AIDED THRESHOLD EQUALIZING NOISE TEST

Sasmita Behera & S. N. Vinay*

Abstract

The inner hair cells of the cochlea 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). The most widely used methods for the detection of the dead region includes psychophysical tuning curve (PTC) and Threshold equalizing noise (TEN) test. But these methods are unable to detect a dead region in individuals with severe to profound sensorineural hearing loss or sloping pattern of audiogram. To detect the dead region in these individuals, an alternative method was devised with the use of hearing aid. This can be termed as Aided TEN (ATEN) test. In the present study 31 participants were tested using the conventional TEN test and the results were compared with that of the thresholds obtained with that of the aided version of the TEN test. Results show the effectiveness of the aided version of TEN test over the conventional method while identifying dead regions in the above mentioned individuals.

Introduction

The role of inner and outer hair cells in the hearing mechanism is well established. In most cochlear hearing losses the hearing loss is associated with the damage to the outer hair cells whereas some of them are due to damage to the inner air cells as well (Engstrom, 1983; Schuknecht, 1993; Borg, Canlon & Engstrom, 1995). When the inner hair cells of the cochlea and/or neurons at certain places along the BM are missing or functioning poorly, then 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).

Moore et al. (2000) developed a more time economical and an effective test called as the Threshold Equalizing Noise (TEN) test. This version of the test is called the TEN (SPL) test. 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). The loudness of the TEN (HL) is less than for the original TEN (SPL) because of the reduced bandwidth.

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

* Lecturer in Audiology, All India Institute of Speech and Hearing, Mysore, India
email: vinaysn@lycos.com

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).

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. For example, a person with near-normal hearing at low frequencies and a person with 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, et al., 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.

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.

Method

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 in at least one ear. The degree of hearing loss ranged from severe to profound for dead region frequencies only. 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. The details of the participants included in the study are provided in Table 1.

Table 1: Audiometric thresholds (in dB HL) for each participant obtained using pure tone presented via headphones

			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 software.
- 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.
- 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 the fitting range for the degree of hearing loss of each participant. This hearing aid catered to the amplification needs of the participants who had hearing losses ranging from mild 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. 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. Aided uncomfortable level (UCL) was also estimated for all the participants.

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.

Results & Discussion

The descriptive statistical analysis was carried out for the comparison of both the unaided and aided TEN (HL) [(ATEN)] 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.

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.
(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.
(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.

The unaided (dark bar) and aided TEN (HL) test conditions (light bars) and their results were 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.

TEN results for 500 Hz in unaided and aided condition

From Table 4 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.

Table 2: Cross tabulation comparison data at the TEN test frequency of 500 Hz in both aided and unaided condition.

500 Hz			Aided		Total
			Present	Absent	
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%

At 500 Hz, as shown in figure 1, 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.

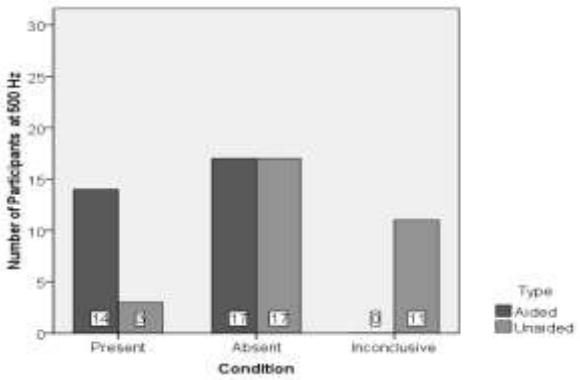

Figure 1: The number of participants for the results of aided & unaided TEN test at 500 Hz.

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.

TEN results for 750 Hz in unaided and aided condition

From Table 3, 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.

At 750 Hz, as shown in figure 2, 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.

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%

Table 3: Cross tabulation comparison data at the TEN test frequency of 750 Hz in both aided and unaided condition.

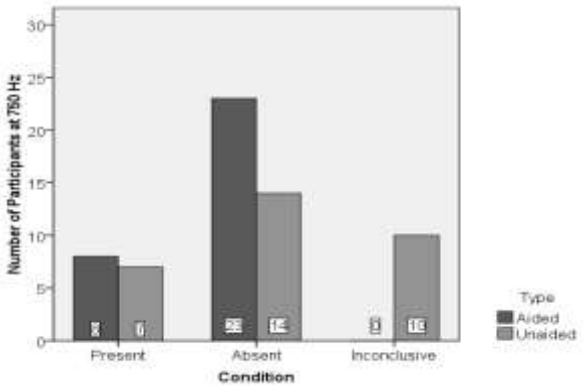

Figure 2: The number of participants for the results of aided & unaided TEN test at 750 Hz.

TEN results for 1000 Hz in unaided and aided condition

From the table 4, 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.

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%

Table 4: Cross tabulation comparison data at the TEN test frequency of 1000 Hz in both aided and unaided condition.

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.

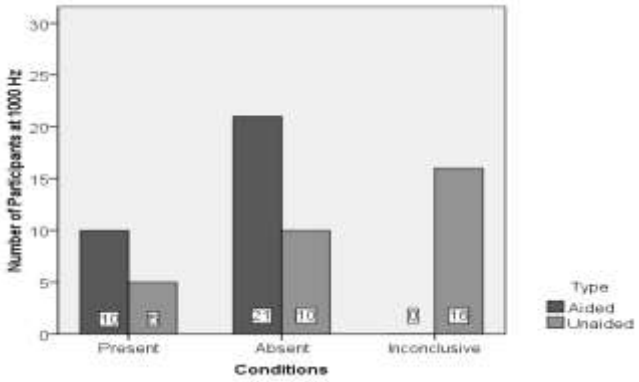

Figure 3: The number of participants for results of aided & unaided TEN test at 1000 Hz.

At 1000 Hz, as shown in figure 3, 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.

TEN results for 1500 Hz in unaided and aided condition

From the table below 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.

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%

Table 5: Cross tabulation comparison data at the TEN test frequency of 1500 Hz in both aided and unaided condition.

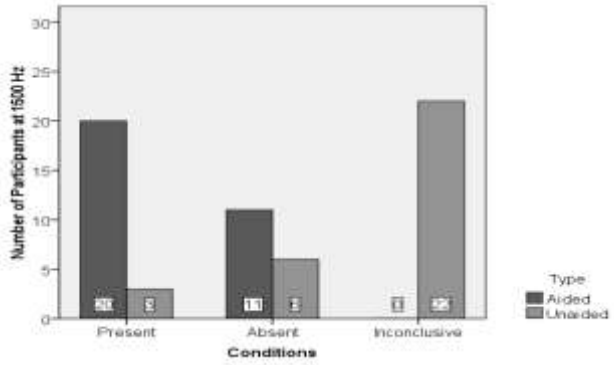

Figure 4. The number of participants for results of aided & unaided TEN test at 1500 Hz.

At 1500 Hz, as shown in figure 4, 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.

TEN results for 2000 Hz in unaided and aided condition

From Table 6, 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.

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%

Table 6: Cross tabulation comparison data at the TEN test frequency of 2000 Hz in both aided and unaided condition.

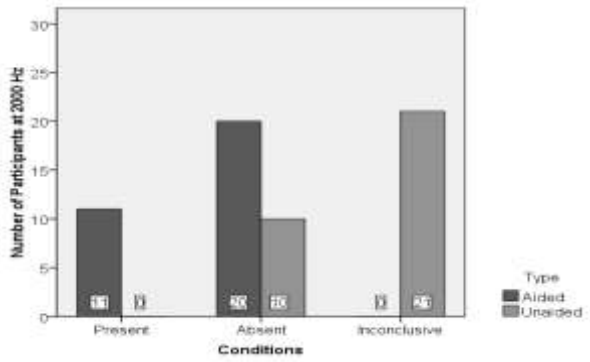

Figure 5: The number of participants for results of aided & unaided TEN test at 2000 Hz.

At 2000 Hz, as shown in figure 5, 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).

TEN results for 3000 Hz in unaided and aided condition

From the table below 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.

Table 7: 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%

At 3000 Hz, as shown in figure 6, 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.

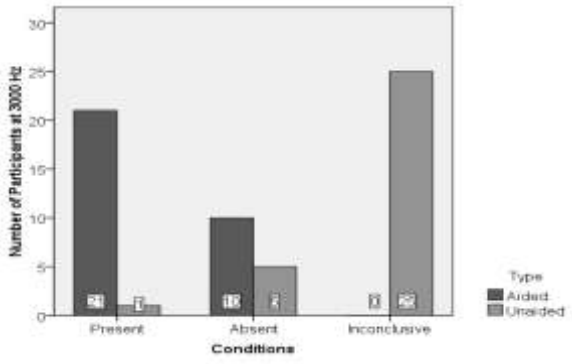

Figure 6: The number of participants for results on aided & unaided TEN test at 3000 Hz.

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.

TEN results for 4000 Hz in unaided and aided condition

From Table 8, 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.

Table 8: 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%

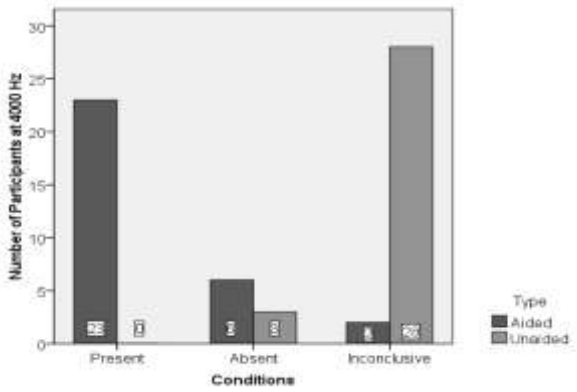

Figure 7: The number of participants for results of aided & unaided TEN test at 4000 Hz.

At 4000 Hz, as shown in figure 7, 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 less 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).

Clinical Implications of Aided Threshold Equalizing Noise (ATEN) 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.

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 9: Tabulation of unaided and aided TEN (HL) test results.

Freq (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). It may be mentioned here that further studies are definitely required in order to validate the results of the ATEN test.

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 neurones in those frequency regions to transmit the signals to the higher centres. 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.

References

Aazh, H., & Moore, B. C. J. (2007). Dead Regions in the cochlea at 4 kHz in elderly adults: Relation to absolute threshold, steepness of audiogram, and pure tone average. *Journal of American Academy of Audiology, 18, 97–106.*

American National Standards Institute (1999). *Maximum permissible ambient noise for audiometric test rooms* (ANSI S3.1-1999). New York: ANSI.

American National Standards Institute (2003). *Specification of Hearing Aid Characteristics* (ANSI S3.22-2003). New York: ANSI.

Baer, T., Moore, B. C. J., & Kluk, K. (2002). Effects of low pass filtering on the intelligibility of speech in noise for people with & without dead regions at high frequencies. *Journal of Acoustical Society of America, 112,* 1133-1144.

Borg, E., Canlon, B., & Engstrom, B. (1995). Noise induced hearing loss- literature review & experiments in rabbits. *Scandinavian Audiology, 24,* (suppl. 40), 1-147.

Carhart, R., & Jerger, J. F. (1959). Preferred method for clinical determination of pure-tone thresholds. *Journal of Speech and Hearing Disorders, 24,* 330-345.

Engstrom, B. (1983). Stereocilia of sensory cells in normal & hearing impaired ears. *Scandinavian Audiology* (Suppl. 19), 1-34.

Florentine, M., & Houtsma, A. J. M. (1983). Tuning curves and pitch matches in a listener with a unilateral, low-frequency hearing loss. *Journal of Acoustical Society of America, 73,* 961-965.

Glasberg, B. R., & Moore, B. C. J. (1986). Auditory filter shapes in individuals with unilateral and bilateral cochlear impairments. *Journal of Acoustical Society of America, 79,* 1020-1033.

Markessis, E., Kapadia, S., Munro, K. J., & Moore, B. C. J. (2006). Modification of the TEN test for cochlear dead regions for use with steeply sloping high-frequency hearing loss. *International Journal of Audiology, 45*, 91–98.

Moore, B. C. J., & Glasberg, B. R. (1997). A model of loudness perception applied to cochlear hearing loss. *Auditory Neuroscience, 3,* 289-311.

Moore, B. C. J., (2001). Dead regions in the cochlea: Diagnosis, perceptual consequences, and implications for the fitting of hearing aids. *Trends in Amplification, 5* (1), 1-34.

Moore, B. C. J. (2004). Dead regions in the cochlea: conceptual foundations, diagnosis and clinical applications. *Ear and hearing, 25* (2), 98-116.

Moore, B. C. J., Huss, M., Vickers, D. A., Glasberg, B. R., & Alcántara, J. I. (2000). A test for the diagnosis of dead regions in the cochlea. *British Journal of Audiology, 34,* 205–224.

Moore, B. C. J., Glasberg, B. R., & Stone, M. A. (2004). New version of the TEN test with calibration in dB HL. *Ear and Hearing, 25*(5), 478-87.

Preminger, J. E., Carpenter, R., & Ziegler, C. H. (2005). A clinical perspective on cochlear dead regions: intelligibility of speech and subjective hearing aid benefit. *Journal of American Academy of Audiology, 16,* 600-613.

Schuknecht, H. F., & Gacek, M. R. (1993). Cochlear pathology in presbycusis. *Annals of Otology, Rhinology and Laryngology, 102,* 1-16.

Simpson, A., McDermott, H. J., & Dowell, R. C. (2005). Benefits of audibility for listeners with severe high-frequency hearing loss. *Hearing Research, 210,* 42-52.

Vinay, S. N., & Moore, B. C. (2007a). Prevalence of dead regions in subjects with sensorineural hearing loss. *Ear and Hearing, 28,* 231-241.

Vinay, S. N., & Moore, B. C. (2007b). Speech recognition as a function of high pass filter cut off frequency for subjects with and without low frequency cochlear dead regions. *Journal of Acoustic Society of America, 122,* 542-553.

Vickers, D. A., Moore, B. C., & Baer, T. (2001). Effects of low pass filtering on the intelligibility of speech in quiet for people with and without dead regions at high frequencies. *Journal of Acoustic Society of America, 110,* 1164-1175.