COMPARISON OF OUTCOMES BETWEEN OCCLUDED AND OPEN FIT CHANNEL FREE HEARING AID

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MAY, 2013.

Dedicated To

three most wonderful people in my life-

Achan Amma, Vichu

& to my Guide

CERTIFICATE

This is to certify that this dissertation entitled "**COMPARISON OF OUTCOMES BETWEEN OCCLUDED AND OPEN FIT CHANNEL FREE HEARING AID**" is a bonafide work submitted in part fulfilment for the Degree of Master of Science (Audiology) of the student (Registration No.: 11 AUD024). This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any of the University for the award of any other Diploma or Degree.

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CERTIFICATE

This is to certify that this dissertation entitled "**COMPARISON OF OUTCOMES BETWEEN OCCLUDED AND OPEN FIT CHANNEL FREE HEARING AID**" has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier in other University for the award of any Diploma or Degree.

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DECLARATION

This is to certify that this dissertation entitled "**COMPARISON OF OUTCOMES BETWEEN OCCLUDED AND OPEN FIT CHANNEL FREE HEARING AID**" is the result of my own study under the guidance of Mr. Sreeraj K, Lecturer in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier in other University for the award of any Diploma or Degree.

Mysore Register No.: 11AUD024

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Chapter 1

Introduction

The National Sample Survey Organization (NSSO), 2002 estimated that 15% of India's population suffers from hearing impairment. Hearing impairment leads to withdrawal from participating in social activities and places a limit on interaction with others (Arlinger, 2003). Due to vast impact of hearing loss, hearing rehabilitation is of critical importance. Hearing aid fitting is one of the first essential steps in hearing rehabilitation though, hearing rehabilitation includes other aspects such as modification or adaptation to the acoustical environment and learning communication strategies (Metselaar, 2010).The first and foremost aim of fitting a hearing aid is to make the speech signal audible and intelligible. Hearing aids have to amplify sound to a level above the hearing threshold to utilize the residual hearing capacity of the ear as much as possible (Metselaar, 2010).Hearing aid use remains the treatment of choice for subjects with sensorineural hearing loss (Garstecki & Erler, 1998).

However, number of patients with high frequency sensorineural hearing loss is raising globally, which may arise from a variety of reasons such as exposure to noise, presbycusis, ototoxicity or a combination of these factors (Arlinger, 2003). Pittman and Stelmachowicz (2005) reported that, most common audiometric configuration in adult subjects are sloping configuration implying that sloping sensorineural hearing loss is becoming most common among sensorineural hearing loss. The only rehabilitation process for sensorineural loss is use of hearing aids. However, for patients who have high-frequency hearing losses; providing proper amplification is always challenging. These patients particularly experience difficulty with speech understanding in background noise (Roup & Noe, 2009; Horwitz, Dubno, &

Ahlstrom, 2002). However, in quiet situations, there is little or no difficulty in understanding speech as the lower-frequency portion of speech are audible to them and hence they are considered as marginal candidates for amplification (Mueller, Bryant, Brown & Budinger, 1991).These patients are often the ones who are hesitant to use hearing aids due to certain disadvantages of traditional hearing aids. Studies over years have attempted various methods to improve speech understanding for persons with high-frequency hearing losses (Horwitz, Ahlstrom, & Dubno, 2008; Dillon, 2012). Even though advantage of cosmetic appearance can be achieved by using Completely-in-the-canal (CIC) and other in-the-ear (ITE) instruments, certain other factors affect satisfaction with the hearing aid. Individuals who have near normal or normal low frequency audiometric thresholds with sloping high frequency hearing loss often experience occlusion effect.

Mac Kenzie (2006) quoted that occlusion effect occurs when the bone-conducted energy, as a result of vocalization, causes vibration of the mandible and soft tissue surrounding the external ear canal; which in turn causes vibration of cartilaginous walls of the ear canal, resulting in energy production that is transferred to the volume of air within the canal. When the external ear canal is occluded this energy gets trapped inside the canal by which the sound pressure level delivered to the tympanic membrane and, to the cochlea is increased. This can often lead to sound being perceived as unnatural, especially own voice sounding hollow, boomy or muffled.

The occlusion effect has been reported as a consistent problem affecting satisfaction with conventional hearing aid fittings for patients with high frequency sloping sensorineural hearing loss (Dillon, 2001; Kiessling, Margolf, Gellar & Olsen

2003). A new breed of hearing aids with open fitting ear tip has been suggested for such individuals, which helps to overcome occlusion effect (Mueller, 2006).

Studies by Cox and Alexander (1983), Kuk (1991), Noble, Sinclair and Byrne (1998) and Mac kenzie (2006), suggested that several advantages such as improvement in localization, appearance, speech intelligibility, ease of maintenance and repair and improved high frequency gain including reduction in occlusion effect can be achieved using open fitting (or open ear fitting) of hearing aid and they are most beneficial for people with milder hearing losses, or high frequency hearing loss with normal low-frequency hearing. Open fitting of hearing aids in modest term is fitting the hearing instrument nonetheless leaving the ear canal open.

Open canal fitting.

Open fit hearing aid is a behind the-ear (BTE) instruments, which makes use of a thin sound delivering tube with a soft, vented silicone ear tip, or uses a thin wire which is connected to a receiver located within the canal with vented ear tip (Kuk, Keenan & Chi-chuen, 2009). These open fit hearing instruments are practical option for patients with high-frequency mild to moderate losses (Mac Kenzie, 2006). The energy produced by bone conduction from vocalizations will not get trapped inside the ear canal in case of open canal fitting as these type of fitting leaves the external ear canal open with its silicon vented tips which helps in eliminating occlusion effect and helps in perceiving the sound as natural (Mac Kenzie, 2006).

Mueller (2006) reports, elimination of the occlusion effect as the most highly rated benefit of open fitting even though there are certain other advantages. There is dearth of literature indicating benefits provided as a result of elimination of occlusion by open canal instruments. In a Study conducted by Kuk, Keenan, Sonne, and

Ludvigsen (2005) with the use of open fit instruments there was no occlusion effect below 700Hz reported, which suggest that bone conducted energy produced by vocalization are almost absent when open fit instruments are worn. Kiessling, Brenner, Jespersen, Jennifer and Ole (2005). Occlusion also found no significant difference between open fitting and un-occluded probe-microphone measurements for a specific instrument, with subjective ratings of naturalness of own voice comparable.

However, Scheller in 2004 stated that open ear canal fitting poses certain challenges, major one being the distortions created by interactions of processed sounds getting into the ear canal and sound leaking out from the ear canal due to the openness of the ear tip. Sounds in the environment can get into the ear canal after being processed by the hearing aid and unprocessed sounds can get into the ear canal via the open canal. Sounds leaking out from the open canal has a high-pass filter characteristic, and sounds getting into the vent have a low-pass filter characteristic. Consequently, the directivity of directional microphones, and the effectiveness of noise reduction algorithms are reduced. But, advancement in technology in the area of active feedback-cancellation techniques has assisted hearing aid manufacturers to develop a new breed of open fit hearing instruments that offer increased venting capabilities, with apt high-frequency gain for many patients without feedback concerns (Scheller, 2004). Moreover, recent advancement in digital signal processing has lead to development of a new digital signal processing algorithm termed as ‘channel free signal processing’ for hearing aids which appears to be a promising tool for individuals with sloping sensorineural hearing loss.

Channel free hearing aid.

Channel free technology processes the incoming signal as a whole without dividing it into different frequency in contrast to a multichannel compression system where frequency and level dependent signal processing is accomplished by dividing the incoming signal into multiple frequency channels (Chung 2004).

In a channel free hearing aid, the algorithm works by estimating the centroid frequency and the loudness of the incoming signal based on the overall input level. The centroid frequency is a measure which represents weighted frequency value and is a commonly used term in digital signal processing to characterise a spectrum. Once the centroid frequency is estimated, the signal is then amplified based on the frequency response corresponding to calculated centroid frequency and loudness level. For very high input levels, microphone output is limited to avoid digital clipping, similar to peak clipping but occurs in the digital domain (Scheller, 2004).

Patients with sensorineural hearing loss prefer channel free hearing aid over other multichannel hearing aids (Dillon, Keidser, O'Brien and Silberstein, 2003) but, there is dreath in literature regarding the effectiveness of channel free processing in high frequency sloping sensorineural hearing loss subjects.

Need for the study

The occlusion effect is a common complaint, especially for participants with some degree of high frequency hearing loss and near to normal low frequency thresholds. They often experience their own voice sounding unnatural as hollow, muffled and boomy, resulting mainly due to occlusion of the ear canal by ear mould. Studies by Mueller (2006), Kuk, Keenan, Sonne, and Ludvigsen (2005) suggest that several advantages can be achieved using open fitting (or open ear fitting) of hearing aids and they are most beneficial for people with milder hearing losses, or high frequency hearing loss with normal low frequency hearing. According to Mac kenzie (2006) poor quality of own voice resulting from the occlusion effect can be effectively be reduced by open canal fittings. With open fitting, sound quality is others voices (Cox and Alexander, 1983; Kuk, 1991) also improved localization ability was noted by Noble, Sinclair, Byrne (1998).

At present channel free hearing aids are available with open fit option using a thin tube and vented silicon tips which might be a better option for sensorineural hearing loss with near normal low frequency thresholds as it helps to eliminate occlusion effect and make use of channel free processing algorithm. But, there is scarcity in studies focusing on the efficacy of channel free hearing aid fitted with open tips in patients with high frequency sensorineural hearing loss. Hence, there is a need to evaluate the benefits of open fit channel free hearing aid for mild to moderate sloping sensorineural hearing loss.

Aim of the study

The study is designed to compare the outcomes of occluded channel free hearing aid using no. 13 tubing with regular ear tip and open fit channel free hearing aid using no 0.9 and no. 1.3 slim fit tubing.

Objectives of the study

1. To measure and compare the following parameters with occluded channel free hearing aid using no. 13 tubing with regular ear tip and open fit channel free hearing aid using no 0.9 and no. 1.3 slim fit tubing:
    i. Speech identification in quiet
    ii. Speech identification in noise (SNR-50)
    iii. Real ear measurements(REM)

2. To assess quality of speech and own voice by qualitative measurements, with occluded channel free hearing aid using no. 13 tubing with regular ear tip and open fit channel free hearing aid using no 0.9 and no. 1.3 slim fit tubing.

Chapter 2

Review of literature

As the present study aims at comparing the outcomes of occluded and open fit channel free hearing aid, review of literature is discussed under the following headings:

2. a. Amplification for high frequency sensorineural hearing loss
2. b. Role of open fitting in high frequency hearing loss
2. c. Channel free amplification and its advantages.

2. a. Amplification for high frequency sensorineural hearing loss.

Listeners with high frequency sensorineural hearing loss exhibit many characteristics including loudness recruitment, tinnitus, loss of frequency selectivity and temporal resolution and speech recognition deficits in addition to loss of audibility (Dancer, Buck, Parmentie & Hamery, 1998; Henderson & Salvi, 1998). They also have speech recognition deficits in the presence of background noise (Horwitz, Dubno, & Ahlstrom, 2002).

Fabry, Launer and Derleth (2007) reported that for patients with steeply-sloping sensorineural hearing loss (slope being in excess of 50dB/octave) options for amplification are limited due to reduced dynamic range and increased distortion that accompanies peripheral loss. Hogan and Turner (1998) studied the relation between degree of hearing loss and ability to use audible speech information using Articulation Index (AI) procedures. In the study, amplified speech (with a high pass frequency shaping) was presented to listeners with various degrees of hearing loss in the high frequencies. Increases in speech audibility were produced for each listener by raising the frequency cut off of a low-pass filter, and the corresponding speech recognition scores were measured for each incremental increase in speech audibility. It was noticed that when the high-frequency regions of speech (especially above 3000 Hz) were made audible to frequency regions with hearing losses above 55 dB HL, the benefits of providing audible speech were often severely reduced compared with presenting audible speech to a normal-hearing listener (at moderate levels) suggesting that there may, however, be some limitations on the efficacy of high-frequency amplification. Ching, Dillon and Byrne, (1998) also quoted similar results.

Providing the optimal degree of amplification for individuals with high-frequency hearing loss has long been problematic as simple amplification of speech (to restore audibility) may not always produce the desired results for an individual with hearing loss (Hogan and Turner, 1998 & Ching, Dillon, & Byrne, 1998). Studies have been conducted exploring the benefits in providing additional amplification in high frequencies for individuals with high frequency sensorineural hearing loss. Some studies (Amos & Humes, 2007; Baer, Moore, & Kluk, 2002; Vickers, Moore, & Baer, 2001) have reported that even with a boost in gain at high frequencies, speech recognition abilities remained constant or sometimes reduced which was explained based on several reasons: First, unwanted distortions are created at high levels as a result of providing high gain which is often required due to higher degree of hearing loss at high frequencies (Rankovic, 1998). But, Hornsby and Ricketts (2006) reported that there was a small increment in improvement in speech recognition performance when the energy in audible high-frequency was extended from 3.2 kHz up to approximately 7 kHz. Other researches (Skinner & Miller, 1983; Vickers, Moore, & Baer, 2001) has stated that listeners with mild-to moderate hearing loss are reported to be benefitted from high-frequency information at least through approximately 6 kHz as evident speech recognition scores.

Roup and Noe, 2009, reported mixed outcomes concerning the benefit of high-frequency amplification which may be due the factors such as:

i. the degree of high-frequency hearing loss;
ii. whether the deductions were inferred from individual data or mean results,
iii. differences in gain-frequency responses across studies,
iv. the extent of increase in audibility of high frequency speech due to increase in cut off frequency or cut off level may not be properly mentioned in studies,
v. Availability of low frequency cues: whether largely available (as when listening in quiet) or largely unavailable (as when listening in noise).

In the past, limitations in the frequency response characteristics of hearing aids have made fitting listeners with high frequency sensorineural hearing loss difficult. Precisely, amplifiers used in hearing aids always failed to provide adequate high-frequency gain, while at the same time providing higher gain at low frequencies (Bratt & Sammeth, 1991; Lee, Humes, & Wilde, (1993). Providing too high gain in the low to mid frequency region will result in upward spread of masking and hence important high frequency speech information is lost (Cook, Bacon, & Sammeth, 1997; Gagné, 1988), resulting in poor speech recognition performance. Also, to this adds the negative effect of occluding ear canal with the conventional ear mould fitting (Chung, 2004; Dempsey, 1990; Lee et al., 1993).

In the recent years, advancement in technology have resulted in hearing aids with more effective and improved feedback management system, more accurate frequency shaping, broader frequency responses, and high-frequency directionality benefit make it potentially making it possible to deliver audible higher frequency speech information to individuals with high-frequency hearing loss (Horwitz, Dubno & Ahlstrom, 2008). But the issue of occlusion effect still pose a problem in conventional hearing aid fitting affecting satisfaction (Dillon, 2001; Kiessling, Margolf & Gellar, 2003).

2. b. Role of open fitting in high frequency hearing loss.

Conventional hearing aid fitting results in occluding the ear canal in order to increase the amount of sound pressure level of the sound reaching to the tympanic membrane and diminish the risk of acoustic feedback. However, this results in occluding the ear canal posing several drawbacks, such as the occlusion effect, less localization cues, reduced sound quality and discomfort.

For people with milder hearing losses, or high frequency hearing loss with normal low-frequency hearing ,using open fitting (or open ear fitting) hearing aid are most beneficial as several advantages can be achieved using the same (Cox and Alexander, 1983; Kuk, 1991; Noble, Sinclair & Byrne, 1998 and Mac kenzie , 2006).

Open fit hearing aid is a behind the-ear (BTE) instruments makes use of a thin sound delivering tube with a soft, vented silicone ear tip, and or a thin wire which is connected to a receiver located within the canal with vented ear tip is a better option for patients with mild to moderate high-frequency losses (Mac Kenzie, 2006) as with its vented tip, it ensures openness of the ear canal relieving the patient from discomfort of occluding the ear canal and also results in many other potential benefits.

While open-canal hearing instruments has been available for decades, enhanced digital signal processing (DSP) technology has made open fittings feasible and effective for a higher hearing loss configurations. Specifically, advances in acoustic feedback reduction algorithms have contributed in making the open fitting more accurate. More sophisticated and accurate feedback reduction algorithms are the most vital part of open fit hearing aids, permitting them to provide an additional gain of about 8 to 15 dB before entering the audible oscillatory state (Parsa, 2006).

Mueller (2006) described the certain benefits of open fit hearing aids which are better comfort of fit, better sound quality, helps in localization, appearance, intelligibility of speech, ease of repair/maintenance, improved high frequency gain and elimination of the hazardous effects of the occlusion effect. Many of these benefits are a result of the vented soft tips allowing the ear canal to be open, permitting air circulation within the ear canal.

Subjective occlusion ratings were evaluated by Jespersen, Groth, Kiessling, Brenner and Jensen (2006) in patients who were experienced bilateral hearing aid users and compared them to normal hearing subjects. The participants were requested to rate their own voice based on naturalness while wearing ear moulds with varying vent sizes in both unilateral and bilateral conditions. The vent sizes that were evaluated were conventional ear moulds with parallel vents, completely-in-the-canal (CIC) dummy hearing aids, shell type ear molds with a novel vent design (Flex Vent ear molds), and non occluding silicone ear tips. Results revealed that both normal and hearing impaired subject rated their own voice as sounding as very natural equivalent to being un-occluded when wearing silicone ear tips; in all other conditions, occlusion of varying degrees were reported.

Study conducted by Kuk, Keenan, Sonne, and Ludvigsen (2005) using open fit instruments found no occlusion effect below 700 Hz. Kiessling, Brenner, Jespersen, Jennifer and Ole (2005) also found no significant difference between open fitting and un-occluded probe-microphone responses for a specific instrument, with comparable subjective ratings of own-voice naturalness.

Noble et al. (1998) conducted a study aimed at investigating the effect of ear mould variation on localization ability in subjects with bilateral high frequency sensorineural hearing losses having normal low frequency hearing that were fitted with bilateral behind-the-ear (BTE) hearing aids. The unaided localization performance of these subjects was better than when using their own hearing aids. The participants completed localization tasks wearing their own ear moulds (occluding), open ear moulds, and “sleeve” ear moulds. It was found that aided localization performance with the open fitting resulted in performance similar to that of unaided. These results suggested that the most likely information for localization were provided by an open canal hearing aid fitting and it is the undistorted low-frequency time/phase differences.

Satisfaction of open canal fittings when compared to closed canal fittings based on several outcome measures was directly compared by Gnewikow and Moss (2006). This study compared the outcomes based on three measures of hearing aid outcomes

(a) the Satisfaction with Amplification in Daily Life (SADL),

(b) the International Outcome Inventory for Hearing aids (IOI-HA)

(c) An empirically designed questionnaire

Greater satisfaction were reported by participants who were fitted with open-canal hearing aids on subscale ‘Negative Features’ of SADL when compared to participants fitted with closed traditional amplification. Furthermore, participants wearing open-canal hearing instruments scored better on questions of occlusion on the

Open-Canal Questionnaire than did closed canal group. Scores on every measure was better for the open canal fitted subjects when compared to closed canal fitted subjects indicating that open canal fitting is the best option.

Mac Kenzie (2006) also in his study, demonstrated that essentially no occlusion effect was present when open canal tube systems are utilized also there was a highly natural perceptual ratings of own voice sound quality in normal listeners suggesting that open canal fittings are an effective means of overcoming one of the major barriers to the acceptance of amplification.

2. c. Channel free amplification and its advantages.

In a channel-free compression system, the incoming signal is processed by taking it as a whole rather than diving it into different frequency channels compared to a multichannel system frequency where the frequency and level dependent signal processing is accomplished by dividing the incoming signal into multiple frequency channels. The channel-free compression provides amplification which is level-dependent by adjusting the frequency response at different input levels. Processing delay of channel free hearing aid is relatively short of 3.5 milliseconds because it does not i.e., as it does not divide the signal into different frequency channel it does not perform time-frequency domain conversion (Chung, 2004)

Moore (2008) proposed that fast acting compression in multiple channels creates spectral deformation because the patterns of gain across frequency alternate so rapidly over time. The channel-free compression system is intended to avoid spectral smearing associated with multichannel compression systems (Scheller, 2004) and provide frequency & level dependent amplification. Spectral smearing occurs when the relative spectral content of sounds are altered leading to reduced spectral contrast.

Spectral contrast is one of the primary cues for phoneme identification especially vowels (Leek, Dorman & Summerfield, 1987). Researchers have reported negative effects of spectral smearing on speech intelligibility (Boothroyd, Mulhearn, Gong, & Ostroff, 1996; VanSchijndel, Houtgast, & Festen, 2001).

Channel free processing was contrived to address the limitations of fast acting multichannel WDRC in order to figure out the trade-off between comfort of the listener and speech intelligibility (Schaub, 2008). One of the main purposes of channel free processing is to amplify the low intensity components of speech without over amplifying high intensity part of speech. Nevertheless, a unique feature of channel free processing is that it detects and operates over wide range of frequencies still providing variable compression ratios across frequency. Subsequently, channel free processing helps in preventing spectral distortion of amplified speech signal, thus providing clear natural sound. Hence, channel free processing may offer a feasible choice to fast acting multichannel WDRC result in in better listener comfort and improved speech intelligibility (Schaub, 2008).

The channel free processing algorithm first estimates the centroid frequency of incoming signal and then determines the normal loudness of the incoming signal based on the estimated centroid frequency and the overall input level. Then the signal is amplified based on the frequency response corresponding to calculated centroid frequency and loudness level. Already the filter parameters of limited input levels will be pre calculated and stored in the algorithm. If the level of incoming signal matches any of these input levels, the system will directly amplify based on the stored data; whereas, if the loudness of the signal at that particular time falls in between two loudness level, frequency response is interpolated from the two immediate loudness levels. Interpolated gain curves are depicted in Figure 2.2. For sounds below 10 sones or above 90 sones the algorithm infers linearly based on the frequency responses at 10 and 90 sones, respectively. For very high input levels, microphone output is limited to avoid digital clipping, similar to peak clipping; but occurs in the digital domain (Scheller, 2004).Channel free processing algorithm is WDRC with controllable lattice filter (Schaub, 2009). Lattice filters are those which have got a constant attenuation across all frequencies but relative phase between input and output varies with frequency. Flowchart of working of lattice filter is shown in Figure 2.1 where it is clearly depicted that controllable lattice filter continuously change its parameters based on the input level. Hence, in channel free processing the controllable filter continuously change it filter characteristics based on the incoming signal rather than diving the signal into different frequency band causing spectral smearing. Steps involved in signal processing in channel free amplification in represented in Figure 2.3.

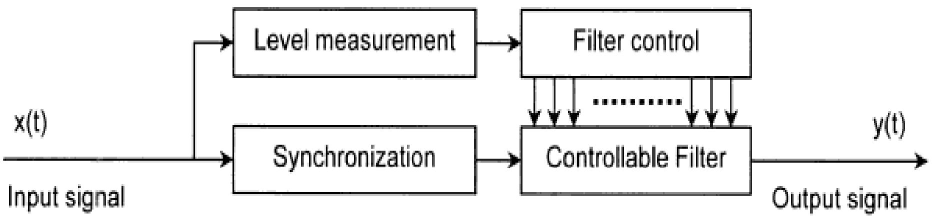

Figure 2.1. Block diagram of wide dynamic range with controllable lattice filter which constitutes channel free processing algorithm. Adapted from Schaub A. (2008). Digital Hearing Aids. New York: Thieme Medical Publishers.

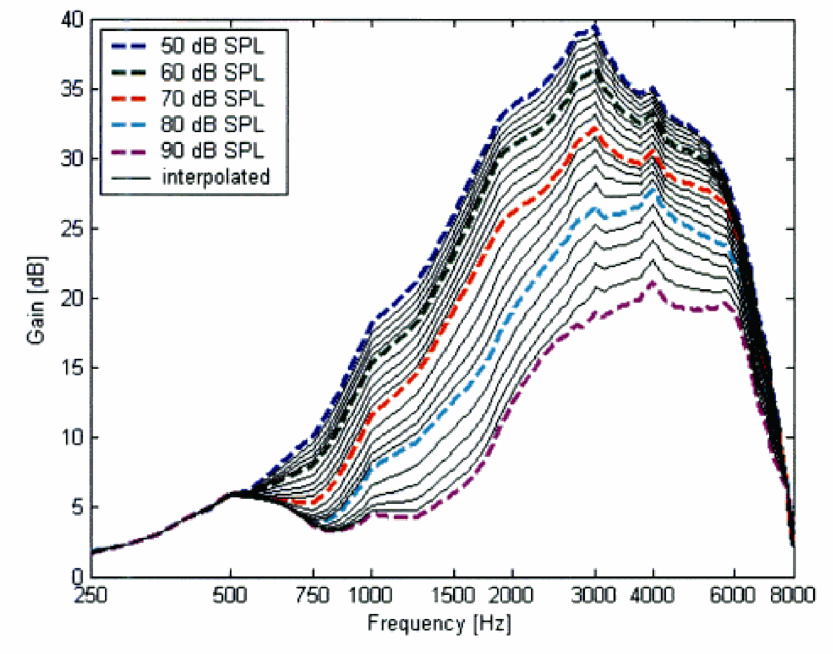

Figure 2.2 Interpolated gain curves at each input levels with a controllable lattice filter. Black coloured curves represent interpolated gain and coloured dashed curves represents pre calculated gain curves at certain input levels. Adapted from Schaub A. (2008) Digital Hearing Aids. New York: Thieme Medical Publishers.

In a study conducted by Dillon, Keidser, O'Brien and Silberstein (2003), the performance of a channel free hearing aid was compared with the performance of three other digital multichannel hearing aids. No significant differences among the hearing aids in most of the listening conditions, except that normal hearing subjects preferred channel free hearing aid in the quiet-room condition and subjects with hearing loss preferred channel free hearing aid when listening to piano music.

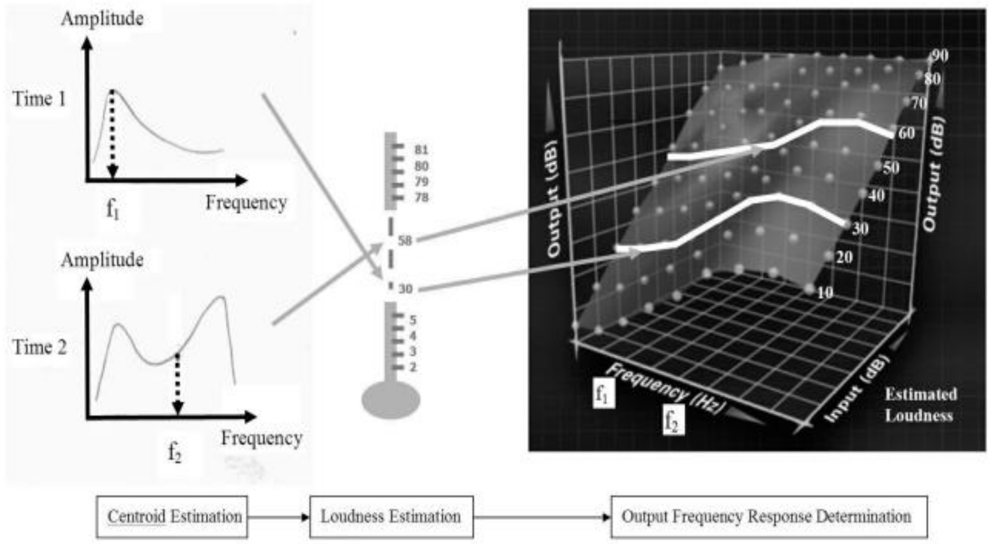

Figure 2.3: Steps involved in signal processing in channel free amplification representing how instantaneous frequency responses are calculated based on incoming signal at two instances in time. Adapted from Chung, K. (2004). Challenges and Recent Developments in Hearing Aids Part II. Feed Back and Occlusion Effect Reduction Strategies, Laser Shell Manufacturing Processes, and Other Signal Processing Technologies. *Trends in Amplification, 8(4)*, 125-164.

Kumar and Rajalakshmi in 2007 compared the performance of channel free hearing aid to other multichannel hearing aids in terms of speech identification both in quiet and in noisy condition. Study was conducted on 12 subjects with sensorineural hearing loss. Results revealed that better speech identification scores in both quiet and noisy conditions with channel free hearing aid for patients with sensorineural hearing loss compared to multichannel hearing aid suggesting that channel free hearing aid is better option for subjects with sensorineural hearing loss.

Plyer, Reber, Kovach, Galloway, and Humphrey (2013) in their study compared the performance multichannel WDRC with Channel Free processing. They found out that Channel free processing showed more amplification above 1800 Hz across input level. They also pointed out that subjects who preferred channel free had greater degrees of hearing loss, which might be due to increased gain at high frequencies. They concluded his study by stating that both multichannel and channel free processing both results in noteworthy improvement for hearing aid users. This study point towards the opinion that, channel free processing is a better option for high frequency sensorineural hearing loss as it provides more headroom for high frequency gain compared to multichannel WDRC.

Since channel free appears to be a promising processing signal processing technique for sensorineural hearing loss and as there is a dearth of literature exploring the effect of open channel free amplification in sloping sensorineural hearing loss; the present study aims at evaluating the benefits of open fit channel free hearing aid for mild to moderate sloping sensorineural hearing loss.

Chapter 3

Method

Participants.

Native Kannada speaking adults in the age range of 18 -50years were included in the study. Data was collected from 20 ears after taking informed consent from all the participants. The participants had to fulfil the following criteria to be included in this study.

1. Individuals with sensory neural hearing loss with a pure tone average of less than 60 dB across the frequencies 250 Hz, 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz; air conduction threshold shall increase by 5-12 dB per octave from 250 to 8000 Hz,
2. Post lingual hearing loss with adequate speech and language skills,
3. Speech identification scores greater than or equal to 75%,
4. Participants should be naive hearing aid users,
5. Negative history of middle ear infections, speech and language disorder, and neurologic disorder or any cognitive listening deficits.

Instrumentation.

1. A calibrated (ANSI S3.6-1996) dual channel audiometer with TDH 39 headphones mounted with MX 14 AR ear cushions was used for the estimation of air conduction threshold.
2. Radio ear B71 bone vibrator was used for bone conduction threshold estimation.

3. Loud speakers were used to measure SIS and SNR 50 for all the participants
4. Calibrated middle ear analyzer was used for immittance measurements.
5. Hearing aids: Two digital behind the ear channel free hearing aids suitable for mild to moderate sloping sensorineural hearing loss of same manufacturer; one with open fit using no. 0.9 and 1.3 slim fit tubing and other using no. 13 tubing fitted with regular occluded ear tip were used. These hearing aids had channel free signal processing, adaptive noise reduction, feedback management, directional microphone and bandwidth of 8 kHz.
6. A personal computer connected with Hi-Pro, specific programming cable and NOAH 3 were used for programming the hearing aids.
7. A calibrated Fonix 7000 hearing aid analyser was used for real ear measurements.

Test materials.

1. High frequency word list developed by Mascarenhas and Yathiraj (2002) was used to find out speech identification scores in quiet.
2. The word list developed by Sahgal (2005) in Kannada was used to measure SNR-50. This list consist of 40 set of bi-syllabic words, each set containing 3 words of low, mid, high frequency combination.
3. The standardized paragraph developed by Sairam (2002) in Kannada was used for quality rating.
4. Quality rating scale developed by Otto (2005) was used to assess the effect on quality of speech and own voice. Six parameters of quality were rated by the listeners using ten point rating scale. The parameters included sound of own voice, pressure feeling, feedback /whistling, comfortable listening level, sound of chewing, appearance/cosmetics.

Test environment.

All the testing was conducted in sound treated room where the noise levels were within permissible limits (ANSI.S3. 1, 1999).

Procedure.

The study is carried out in the following stages:

Stage1: Routine audiological evaluation for selection of participants and hearing aid fitting

Stage2: Comparison of performance in unaided and aided condition

Stage3: Qualitative measurement

Stage 1: Routine audiological evaluation for selection of participants and hearing aid fitting.

The routine audiological testing including pure tone audiometry, speech audiometry and immittance evaluation was carried out for each test ear of each participant. Air conduction thresholds were estimated by pure tone audiometry between 250 Hz to 8 kHz audiometric frequencies. Further, the bone conduction thresholds were estimated between 250 Hz to 4 kHz. Modified Hughson and Westlake method (Carhart & Jerger, 1959) was used to estimate both air and bone conduction thresholds.

Speech audiometry was administered to measure speech reception threshold (SRT), speech identification score (SIS) and uncomfortable loudness level (UCL). Immittance testing was also done in order to rule out presence of any middle ear pathology.

Hearing aid fitting.

Participant was seated comfortably in a chair and the channel free hearing aid using tubing of no. 13 with a regular ear tip was fitted. The hearing aid was connected to a personal computer via Hi-Pro interface using the specific programming cable. The personal computer installed with specific NOAH fitting software was used to program the hearing aid using NAL NL-1 prescriptive formula keeping acclimatization level at 2. Hearing aid was programmed according to the participant's comfort. The audibility of ling sounds (/a/, /i/, /u/, /s/, /sh/, /m/) was assessed while programming to ensure the gain setting are appropriate. The program was then saved to the hearing instrument. The same procedure was repeated for programming the open fit channel free hearing with no. 0.9 and no. 1.3 slim fit tubing separately.

Step 2: Comparison of performance in unaided and aided condition.

Speech Identification Score (SIS) was measured for both unaided and aided condition. SNR 50, real ear measurement and qualitative judgments using a rating scale was also assessed in the following conditions:

I. Aided condition with occluded fit channel free BTE.

II. Aided condition with open fit channel free BTE using no 0.9 slim fit tube.

III. Aided condition with open fit channel free BTE using no 1.3 slim fit tube.

1. *Speech Identification Score (SIS)*: For assessment of speech identification score recorded high frequency word in Kannada developed by Mascarenhas and Yathiraj (2002) was used. The recorded words were routed through the audiometer to a loudspeaker at 0^0 azimuth located at a distance of one metre away from the participant at the most comfortable level of the listener. Participant was instructed to repeat back the presented words. For each correct

response a score of 1 was given and for each wrong response a score of zero was given to the participant. Total number of correct responses was taken as the participant's SIS. Separate word list of 25 words was presented to measure SIS for each of the conditions.

2. *Speech identification in noise (SNR 50):* The SNR 50 was measured using recorded Kannada wordlist developed by Sahgal (2005) (Appendix A). The recorded speech material was routed through the audiometer to a loudspeaker at 0^0 azimuth located at a distance of one metre away from the participant at 40 dB HL. The speech noise was routed through the audiometer to a loudspeaker at 180^0 azimuth placed one meter away from the participant as shown in figure 3.1. Initially the presentation level of noise was kept at 10 dB lower the level of speech signal and was varied to measure SNR 50. Participant was instructed to repeat back the words presented in the presence of competing noise. At each noise level a set of three words were presented. If the participant was able to repeat back two of them, then the noise was increased in 4 dB step and if the participant failed to repeat back two out of three words, the noise was decreased in 2 dB steps. This was continued till the participant repeated two out of three words correctly. The difference between intensity of speech signal and noise in dB, at which the participant repeated at least 50% of the words presented correctly, was taken as SNR 50.

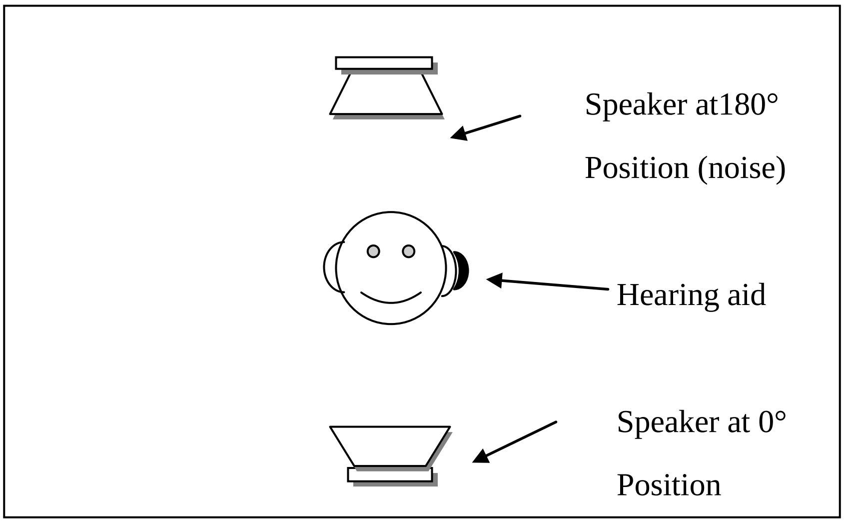

Figure 3.1: position of participant and loudspeakers for measuring SIS, SNR-50.

3. *Real ear measurement:* Real ear measurement was carried out using calibrated Fonix-7000 hearing aid analyzer. Participants were seated in a chair at 45° azimuth and one foot distance from the loud speaker of the hearing aid analyzer. First, to ensure correct insertion of probe tube, insertion depth was marked prior to the measurement. For this, the probe tube was detached from the microphone and laid on a flat surface next to the hearing aid with the tip of the probe tube and the ear tip of the hearing aid in level with each other. Next, the tip of the probe tube was extended 5 mm from the ear tip of the hearing aid then, with the use of a marker pen the point on probe tube where the probe tube lies in level with outer end of the ear tip (which lies facing towards the outer part of external ear canal) was marked. Then, the probe tube was reattached to the microphone. For all the real ear measurement this marking was used as insertion depth. Further, the audiometric threshold of the participant was entered and levelling of the system was done to ensure the accurate probe microphone measurement. Next from the home screen, of real

ear analyzer real ear measurement option was selected, after which insertion gain option was selected from the next page. From the main screen page of insertion measurement, NAL-NL1 was selected as the target. Next, REUG, REAG, REIG were measured for each condition. Procedure for measurement of REUG, REAG, and REIG is explained in detail in the following sections. Protocol followed for measuring REUR, REAR, REIG for both occluded and open fit condition are depicted in Table 3.1.

Table 3.1 Protocol for measuring REUG, REAG, REIG

Type of stimuli	Digi speech
Stimulus level	65 dB SPL
Reference microphone	On - for occluded fit conditions Off - for open fit conditions
Smoothing	Log
Prescriptive formula	NAL NL-1
Output limiting	120 dBSPL
Test type	Insertion Gain

a. *Measurement of real ear unaided gain (REUG)*: The marked probe tube attached to the microphone was inserted into the ear canal of the patient, the marking lying at the level intertragical notch. The reference microphone was mounted above the pinna of the patient. Using digi speech at 65dBSPL as stimuli, REUG measurement was acquired by pressing the start button. The REUG curve was obtained with frequency on X axis and gain in dB on Y axis.

b. *Measurement of real ear aided gain (REAG)*: With the probe tube and reference microphone in place, the programmed hearing instrument was placed behind the ear of the patient with the ear tip appropriately placed in the canal as shown in Figure 3.1. Then the REAG curve was selected. Farby (2005) reported that it may be necessary to disengage the reference microphone while doing real ear measurement of open fit hearing aid, because if the reference microphone is in 'on' mode, it will be influenced by sound coming back out through the open tip resulting in REAG measure which could be either artificially high or artificially low. Hence, in this study while measuring REAR for channel free hearing aid in open fit condition (for both tube size 0.9mm and 1.3mm), reference microphone was kept in 'off' mode. This was done by selecting 'menu' and selecting reference microphone to 'off' mode whereas for occluded fit condition, the reference microphone was kept 'on'. Measurement was acquired by pressing the start button. The dB gain at different frequencies was displayed as real ear aided gain. The REAG curve was obtained for occluded fit channel free BTE hearing aid, open fit channel free BTE hearing aid with no. 0.9 slim fit tubing and no. 1.3 slim fit tubing separately. The values of REAG were noted at 200 Hz, 500 Hz, 1000 Hz, 1500 Hz, 2000 Hz, 2500 Hz, 3000 Hz, 3500 Hz, 4000 Hz, 4500 Hz, 5000 Hz, 5500 Hz, 6000 Hz, 6500 Hz, 7000 Hz, 7500 Hz and 8000 Hz frequencies from the data table for each test ear of every participant.

c. *Measurement of real ear insertion gain (REIG)*: Separate REIG cures were obtained for each hearing aid as hearing aid analyzer automatically calculates REIG by subtracting REUG from REAG values. The values of the all REIG curves were noted at 200 Hz, 500 Hz, 1000 Hz, 1500 Hz, 2000 Hz, 2500 Hz, 3000 Hz, 3500 Hz, 4000 Hz, 4500 Hz, 5000 Hz, 5500 Hz, 6000 Hz, 6500 Hz, 7000 Hz, 7500 Hz and 8000 Hz frequencies from the data table.

Figure 3.2 Placement of probe tube along with reference microphone & probe microphone set up with the hearing instrument behind the ear.

4. *Qualitative measurement:* The standardized paragraph developed by Sairam (2002) in Kannada was used for quality rating (Appendix C). First, the recorded speech material was routed through the audiometer to a loudspeaker at 40 dB HL. Participant was instructed to assess quality of speech on parameters such as: pressure feeling, feedback/whistling, comfortable listening level, and appearance & cosmetics. Also, participant was asked to assess the quality of own voice and sound of chewing after reading a paragraph in Kannada (Sairam, 2002) for 2-3 minutes and the comments were noted down. Qualitative measurements were assessed with a quality rating scale developed by Otto (2005), which is a ten point rating scale (Appendix B).

Chapter 4

Results and Discussion

The study aimed at comparing the performance of channel free hearing aid in sloping sensorineural hearing loss under two conditions - occluded fit and open fit. This was carried out using different subjective and objective measures. Subjective measures included speech identification in quiet, speech identification in noise and quality rating of recorded speech and own voice. Objective measures included real ear measurements (REIR) at 200 Hz, 500 Hz, 1000 Hz, 1500 Hz, 2000 Hz, 2500 Hz, 3000 Hz, 3500 Hz, 4000 Hz, 4500 Hz, 5000 Hz, 5500 Hz, 6000 Hz, 6500 Hz, 7000 Hz, 7500 Hz and 8000 Hz frequencies using hearing aid analyzer. Data were collected from 20 ears of 16 participants for each of the above mentioned measures under two conditions, occluded fit and open fit. Parameters measured and analyzed in the two aided condition are discussed under the following headings:

4.1 Speech identification scores (SIS) in quiet

4.2 Speech recognition threshold in noise (SNR-50)

4.3 Quality judgment

    4.3.1 Quality of recorded speech

    4.3.2 Quality of own voice

    4.3.3 Quality of other factors

4.4 Real Ear Insertion Gain (REIR)

Statistical analysis.

Statistical analysis of the data was done to examine whether there was any significant difference in measures obtained (SIS, SNR50, REIR, and Quality of speech) in the two aided conditions (occluded fit and open fit). For this, Statistical

Package for the Social Sciences, SPSS (Version 16) was used. The statistical measures that were used are:

i. Descriptive statistics to acquire mean and standard deviation of all the measures in two aided condition.
ii. Parametric test: Repeated measure ANOVA
iii. Non parametric tests: Wilcoxon Signed Ranks Test and Friedman Test

4.1 Speech identification scores (SIS) in quiet.

The mean and standard deviation of speech identification scores in quiet were obtained for occluded fit condition with 13 mm tube size and for open fit condition separately for two tube sizes (0.9 mm and 1.3 mm) of channel free hearing aid and is shown in the Table 4.1. It can be noted from the table that the mean speech identification scores obtained in both the aided condition is higher compared to unaided condition; this improvement in speech identification in aided condition relative to unaided condition is due to the benefit from amplification. Quite a lot of studies also state the same (Roup & Noe, 2009; Hornsby & Ricketts, 2003; Plyer & Fleck, 2006; Schwartz, Surr, Montgomery, Prosek, & Walden, 1979; Sullivan, Allsman, Nielsen, & Mobley, 1992; Turner & Henry, 2002). Also, it can be noted that speech identification scores of occluded fit and open fit conditions are almost same, which means that when fitted with channel free hearing aid, speech performance in quiet does not differ in open fit or occluded fit condition for individuals with sloping sensorineural hearing loss.

Table 4.1 Mean and standard deviation of Speech Identification Scores in quiet and in the two aided conditions

Aided condition	***Speech identification score(SIS) (Maximum score 25)***	***SD***
Unaided	17.30	4.30
Occluded fit (13mm tube size)	21.00	1.58
Open fit		
0.9mm tube size	21.75	1.61
1.3mm tube size	21.90	1.25

Repeated measure ANOVA was performed to reveal whether there was a significant difference between speech identification scores in quiet between two aided condition, occluded fit and open fit. Results revealed that there is no significant difference in the speech identification scores in quiet obtained in two aided condition i.e., occluded fit and open fit condition ($F (2, 38) = 3.116$, $P=0.056$).

4.2 Speech recognition threshold in noise (SNR-50).

The mean and standard deviation obtained for SNR-50 which is the signal-to-noise ratio required for obtaining 50% recognition scores (speech recognition in noise) are shown in the Table 4.2. As shown in the table SNR-50 value is less in the open fit condition when compared to occluded fit condition. Lower SNR-50 values signifies better performance, i.e. performance is better even when the difference between the levels of speech and noise is less. Also, it can be noted that the SNR-50 value is same for 0.9 mm and 1.3 mm tube in open fit condition. This shows that there is benefit of better performance for speech in the presence of noise when using channel free hearing aid in open fit condition; but, at the same time there seems to be no effect in performance for speech in presence of noise due to different tube size (0.9mm, 1.3mm) in open fit condition. Magnusson (2013) also reported better speech identification score in open fit condition than in closed fit condition. Kumar (2010) reported that this betterment could be due to reduction in excess of low frequency energy escaping through the open tip contributing to better speech perception in noise. Also, speech perceived in open fit condition will be enhanced because of improved ability to extract spectral cues as the natural resonance of ear canal is left intact. Bar graph representing mean SNR-50 of all aided condition is depicted in Figure 4.1.

Table 4.2 Mean and Standard Deviation of SNR-50 in the two aided conditions

Aided condition	***SNR-50 (dB)***	***SD***
Occluded fit		
13 mm tube size	-4.40	2.39
Open fit		
0.9 mm tube size	-6.10	2.63
1.3 mm tube size	-6.10	2.29

Friedman's Test was performed to reveal whether there was any significant difference in SNR-50 values in both the conditions, occluded fit and open fit. Results revealed that there is a significant difference in SNR-50 value of occluded fit with 13 mm tube and SNR-50 value of open fit with 0.9 mm tube, χ^2 (17, N = 20) =232.483, p <0.05.Significant differences were also noted between SNR-50 values of occluded fit with 13mm tube and SNR-50 value of open fit with 1.3 mm tube. But, there was no significant difference in the SNR-50 value of open fit with 0.9 mm tube and SNR-50 value of open fit with 1.3 mm tube. The Z value and significance value for each pair is shown in Table 4.3.

Table 4.3 Z value and significance of SNR-50 in the two aided conditions

Condition	***Z value***	***p value***
SNR 50 Occluded fit (13 mm tube) – SNR-50 Open fit (0.9 mm tube)	-3.690	.000*
SNR 50 Open fit(1.3 mm tube) – SNR 50 Occluded fit(13 mm tube)	-3.532	.000*
SNR 50 Open fit (1.3 mm tube) – SNR 50 Open fit (0.9 mm tube)	0.0001	1.000

*p< 0.05 indicating significant difference

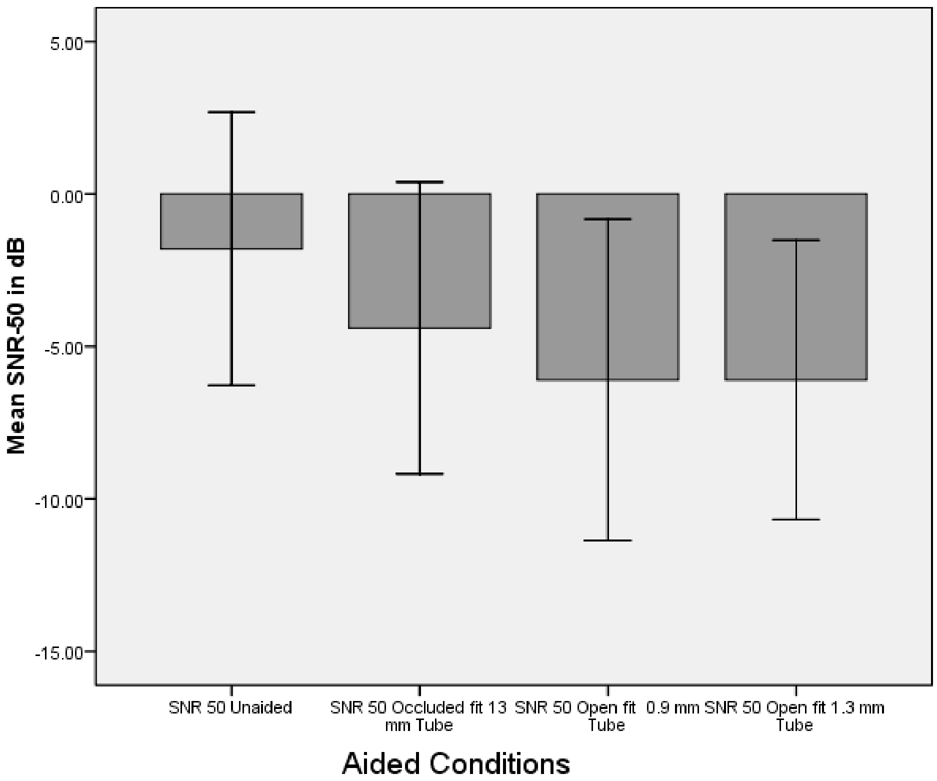

Figure 4.1 Mean SNR-50 in dB in all aided condition.

4.3 Quality judgment: Quality of own voice and of recorded speech were both assessed. The results are given below.

4.3.1. Overall quality for recorded paragraph.

Quality judgment of recorded speech was assessed by asking the subject to judge 4 parameters of quality from rating scale developed by Otto (2005), after playing the recorded paragraph developed by Sairam (2002) through audiometer at 40 dB HL. The parameters judged were: pressure feeling, feedback whistling and comfortable listening level. Also, participant was asked to assess the quality of own voice and sound of chewing after reading a paragraph in Kannada (Sairam, 2002) for 2-3 minutes. This was done for two conditions: open fit and occluded fit. Within each condition, these six parameters were rated on a 10 point rating scale. Zero indicating the lowest and ten indicating the highest score on quality. Table 4.3.1.a represents the mean and standard deviation ratings for all parameters of quality across the two aided condition.

Table 4.3.1.a Mean and Standard deviation of quality judgment parameters of recorded speech, in the two aided conditions

Parameters	***Conditions***	***Mean***	***SD***
Pressure Feeling	Occluded fit with 13 mm tube	3.60	1.04
	Open fit with 0.9 mm tube	8.20	0.61
	Open fit with 1.3 mm tube	8.40	0.82
Feedback/	Occluded fit with 13 mm tube	9.20	1.00
Whistling	Open fit tube 0.9 mm tube	9.20	1.00
	Open fit with 1.3 mm tube	9.10	1.02
Comfortable	Occluded fit with 13 mm tube	7.00	1.65
Listening Level	Open fit 0.9 mm with tube	8.50	1.10
	Open fit with 1.3 mm tube	8.50	1.10

From Table 4.3.1.a it can be noted that the quality parameters like pressure feeling, comfortable listening level are better rated in open fit condition compared to occluded fit condition, which means that in open fit condition, quality of speech perceived is high compared to occluded fit. Also, it can be noted that quality ratings are almost same for two tube sizes (0.9 mm & 1.3 mm) in open fit conditions which indicates that there is no effect of tube size on perceived quality of speech.

Friedman Test was performed to reveal whether there was any significant difference in quality judgment in both the conditions, occluded fit and open fit. Results revealed that there is significant difference in parameters like: pressure feeling, comfortable listening level between open and occluded fit conditions, with quality in open fitting rated high χ^2 (17, 20) =232.483, $p < 0.05$. Mueller (2006) and Jaspersen, Groth, Kiessling, Brenner and Jensen (2006) found the same in their study. This could be due to reduction in occlusion effect. Also, it can be noted that there is no significant difference in quality rating between the tube size (0.9 mm & 1.3 mm) in open fit condition. Z value and significance for each of the condition is shown in Table 4.3.1.b.

Table 4.3.1.b Z value and significance of quality parameters of recorded speech in the two aided conditions, occluded fit and open fit (0.9 mm & 1.3 mm)

Parameters	***Conditions***	***Z value***	***P value***
Comfortable Listening Level	Open fit (0.9 mm)- Occluded fit (13mm)	-2.519	0.012
	Open fit (1.3 mm)- Occluded (13 mm)	-2.519	0.012
	Open (1.3 mm) - Open (0.9 mm)	0.000	1.000
Feedback/ Whistling	Open fit (0.9 mm)- Occluded fit (13mm)	0.000	1.000
	Open fit (1.3 mm)- Occluded (13 mm)	-0.447	0.655
	Open (1.3 mm) - Open (0.9 mm)	-1.000	0.317
Pressure Feeling	Open fit (0.9 mm)- Occluded fit (13mm)	-4.042	0.000
	Open fit (1.3 mm) - Occluded (13 mm)	-4.029	0.000

Open (1.3 mm) - Open (0.9 mm)	-1.414	0.157

From Table 4.3.b.1it can be noted that rating between parameters like comfortable listening level, pressure feeling has significant difference between the two aided, open fit and occluded fit conditions. Subjective preference is high for open fitting; whereas, between the two open fit conditions there is no significant difference showing that different slim fit tube (1.3 mm &0.9 mm) does not affect subjective rating. Also, there is no significant difference between two aided conditions in the case of rating for feedback/whistling, the mean rating being above 9 in all the three condition shows that feedback is rarely a problem in all the condition. This could be due effective feedback management system available in open fit hearing aids similar to that available in conventional BTE resulting in minimal feedback. Scheller and Scheller, 2006; Parsa, 2006 also stated that, same could be possible reason.

4.3.2 Overall quality for own voice.

Participants were also instructed to rate quality of their own voice and sound of chewing which were two parameters of quality from Otto's 10 point rating scale after reading a paragraph (developed by Sairam, 2002) for 2-3 minutes. Mean and standard deviation were obtained and is shown in table 4.3.2.a.

Table 4.3.2.a Mean and Standard deviation of parameters of quality rating

Parameters of quality	***Conditions***	***Mean***	***SD***
Sound of own voice	Occluded 13 mm Tube	3.20	1.19
	Open 0.9 mm Tube	8.20	1.28
	Open 1.3 mm Tube	9.00	1.02
Sound of own Chewing	Occluded 13 mm Tube	3.80	1.82
	Open 0.9 mm Tube	9.30	0.97
	Open 1.3 mm Tube	9.80	0.61

It can be noted down from Table 4.3.2.a that, mean rating for 'sound of own voice' and 'sound of chewing' of open fitted channel free hearing is higher compared to occluded fit condition.

Friedman Test was performed to reveal whether there was any significant difference in quality judgment in both the conditions, occluded fit and open fit. Results revealed that there is significant difference in quality judgments of the parameters: sound of own voice and chewing in both the aided condition χ^2 (17, N = 20) =232.483, $p < 0.05$. This shows that subjects preferred open fit fitting over closed fit in channel free hearing aid in terms of quality of own speech and sound of chewing. Z value and significance are shown in Table 4.3.2.b. there is significant difference between sound of own voice and own chewing in open fit condition compared to occluded fit condition, open fit condition rated high. This is due to reduction in excess of low frequency energy getting trapped in ear canal which if causes perception of unnatural quality of own. Studies by Mac Kenzie, 2006; Gnewikow and Moss, 2006 also quoted the same. Moreover, similar to earlier result there is no significant difference in subjective rating of own voice and chewing between two tube sizes in open fit.

Table 4.3.2.b Z value and significance of sound of own voice and own chewing

Parameter	***Conditions***	***Z value***	***Sig.***
Sound of own voice	Open fit (0.9 mm)- Occluded fit (13 mm)	-3.951	.000
	Open fit (1.3 mm)- Occluded (13 mm)	-3.974	.000
	Open (1.3 mm) - Open (0.9 mm)	-2.530	.011

Sound of Own Chewing	Open fit (0.9 mm)- Occluded fit (13 mm)	-3.872	.000
	Open fit (1.3 mm)- Occluded (13 mm)	-3.880	.000
	Open (1.3 mm) - Open (0.9 mm)	-2.236	.025

4.3.3 Quality of other factors.

Other factors like appearance and cosmetic appeal were also rated using rating scale by Otto (2005). Mean and standard deviation of rating of other factors like appearance/cosmetics are shown in Table 4.3.3.a. As depicted in table, mean rating is high for open fit conditions than for closed fit conditions showing that open fitted channel free are most acceptable in terms of appearance and cosmetic appeal compared to occluded fitted channel free hearing aid. As occluded fit condition uses conventional 13 mm size tube which is bigger in size compared to open fitting which uses slim fit tubes of smaller size (0.9 mm & 1.3 mm), subjects preferred open fitted channel free hearing as it less visible and more comfortable to wear.

Table 4.3.3.a Mean and Standard deviation of quality rating on appearance/cosmetics

Parameters	**Conditions**	**Mean**	**SD**
Appearance/Cosmetics	Occluded fit with 13 mm Tube	4.70	1.34
	Open fit with 0.9 mm Tube	8.70	1.17
	Open fit with 1.3 mm Tube	8.70	1.17

Friedman Test was performed to reveal whether there was any significant difference in quality judgment of in both the conditions, occluded fit and open fit χ^2 (17, N = 20) =232.483, $p < 0.05$. Results revealed that there is a significant difference in all the parameters of quality judgments ($p<0.05$) and is shown in Table 4.3.3.b

Table 4.3.3.b Z and P value of quality rating of factor: appearance/cosmetics

Parameters	***Conditions***	***Z value***	***P value***
	Open fit with0.9 mm Tube-Occluded 13 mm Tube	-3.970	0.000
Appearance/Cosmetics	Open fit with 1.3 mm Tube- Occluded fit with 13 mm Tube	-3.970	0.000
	Open fit with1.3 mm Tube- Open fit with 0.9 mm Tube	0.000	1.000

4.4 Real Ear Insertion Gain (REIG).

Mean and standard deviation values for real ear gain (REIG) across different frequencies are were estimated and are depicted in Table 4.4. From the table it can be noted that mean RIEG for 200 Hz and 500 Hz is less for both the open fit condition compared to occluded fit condition which means, the gain provided by the hearing aid is less in low frequencies as in open fit condition since the ear canal is left open, there is less requirement of low frequency gain which ultimately results in reduced occlusion effect. Also, it can be noticed that within the open fit 1.3 mm tube gives comparatively less gain in low frequencies than 0.9 mm tube.

Table 4.4 Mean and Standard deviation of RIEG across frequencies of both occluded and open fit condition

	REIG in dB					
Frequencies	***Occluded fit with 13 mm tubing***		***Open fit with 0.9 mm tubing***		***Open fit 1.3 mm tubing***	
	Mean	***SD***	***Mean***	***SD***	***Mean***	***SD***
200 Hz	2.72	0.88	-0.54	2.65	-2.03	5.56
500 Hz	5.92	4.13	2.21	1.99	1.21	6.51
1000 Hz	18.49	5.68	8.83	5.88	11.6	5.90
1500 Hz	25.93	3.52	14.34	6.42	13.5	7.34
2000 Hz	23.88	3.92	17.88	5.42	17.73	4.89
2500 Hz	21.21	4.23	22.09	4.86	22.76	5.83
3000 Hz	16.16	2.66	17.00	5.28	16.8	5.60
3500 Hz	15.86	1.79	12.53	4.48	18.43	5.99
4000 Hz	13.64	2.35	10.67	4.81	10.76	4.39
4500 Hz	10.50	2.53	9.66	4.87	4.97	3.96
5000 Hz	8.50	2.92	5.28	4.07	6.81	3.76
5500 Hz	9.09	3.87	4.57	4.03	7.83	5.04
6000 Hz	8.61	3.93	3.08	4.31	5.19	6.15
6500 Hz	4.73	4.77	3.14	3.62	5.98	4.69
7000 Hz	1.91	2.60	1.14	4.98	2.98	4.93
7500 Hz	-0.06	1.88	-0.98	2.42	0.83	5.57
8000 Hz	-0.54	2.65	-1.93	4.31	3.44	6.37

Friedman Test was performed to reveal whether there was any significant difference in REIG across frequencies in both the conditions, occluded fit and open fit. Results revealed that there is a significant difference in REIR across frequencies mentioned below χ^2 (50, N = 20) =781.376, p <0.05. In low frequencies (200 Hz & 500 Hz) there is a significant difference between occluded fit and open fit, which was expected as open canal fitting's main aim is to provide less or no gain in low frequencies for individuals with sloping loss for they have normal or near normal low frequency thresholds. Also significant difference between the RIEG of open fit and occluded fit was also found on 1000Hz, 1500Hz, 2000Hz, 4000Hz, 5500Hz, 6000Hz, and 7500 Hz. This could be attributed to difference in tube resonance as tubes are of different size for closed and occluded fit and this could also be occluding of the ear canal. Mean REIG curves of occluded fit (13 mm), open fit (0.9 mm & 1.3 mm) are depicted in figure 4.2. It can be noticed from the figure that gain from occluded fit is higher gain till around 2500Hz compared to open fitting. This might be due to two possible reasons, first being low frequency energy being trapped inside due occluded fit (Kumar, 2010), second being more capability of instrument to provide more amount of gain compared to open fit condition before feedback occurs. There was a significant difference between the RIEG of open fit 1.3 mm tube and RIEG of open fit with 0.9 mm at 4500 Hz, 5500 Hz, 6500 Hz and 8000 Hz, the mean RIEG of open fit with 1.3 mm being higher which shows that open fit with 1.3mm gave higher gain in high frequencies compared to open fit with 0.9mm tube, also as mentioned earlier, open fit using 1.3mm slim fit gave lesser gain compared to 0.9mm slim fit tube in low frequencies which could also be due to the difference in size of the tube. This which implies that using 1.3 mm tube size in open fit channel free is a viable option for patients with normal low frequency threshold and for patients with minimal or mild low frequency threshold with higher high frequency thresholds compared to open fit channel free with 0.9 mm tube can be used.

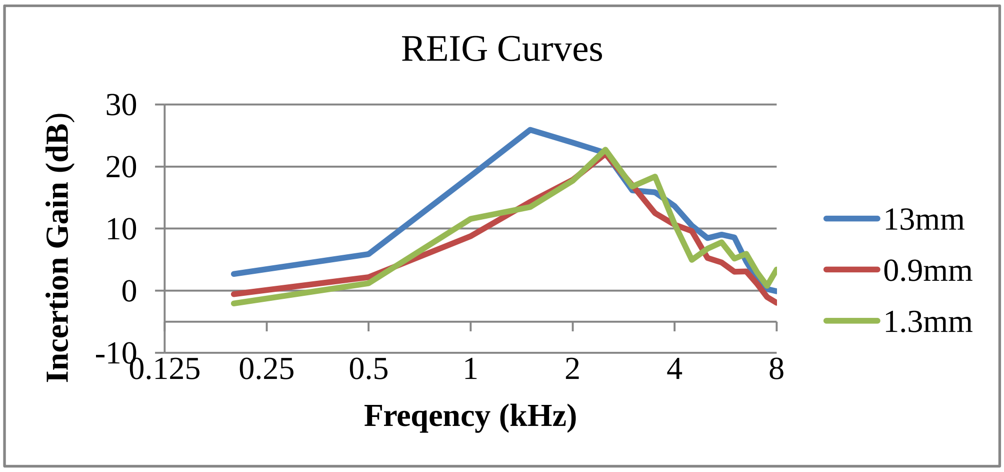

Figure 4.2 Mean REIG curves representing occluded fit, open fit (0.9mm & 1.3mm)

From RIEG measured it can be inferred that open fit channel free is better option for sloping configuration as it provided less or minimal gain in low frequencies, also tube size (0.9 mm & 1.3 mm) in open fitting has an effect only in low frequencies and 1.3 mm tube is preferable in subjects with normal or minimal low frequency thresholds. However, more gain in mid to high frequency range is provided by occluded fitting compared to open fit.

Chapter 5

Summary and Conclusion

The study aimed at comparing the performance of channel free hearing aid in both closed and open fit conditions on subjects with sloping sensorineural hearing loss. The study compared speech identification scores in quiet, SNR-50, quality judgments and real ear measurement of 20 naïve hearing aid users. The measurement was done in three conditions: occluded fit using13 mm tube size, open fit using 0.9 and 1.3 mm. The following results were obtained:

1. Speech identification scores in quiet was almost same for all the three conditions indicating that when fitted with channel free hearing aids, occluded fitting doesn't affect speech identification scores in quiet.

2. In case of SNR-50; i.e. speech recognition in noise, performance was better in open fit condition compared to occluded fit condition.

3. Subjective quality ratings showed that individuals preferred open fit condition compared to closed fit condition. Parameters like 'quality of own voice', 'sound of chewing' 'comfortable listening level' were all rated high in open fit than in occluded fit.

4. REIR of open and occluded fit conditions showed that open fit gave preferably less gain in low frequencies compared to occluded fit, however higher amount of gain was provided by occluded fit condition till around 3000 Hz . Also, within the open fit 1.3 mm slim fit tube condition gave even lesser gain in low frequencies and higher gain in high frequencies than 0.9 mm slim fit tube condition.

From the result of this study it can be concluded that channel free open fit hearing aid is better choice for subjects with sloping sensorineural hearing loss compared to occluded fit channel free hearing aid. It is evident as open fit condition results in better speech perception in noise, greater patient satisfaction due to elimination of occlusion effect and as it gives less or minimal amount of gain in low frequencies, as required.

Clinical implication.

The common practice in hearing aid fitting is to prescribe hearing aid based on speech identification scores in quiet and according to patient's choice; however, this study shows that additional measures should be considered before prescribing. When prescribing hearing aid, especially for sloping sensorineural hearing loss subjects, taking only speech identification scores in quiet into consideration will lead to poor patient satisfaction. Measurement of speech identification performances in the presence of noise would bring better clarity in making a decision about actual benefit that can be obtained from a hearing aid.

Also, open fit channel free hearing aid proves to be a better option than occluded fit channel free hearing aid for sloping sensorineural hearing loss subjects as it gives less gain at low frequencies which enables the listeners to effectively use low frequency through natural hearing and amplified high frequencies through hearing aid.

Future indications for research.

1. To study the effectiveness of directional microphone in open fit hearing aids.

2. To study the effect on localization due to open fitting of hearing aids

3. To compare open fit channel free hearing aid with multichannel open fit hearing aid.

References

Amos, N. E., & Humes, L. E. (2007). Contribution of high frequencies to speech recognition in quiet and noise in listeners with varying degrees of high-frequency sensorineural hearing loss. *Journal of Speech, Language, and Hearing Research, 50*, 819-834.

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

ANSI S3.6 (1996). American National Standard specification for audiometers. New York: *American National Standards Institute Inc.*

Arlinger. S., (2003). Negative consequences of uncorrected hearing loss-a review. *lnternational Journal of Audiology, 422, S17-S21.*

Baer, T., Moore, B. C. J., & Kluk, K. (2002). Effects of low pass filtering on the intelligibility of speech in noise for people with and without dead regions at high frequencies. *The Journal of the Acoustical Society of America, 112,*1133-1143.

Boothroyd, A., Mulhearn, B., Gong, J., & Ostroff, J. (1996). Effects of spectral smearing on phoneme and word recognition. *Journal of Acoustical Society of America, 100(3),* 1807-1818.

Bratt, G. W., & Sammeth, C. A. (1991). Clinical implications of prescriptive formulas for hearing aid selection In G. Studebaker, F. Bess, & L. Beck (Eds.), The Vanderbilt hearing aid report II (pp. 23–33). Parkton, MD: YorkPress.

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

Ching, T. Y. C., Dillon, H., & Byrne, D. (1998). Speech recognition of hearing-impaired listeners: Predictions from audibility and the limited role of high-frequency amplification. *Journal of Acoustical Society of America.103(2).* 1128-1140.

Chung, K. (2004). Challenges and Recent Developments in Hearing Aids Part II. FeedBack and Occlusion Effect Reduction Strategies, Laser Shell Manufacturing Processes, and Other Signal Processing Technologies. *Trends in Amplification, 8(4),* 125-164.

Cook, J. A., Bacon, S. P., & Sammeth, C. A. (1997). Effect of low-frequency gain reduction on speech recognition and its relation to upward spread of masking. *Journal of Speech, Language, and Hearing Research, 40,* 410-422.

Cox, R., & Alexander, G. (1983). Acoustic versus electronic modifications of hearing aid low-frequency output. *Ear and Hearing, 4(4),* 190-196.

Dancer, A., Buck, K., Parmentier, G., & Hamery, P. (1998). The specific problems of noise in military life. *Scandinavian Audiology, 27,* 123-130.

Dempsey, J. J. (1990). The occlusion effect created by custom canal hearing aids. *American Journal of Otology, 11(1),* 44-46.

Dillon, H. (2001). Hearing Aids: Hearing Aid Ear molds, Ear shells, and Coupling Systems. Sydney, Australia: Boomerang Press.

Dillon, H. (2012). Hearing Aids: Advanced signal processing schemes. Sydney, Australia: Boomerang Press.

Dillon, H., Keidser, G., O'Brien, A., Silberstein, H. (2003). Sound quality comparisons of advanced hearing aids. *Hearing Journal 56(4*), 1-6.

Fabry, D. (2006). Real-ear Measures for Open-fit Devices, *Audiology online. Ed. Paul D. Dybala*.

Fabry, D. A., Launer, S., & Derleth, P. (2007). Hearing aid technology vs. steeply sloping sensorineural hearing loss: win, lose, or tie? *The Hearing Review*.

Gagné, J. P. (1988). Excess masking among listeners with a sensorineural hearing loss. *Journal of the Acoustical Society of America, 83,* 2311-2321.

Garstecki, D. C., & Erler, S. F. (1999). Older adult performance on the Communication Profile for the Hearing Impaired: Gender difference. *Journal of Speech-Language-Hearing Research, 42,* 785-796.

Gnewikow, D., Moss, M. (2006). Hearing aid outcomes with open- and closed- canal fittings. *The Hearing Journal*, *59*(11): 66-72.

Henderson, D., & Salvi, R. J. (1998). Effects of noise exposure on the auditory functions. *Scandinavian Audiology, 27,* 63-73.

Hogan, C. A., & Turner, C. W. (1998). High-frequency audibility: Benefits for hearing-impaired listeners. Journal of the Acoustical Society of America, 104, 432-441.

Hogan, C. A., & Turner, C. W. (1998). High-frequency audibility: Benefits for hearing impaired listeners. *The Journal of the Acoustical Society of America, 104*, 432-441.

Hornsby, B. W., & Ricketts, T. A. (2006). The effects of hearing loss on the contribution of high- and low-frequency speech information to speech understanding. II: Sloping hearing loss. *The Journal of the Acoustical Society of America, 119*, 1752–1763.

Hornsby, B. Y., & Ricketts, T. A. (2003). The effects of hearing loss on the contribution of high- and low-frequency speech information to speech understanding. *Journal of the Acoustical Society of America, 113,* 1706-1717.

Horwitz, A. R., Ahlstrom, J. B., & Dubno, J. R. (2008). Factors affecting the benefits of high-frequency amplification. *Journal Speech Language and Hearing Research. 51*, 798-813.

Horwitz, A. R., Dubno, J. R., & Ahlstrom, J. B. (2002). Recognition of low-pass-filtered consonants in noise with normal and impaired high-frequency hearing. *The Journal of the Acoustical Society of America, 111*, 409-416.

Jespersen, C., Groth, J., Kiessling, J., Brenner, B., Jensen, O. (2006). The Occlusion Effect in Unilateral versus Bilateral Hearing Aids. *Journal of American Academy of Audiology, 17*, 763-773.

Kiessling, J., Brenner, B., Jespersen, C. T, Jennifer, G., Ole, D., J. (2005). Occlusion effect of ear molds with different venting systems. *Journal of American Academy of Audiology,16* (4), 237-249.

Kiessling, J., Margolf-Hackl, S., Geller, S. & Olsen, S. O. (2003). Researchers report on a field test of a non-occuding hearing instrument. *Hearing Journal, 56*(9), 36-41.

Kuk, F. (1991). Perceptual consequences of venting in hearing aids. *British Journal of Audiology, 25,* 163-169.

Kuk, F., Keenan, D., & Chi-chuen, L. (2009). Comparison of vent effects between a solid ear mold and a hollow ear mold. *Journal of American Academy of Audiology, 20,* 480–491.

Kuk, F., Keenan, D., Sonne, M., & Ludvigsen, C. (2005). Efficacy of an open-fitting hearing aid. *The Hearing Review, 12(3),* 26-32.

Kumar, R. A. & Rajalakshmi., K. (2007). *Speech identification with single channel multichannel and channel free hearing aid,* . (Unpublished master degree dissertation), University of Mysore.

Kumar, S. & Manjula, P. (2010). *Evaluation of Performance with Occluded and Open Fit Receiver in Canal (RIC) Hearing Aids.*(Unpublished master degree dissertation), University of Mysore.

Lee, L. W., Humes, L. E., & Wilde, G. (1993). Evaluating performance with high-frequency emphasis amplification. *Journal of the American Academy of Audiology, 4,* 91-97.

Leek, M., Dorman, M., & Summerfield, Q. (1987). Minimum spectral contrast for vowel identification by normal-hearing and hearing-impaired listeners. *Journal of Acoustic Society of America. 81,* 148-154.

Mackenzie, D. J. (2006). Open canal fitting and hearing aid occlusion effect. *The Hearing Journal*, *59*(11), 50-56.

Magnusson, L., Claesson, A., Persson, M., & Tengstrand, T. (2013).Speech recognition in noise using bilateral open-fit hearing aids: The limited benefit of directional microphones and noise reduction. *International Journal of Audiology*, *52 (1)*, 29-36.

Mascarenhas, K., & Yathiraj, A. (2002). *High frequency word Kannada speech identification test*. (Unpublished master degree independent project), University of Mysore.

Metselaar, R. M. (2010). Aspects of hearing aid fitting procedures, published thesis submitted to Erasmus University Rotterdam: the Netherlands.

Moore, B. C. J. (2008). The choice of compression speed in hearing aids: theoretical and practical considerations and the role of individual differences. *Trends in Amplification, 12*, 103-112.

Mueller, H. G. (2006). Open is in. *The Hearing Journal*, *59(11)*, 11-14.

Mueller, H. G., Bryant, M. P., Brown, W. D., & Budinger, A. C. (1991). Hearing aid selection for high frequency hearing loss. *The Vanderbilt hearing aid report II.* 269-286. Parkton, MD: York Press.

National Sample Survey Organization. (2002). Disabled Persons in India: NSS 58th Round. Report No. 485. New Delhi: Ministry of Statistics and Program Implementation, Government of India.

Noble, W., Sinclair, S., & Byrne, D. (1998). Improvement in aided sound localization with open earmolds: observations in people with high-frequency hearing loss. *Journal of American Academy of Audiology, 9(1),* 25-34.

Otto, C. W. (2005). Evaluation of an open-canal hearing aid by experienced users. *The Hearing Journal, 58(8),* 26-32.

Parsa, V. (2006). Acoustic feedback and its reduction through digital signal processing. *Hearing Journal, 59*, (11), 16-23.

Pittman, A. L., &Stelmachowicz, P. G. (2003). Hearing loss in children and adults:Audiometric configuration, asymmetry, and progression. *Ear Hearing, 24*(3), 198-205.

Plyer, P. N., & Fleck, E. L. (2006). The effects of high-frequency amplification on the objective and subjective performance of hearing instrument users with varying degrees of high-frequency hearing loss. *Journal of Speech, Language, and Hearing Research, 49*, 616-627.

Plyler, P. N., Reber, M. B., Kovach, A., Galloway, E., &Humphrey, E., (2013). Comparison of Multichannel Wide Dynamic Range Compression and Channel Free Processing in Open Canal Hearing Instruments. *Journal of American Academic Audiolology, 24,*126-137.

Rankovic, C. M. (1998). Factors governing speech reception benefits of adaptive linear filtering for listeners with sensorineural hearing loss. *The Journal of the Acoustical Society of America, 103,* 1043-1057.

Roup, C. M., & Noe, C. M. (2009). Hearing aid outcomes for listeners with high-frequency hearing loss. *American Journal of Audiology. 18,* 45-52.

Sahgal. (2005). *A comparative study of the proprietary and generic prescriptive procedures for non-linear hearing aids*. (Unpublished master degree dissertation), University of Mysore.

Schaub A. (2008). Digital Hearing Aids. New York: Thieme Medical Publishers.

Scheller, T. (2004). Vents and digital hearing aids. Presentation to *European Union of Hrgeräte Akustiker*. Frankfurt, Germany.

Scheller, T., & Scheller, L. (2006). Open fitting of DSP instruments is not as simple as it may seem. *The Hearing Journal. 59*(1), 34-41.

Schwartz, D. M., Surr, R. K., Montgomery, A. A., Prosek, R. A., & Walden, B. E. (1979). Performance of high frequency impaired listeners with conventional and extended high frequency amplification. *Audiology, 18,* 157-174.

Sairam, V. V. (2002). *Long term average spectrum in Kannada*. (Unpublished master degree independent project) University of Mysore.

Skinner, M. W., & Miller, J. D. (1983). Amplification Bandwidth and Intelligibility of Speech in Quiet and Noise for Listeners with Sensorineural Hearing Loss. *International Journal of Audiology*, *22* (3), 253-279.Bratt, G. W., & Sammeth, C. A. (1991). Clinical implications of prescriptive formulas for hearing aid selection. In G. Studebaker, hearing loss. *Journal of Speech, Language, and Hearing Research, 49,* 616-627.

Sullivan, J. A., Allsman, C. S., Nielsen, L. B., & Mobley, J. P. (1992). Amplification for listeners with steeply sloping, highfrequency hearing loss. *Ear and Hearing, 13(1),* 35-45.

Turner, C. W., & Henry, B. A. (2002). Benefits of amplification for speech recognition in background noise. *Journal of the Acoustical Society of America*, *112*(4), 1675-1680.

Van Schijndel, N., Houtgast, T., & Festen J, M., (2001). Effects of degradation of intensity, time or frequency content on speech intelligibility for normal-hearing and hearing-impaired listeners. *Journal of Acoustical Society of America 119*(1), 529-542.

Vickers, D. A., Moore, B. C. J., & 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. *The Journal of the Acoustical Society of America, 110*, 1164-1175.

Appendix – A (Word list for SNR-50)

Word list with a combination of low-mid, low-high and high-mid frequency speech sounds developed by Sahgal (2005)

	Low-Mid	***Low-High***	***High-Mid***
1	/gu:be/	/nalli/	/tʃa:ku/
2	/me:ke/	/sɛ:bu/	/ko:Li/
3	/bi:ga/	/mola/	/la:ri/
4	/mu:gu/	/bassu/	/d̪a:ra/
5	/rave/	/bal.e/	/kivi/
6	/kaNNu/	/d̪ana/	/tʃikka/
7	/ni:ru/	/tʃindi/	/i:ruLLi/
8	/mara/	/ni:vu/	/kuTTu/
9	/kone/	/mi:se/	/tʃakra/
10	/pu:ri/	/t̪inDi/	/dʒinke/
11	/bekku/	/haNa/	/radʒa/
12	/ganTe/	/suma/	/si:re/
13	/ru:pa/	/biLi/	/gaɳTe/
14	/nid̪re/	/tand̪e/	/kat̪t̪i:/
15	/kabbu/	/tʃenDu/	/giNi/
16	/magu/	/d̪o:Ni/	/vitʃa:ra/
17	/kappu/	/dʒi:pu/	/se:ru/
18	/bi:ru/	/To:pi/	/ko:ti/
19	/na:ri/	/bila/	/tʃikka/
20	/mu:ru/	/ba:vi/	/rutʃi/
21	/kemmu/	/ni:li/	/sukha/
22	/pad̪a/	/baTlu/	/i:ruLLi/
23	/ravi/	/d̪i:pa/	/kelasa/
24	/reppe/	/Dabbi/	/katte/
25	/buguri/	/hind̪e/	/kuLLi/
26	/kombe/	/ivanu/	/roTTi/
27	/ra:Ni/	/bi:dza/	/ko:su/
28	/ma:rga/	/baTTe/	/iruve/
29	/pennu/	/moLe/	/sari/
30	/gamana/	/t̪amma/	/guDi/
31	/rama/	/meTlu/	/gedʒdʒe/
32	/be:ru/	/beTTa/	/railu/
33	/maɳga/	/me:dʒu/	/rasa/
34	/guNa/	/ba:Le/	/ka:su/
35	/pa:naka/	/no:vu/	/ke:Lu/
36	/kappe/	/bassu/	/kelavu/
37	/nu:ru/	/ma:tre/	/tʃakli/
38	/gombe/	/noDu/	/kaDDi/
39	/ramja/	/haNNu/	/ka:fi/
40	/nuɳgu/	/beTTa/	/go:De/

Appendix – B

Questionnaire (developed by Otto, 2005) used for quality measurement.

Please rate your present hearing instruments

Place an X on each of these scales that best describes your experience:

Sound of your own voice:

0 2 4 6 8 10

Hollow/Echo Quality "Head in a Barrel" — Natural

Pressure feeling:

0 2 4 6 8 10

Plugged/Pressure — Open/Unoccluded

Feedback/Whistling:

0 2 4 6 8 10

Frequent (6 or more times per day) — Never

Comfortable Listening Level:

0 2 4 6 8 10

Not loud enough* — No problem with loudness

Sound of your own chewing:

0 2 4 6 8 10

Too Loud — Natural

Feedback when using the telephone:

0 2 4 6 8 10

Whistles When Hold Up Receiver — No problem

Clarity on the telephone:

0 2 4 6 8 10

Muffled — Clear

Appearance/Cosmetics:

0 2 4 6 8 10

Unacceptable — Acceptable

*(I cannot turn up the volume to a desired level without feedback/whistling.)

Appendix – C

The standardized paragraph developed by Sairam (2002) in Kannada used for quality rating.

ಸುಳ್ಳಿನ ಫಲ

ಒಂದು ಹಳ್ಳಿಯಲ್ಲಿ ಒಬ್ಬ ಕುರುಬ ಹುಡುಗ ವಾಸವಾಗಿದ್ದನು. ಅವನು ಮುಂಜಾನೆಯೇ ಕಾಡಿಗೆ ಹೋಗಿ ಅಲ್ಲಿಯೇ ಝರಿಯಲ್ಲಿ ಸ್ನಾನಮಾಡಿ ಸಂಜೆಯವರೆಗೆ ಕುರಿಯನ್ನು ಮೇಯಿಸಿ, ಸಂಜೆ ಹಳ್ಳಿಗೆ ವಾಪಸಾಗುತ್ತಿದ್ದ. ಒಮ್ಮೆ ಅವನು ಕುರಿ ಮೇಯಿಸುವಾಗ ಇದ್ದಕ್ಕಿದ್ದಂತೆಯೇ ಹತ್ತಿರದ ಹೊಲದಲ್ಲಿ ಕೆಲಸ ಮಾಡುತ್ತಿದ್ದ ರೈತರನ್ನು ತಮಾಷೆ ಮಾಡಬೇಕು ಎಂದುಕೊಂಡ. ಅಂತೆಯೇ ಅವನು ಎಅಯ್ಯೋ ! ಹುಲಿ ! ಹುಲಿ! ಕಾಪಾಡಿ ಎಂದು ಕೂಗತೊಡಗಿದ. ಇದನ್ನು ಕೇಳಿದ ರೈತರು ಖಡ್ಗಗಳನ್ನು ತೆಗೆದುಕೊಂಡು ಹುಲಿಯನ್ನು ಕೊಲ್ಲಲು ಸಿದ್ದರಾಗಿ ಓಡಿಬಂದರು. ಇದನ್ನು ನೋಡಿದ ಹುಡುಗ ನಕ್ಕುಬಿಟ್ಟ. ರೈತರು ಕೋಪಗೊಂಡು ವಾಪಸಾದರು. ಹುಡುಗ ಇದೇ ರೀತಿ ಐದಾರು ಬಾರಿ ಮಾಡಿದ. ರೈತರು ಆ ಹುಡುಗನ ಮೇಲಿನ ನಂಬಿಕೆ ಕಳೆದುಕೊಂದರು.

ಒಮ್ಮೆ ಸುಮಾರು ಹನ್ನೆರಡು ಘಂಟೆ, ಬಿಸಿಲು ತಾಳಲಾರದೆ ಹುಡುಗ ಛತ್ರಿಯನ್ನು ಹಿಡಿದು ಕುಳಿತ್ತಿದ್ದ. ಇದ್ದಕ್ಕಿದ್ದಂತೆ ನಿಜವಾಗಿಯು ಠಕ್ಕಹುಲಿ ಬಂದೇ ಬಿಟ್ಟಿತು. ಹುಡುಗ ಮತ್ತೆ ಕಾಪಾಡಿ ! ಕಾಪಾಡಿ ! ಎಂದು ಚೀರಿದ. ಆದರೆ ಯಾರೂ ಸಹ ಅವನ ಸಹಾಯಕ್ಕೆ ಬರಲ್ಲಿಲ್ಲ. ಹುಲಿಯು ಅವನ ಸಣ್ಣ ಸಣ್ಣ ಕುರಿಗಳನ್ನು ಕೊಲ್ಲಲಾರಂಭಿಸಿತು. ಅದನ್ನು ಕಾಪಾಡಲು ಹೋದ ಆ ಹುಡುಗನ ಮೇಲೆ ಆ ಹುಲಿ ಹಾರಿ, ಅವನನ್ನು ಕೊಂದಿತು. ಈ ಕಥೆಯ ನೀತಿ ಏನೆಂದರೆ, "ಸುಳ್ಳುಗಾರನಿಗೆ ಶಿಕ್ಷೆ ತಪ್ಪದು".