# CONVENTIONAL BTE vs. RECEIVER IN THE CANAL BTE: AN EVALUATION OF PERFORMANCE WITH DIFFERENT EAR-COUPLING DEVICES IN SLOPING SENSORINEURAL HEARING LOSS

Nandu P U

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Master of Science (Audiology)

University of Mysore, Mysore.

**ALL INDIA INSTITUTE OF SPEECH AND HEARING**

**MANASAGANGOTHRI, MYSORE – 570 006**

**MAY, 2013.**

Dedicated To

My Family & My Guide

## CERTIFICATE

This is to certify that this dissertation entitled "**Conventional BTE vs. Receiver in the Canal BTE: An Evaluation of Performance with Different Ear-coupling Devices in Sloping Sensorineural Hearing Loss**" is a bonafide work submitted in part fulfilment for the Degree of Master of Science (Audiology) of the student (Registration No.: 11 AUD015). 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.

Mysore

May, 2013

**Dr. S. R. Savithri**
***Director***
All India Institute of Speech and Hearing
Manasagangothri, Mysore -570 006.

## CERTIFICATE

This is to certify that this dissertation entitled "**Conventional BTE vs. Receiver in the Canal BTE: An Evaluation of Performance with Different Ear-coupling Devices in Sloping Sensorineural Hearing Loss**" 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.

Mysore

May, 2013

**Mr. Sreeraj. K.**
***Guide***
Lecturer in Audiology
All India Institute of Speech and Hearing
Manasagangothri, Mysore - 570 006.

# DECLARATION

This is to certify that this dissertation entitled "**Conventional BTE vs. Receiver in the Canal BTE: An Evaluation of Performance with Different Ear-coupling Devices in Sloping Sensorineural Hearing Loss**" 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.

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# Chapter 1

## Introduction

‘Hearing impairment’ refers to the reduced function or loss of the normal function of the hearing mechanism which limits the person’s sensitivity to perform different tasks like listening or understanding speech (Capulong, 2007). The degree of disability due to hearing impairment depends on the degree, type and configuration of hearing loss to a larger extent. Sloping configuration is associated with hearing loss in majority of the cases especially in the elderly (Cruickshanks, 1998). Stephens and Rintlemann (1978) reported of two kinds of sloping patterns. The gradually sloping pattern is defined as having near normal thresholds (≤ 25 dBHL) till 500 Hz with a 5-12 dB per octave slope thereafter and the difference between highest and the lowest threshold being not more than 35 dB. The sharply sloping hearing loss is defined as having near normal thresholds (≤ 30 dBHL) till 500 Hz and beyond 500 Hz the hearing sensitivity reduces steeply with at least 20 dB slop per octave (between 0.5 - 1 kHz or 1 - 2 kHz) and the difference between highest and the lowest being more than 40 dB. The benefits from fitting an amplification device for sensorineural hearing loss may vary depending on the configuration of the loss. In most sensorineural hearing loss cases, hearing aid is the option to achieve their listening needs in the day to day life.

A hearing aid is an amplification device which are designed and fitted to lessen the problems faced by people with hearing impairment (Dillon, 2001). Hearing aids can be classified as analog and digital with respect to the type of signal processing. According to Dillon (2001) a digital hearing aid is an electrical instrument which converts acoustic energy (sound waves) into electrical energy (in binary digit forms) using some complex mathematical calculations. This helps in precise control over the signal while processing and hence the original signal will be accurately represented. The increased demands on cosmetic appearance have led the hearing aid manufacturers to move on to the sophisticated technology in order to reduce the size of the hearing aids. Hence, different types of hearing aids are available in the market ranging from high fidelity behind the ear (BTE) to invisible in the canal hearing aids.

According to the placement of receiver, the hearing aids are classified mainly in to two (Mueller et al., 2009).

1. Conventional BTE hearing aids
2. BTE hearing aids with Receiver in the canal (RIC)

BTE hearing aids can provide fitting for widest range of hearing losses (from mild to profound) and are housed in curved cases that fit nearly behind or over the ear. Sandlin (2000) pointed out that the major challenges faced by the end users of conventional BTE are occlusion effect and occurrence of feedback. In conventional BTE hearing aids the issues related to occlusion effect is generally managed with the help of venting modification of the ear-mold. The dramatic impact of venting on hearing aid performance in minimizing occlusion, reducing moisture, modifying the frequency response, and improving aided localization were reported by Scheller and Scheller (2006). However, he also reported feedback, reduced low-frequency audibility and loss of control as the main disadvantages of venting. Further, most of the conventional hearing aids are not cosmetically appealing due their size. These problems may pull back the hearing impaired individuals from wearing conventional hearing aids.

These problems are well taken care in Receiver in the Canal (RIC) hearing aids. Both occlusion effect and feedback occurrence are well minimized in RIC hearing aids when compared to conventional hearing aids. In instruments with external receivers (RIC), the core components of the hearing aid are left in a standard BTE housing; and the receiver is mounted on a soft dome or a custom shell inserted in the ear canal. Using an external receiver would save space in the main housing of the instrument, so that the BTE part can be dramatically reduced in size (Hoen & Fabry, 2007). The part of an instrument with an external receiver can be reduced to a two gram micro-housing and it will easily disappear behind the pinna in most wearers. Open fitting in RIC hearing aids drastically minimizes the occlusion effect. Very thin wires in the slim tube serve connection between the BTE and those parts inside the ear. Hence, BTE with Receiver in the canal (RIC) hearing aids solve issues related to occlusion effect as well as occurrence of feedback.

Since the BTE with Receiver in the canal (RIC) hearing aids utilizes different types of domes and thin tube for fitting, occlusion management is achieved better (Teie, 2009).

Different types of domes for RIC hearing aids (Teie, 2009) are

1. Open dome
2. Closed dome
3. Tulip dome
4. Double dome (Power dome)

While fitting a patient, the selection of appropriate dome is still questionable and the selection of the most suitable dome depends on the output characteristics of each of these ear-coupling systems. However, there, is dearth in literature defining a strict criterion for when to use each of these coupling devices for patients with sloping sensorineural hearing loss and its effects on performance of the hearing aid. A detailed study exploring the effect of different ear-coupling devices on sloping sensorineural hearing loss will clinically be useful for the appropriate selection of ear-coupling devices.

**Need for the study**

i. The idea of fitting hearing aids with vented custom ear-mold for individuals with sloping hearing loss exists in the field since many years. With the invention of RIC hearing aids, which is usually fitted with different domes as per the suggestion of respective company software's, the need for a custom made vented ear-mold is reduced to an extent. However, there have been not many investigations on its benefit in sloping hearing loss when compared to that of conventional behind the ear with occluded ear-mold. Teie (2009) reported that the open domes with slim tube in receiver in the aid (RITA) showed sufficient gain reduction in the lower frequencies in the individuals with moderate sensorineural flat hearing loss. Likewise, if these open domes used in receiver in the canal (RIC) hearing aids can improve the performance of individuals with sloping hearing loss then the demand on the patient to get custom vented mold will sufficiently reduce. Hence, there arises a need for the study of effectiveness of open fitting using RIC with open domes.

ii. The common practice when fitting a hearing aid for a sloping configuration is to fit with a custom ear-mold or conventional occluded ear tip to meet the requirements of higher gain for higher frequency components. But, in RIC hearing aids these needs are met with the help of closed and power domes. However, the extent to which these domes can benefit an individual with high frequency hearing loss is still questionable. Hence, there exists a need to investigate on the effectiveness of closed and open domes in individuals with sloping hearing loss in terms of performance of speech in noise, measurement of output characteristics and quality judgement.

iii. Since RIC hearing aid uses slim tubes and different types of domes, which is different from the conventional BTE which uses no.13 standard tubes and custom ear-mold or common ear tips, there exist a need to investigate effect of these domes on performance of performance of speech in noise, measurement of output characteristics and quality judgement.

## Aim of the study

The aim of the study is to evaluate the performance conventional BTE and receiver in the ear (RIC) hearing aids with different ear-coupling devices in individuals with sloping sensorineural hearing loss.

## Objectives of the study

The objectives of the study are:

1. To measure and compare the following parameters with BTE hearing aid with RIC using different domes (open, closed and tulip) and conventional BTE with no. 13 tubing and regular ear tip:
   - i. Speech Recognition Threshold in Noise (SNR-50)
   - ii. Real Ear Measurement values
2. To assess performance by qualitative measurements with BTE hearing aid with RIC using different domes and conventional BTE with no. 13 size tubing.

# Chapter 2

## Review of literature

Since the present study aiming at evaluating the performance of different ear-coupling systems in conventional BTE and receiver in the canal (RIC) hearing aids in individuals with sloping sensorineural hearing loss, review of literature is discussed under the following headings:

2. 1 Receiver in the canal (RIC) hearing aids

2. 2 Open fit RIC, a better amplification option for high frequency sloping sensorineural hearing loss

2. 3 Effect of different ear-coupling devices in receiver in the canal (RIC) fitting

### 2.1 Receiver in the canal (RIC) hearing aids.

Receiver in the canal (RIC) hearing aids has its core components left in a standard BTE housing; and the receiver is mounted on a soft dome or a custom shell inserted in the ear canal. These hearing aids were generally recommended for mild low frequency hearing losses, and not greater than moderately severe in the high frequencies (Teie, 2009). These instruments use soft ear inserts, typically of silicone, to position the loudspeaker in the ear.

Relocating the receiver outside the BTE housing eliminates several feedback transmission lines, including structural and acoustic transmission within the device, as well as acoustic leakage at the couplings between ear hook and tubing and the tubing and ear-mold.

Ross and Cirmo (1980) quantified the difference in frequency response and maximum achievable gain for three BTE devices from different manufacturers measured serially in one ear. In their experiment, an initial measurement of gain before feedback was obtained by increasing the gain potentiometer of the hearing aid while speech stimuli were presented via live voice at a conversational level (65 dB SPL) for each of the hearing aids coupled to the ear in the conventional manner with tubing and ear-molds. A 2-cc coupler measurement of frequency response with a 50dB input was obtained at the level where feedback occurred. Then, the receivers were removed from the devices and placed in full-concha instamolds (a temporary silicone ear plug which molds to the concha), and the measurements were repeated and compared. They reported 2-cc coupler peak outputs of approximately 10 dB SPL with the receiver in the devices. When the receivers were placed in the ear canal, increase of 7 to 13 dB was observed in the maximum achievable output before feedback.

Hallenbeck and Groth (2008) compared the attainable gain before feedback between two open-fit devices that are virtually the same in every way except placement of the receiver speaker in 12 subjects with mild to moderately severe sloping hearing loss. They observed significant differences only at two frequencies, with the receiver in the canal hearing aid response exceeding that of the open fit hearing aid approximately 5 dB at 2000 Hz and 6 dB at 6000 Hz which are most likely attributable to tube resonances and receiver performance differences.

An advantage of placing the receiver in the canal, whether in a custom instrument is a smoother frequency response. This is because of resonances of the tubing used to couple BTE instruments to the ear canal, and is typically demonstrated by contrasting the response of a receiver driven directly into a coupler versus one attached to the coupler with BTE tubing (Hallenbeck & Groth, 2008).

Alworth, Plyler, Reber and Johnstone (2010) compared speech in noise perception, real ear measurements and subjective quality rating of speech with RIC hearing aid and RITA hearing aid. They found that subjects reported greater satisfaction with RIC than with RITA for overall quality of sound, own voice and speech clarity which showed that subjects preferred RIC over RITA. Speech perception in quiet and noise scores showed that although subjects preferred RIC in quiet and noise condition, there was no statistical significance in the scores. Real ear measurements showed that RIC hearing aid was able to provide maximum gain before feedback at 4000 Hz and 6000 Hz (4 dB and 6.5 dB respectively) compared to RITA hearing aid which they attributed to higher Full-On-Gain (FOG) at high frequencies in RIC hearing aid and also due to decreased sound transfer at high frequencies in RITA hearing aid due to tubing effect.

Performance of receiver in the canal hearing aid with open and occluded fitting in terms speech in noise, noise reduction and directional benefit through real ear insertion gain (REIG) was compared by Chhabra, Jahfar & Manjula (2010) on 17 subjects with mild to moderate sloping sensorineural hearing loss. Their results showed better performance when RIC was fitted in open condition than closed fit condition for speech in noise, on REIG, Real ear RMS output were better at 145° azimuth when compared to 135° azimuth for open fit which shows no directional benefit at low frequencies in contrast directional advantage was seen for high frequency at 45° azimuth (front incidence). As the study revealed better speech recognition with RIC in open fitted condition, they concluded that open fit RICs are more beneficial for people with mild to moderate sloping sensorineural hearing loss.

### 2.2 Open fit RIC, abetter amplification option for high frequency sloping sensorineural hearing loss.

Kumar and Manjula (2010) evaluated the performance of both open and closed fit RIC hearing aid in terms of speech recognition in quiet and in noise and subjective rating of quality of speech in flat (10 subjects) and sloping sensorineural hearing loss (10 subjects). Results revealed that both subjects with flat & sloping sensorineural hearing loss showed no significant difference in performance in speech recognition in open and closed fit condition in quiet condition whereas significant difference was noted and recognition scored were better in open fit RIC in noise condition for both the group.Subjects with sloping sensorineural hearing loss also rated better quality of speech in open fit condition. Further, individuals with flat sensorineural hearing loss rated open fit RIC better for quality such as “naturalness”, “fullness”; suggesting open fit RIC as a better option for both flat & sloping sensorineural hearing loss. Better patient satisfaction  was also is reported with RIC open fit hearing aids as shown by Taylor, 2006 and Smith, Mack & Davis, 2008.

### 2.3 Effect of different ear-coupling devices in receiver in the canal (RIC) fitting.

Kuk and Baekgaard (2008) stated that BTE couplings can be broadly grouped by two distinct dimensions: one involving the "diameter of the tubing" and one involving the "openness" of the fittings. Using these two dimensions (and adding thin-wire fittings) BTE coupling can be classified as into six as follows:

***Standard (traditional) occluded fittings:*** Typically refers to the use of a BTE hearing aid (of any size) coupled to an ear-mold that uses a #13 tubing (inner diameter of 1.9 mm). Although the ear canal is typically occluded, the use of vents of various dimensions allows degrees of sound leakage into and out of the ear canal.

***Standard (traditional) open fittings:*** Traditionally, an "open fitting" refers to the use of a BTE coupled to#13 tubing or a Libby Horn (3 or 4 mm bore opening) where the ear canal is left un-occluded. These two categories existed for decades, until the more recent widespread implementation of thin-tubing and receiver-in-canal (RIC) models created four more general fitting categories for BTEs:

***Thin-tube occluded fittings:*** This refers to the use of a miniature BTE hearing aid that is coupled to an ear insert or ear-mold (vented or unvented) via a tubing of approximately 0.8 mm inner diameter.

***Thin-tube open-fittings:*** The current open-fittings (or open-ear fittings) refer to the use of a miniature BTE hearing aid that is coupled to an open ear-tip via a 0.8 mm (inner diameter) tube. This will leave the ear canal as open for its natural resonance properties. The distinction between thin-tube open-fittings and traditional open-fittings is the diameter of the tubing used (0.8 mm vs. 1.9 mm).

***Thin-wire occluded fittings:***This refers to the use of a BTE hearing aid where the receiver (loudspeaker) is placed outside of the hearing aid case and inside the wearer's ear canal. A thin-wire that is insulated in a thin-tube connects the receiver to the BTE case. The receiver is typically housed inside an occluding ear insert (vented or unvented). This is also commonly known as a RIC or RITE hearing aid.

***Thin-wire open fittings:*** To maintain the openness of the ear canal, the receiver of a thin-wire (RIC/RITE) hearing aid must be smaller than the diameter of the ear canal to leave it un-occluded for a majority of its wearers. The ear-insert, in which the receiver is encased, must remain small as well.

Since the BTE with Receiver in the canal (RIC) hearing aids utilizes different types of domes and thin tube for fitting, occlusion management is achieved better (Teie, 2009). Nevertheless, the diameter of the ear canal and receiver has to be taken into consideration for open fit RIC hearing aids. According to Kuk and Baekgaard (2008) for thin-wire open fittings, the receiver of a thin-wire (RIC) hearing aid must be smaller than the diameter of the ear canal to leave it un-occluded for a majority of its wearers to maintain the openness of the ear canal. The ear-insert, in which the receiver is encased, also should be remaining small as well. Otto (2005) reported that patients with near normal hearing at low frequencies but sensorineural hearing loss in the middle and higher frequencies rated BTE with Receiver in the canal (RIC) hearing aids as superior because of reduction in hollow quality of voice, reduced pressure feeling, fewer feedback problems and reduced loudness of their own chewing sounds.

Different types of domes for RIC hearing aids are (Teie, 2009)

i. Open dome
ii. Closed dome& Tulip dome
iii. Double dome (Power dome)

Data is emerging that some of the occluding non-custom ear-coupling devices (i.e., closed and double domes) do not provide as much low frequency gain as expected. A recent study by Blau, Sankowski, Stirnemann, Oberdanner and Schmitt

(2008) suggested that some of the more commonly used ear-coupling systems have less of an effect on low frequency amplification than expected.

Teie in 2009 studied the ear canal acoustics of some of the more common ear-coupling devices in a RIC hearing aid. In his study a fully featured RIC hearing aid from a major hearing aid manufacturer was programmed for a flat 45 dBHL hearing loss to an NAL-NL1 prescriptive target with no reduction for acclimatization. The hearing aid was programmed to a first fit, and no attempt was made to fine-tune the response. The response of the hearing aid was verified in 9 ears (6 male and 3 female). The ear-couplings by means of a real-ear analyzer using with a calibrated speech signal delivered at 65 dBSPL. The ear-coupling devices used were:

i. Open dome (8 or 10 mm)
ii. Closed dome (8 or 10 mm)
iii. Double dome (8 or 10 mm)
iv. Custom ear-mold with slim tube
v. Custom ear-mold with regular #13 slim tubing

Results revealed that the open-dome condition showed considerably less low frequency output than did the custom ear-mold conditions. The degree of increase in output in the low frequencies for the closed and double domes was less than might have been expected.

In the *open-dome condition*, virtually no gain is present below 2000 Hz.

In the *closed-dome* the ear canal is insufficiently occluded by the closed dome to allow for significant increase in low frequency gain.

In the *double-dome* condition, an increase in low frequency response is observed in most ears. High frequency responses are consistent with open- and closed-dome conditions.

In the *custom ear-mold with slim-tube condition* low frequencies are fully engaged with little change in the high frequencies.

Study suggested that when trying to extend the fitting range of RIC products into the low frequencies; closed domes, and to a lesser degree double domes are ineffective. Supported by similar findings to those obtained by Blau, Sankowski, Stirnemann, Oberdanner and Schmitt (2008) and reason for lower than expected low frequency output is the difference between the shapes of the typical dome and double dome coupler (circular), and the shape of most ear canals (elliptical). Therefore, when attempting to fit patients with significant low frequency hearing loss, custom ear-molds are required. This study also suggests that while fitting a patient with RIC hearing aid the acoustics of ear-coupling devices should be taken into considerations and appropriate coupling device should be chosen based on the configuration of hearing loss.

Jespersen and Moller (2013) examined the reliability of real ear measurement with different coupling systems in RIC (receiver in the canal) and RITA (receiver in aid). The coupling systems used in RIC were: open and double dome. They found out that there is a high inter- examiner reliability for real ear measurement with open and double dome in RIC in the order of 15 dB. Considerably less reliability was found at 5000 & 6000 Hz in RIC with open dome. They also mentioned that real ear aided gain (RIEG) obtained with different coupling systems (open & closed dome) was significantly different. They attributed this to the effect to the tube size. It was also found that RIC when fitted with open dome gave higher insertion gain (RIEG) for frequencies 2000 Hz, 3000 Hz, 4000 Hz, and 5000 Hz compared to RIC fitted with double dome; whereas, in all other frequencies (250 Hz, 500 Hz, 750 Hz and 1000 Hz) double dome gave more RIEG.

All these studies point to the fact that output characteristics are different for different ear-coupling devices; nonetheless, performance of hearing aid when fitted with different ear-coupling devices for sloping hearing loss subjects has seldom been mentioned. For individuals with sloping sensorineural hearing loss, effect of these different ear-coupling devices may result in drastic difference in speech in noise perception and subjective preference. Consequently present study aims at evaluating the performance of different ear-coupling devices in conventional BTE and receiver in the ear (RIC) hearing aids in individuals with sloping sensorineural hearing loss.

# Chapter 3

# Method

The study aimed at investigating the effectiveness of ear-coupling devices in RIC hearing aid in individuals with sloping sensorineural hearing loss in terms of performance of speech in noise, measurement of output characteristics and quality judgement. The objectives were to compare unaided and aided SNR 50, Real ear measurement and quality judgement within different ear-coupling devices in RIC hearing aids and conventional BTE hearing aid.

## Participants.

Adults in the age range of 18 - 55 years were included in the study. Data was collected from 20 ears. Informed consent was taken from all participants.

### *Participant selection criteria.*

1. Participants were native speakers of Kannada language.
2. Individuals with sloping sensorineural hearing loss with a pure tone average (500 Hz, 1 kHz & 2 kHz frequencies) of less than 60 dB; air conduction threshold shall increase by 5-12 dB per octave from 250 to 8000 Hz.
3. Participants did not have any active middle ear infections, speech and language disorder, neurologic disorder or any cognitive listening deficits.
4. Speech Identification Score (SIS) of a minimum of 75 %.

## Instrumentation.

1. A calibrated (ANSI S3.6. 1996) dual channel audiometer with TDH 39 headphones with MX 14 AR ear cushions and loud speakers were used for estimation of air conduction threshold, SIS and SNR 50 for all the participants.

Radio ear B71 bone vibrator was used for bone conduction threshold estimation.

2. Calibrated middle ear analyzer was used for immittance measurements.
3. NOAH version-3 based software was used to program the digital hearing aid and the hearing aid was connected to the computer using HiPro.
4. A Fonix 7000 hearing aid test system with probe tube microphone option was used to perform insertion gain measurements.
5. Hearing aid
   i. Digitally programmable six channel conventional BTE air conduction hearing aid with a fitting range of 40-120 dB useful for mild-to-severe sloping sensorineural hearing loss.
   ii. Digitally programmable six channel RIC air conduction hearing aid (of same manufacturer of BTE hearing aid) with a fitting range of 0-100 dB useful for mild-to-severe sloping sensorineural hearing loss.
   iii. Regular ear tip with standard tubing (#13 tube) was used as ear-coupler for regular BTE.
   iv. Different domes such as open dome, closed dome and tulip dome were fitted with RIC hearing aid for each condition.

**Test environment.**

The tests described above were carried out in an acoustically treated air-conditioned room (as per ANSI S3.1, 1999 specifications) with adequate illumination.

**Test material.**

1. The word list (combination of low-mid, low-high and high-mid frequency speech sounds) developed by Sahgal (2005) in Kannada was used to measure

SNR50. This list consist of 40 sets of bi-syllabic words, each set containing three words of low, mid, high frequency combination.

2. The standardized paragraph developed by Sairam (2002) in Kannada was used for quality rating.
3. 10 point rating scale (Otto, 2005) was used to judge quality. Parameters such as: feedback/whistling, comfortable listening level, sound of own voice, sound of own chewing,pressure feeling, and appearance/cosmetics were rated in different domes.

**Procedure.**

The study was carried in four phases:

1. Audiological evaluation
2. Hearing aid fitting
3. Evaluation of aided performance
4. Qualitative judgement

***Phase I: Audiological Evaluation.***

Preliminary procedure included otoscopy and a behavioural audiometric evaluation. Pure tone thresholds were obtained using modified Hughson and Westlake procedure (Carhart & Jerger, 1959), across the frequencies 250 Hz to 8000 Hz for air conduction and 250 Hz to 4000 Hz for bone conduction.  Immittance evaluation was done to ensure that all the subjects have normal middle ear functioning. Speech audiometry was administered in all participants to measure Speech Reception Threshold (SRT), Speech Identification Score (SIS), Most Comfortable Level (MCL) and Uncomfortable Level (UCL).

***Phase II: Hearing aid fitting.***

The participants were seated comfortably on a chair and fitted with a 6 channel RIC hearing aid. RIC hearing aid was coupled with the test ear by using a specific dome at a time. Hearing aids were programmed using the specific programming software in NOAH with Hi-Pro as the interface. Hearing aids were programmed to "autofit" option (first fit) keeping NAL-NL1 as the fitting formula and acclimatization level at 2. Real ear measurement was carried out to optimize hearing aid parameters.

***Phase III: Evaluation of aided performance.***

Speech recognition in noise (SNR 50), real ear measurement and qualitative judgments by using a rating scale (Otto, 2005) were carried out for aided conditions; with conventional BTE hearing aid and RIC with different domes separately.

A. *Speech recognition score in noise (SNR 50):* SNR-50 was measured in a sound field condition using the recorded Kannada word list developed by Sahgal (2005). The speech material was routed through the auxiliary input of the audiometer to the loud speaker positioned at 0° azimuth from the patient. The loudspeakers were positioned at a distance of one meter from the patient. The presentation level of the stimulus was kept constant at 40 dBHL. Simultaneously, speech noise was routed through another loudspeaker positioned at 180° azimuth, at a distance of one meter from the patient. The initial presentation level of speech noise kept 10 dB below the speech signal. The participants were instructed to repeat the words heard in the presence of background noise. A set of 3 words were presented at each level of noise. If the participant repeated at least 2 out of 3 words correctly; the level of the noise was increased by 4 dB. Whereas, if the participant failed to repeat at least 2 words, the noise level was decreased by 2 dB. This was repeated until the participants were able to repeat at least 2 out of 3 words correctly. The difference between the speech signal and noise in dB, at which the participant repeated at least 50% of words correctly, was considered as SNR-50. The same was measured separately for different ear-coupling devices.

B. *Real ear measurement*: Real ear measurement was carried out using a calibrated Fonix 7000 hearing aid analyzer. Participants were seated at one foot distance and 45̊ azimuth from the loud speaker of the hearing aid analyzer. Before the actual testing, levelling of the system was done. Air conduction threshold of the participants were plotted and insertion gain option was selected for insertion gain measurement. NAL-NL1 was selected as the target formula. The length of the tube inserted was held constant for real ear unaided and aided gain.

   a. *Measurement of real ear unaided gain (REUG):* The marked probe tube was attached to the microphone was inserted to the ear canal of the participant's test ear without the ear tip or hearing aid. Stimulus used was digi speech at 65 dBSPL. The REUG curve obtained with frequency on X axis and gain in dB on Y axis.

   b. *Measurement of real ear aided gain (REAG):* The hearing aid was fitted into the test ear of the patient with the probe tube and the microphone in place. Then, the REAG curve option was selected from the curve select navigation key and the test was initiated. The test was terminated when the frequency responses were stabilized. The dB gain at different frequencies displayed as real ear aided gain. The values of REAG were noted down from the data table at 200 Hz, 500 Hz, 800 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 for each test ear of each participant with different ear-coupling devices.

c. *Measurement of real ear insertion gain (REIG)*: The hearing aid analyzer automatically calculates REIG by subtracting REUG from REAG values. Separate REIG cures were obtained for each ear-coupling device. The values were noted down from the data table for the frequencies 200 Hz, 500 Hz, 800 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.

***Phase IV: Qualitative measurement.***

The quality judgments in terms of feedback/whistling, comfortable listening level, sound of own voice, sound of own chewing, pressure feeling, and appearance/cosmetics were made for each subject with each of the ear-coupling devices fitted with RIC hearing aid. Subjects were asked to rate each of the parameter on a 10 point rating scale developed by Otto (2005). The standardized paragraph developed by Sairam (2002) in Kannada was used for this purpose. The recorded paragraph was played through loudspeaker at 40 dB and the subjects were asked to rate the parameters: pressure feeling feedback/whistling and comfortable listening levels. Next, the subjects were given a printed copy of the same paragraph and were asked to read it aloud and afterwards to rate the parameters: sound of own voice and sound of chewing.

# Chapter 4

## Results and Discussion

The aim of the present study was to evaluate the performance of conventional BTE and receiver in the canal (RIC) hearing aids with different ear-coupling systems in individuals with sloping sensorineural hearing loss. The specific objectives were to compare speech recognition threshold in noise (SNR-50) and to obtain real ear measurement values across different domes (open, closed and tulip) in RIC hearing aid and regular ear tip with # 13 tubing in conventional BTE. Further, rate of quality of different ear-coupling systems using a 10 point rating scale (Otto, 2005).

Data were collected from 20 ears of 16 participants having sloping sensorineural hearing loss under four ear-coupling (aided) conditions and unaided condition. Parameters measured and analysed in the different conditions are discussed under the following headings:

4.1 Speech recognition threshold in noise (SNR-50)

4.2 Real Ear Insertion Gain (REIG)

4.3 Quality judgement

4.3.1 Quality of recorded speech

4.3.2 Quality of own voice

4.3.3 Quality of miscellaneous factors

**Statistical analysis.**

To examine whether there was any significant difference for measures obtained (SNR50, REIG & Quality judgement); statistical analysis of the data was done for four ear-coupling conditions. Statistical Package for the Social Sciences, SPSS (Version 16.0) was used for this purpose. The statistical measures used are:

i. Descriptive statistics to acquire mean and standard deviation (SD) of all the measures with the four ear-coupling devices.

ii. Non parametric tests: Friedman Test and Wilcoxon Signed Ranks Test were used to verify the significance of the test result. Non-parametric statistics were used because of higher standard deviation in SNR-50 assessment and real ear measurements. Non-parametric tests were needed for quality judgement since rating scale was used for ranking the coupling devices.

**4.1 Speech recognition threshold in noise (SNR-50).**

The mean and standard deviation for SNR-50 measurement were obtained through descriptive statistics and the values are shown in Table 4.1.

Table 4.1 Mean and Standard deviation for SNR-50 measurement

| ***Conditions*** | ***Mean (dB)*** | ***SD*** |
|---|---|---|
| Unaided | -1.800 | 2.238 |
| Ear Tip | -4.500 | 2.328 |
| Open Dome | -6.300 | 2.849 |
| Closed Dome | -5.200 | 2.191 |
| Tulip Dome | -5.400 | 2.521 |

*Note: SD= Standard deviation*

Friedman Test was carried out to find whether there is any significant effect using different ear-coupling systems on SNR-50 values. The results revealed highly significant effect on SNR-50 across different ear-coupling devices, $\chi^2$ (4, 20) = 55.00, p = 0.000. Further, Wilcoxon Signed Ranks Test was done to obtain pair wise comparison and the results are given in Table 4.2.

Table 4.2. Wilcoxon Signed Ranks Test results for SNR-50 measurements

| ***SNR-50 Conditions*** | ***Z value*** | ***p value*** |
|---|---|---|
| Unaided - Ear Tip | 3.954 | 0.000 |
| Unaided - Open Dome | 3.880 | 0.000 |
| Unaided - Closed Dome | 3.981 | 0.000 |
| Unaided - Tulip Dome | 3.888 | 0.000 |
| Ear Tip - Open Dome | 3.218 | 0.001 |
| Ear Tip - Closed Dome | 1.941 | 0.052* |
| Ear Tip - Tulip Dome | 2.324 | 0.020 |
| Open Dome - Closed Dome | 2.840 | 0.005 |
| Open Dome - Tulip Dome | 2.714 | 0.007 |
| Closed Dome - Tulip Dome | 0.816 | 0.414* |

*Note: *p>0.05*

From this result, it is clear that the ear-coupling devices have a significant effect on speech in noise. All aided conditions showed better scores than unaided condition. Open dome showed better SNR-50 scores than any other aided conditions. Further, the ear tip condition showed poorer SNR-50 scores among the aided conditions. There was no significant difference between ear tip vs. closed dome condition and closed dome vs. tulip dome condition on SNR-50 values. The SNR-50 scores obtained by different ear-coupling devices are charted in Figure 4.1.

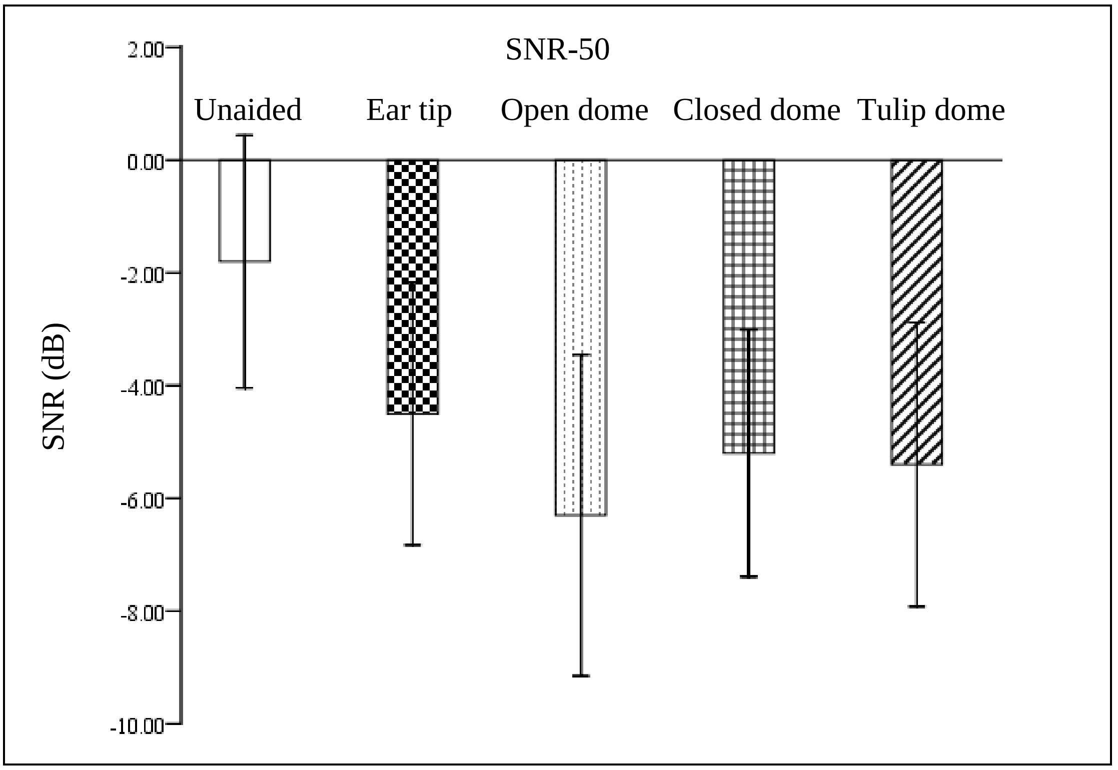


Figure 4.1.SNR-50: Comparison of ear-coupling devices.

From the Figure 4.1 it is clear that speech in noise performance scores were better in all the aided conditions than the unaided condition. The hearing aids used in the study have noise management feature activated which could have helped the participants to perform better in noisy conditions. Studies reported that amplification can also improve speech in noise performance in individuals with hearing loss. People with high frequency hearing loss have shown marked improvementin speech recognition performance compared to the unaidedcondition (Hornsby & Ricketts, 2003; Plyer & Fleck, 2006; Schwartz, Surr, Montgomery, Prosek, &Walden, 1979; Sullivan, Allsman, Nielsen, & Mobley, 1992; Turner & Henry, 2002). Cook, Bacon, and Sammeth (1997) reported that low-frequency energy will be amplified needlessly and can mask important high-frequency speech information by increasing the level of the entire speech signal. When the frequency response of the signal is manipulated in such a way to amplify only the high-frequency region, listeners with high-frequency sensorineural hearing loss exhibit considerable improvements in speech recognition (Lee, Humes, & Wilde, 1993; Plyer & Fleck, 2006; Schwartz, Surr, Montgomery, Prosek & Walden, 1979; Sullivan, Allsman, Nielsen, & Mobley, 1992; von Buchwald, Pedersen, & Parving, 1991). The results of these studies recommend that high-frequency audibility can give benefit to listeners with high-frequency SNHL, especially when listening to a speech signal in the presence of degrading background competitor.

Ghent, Bray and Nilsson (2006) stated that RIC hearing aid with open fitting has better speech recognition performance than RIC hearing aid with occluded tip (closed dome) in noisy environment. This could be due to early escape of noise (mainly low frequency) large vent in the open dome leading to better speech perception. Also, it was noticed in this study that ear tip provides more gain at low frequencies than open and tulip dome conditions. This could be another reason for getting poor SNR score for ear tip condition than other aided conditions since noise has mainly low-frequency components.

***4.2 Real Ear Insertion Gain (REIG).***

Real ear measurement was done to compare output characteristics of different ear-coupling devices. Real ear measurement (REMs) is very important in evaluating the benefits provided by hearing aids and itprovides audiologists with a valid and consistent way of assessing hearing-aid gain and output in situ. According to Jespersen and Moller (2013), real ear measurement is the only resource by which the hearing aids and coupling system’s gain or output in the ear of the hearing aid user can be identified.

Real ear insertion gain (REIG) responses were compared across all test frequencies. Mean and standard deviation for REIG responses were obtained by using descriptive statistics and are as shown in Table 4.3.

Table 4.3. Mean and Standard deviation of REIG measures

| ***Freq*** | ***Ear tip*** | | ***Open dome*** | | ***Closed dome*** | | ***Tulip dome*** | |
|---|---|---|---|---|---|---|---|---|
| ***(kHz)*** | *Mean* | *SD* | *Mean* | *SD* | *Mean* | *SD* | *Mean* | *SD* |
| *0.200* | 4.820 | 2.592 | 3.865 | 1.753 | 5.671 | 3.037 | 1.850 | 7.016 |
| *0.500* | 7.295 | 3.295 | 4.425 | 2.251 | 8.362 | 4.640 | 2.535 | 7.721 |
| *1.000* | 13.915 | 6.106 | 8.302 | 4.701 | 17.512 | 9.317 | 8.100 | 8.602 |
| *1.500* | 18.570 | 7.809 | 14.820 | 7.527 | 21.184 | 9.721 | 14.935 | 9.073 |
| *2.000* | 25.250 | 7.264 | 19.135 | 7.760 | 18.461 | 7.439 | 16.160 | 5.894 |
| *2.500* | 17.640 | 3.772 | 26.055 | 6.296 | 21.188 | 6.075 | 19.250 | 6.736 |
| *3.000* | 12.045 | 3.759 | 25.165 | 9.283 | 20.443 | 7.076 | 19.300 | 7.688 |
| *3.500* | 10.400 | 4.003 | 22.375 | 11.356 | 16.733 | 6.485 | 14.780 | 6.518 |
| *4.000* | 9.160 | 3.436 | 15.725 | 6.496 | 13.363 | 5.701 | 10.335 | 5.347 |
| *4.500* | 7.485 | 3.380 | 13.350 | 6.170 | 12.240 | 6.155 | 10.015 | 6.634 |
| *5.000* | 7.450 | 3.181 | 9.410 | 5.308 | 10.885 | 5.415 | 5.135 | 5.888 |
| *5.500* | 5.085 | 2.960 | 5.835 | 4.843 | 9.309 | 5.945 | 1.685 | 5.503 |
| *6.000* | 3.895 | 2.698 | 2.170 | 3.460 | 10.302 | 7.017 | 1.735 | 5.001 |
| *6.500* | 2.750 | 3.662 | 2.385 | 3.137 | 4.732 | 5.796 | 0.270 | 4.749 |
| *7.000* | 2.460 | 5.163 | 0.905 | 3.628 | 0.321 | 3.181 | -2.005 | 5.038 |
| *7.500* | 2.720 | 4.421 | 0.340 | 2.556 | 0.613 | 1.874 | -2.090 | 3.968 |
| *8.000* | 1.450 | 4.424 | -0.495 | 3.332 | -0.174 | 2.163 | -2.440 | 3.346 |

*Note: SD= Standard deviation*

Friedman test was carried out to verify if there is any significant in performance with different coupling devices. The results indicate that there are significant effects of ear-coupling systems on frequency in terms of output characteristics except at 7 kHz. The results were as in Table 4.4.

Table 4.4. Friedman test results for REIG

| ***Frequency*** | ***df*** | ***X2 value*** | ***p value*** |
|---|---|---|---|
| 200 Hz | 3 | 38.071 | 0.000 |
| 500 Hz | 3 | 35.700 | 0.000 |
| 1 kHz | 3 | 42.960 | 0.000 |
| 1.5 kHz | 3 | 38.160 | 0.000 |
| 2 kHz | 3 | 31.140 | 0.000 |
| 2.5 kHz | 3 | 36.840 | 0.000 |
| 3 kHz | 3 | 36.780 | 0.000 |
| 3.5 kHz | 3 | 36.515 | 0.000 |
| 4 kHz | 3 | 31.591 | 0.000 |
| 4.5 kHz | 3 | 31.740 | 0.000 |
| 5 kHz | 3 | 37.197 | 0.000 |
| 5.5 kHz | 3 | 41.412 | 0.000 |
| 6 kHz | 3 | 32.545 | 0.000 |
| 6.5 kHz | 3 | 18.682 | 0.000 |
| 7 kHz | 3 | 7.400 | 0.060* |
| 7.5 kHz | 3 | 9.167 | 0.027 |
| 8 kHz | 3 | 9.400 | 0.024 |

*Note: df= Degrees of freedom;*
**p>0.05, indicating no significance difference*

Wilcoxon signed ranks test was done to obtain pair-wise comparison of coupling devices except at 7 kHz and the results were as in Table 4.5.

Table. 4.5. Wilcoxon signed ranks test results for REIG

| Frequency (kHz) | ET-OD | | ET-CD | | ET-TD | | OD-CD | | OD-TD | | CD-TD | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Z value* | *p value* | *Z value* | *p value* | *Z value* | *p value* | *Z value* | *p value* | *Z value* | *p value* | *Z value* | *p value* |
| *0.200* | 2.578 | 0.010 | 2.901 | 0.004 | 3.436 | 0.001 | 3.220 | 0.001 | 2.727 | 0.006 | 3.679 | 0.000 |
| *0.500* | 3.286 | 0.001 | 1.737 | 0.082* | 3.100 | 0.002 | 3.660 | 0.000 | 2.259 | 0.024 | 3.435 | 0.001 |
| *1.000* | 3.696 | 0.000 | 2.857 | 0.004 | 3.211 | 0.001 | 3.883 | 0.000 | 0.952 | 0.341* | 3.883 | 0.000 |
| *1.500* | 3.024 | 0.002 | 2.539 | 0.011 | 3.211 | 0.001 | 3.846 | 0.000 | 0.878 | 0.380* | 3.529 | 0.000 |
| *2.000* | 3.285 | 0.001 | 3.547 | 0.000 | 3.847 | 0.000 | 0.429 | 0.668* | 1.923 | 0.054* | 3.118 | 0.002 |
| *2.500* | 3.771 | 0.000 | 3.024 | 0.002 | 2.651 | 0.008 | 3.342 | 0.001 | 3.585 | 0.000 | 2.614 | 0.009 |
| *3.000* | 3.920 | 0.000 | 3.771 | 0.000 | 3.173 | 0.002 | 2.576 | 0.010 | 2.688 | 0.007 | 0.000 | 1.000* |
| *3.500* | 3.783 | 0.000 | 3.845 | 0.000 | 3.286 | 0.001 | 2.800 | 0.005 | 3.248 | 0.001 | 2.737 | 0.006 |
| *4.000* | 3.696 | 0.000 | 3.173 | 0.002 | 2.277 | 0.023 | 2.274 | 0.023 | 3.603 | 0.000 | 3.019 | 0.003 |
| *4.500* | 3.323 | 0.001 | 3.248 | 0.001 | 2.539 | 0.011 | 1.848 | 0.065* | 2.613 | 0.009 | 2.577 | 0.010 |
| *5.000* | 3.060 | 0.002 | 3.175 | 0.001 | 2.455 | 0.014 | 2.540 | 0.011 | 3.174 | 0.002 | 3.548 | 0.000 |
| *5.500* | 2.662 | 0.008 | 3.398 | 0.001 | 3.211 | 0.001 | 3.604 | 0.000 | 2.895 | 0.004 | 3.883 | 0.000 |
| *6.000* | 2.035 | 0.042 | 3.659 | 0.000 | 3.099 | 0.002 | 3.696 | 0.000 | 0.697 | 0.486* | 3.808 | 0.000 |
| *6.500* | 0.710 | 0.478* | 2.194 | 0.028 | 2.134 | 0.033 | 2.091 | 0.037 | 2.672 | 0.008 | 3.062 | 0.002 |
| *7.500* | 2.035 | 0.042 | 2.240 | 0.025 | 2.717 | 0.007 | 0.373 | 0.709* | 1.831 | 0.067* | 2.878 | 0.004 |
| *8.000* | 1.429 | 0.153* | 1.998 | 0.046 | 2.309 | 0.021 | 0.168 | 0.867* | 1.852 | 0.064 | 1.992 | 0.046 |

*Note: ET= Ear Tip; OD= Open Dome; CD= Closed Dome; TD= Tulip Dome;*

**p>0.05, indicating no significant difference.*

Real ear insertion gain curves obtained for different ear-coupling devices are shown in Figure 4.2.

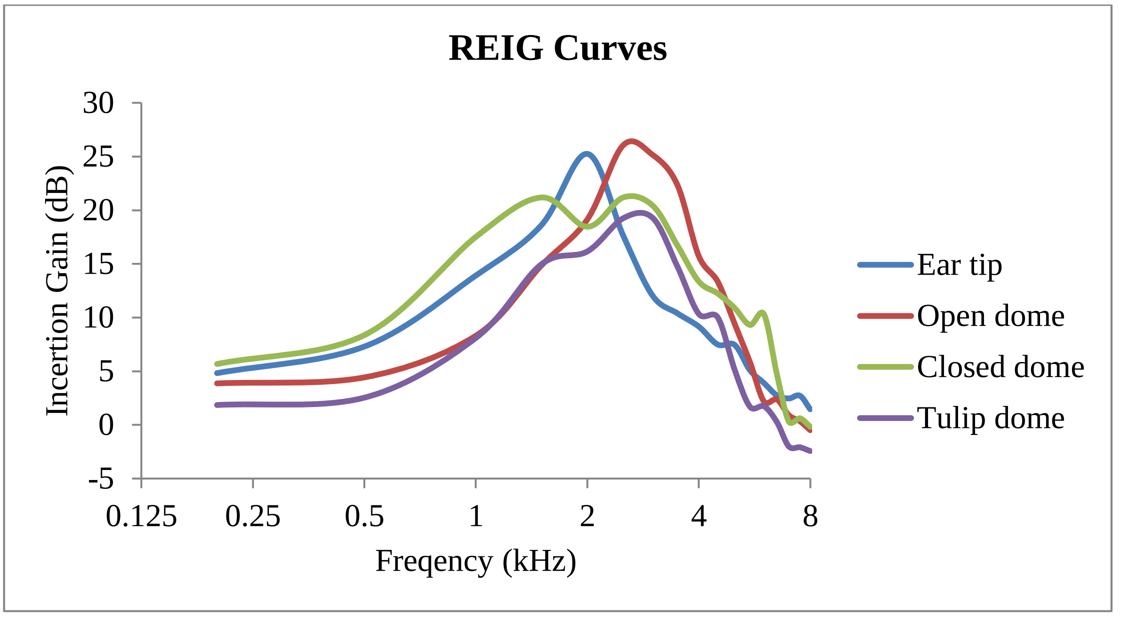


Figure 4.2. REIG curves for different ear-coupling systems.

The Table 4.5 and Figure 4.2 shows that output characteristics of hearing aid vary depending on the ear-coupling systems used. Ear tip and closed dome conditions provide more gain at low frequency region (till 2000 Hz) compared to open dome and tulip dome. Closed dome provided more gain till 1500 Hz, when compared to all other aided conditions. It also provides gain over a wider range of frequencies, with maximum gain at 2500 Hz. Ear tip provides gain over a narrow range of frequencies with maximum gain at 2000 Hz. Open dome and tulip dome curves are not showing as much gain at low frequencies than with closed dome and with ear tip. Open dome provides more gain over a mid-frequency range with maximum gain at 2500 Hz. Tulip dome provide gain mainly in mid-frequency region with maximum gain at 3000 Hz. Gain curve of tulip dome was inferior on comparison with open dome and closed dome conditions.

The reason for higher gain at low frequencies for occluded canal conditions (ear tip & closed dome) could be due to trapped low frequency energy in the ear canal (Kumar, 2010). This will not happen in open fit conditions due to the presence of venting.

***4.3 Quality Judgement.***

Quality judgement of the conventional BTE with regular ear tip (with #13 tube) and RIC hearing aid with different ear-coupling systems (such as open dome, closed dome & tulip dome) was done using a ten point rating scale developed by Otto (2005). Quality judgement was done for recorded speech and own voice separately. Some miscellaneous factors like cosmetics and occlusion of the ear canal were also considered. A total of six parameters were compared across different ear-coupling devices.

Friedman test was used to verify the significant effect of ear-coupling systems in quality judgement for each parameter separately. If Friedman test showed a significant effect, Wilcoxon signed ranks test was done for pair-wise comparison.

**4.3.1 Quality of recorded speech.**

The participants were asked to rate the recorded speech stimulus for feedback/whistling and comfortable listening level, using different ear-coupling devices.

***4.3.1.a Feedback/Whistling (FW).***

The mean and standard deviation of ratings provided for different ear-coupling devices were estimated. The data is given in Table 4.6.

Table 4.6. Mean and Standard deviationfor the parameter-feedback/whistling

| ***FW Conditions*** | ***Mean*** | ***SD*** |
|---|---|---|
| Ear Tip | 9.200 | 1.005 |
| Open Dome | 9.200 | 1.005 |
| Closed Dome | 9.100 | 1.021 |
| Tulip Dome | 9.200 | 1.005 |

*Note: SD= Standard deviation*

Friedman test was carried out to verify the significance and the result show that there is no significant difference across different ear-coupling devices, $\chi^2$ (3, 20) = 0.529, p = 0.912. Participants did not have any complaints regarding feedback or whistling in any of the test conditions. All the hearing aids used in this study had feedback cancellation feature activated. The mean rating for ear tip condition is 9.2 out of the ten point rating scale. The absence of feedback could be explained based on findings of Chung (2004) who reported that feedback in regular BTE hearing aids could be reduced by decreasing the vent size. Also, it is observed that mean rating for open and tulip dome were 9.2 along with 9.1 mean rating for closed dome using RIC hearing aid. This could be due to larger distance between the microphone and the receiver in RIC hearing aid compared to conventional BTE hearing aid, reducing the chances for occurrence of feedback (Spriet, Moonen, & Proudler, 2002).

#### *4.3.1.b Comfortable Listening Level (CLL).*

Mean and standard deviation for the rating of comfortable listening level on ten point rating scale is obtained and as mentioned in Table 4.7.

Table 4.7. Mean and Standard deviation for the parameter-comfortable listening levels

| ***CLL Conditions*** | ***Mean*** | ***SD*** |
|---|---|---|
| Ear Tip | 8.000 | 1.298 |
| Open Dome | 7.900 | 1.210 |
| Closed Dome | 8.000 | 1.124 |
| Tulip Dome | 8.000 | 1.124 |

*Note: SD= Standard deviation*

Table 4.7 shows that mean rating of CLL for ear tip, closed dome were same, with rating of open dome being slightly lower. Friedman test was carried out to verify the significance and the result showed no significant difference across different ear-coupling devices, $\chi^2$ (3, 20) = 0.185, p = 0.980. Both, the regular BTE and the RIC hearing aids taken for the study were similar in gain characteristics with similar fitting range. This could be the possible reason for non-significant effect of ear-coupling systems on comfortable listening levels.

**4.3.2 Quality of own voice.**

Ratings of quality of own voice were obtained for sound of own voice and sound of own chewing, using different ear-coupling conditions.

***4.3.2.a Sound of Own Voice (SOV).***

The mean, median and standard deviation for rating of "sound of own voice" were obtained and the values are shown in Table 4.8.

Table 4.8. Mean and Standard deviation for the parameter-sound of own voice

| ***SOV Conditions*** | ***Mean*** | ***SD*** |
|---|---|---|
| Ear Tip | 3.200 | 1.196 |

| | | |
|---|---|---|
| Open Dome | 8.300 | 1.174 |
| Closed Dome | 5.300 | 0.979 |
| Tulip Dome | 6.600 | 0.940 |

*Note: SD= Standard deviation*

Friedman test showed that the mean ratings were significantly different, $\chi^2$ (3, 20) = 55.131, p = 0.000, across all ear-coupling devices. Wilcoxon signed ranks test was administered to verify the significance between each pair of ear-coupling device. The test results are shown in Table 4.9.

Table 4.9. Wilcoxon signed ranks test result for the parameter-sound of own voice

| ***SOV- conditions*** | ***Z value*** | ***p value*** |
|---|---|---|
| Ear Tip - Open Dome | 3.956 | 0.000 |
| Ear Tip - Closed Dome | 4.001 | 0.000 |
| Ear Tip - Tulip Dome | 3.895 | 0.000 |
| Open Dome - Closed Dome | 3.919 | 0.000 |
| Open Dome - Tulip Dome | 3.900 | 0.000 |
| Closed Dome - Tulip Dome | 3.606 | 0.000 |

The results suggest that sound of own voice was heard best in open dome condition followed by tulip dome and closed dome conditions. Ear tip condition was rated as worst aided condition. These findings could be explained based on the occlusion effect which leads to unnatural perception of own voice (Chung, 2004). The occlusion effect is predominant in ear tip condition due to close proximity with ear canal, causing poor perception. Similarly, closed dome also have marked occlusion effect which however, is not as marked as ear tip condition. This could be the possible explanation for better rating of closed dome compared to ear tip. The tulip dome is a semi-closed dome providing some amount of occlusion effect which is lesser than that of closed dome. The occlusion effect is very minimal in the case of open dome, causing perception of own voice as natural compared to other aided conditions. The differences were significant in all paired conditions.

#### *4.3.2.b Sound of own chewing (SOC).*

The mean and standard deviation for rating of "sound of own chewing" were obtained and are shown in Table 4.10.

Table 4.10. Mean and Standard deviation values for the parameter-sound of own chewing

| ***SOC-Conditions*** | ***Mean*** | ***SD*** |
|---|---|---|
| Ear Tip | 3.800 | 4.000 |
| Open Dome | 9.300 | 10.000 |
| Closed Dome | 5.800 | 6.000 |
| Tulip Dome | 7.400 | 8.000 |

*Note: SD= Standard deviation*

Friedman test results revealed significant difference, $\chi^2$ (3, 20) = 53.494, p = 0.000, across different ear-coupling devices when assessed for sound of own chewing. Further, Wilcoxon signed rank test was carried out to verify the significance between each pair of coupling devices. The result data is given in Table 4.11.

Table 4.11.Wilcoxon signed ranks test result for the parameter-sound of own chewing

| *SOC- conditions* | *Z value* | *p value* |
|---|---|---|
| Ear Tip - Open Dome | 3.872 | 0.000 |
| Ear Tip - Closed Dome | 3.704 | 0.000 |

| | | |
|---|---|---|
| Ear Tip - Tulip Dome | 3.861 | 0.000 |
| Open Dome - Closed Dome | 4.017 | 0.000 |
| Open Dome - Tulip Dome | 3.945 | 0.000 |
| Closed Dome - Tulip Dome | 3.557 | 0.000 |

Result showed significant difference in all four conditions. Open dome showed significantly better response in all aided conditions followed by tulip dome and closed dome. Ear tip condition was rated poorly compared to all other aided conditions. The results could be attributed to occlusion effect. Chung (2004) stated that the occlusion effect can enhance the chewing sounds unusually loud, due to trapped boneconduction energy (while chewing) in the ear canal. Since, open dome has very less amount of occlusion due to large vent size, the sound of own chewing is perceived more naturally compared other aided conditions. Ear tip condition on the other hand, has rigid form and completely occludes ear canal which leads to unnatural perception of chewing sounds. Tulip dome is a semi-closed dome and the occlusion effect is lesser than that of closed dome, thus causing superior ratings compared to closed dome.

### 4.3.3 Quality of miscellaneous factors.

Rating of other miscellaneous factors includes pressure feeling (PF) and appearance/cosmetics (AC) were obtained across different ear-coupling conditions.

#### *4.3.3.a Pressure Feeling (PF).*

The mean and standard deviation for rating of “pressure feeling” were obtained and the values are shown in Table 4.12.

Table 4.12. Mean and Standard deviationfor the parameter-pressure feeling

| ***PF Conditions*** | ***Mean*** | ***SD*** |
|---|---|---|
| Ear Tip | 3.600 | 1.046 |
| Open Dome | 8.200 | 0.616 |
| Closed Dome | 5.300 | 0.979 |
| Tulip Dome | 6.800 | 1.005 |

*Note: SD= Standard deviation*

Friedman test showed significant effect of different ear-coupling devices on "pressure feeling", $\chi^2$ (3, 20) = 54.934, p = 0.000. Pair-wise comparison was done using Wilcoxon signed ranks test. The result is given in Table 4.13.

Table 4.13. Wilcoxon signed ranks test resultfor the parameter-pressure feeling

| ***PF- conditions*** | ***Z value*** | ***p value*** |
|---|---|---|
| Ear Tip - Open Dome | 4.042 | 0.000 |
| Ear Tip - Closed Dome | 3.900 | 0.000 |
| Ear Tip - Tulip Dome | 3.934 | 0.000 |
| Open Dome - Closed Dome | 4.041 | 0.000 |
| Open Dome - Tulip Dome | 3.742 | 0.000 |
| Closed Dome - Tulip Dome | 3.873 | 0.000 |

Wilcoxon signed rank test showed significant difference in all paired condition. Open dome was rated as most preferable in all aided condition. Tulip dome showed significantly better rating than closed condition whereas the ear tip condition was rated inferior compared to all other conditions. Here also occlusion effect and the type of material play a major role. Ear tip is thicker and slightly harder than other coupling systems with absence of vent. This could be the reason for plugged feeling in the ear canal while ear tip as coupling system. Though closed dome also has higher occlusion effect, it is softer and thinner than ear tip. This could be the reason for better rating of closed dome compared to ear tip. Even though closed dome, tulip dome and open dome are almost similar in physical characteristics (thickness & softness), tulip dome and open dome are ranked superior to closed dome. Tulip dome has a slit vent and this reducing the occlusion effect compared to closed dome. The vent size of open dome is much bigger compared to tulip dome causing minimal occlusion effect compared to all other ear-coupling systems. This could be the reason for the superior ranking of open dome in terms of pressure feeling compared to all other ear-coupling systems.

#### 4.3.3.b Appearance/Cosmetics (AC).

The mean and standard deviation for rating of "Appearance/Cosmetics" were obtained and the values are shown in Table 4.14.

Table 4.14. Mean and standard deviation for the parameter-appearance/cosmetics

| ***AC-Conditions*** | ***Mean*** | ***SD*** |
|---|---|---|
| Ear Tip | 4.700 | 4.000 |
| Open Dome | 8.700 | 8.000 |
| Closed Dome | 8.700 | 8.000 |
| Tulip Dome | 8.700 | 8.000 |

*Note: SD=Standard deviation*

Friedman test result showed significant difference between different ear-coupling systems $\chi^2$ (3, 20) = 60.00, p = 0.000. Wilcoxon signed ranking test was carried out to find the significance of each dome in paired conditions. The data is given in Table 4.15

Table 4.15. Wilcoxon signed ranks test resultfor the parameter-Appearance/cosmetics

| ***AC- conditions*** | ***Z value*** | ***p value*** |
|---|---|---|
| Ear Tip - Open Dome | 3.970 | 0.000 |
| Ear Tip - Closed Dome | 3.970 | 0.000 |
| Ear Tip - Tulip Dome | 3.970 | 0.000 |
| Open Dome - Closed Dome | 0.000 | 1.000 |
| Open Dome - Tulip Dome | 0.000 | 1.000 |
| Closed Dome - Tulip Dome | 0.000 | 1.000 |

Results revealed significant difference for ear tip condition compared to all other conditions. Ear tip condition was rated inferior compared to other conditions. There was however, no significant difference among open dome, closed dome and tulip dome. Within RIC conditions, no significant difference was seen among any pairs. This is because; the loudspeaker in the RIC hearing aid is outside the main housing which is in contrast with BTE hearing aids. This leads to the reduction in physical size of RIC hearing aid when compared to conventional BTE hearing aids (Hoen & Fabry, 2007). Even though the regular BTE is placed behind the pinna, it is easily noticeable especially from side and back views. However, RIC hearing aids can hide behind the pinna. Also, the diameter of ear hook and tubing of the conventional hearing aid is much bigger than the diameter of slim tube of RIC hearing aid. This variance in the physical size and appearance could be the possible reason for the low rating of ear tip compared to other coupling devices. In the case of open, closed and tulip dome, the external appearance is same. Thus, there would not be any difference in cosmetic appeal among open, closed and tulip dome.

The present study gives an insight for the selection of appropriate ear-coupling devices for individuals with sloping sensorineural hearing loss. RIC hearing aids are better option for sloping sensorineural hearing loss compared to conventional BTE hearing aids based on speech in noise performance. Open canal fitting will be much preferable than occluded canal fitting in terms of wearing comfort. If the hearing impaired individual having near normal hearing sensitivity in low frequency region (till 1000 Hz), open fitting will be most suitable and practical option for them as open fitting hardly gives any gain at low frequencies with appropriate amplification in high frequencies. For individual having further loss in low frequency region, closed dome will be a better choice as it gives better amplification in low frequencies and provide a wider response range. Subjective satisfaction will be more for RIC hearing aids compared to conventional BTE hearing aids as shown by quality judgement.

# Chapter 5

## Summary and Conclusion

The present study focused on comparing the performance of conventional BTE and receiver in the ear (RIC) hearing aids across different ear-coupling devices in individuals with sensorineural hearing loss. The performance were assessed in terms of SNR-50, real ear measurements and quality judgement.

16 individuals (20 ears) with sloping sensorineural hearing loss participated in this study. Word list (Kannada) developed by Sahgal (2005) was used for SNR-50 measurements and standardized paragraph in Kannada developed by Sairam (2002) was used for quality judgement. A ten point rating scale (by Otto, 2005) was used for quality rating of different ear-coupling devices.

Non-parametric statistics tests were used for data analysis. In all the aided conditions performance was significantly better compared to unaided condition in SNR-50 measurement. Among aided conditions, performance in open dome was better compared to performances using other ear-coupling systems; followed by tulip dome and closed dome. Performance in ear tip condition was the poorest in SNR-50 among all aided conditions assessed in this study.

Output characteristics of each ear-coupling system were measured using real ear measurement. Real ear insertion gain was compared across four different ear-coupling devices. Main conclusion obtained from real ear measurement was that ear tip and closed domes provide significantly higher insertion gain in low frequency region compared to open and tulip dome. Occlusion effect could be the presumable reason behind it. Closed dome and ear tip conditions provide more gain for a wider range of frequencies.

Quality judgement was done to compare the ear-coupling devices in six parameters. The patients were asked to rate the coupling systems in a ten point scale (given by Otto, 2005). Results are as in Figure 5.1.

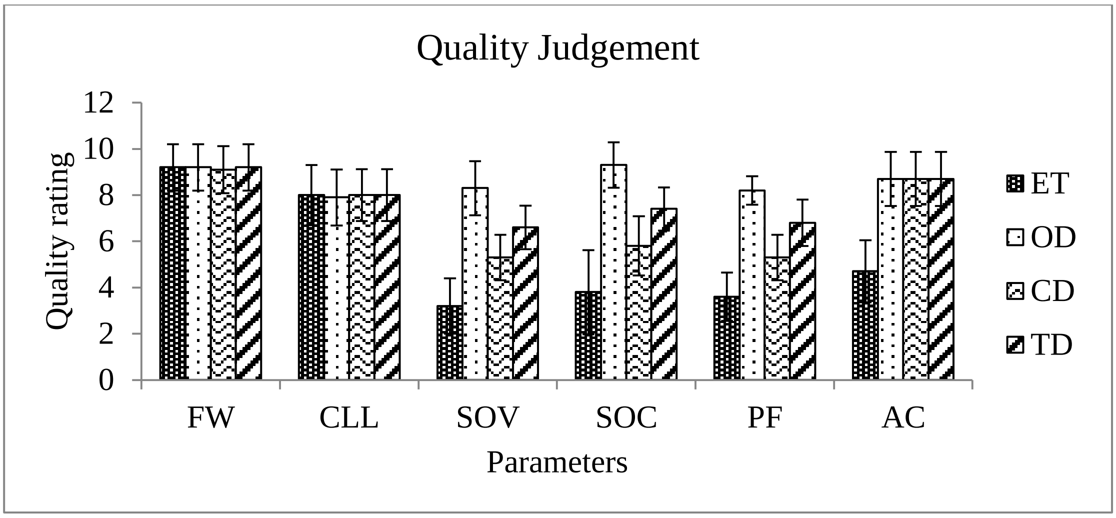


Figure 5.1. Quality judgement results for various ear-coupling devices

*Note: ET=Ear tip; OD=Open dome; CD=Closed dome; TD=Tulip dome; FW=Feedback/Whistling; CLL=Comfortable listening levels; SOV=Sound of own voice; SOV=Sound of own voice; PF=Pressure feeling; AC=Appearance/Cosmetics.*

There were no significance differences across ear-coupling devices in terms of feedback/whistling and comfortable listening level. Open dome was rated superior followed by tulip dome compared to closed dome in terms of quality of own voice. Ear tip condition was rated poorly compared to all other aided conditions. This could be attributed to the occlusion effect which will enhance the sounds (through bone conduction mode) unnecessarily loud. Similar ratings were obtained for the quality assessment of sound of own chewing and pressure feeling. In appearance/cosmetics the BTE hearing aid (coupled with ear tip) was rated poorly compared to RIC hearing aid's ear-coupling devices (open, closed & tulip dome). There were no significant differences across different ear-coupling systems within RIC hearing aid condition. The difference in physical size of conventional BTE and RIC hearing aid could be the possible reason behind it.

**Limitations of the study.**

1. Test retest reliability of all the parameters measured was not done.
2. Another frequently used ear-coupling device, the double dome or power dome is not tested for its efficiency in this study.

**Future implications.**

1. To study the effect of different ear-coupling devices on localization.
2. To study the effect of different ear-coupling devices on different audiometric configurations and varying degree of hearing losses.

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**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/ | /ʤi: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/ | /geʤʤe/ |
| 32 | /be:ru/ | /beTTa/ | /railu/ |
| 33 | /maɳga/ | /me:ʤu/ | /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 ಸಿದ್ಧರಾಗಿ 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".