COMPARISON OF SUBJECTIVE BENEFIT OF DIRECTIONAL MICROPHONE IN HIGH COST AND LOW COST DIGITAL HEARING AIDS IN NOISE

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This Dissertation is submitted as part fulfillment

For the Degree of Master of Science in Audiology

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CERTIFICATE

This is to certify that this dissertation entitled **“Comparison of Subjective Benefit of Directional Microphone in High Cost and Low Cost Digital Hearing Aids in Noise”** is the bonafide work submitted in part fulfillment for the Degree of Master of Science (Audiology) of the student with Registration No: **18AUD037**. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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July, 2020

CERTIFICATE

This is to certify that this dissertation entitled **"Comparison of Subjective Benefit of Directional Microphone in High Cost and Low Cost Digital Hearing Aids in Noise"** has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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DECLARATION

This is to certify that this Master's dissertation entitled **"Comparison of Subjective Benefit of Directional Microphone in High Cost and Low Cost Digital Hearing Aids in Noise"** is the result of my own study under the guidance of Dr. Geetha C., Reader in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysuru, and has not been submitted earlier in other University for the award of any Diploma or Degree.

Register No: 18AUD037

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ABSTRACT

The advance features in the hearing aids have evolved over time and each addition of technology in the hearing aids is expected to help in better perception and ease of listening for the hearing aid users. Directionality is one such feature. With evolving technology, the cost of the hearing aid has also increased. Therefore, there is a need to know whether there is a difference in performance between the high cost and low cost hearing aid. Thus, the current study aimed to measure the perceptual benefits of microphone directionality in high cost and low cost hearing aids and also to measure the quality rating between these two ranges of hearing aid. Fifteen elderly individuals, age ranged from 55 to 76 years, were fitted with the high cost and low cost hearing aids. Speech intelligibility in the presence of noise was assessed with directionality on and off conditions in both the hearing aids. Quality rating assessment for loudness, clearness and naturalness parameters were measured for both the hearing aids. The results showed a significant difference between the high cost and low cost hearing aids in the omni-directional mode. The above results may be attributed to the better frequency shaping and signal processing in the high cost hearing aid. There was a difference in SNR-50 between high and low cost directional conditions, but, the difference was not significant. Analysis of quality rating revealed no significant difference between the high cost and low cost hearing aids.

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CHAPTER 1

INTRODUCTION

Presbycusis is the most common cause of non-infectious hearing loss in India. About 40% of the geriatric individuals over 75 years have been noted with hearing loss (Singh, 2015). With large number of older adult population being affected by hearing impairment, the need for effective rehabilitation services has increased. Management of hearing loss through hearing aids has been of primary importance and is said to be the primary source of management.

During recent years, a lot of progression in hearing aid technology with respect to noise reduction algorithms, adaptive directional microphones, feedback reduction algorithms, wireless technologies etc has been made. Due to differences seen across the manufacturers in the implementation of these features, it has become difficult to predict the outcomes of the advance features.

Invention of directional microphones in hearing aids is a breakthrough technology. There are many developments with reference to directional microphones in hearing aids. Directional microphones are one among many alternatives for improving speech perception in the presence of noise (Kochkin, 1993). Directional microphones improve the signal to noise ratio (SNR) by amplifying the input sound coming from front more than the sounds arriving from other directions. Whereas the omni-directional microphones give equivalent weightage to sounds coming from all the directions when the testing is done in a free field condition (Ricketts 2001a). There are different ways in which directional microphone can function. The number and type of directionality function vary depending on the cost of the hearing aid (Bentler and Chiou 2006).

In other words, the hearing aid cost increases as there is a rise in technological development. The premium or higher end hearing devices incorporate a more complex, adaptive version of the features along with other advanced features which are not usually available in the primary/basic level hearing aids. Though the cost of the device is not the only variable essential for hearing aid selection, the perceived subjective benefit per unit cost has a pivotal role in decision making.

In recent years, though there has been an increase in the numbers of older individuals prescribed with hearing aids, many of them do not procure hearing aids mainly due to non-affordability (Gates, Mills, Lancet, 2005). Another reason for not procuring hearing aids is the belief that the amount of benefits provided by the hearing aid does not justify its cost (Chien & Lin, 2012). Though perceptual benefits are the main criteria for hearing aid selection, the hearing aid users perform a cost-benefit analysis of their hearing device (Kochkin, 2003; Newman & Sandridge, 1998). Hence, empirical evidence is required to justify the prescription of high priced hearing aids with the advanced features. There are a few studies available that provides information on the cost effectiveness of the hearing aids.

Mulrow et al. (1990) is among the first to investigate the cost-effectiveness of a hearing aid. They studied the hearing quality of individuals who wore hearing aids with those who did not wear hearing aids. Results showed that hearing aids were an inexpensive option for the amount of benefit received. Newman and Sandridge (1998) studied the cost effectiveness of hearing aids in adult hearing aid users with sensori-neural hearing loss. Results revealed that more than 75% of the individuals preferred the higher cost instruments based on their performance than the low cost hearing aids. When the cost of the hearing aid was informed, about 33% of the subjects changed their preference.

1.1.Need for the Study

During the recent years, a lot of progression in hearing aid technology with respect to strategies for amplification, noise reduction algorithms, adaptive directional microphones, feedback reduction algorithms, wireless technologies etc. has been made (Chung, 2004). The need for this research arises given the increased cost associated with the newer hearing aids. There are very less studies available that provides information on the cost effectiveness of the hearing aids.

Newman and Sandridge (1998) studied the cost effectiveness of hearing aids in adult hearing aid users with sensori-neural hearing loss and they found that more than 75% of the individuals preferred the “higher end” instruments based on their performance than “lower end” hearing aids. Wu et al. (2019) compared premium hearing aids with basic hearing aids and found that premium hearing aids with all the advanced features resulted in better speech perception and localization than the basic level hearing aids with no features.

Shiyaam (2018) studied the quality of hearing in elderly individuals with wireless synchronization feature in binaural hearing aids through Speech, Spatial and Quality (SSQ) questionnaire. Though this study revealed that there was a slight better performance in spatial and quality of hearing aid with wireless synchronization, the difference between the groups was minimal. Further, the self-perceived speech performance was poor with wireless synchronization. These results imply that the benefit provided by wireless synchronization may not be cost-effective considering that hearing aids with the wireless synchronization cost significantly higher compared to that without the synchronization feature. Hence, in order to justify the prescription of high priced hearing aids with the advanced features, the listeners’ perceived benefit needs to be assessed and compared between premium and basic hearing aids. There is dearth of research in this area.

In addition, directional microphone is a feature that is available in all digital programmable hearing aids. The working of them can be different depending on the cost of device. Hence, it is essential to evaluate the efficacy of directional microphones in the high cost and low cost hearing aids.

1.2. Aim of the study

Hence, the aim of the study was to compare the perceptual benefit of high cost and the low cost digital hearing aids with directional microphone in elder hearing aid users.

1.3. Objectives of the study

The objectives of the present study were –

- To compare speech identification scores between the high priced and low priced hearing aids with directional microphones.
- To compare self-related quality of speech between the high priced and low priced hearing aids with directional microphones.

CHAPTER 2

REVIEW OF LITERATURE

As the listening needs of a person with hearing impairment increases, the need for advanced processing features of the hearing aid also increases. The advanced features may include directional microphone, noise reduction algorithms, feedback algorithm etc. (Gordon-Salant 2005; Mamo et al. 2016). At present, consumers seek products with different price ranges and variety of features, and choose a hearing aid according to their convenience (Callaway and Punch 2008). Making a clinical decision is becoming more difficult as the cost and technology of the hearing aid keeps increasing, and a wide price range is available (Palmer et al., 2009).

Selection of the appropriate feature in the hearing aid is crucial. Especially elderly individuals, as they have more difficulties in perceiving speech when the signal is degraded, require the advanced features to cut down the noise. Directional hearing aids remain one of the few ways to increase the signal to noise ratio (SNR) when speech and noise eventuate in the same frequency band, but are separated spatially (Ricketts & Mueller, 1999). It is important that strong empirical evidence be available to justify the selection of a particular hearing aid and the advanced features. Since there is a substantial increase in cost of the hearing aids due to the advancement in the technology of hearing aids, there is a demand to undertake clinical research comparing technology between hearing aids with different price range to justify the expanding cost of the hearing aids. The current study aimed to assess the effect of cost and microphone directionality on speech perception and perceived quality of speech. Hence, the literature has been reviewed under the following headings:

2.1 Factors affecting hearing aid benefit

2.2 Effect of cost of hearing aid

2.3 Effect of directionality

2.1. Factors affecting hearing aid benefit

Turner et al. (1996) have defined the hearing aid benefit as the improvement in the hearing ability due to the usage of hearing aid. Benefit from the hearing aid is influenced by several factors which would in turn affect the customer satisfaction. Few of the key factors that are reported to be affecting the perceived benefit of hearing aid are severity of the hearing impairment, cost of the hearing aid, the availability of advanced features, stigma towards the hearing aid and lack of support (Hearing Industries Association, 1990; Kochkin, 1993). Apart from the above mentioned factors, several other authors have also mentioned of the factors such as cosmetic appeal, comfort and sound quality (Brooks, 1994), client attitude (Brooks, 1989), handling the hearing (Sorri et al., 1984). Motivation also plays an important role in the successful rehabilitation (Thomas, 1988; Weinstein, 1994).

In this study, the primary focus is on the cost of the hearing aid in the elderly individuals. Kochkin (1993) had reported that about 44% of his subjects gave cost of the hearing aid as one of the reasons for non-purchase of the hearing aid. With recent improvement in the technology, inclusion of new features in the hearing aid results in increase in the cost of the hearing (Johnson, Xu, and Cox 2017). Therefore, the premium hearing aid or the high cost hearing aid includes advanced processing capabilities which are not included in a basic level or a low priced hearing aid. The premium hearing aids are expected to yield a better hearing experience in everyday situations when compared to a basic level hearing aid (Cox, Johnson, and Xu 2016). Thus, cost has been considered as one of the major factor which can have an impact on the benefit obtained form a hearing aid (Baumfield and Dillon 2001; Korkmaz et al. 2016; Solheim et al. 2012). The secondary focus is on the microphone directionality features that are available in the hearing aids. Improving the signal-to-noise ration is one of the important goal and directional microphones are one among the options in the hearing aids to improve the SNR (Keidser et al. 2013).

2.2 Effect of cost of hearing aid

Cost of the hearing aid is one of the important factors that can affect the functionality of hearing aids. There are few studies which have evaluated the influence of cost of the hearing aids on subjective and objective outcome measures. The quality of the hearing directly is responsible for obtaining the benefit of the hearing aid.

Mulrow et al. (1990) became the one of the first authors to determine the cost-effectiveness of hearing aids. The psychosocial benefit perceived by the listener and their family members was measured using the Hearing Handicap Inventory for the Elderly (HHIE). The psychosocial benefit was compared to the actual hearing aid related service cost. They concluded hearing aid is a cost-effective rehabilitation option for the amount of benefit obtained.

Wu et al (2018) performed a systematic analysis evaluating the real-world utility of microphone directionality and digital noise reduction and compared between premium and basic level hearing aids. The performance in terms of speech comprehension, listening effort, audio quality, localization and HA satisfaction were assessed using laboratory tests, retrospective self-reports (i.e. standardized questionnaires), and in-situ self-reports (i.e. real-time self-reports).

Results revealed that in well-controlled laboratory test conditions premium directional microphone (DM) and noise reduction (NR) technologies outperformed their basic-level counterparts; however, benefits have not been seen in the real world. Compared to no DM/NR features in the hearing aid, both in the laboratory and in the real world condition, the effect seen with DM and NR on condition had reliable results. Consequently, while both premium and basic DM and NR technologies tested in the study are able to enhance the outcomes of hearing aids, older adults with mild to severe hearing loss are unlikely to receive the added benefits of premium DM and NR features in their everyday lives.

Smith et al. (2016) also compared the fitting capabilities and did the electro-acoustic analysis of low cost and high cost hearing aids. Their result revealed that high cost hearing devices were more helpful in fitting most of the audiometric configurations. On the other hand, the low cost hearing aids provided unnecessarily huge range of gain in the low frequency. They also reported that the hearing aids falling under the high cost category had good directionality benefit than the low cost hearing aids, when electro-acoustic analysis was done. Comparing the harmonic distortion and internal noise aspects, there was little to no difference seen between the categories.

A contrasting result was found in the study conducted by Cox, Johnson and Xu (2014) where they examined whether there is a benefit seen with the increase in technology and its price. They had included hearing aids from two major companies and each company’s basic and premium level hearing aids. The findings showed no significant difference in the functioning of individuals fitted with basic level hearing aid and who were fitted with premium level hearing aids. They also reported that there was no significant difference in the quality of life changes among the hearing aids.

Barry (2018) assessed the objective differences between premium and mid-level hearing aids, where the author mainly focused on the benefits of noise reduction algorithms in these two hearing aid categories. The data showed that there was a difference in the performances between the mid-level and premium hearing aids when collected from the steady state stimuli. On the other hand, when a frequency specific response was obtained, there was a significant difference in the performance of mid-level and premium hearing aids. The author emphasized on conducting a subjective assessment using self reports and questionnaires to get holistic information regarding the benefits obtained in a premium versus a mid-level hearing aid.

To summarize, a few research studies have explored the actual benefits of the advanced signal processing features in premium and basic level hearing aids where they had assessed the speech understanding and listening effort outcomes after each one month trial in these two hearing aid ranges (Johnson, Xu & Cox, 2016). The results of these studies are not conclusive as each one of them has assessed different aspects. Clinicians are made to rely on the information's given by the manufacturers to recommend (Cox, Johnson & Xu, 2016). Therefore, there is a need to find out the objective and subjective benefits between the premium level and basic level hearing aids, which can thereby help in making recommendations to the patients.

2.3 Effect of directionality

Directional hearing aids were introduced first in 1971 to the U.S. market and were included in nearly 20 percent of hearing aids sold by 1980 (Mueller, 1981). As mentioned earlier, directional microphone is an efficient addition in the hearing aid to improve the SNR when speech and noise are separated spatially (Ricketts & Mueller, 1999).

Directional hearing aids operate by contrasting the input signals detected at two distinct positions (two inlet ports, separated by 4–12 mm, are situated on the instrument case). Timing disparities between the sampled sounds at these two points are used to attenuate noises coming from unwanted zones (Ricketts 2001b). The directional effect can be changed either continuously or in stepwise manner (Arndt 2003).

In conventional hearing aids, the attenuation can be achieved in one of two forms (Bauer, 1987; Borwick, 1990). The first option is acoustic cancellation using an acoustic phase shifting network. Second option is to use an electronic cancellation with two microphones. The working procedure of the acoustic cancellation can be described from the direction of a sound wave. If a signal appears at the hearing aid from behind the audience, the signal reaches the rear gap first. This signal is distorted acoustically and redirected (internal delay) to one direction of the microphone diaphragm. This very same signal enters the front opening slightly later due to travel time (external delay) and is redirected towards the other corner of the microphone diaphragm.

Optimally, the internal delay and the external delay are identical, such that the input from the front and posterior outlets occurs concurrently at each side of the diaphragm, culminating in the cancellation. The sounds that originate from the audience front first enter the amplifier's front opening and move to the diaphragm unimpeded. No cancellation happens after the external delay and internal delay, since the signals have reached the opposite direction of the diaphragm through the rear opening (Ricketts & Mueller, 1999).

Hearing aids with adaptive directional microphone modify their response pattern automatically so that the SNR is balanced in constantly changing environments. The system is very similar to automatically triggered directional microphone wherein there is an option of enabling and disabling the directional microphone whenever necessary. It may even modify the polar pattern with respect to spatially sensitive listening conditions by modifying the internal microphone time delay. Auto Adaptive Directionality is typically a function of the 'upper end' product range and enables either manual or automated collection of accessible polar plots (Blamey, Fiket, and Steele 2006).

Hearing aids which are able to turn automatically to a fixed directionality from omni-directionality mode will be useful to improve SNR at different noisy situations. Fixed directionality permits putting the hearing aid, in a directional configuration for all situations. As the system does not turn to another directional condition, this configuration is especially useful for testing directionality, either in the test box or on-ear. It has an unchanging, static hyper-cardioid directional response pattern. In the fixed directionality option, the environmental sounds are enhanced more for the input in the front direction than the back and side directions. Patients who want to go for more of a traditional processing pattern of directionality will benefit more from this type of setting. In addition, fixed directionality is more applicable for hearing aids with either a “restaurant” or “party” programs which are specially designed for noisy conditions (Ricketts and Henry 2002)

2.3.1 Benefits of directional microphones

The directional advantage is the improved speech recognition in the presence of noise, obtained in directional microphone mode when compared to the omni directional microphone mode. This is represented in SNRs as the decibel gap (Ching et al. 2009).

Valente et al. (1995) recorded a directional benefit of 7.6 dB in SNR for directional microphones against omni-directional mode in a group of hearing impaired listeners. The improvement was seen after the addition of dual microphone as reported by the authors. The directional advantage, however, varied considerably ranging from as little as 3.5 dB and as high as 16.1 dB (Nilsson et al., 1994).

When it comes to benefits with respect to speech perception with directional microphones, a study conducted by Bentler et al. (2006) showed that the directional microphones showed better speech perception than omni-directional microphones in the presence of stationary noise. Similar study by Blamey and his colleagues in 2006 assessed speech perception in omni-directional, super-cardoid and adaptive directional microphone mode showed that the adaptive directional microphone gave better performance in Hearing in Noise Test and was widely preferred by most listeners.

A contrasting result was shown in a study conducted by Bentler et al. (2004). Directivity of the hearing aid and listener performance were assessed. The results showed that no substantial difference was observed in Hearing in Noise Test (HINT) results and Connected Speech test (CST) across omni-directional, cardoid, hyper-cardodi, super-cardoid and monofit. The listeners initially attempted directional mode in an unfavourable listening conditions after obtaining their hearing aids, but did not find much change in their ability to interpret directional speech. As a consequence, they actually left their hearing aids in all listening conditions set in the default omni-directional mode.

For certain experiments in which subjective gain, preference, or both were measured in daily life, directional microphones in some listening conditions appeared to have a significant performance advantage over omni-directional microphones (Mueller et al., 1983; Kochkin, 1996; Kuk, 1996; Schuchman et al., 1999; Yueh et al., 2001). Many experiments wherein the field and laboratory measurements have been performed imply that the directional gain usually experienced in daily listening conditions is smaller than predicted, on the basis of the directional advantage found in the research lab. (Nielsen, 1973; Valente et al, 1995; Preves et al, 1999; Boymans & Dreschler, 2000).

In a clinical trial of switchable omnidirectional / directional microphone hearing aids, a disparity between field and laboratory measures was also noted (Walden et al., 2000). When using a directional microphone mode, the listeners did notably better on speech recognition in noise tasks in the laboratory relative to how they performed in the omnidirectional microphone mode. Those differences in performance, however, were not seen in perceived benefit measurements in daily situations. There seem to be a variety of potential reasons for the difference between real world and laboratory output of directional microphones. One of the significant reasons is that the laboratory assessments helps to recognize the speech in noise well in a laboratory condition and this can exaggerate the practical advantages of directional microphones (Amlani, 2001). Therefore lab test situations are sometimes designed to take control of directional microphone technology (i.e., front signal and back or side noise) and could be very different from the real-world patient listening situations.

2.3.2 Factors affecting directional microphone functionality

There are many factors that could affect the proper functioning of the directional microphones. The following are few of the factors which can deviate the directional microphone's performance:

- Noise and reverberation
- Hearing aid positioning
- Type of hearing aid
- Degree of hearing loss
- Audiometric configuration
- Listening environment of the user

Simulation of a noisy listening environment has been achieved in many studies by placing a single source of noise directly behind the recipient, i.e., at 180º azimuth (Lentz, 1972). In comparison, the measurement approach that utilizes the signal in front of the listeners and the noise immediately behind the listener would provide full advantage to microphones with a fixed sensitivity of 180º azimuth. In addition to the spatial separation between speech and noise, even presence of revebration affects directionality in hearing aids (Hawkins & Yacullo, 1984; Madison & Hawkins, 1983; Studebaker, Cox & Formby, 1980).

Comparing the directional microphone, omni-directional and ear microphone positioning, Dillon and Macrae (1984) inferred that, at least at 2 kHz, the directional aid received a SNR of 4 to 5 dB greater than that of a non-directional aid or an ear microphone model. Many hearing disabled individuals are generally best suited by a directional microphone positioned above the ear than by a non-directional microphone in the ear. A research performed by Hausler (1985) found that the hearing aids with directional microphones behind the ear did much better than those using other types of hearing aids.

Directional hearing aids may help most hearing disabled with mild to moderate hearing impairment, their use to those with severe to profound hearing loss may be less general as the higher frequency response provided with the directional microphone cannot have adequate low frequency enhancement, particularly for someone with intermittent low frequency hearing. On the other hand, for those with severely sloping high frequency hearing losses, directional high gain hearing aid may be of great benefit (Buerkli & Halevy, 1986).

Ricketts and Mueller (2000) analyzed the outcomes of three independent laboratory studies to decide whether the slope of the audiometric configuration, the hearing impairment in high frequency, and/or the aided omni-directional output of speech-in-noise intelligibility tasks is linked to the directional benefit. The authors did not find any connection between any of the above mentioned parameters for each of the studies.

Apart from these factors, cost of the hearing aid also is an important factor affecting the directionality. Within directional microphones, there are different types. The number and type of directionality functions vary depending on the cost of the hearing aid (Bentler and Chiou 2006). In other words, the hearing aid cost increases as there is a rise in technological development. The premium or higher end hearing devices incorporate a more complex, adaptive version of the features along with other advanced features which are not usually available in the primary/basic level hearing aids. Johnson et al. (2017) conducted a study to check the directionality functions in a premium and a basic level hearing aid. In their study, the premium hearing aids showed better performance than the basic level hearing aids.

Studies which have assessed the cost-effectiveness of the hearing aids have revealed mixed results. In addition, there have been a very few studies that have focused on the cost-benefit obtained in certain features of the hearing aid. Therefore, there was a need to find out, whether there is an actual difference in the performance and whether there is a variation in the quality of perception in a high-end hearing aid when compared to low-end hearing aid or not. Hence, the present was taken up.

CHAPTER 3

METHOD

In the current study aimed to compare the subjective benefits of directional microphone in high cost with that of low cost hearing aids in older adults. The subjective benefit was assessed using speech intelligibility and speech quality measures.

3.1. Participants

A total of 15 older individuals in the age range of 50 to 76 years (Mean = 61; SD = 8.93) were included in the study. Following selection criteria was used to select participants and informed consent was received from the selected participants.

3.1.1. Inclusion criteria

- Individuals with bilateral symmetrical mild to moderately-severe hearing loss or an asymmetrical hearing loss of within 15 dB (Gatehouse, Naylor & Elberling, 2006) were included.
- Individuals who were first time users of hearing aid with Kannada as their native language were included.
- Participants with ‘A’ or ‘As’ type of tympanogram were included
- The acoustic reflex thresholds were appropriate to the degree of hearing loss,.
- Individuals with speech identification scores (SIS) of > 70%, indicating no possible retro cochlear pathology, were included (Narne & Vanaja, 2008).

3.1.2. Exclusion criteria

- Individuals with any active middle ear pathology were excluded
- Individuals with neurological, cognitive and psychological problems were excluded. The details on above aspects were obtained from a detailed case history.

3.2. Instrumentation

- A calibrated clinical audiometer (GSI 61) with TDH-39 earphones included in MX-41 AR supra-aural ear cushions were used to estimate air-conduction thresholds, speech recognition thresholds (SRT) and SIS; and Radio Ear B-71 bone vibrator to estimate bone conduction thresholds was used.
- A calibrated middle ear analyzer 'Grason- Stadler Tympstar' (version 2) was used to assess the middle ear status and functioning of the middle ear.
- Two digital behind-the-ear hearing aids of same company with different cost range were used. They had a fitting range of mild to moderate hearing loss. The cost of the high cost hearing aid and low cost hearing aid was ₹1,00,000 and the ₹20,000 respectively. The high cost had nine channels with multiple options for directionality, such as, autoscope adaptive directionality, DIR control, omni directionality and fixed directionality features. The low cost hearing that was selected had options of omni and fixed directionality features only.
- The hearing aids had the option to enable and disable directionality and digital noise reduction algorithms.
- A personal computer with NOAH-3 software connected with Hi-Pro and Airlink, appropriate programming cable and hearing aid specific program was used to program the hearing aid. Appropriate cable for programming and specific program software

given by that particular hearing aid company had been used to program the hearing aid.

- A personal computer connected to the auxiliary input to the speaker was used to present the stimuli for testing.

3.3. Stimuli:

- SRT testing was carried out using Kannada spondee word list developed by the Department of Audiology, All India Institute of Speech and Hearing, Mysuru.
- The SIS was obtained using the PB word lists (4 lists of 25 words) which were developed in Kannada by Yathiraj and Vijayalakshmi (2005)
- A paragraph in Kannada, developed by Sairam (2003) having all the speech sounds of Kannada was used for quality rating.
- The quality rating scale developed by Eisenberg and Dirks (1995) was adapted and modified for the study. The rating scale was slightly modified and quality with four parameters was rated by the listeners using a five point rating scale.

3.6. Test environment

The complete testing was done in a sound treated double room set up with ambient noise level within the test room within the permissible limits (ANSI S3. 1999).

3.4. Procedure

3.4.1 Routine hearing evaluation

All participants were subjected to pure-tone audiometry for octave frequencies between 250 to 8000 Hz for air conduction, and 250 to 4000 Hz for bone conduction using modified Hughson and Westlake procedure (Carhart & Jerger, 1959). A calibrated dual channel diagnostic audiometer was used for the same. Calibrated GSI-61, dual channel diagnostic audiometer with TDH-39 supra-aural headphone housed in MX-41 AR cushion, B-71 bone vibrator and loudspeakers were used for routine audiological evaluation. SRT and SIS were also obtained.

Immittance evaluation included both tympanometry and acoustic reflexes. Acoustic reflexes were traced using 226 Hz probe tone at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz.

3.4.2. Hearing aid fitting

The low cost hearing aid which was about ₹22,000 in cost approximately was connected to a personal computer with NOAH-3 software connected through Hi-PRO with appropriate programming cable. The high cost hearing aid which was about ₹1, 00,000 approximately was connected to Airlink through the personal computer. The programming was done based on the NAL-NL2 formula for mild to moderately-severe sensori-neural hearing loss and hearing aid was fitted to the listener. Gain was modified till the listener was able to repeat all the ling sounds and based on the listeners' comfort. A routine hearing aid evaluation was carried out by testing with five questions and by obtaining SIS at 40 dB HL to ensure that the gain settings were adequate. The compression settings and gain settings was comparable between the two hearing aids. Digital noise reduction and feedback algorithms were disabled. Fixed directionality option was chosen in both the categories of hearing aids.

3.4.3. Procedure to assess speech perception in noise

Speech intelligibility in noise was evaluated by using the sentence test in Kannada developed by Geetha et al. (2014). This test has 25 equivalent lists with ten sentences each. The sentence used was calibrated and presented from the front (0º angle) and the noise from 180º angle. There were four aided conditions: 1) testing with a high cost hearing aid with directionality enabled; 2) testing with a high cost hearing aid with directionality disabled; 3) testing with a low cost hearing aid with directionality enabled; 4) testing with a low cost hearing aid with directionality disabled.

In all the conditions, the sentences were given at different signal to noise ratios. Four talker Kannada speech babble developed by Nayana, Keerthi and Geetha in 2016 was used as background noise. The sentences were presented at a constant level of 40 dB HL and the intensity of noise was varied to find out SNR-50. The signal to noise ratio was decreased from +8 dB SNR to -10 dB SNR in 3 dB steps from sentence 1 to 10 in each list. The listener was instructed to repeat what they heard. The tester wrote down the responses. The difference in the level of noise and speech that resulted in 50% speech recognition scores were noted down as the SNR-50.

Before the actual test started, a practice session was held. Participants were instructed that they will be presented with sentence in Kannada in the midst of multi-talker babble at various SNR's in the background and were asked either to write down the sentence or repeat the sentences. In order to reduce the order effect, the test conditions were given randomly. Each sentence lists were used only once in order to avoid practice effect. The correct key words identified were counted at each SNR. The SNR-50 was calculated using the Spearman-Karber equation:

SNR-50= I + ½ (d)- (d((#correct)/ (w)

Where,

I = the initial presentation level

D = the attenuation step size

W = the number of key words decrement

#correct = total number of correct key words

3.4.4. Procedure to obtain self-perceived quality rating

The participants were instructed to rate the quality of speech with two hearing aids using the five point rating scale. For this, Kannada sentence list developed by Sairam (2003) was presented through loudspeakers at most comfortable levels. The speech babble was presented at +10 dB SNR from a loudspeaker kept at 180º angle. Participants were asked to rate three parameters of quality on a five point rating scale. The parameters included loudness, clearness and naturalness parameters. The five point rating scale is as follows:

- 0 = very poor
- 1 = poor
- 2 = fair
- 3 = good
- 4 = excellent

Following are the parameters and the instructions used for speech quality assessment:

- Loudness: The passage given is loud enough, as opposed to soft or faint
- Clearness: the passage is clear and distinct as opposed to blurry and diffuse.
- Naturalness: The passage sounds as if there is no hearing aid, and the narration sounds close to the original.

3.5. Statistical analysis

The data were subjected to statistical analysis using the SPSS (Statistical package for social science) software version 20. Shaprio-Wilks test of normality revealed that the SNR-50 data had normality; therefore, parametric tests were used to analyze the data. A repeated measure ANOVA was used to find the significant difference between the high cost and the low cost hearing aids' performance. Bonferroni pair-wise comparisons were carried out to compare between the two conditions. The normality assessment for the quality rating assessment revealed that the data did not have normal distribution. Therefore, Wilcoxon signed rank test was used to analyze the data.

CHAPTER 4

RESULTS

The current study aimed to compare the perceptual benefits of directionality in high priced and low priced hearing aids through SNR-50, and to compare self related quality of speech between the high cost and low cost hearing aids. The results are presented under the following headings:

4.1.Effect of cost of the hearing aids on speech intelligibility in noise.

4.2.Effect of cost of the hearing aids on quality rating

4.1. Effect of cost of the hearing aids on speech intelligibility in noise

The SNR-50 is the signal-to-noise ratio required for the listener to repeat 50% of the words correctly. The target sentences were presented at a fixed level and the level of babble was changed, therefore altering the SNR for each sentence. The scoring was based on the correct repetition of four key words per each sentence. SNR-50 was obtained in high priced and low priced hearing aids with and without directionality. The mean and standard deviation (SD) of the SNR-50 in all four conditions are given in Table 4.1.

Table 4.1

Mean and standard deviation of SNR-50 in all the conditions (N= 15)

Conditions	Mean	SD
High cost hearing aid with Directionality OFF	-1.90	4.57
High cost hearing aid with Directionality ON	-2.95	4.75
Low cost hearing aid with Directionality OFF	0.95	5.27
Low cost hearing with Directionality ON	-2.68	5.82

In Table 4.1, it is clear that the high cost hearing aids yielded better scores than the low cost hearing aids. There was also a difference seen in the performance between the two selected hearing aids. The directionality "on" condition in each of the hearing aids yielded best scores than in "off" condition. The normality assessment was carried out using Shapiro-Wilk normality test and the results showed that data followed normal distribution.

Repeated measures ANOVA was done to check whether there was a significant difference in the SNR-50 between the above mentioned conditions. The results of Repeated measures ANOVA showed that there was a significant difference observed among the conditions tested [$F(3, 42) = 9.930$, $p < 0.001$]. Bonferroni pair-wise comparisons was done to find out which of the conditions differed from each other.

Table 4.2

Results of Bonferroni pair-wise comparison of SNR-50 between different aided conditions

Conditions	Factor	Mean Difference	Standard Error	Significance
High cost hearing aid with Directionality OFF	High cost hearing aid with Directionality ON	1.050	0.577	0.543
	Low cost hearing aid with Directionality OFF	-2.850	0.775	0.15*
	Low cost hearing with Directionality ON	0.783	0.830	1.000
High cost hearing aid with Directionality ON	High cost hearing aid with Directionality OFF	-1.050	0.577	0.543
	Low cost hearing aid with Directionality OFF	-3.900	1.035	0.012*
	Low cost hearing with Directionality ON	-0.267	0.844	1.000
Low cost hearing aid with Directionality OFF	High cost hearing aid with Directionality OFF	2.850	0.775	0.543
	High cost hearing aid with Directionality ON	3.900	1.035	0.012*
	Low cost hearing with Directionality ON	3.633	0.672	1.000
Low cost hearing with Directionality ON	High cost hearing aid with Directionality OFF	-0.783	0.830	1.000
	High cost hearing aid with Directionality ON	0.267	0.844	1.000
	Low cost hearing aid with Directionality OFF	-3.633	0.672	0.001*

Note. $p < 0.05$.

Table 4.2 shows that there is a significant difference seen between the SNR-50 of high cost and low cost hearing aids. The high cost hearing aid yielded significantly better scores than the low cost hearing aid with directionality off. When the directionality was enabled there was no significant difference observed between two hearing aids. The SNR-50 of low cost hearing aid with directionality disabled condition had the poorest performance out of all four conditions. In contrast, the high cost hearing aid with directionality enabled condition gave the best performance out of all the four conditions, though it was statistical significant different from low cost hearing aid with directionality on condition.

4.2. Effect of cost of the hearing aids on quality rating

The subjective quality rating was done by the listeners for both the high cost and low cost hearing aids. The listeners quantified the loudness, clearness and naturalness using a four point rating scale. The mean and standard deviation of this is given in the Table 4.3. The table contains the rating of loudness, clearness and naturalness for both high cost and low cost hearing aids.

Table 4.3

Mean and SD of all the conditions of quality rating

Conditions	Parameter of Quality	Mean	SD
High cost hearing aid	Loudness	3.20	0.676
	Clearness	2.33	0.723
	Naturalness	2.06	0.703
Low cost hearing aid	Loudness	3.133	0.743
	Clearness	2.66	0.487
	Naturalness	2.40	0.632

The Wilcoxon pair-wise comparison was used to know whether there were any statistical differences among the conditions. Results of the Wilcoxon pair-wise comparison showed that there was no significant difference between high cost and low cost hearing aids on the self-perceived quality rating task. The results are provided in Table 4.4.

Table 4.4

Results of Wilcoxon Signed Rank test with pair-wise comparison of sound quality between high cost and low cost hearing aids

Conditions	Z value	P value
Loudness	-1.000	0.31
Clearness	-1.508	0.13
Naturalness	-1.890	0.06

CHAPTER 4

DISCUSSION

The perceptual benefits of high cost and low cost hearing aids were assessed in the elderly population with hearing impairment. The perceptual benefits were assessed by obtaining the speech intelligibility in noise using SNR-50 measure, and by conducting a quality rating assessment in the high cost and low cost hearing aids.

4.1. Effect of cost of the hearing aids on speech intelligibility in noise

The results showed a significant difference in SIS obtained between the high cost and low cost hearing aids when the directionality was off. The least scores were obtained in the omni-directional mode of low-end hearing aid. The above results were similar to the study conducted by Wu et al. (2019). Wu et al. reported that premium hearing aids have greater advantage with respect to microphone directionality and noise reduction algorithm than a basic level hearing aid, in a laboratory setup. These results could be explained with the difference in the technology level which often means a difference in cost (Newman and Sandridge 1998). For instance, the number of frequency bands for processing speech signal could be different.

There was a difference in SNR-50 between high and low cost directional conditions, but, the difference was not significant. There are different ways in which directionality can be achieved. Directional mix option is an exclusive feature available in some high cost hearing aids. The hearing aid included in the current study also had this option. The directional mix hearing aid allows the high frequency and low frequency to be treated separately and differently. Directionality is applied to high pitches, while low pitches always remain in omni-directionality option (Cox, Johnson, and Xu 2014a). This could have contributed to the slight improvement in performance in high cost hearing aids.

A similar study was conducted by Johnson et al. (2017) on localization in premium and basic level hearing aids. The results showed that the premium hearing aids yielded overall better performance than the basic level hearing aids when tested in a laboratory set-up. The premium hearing aid used by the authors in their study had multi- channel adaptive directional microphones, advanced synchronization which helped in binaural volume, program control and noise reduction control for the two devices and pinna ear stimulation. It also included more advanced versions of feedback cancellation, noise reduction algorithms of basic level hearing aids as reported by the authors. A device with more benefits for a particular cost is considered to facilitate greater value than that with the same cost with lesser benefits. This is suggestive that a patient accepts the device if they facilitate a greater benefit per unit cost.

However, in the current study, the difference in SNR-50 between high and low cost directional conditions was not significant. One of the reasons could be that, except for the directionality settings all the other advanced features were turned off. Environment auto balance feature of the premium hearing is not accessible in the basic level hearing aid. This feature employs speech and noise detection algorithms based on the frequency content and spectral balance resulting in classification of listening environments which shows good consistency with the listener perception (Cox et al. 2014a). However, this option was not enabled as the aim was to assess only the directionality. Another reason could be that the test conditions were too simple, i.e., the speech was from front and the noise from the back which is an ideal condition, and fixed directionality mode was assessed. These results indicate that, in the tested conditions, directionality feature in the premium or the high cost hearing aid lead to only slight improvement. Nevertheless, the participants informally expressed their preference for the high cost hearing aid. Similar results were noted in the study conducted by

Johnson et al. (2017) where the author has explained that in order to view and compare between the hearing aids, a careful, informed and mindful comparisons is required.

When the benefit of directionality versus the omni-directional options within each hearing aid was compared, the results revealed that the directionality gave a better performance than the omni-directional microphones in both high cost and low cost hearing aids. The directional microphones are contrasted to omni-directional microphones as their output level is completely dependent on the direction of the sound origin. By and large the omni-directional microphones give equivalent yield to sounds coming from all the directions when the testing is done in a free field condition (Cord et al., 2004; Hawkins & Yacullo, 1984; Ricketts & Dhar, 1999; Wu et al., 2019).

4.2. Effect of cost of the hearing aid on quality rating

The results revealed no significant difference in quality ratings between high cost and low cost hearing aids. Similar results can be seen in the study conducted by Cox, Johnson, and Xu (2014b). Cox et al. assessed the quality of life in a premium hearing aid and a basic level hearing aid. The results revealed that the lower cost hearing aid resulted in similar performance as that of high cost hearing aid.

Newman and Sandridge (1998) considered three different hearing aids technologies and assessed the benefit, satisfaction and cost effectiveness. The results revealed that in the self report measurement for the perceived benefits and satisfaction in everyday life, there was no significant difference seen between the three hearing aids. The reason for lack of significant difference was attributed to the large within and between subject response variability and also due to the number of non-audiological factors such as the mood, concentration and expectations of the subjects.

However, Wu et al., (2019) reported a slightly better performance in the self reports of the subjects fitted with premium and basic level hearing aids with directional microphone/ noise reduction feature on condition. A better quality report might have been obtained with multiple advanced features on condition in high cost hearing aid than in basic level, where a clear picture of quality performance might have been reported between the two ranges of hearing aids.

CHAPTER 5

SUMMARY AND CONCLUSION

The current study aimed to compare the benefits of a high cost hearing aid with that of a low cost hearing aid in elderly individuals. Speech intelligibility in noise test was carried out along with quality rating assessment. The fixed and omni-directionality features were also compared between the high cost and low cost hearing aids. Fifteen individuals, with the age range of 50 to 70 years were considered for the study. All the fifteen participants were native speakers of Kannada and were naïve users of hearing aid. Statistics were carried out using the SPSS software (v. 17 for windows).

The results revealed a significant difference between the high cost and the low cost hearing aids giving the best performance than the low cost hearing aid in some conditions on the speech intelligibility in noise task. There was a difference in SNR-50 between high and low cost directional conditions, but, the difference was not significant. The high cost hearing aid with directionality enabled gave the best performance among the four conditions and omni-directionality with low cost hearing aid yielding the poorest performance. Comparison of the directionality enabled conditions with the omni-directionality features within each hearing aid revealed that the performance of directionality yielded better performance in the presence of noise, in both high cost and the low cost hearing aids, though the difference was not statistically significant.

Quality rating assessment was done where the subjects had to rate the performance of the two ranges of hearing aids, on loudness, clearness and naturalness of the sound perceived. There was no significant difference seen between the high cost and low cost hearing aid on quality rating task.

To conclude, the high cost hearing aid yielded comparatively better performance than a basic level hearing aid in the speech intelligibility in noise task. However, most conditions failed show a significant difference. There were no significant differences obtained with respect to quality rating between the premium and the basic level hearing aid. The results apply to the settings used in the current study. If the testing conditions made more complex and there might have been differences between high cost and low cost hearing aids.

5.1. Implications

- The results of the current study can be utilized to counsel the individuals during the selection of the hearing aids while considering cost in elderly populations with mild to moderate hearing loss.

5.2. Future directions

- Assessment of real life performance with the low cost and high cost hearing aids can be done.
- Further studies on the benefits of other advanced features such as noise reduction algorithms in high cost and low cost hearing aids would be helpful.

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