 Hz.

Moore et al. (2000) analyzed 10 normal hearing subjects and measured the masked threshold in the TEN and found that masked thresholds are specified in dB SPL, not dB HL. The TEN produces sufficient masking and it produces nearly equal masked thresholds for all signal frequencies. Figure 6 illustrates the masked thresholds in the TEN specified in dB SPL, for TEN levels of 30, 50 and 70 dB/ERB, averaged across ten normally hearing subjects.

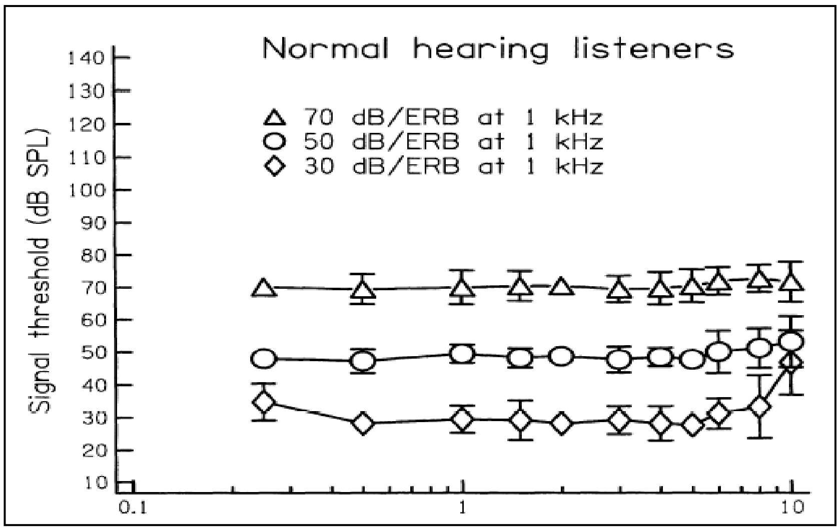

Figure 6. Masked thresholds in the TEN, specified in dB SPL, for TEN levels of 30, 50 and 70 dB/ERB, averaged across ten normally hearing subjects. Error bars indicate 95% confidence intervals.

2.5. Clinical use of Threshold Equalizing Noise test

Moore et al. (2000) used the TEN (SPL) test and PTCs to assess 20 ears of 14 subjects with moderate to severe sensorineural hearing loss with different audiometric configurations. Sixty-eight percent of their subjects met the criteria for a DR. Results suggested that DRs at high frequencies are often associated with steeply sloping hearing losses and a high frequency dead region can be present even at a frequency where the absolute threshold indicates only mild to moderate hearing loss. Hearing losses greater than 70 dB at high frequencies were often associated with a dead region, but there were some cases with absolute thresholds of 70 to 80 dB HL with no diagnosed dead region.

Moore, Killen and Munro (2003) applied the TEN (SPL) test to teenagers with severe to profound sensorineural hearing loss with variety of audiometric configurations. The results for the majority of ears showed inconclusive results at some frequencies due to the maximum output of the system being reached. However, the criteria for dead region were met at medium or high frequencies in at least one ear for 70% of subjects.

Preminger, Carpenter & Zeigler (2005) studied the prevalence of dead regions in 49 subjects. They used some different criteria for diagnosing dead regions than used in most other studies i.e. ears for which the masked threshold was 15 dB above the absolute threshold and 15 dB above the TEN level were considered to have DRs at the test frequency. Results indicated that 29% of the subjects met their criteria for a DR. The slope of the audiogram was found to be significantly higher for ears with high frequency dead regions than for ears with no DR. However, there was a considerable overlap between the audiogram slopes for subjects with and without dead regions.

Markessis et al. (2006) used the TEN (SPL) test to assess 35 adults with moderate to severe sensorineural hearing loss. Results indicated that 87% of the ears met the criteria for a DR for at least one test frequency. Absolute threshold at 4 kHz were between 65 and 90 dB HL, and 52% of the tested ears met the criteria for a DR at 4 kHz. The reduced proportion of ears meeting the criteria at frequencies above 4 kHz can be attributed to the difficulty in making the TEN sufficiently intense at these high frequencies.

Aazh and Moore (2007) used the TEN (HL) test to assess the prevalence of dead regions at 4 KHz in 98 ears of elderly people who has greater hearing loss at high frequencies than at low frequencies. Thirty seven precent had a DR. The slope of the audiogram did not differ significantly for ears with and without dead regions.

A recent study on Indian population by Vinay and Moore (2007a) estimated the prevalence of dead regions in 317 (592 ears) adult individuals with sensorineural hearing impairment as a function of audiometric threshold and frequency. Results showed that 177 (57.4%) individuals were found to have a dead region in one or both ears for at least one frequency. Fifty four women and 123 men had DRs in one or both ears. It was observed that 41.9% individuals had only a high frequency dead region, 2.3% individuals had only a low frequency dead region.

2.6. Limitations of Threshold Equalizing Noise Test

Although the TEN (HL) test is easier to administer and the noise gives rise to less loudness than for the TEN (SPL) test, it is still the case that, when assessing the presence of DRs in subjects with severe and profound hearing loss, the level of the TEN (HL) that can be generated via the audiometer may be insufficient to produce 10 dB of masking, leading to an inconclusive result (Aazh & Moore, 2007; Simpson, McDermott & Dowell, 2005; Vinay & Moore, 2007a). Also, some subjects may find the TEN (HL) to be too loud, even if the TEN (HL) level is only slightly above their pure tone threshold at the test frequency. This typically happens when the hearing loss is much greater at some frequencies than at others; the loudness produced by the TEN (HL) in regions of less severe loss makes it difficult to apply the test in regions of more severe loss.

Thus, it may be useful to administer the TEN test through the aided condition, which may result in significant reduction of the TEN level required for administration in individuals with a higher degree of sensorineural hearing loss. Usually, the maximum power output of a hearing aid is typically set to safeguard residual hearing, and to avoid loudness discomfort. Thus, when the TEN is heard via a hearing aid, its level should be limited to a tolerable and safe value, while potentially giving more masking than could be obtained through an audiometer and headphones. In addition, the gain of a hearing aid will be greater for frequencies where hearing is poorer. Thus, the TEN should be above threshold for frequencies where hearing is poor, but not excessively loud for frequencies where hearing is better. This should increase the likelihood of the TEN producing at least 10 dB of masking, giving a reduced incidence of inconclusive results for the diagnosis of presence or absence of cochlear dead regions in individuals with sensorineural hearing loss.

Chapter 3

METHOD

The present study aimed at indicating the effectiveness of the aided TEN (HL) test over the conventional unaided TEN (HL) test for the diagnosis of a dead region (DR) at a certain frequency. In the study, the conventional TEN (HL) test results were obtained and compared with the aided TEN (HL) test results. The unaided TEN (HL) test was administered without the individual wearing the hearing aid (HA). The aided TEN (HL) (ATEN) test was administered with the hearing aids on the participants' ears. The TEN noise was presented through free field speaker for both the unaided and aided TEN (HL) test conditions.

Participant selection

Thirty one individuals in the age range of 11 to 80 years (mean age = 54.55 years, standard deviation = 18.25) were evaluated in the present study. Out of these participants, 12 were female and 19 were male. Only one ear of each participant was tested. All participants had acquired post lingual sensorineural hearing loss. The degree of hearing loss ranged from severe to profound for dead region frequencies only. The pure tone average of the participants ranged from moderate to profound degree. Air bone gap did not exceed 10 dB at any of the test frequencies. All participants had either flat or high frequency sloping sensorineural hearing loss. In addition to this, all participants had aided pure tone threshold within 45 dB HL. None of the participants had any history of ear disorder. Presence of auditory neuropathy was ruled out based on the absence of TEOAE and consistent audiometric responses. All participants were in good physical and mental health. The details of the participants included in the study are provided in Table 1 below.

Table 1.

Audiometric thresholds (in dB HL) for each participant obtained using pure tones

				Pure Tone Threshold (dB) at frequency (Hz)										
Subject	Age (Yrs)	Sex	Ear	250	500	750	1000	1500	2000	3000	4000	6000	8000	PTA (dB)
1	53	M	L	55	70	80	85	90	95	90	95	95	100	83.3
2	37	F	L	40	65	75	80	85	95	100	105	110	100N	80
3	44	M	L	60	65	65	70	75	80	80	85	100	100N	71.6
4	54	M	R	60	80	75	80	95	110	100	110	110	100N	90
5	50	M	R	90	95	95	100	100	105	105	110	115	100N	>90
6	42	M	L	80	85	80	85	95	100	105	110	110	100N	90
7	23	M	R	85	85	80	85	90	95	95	100	115	100N	88.3
8	30	M	L	80	90	85	90	90	95	95	100	105	100	91.6
9	60	M	R	100	100	95	90	90	95	90	95	100	100	95
10	11	M	L	35	50	55	65	75	80	90	100	110	100N	65
11	50	F	L	75	75	70	70	75	80	85	90	105	100N	75
12	37	M	R	50	55	65	70	80	85	80	85	95	100	70
13	75	M	R	60	65	65	70	75	80	80	85	80	75	71.6
14	49	M	L	45	55	65	80	85	90	100	110	115	100N	75
15	75	M	R	70	75	75	80	80	85	95	110	110	100N	80
16	63	M	R	35	45	60	70	70	75	70	75	70	70	63.3
17	29	M	L	60	75	80	90	85	80	80	80	100	100N	81.6
18	52	M	R	55	70	75	80	75	75	95	115	110	100	75
19	47	M	R	40	50	60	70	75	80	85	90	100	100N	66.6
20	72	F	R	50	55	55	60	70	75	80	80	90	100	63.3
21	58	M	R	30	35	55	75	80	85	80	80	80	80	65
22	62	M	L	85	90	85	85	80	75	70	75	70	65	83.3
23	76	M	R	30	35	35	35	50	60	70	80	100	100N	43.3
24	74	M	L	45	50	45	45	50	55	75	90	95	100	50
25	78	F	L	45	60	60	65	65	70	80	90	100	100N	65
26	78	M	L	55	55	60	65	65	75	80	85	95	100	65
27	70	M	R	30	35	45	55	55	60	75	90	110	100N	50
28	80	F	R	30	35	40	45	50	55	70	85	105	100N	45
29	75	M	R	45	70	75	80	80	85	100	110	115	100N	78.3
30	47	M	L	35	45	50	55	70	80	90	95	105	100N	60
31	40	M	R	45	65	70	75	70	70	75	80	100	100N	70

Note: N: No response

Instrumentation

- A calibrated double channel, diagnostic audiometer, Madsen Orbiter 922 with Madsen external sound field speakers for obtaining aided & unaided pure tone & TEN thresholds.
- A calibrated middle ear analyzer, (GSI-Tympstar) for tympanometry and reflexometry.
- A digital two channel behind the ear hearing aid for obtaining the aided threshold.
- Hi-Pro (Hearing aid programming interface unit) connected to the personal computer (PC) with NOAH-3 and hearing aid programming softwares.
- TEN (HL) test Compact Disc (CD), developed by Moore et al. (2004) to detect the presence or absence of cochlear dead regions.
- Fonix 7000 hearing aid analyzer to verify the output of the hearing aid
- The TEN (HL) CD was played from a Philips 729K CD player connected to the calibrated two channel audiometer, Madsen Orbiter 922.

Instruments were connected based on the method provided by Moore et al. (2004). The left output from the CD player was connected to the left (A) line-level input of the audiometer, and the right output from the CD player to the right (B) input. Track1 of the TEN (HL) CD, which contains the calibration tone, was played to adjust the dial of the audiometer to provide appropriate output. After calibration was done the inputs were switched off. Both the channels were mixed in such a way that the TEN (HL) noise and the warble tone signal with 5% frequency modulated depth were directed to the same test ear. Figure 7 illustrates the set up for the administration for TEN (HL) test.

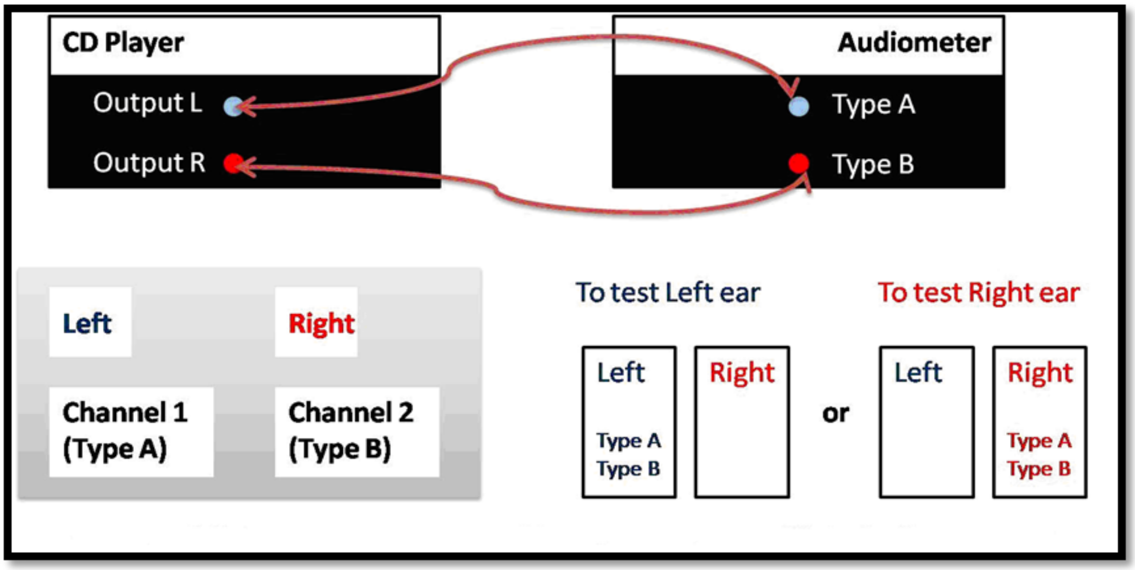

Figure 7. Test setup for administration of TEN (HL).

All the tests were carried out in a two chamber sound treated suite. The noise levels were within permissible levels specified by ANSI (1999).

Procedure

The test procedure consisted of the following steps.

1. Absolute threshold estimation

Air conduction thresholds were estimated using warble tones at frequencies of 250, 500, 750, 1000, 1500, 2000, 3000, 4000 and 8000 Hz using modified Hughson-Westlake procedure developed by Carhart and Jerger (1959). Similar procedure was carried out by using warble tone for estimating bone conduction thresholds (for frequencies 250, 500, 1000, 2000, & 4000 Hz).

2. *Hearing aid selection:*

Two channel digital hearing aids were selected according to fitting range for the degree of hearing loss of each participant. This hearing aid catered to the amplification needs of the participants who had pure tone average ranging from moderate to profound. All the participants in the study had either flat or sloping pattern of hearing loss. For the ease of programming and effectiveness of the gain in low and high frequencies, a double channel hearing aid was suitable. The electro acoustic measurements of the hearing aid were carried out to confirm that the hearing aid's output was within the comfortable range of the participant. This was done to ensure that during the administration of the aided TEN (HL) test, the test signals were not uncomfortable to the participant.

For verification of the output of the hearing aid, electro acoustic measurements were carried out using Fonix 7000 hearing aid analyzer as per ANSI (2003) standards before testing each participant. The hearing aid was connected to PC through Hi-pro and programmed to full on gain. The hearing aid was placed in the test position in the test chamber. Input (digispeech) was given across frequencies 200 Hz to 8000 Hz at 90 dB SPL. The average SSPL 90 was calculated by taking the average output at 500 Hz, 1000 Hz and 2000 Hz. The maximum output of hearing aid was matched with the obtained uncomfortable level (UCL) of individual participants so that the output does not exceed the uncomfortable level.

Audiometric data of each participant was fed into the NOAH database. The hearing aids were connected to the computer through the Hi-Pro and were programmed to the comfort level of the participants (with NAOH software) based on the generic NAL-NL1 fitting rationale (Figure 8).

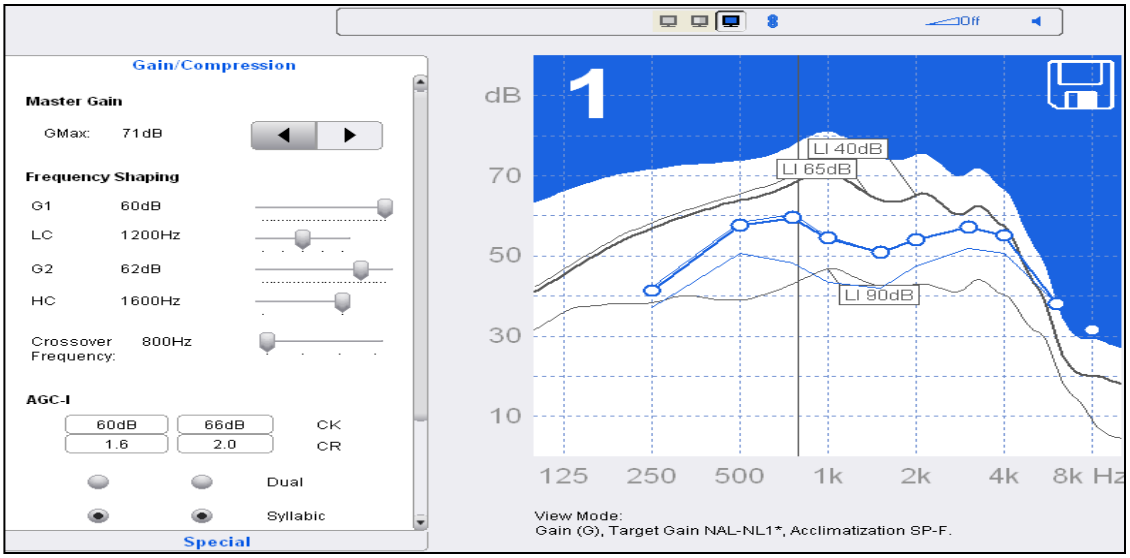

Figure 8. Final programming window for a subject fitted with the hearing aid in the left ear with appropriate gain level considering the MCL and UCL.

Aided free field pure-tone thresholds were established using the OB 922 audiometer for each participant with the programmed hearing aid which he/she wore with an appropriately sized standard ear tip during the test (table 2). Aided uncomfortable level (UCL) was also estimated for all the participants.

Table 2.

Aided thresholds (dB HL) for each participant obtained with the two channels digital behind the ear hearing aid programmed optimally.

Aided thresholds (dB HL) at Frequency (Hz)							
Subject	500 Hz	750 Hz	1000 Hz	1500 Hz	2000 Hz	3000 Hz	4000 Hz
1	40	40	35	40	30	35	50
2	25	30	35	35	35	45	45
3	45	45	40	40	40	45	45
4	30	30	35	35	45	45	50
5	20	20	30	35	35	40	40
6	30	35	30	35	30	40	40
7	35	40	40	45	45	45	55
8	35	35	35	35	40	45	45
9	25	30	25	40	40	45	45
10	20	30	25	30	35	45	50
11	30	30	35	35	35	30	35
12	36	25	25	30	25	35	35
13	30	30	20	30	30	40	50
14	35	30	30	35	40	45	50
15	30	35	35	35	30	35	40
16	30	25	25	30	25	35	45
17	25	30	30	35	35	40	40
18	25	30	30	35	40	40	45
19	25	30	30	35	40	40	55
20	30	30	35	35	35	40	45
21	25	30	35	35	40	45	45
22	20	20	25	30	30	35	35
23	20	25	30	30	35	35	50
24	30	30	30	35	35	45	55
25	25	30	30	35	35	35	45
26	25	25	30	30	35	35	35
27	25	25	25	30	30	40	45
28	25	25	30	30	30	35	35
29	30	30	30	35	35	40	45
30	25	30	30	35	40	40	45
31	30	35	35	35	40	40	45

3. *Estimation of TEN Threshold*

The TEN (HL) test CD was played via a Philips 729 K CD player connected to Madsen OB922 audiometer equipped with free field speakers. The level of the test signal (warble tone) and the TEN (noise) were controlled using the attenuators in the audiometer. TEN thresholds were estimated in two conditions, unaided and aided. During both the conditions, the non test ear was blocked with broadband noise at 70dB SPL presented through the insert ear phone. For the unaided condition, the TEN level was set at 60 dB/ERB_N for participants who had moderate to severe degree of hearing loss and 70 dB/ERB_N for participants who had severe to profound degree of hearing loss. For the aided condition, TEN level was set at 50 dB/ERB_N for all the participants. The TEN masked thresholds for each participant were measured in dB at 500, 750, 1000, 1500, 2000, 3000 and 4000 Hz using tracks 2-8 of the CD as recommended by Moore et al. (2004). A 2dB ascending and 4dB descending step size was taken to estimate the masked thresholds.

The presence or absence of a dead region at a specific frequency was based on the criteria suggested by Moore et al. (2004). If the masked threshold in the TEN (HL) was 10 dB or more above the TEN (HL) level/ ERB_N, and the TEN (HL) elevated the absolute threshold by 10 dB or more, then the DR was assumed to be present at the signal frequency. If the masked threshold in the TEN (HL) was less than 10 dB above the TEN (HL) level/ ERB_N, and the TEN (HL) elevated the absolute threshold by 10 dB or more, then the dead region was assumed to be absent. If the masked threshold in the TEN (HL) was 10 dB or more above the TEN (HL) level/ ERB_N, but the TEN (HL) did not elevate the absolute threshold by 10 dB or more, then the result was considered inconclusive. A "no response (NR)" was recorded when the subject did not indicate hearing the signal at the maximum output level of the audiometer, which was 86 dB HL for the signals derived from the TEN (HL) CD. The unaided and aided TEN (HL) thresholds for all participants at 500 Hz to 4000 Hz were compared and statistically analyzed.

Analysis

The descriptive statistical analysis (Cross tabulation) was carried out for the comparison of both the unaided and aided TEN (HL) test conditions for all 31 participants for all frequencies at 500 Hz, 750 Hz, 1000 Hz, 1500 Hz, 2000 Hz, 3000 Hz, and 4000 Hz for the diagnosis of cochlear dead regions.

The analyses were carried out for the above mentioned frequencies and the TEN test results are discussed in terms of the following criteria:

a) Helpful in diagnosis
b) Confirmation in diagnosis
c) Change in diagnosis
d) Limitation in diagnosis

The above terms are discussed in detail in the next chapter.

Chapter 4

RESULTS AND DISCUSSION

The results and discussion of the present study are highlighted based on the objectives of the study:

- To assess the presence or absence of cochlear dead regions in participants with severe or profound hearing loss using unaided TEN (HL) test and aided TEN (HL) test at various frequencies.
- To assess the effectiveness of aided TEN (HL) test in diagnosis of dead regions.

The descriptive statistical analysis was carried out for the comparison of both the unaided [TEN (HL)] and aided [ATEN (HL)] test conditions, for all the 31 participants. Cross tabulation was also computed across the frequencies i.e., at 500 Hz, 750 Hz, 1000 Hz, 1500 Hz, 2000 Hz, 3000 Hz and 4000 Hz for the diagnosis of cochlear dead region. Cross tabulation was expressed as a contingency table to compare the distribution of all the variables simultaneously in a matrix format.

4.1. Results of the unaided TEN (HL) and aided TEN (HL) tests

The results of the unaided TEN (HL) test and the ATEN test are given separately for each subject and for each test frequency as shown in Table 3. The results are discussed based on the results of the TEN (HL) test as follows:

(1) "P" indicates the presence of dead region in both unaided TEN (HL) test and aided TEN (HL) test condition. In this case, the masked threshold in the TEN (HL) was 10 dB or more above the TEN (HL) level/ ERB_N, and the TEN (HL) elevated the absolute threshold by 10 dB or more. These responses are indicated by red color.

(2) "A" indicates the absence of dead region when the TEN (HL) test produced 10 dB or more of the masking, but the masked threshold was less than 10 dB above the TEN levels/ ERB_N. These responses are indicated by green color.

(3) "I" indicates inconclusive results when the masked threshold of both unaided and aided TEN (HL) test condition was less than 10 dB above the absolute threshold, leading to an inconclusive result. These responses are indicated by blue color.

The unaided (green bars) and aided TEN (HL) test conditions (blue bars) and their results were depicted as present, absent or inconclusive for all the participants across the frequencies (at 500 Hz, 750 Hz, 1000 Hz, 1500 Hz, 2000 Hz, 3000 Hz and 4000 Hz) are shown in Figure 9 to 15.

To check the effectiveness of the aided and unaided TEN (HL) test for the diagnosis of dead region (DR) in participants with different absolute threshold levels at a certain frequency, all the absolute thresholds were categorized in intervals of 5 dB ranging from 70 dB to maximum limits of audiometer. The ATEN test results are discussed based on information regarding helpfulness in the diagnosis, accuracy, change in diagnosis and limitations.

Table 3.

Results of the unaided TEN (HL) test and the aided TEN (HL) test for each subject and each test frequency (Hz).

			Dead region presence/absence in frequency (Hz)											
subjects	U500	A500	U750	A750	U1000	A1000	U1500	A1500	U2000	A2000	U3000	A3000	U4000	A4000
1	P	P	I	A	I	A	I	A	I	A	I	A	I	A
2	A	A	I	A	I	A	I	A	I	A	I	P	I	P
3	A	P	A	A	A	A	I	P	I	A	I	A	I	A
4	P	P	I	A	I	A	I	P	I	P	I	P	I	P
5	I	P	I	P	I	A	I	P	I	P	I	P	I	P
6	I	A	A	A	I	P	I	P	I	P	I	A	I	P
7	I	P	P	P	I	P	I	P	I	P	I	P	I	P
8	I	A	I	A	I	A	I	P	I	P	I	P	I	I
9	I	P	I	P	I	P	I	P	I	P	I	P	I	P
10	A	P	A	A	A	A	I	P	I	A	I	P	I	P
11	I	A	P	A	P	A	I	P	I	A	I	P	I	P
12	A	P	P	P	I	P	I	P	I	P	I	P	I	P
13	P	P	P	P	P	P	P	P	I	P	I	P	I	P
14	A	A	P	A	I	A	I	P	I	A	I	P	I	I
15	I	P	I	A	I	A	I	P	I	A	I	P	I	P
16	A	P	P	P	P	A	I	P	I	A	P	P	I	P
17	I	A	A	A	I	P	I	P	A	A	I	A	I	P
18	A	A	I	A	I	A	I	A	I	A	I	P	I	P
19	A	A	A	A	A	A	I	A	A	A	I	P	I	P
20	A	P	A	A	P	P	P	P	A	A	I	P	I	P
21	A	A	A	A	A	P	I	P	A	P	I	P	I	P
22	I	P	I	P	I	P	A	P	A	A	A	A	A	A
23	A	A	A	A	A	A	A	A	A	A	A	P	A	A
24	A	A	A	A	A	A	A	A	A	A	A	P	I	P
25	A	A	P	P	P	A	P	A	I	A	I	A	I	A
26	A	A	A	A	A	A	A	A	A	A	A	A	A	A
27	A	A	A	A	A	A	A	A	A	A	I	A	I	P
28	A	A	A	A	A	A	A	A	A	A	A	A	I	P
29	I	P	I	A	I	A	I	P	I	P	I	P	I	P
30	A	A	A	A	A	A	I	A	I	P	I	P	I	P
31	I	A	A	A	I	P	I	P	I	A	I	A	I	P

Note: P: Present (red colour); A: Absent (green colour); I: Inconclusive (blue colour)
U: unaided, A: aided

4.1.1 TEN (HL) results for 500 Hz in unaided and aided condition

The results of the unaided and ATEN test at 500 Hz are tabulated as follows.

Table 4.

Cross tabulation comparison data at the TEN test frequency of 500 Hz in both aided and unaided condition

500 Hz			**Aided** Present	**Aided** Absent	Total
Unaided	Present	Count	3	0	3
		% within Unaided	100%	0%	100%
	Absent	Count	5	12	17
		% within Unaided	29.4%	70.6%	100%
	Inconclusive	Count	6	5	11
		% within Unaided	54.5%	45.5%	100%
Total		Count	14	17	31
		% within Unaided	45.2%	54.8%	100%

From the above table it was observed that for the test frequency of 500 Hz, three (100%) participants were diagnosed of having DR in both aided and unaided TEN (HL) condition. Out of the 17 participants who were diagnosed as not having DR in the unaided TEN (HL) condition, five (29.4%) were diagnosed as having of DR present and 12 (70.6%) were diagnosed as having absence of DR in ATEN condition. For 11 participants the results were inconclusive in the unaided TEN (HL) test. However, the aided TEN (HL) test showed six (54.5%) of these participants had the presence of dead region and five (45.5%) had no DR. This indicated that ATEN test showed conclusive results of either having presence or absence of a DR, where as the unaided TEN (HL) test results showed a greater degree of inconclusive results.

4.1.1.a. Helpful in diagnosis

It was observed that based on the absolute thresholds, all the results were evaluated on the criteria of presence or absence of DR and inconclusive results at the test frequency of 500 Hz. This was to verify the predictability of ATEN test in comparison to the unaided TEN (HL) test. For an absolute threshold of 70 dB HL, only one participant was diagnosed as having inconclusive result in unaided TEN (HL) test, where as the ATEN test result showed positive for the presence of DR. Similarly at 90 dB HL, one participant and at more than 90 dB HL two participants had an inconclusive unaided TEN (HL) result. This was confirmed for the presence of DR in the ATEN test. This indicated the helpfulness of ATEN test over the unaided TEN (HL) test.

4.1.1.b. Confirmation in diagnosis

In another case with absolute threshold of 70 dB HL it was observed that both aided and unaided TEN (HL) test results showed absence of DR. Similarly for an absolute threshold of 80 dB HL, one subject was diagnosed as DR to be present in both aided and unaided TEN (HL) test. This ascertained the effectiveness of the diagnosis of DR with ATEN test.

4.1.1.c. Change in diagnosis

No such result was observed for change in diagnosis.

4.1.1.d. Limitation of TEN

No such result was observed for limitation of TEN.

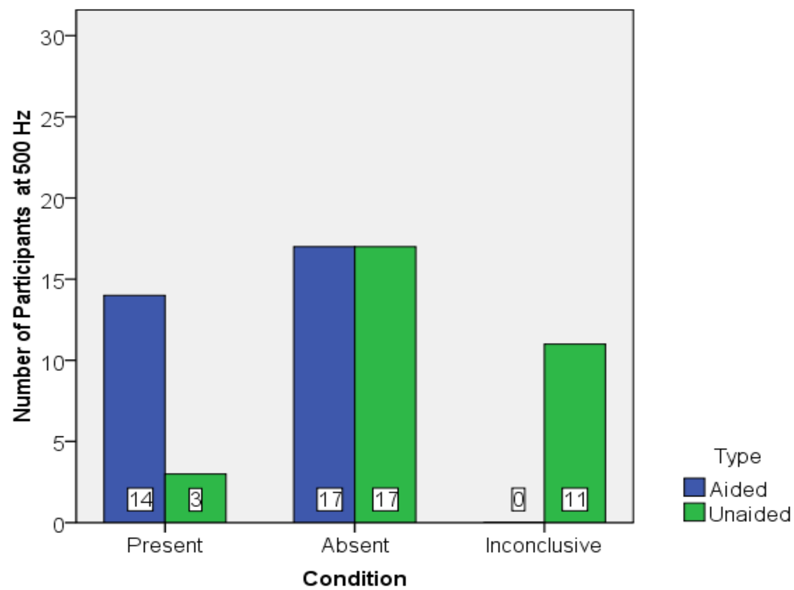

Figure 9. The number of participants for results of aided & unaided TEN test at 500 Hz.

At 500 Hz, as shown in figure 9, out of 31 participants, 14 participants were diagnosed as presence of DR in ATEN condition and in unaided TEN (HL) test condition, three participants were diagnosed as presence of dead region. Seventeen participants were diagnosed as absence of DR in both unaided and ATEN test condition whereas for 11 participants, the results were inconclusive in unaided TEN (HL) test condition but in ATEN test condition no inconclusive results observed for 500 Hz frequency.

Thus, from the results obtained, 11 participants had inconclusive results in the unaided TEN (HL) test where as the ATEN test showed six (54.5%) participants as having presence of DR and five participants had no DR. Out of 17 participants, who were diagnosed as absence DR in the unaided TEN (HL) condition, 12 were diagnosed as DR absent and five (29.4%) were diagnosed as DR present in the ATEN condition. Three participants were diagnosed of having DR in both unaided and ATEN test condition. Similar results were reported by Marriage, Moore and Stone (2008) regarding the efficacy of ATEN test. They found that for one subject at 500 Hz, the criteria for DR were not met for the TEN (HL) test, but were met for the ATEN test.

4.1.2. TEN (HL) results for 750 Hz in unaided and aided condition

The results of unaided and ATEN test at 750 Hz are tabulated as follows.

Table 5.

Cross tabulation comparison data at the TEN test frequency of 750 Hz in both aided and unaided condition

750 Hz			**Aided**		Total
			Present	Absent	
Unaided	Present	Count	5	2	7
		% within Unaided	71.4%	28.6%	100%
	Absent	Count	0	14	14
		% within Unaided	0%	100%	100%
	Inconclusive	Count	3	7	10
		% within Unaided	30%	70%	100%
Total		Count	8	23	31
		% within Unaided	25.8%	74.2%	100%

From the above table 5, it was observed that for the test frequency of 750 Hz, seven (100%) participants were diagnosed of having DR in unaided TEN (HL) condition. Out of these seven (100%) participants, five (71.4%) were diagnosed as having of DR present and two (28.6%) participants were diagnosed as having absence of DR in ATEN condition. Fourteen (100%) participants were diagnosed as having absence of DR in both unaided and ATEN test condition. For 10 participants the results were inconclusive in the unaided TEN (HL) test condition. However, the ATEN test showed three (30%) participants had presence of DR and seven (70%) had no DR. This indicated that ATEN test showed conclusive results of either having presence or absence of a DR, where as the unaided TEN (HL) test results showed a greater degree of inconclusive results.

4.1.2.a. Helpful in diagnosis

It was observed that at 750 Hz frequency, results showed that at an absolute threshold of 85 dB HL, only one participant and at more than 90 dB HL two participants were diagnosed as inconclusive result in unaided TEN (HL) test condition where as in ATEN test they were diagnosed as presence of DR. At 75 dB HL absolute threshold, five participants, at 80 dB HL and at 85 dB HL, two participants showed inconclusive results in unaided TEN (HL) test condition which was confirmed by the ATEN test for the absence of DR. These results uphold the importance of ATEN test over the unaided TEN (HL) test for diagnosis of DR.

4.1.2.b. Confirmation in diagnosis

At 80 dB HL absolute threshold level, only one participant showed the presence of DR in both unaided and ATEN test condition where as one participant at 70 dB HL and two participants at 80 dB HL showed absence of DR in both the unaided and ATEN test condition which indicated the confirmation in diagnosis.

4.1.2.c. Change in diagnosis

At an absolute threshold of 70 dB HL, one participant showed the presence of DR in unaided TEN (HL) test condition where as ATEN test showed the absence of DR which led to the change in diagnosis.

4.1.2.d. Limitation of TEN

No such result was observed for limitation of TEN.

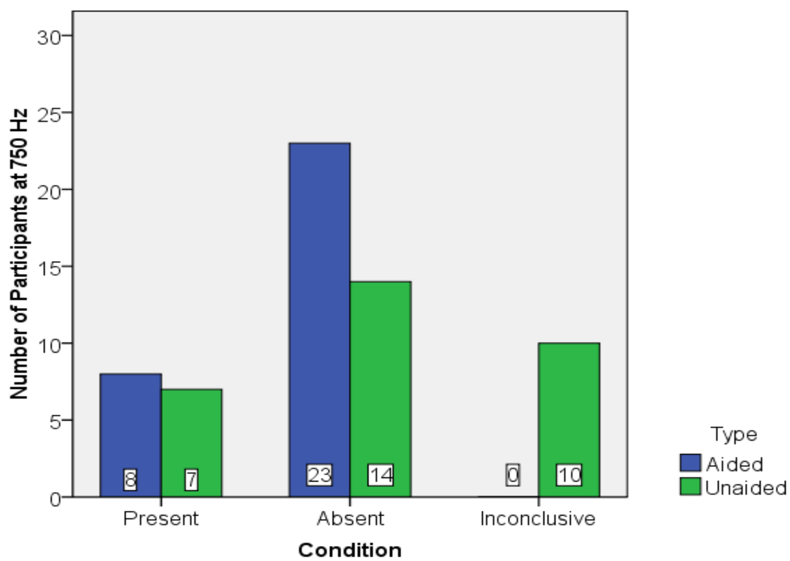

Figure 10. The number of participants for results of aided & unaided TEN test at 750 Hz.

At 750 Hz, as shown in figure 10, out of 31 participants, eight participants were diagnosed as presence of DR in ATEN condition and seven participants were diagnosed as presence of DR in unaided TEN (HL) test condition. Twenty-three participants were diagnosed as absence of DR in ATEN test condition and in unaided TEN (HL) test condition 14 participants diagnosed as absence of DR whereas for 10 participants, the results were inconclusive in unaided TEN (HL) test condition but in ATEN test condition no inconclusive results observed at 750 Hz frequency.

4.1.3. TEN (HL) results for 1000 Hz in unaided and aided condition

Results of the unaided and ATEN test at 1000 Hz are tabulated as follows.

Table 6.

Cross tabulation comparison data at the TEN test frequency of 1000 Hz in both aided and unaided condition

1000 Hz			**Aided**		Total
			Present	Absent	
Unaided	Present	Count	2	3	5
		% within Unaided	40%	60%	100%
	Absent	Count	1	9	10
		% within Unaided	10%	90%	100%
	Inconclusive	Count	7	9	16
		% within Unaided	43.8%	56.2%	100%
Total		Count	10	21	31
		% within Unaided	32.3%	67.7%	100%

From the above table it was observed that for the test frequency of 1000 Hz, five (100%) participants were diagnosed of having DR in unaided TEN (HL) condition. Out of five (100%) participants, two (40%) were diagnosed as having of DR present and three (60%) were diagnosed as having absence of DR in ATEN test condition. Out of 10 participants who were diagnosed as not having DR in unaided TEN (HL) test condition, one (10%) was diagnosed as having of DR present and nine (90%) were diagnosed as having absence of DR in ATEN test condition. For 16 (100%) participants the results were inconclusive in the unaided TEN (HL) test. However, the ATEN test showed seven (43.8%) had presence of DR and nine (56.2%) had no DR. This indicated that ATEN test showed conclusive results of either having presence or absence of a DR, where as the unaided TEN (HL) test results showed a greater degree of inconclusive results.

4.1.3.a. Helpful in diagnosis

It was observed that at 1000 Hz frequency, results showed that at an absolute threshold of 70 dB HL and at 75 dB HL, one participant, at 85 dB HL, three participants and at 90 dB HL two participants were diagnosed as inconclusive results in unaided TEN (HL) test condition where as with the ATEN test they were diagnosed as presence of DR. For an absolute threshold of 80 dB HL, six participants, at 90 dB HL and at more than 90 dB HL, one participant had an inconclusive result in unaided TEN (HL) test condition. This was confirmed for the absence of DR in the ATEN test. This indicated the helpfulness of ATEN test over the unaided TEN (HL) test.

4.1.3.b. Confirmation in diagnosis

In other condition, at 70 dB HL absolute threshold, one participant diagnosed as presence of DR in both unaided TEN (HL) test and ATEN test condition where as one more participant diagnosed as absence of DR in both the unaided and ATEN test condition. These results helped in confirmation in diagnosis.

4.1.3.c. Change in diagnosis

At an absolute threshold of 70 dB HL, two participants showed the presence of DR in unaided TEN (HL) test condition where as in ATEN test condition, they were diagnosed as absence of DR. One participant at an absolute threshold of 75 dB HL, diagnosed as absence of DR where as ATEN test showed the presence of DR. These results can lead to the change in diagnosis.

4.1.3.d. Limitation of TEN

No such result was observed for limitation in diagnosis.

At 1000 Hz, for eight participants the outcome of the TEN (HL) test was inconclusive where as with the ATEN test they were diagnosed as absence of DR. Similar kinds of findings were reported by Marriage et al (2008). In their study, for one participant, the outcome of the TEN (HL) test was inconclusive where as ATEN test showed the absence of DR.

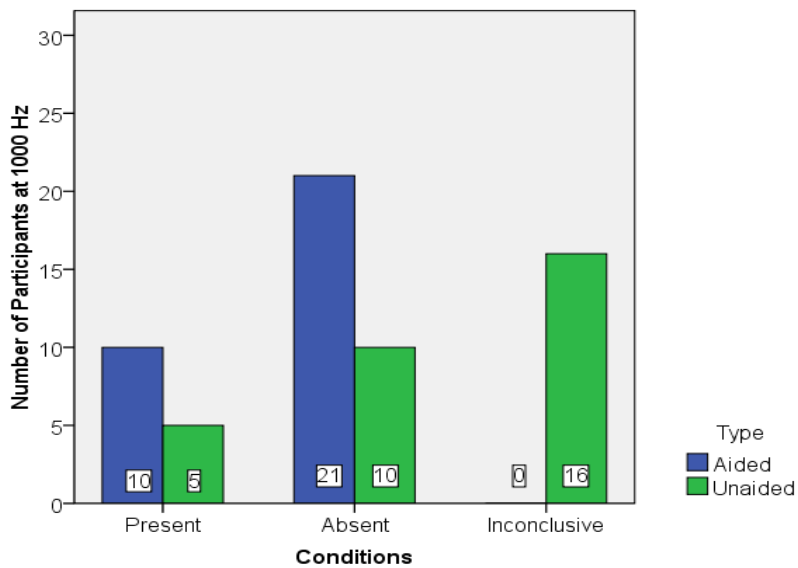

*Figure 11.*The number of participants for results of aided & unaided TEN test at 1000Hz.

At 1000 Hz, as shown in figure 11, out of 31 participants, 10 participants were diagnosed presence of DR in ATEN condition and five participants were diagnosed as having DR present in unaided TEN (HL) test condition. Twenty-one participants were diagnosed as absence of DR in ATEN test condition and in unaided TEN (HL) test condition 10 participants were diagnosed as absence of DR whereas for 16 participants, the results were inconclusive in unaided TEN (HL) test condition but in ATEN test condition no inconclusive results observed at 1000 Hz frequency.

4.1.4. TEN (HL) results for 1500 Hz in unaided and aided condition

Results of the unaided and ATEN test at 1500 Hz are tabulated as follows.

Table 7.

Cross tabulation comparison data at the TEN test frequency of 1500 Hz in both aided and unaided condition

1500 Hz			**Aided**		Total
			Present	Absent	
Unaided	Present	Count	2	1	3
		% within Unaided	66.7%	33.3%	100%
	Absent	Count	1	5	6
		% within Unaided	16.7%	83.3%	100%
	Inconclusive	Count	17	5	22
		% within Unaided	77.3%	22.7%	100%
Total		Count	20	11	31
		% within Unaided	64.5%	35.5%	100%

From the above table it was observed that for the test frequency of 1500 Hz, three participants were diagnosed of having DR in unaided TEN (HL) test condition. Out of these three, two (67.7%) were diagnosed of having DR and one (33.3%) was diagnosed as having absence of DR in the ATEN test condition. six (100%) participants who were diagnosed as not having DR in the unaided TEN (HL) condition, one (16.7%) was diagnosed as having of DR present and five (83.3%) were diagnosed as having absence of DR in ATEN test condition. For 22 participants the results were inconclusive in unaided TEN (HL) test condition. However, the ATEN test showed 17 (77.3%) had presence of DR and five (22.7%) had no of DR. This indicated that ATEN test showed conclusive results of either having presence or absence of a DR, where as the unaided TEN (HL) test results showed a greater degree of inconclusive results.

4.1.4.a. Helpful in diagnosis

It was observed that at 1500 Hz frequency, results showed that at an absolute threshold of 70 dB HL, two participants, at 75 dB HL, three participants, at 80 dB HL, four participants, at 85 dB HL, two participants, at 90 dB HL, three participants and at more than 90 dB HL, three participants were diagnosed as inconclusive result in unaided TEN (HL) test condition where as with the ATEN they were diagnosed as presence of DR. Similar to this, at the absolute threshold of 70 dB HL and at 85 dB HL, one participant and two participants at 75 dB HL, had an inconclusive diagnosis of DR which was confirmed by the ATEN test for the absence of DR. This indicated the helpfulness of ATEN test over the unaided TEN (HL) test.

4.1.4.b. Confirmation in diagnosis

In another two participants, with an absolute threshold of 70 dB HL and at 75 dB HL, it was noticed that both aided and unaided TEN (HL) test results concluded of DR to be present which indicated the confirmation in diagnosis.

4.1.4.c. Change in diagnosis

At the absolute threshold level of 70 dB HL, two participants diagnosed as presence of DR in unaided TEN (HL) test condition where as with the ATEN test they were diagnosed as absence for DR. Similar to this, at 80 dB HL, one participant diagnosed as absence of DR in unaided TEN (HL) test condition where as with the ATEN test condition, it was diagnosed as presence for DR. These results led to the change in diagnosis.

4.1.4.d. Limitation of TEN

No such result was observed for the limitation of TEN (HL) test.

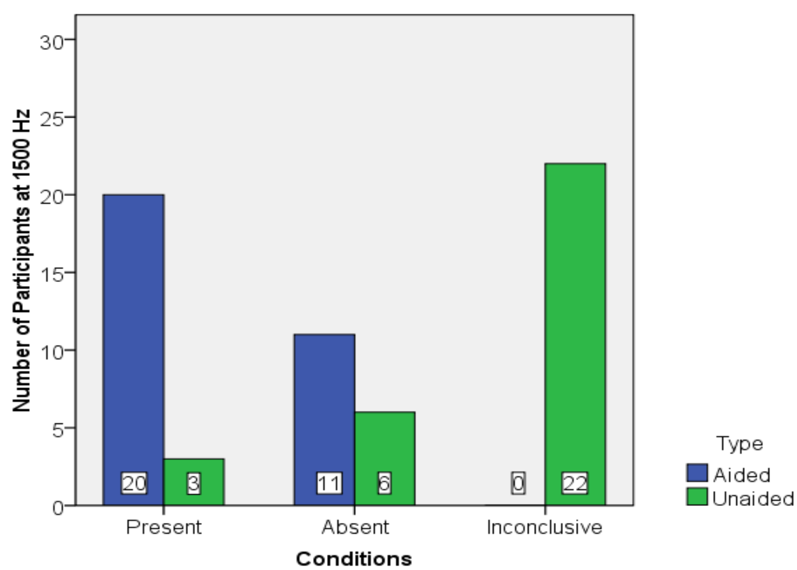

*Figure 12.*The number of participants for results of aided & unaided TEN test at 1500Hz.

At 1500 Hz, as shown in figure 12, out of 31 participants, 20 participants were diagnosed presence of DR in ATEN test condition and three were diagnosed as having DR present in unaided TEN (HL) test condition. Eleven participants were diagnosed as absence of DR in ATEN test condition and in unaided TEN (HL) test condition six participants were diagnosed as absence of DR whereas for 22 participants, the results were inconclusive in unaided TEN (HL) test condition but in ATEN test condition no inconclusive results observed at 1500 Hz frequency.

4.1.5. TEN (HL) results for 2000 Hz in unaided and aided condition

Results of the unaided and ATEN test condition at 2000 Hz are tabulated as follows.

Table 8.

Cross tabulation comparison data at the TEN test frequency of 2000 Hz in both aided and unaided condition

2000 Hz			**Aided**		Total
			Present	Absent	
Unaided	Absent	Count	1	9	10
		% within Unaided	10.0%	90.0%	100%
	Inconclusive	Count	10	11	21
		% within Unaided	47.6%	52.4%	100%
Total		Count	11	20	31
		% within Unaided	35.5%	64.5%	100%

From table 8 it was observed that for the test frequency of 2000 Hz, 10 (100%) participants were diagnosed as not having DR in unaided TEN (HL) condition, and out of 10 (100%), one (10%) was diagnosed as having of DR present and nine (90%) were diagnosed as having absence of DR in ATEN test condition. For 21 participants the results were inconclusive in the unaided TEN (HL) test condition. However, ATEN test showed 10 (47.6%) participants had presence of DR and 11 (52.4%) had no DR. This indicated that ATEN test showed conclusive results of either having presence or absence of a DR, where as the unaided TEN (HL) test results showed a greater degree of inconclusive results.

4.1.5.a. Helpful in diagnosis

It was observed that at 2000 Hz frequency, results showed that at an absolute threshold of 80 dB HL and at 85 dB HL, two participants, and at more than 90 dB HL, six participants were diagnosed as inconclusive result in unaided TEN (HL) test condition where as with the ATEN test they were diagnosed as presence for DR. similar to this, two participants at 70 dB HL and at 75 dB HL, four participants at 80 dB HL and one participant at 85 dB HL, at 90 dB HL and at more than 90 dB HL were diagnosed as inconclusive result in unaided TEN (HL) test condition where as with the ATEN test they were diagnosed as absence for DR. These results uphold the importance of ATEN test over the unaided TEN (HL) test condition for the diagnosis of dead region.

4.1.5.b. Confirmation in diagnosis

Another three participants, at 75 dB HL and one participant at 80 dB HL diagnosed as absence of DR in both unaided TEN (HL) test and ATEN test condition which indicates the confirmation in diagnosis.

4.1.5.c. Change in diagnosis

One participant at 85 dB HL, diagnosed as absence of DR in unaided TEN (HL) test Condition where as in ATEN test Condition it diagnosed as presence of DR. These results led to the change in diagnosis of DR.

4.1.5.d. Limitation of TEN

No such result was observed for the limitation of TEN (HL) test.

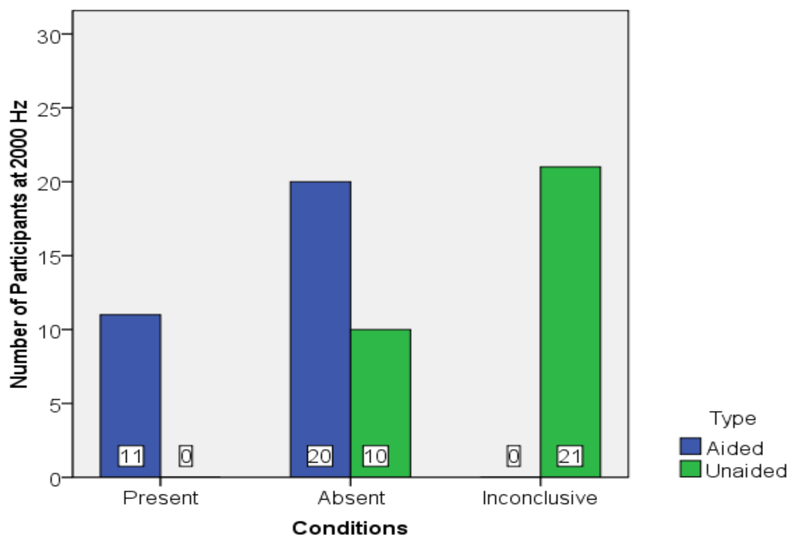

*Figure 13.*The number of participants for results of aided & unaided TEN test at 2000Hz

At 2000 Hz, as shown in figure 13, out of 31 participants, 11 participants were diagnosed presence of DR in ATEN test condition and no participants were diagnosed as having DR present in unaided TEN (HL) test condition. Twenty participants were diagnosed as absence of DR in ATEN test condition and in unaided TEN (HL) test condition 10 were diagnosed as absence of DR whereas for 21 participants, the results were inconclusive in unaided TEN (HL) test condition but in ATEN test condition no inconclusive results observed at 2000 Hz frequency.

There were cases whose results indicated that absence of DR in unaided TEN (HL) test condition where as the ATEN test condition indicated that dead region was present. Similar findings obtained in Marriage et al (2008).

4.1.6. TEN (HL) results for 3000 Hz in unaided and aided condition

Results of the unaided and ATEN test at 3000 Hz are tabulated as follows.

Table 9.

Cross tabulation comparison data at the TEN test frequency of 3000 Hz in both aided and unaided condition

3000 Hz			**Aided**		Total
			Present	Absent	
Unaided	Present	Count	1	0	1
		% within Unaided	100.0%	.0%	100%
	Absent	Count	2	3	5
		% within Unaided	40.0%	60.0%	100%
	Inconclusive	Count	18	7	25
		% within Unaided	72.0%	28.0%	100%
Total		Count	21	10	31
		% within Unaided	67.7%	32.3%	100%

From the above table it was observed that for the test frequency of 3000 Hz frequency, one participant was diagnosed of having DR in both unaided and ATEN condition. Out of the five (100%) participants who were diagnosed as not having DR in the unaided TEN (HL) condition, two (40.0%) were diagnosed as having of DR present and three (60.0%) were diagnosed as having absence of DR in ATEN test condition. For 25 participants the results were inconclusive in the unaided TEN (HL) test condition. However, the ATEN test showed 18 (72.0%) participants out of these 25 (100%) had the presence of DR and seven (28.0%) had no DR. This indicated that ATEN test showed conclusive results of either having presence or absence of a DR, where as the unaided TEN (HL) test results showed a greater degree of inconclusive results.

4.1.6.a. Helpful in diagnosis

It was observed that at 3000 Hz frequency, results showed that at an absolute threshold of 80 dB HL four participants, at 85 dB HL two participants, and at 90 dB HL three participants and at more than 90 dB HL nine participants were diagnosed as inconclusive result in unaided TEN (HL) test condition where as with the ATEN test it was diagnosed as presence for DR. Similar to this, two participants at an absolute threshold of 75 dB HL, three participants at 80 dB HL, and one participant at more than 90 dB HL were diagnosed as inconclusive result in unaided TEN (HL) test condition where as with the ATEN test it was diagnosed as absence of DR. These results helpful in diagnosis of DR in ATEN test over the unaided TEN (HL) test condition.

4.1.6.b. Confirmation in diagnosis

One participant at 70 dB HL diagnosed as presence of DR in both unaided and ATEN test Condition and two participants at 70 dB HL and one participant at 80 dB HL diagnosed as absence of DR in both unaided and ATEN test Condition. These results indicated the confirmation in diagnosis.

4.1.6.c. Change in diagnosis

At 70 dB HL and at 75 dB HL, one participant, diagnosed as absence of DR in unaided TEN (HL) test Condition where as in ATEN test Condition it diagnosed as presence of DR. These results led to the change in diagnosis of DR.

4.1.6.d. Limitation of TEN

No such result was observed for limitation of TEN (HL) test

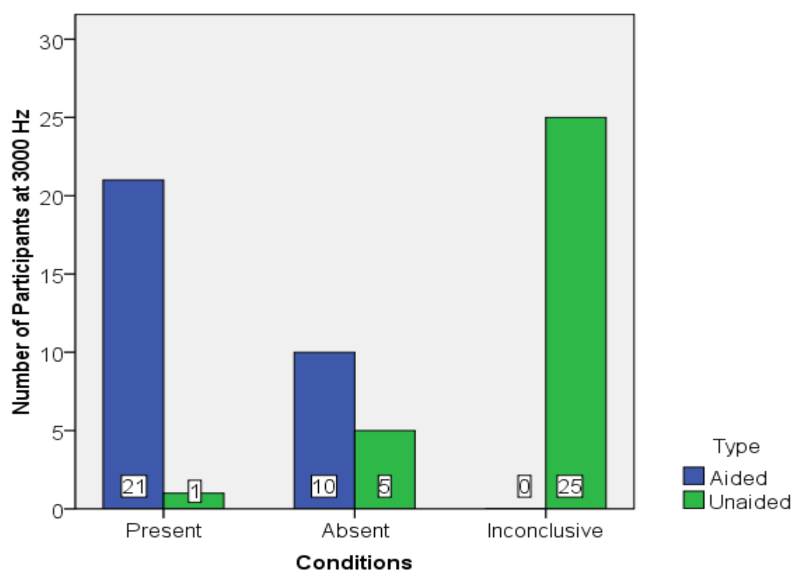

*Figure 14.*The number of participants for results on aided & unaided TEN test at 3000Hz

At 3000 Hz, as shown in figure 14, out of 31 participants, 21 participants were diagnosed presence of DR in ATEN test condition and one was diagnosed as having DR present in unaided TEN (HL) test condition. Ten participants were diagnosed as absence of DR in ATEN test condition and in unaided TEN (HL) test condition five participants were diagnosed as absence of DR whereas for 25 participants, the results were inconclusive in unaided TEN (HL) test condition but in ATEN test condition no inconclusive results observed at 3000 Hz frequency.

Moore et al., 2007 affirmed that due to severity of hearing impairment, the results were inconclusive at some frequencies as the unaided TEN (HL) test could not be made intense enough to produce sufficient masking, or because absolute or masked thresholds exceeded the maximum output of the audiometer.

4.1.7. TEN (HL) results for 4000 Hz in unaided and aided condition

Results of the unaided and ATEN test at 4000 Hz are tabulated as follows.

Table 10.

Cross tabulation comparison data at the TEN test frequency of 4000 Hz in both aided and unaided condition

4000 Hz			**Aided**			Total
			Present	Absent	Inconclusive	
Unaided	Absent	Count	0	3	0	3
		% within Unaided	0%	100%	0%	100%
	Inconclusive	Count	23	3	2	28
		% within Unaided	82.1%	10.7%	7.1%	100%
Total		Count	23	6	2	31
		% within Unaided	74.2%	19.4%	6.5%	100%

From table 10 it was observed that for the test frequency of 4000 Hz, three (100%) participants were diagnosed as absence of DR in both unaided and ATEN test condition. For 28 participants the results were inconclusive in the unaided TEN (HL) test condition. However, the ATEN test showed 23 (82.1%) participants out of these 28 (100%) had presence of DR and three (10.7%) had no DR and two (7.1%) had inconclusive results. This indicated that ATEN test showed conclusive results of either having presence or absence of a DR, where as the unaided TEN (HL) test results showed a greater degree of inconclusive results.

4.1.7.a. Helpful in diagnosis

It was observed that at 4000 Hz, results showed that at an absolute threshold of 75 dB HL, one participant, at 80 dB HL four participants, at 85 dB HL, three participants, at 90 dB HL four participants and at more than 90 dB HL ten participants were diagnosed as inconclusive result in unaided TEN (HL) test condition where as with the ATEN test it was diagnosed as presence for DR. Similar to this, one participant at 85 dB HL and one participant at 90 dB HL and at more than 90 dB HL also one participant were diagnosed as inconclusive result in unaided TEN (HL) test condition where as with the ATEN test it was diagnosed as absence of DR. These results are helpful in diagnosis of DR.

4.1.7.b. Confirmation in diagnosis

One participant at 75 dB HL, one participant at 80 dB HL and one participant at 85 dB HL diagnosed as absence of DR in both unaided and ATEN test Condition. This result helps in the confirmation in diagnosis.

4.1.7.c. Change in diagnosis

At more than 90 dB HL, two participants diagnosed as inconclusive results for DR in both the unaided and ATEN test Condition. This results lead to change in diagnosis of DR.

4.1.7.d. Limitation of TEN

At greater than 90 dB HL, two participants diagnosed as inconclusive result in both unaided and ATEN test condition. These results led to limitation of TEN (HL) test.

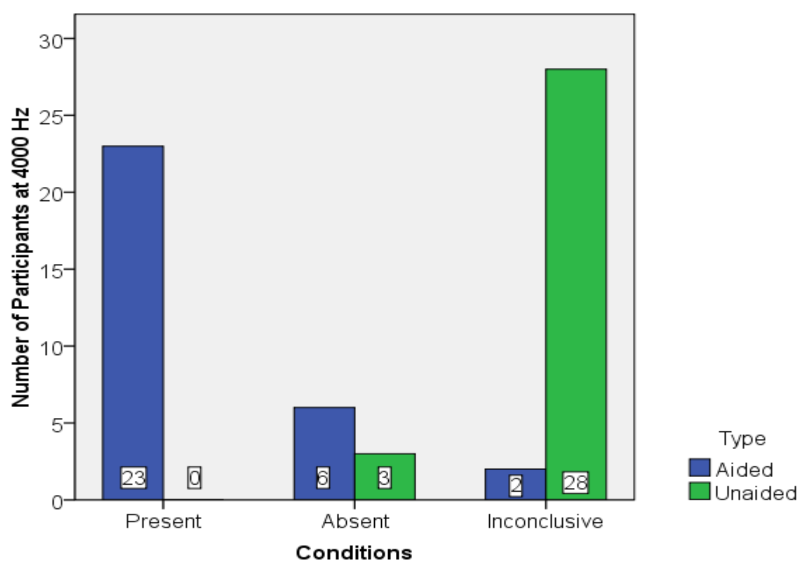

*Figure 15.*The number of participants for results of aided & unaided TEN test at 4000Hz

At 4000 Hz, as shown in figure 15, out of 31 participants, 23 participants were diagnosed presence of DR in ATEN test condition and no participants were diagnosed as presence of DR in unaided TEN (HL) test condition. six participants were diagnosed as absence of DR in ATEN test condition and in unaided TEN (HL) test condition three participants were diagnosed as absence of DR whereas for 28 participants, the results were inconclusive in unaided TEN (HL) test condition but in ATEN test condition, the results were inconclusive for two participants at 4000 Hz frequency.

When the hearing loss was greater than 70 dB (HL), there was a relatively high incidence of inconclusive results for the TEN (HL) test and only 2 participants at 4000 Hz has inconclusive results in ATEN test condition. There are many cases where the results were inconclusive for the TEN (HL) test while there were fewer cases for the ATEN test, which is consistent with our expectation that the gain provided by the participant's hearing aids would reduce the incidence of inconclusive results. Similar results were reported in Marriage et al. (2008).

4.2. Clinical implications of the aided Threshold Equalizing Noise test

The results of the aided Threshold Equalizing Noise (ATEN) test have important implications for identification and rehabilitation of individuals with cochlear dead regions (Vickers et al. 2001; Vinay & Moore, 2007). The implications are discussed separately for identification and rehabilitation of individuals with cochlear dead regions.

4.2.1. Implications of aided Threshold Equalizing Noise (ATEN) test for identification of cochlear dead regions

While the results support our expectation that the ATEN test would lead to a lower incidence of inconclusive results than the TEN (HL) test, the results also reveal some modifications required with the ATEN test. In particular, for most subjects the inconclusive results in the unaided condition lead to a clear diagnosis (DR either present or not), in the aided condition. One another finding was a relatively high incidence of cases for which the TEN (HL) test indicated that no DR was present, but the ATEN test indicated that a DR was present. This can be explained by the fact that some of the hearing aids, reduced the level of the tone relative to the noise. Therefore, for the tone to be heard, its level had to be raised relative to the noise, and this caused the tone level at threshold to be 10 dB or more above the “nominal” TEN level/ ERB_N.

Table 11.

Tabulation of unaided and aided TEN (HL) test results

Frequency (Hz)	No. of subjects	Unaided TEN (HL) test			Aided TEN (HL) test		
		Presence	Absence	Inconclusive	Presence	Absence	Inconclusive
500	31	3	17	11	14	17	NIL
750	31	7	14	10	8	23	NIL
1000	31	5	10	16	10	21	NIL
1500	31	3	6	22	20	11	NIL
2000	31	NIL	10	21	11	20	NIL
3000	31	1	5	25	21	10	NIL
4000	31	NIL	3	28	23	6	2

However, some of the findings of this study that require careful interpretation of the results is connected with the fact most hearing aids incorporate some form of automatic gain control. This meant that, for the ATEN test, the gain applied when absolute thresholds were being measured alone would have been greater than when the masked thresholds were being measured. This change in gain would have increased the likelihood of achieving the required threshold shift to meet the criteria for a DR (masked threshold 10 dB or more above absolute threshold). For example, assume that the hearing loss at a given frequency was 90 dB, and that the aided threshold was 50 dB HL. This would mean that a gain of 40 dB was applied for a tone presented at 50 dB HL. Assume that the TEN was now turned on with a level of 50 dB/ ERB_N, and the threshold level of the tone was found to be 60 dB HL. This difference of 10 dB between the masked threshold and TEN would be taken as just meeting the criteria for a DR. However, when the TEN and the 60 dB HL test tone were presented, the gain of the hearing aid at the signal frequency might have decreased to, say 35 dB. So that, the level of the test tone in the ear canal would have been only 5 dB above the absolute threshold. Generally, the effect of the changes in gain with level would have been to increase the likelihood of a "false positive" (Marriage et al. 2008). It may be mentioned here that further studies are definitely required in order to validate the results of the ATEN test.

4.2.2. Implications of aided Threshold Equalizing Noise (ATEN) test for rehabilitation of individuals with cochlear dead regions

For individuals with high frequency dead regions, amplification of the high frequencies may not be beneficial because of the amount of gain that is provided from the hearing aid resulting in distortion and the inability of the neurons in those frequency regions to transmit the signals to the higher centers. Hence, before deciding what form of amplification should be provided for a patient with high-frequency hearing loss, it is important to determine whether the individual has a high-frequency dead region. It is in this case that the ATEN test is recommended for this purpose (Marriage et al. 2008). The importance of the diagnosis of cochlear dead regions and its implications for rehabilitation has been reported by many authors.

According to Vickers et al. (2001) for a patient with a dead region at high frequencies, there may be several benefits of reducing the gain at high frequencies. (1) It can sometimes lead to improved speech intelligibility. (2) It may reduce problems associated with acoustic feedback, which often occurs when trying to achieve the gains appropriate for a severe to profound loss. (3) It may reduce distortion in the hearing aid, especially intermodulation distortion. Such distortion can lead to reduced speech intelligibility (Crain and Van-Tasell, 1994). An alternative approach for people with extensive high frequency dead regions is to use frequency transposition or frequency compression (Johansson, 1966; Velmans and Marcuson, 1983; Posen, Reed & Braida 1993; Parent, Chmiel & Jerger, 1997; McDermott, Dorkos, Dean & Ching, 1999; Turner and Hurtig, 1999). Hearing aids incorporating frequency transposition and/ or compression move high-frequency components to lower frequencies. In some studies limited benefit demonstrated because the transposition/ compression aids have been fitted to patients without clear knowledge of the extent of the dead regions.

Many authors have also reported the high prevalence of cochlear dead regions in subjects with sensorineural hearing loss, indicating its need for identification and to help in better rehabilitation abilities. Moore (2004) suggested that a steeply sloping hearing loss (slope of 50 dB/ octave or more) may be indicative of a high-frequency DR.

Preminger, Carpenter & Zeigler (2005) suggested that an audiogram slope steeper than 19 dB/ octave is associated with an increased probability of a DR, and Markessis et al. (2006) showed that 87% of participants with an audiogram slope of more than 20 dB/octave met the criteria for a dead region. Aazh and Moore (2007) found that the presence/absence of a DR cannot be predicted reliably from the slope of the audiogram when the audiogram slope is less than 20 dB/ octave, although previous finding suggests that a slope greater than 20 dB/octave may be indicative of a DR. Vinay and Moore (2007) have also reported high prevalence rate of DRs in individuals with sensorineural hearing loss.

From the present study it was clear that, the TEN test is a very useful test in the diagnosis of cochlear dead regions in individuals with sensorineural hearing loss. However, the TEN test administered in the unaided condition exhibits some inherent problems related to loudness recruitment and distortion produced at high test intensity levels in individuals with sensorineural hearing loss. The results of the present study indicated that, with the unaided TEN (HL) test, not all the individuals with a severe to profound degree of hearing loss could be accurately diagnosed of dead region being present or absent. The unaided test results showed inconclusive results for most individuals having severe or profound degree of hearing loss in terms of the diagnosis for dead regions. However, the results showed that the ATEN test reported more accurate diagnosis of either the presence or absence of DRs. Hence the aided version of TEN (HL) test can be more appropriate in the diagnosis of dead region in clinical practice.

Limitation of the study

The present study is an initial step in exploring the possibility of an accurate diagnosis using the ATEN in individuals with sensorineural hearing loss. This study has reported the results of ATEN based on categorization of different frequencies. The pattern of results may appear stereotypic across frequencies in this study, however, the present study aimed at reporting the results frequency wise only because the presence or absence of DR is influenced by the frequency. This difference observed in the ATEN across frequencies gives a diagnostic criterion for the accurate identification and rehabilitation of individuals with sensorineural hearing loss with cochlear dead regions.

Chapter 5

SUMMARY AND CONCLUSIONS

An area in the cochlea with no functioning inner hair cells and/or neurons is described as a dead region (DR). A DR may not be evident from the audiogram, because a tone with frequency falling in a DR may be detected through off-frequency listening. The TEN test was designed as a simple way of detecting DRs (Moore and Alcantara, 2001). The TEN noise was derived from the TEN (HL) CD. This test administered when the participant is wearing a hearing aid is known as aided threshold equalizing noise (ATEN) test.

In the present study the results obtained from the 31 participants (12 females and 19 males) in the age range of 11 to 80 years in both aided and unaided TEN (HL) test conditions were compared to see the effectiveness of both the test conditions for the diagnosis of the DR. Cross tabulation was computed across the frequencies at 500 Hz, 750 Hz, 1000 Hz, 1500 Hz, 2000 Hz, 3000 Hz and 4000 Hz.

The present study has indicated the effectiveness of using ATEN over the conventional TEN test. The accuracy of the diagnosis in the ATEN condition was more compared to the conventional TEN. In the conventional TEN the results were inconclusive for 133 test conditions across the test frequencies of 500 Hz to 4000 Hz for all participants. These results became conclusive in the ATEN condition which showed the presence of DR for 88 test conditions and the absence of DR for 43 test conditions.

However, there were only two test conditions reported as inconclusive in the ATEN result at 4000 Hz.

It is evident that aided TEN (HL) test is more effective in diagnosing DR at any frequency compared to the unaided version of the TEN (HL) test. Apart from this the aided version of the TEN (HL) test reduced the chance of inconclusive results. However, the results need to be interpreted considering many factors including hearing aid design and other test factors.

The present study provides a unique evidence of the effectiveness of the ATEN test while diagnosing the presence or absence of a DR at a particular frequency irrespective of the degree of the hearing loss. The study again provides an insight towards the advantage of the aided version over the unaided version with respect to the degree and pattern of the hearing loss. With unaided TEN (HL) test most often it is impossible to obtain any conclusive results of DR, due to the uncomfortable level of the participant at a particular frequency or the maximum limit of the audiometer is reached, where as with the aided condition these problems are being taken care and provides more effective results.

Taking a careful consideration, the use of the ATEN test may lead to a more accurate diagnosis of the presence or absence of DRs, and also to an extent that helps in better fitting of the hearing aids in these individuals. This study is an initial step taken in the direction to assist in better diagnosis and rehabilitation of individuals with sensorineural hearing loss with cochlear dead regions.

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