COMPARISON OF HEARING AID PROCESSED PHONEME OBJECTIVELY ACROSS DIFFERENT MANUFACTURERS, MODELS AND COST OF HEARING AID

SAHIL SHARMA

Register No: 20AUD028

A Dissertation Submitted in

Part Fulfilment of

Degree of Master of Science in Audiology

University of Mysore, Mysuru

ALL INDIA INSTITUTE OF SPEECH AND HEARING,

MANASAGANGOTHRI,

MYSURU-570006

CERTIFICATE

This is to certify that this dissertation entitled "**Comparison of Hearing Aid Processed Phoneme Objectively Across Different Manufacturers, Models, and Cost of Hearing Aid"** is a Bonafide work submitted in part fulfilment for the degree of Master of Science in Audiology of the student Registration number 20AUD028. 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 award of any other Diploma or Degree.

August, 2022
Mysuru

Dr. M. Pushpavathi
Director
All India Institute of Speech and Hearing
Manasagangothri, Mysuru- 570006

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August, 2022
Mysuru

Dr. Animesh Barman
Guide
Professor
Department of Audiology
All India Institute of Speech and Hearing
Manasagangothri, Mysuru- 570006

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DECLARATION

This is to certify that this dissertation entitled "**Comparison of Hearing Aid Processed Phoneme Objectively Across Different Manufacturers, Models, and Cost of Hearing Aid** " is the result of my own study under the guidance of Dr. Animesh Barman Professor in Audiology, All India Institute of Speech and Hearing, Mysuru and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

August, 2022 **Registration**

Mysuru **No.:20AUD028**

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Acknowledgements

This dissertation has been a great learning experience throughout its course. At the very outset of this report, as I stand to complete this work, I would like to extend my heartfelt obligation to all the persons who have helped me in this endeavour. Without their active guidance, support, helps, cooperation and encouragement, I would not have made headway in this study.

I am highly thankful to my faculty guide ***Dr Animesh Barman*** *for his guidance and valuable advice and support in accomplishing this study. The little things you have taught me regarding the writing, presentation and overall approach during the dissertation are impeccable. Thank you for believing in me and playing a significant role in moulding me into the person I am today.*

I would also like to extend my gratitude to our director, ***Dr M Pushpavathi****, for providing me with the opportunity and resources to carry out this research*

A special mention goes to ***Ms. Shubhganga*** *for your precious time despite being busy with your thesis works. You were prompt and concerned, and I am thankful for being directed to you for help during my dissertation journey. I want to thank* ***Dr SundarRaju*** *for guiding me whenever I went to ENT clinics. I want to mention our faculty member, mentor, and warden* ***Dr Sujeet Kumar*** *for helping me and guiding me whenever I needed help. Noteworthy to say to* ***Dr Prawin Kumar, Dr Niraj Singh, Dr Sandeep Maruthy, Dr Geetha, Dr Sreeraj,*** *and* ***Dr Prashant Prabhu*** *for your teaching, and guidance, throughout the Master's Life.*

I want to acknowledge my heartfelt gratitude towards ***Mumma, papa****, and* ***Sethu****, who has always supported me morally, with a deep sense of reverence.* ***Akshuu, Ravinder sir, Guri sir, Himanshu sir, Gaggu veer, Vivek, Rahul, Robin,*** *you have*

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been there for me. Thank you for all those fun, parties, exam nights, and countless conversations and discussions. Thank you for always watching out for me and being there for support. Thank you for being my extended family.

A sincere vote of thanks to ***Vrushali*** *who helped me a lot during this dissertation, thanks to you for the laughters, food sessions, walks, drives, and helping me out in every possible way. A vote of thanks to all the participants who were such a support and volunteered for my dissertation.*

I want to extend my gratitude towards my Seniors, fellow batchmates, juniors in PGI, ***Raman mam, Rajwinder mam, Appu sir, Kirti sir, Himanshi, Ritika, Manisha, Sagrika, Komal, Atul, Mohit, Payal, Tanvi and Akshay****. I would like to thanks* ***'Shanivaar raat'*** *thank you for your timely motivation, right from the beginning and throughout the journey in MYSORE.* ***Vrushali, Yasha, Sajana, Ankita, Mudra, Amit, Ashish, Bhawani,*** *we laughed at the silliest jokes, put up with the worst mood of each other, had endless daily doses of fun and went along with the craziest ideas and plans. Those stupid things that we did together made my college life filled with wonderful memories.* ***Shubham, Rohit, Jargar, Amar, Shashish, bahis, Delvin, Akshay,*** *thank you for being good friends throughout and all the amazing chats we have had.* ***Dwijender, Abishek, Rohan, Ahnaf, Sooraj, Abranil, Avesh, Saroj, Nishant, Rounak*** *My brothers who made my hostel life better. Just so you know, you're few of the people I truly look up to. Thankyou* ***Akhil sir, Prajwal sir, Sachin sir, Aman sir, Sunny sir, Khakha sir, and Surya sir Last but not least, I want to thank me, I want to thank me for believing in me.*** *Any omission in this brief acknowledgement does not mean a lack of gratitude. Thank you for all the little things I picked up from you people. It was fun with you all. And, dear readers, this research's value lies in how you see it. I trust you and thank you for the proper use in advance.*

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CHAPTER I

INTRODUCTION

Hearing loss is a common health problem that affects 10% of children (Niskar etal., 1998), 20% of adults, and 50% of older adults in the United States. Hearing loss is the Second most prevalent impairment in India (0.3%), (National Sample Survey Office (NSSO), 2018). The prevalence of hearing loss is observed to be higher in rural regions and among the elderly. Community-based studies (all ages) revealed a prevalence of hearing loss between 6 and 26.9 per cent and a majority of debilitating hearing loss between 4.5 and 18.3 per cent (Verma,2022). The prevalent issue of hearing loss is brought on by loud exposure, ageing, illness, and hereditary reasons. Hearing loss if left untreated, not only can lead to communication problems but also social withdrawal, isolation, depression and a lower quality of life (Chisolm et al., 2007). Besides, additional impacts of hearing loss as social involvement, emotional-behavioural well-being and work status are also affected. (Northern & Downs, 2002). Though communication issues are unavoidable among individuals with hearing loss, the severity of impact would depends upon degree of hearing loss and speech perception abilities to a greater extent.

The majority of hearing losses (92%) are mild or moderate, according to the 'Action On Hearing Loss' (AOHL), (2015) which considers all the data for hearing impaired in Unitrd Kingdom. In addition to the audibility, temporal and spectral processing deficits are also reported in individuals with hearing loss which often worsens their speech perception (Goossens et al., 2017). It has been noted (Dubno et, al.,1984) that people with even a moderate hearing loss, whose speech discrimination in quiet is as excellent as that of listeners with normal hearing, may struggle to interpret speech in the natural noisy environment. It is because of these communication

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challenges faced by individuals with hearing loss in daily life that seeking a management strategy is critical.

Except for conductive pathology, it is expected that the most common type of hearing loss is sensorineural, which might involve some loss of outer hair cells. Furthermore, there are no viable medical or surgical treatments exists for mild to moderate sensorineural hearing loss (Chisolm et al., 2007), leaving hearing aids as the best alternative for rehabilitation for hard-of-hearing individuals.

Reduced audibility and frequency selectivity are the results of outer hair cell loss (cochlear loss). One of the major factors influencing speech perception is likely to be reduced frequency selectivity. Depending on the patient and the situation, the use of hearing aids reduces the hearing handicap up to 70 percent (Kochkin, 2011). A hearing aid should deliver the right amount of amplification to maximize speech recognition, provide high-quality sound, and provide comfortable amplification for a successful fitting (Skinner, 1988).

Hearing aids improve speech audibility while preserving important speech cues and avoiding distortion. Hearing aids are effective in many situations, especially in quiet environments, despite the difficulties. However, they are of limited use in difficult listening situations such as distant talkers, noisy rooms, and high reverberant situations. In order to cope up with the expectation of end users, hearing aid manufacturers have incorporated many digital technologies inside these devices. Hearing aid speech processing strategies are those technologies which process the speech signal and helps in making the signal audible for the hearing impaired person. The process involves making the signal more audible and intelligible. These processing techniques are also

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known as the hearing aid speech processing strategies. Several types of Hearing aid speech processing strategies can be used to address these issues.

Hearing aids are typically designed so that frequency bands with lower hearing thresholds receive more gain. The first, NAL-NL2 (Dillon et al., 2011), aims to maximise speech intelligibility while limiting overall signal loudness. In the United States and Australia, this is the most common procedure used for fitting hearing aids to adults. The second is DSL v5 (Scollie et al.,2005) which often result in wider audible bandwidth, greater gain, and sometimes higher compression ratios than NAL-NL2. The third procedure is CAMEQ, it has two goals, one is to give an overall loudness and second is to make all frequency components in speech equally loud (500–4K Hz). This has shown an improve in speech clarity and recognition of specific high-frequency phonemes (Moore, 2013). However, all these fomule are likely to alter acoustic parameters of the processed output of the signal.

When providing gain it is unlikely to achieve high-frequency audibility, frequency lowering can be used to shift the frequency of the input signal to a lower frequency region. However, frequency lowering alters the acoustic characteristics of the shifted phoneme. Amplitude compression is the feature working towards loudness compression and is available in most of the modern hearing aids. The incoming signal is first divided into frequency bands. When the level in a given band exceeds the compression threshold, the gain decreases progressively as the input level increases, which is likely to alter the acoustic characteristcs of output signal from the hearing aids. Directionality and digital noise reduction (DNR) are the two common technologies of hearing aid used in distinguishing speech and background noise. However, in the process of noise cancelation, it might also alter the acoustic properties of speech signal.

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Hence from the above facts it is evident that when hearing aids are used, the signal processing can significantly alter and/or degrade the speech signal. Such signal processing may include WDRC with a short release time, frequency reduction, and digital noise reduction, or it may introduce amplitude fluctuations that affect intelligibility. Reliance on affected transmitted information has repercussion for speech perception (Romberg et al., 2013).

Hence there is a need to verify the hearing aid processed signal with respect to unprocessed or unaided signal. Hearing aid verification is an important component of the hearing aid evaluation (Cox, 1999). There are different methods for verification of hearing aids. Behavioral Comparisons method is the easiest and simple method in which patient performance with or without hearing aids was evaluated using traditional word recognition tests. Real-Ear Verification Measures is another approach where probe-microphone measurements were used to confirm that the hearing aid's prescribed real-ear gain met the desired targets. They calculated insertion gain correctly, but the bad news is that they do not provide any information about the patient's speech understanding ability in realistic listening situations and also the quality of the acoustic features of the hearing aid processed signal.

Electro Acoustic Characteristics (EAC) measurements is one of the objective measure for the performance characteristics of a hearing aid, that is the changes affected in a signal as it is transduced from acoustic to electric to acoustic energy. Standard parameters assessed are like, Output sound pressure level (OSPL-90), HF average OSPL 90, Full-on gain, and HFA full-on gain, frequency response curve ,battery current drain**,** and Equivalent input noise level (EIN). However, measurements of all these parameters precisely does not indicate the quality of the hearing aid processed

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signal, it temrs of change in frequency, harmonic distortion, jitter etc between unprocessed and hearing aid processed acoustic signals.

There is a lack of evidence suggesting that present objective methods of assessing hearing aids are appropriate. Thus being an audiologist we find the requirement of the new methods for assessing hearing aids that incorporates both subjective and objective information. By utilizing the knowledge of Audiology and Speech and language pathology, one assess the objective components of speech and speech processed from a hearing aid and see how various parameters are affected**.**

Need of the Study

Hearing aids are continued to be the most favoured option for the sensorineural hearing loss. Processing strategies like compression (WDRC), and frequency lowering affect the temporal features of the signal which sometimes makes the signal difficult or complex to understand. However, processes like amplitude compression cause signal distortion and fidelity loss by compressing the amplitude of signal. Reliance on this distorted hearing aid transmitted information can also distort the signal and affect speech perception (Romberg et al. 2013). Theoretically, it may necessitate that parameters like high gain, skewed frequency response, and extreme compression can improve speech perception, but also this could degrade the acoustic characteristics of the signal more. Instead of that those parameters must be chosen to improve audibility, which is essential for speech perception, while minimising distortion. According to the previously mentioned studies, approximately half of hearing aid dispensers perform aided speech recognition testing in quiet using monosyllabic words, while only 6% use sentence stimuli such as the HINT (Nilsson et al., 1994), SIN (Fikret-Pasa, 1993), or R-SPIN (Bilger, 1984). Few audiologists were using EAC as a method of verifying and

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prescribing the hearing aids that too not on the daily basis. Drawbacks were due to the time-consuming and expensive nature of testing. There is a lack of evidence suggesting that present objective methods of assessing hearing aids are appropriate. There has been a lack of evidence too regarding the objective comparisons between the BTE and RICs processed signal.

Thus being an audiologist we find the requirement of a new method for assessing hearing aids that incorporates objective information. There is an utmost need to measure that provide a better picturisation of the parameters affected during this process of conversion. The spectrum of the speech signal contains perturbations and spectral pieces of information which are crucial for speech perception. Parameters like Fundamental frequency(F0), Jitter (%), Shimmer (dB), Shimmer(%), NHR, and HNR can provide information about these perturbations and spectral splatters. Thus, comparing these parameters pre and post-HA processing can provide us with information regarding these changes happening in the signal objectively. Additionally, when features like digital noise reduction, directionality, and noise masker, were turned off then the hearing aids relied on basic signal processing. Secondly, hearing aid is an electronic devices having several component. Each component is likely to have its own attack time to initiate the function. Like any other equipment hearing aids also are likely to alter the the output of the signal. Thus, objective assessment of hearing aid output is essential.

Objective measurement of the above mentioned acoustic parameters of hearing processed acoustic signal can provide solutions to the problem faced by hearing aid users and help audiologists for considering different factors during the programming and selection of the hearing aids and effectively counsel the client.

Aim of the study

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To objectively assess the hearing aid processed phoneme with respect to the unprocessed or unaided phoneme.

Objectives of the study

(a) To compare the different acoustic parameters (Fundamental frequency, Jitter, Shimmer, NHR, HNR) between hearing aid processed phonemes with unprocessed and unaided phoneme between the male and female voice for different types of hearing aids and phoneme.

(b) To compare the different acoustic parameters (Fundamental frequency, Jitter, Shimmer, NHR, HNR) between hearing aid processed phonemes with unprocessed and unaided phoneme independently across different phoneme.

(c) To compare the different acoustic parameters (Fundamental frequency, Jitter, Shimmer, NHR, HNR) between hearing aid processed phonemes with unprocessed and unaided phonemes between different manufacturers of hearing aids.

(d) To compare the different acoustic parameters (Fundamental frequency, Jitter, Shimmer, NHR, HNR) between hearing aid processed phonemes with unprocessed and unaided phonemes between the RIC and BTE hearing aids across phoneme.

(e) To compare the different acoustic parameters (Fundamental frequency, Jitter, Shimmer, NHR, HNR) between hearing aid processed phonemes with unprocessed and unaided phonemes between the low and high-cost hearing aids across phonemes.

(f) To compare the different acoustic parameters (Fundamental frequency, Jitter, Shimmer, NHR, HNR) between hearing aid processed phonemes with

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unprocessed and unaided phonemes recorded at two different input intensity levels for different types of hearing aids and phoneme.

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CHAPTER II

Review of Literature

The World Health Organization (WHO) defines a disabling hearing loss as a loss in better ear that is greater than 40 dB in adults and 30 dB in children. There are approximately 465 million people around the world who have disabling hearing loss, which is 5% of the global population (Rasiah & Sulakshan, 2018), (WHO; Deafness and hearing loss, 2021). Ruckenstein (1995) (Zahnert, 2011) classified hearing loss as, Conductive and Sensori-neural hearing loss (SNHL). SNHL accounting for almost 90% of hearing loss which is caused due to permanent damage of the hair cells in the inner ear. There is currently no known cure for the damage to hair cells in the ear, so amplification devices such as hearing aids may be one of the most effective ways to manage the condition (Zahnert, 2011). However, there are equivocal reports on the acceptance and benefits of hearing aids by the users. The technology of hearing aids and quality of the processed speech could be a main factor in deciding the satisfaction with hearing aids (Khiavi & Bayat, 2016). Hence the present study is looking further for validation of the objective measures for the analysis of speech parameters which gets affected by the speech processing strategies when speech is processed through the hearing aids. Signal processing Strategies of different hearing aids (BTE and RIC) having implication on the benefits of individuals with SNHL.

A speech signal can be described in physical terms as a modulated spectrum in which both aspects i.e., spectral information and temporal information are relevant. Vowels, semi-vowels, and nasals require good spectral resolution (separate detection of Fl and F2) while fricatives and plosives, on the other hand, are strongly modulated signals differing mainly in time structure. All this information needs to be accurately

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passed through the hearing aids during speech processing for better understanding of speech. Thus, the focus of hearing aid selection should be to make thespeech audible, comfortable and good in quality as far as possible (Mormer, 2000). These goals should dictate how the hearing aids are selected and assessed.

The **amplification strategy** helps in amplifying the signal and making it audible to the hearing aid user. These strategies are broadly divided into linear amplification strategy and Compression amplification strategy. In Hearing aids under **linear amplification strategy,** a constant gain is applied to all input levels until the hearing aids saturation limit is reached. Since daily speech include such a wide range of intensity levels, from low intensity /f/ to high intensity /i/ and soft to loud speech. The benefit of linear amplification gets restricted when it amplifies high intensity sounds to the point of discomfort. To solve the limitations of linear amplification strategy most of the hearing aids now incorporate some form of **compression amplification** strategy in which gain is automatically adjusted based on the intensity of the input signal. The higher the input intensity more the gain is reduced. It is expected that individual using compression hearing aids perform better than those using peak clipping aids in listening condition that include wide range of speech levels (Turner, 1999).

2.1 Effect of processing strategies on Speech

A major problem limiting the efficacy of acoustic amplification systems for SN hearing impairments is that the dynamic range of hearing is reduced significantly. One approach to the problem is to reduce the dynamic range of the speech signal. In order to do so,it is important to take into account the temporal structure of

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speech. Different signal processing strategies results in acoustic modification of the speech signal in both spectral and temporal aspects. These changes might affect the speech perception of the individuals with hearing impairments. There have been various studies reported in literature that shows the relationship of different strategies and speech recognition performance.

2.1 (i) Effect of linear processing strategies on speech

Peak clipping was the commonly used strategy in hearing aids in the 90's in US to limit maximum output. Several earlier studies reported that peak clipping actually increased the intelligibility of speech when the speech was presented in either a background noise (Licklider & Pollack, 1948, Miller & Mitchell, 1947) or in quiet (Martin,1950; Pollack, 1952). But studies by Pollack & Pickett (1958) also reported a slight decrease in word recognition scores as the amount of peak clipping increased. The listeners who have normal or near-normal spectral discrimination ability (Moore, 1996) should be able to extract sufficient spectral and contextual information to compensate for altered temporal cues.

But similar result was found lately (Crain & Tasell, 1994), that the speech recognition thresholds increased both for normal and hearing-impaired subjects with increasing level of peak clipping, with significant threshold shift occurring for clipping levels 18 to 24 dB. With the advancement of technology there has been a development of advanced signal processing circuitry for hearing aids.

2.1 (ii) Effect of nonlinear processing strategies on speech

With the advancement of technology there has been a development of advanced signal processing circuitry for hearing aids. Various forms of nonlinear

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processing came in to use. The commonly used signal processing strategies are Compression Limiting and Wide Dynamic Range Compression (WDRC). Compressing the speech signal into a very small dynamic range using a WDRC for a severely hearing-impaired individual might have deteriorating effects on speech intelligibility by reducing the depth of amplitude modulation in speech by introducing distortion in temporal envelopes, and reducing spectral contrast (Plomp 1988, Stone and Moore, 2004). Marriage and Moore, (2003) reported that WDRC can give significant improvement in consonant discrimination for children with moderate and severe- profound hearing loss.

2.1 (iii) Comparison of effect of linear and nonlinear strategies on speech

Extensive research has compared linear and WDRC circuitry. Some of these studies have shown benefits of compression (Benson, Clark & Johnson, 1992; Moore et al, 1992, Souza and Turner, 1999). Others have reported no significant difference (Plomp, 1994; Crain and Yund, 1995). There has been a report of negative effects of compression on speech perception for some individuals (Hickson et al., 1995). It has been suggested that closer examination of the acoustic properties of the compressed speech signal may help to explain the variations in the findings (Hickson, 1999).

Jenstad and Shantz, (1999) reported that the WDRC hearing aid resulted in high and uniform speech recognition scores. In contrast, the linear gain aid resulted in a lower recognition scores for softer speech and shouted speech relative to that obtained with average speech level. There are reports in literature that show that different degrees of hearing loss get advantage across different amplification strategies. Shanks and Williams, (2002) reported that significant differences favored the peak clipping and compression limiting circuits over the WDRC in mild hearing

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loss groups and favored the WDRC over the peak clipping in the more severe slopping hearing loss groups.

John and Thomas et.al., (2003) studied the effects of the interaction of compression release time and prescribed gain on running speech processed through a hearing aid on KEMAR. A hearing aid programmed to fit a mild to moderate sloping hearing loss, using probe microphone measures to reach targets prescribed by NAL-NL1, DSL I/O, FIG6. Recordings were analyzed to determine the long-term-average-speech spectra, consonant- to-vowel ratios and the RMS amplitude of 32 phonemic units. Aided and unaided results were compared. Within each prescriptive formula, the short release-time condition produced the greatest alteration to the speech signal. Hence, concluding that release time may need consideration when fitting hearing aids to target gain prescriptions.

Souza P.E., and Jenstad L.M, (2005) also attempted to compare speech recognition scores across two different amplification strategies (fast acting WDRC, control compression limiting) for listeners with severe hearing loss and found that the benefits of fast acting WDRC relative to more linear amplification may be reduced in listeners with severe hearing loss when compared to mild-moderate hearing loss.

Moore and Marriage, (2005) studied the effect of three amplification strategies (linear with peak clipping, linear with compression limiting, WDRC) on speech perception by children with severe and profound hearing loss and found that speech score on close set testing for the profound group showed significant benefit for WDRC over the other two algorithms.

Lorenzi, Gilbert, and Brian C. J. Moore, (2006) studied the people with sensori-neural hearing loss ability to resolve the frequency components of complex speech sounds. Speech sounds were processed by filtering them into 16 adjacent

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frequency bands. The signal in each band was processed (by Hilbert transform) to preserve either the envelope (E) or the temporal fine structure (TFS). The band signals were then recombined and presented to subjects for identification. Both young and elderly subjects with moderate flat hearing loss performed well with unprocessed and E speech but performed very poorly with TFS speech, indicating a greatly reduced ability to use TFS. For the younger HI group, TFS scores were highly correlated with the ability to take advantage of temporal dips in a background noise when identifying unprocessed speech during speech identification task. The results suggest that the ability to use TFS plays critical role for 'dip listening' (Lorenzi & Moore, 2006) in background noise. It may be useful in evaluating impaired hearing and in guiding the design of hearing aids and cochlear implants.

Christoph et. al., (2015) did a comprehensive evaluation of eight signal pre-processing strategies, including directional microphones, coherence filters, single-channel noise reduction. This study was undertaken with ten normal-hearing (NH) and 12 hearing-impaired (HI) listeners. Speech reception thresholds (SRTs) were measured in three noise scenarios (multi-talker babble, cafeteria noise, and single competing talker). Results suggest that no significant differences in SRT benefit from the different algorithms were found between the two groups. With the exception of single-channel noise reduction, all algorithms showed an improvement in SRT of between 2.1 dB (in cafeteria noise) and 4.8 dB (in single competing talker condition). Regarding the benefit from the algorithms, the instrumental measures were not able to predict the perceptual data in all tested noise conditions. Although the model can predict the individual SRTs without pre-processing, further development is necessary to predict the benefits from the algorithms at an individual level

Glista, (2017) assessed the Effect of Adaptive Nonlinear Frequency

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Compression on Phoneme Perception. A total of 8 participants, including children and young adults, participated in real-world hearing aid trials. The hearing aid conditions included adaptive nonlinear frequency compression (NFC), static NFC, and conventional processing. Results showed that Enabling either adaptive NFC or static NFC improved group-level detection and recognition results for some high-frequency phonemes, when compared with conventional processing. Mean results for the distinction component of the Phoneme Perception Test (Boretzki & Holube, 2016) were similar to those obtained with conventional processing. Findings suggest that both types of NFC tested in this study provided a similar amount of speech perception benefit, when compared with group-level performance with conventional hearing aid technology.

Valente and Oeding, (2018) investigated the differences in monosyllabic word and phoneme recognition (CNC) in quiet, sentence recognition in noise (HINT), and subjective outcomes using the APHAB and SSQ questionnaires between hearing aids with a first-fit from one manufacturer and the same hearing aids with a programmed-fit using REM for NAL-NL2 prescriptive target. Even though the processing strategies remain same other factors can contribute to the difference in performance and needs to be investigated or controlled. One investigator did all of the REM, while another measured speech recognition scores in quiet and noise. Subjects included twenty-four adults with bilateral sloping (normal to moderately severe) sensori-neural hearing loss and no prior experience with amplification. Participants were acclimatised to each setting for four weeks before returning for evaluation. The results show (1) a significant median advantage of 15% for words and 7.7% for phonemes for the programmed-fit compared to the first-fit at 50 dB SPL and 4% for words at 65 dB SPL for the programmed-fit; and (2) no significant differences for the HINT reception threshold for

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sentences. (3) A significant median advantage of 4.2 percent for the programmed-fit versus the first-fit for the APHAB background noise subscale problem score; (4) No significant differences on the SSQ. They came to the conclusion that 79% of the participants preferred programmed-fitting over first-fit. Hearing aids should therefore be verified and programmed to a prescriptive target using REM rather than no verification using a first-fit.

2.2 Effect of cost of the hearing aid (High End v/s Low End) on speech

Cost of the hearing aid is one of the important factors that can affect the functionality of hearing aids because of the differences in the technology used. There are few studies which have evaluated the influence of cost of the hearing aids on subjective and objective outcome measures.

Mulrow et al., (1990) became one of the pioneers to determine the cost-effectiveness of hearing aids. He measured the psychosocial benefit perceived by the listener and their family members using the Hearing Handicap Inventory for the Elderly (HHIE) and concluded that hearing aid is a cost-effective rehabilitation option for the amount of benefit obtained. Consequently, while both premium and basic directional microphone (DM) and noise reduction (NR) technologies tested in the study are able to enhance the outcomes of hearing aids. However, the older adults with mild to severe hearing loss had no significant differences in the benefits of premium DM and NR features over the basic features.

A contrasting result was found 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 assessment was done using speech recognition

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tests, localization tasks, self-reports like APHAB, SSQ and SADL. 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.

Smith et al., (2016) also compared the fitting capabilities and did the electro-acoustic characteristics analysis for low cost and high-cost hearing aids using OSPL 90, Total harmonic distortion, Equivalent noise level, and REM. 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 gain in the low frequency region. Comparing the harmonic distortion and internal noise aspects, there were no significant differences seen between the categories.

Barry (2018) assessed the objective differences between premium and mid-level hearing aids, where the main focus was on the benefits of noise reduction algorithms in these two hearing aid categories. The data showed that there was no difference in the performances between the mid-level and premium hearing aids when collected from the steady state stimuli. But, 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.

Wu et al., (2018) performed a systematic analysis evaluating the real-world utility of microphone directionality and digital noise reduction between high end and basic level hearing aids. The performance in terms of speech comprehension, listening effort,audio quality, localization and HA satisfaction were assessed using laboratory

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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 and noise reduction technologies outperformed their basic-levelcounterparts. Although both retrospective and in-situ self-reports indicated that participants were more satisfied with HAs equipped with DM/NR features than without, there was no strong evidence to support the benefit of premium DM/NR features and premium HAs over basic DM/NR features and basic HAs, respectively.

2.3 Effect of style of hearing aids on speech BTE versus RIC

Lynzee N., Alworth et al., (2010) determined the effect of receiver location on performance of listeners using open canal hearing instruments. An experimental study was carried on 25 adult subjects with mild to moderately severe sloping hearing loss (mean age 67 year). Probe microphone, objective, and subjective measures (quiet, noise) were conducted for unaided and aided at the end of each trial period. The frequency range was extended in the RIC instruments, resulting in significantly greater gain at 4000 and 6000 Hz. Objective performance in quiet or in noise was unaffected by receiver location. Subjective measures revealed significantly greater satisfaction ratings for the RIC than for the BTE instruments. These authors concluded that although no occlusion differences were noted between instruments, however the RIC hearing aid demonstrate a significant difference in reserve gain before feedback at 4000 and 6000 Hz. These results suggest that such testing may not be sensitive enough to determine aided benefit with open canal instruments.

Prakash et. al., (2013) compared the performance of Receiver-In-Canal (RIC) to traditional ear tip (ET), ear molds (EM) fittings using Functional gain measures.

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They had ten subjects with flat moderately severe sensori-neural hearing loss participating in the study. Subjective unaided and aided pure tones (250 Hz to 4000 Hz) were obtained for digital BTE hearing aids with ear tip or ear mould & Receiver-In-Canal Hearing aids. Result indicates that the RIC hearing aids had highest functional gain values compared to ear mould and ear tip at high frequencies. The lowest functional gain values are for ear tip fitting. There is a significant difference in ET v/s EM only at 2000 Hz and no significant difference at other frequencies. There is significant difference in ET v/s RIC at all frequencies except 500 Hz; and also, there is significant difference in EM v/s RIC at all other frequencies except 500 Hz, 2000 Hz, indicating that RIC is significantly better than ear tip and ear mold fitting in most conditions. Hence this study suggests that RIC fitting is an effective means of overcoming the barriers to the acceptance of amplification and further suggest the clinical importance of subjective parameters in measuring aided benefits of devices in the rehabilitation of persons with hearing loss.

Recently, Mondelli et al., (2015) also compared the performance of speech perception using the receiver in the aid (BTE) and receiver in the ear hearing aids (RIC). The authors found no significant difference in speech perception between the two types of hearing aids. It was inferred that similar speech perception in these two types of hearing aids could be because of the similar output characteristics as revealed by the probe microphone measurements in the study.

In his study "Open Versus Closed Hearing-Aid Fittings: A Literature Review of Both Fitting Approaches," Alexandra Winkler (2016) concluded that occlusion can be reduced with open-fit hearing aids, as well as sound quality, localization, and wearing comfort can be improved. However, open-fit hearing aids have some limitations. First, if the required Real-Ear Insertion Gain (REIG) is greater than 20 dB, Real-Ear

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Measurements (REM) verification of hearing-aid fittings should be performed using the stored equalization method. Second, the interaction of direct and amplified sounds could be possible and result in audible artifacts and a reduction in subjective sound quality. Third, the benefit of adaptive features such as directional microphones or noise reduction algorithms can be reduced, as can the maximum gain available before feedback. Hearing aids with hollow ear-molds, domes, or a large vent are appropriate for listeners with near-normal low frequency hearing and mild to moderate hearing loss at mid and high frequencies of up to 70 dB HL.

As it is not clear from the earlier studies that how speech gets affected from signal processing strategies in different type of hearing aids of different manufacturers, high-cost and low-cost. There is no study available which provides comparison of various objective parameters (Fundamental frequency (Hz), Jitter (%), Shimmer (dB), Intensity, Shimmer (%), NHR (noise to harmonic ratio), and (harmonics to noise ratio) HNR) between the unprocessed speech and the hearing aid processed speech. Hence the present study was planned.

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CHAPTER III

Methods

In the current study, no participants have been appointed as it is an instrument-based objective assessment study by comparing the pre and post-hearing aid processed acoustic signal.

3.1 Instrumentations:

The present study has been carried out using the sound-treated room along with various equipment. Praat software, microphone (B-2 PRO), preamplifier(MOTU M2), hearing aids (Danavox & Hansaton), KEMAR, sound level meter (B&K), adobe audition 3.0 software and speaker (Genelec) were used for signal generation, recording and analysis of the hearing aid processed and unprocessed phoneme objectively. The recording for the unprocessed, processed stimuli and unaided recording was carried out in the acoustically treated room. The use of each instrument and software are described below:

a) The B-2 PRO (Behringer B-2 Pro) microphone is a professional-quality condenser microphone used to record different speech sounds for both male and female voices as it captures sound with incredible realism, sensitivity, and accuracy.

b) MOTU Micro book II is a USB audio interface that provides simultaneous inputs from a microphone to the computer. This was used to transfer the microphone recorded signal to a computer.

c) PRAAT software was used for the recording and analysis of the unprocessed stimuli, unaided phonemes, and aided phonemes.

d) Hearing aids were used to record the aided signal.

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e) Adobe Audition 3.0 software was used for recording, mixing, editing, noise cancellation, stimulus presentation and amplitude normalization of the signal. It was also used for forming the chain stimuli by adding the phoneme.

f) KEMAR was used for recording the unaided, as well as aided stimulus using a hearing aid.

g) Sound Level Meter (SLM) (B&K 2270) was used to record and capture the aided and unaided stimuli from the KEMAR.

h) The Finnish Genelec (8020B) loudspeaker was used for the presentation of unprocessed stimuli at different intensity levels.

The present experimental study was carried out using comparative research and the Mixed research design was used. It was completed in three different phases:

Phase I: Stimuli Recording

Phase II: Recording of unaided and hearing aid processed signals. It also involved the following three steps.

a). Hearing Aids and models used

b). Hearing Aid Programming

c). Recording

Phase III: Objective Analysis of the recorded stimulus.

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Phase I: Stimuli Recording

Stimuli were recorded to have phoneme-in-isolation contexts. Seven phonemes (/a/, /i/, /u/, /s/, /ʃ/, /ma/, & /ga/) were identified and taken as a material for the assessment of the characteristics of processed speech. Most of these phonemes represent the basic ling sounds which cover a broad frequency range, hence providing a better representation of the speech. Three males and three females (age range of 20-24 years), with no history of any voice problems, were selected for the recording of stimuli.

PRAAT software was used for the recording of unprocessed phonemes using a Behringer-2 Pro (B-2 PRO) microphone, and MOTU M2 audio interface was used to connect the microphone to the laptop in an acoustically treated room. Three trials of all the seven phonemes were spoken by each talker (3 male & 3 female) leading to a total of 126 samples. The recording duration of these phonemes differed naturally and was not modified to allow direct comparisons.

Thereafter, all phonemes were processed from AUDITION 3.0 software for noise cancellation and amplitude normalization. Adobe Audition 3.0 was chosen for the present study as it is an appropriate platform for recording, mixing, editing, and mastering audio. The noise cancellation process starts with selecting a recorded sample from the Audition 3.0 window toolbar file section. As the spectrum of the selected stimuli is visible with the noisy part, the same has been selected in the recording with the help of the Alt (+) N and also the whole spectrum with Ctrl (+) A. The restoration process was initiated by selecting: Effects -> restoration -> Noise reduction process (Fig 3.1). After completing the Noise reduction, the investigator proceeded with the normalization. Normalization is applying a constant amount of gain in an audio

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recording to bring the intensity to a fixed normalized level. So, the same gain is applied across the entire recording, and the SNR and relative stimulus dynamics are unchanged. Normalization is completed by selecting: favorites -> normalize to -3 dB (Fig 3.2) from the toolbar section. -3dB was selected (out of -1dB or -3dB) for providing the constant amount of gain due to multiple intensity fluctuations in the stimuli presented.

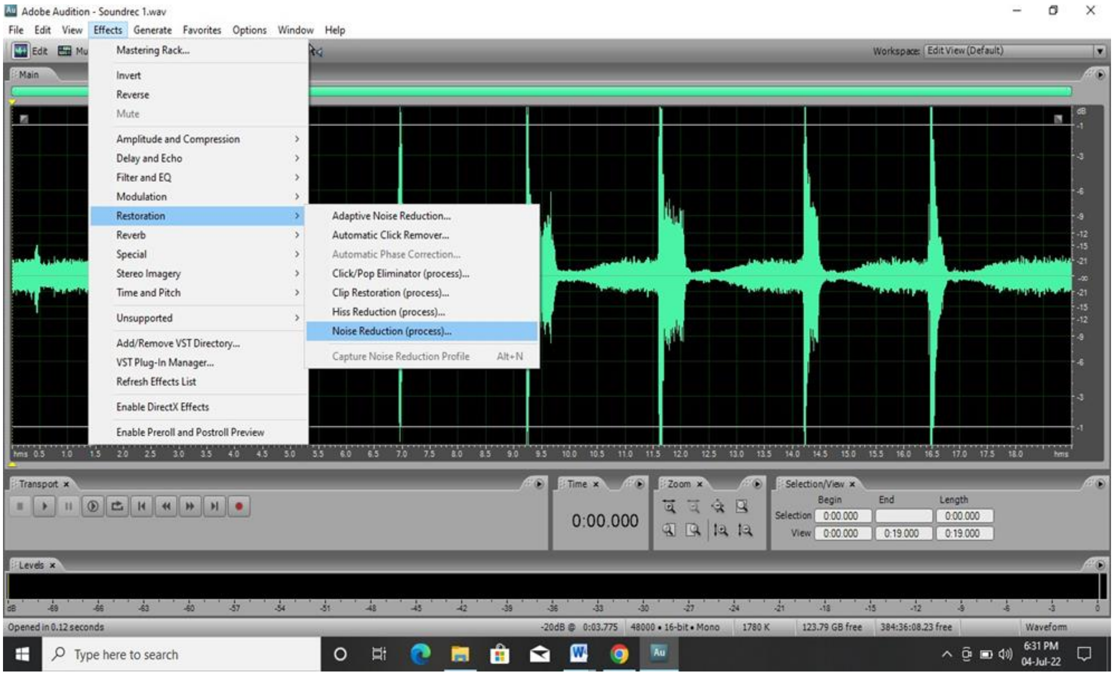

Figure 3.1: *The step used for noise cancellation and waveform of signals before noise cancellation has been applied.*

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Figure 3.2: *The procedure used for normalization and waveform of signals before normalization.*

After noise reduction and normalization, all the samples went through goodness of fit test by ten audiologists and speech-language pathologists for the naturalness of the sample. The goodness of fit test was done with the help of a 5-point 'Richter Scale' (5- representing excellent and 1- representing very poor). All seven phonemes with the best scores in each category (male & female) were selected. for the analysis and later analyzed in phase III using the PRAAT software for various parameters like Fundamental frequency, SD F0, Jitter(%), Jitter(dB), Shimmer, NHR(noise to harmonic ratio), and HNR(harmonics to noise ratio).

Adobe Audition 3.0 software was used for forming the chain stimuli (Fig 3.1) by adding the selected phoneme. The phoneme chain was made separately for the male and the female talker.

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Phase II: Recording of unaided and hearing aid processed signals

(a) Hearing Aids and models used for the study

The recording was done using the hearing aid of two different manufacturers i.e., Danavox and Hansaton because both had high-cost and low-cost hearing aid products with the same set of basic and advanced features for BTEs and RICs. Hence, one low-cost and one high-cost hearing aid was selected for both behind-the-ears (BTEs) and Receivers in the canal (RICs) from each manufacturer. Table 3.1 documents the hearing aid models of both BTE and RIC from Danavox and Hansaton.

Table 3.1

Hearing aids and models used for the study

Companies	Danavox (High-cost)	Danavox (low-cost)	Hansaton (High-cost)	Hansaton (low-cost)
BTE	KLAR488 DW HP BTE	KLAR388 DWHP BTE	BEAT 9 AQ BTE	BEAT 3 AQ BTE
RIC	KLAR461 RIE	KLAR361 RIE	SOUND9 AQ RIE	SOUND 3 AQ RIE

(b) Hearing Aid Programming

An audio-logical profile was created with flat moderate sensorineural hearing loss on NOAH software. All the eight hearing aids (4 BTEs and 4 RICs) were connected through NOAH link wireless interface to the computer using particular options in NOAH software (Fig 3.3). Fitting software named Hansaton Scout 5.0 and Be More were used for programming Hansaton and Danavox Hearing aids, respectively. Using these programming software, all hearing aids were programmed and verified to meet NAL-NL2 adult prescription targets for moderate flat Sensori-

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Neural hearing loss (thresholds plotted in 1/3rd octaves from 125 Hz to 8000 Hz). It is because NAL-NL2 provides preferred gain setting better than that of NAL-NL1 (Keidser et al., 2012).

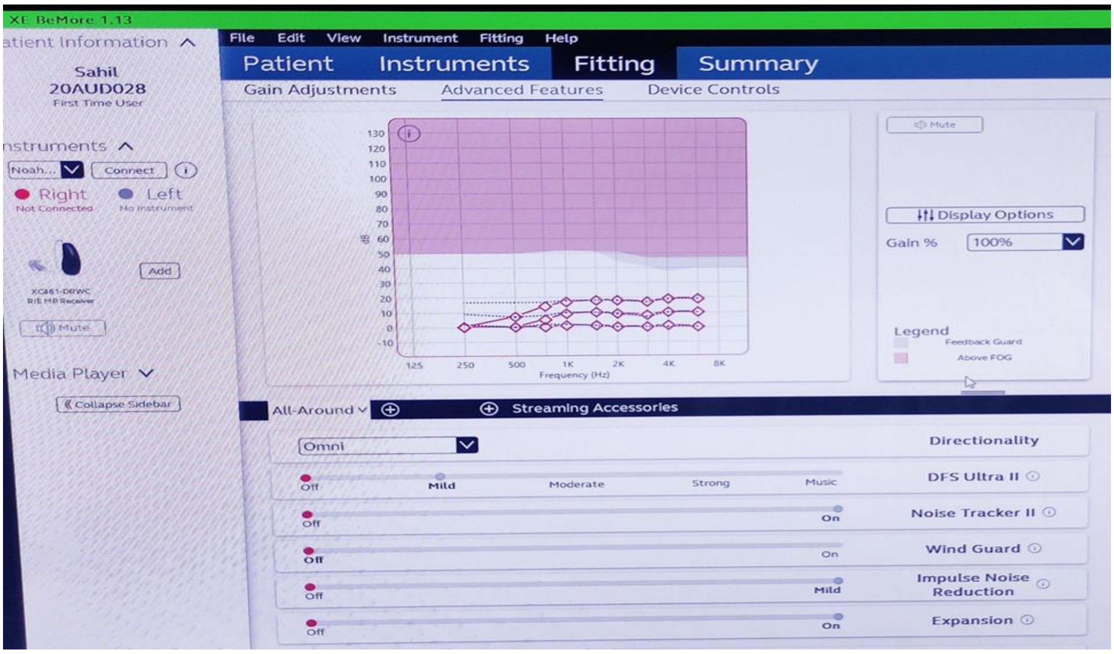

Figure 3.3: *Prescribed targets according to the NAL-NL2 prescription formula for danavox hearing aids.*

High-cost hearing aids had few additional advanced features as compared to the relatively low-cost model. But, all hearing aids were programmed to function on a basic program with additional features such as noise reduction, noise tracker, directionality, wind guard, expansion, DFS ultra, feedback cancellation, and frequency lowering disabled or turned off during verification and recording. And hence, all the Hearing aids were working with a set of basic features only, which helped us to control the effect of other features on signal output and find the correlation between these hearing aids regarding the microphone-receiver position for BTE v/s RIC. Speech processing through the microphone with basic features only helped the correlation between the high-cost v/s the low-cost models of both BTEs and RICs hearing aids. All these

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hearing aids were programmed for first fit to record hearing aid processed signal through KEMAR.

c). Recording Procedure: The recording was carried out in three steps:

Step I: Unaided Recording of signal

1. All the speakers were turned on to assess the working condition. After this check, a speaker with 0-degree azimuth was selected for the study.

2. Adobe Audition 3.0. was used for the stimulus presentation.

3. The speech test stimuli (phoneme chain) were continuously presented for calibration purposes with the help of The Finnish Genelec(8020B) loudspeaker, which was directed towards the KEMAR (0-degree azimuth) (fig 3.4) at a distance of one meter away.

4. The volume dial on the loudspeaker was used to control the speaker's output level for calibrating the intensity levels (50 dB & 80 dB) along with the SLM.

5. The calibrated stimulus was presented at 50 dB and 80 dB separately from the speaker and received by the microphone (model 4187) mounted in the manikin (KEMARs) right ear as mentioned (Fig 3.4).

6. Then, the direct audio output wire connected from KEMAR's right ear output port was the stimulus information to the amplifier input port.

7. The amplifier acts as an interface between the SLM (B & K, 2270) (Fig 3.6) and KEMAR sending all the information to the SLM. The sound level meter (SLM) was used to record the microphone's output, and all the data was stored on the memory card.

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8. Then, the recordings were done for different intensity parameters for both male and female audio stimuli after calibrating each one separately.

9. All the data stored on the memory card was easily accessible and transferred for analysis.

Step II : Recording of the Hearing aid processed stimuli

Steps 1, 2, 3, and 4 were followed as done for unaided recording.

5. The calibrated stimulus presented from the speaker was received by the programmed hearing aid placed on the (KEMARs) right ear, which was then sent the hearing aid processed signal to the microphone (model 4187) mounted on the coupler placed inside the manikins (KEMAR) ear.

Steps 6, 7, 8 and 9 are the same as mentioned for unaided signal recording.

Figure 3.4: *The Kemar facing the loudspeaker kept at a distance of 1 meter at 0 degree azimuth*

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Figure 3.5: *Kemar facing the loudspeaker, and the hearing aid was placed on Kemar right ear*.

Figure 3.6: *The Kemar was connected to the amplifier and the sound level meter (SLM) and the right panel showed the output level.*

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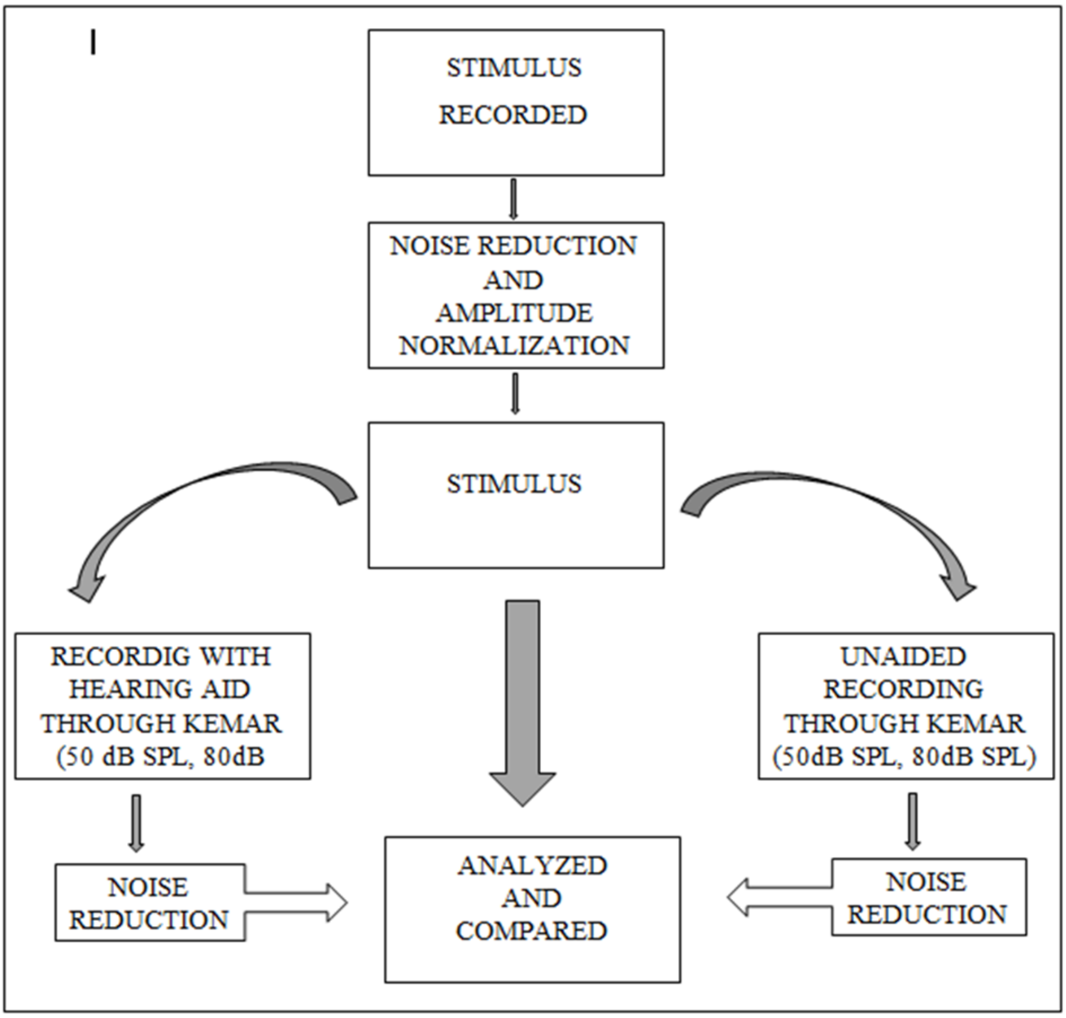

Figure 3.7: *Block diagram of steps followed in the study.*

Phase III: Objective Analysis of the recorded stimulus

PRAAT software was used to analyze unprocessed, unaided and hearing aid processed stimuli for various parameters like Fundamental frequency, Jitter(%), Jitter(dB), Shimmer, NHR(noise to harmonic ratio), and HNR(harmonics to noise ratio). Analysis was done in various steps as follows:

1. PRAAT software was opened, and two short tabs appeared. Upon moving to the first tab and selecting 'open' from the toolbar, another list of options was displayed. Among these options, the 'read from file' option was chosen.

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2. Then the selected stimuli appeared marked as blue in the first window. Now from the vertical menu options, 'view and edit' was selected. A 'new tab' was opened with new toolbar.

3. In the currently appeared new toolbar, section 'Pulses' was clicked and subsequently selected the spectrum of a particular phoneme and chose first sub-option 'show pulses' after selecting the 'pulses' option, which showed the meaningful or readable spectral information (Fig 3.8). Afterwards, 'voice report' option was selected in the same menu.

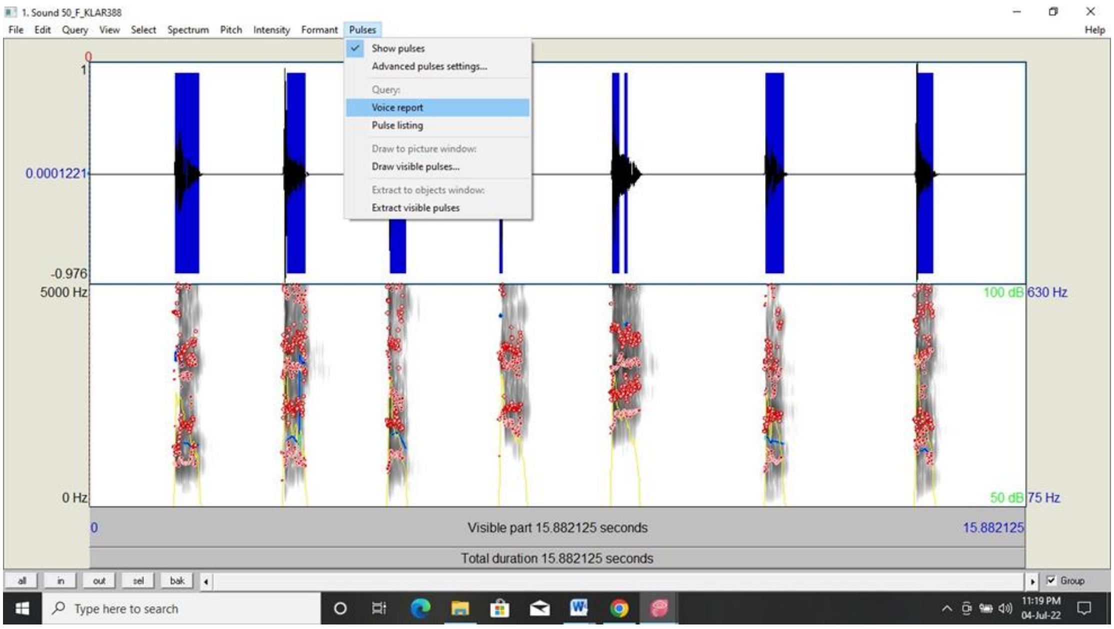

Figure 3.8: *Depicting wave of the phone in the upper panel and spectrograph in the lower panel.*

4. Now, the final result of the selected phoneme has been acquired, with the required information of various parameters as shown in the figure 3.9.

5. Data values of various parameters like Fundamental frequency, Jitter(%), Jitter(dB), Shimmer, NHR(noise to harmonic ratio), and HNR(harmonics to noise ratio) according to the need of study were selected.

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Praat Info
File  Edit  Search  Convert  Font
-- Voice report for 1. Sound 50_F_KLAR388 --
Date: Mon Jul 04 23:19:50 2022

Time range of SELECTION
   From 3.136172 to 3.837314 seconds (duration: 0.701143 seconds)
Pitch:
   Median pitch: 247.684 Hz
   Mean pitch: 305.808 Hz
   Standard deviation: 92.602 Hz
   Minimum pitch: 198.939 Hz
   Maximum pitch: 480.545 Hz
Pulses:
   Number of pulses: 95
   Number of periods: 94
   Mean period: 3.283874E-3 seconds
   Standard deviation of period: 0.934522E-3 seconds
Voicing:
   Fraction of locally unvoiced frames: 51.429%   (108 / 210)
   Number of voice breaks: 0
   Degree of voice breaks: 0   (0 seconds / 0 seconds)
Jitter:
   Jitter (local): 1.118%
   Jitter (local, absolute): 36.722E-6 seconds
   Jitter (rap): 0.574%
   Jitter (ppq5): 0.585%
   Jitter (ddp): 1.721%
Shimmer:
   Shimmer (local): 17.483%
   Shimmer (local, dB): 1.486 dB
   Shimmer (apq3): 7.949%
   Shimmer (apq5): 11.355%
   Shimmer (apq11): 17.860%
   Shimmer (dda): 23.846%
Harmonicity of the voiced parts only:
   Mean autocorrelation: 0.798389
   Mean noise-to-harmonics ratio: 0.290660
   Mean harmonics-to-noise ratio: 6.805 dB
```

Fig 3.9: *Voice Report highlighting different acoustic parameters of the signals*

Analysis:

Above mentioned parameters were tabulated from the voice report for unprocessed, unaided and processed signals. Data for each parameter was compared between Unprocessed vs processed signal, unaided vs processed signal, BTE vs RIC hearing aid, high-cost vs low-cost hearing aid, and Hansaton vs Danavox, between male voice vs female voice and also recorded between two intensity levels. Descriptive analysis was carried out and no inferential statistics were done as there were only single values present between any two conditions.

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CHAPTER IV

RESULTS

The present study aimed to compare the hearing aid processed phonemes objectively. Seven phonemes spoken by male and female speakers were taken as a stimulus in the study. This recorded stimulus was considered the 'unprocessed' stimulus. The unprocessed phones were presented through the speakers and output from the KEMAR without a hearing aid was also recorded at two different intensity levels and considered as 'unaided condition'. The unprocessed stimulus was presented through various hearing aids at two intensity levels and considered as hearing aid processed stimuli. The unprocessed, unaided, and hearing aid processed phoneme was analysed with the help of PRAAT software for the following parameters: (i) Fundamental frequency (Hz), (ii) Jitter (%), (iii) Shimmer (dB), (iii) Intensity, (iv) Shimmer (%), (v) NHR (noise to harmonic ratio), and (vi) HNR (harmonics to noise ratio). The hearing aid processed speech was compared with the unprocessed and unaided stimuli for the above-mentioned parameters.

4.1 Comparison of unprocessed, unaided and processed phoneme through different hearing aid

The data obtained after the analyses with PRAAT was tabulated with respect to different phonemes spoken by males and females and processed through different hearing aids presented at different input intensity levels of stimuli. The outcome of the objective analysis of unprocessed, unaided and processed signals through different hearing aids for male and female voice (phoneme) and presented at different input intensity level has been given separately.

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Table 4.1

Objective parameters value for female /a/ presented at 50 dB SPL across different conditions.

F-/a/-50dB	F0(Hz)	Intensity (dB)	Jitter (%)	Shimmer (dB)	Shimmer (%)	NHR	HNR(dB)
Unprocessed	229.87	81.15	1.23	0.569	4.87	0.064	17.67
Unaided	274.48	68.02	0.89	1.209	10.67	0.170	9.484
DAN BTE H	275.03	68.31	1.63	1.038	10.719	0.206	9.794
DAN BTE L	232.25	69.64	1.09	1.241	14.617	0.195	9.136
DAN RIC H	281.48	71.88	1.62	1.467	15.679	0.276	7.558
DAN RIC L	260.60	72.26	1.48	1.67	20.333	0.316	6.695
HAN BTE H	258.41	75.19	1.03	1.449	14.734	0.276	7.035
HANS BTE L	259.30	74.55	1.09	1.316	13.392	0.271	6.884
HANS RIC H	244.91	77.21	1.37	1.382	15.067	0.329	6.589
HANS RIC L	254.97	75.87	1.12	1.624	16.657	0.373	6.062

Note: F: female, F0: fundamental frequency, NHR: noise-to-harmonics Raito, HNR: harmonics-to-noise Raito, DAN BTE H: Danavox BTE high cost hearing aid, DAN BTE L: Danavox BTE low cost hearing aid, DAN RIC H: Danavox RIC high cost hearing aid, DAN RIC L: Danavox RIC low cost hearing aid, HANS BTE H: Hansaton BTE high cost hearing aid, HANS BTE L: Hansaton BTE low cost hearing aid, HANS RIC H: Hansaton RIC high cost hearing aid , HANS RIC L: Hansaton RIC low-cost hearing aid, RIC: Receiver-in-canal, BTE: Behind-the-ear.

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a) F0 (Hz): It can be noticed in the above table that F0 for hearing aid (HA) processed phoneme is more than the unprocessed and unaided stimulus F0 (Hz). Danavox hearing aids have shown a **greater** variation of F0 compared to Hansaton hearing aids, irrespective of the model (BTE & RIC). Danavox RIC HA's showed an **increase** in F0 compared to BTE hearing aids. Whereas, Hansaton showed the opposite results for BTE v/s RIC. Low-cost HA's showed slight increase in F0 compared to high-coa st HA's.

b) Intensity (dB): It can be noticed in the above table that the intensity for the hearing aid processed phoneme /a/ is negligibly changed when compared to unaided phoneme /a/. However, it is evident in the above table that the intensity of the HA processed stimulus did increase marginally up to 9 dB SPL across different hearing . Still, not no differences can be noted between models of the hearing aid manufacturers and different cost hearing aids.

c) Jitter (%): It can be noticed (Table 4.1) that a slight decrease exists in Jitter for hearing aid processed phoneme with reference to the unprocessed stimuli, but slight increase in Jitter are noticed for most of the hearing aid processed phoneme /a/ when compared to the unaided phoneme. Danavox hearing aids have shown a **greater** Jitter variation in most cases compared to Hansaton hearing aids, irrespective of the model (BTE & RIC). RIC hearing aids of both the manufacturer showed a **slight increase** in Jitter compared to BTE hearing aids. Between the low-cost and high-cost hearing aids, high-cost hearing aids showed **more** variation than low-cost hearing aid processed phonemes.

d) Shimmer (dB): Increase can be noticed across all hearing aids processed /a/ with reference to (w.r.t) the unprocessed stimuli and unaided phoneme. But, no noticeable differences can be obse in the table 4.1 for comparison between

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models of the hearing aid, different manufacturers, and different cost hearing aids.

e) Shimmer (%): It can be noticed in the above table that there is an **increase** of 10 to 15 % in shimmer (%) for all hearing aids processed phoneme /a/ w.r.t the unprocessed stimuli. While there is an increase of only 5 to 10 % for all hearing aids processed phonemes w.r.t the unaided recording. However, more differences can be observed for Danavox HAs compared to the Hansaton HAs, irrespective of the model of hearing aids (BTE & RIC). Shimmer is **higher** in case of RIC HA compared to the BTE HA processed phoneme. In 3 out of 4 cases of high-cost points v/s low-cost comparison, low-cost hearing aids showed **more** variations as compared to the high-cost hearing aids.

f) NHR: From the above table, it can be noticed that, across all hearing aid processed phoneme, NHR is increased with reference to the unprocessed and unaided phone stimuli. Danavox and Hansaton hearing aids have shown similar variations of NHR, irrespective of the model (BTE & RIC). So, **no differences** can be observed between Danavox and Hansaton, RIC and BTE, and between low-cost and high-cost hearing aids.

g) HNR: It can be noticed that there is a decrease of 10 dB HNR across all hearing aids with reference to (w.r.t) unprocessed stimuli and unaided recording. Hansaton hearing aids have shown a **slightly more** variation of HNR compared to Danavox hearing aids, irrespective of their model (BTE & RIC). However, no differences can be observed between RIC and BTE, and between low-cost and high-cost hearing aids.

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Table 4.2

Objective parameters value for female /i/ presented at 50 dB SPL across different conditions

F-/i/-50dB	F0(Hz)	Intensity (dB)	Jitter (%)	Shimmer(dB)	Shimmer (%)	NHR	HNR (dB)
Unprocessed	232.832	84.96	0.801	0.49	3.692	0.027	20.046
Unaided	232.809	69.07	0.857	1.191	12.765	0.274	7.498
DAN BTE H	253.313	72.25	1.476	1.451	16.822	0.287	7.217
DAN BTE L	295.808	73.67	1.118	1.486	17.483	0.290	6.805
DAN RIC H	333.246	77.16	3.664	1.643	21.033	0.281	7.049
DAN RIC L	326.321	74.97	4.267	1.711	19.021	0.341	6.054
HAN BTE H	232.908	79	1.285	1.363	12.043	0.309	6.717
HANS BTE L	232.516	77.85	1.59	1.239	13.968	0.358	5.977
HANS RIC H	290.162	79.24	3.02	1.602	16.09	0.307	6.414
HANS RIC L	252.69	79.05	3.289	1.577	15.983	0.357	5.895

Note: F: female, F0: fundamental frequency, NHR: noise-to-harmonics ratio, HNR: harmonics-to-noise ratio, DAN BTE H: Danavox BTE high cost hearing aid, DAN BTE L: Danavox BTE low cost hearing aid, DAN RIC H: Danavox RIC high cost hearing aid, DAN RIC L: Danavox RIC low cost hearing aid, HANS BTE H: Hansaton BTE high cost hearing aid, HANS BTE L: Hansaton BTE low cost hearing aid, HANS RIC H: Hansaton RIC high cost hearing aid , HANS RIC L: Hansaton RIC low-cost hearing aid, RIC: Receiver-in-canal, BTE: Behind-the-ear.

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a) F0 (Hz): It can be noticed in the above table that F0 for hearing aid processed phoneme /i/ is more than the unprocessed stimulus and unaided phoneme F0 (Hz). Danavox hearing aids have shown a **greater** variation of F0 compared to Hansaton hearing aids, irrespective of the model (BTE & RIC). RIC HA shows **more increase** as compared to the BTE HA processed phoneme /i/ for both the manufacturers. However, no differences can be observed between low-cost and high-cost hearing aid processed phoneme /i/.

b) Intensity (dB): Overall phoneme intensity level for all hearing aids with reference to unaided phoneme /i/, marginally increased nearly up to 10dB. Hansaton hearing aids have shown a Danavox **slightly more** variation of intensity compared to hearing aids, irrespective of the model (BTE & RIC). However, no differences can be noticed between RIC and BTE, and between low-cost and high-cost hearing aids.

c) Jitter (%): Increase for jitter can be noticed (Table 4.2) for all hearing aids with reference to the unprocessed stimuli and unaided recording. Both Danavox and Hansaton showed nearly **similar** variations for Jitter, irrespective of their model. Although, a noticeable **increase** in Jitter for all the RICs hearing aid processed phoneme as compared to the BTEs. However, **no differences** can be noticed between low-cost and high-cost hearing aids.

d) Shimmer (dB): It can be noticed that there is an increase across all hearing aids with reference to the unprocessed stimuli, while there is no difference across hearing aids with reference to unaided recording. Across all HAs, shimmer (dB) was similar irrespective of the type of hearing aids, company of hearing aids and also between low and high-cost hearing aids.

e) Shimmer (%): It can be noticed that there is an increase of shimmer (%) across all hearing aid processed phoneme when compared to the unprocessed stimuli and unaided recording

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respectively. Danavox HAs have shown a **greater variation** of shimmer (%) compared to Hansaton HAs, irrespective of the model (BTE & RIC). Danavox RIC hearing aid showed an **increase** in shimmer (%) compared to BTE hearing aids. Whereas, Hansaton showed no such increase in NHR between models of HAs (RIC & BTE). Danavox high-cost RIC HA showed a **slight increase** in shimmer (dB) compared to low-cost RIC aid.

f) NHR: It can be noticed that there is an increase in all hearing aids for NHR with reference to the unprocessed stimuli. However, no differences are noticed across hearing aids with reference to unaided recording. Hansaton HAs NHR is **slightly more** than the Danavox HAs. No differences between BTE and RIC and also low v/s high-cost hearing aids have been noticed.

g) HNR: Decrease of HNR can be noticed (Table 4.2) for all hearing aids with reference to the unprocessed stimuli. But, while comparing w.r.t unaided phoneme /i/ no differences are noticed across hearing aids. It can be noticed that there are no differences observed between different manufacturers, and between the RIC and BTE HA processed phoneme. HNR for high-cost HAs is **slightly more** compared to the low-cost hearing aids processed phoneme.

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Table 4.3

Objective parameters value for female /u/ presented at 50 dB SPL across different conditions

F-/u/-50dB	F0(Hz)	Intensity(dB)	Jitter (%)	Shimmer(dB)	Shimmer (%)	NHR	HNR(dB)
Unprocessed	240.99	85.88	1.196	0.406	3.143	0.026	26.88
Unaided	247.86	62.09	0.58	0.773	6.572	0.076	14.359
DAN BTE H	246.75	70.41	0.599	0.974	8.899	0.131	12.331
DAN BTE L	248.81	69.9	0.362	0.939	8.551	0.149	11.433
DAN RIC H	247.87	71.35	0.479	1.042	9.874	0.235	9.449
DAN RIC L	246.61	70.5	0.46	1.337	13.589	0.255	8.402
HAN BTE H	245.09	72.71	0.482	0.889	8.373	0.176	10.592
HANS BTE L	246.54	71.64	0.607	0.754	8.165	0.176	10.018
HANS RIC H	248.53	73.29	0.43	1.073	10.135	0.243	9.446
HANS RIC L	261.50	72.98	1.02	1.247	12.037	0.199	8.31

Note: F: female, F0: fundamental frequency. NHR: noise-to-harmonics ratio, HNR: harmonics-to-noise ratio, DAN BTE H: Danavox BTE high cost hearing aid, DAN BTE L: Danavox BTE low cost hearing aid, DAN RIC H: Danavox RIC high cost hearing aid, DAN RIC L: Danavox RIC low cost hearing aid, HANS BTE H: Hansaton BTE high cost hearing aid, HANS BTE L: Hansaton BTE low cost hearing aid, HANS RIC H: Hansaton RIC high cost hearing aid , HANS RIC L: Hansaton RIC low-cost hearing aid, RIC: Receiver-in-canal, BTE: Behind-the-ear.

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a) F0 (Hz): It can be noticed that there is not much change in fundamental frequency values across the different hearing aid processed phoneme with reference to the unprocessed stimuli and unaided phoneme. It can also be noticed that there are **no differences** observed between different manufacturers (Danavox & Hansaton), RIC and BTE and between the high-cost and low-cost hearing aids.

b) Intensity (dB): Overall Intensity can be noticed to increase for all hearing aids with reference to the unaided stimuli. While comparing between different manufacturers, Hansaton HA have shown **slightly similar** variations compared to the Danavox HA processed phoneme. RIC HA have shown **slightly more** intensity compared to the BTE HA processed phoneme and between low-cost and high-cost hearing aids, high-cost hearing aid have **slightly more** intensity as compared to the low-cost HA processed phoneme.

c) Jitter (%): It can be noticed from above table that there is a decrease in Jitter for most of all hearing aids w.r.t the unprocessed stimuli and unaided phoneme. While comparing between different manufacturers, Hansaton HA have shown **slightly more** variations as compared to the Danavox HA processed phoneme. There are no observable differences across different hearing aid processed phoneme /u/ between RIC and BTE, and between low-cost and high-cost hearing aid.

d) Shimmer (dB): It can be noticed from above table that an increase in shimmer (dB) is there for all hearing aids w.r.t the unprocessed stimuli and unaided phoneme /u/. Danavox and Hansaton have observable variations across hearing aid processed phonemes, Variations are **slightly similar** between the company, between the type of hearing aid and also between the low-cost and high-cost HAs.

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e) Shimmer (%): It can be noticed from above table that there is an increase in shimmer (%) for all hearing aids w.r.t the unprocessed stimuli and unaided phoneme /u/. Although, the changes are more with reference to the unprocessed stimuli compared to the variation w.r.t the unaided phoneme. Danavox and Hansaton have **nearly equal** variations across hearing aid processed phoneme. RICs have **slightly more** variations in shimmer (%) compared to the BTEs processed phoneme. However, low-cost RIC HAs have **slightly more** variations in shimmer (%) as compared to the high-cost RIC HAs processed phoneme, irrespective of their manufacturers.

f) NHR: Increase in NHR can be noticed for all hearing aid processed phoneme w.r.t the unaided /u/ and unprocessed stimuli. Danavox and Hansaton have **similar** variations for NHR across the hearing aid processed phonemes, irrespective of the cost and model of the hearing aids. RIC HAs have slightly **more** NHR compared to the BTE HA processed phoneme, irrespective of their cost. There are no observable differences across different hearing aid processed phoneme when comparing between different manufacturers, and between low-cost and high-cost hearing aid.

g) HNR: It can be noticed from above table that decrease of HNR for all hearing aid processed phones when compared to the unprocessed stimuli and unaided phoneme respectively. Both Danavox and Hansaton have **slightly more** variations of NHR that are **greater** for RIC hearing aid processed phonemes compared to the BTEs, irrespective of the cost of hearing aids. High-cost HA have shown slight to no differences compared to the low-cost HA processed phoneme.

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Table 4.4

Objective parameters value for female /s/ presented at 50 dB SPL across different conditions

F-/s/-50dB	F0(Hz)	Intensity(dB)	Jitter (%)	Shimmer(dB)	Shimmer (%)	NHR	HNR(dB)
Unprocessed	528.59	77.22	8.614	1.891	19.987	0.652	2.026
Unaided	469.17	68.52	8.94	1.845	24.332	0.437	4.264
DAN BTE H	394.44	69.09	9.394	2.179	16.24	0.535	3.988
DAN BTE L	551.46	69.9	6.65	1.686	19.362	0.317	5.778
DAN RIC H	478.77	72.35	7.338	1.824	27.465	0.484	4.809
DAN RIC L	550.42	71.82	6.455	1.7	16.522	0.354	4.613
HAN BTE H	553.94	77.27	9.987	1.9	15.201	0.615	2.282
HANS BTE L	553.78	76.62	11.38	1.855	19.405	0.474	3.311
HANS RIC H	401.43	75.68	9.039	1.85	17.204	0.417	4.998
HANS RIC L	422.79	74.97	10.204	1.78	18.945	0.652	2.056

Note: F: female, F0: fundamental frequency, NHR: noise-to-harmonics ratio, HNR: harmonics-to-noise ratio, DAN BTE H: Danavox BTE high cost hearing aid, DAN BTE L: Danavox BTE low cost hearing aid, DAN RIC H: Danavox RIC high cost hearing aid, DAN RIC L: Danavox RIC low cost hearing aid, HANS BTE H: Hansaton BTE high cost hearing aid, HANS BTE L: Hansaton BTE low cost hearing aid, HANS RIC H: Hansaton RIC high cost hearing aid , HANS RIC L: Hansaton RIC low-cost hearing aid, RIC: Receiver-in-canal, BTE: Behind-the-ear.

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a) F0 (Hz): It can be noticed in the above table that changes in F0 for hearing aid processed phoneme in most of the HAs is more w.r.t to the unprocessed stimulus and unaided phoneme /s/. Danavox hearing aids have shown a **slightly more** variation of F0 compared to Hansaton hearing aids, irrespective of the model (BTE & RIC). Changes for Danavox BTE are more as compared to the RICs. Whereas, Hansaton showed no such results. Between the low-cost and high-cost hearing aids of Danavox, high-cost hearing aids showed **more variation** compared to low-cost.

b) Intensity (dB): It can be noticed in the table 4.4 that increase is there for all hearing aids processed phoneme /s/ w.r.t the unprocessed stimuli and the unaided phoneme /s/. Both Danavox and Hansaton hearing aids have shown similar variations, irrespective of the model of hearing aid (BTE & RIC). However no other differences are noticeable across the different models of hearing aids and the high-cost v/s low-cost hearing aids.

c) Jitter (%): Increase jitter (%) can be observed in Table 4.4 for most of the hearing aids w.r.t the unprocessed stimuli and unaided phoneme /s/. Hansaton hearing aids shows **slightly more** variations compared to the Danavox hearing aids, irrespective of their model (BTE & RIC). However, no other differences are observed between RIC and BTE, between high-cost and low-cost hearing aid processed phoneme /s/.

d) Shimmer (dB): There are no noticeable changes for Shimmer (dB) across hearing aid processed phoneme with reference to the unprocessed stimuli and the unaided phoneme /s/. Although, Danavox hearing aids have shown slightly more shimmer compared to Hansaton hearing aids, irrespective of the model (BTE & RIC). Low-cost hearing aids have shown **slightly less** value as compared to the high-cost HA

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processed phoneme /s/.

e) Shimmer (%): Changes can be noticed for shimmer (%) across hearing aids with reference to both the unprocessed stimuli and unaided phoneme /s/. Danavox hearing aids have **more variation** compared to the Hansaton hearing aids. Danavox high-cost RIC has **more shimmer** (%) compared to the BTEs and other low-cost RIC hearing aids. No, such variations are noticeable for Hansaton HAs with respect to the model of hearing aid.

f) NHR: It can be noticed in the above table that differences in NHR are not there across hearing aids processed phonemes w.r.t the unprocessed stimuli and unaided phoneme /s/. However, no other differences are observable for NHR in different comparisons like between manufacturer, between RIC and BTE, and between high-cost and low-cost hearing aid processed phoneme.

g) HNR: It can be noticed in the above table that differences in HNR are not there across hearing aids processed phonemes with reference to the unprocessed stimuli and unaided phoneme. However, no other differences are observable for HNR in different comparisons like between manufacturer, between RIC and BTE, and between high-cost and low-cost hearing aid processed phoneme.

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Table 4.5

Objective parameters value for female /ʃ/ presented at 50 dB SPL across different conditions

F-/ʃ/-50dB	F0(Hz)	Intensity(dB)	Jitter (%)	Shimmer(dB)	Shimmer (%)	NHR	HNR(dB)
Unprocessed	527.77	69.88	5.574	1.772	18.996	0.557	2.671
Unaided	499.44	72.04	8.355	1.947	22.249	0.622	2.71
DAN BTE H	410.99	70.91	8.88	1.778	20.181	0.724	2.219
DAN BTE L	521.53	71.7	8.634	1.978	23.741	0.757	1.739
DAN RIC H	475.49	76.3	11.32	1.737	19.035	0.414	4.606
DAN RIC L	442.06	74.69	9.518	1.594	20.983	0.529	3.431
HAN BTE H	521.61	78.7	9.017	1.27	16.533	0.589	2.912
HANS BTE L	425.21	77.96	8.684	1.951	26.307	0.360	4.033
HANS RIC H	484.94	75.64	8.126	1.51	17.538	0.461	4.372
HANS RIC L	508.83	77.91	7.798	1.544	19.669	0.571	3.324

Note: F: female, F0: fundamental frequency, NHR: noise-to-harmonics ratio, HNR: harmonics-to-noise ratio, DAN BTE H: Danavox BTE high cost hearing aid, DAN BTE L: Danavox BTE low cost hearing aid, DAN RIC H: Danavox RIC high cost hearing aid, DAN RIC L: Danavox RIC low cost hearing aid, HANS BTE H: Hansaton BTE high cost hearing aid, HANS BTE L: Hansaton BTE low cost hearing aid, HANS RIC H: Hansaton RIC high cost hearing aid , HANS RIC L: Hansaton RIC low-cost hearing aid, RIC: Receiver-in-canal, BTE: Behind-the-ear.

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a) F0 (Hz): It can be noticed in the above table that changes in F0 for hearing aid processed out phoneme /ʃ/ are not consistent w.r.t the unprocessed stimulus F0(Hz) and unaided phoneme (F0). Danavox hearing aids have **shown more** variation of F0 compared to Hansaton hearing aids, irrespective of the model (BTE & RIC). However no such consistent differences can be noticed in the table for BTE v/s RIC, and difference between the low-cost and high-cost hearing aids, irrespective of their manufacturer.

b) Intensity (dB): It is noticeable in the table (Table 4.5) that increase in intensity for most of the hearing aids processed phoneme is there w.r.t the unaided phoneme /ʃ/ intensity level. Hansaton hearing aids have shown a **slightly more** variation of intensity compared to Danavox HAs, irrespective of the model. Danavox RIC HAs have shown **more variation** compared to the Danavox BTE HAs. However, no other differences are noticeable for the comparison between high-cost and low-cost hearing aids.

c) Jitter (%): Increase of jitter can be noticed (Table 4.5) for all hearing aid processed phoneme /ʃ/ with reference to the unprocessed stimuli and unaided stimuli. Danavox variations are **more** compared to the Hansaton hearing aid processed phoneme. High cost hearing aids have **more** jitter compared to the low cost in most of the HAs. However, no differences can be noticed for comparison between different type of hearing aids (BTEs & RICs).

d) Shimmer (dB): It can be noticed in the above table (Table 4.5) that differences in shimmer (dB) are negligible across hearing aids processed phonemes w.r.t the unprocessed stimuli and unaided phoneme /ʃ/. Hansaton hearing aids have **slightly**

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more variation compared to Danavox hearing aid processed phoneme. However, no differences are noticeable for shimmer (dB) in different model i.e. between RIC and BTE. Low cost hearing aids have slightly more shimmer compared to the high-cost hearing aid processed phoneme /ʃ/.

e) Shimmer (%): It can be noticed (Table 4.5) that increase in shimmer (dB) is there across most of hearing aids processed phonemes w.r.t the unprocessed stimuli but while comparing w.r.t the unaided phoneme /ʃ/ decrease in shimmer (%) can be noticed for most of the HAs. Both the manufacturers i.e. Danavox and Hansaton have shown slight to no variations. However, **increase** can be observed for low-cost BTEs of both Danavox and Hansaton compared when compared to the RICs. Low-cost hearing aids have **more** variations compared to the high-cost hearing aids.

f) NHR: It can be noticed in the above table (Table 4.5) that differences in NHR are not there across hearing aids processed phonemes w.r.t the unprocessed stimuli and unaided phoneme /ʃ/. Danavox hearing aids have shown **slightly more** variations as compared to the Hansaton hearing aids. HNR is slightly more for Danavox BTEs compared to the RIC. Hansaton have not shown such results. However, no other differences are observable for NHR in between high-cost and low-cost hearing aid processed phoneme /ʃ/.

g) HNR: It can be noticed in the above table (Table 4.5) that slight to no differences in HNR are there across hearing aids processed phonemes w.r.t the unprocessed stimuli and unaided phoneme. Although variations are little more for Hansaton HAs compared to the Danavox HAs. But no differences are noticeable for BTE and RIC

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Has processed phoneme. High-cost hearing aids have more HNR compared to the low-cost hearing aid processed phoneme /ʃ/

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Table 4.6

Objective parameters value for female /ma/ presented at 50 dB SPL across different conditions

F-/ma/-50dB	F0(Hz)	Intensity(dB)	Jitter (%)	Shimmer(dB)	Shimmer (%)	NHR	HNR(dB)
Unprocessed	243.274	85.25	0.574	0.473	3.616	0.006	24.432
Unaided	237.926	64.34	0.404	0.707	7.157	0.050	15.281
DAN BTE H	238.536	68.54	0.985	1.043	11.656	0.132	13.556
DAN BTE L	237.892	67.7	0.933	1.025	11.474	0.154	13.463
DAN RIC H	237.389	71.86	0.944	0.949	10.863	0.177	11.176
DAN RIC L	236.869	68.94	0.847	1.122	11.213	0.147	11.092
HAN BTE H	237.956	72.13	0.498	0.981	11.58	0.147	11.568
HANS BTE L	238.014	69.02	0.549	0.927	9.338	0.104	12.472
HANS RIC H	237.672	76.08	0.637	1.291	15.515	0.240	7.956
HANS RIC L	239.158	72.34	1.047	1.195	12.153	0.265	8.26

Note: F: female, F0: fundamental frequency, NHR: noise-to-harmonics raito, HNR: harmonics-to-noise ratio, DAN BTE H: Danavox BTE high cost hearing aid, DAN BTE L: Danavox BTE low cost hearing aid, DAN RIC H: Danavox RIC high cost hearing aid, DAN RIC L: Danavox RIC low cost hearing aid, HANS BTE H: Hansaton BTE high cost hearing aid, HANS BTE L: Hansaton BTE low cost hearing aid, HANS RIC H: Hansaton RIC high cost hearing aid , HANS RIC L: Hansaton RIC low-cost hearing aid, RIC: Receiver-in-canal, BTE: Behind-the-ear.

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a) F0 (Hz): It can be noticed in the above table (Table 4.6) that negligible differences in F0 are there across hearing aids processed phonemes w.r.t the unprocessed stimuli and unaided phoneme /ma/. However, no other differences are observable for F0 in different comparisons like between manufacturer, between RIC and BTE, and between high-cost and low-cost hearing aid processed phoneme /ma/.

b) Intensity (dB): It can be noticed in the above table that for intensity is **more** for all hearing aid processed phoneme w.r.t the unaided phoneme /ma/ respectively. It can be noticed that variation is **slightly more** for Hansaton hearing aids compared to the Danavox hearing aid processed phoneme. Intensity is **slightly more** for RIC devices compared to the BTE hearing aid processed phoneme for both the manufacturers. It can also be noticed that intensity is **slightly more** for high cost hearing aid compared to the low-cost hearing aid processed phoneme.

c) Jitter (%): Jitter can be noticed slightly increased across all hearing aid processed phoneme w.r.t the unprocessed stimuli and unaided phoneme. Hansaton hearing aids processed phoneme /ma/ shows slight to no variations compared to the Danavox HA, irrespective of the model of hearing aids (BTE & RIC). RIC HAs have shown **slightly more** jitter compared to the BTE HA processed phoneme, in Hansaton HAs. For Hansaton, Low cost hearing aids have slightly more jitter compared to the high-cost of hearing aid, only for the RICs.

d) Shimmer (dB): It can be observed (Table 4.6) that there is slight increase across all hearing aid processed phoneme with reference to the unprocessed stimuli and unaided phoneme /ma/. Danavox and Hansaton hearing aids processed phoneme shows **slight to no** variations for shimmer (dB), irrespective of the model of hearing

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aids (BTE & RIC) and cost of hearing aid (low-cost & high-cost).

e) Shimmer (%): It can be noticed that increase for shimmer (%) is seen for all hearing aids w.r.t the unprocessed stimuli and the unaided phoneme. Hansaton hearing aids processed phoneme /ma/ shows more variations for shimmer (%) compared to the Danavox HA, irrespective of the model of hearing aids (BTE & RIC) and cost of hearing aid (low-cost & high-cost).

f) NHR: It can be observed in the table (4.6) that NHR is increased for all hearing aid processed phoneme with reference to the unprocessed and unaided phoneme /ma/. HAs processed phoneme /ma/ shows slight to no variations for shimmer (%) in between Danavox and Hansaton, model of hearing aids (BTE & RIC) and cost of hearing aid (low-cost & high-cost).

g) HNR: It can be observed in the table (4.6) that HNR is decreased for all hearing aid processed phoneme w.r.t the unprocessed phoneme /ma/. However, slight variations for all hearing aids processed phoneme w.r.t the unaided phoneme /ma/. Hansaton RICs hearing aids processed phoneme shows **more** variations for shimmer (%) compared to the Danavox hearing aid. High-cost HAs have shown slight to no variation for HNR compared to the low-cost hearing aid processed phoneme /ma/.

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Table 4.7

Objective parameters value for female /ga/ presented at 50 dB SPL across different conditions

F-/ga/-50dB	F0(Hz)	Intensity(dB)	Jitter (%)	Shimmer (dB)	Shimmer (%)	NHR	HNR(dB)
Unprocessed	212.96	81.09	0.532	0.556	4.452	0.019	20.923
Unaided	212.02	67.86	0.297	0.711	6.738	0.132	9.792
DAN BTE H	212.55	75.04	0.564	0.875	9.762	0.141	11.39
DAN BTE L	212.39	74.04	0.548	0.858	9.339	0.178	10.281
DAN RIC H	212.36	76.13	0.266	1.285	14.563	0.155	9.287
DAN RIC L	226.72	75.34	0.977	1.233	17.522	0.236	7.538
HAN BTE H	211.90	78.99	0.53	0.883	9.383	0.231	8.096
HANS BTE L	211.91	76.69	0.405	0.846	9.06	0.224	7.787
HANS RIC H	213.88	79.67	0.341	1.16	12.211	0.197	8.217
HANS RIC L	213.47	77.47	0.222	1.258	13.425	0.208	7.656

Note: F: female, F0: fundamental frequency, NHR: noise-to-harmonics ratio, HNR: harmonics-to-noise ratio, DAN BTE H: Danavox BTE high cost hearing aid, DAN BTE L: Danavox BTE low cost hearing aid, DAN RIC H: Danavox RIC high cost hearing aid, DAN RIC L: Danavox RIC low cost hearing aid, HANS BTE H: Hansaton BTE high cost hearing aid, HANS BTE L: Hansaton BTE low cost hearing aid, HANS RIC H: Hansaton RIC high cost hearing aid , HANS RIC L: Hansaton RIC low-cost hearing aid, RIC: Receiver-in-canal, BTE: Behind-the-ear.

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a) F0 (Hz): It can be noticed in the above table (Table 4.7) that differences are not there across hearing aids processed phonemes in F0 w.r.t the unprocessed stimuli and unaided phoneme /ga/. However, no other differences are observable for F0 (Hz) in different comparisons like between manufacturer, between RIC and BTE, and between high-cost and low-cost hearing aid processed phoneme.

b) Intensity (dB): It can be noticed in the above table (Table 4.7) that variations in intensity level are more across hearing aids processed phonemes w.r.t the unaided phoneme /ga/. Hansaton RICs hearing aids processed phoneme shows **slightly more** variations for intensity compared to the Danavox hearing aid. RIC hearing aids have **slightly more** intensity compared to the BTE hearing processed phoneme /ga/. High-cost hearing aids have shown **slightly more** intensity compared to the low-cost hearing aid processed phoneme /ga/.

c) Jitter (%): It can be noticed in the above table (Table 4.7) that increase in Jitter (%) is there across all hearing aids processed phonemes Jitter w.r.t the unprocessed stimuli and unaided phoneme /ga/. Danavox RICs hearing aids processed phoneme shows **more** variations for jitter (%) compared to the Hansaton hearing aid. When high-cost is compared to low cost, High-cost have **slightly more** jitter compared to the low-cost in most of the HAs.

d) Shimmer (dB): It can be noticed in the above table (Table 4.7) that slight increase in shimmer (dB) is there across all hearing aids processed phonemes Jitter w.r.t the unprocessed stimuli and unaided phoneme /ga/. Variations in the shimmer (dB) across Danavox and Hansaton are nearly similar. The Increase in the shimmer (dB) is **more** for RICs compared to the BTEs of both manufacturers, irrespective of their

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cost.

e) Shimmer (%): It can be noticed in the above table (Table 4.7) that there is increase in shimmer (%) across all hearing aids processed phonemes w.r.t the unprocessed stimuli and unaided phoneme /ga/. Variations in the shimmer (dB) across Danavox are **slightly more** compared to the Hansaton HA processed phoneme. The Increase in the shimmer (dB) is **more** for RICs compared to the BTEs of both manufacturers, irrespective of their cost. Slight to no increase in shimmer (%) can be noticed in case of low-cost hearing aid compared to the high-cost hearing aid processed phoneme /ga/.

f) NHR: It can be noticed that there is slight increase in NHR (Table 4.7) for all hearing aid processed phonemes w.r.t the unprocessed stimuli and the unaided phoneme /ma/ NHR. Danavox HAs have shown slightly more variation as compared to the Hansaton HA processed phoneme. Danavox RIC hearing aids have **more** NHR compared to the BTE HAs. Low-cost hearing aids have slightly more NHR compared to the high-cost HA processed phoneme /ga/.

g) HNR: It can be noticed in the table 4.7 that there is decrease of HNR (dB) for all hearing aid processed phoneme w.r.t the unprocessed stimuli. However, no such change is there w.r.t the unaided phoneme. Hansaton HAs have shown slightly more variation as compared to the Danavox HA processed phoneme. BTE have **more** HNR compared to the RIC HAs for Danavox but no such difference is noticed for the Hansaton hearing aids. It can also be observed that high-cost hearing aids have **more** HNR as compared to the low-cost hearing aids.

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Table 4.8

Objective parameters value for male /a/ presented at 50 dB SPL across different conditions

M-/a/-50dB	F0(Hz)	Intensity(dB)	Jitter (%)	Shimmer(dB)	Shimmer (%)	NHR	HNR(dB)
Unprocessed	108.72	80.36	1.638	1.314	11.835	0.212	9.868
Unaided	104.82	70.75	1.994	1.5	20.184	0.434	5.339
DAN BTE H	104.34	72.78	3.112	1.102	15.02	0.424	5.538
DAN BTE L	127.32	73.43	0.705	1.403	16.43	0.318	6.994
DAN RIC H	248.22	75.61	3.947	1.752	22.533	0.402	4.916
DAN RIC L	240.33	74.36	4.275	1.368	19.755	0.428	4.782
HAN BTE H	156.55	69.75	4.941	1.705	19.994	0.428	7.336
HANS BTE L	103.60	75.77	2.885	1.586	18.513	0.484	4.791
HANS RIC H	158.25	78.21	3.827	1.601	21.314	0.499	3.866
HANS RIC L	217.08	78.67	4.565	1.619	19.567	0.447	4.854

Note: M: male, F0: fundamental frequency, NHR: noise-to-harmonics raito, HNR: harmonics-to-noise ratio, DAN BTE H: Danavox BTE high cost hearing aid, DAN BTE L: Danavox BTE low cost hearing aid, DAN RIC H: Danavox RIC high cost hearing aid, DAN RIC L: Danavox RIC low cost hearing aid, HANS BTE H: Hansaton BTE high cost hearing aid, HANS BTE L: Hansaton BTE low cost hearing aid, HANS RIC H: Hansaton RIC high cost hearing aid , HANS RIC L: Hansaton RIC low-cost hearing aid, RIC: Receiver-in-canal, BTE: Behind-the-ear.

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a) F0 (Hz): It can be noticed that there is increase in fundamental frequency values for most of all the hearing aid processed phoneme w.r.t the unprocessed stimuli and unaided phoneme /a/. Danavox have **more variations** compared to Hansaton. RICs have shown **increased** F0 compared to the BTEs processed phoneme, irrespective of their cost. While comparing hearing aid processed phoneme for F0 across high-cost and low-hearing aids, no noticeable variations are there.

b) Intensity (dB): It can be noticed that there is increase in intensity (dB) for most of all the hearing aid processed phoneme w.r.t the unaided phoneme /a/. Hansaton HAs have shown slightly more variations compared to the Danavox HA processed phoneme /a/. Intensity of HA phoneme for Danavox RIC's is **slightly more** compared to BTE's in both the manufactures, irrespective of their cost.

c) Jitter (%): It can be noticed that there is an increase in Jitter for all hearing aid processed phonemes w.r.t the unprocessed stimuli and unaided phoneme. Hansaton HAs have shown slightly more variation when compared to the Danavox. Low-cost BTEs has shown decrease in the jitter compared to the high cost HA.

d) Shimmer (dB): It is noticed there is a **slight increase** in shimmer (dB) for most of the HA processed phonemes w.r.t unprocessed stimuli and unaided phoneme. Danavox HAs have shown slight to no variation when compared to the Hansaton HA processed phoneme /a/. However, no other differences are observed for shimmer (dB) variations in different comparisons like between RIC and BTE, and between high-cost and low-cost hearing aid processed phoneme /a/.

e) Shimmer (%): It is noticed there is an increase in shimmer (%) for most of the HA processed phonemes w.r.t unprocessed stimuli. When HA processed phoneme

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compared w.r.t the unaided phoneme there is not much increase in shimmer (%). It can be observed in table (4.8) that Danavox have shown **slightly more** variations compared to the Hansaton HA processed phoneme. There is **more** increase for RIC as compared to BTEs, irrespective of cost and manufacturer.

f) NHR: It is noticed that there is an **increase** in NHR across all HA processed phonemes w.r.t the unprocessed stimulus. No increase is observed in NHR when HA processed are compared to the unaided phoneme /a/. However, no other differences are observed for NHR variations in different comparisons like between manufacturers, between RIC and BTE, and between high-cost and low-cost hearing aid processed phoneme /a/.

g) HNR: It is noticed that there is **decrease** in HNR across all HA processed phonemes w.r.t the unprocessed stimulus. No increase is observed in HNR when HA processed are compared to the unaided phoneme /a/. It can be observed in table 4.8 that Danavox have shown slight to no variations compared to the Hansaton HA processed phoneme. HNR is slightly more for the BTE as compared to RIC HA processed phoneme. HNR is **slightly more** for high- cost HA compared to the most of low-cost HA processed phoneme /a/.

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Table 4.9

Objective parameters value for male /i/ presented at 50 dB SPL across different conditions

M-/i/-50dB	F0(Hz)	Intensity(dB)	Jitter (%)	Shimmer(dB)	Shimmer (%)	NHR	HNR(dB)
Unprocessed	130.34	83.44	1.079	0.677	5.444	0.061	14.99
Unaided	125.9	70.3	0.462	1.252	16.452	0.268	6.649
DAN BTE H	125.57	71.64	1.434	1.277	13.458	0.310	6.048
DAN BTE L	125.55	73.03	1.418	1.611	18.09	0.272	6.507
DAN RIC H	228.85	75.52	4.725	1.534	15.971	0.517	3.765
DAN RIC L	179.46	73.3	4.184	1.839	17.445	0.576	3.412
HAN BTE H	128.70	68.77	1.706	1.169	10.323	0.184	8.116
HANS BTE L	228.91	75.13	3.58	1.535	17.049	0.436	7.147
HANS RIC H	251.44	80.19	5.519	1.29	14.244	0.469	4.324
HANS RIC L	359.09	77.14	7.81	1.878	18.927	0.681	2.035

Note: M: male, F0: fundamental frequency, NHR: noise-to-harmonics ratio, HNR: harmonics-to-noise ratio, DAN BTE H: Danavox BTE high cost hearing aid, DAN BTE L: Danavox BTE low cost hearing aid, DAN RIC H: Danavox RIC high cost hearing aid, DAN RIC L: Danavox RIC low cost hearing aid, HANS BTE H: Hansaton BTE high cost hearing aid, HANS BTE L: Hansaton BTE low cost hearing aid, HANS RIC H: Hansaton RIC high cost hearing aid , HANS RIC L: Hansaton RIC low-cost hearing aid, RIC: Receiver-in-canal, BTE: Behind-the-ear.

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a) F0 (Hz): It is observed that there is an increase in the fundamental frequency values for most of the HA processed phonemes w.r.t the unprocessed stimuli and unaided phoneme /i/. Hansaton HAs have shown more variation compared to the Danavox HA. F0 variations for RICs processed phoneme is more compared to the BTEs, and in case of high-cost and low-cost, more varied for low-cost hearing aid.

b) Intensity (dB): As observed in the table 4.9, increase in intensity is minimal when HA processed phonemes w.r.t the unaided phoneme /i/. It can also be seen that Hansaton HA shows slightly more variation compared to the Danavox HA processed phoneme. RIC HAs have **slightly more** intensity variation when compared to the BTE HA processed phoneme. When comparing low-cost and high-cost, high cost RIC HA's have **more intensity** but opposite in case of BTE HA processed phoneme /i/.

c) Jitter (%): From the above table, it can be noticed that there is an increase for all the HA processed phoneme w.r.t the unprocessed stimuli and unaided phoneme /i/. Hansaton HA shows more variation compared to the Danavox HA processed phoneme. RIC HAs have **more** variation when compared to the BTE HA processed phoneme irrespective of their cost and manufacturer. Hansaton low-cost HAs have more variation in jitter compared to the high-cost HA processed phoneme /i/.

d) Shimmer (dB): From the above table, it can be noticed that there is a slight noticeable **increase** for all the HA processed phoneme w.r.t the unprocessed stimuli and unaided phoneme /i/. Danavox HAs have slightly more variations compared to the Hansaton HA processed phoneme for shimmer (dB). RIC HAs have slightly more shimmer as compared to the BTE HA processed phoneme. Low-cost hearing

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aids have **slightly more** shimmer (dB) compared to the high-cost hearing aid processed phoneme, irrespective of their model (BTEs & RICs).

e) Shimmer (%): It can be noticed from the above table, that there is an **increase** for all the HA processed phoneme w.r.t the unprocessed stimuli and unaided phoneme /i/. Danavox HAs have slight to no variations compared to the Hansaton HA processed phoneme for shimmer (%). Low-cost RIC HAs have slightly more shimmer as compared to the BTE HA processed phoneme /i/. Low-cost hearing aids have comparably **more** shimmer (%) compared to the high-cost hearing aid processed phoneme, irrespective of their model (BTEs & RICs).

f) NHR: It can be noticed from the above table (4.9), that there is an **increase** in NHR for mostly all of the HA processed phoneme w.r.t the unprocessed stimuli and unaided phoneme /i/. Variations are negligible for Hansaton HA compared to Danavox hearing aid processed phoneme. NHR is **slightly more** for the RIC HA compared to the BTE HA processed phoneme. NHR is noticed to be **more** for Low-cost hearing aids as compared to the high-cost hearing aids

g) HNR: It can be noticed from the above table (4.9), that there is decrease in HNR for all of the HA processed phoneme w.r.t the unprocessed stimuli. There is no noticeable difference in HNR for HA processed phonemes w.r.t unaided phoneme. Hansaton HA shows slightly more HNR compared to Danavox HA processed phoneme /i/. HNR is lesser for RICs compared to the BTEs HA processed phoneme, irrespective of their manufacturers. High –cost hearing aids processed phoneme /i/ have shown **slightly more** HNR as compared to the low-cost hearing aid.

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Table 4.10

Objective parameters value for male /u/ presented at 50 dB SPL across different conditions

M-/u/-50dB	F0(Hz)	Intensity(dB)	Jitter (%)	Shimmer(dB)	Shimmer (%)	NHR	HNR(dB)
Unprocessed	165.26	86.12	1.326	0.355	1.326	0.033	23.829
Unaided	157.99	61.25	0.965	1.007	8.341	0.198	10.053
DAN BTE H	169.29	68.36	0.614	1.19	12.452	0.258	9.13
DAN BTE L	169.26	70.22	0.558	1.019	11.204	0.208	10.084
DAN RIC H	185.90	70.87	1.977	1.31	14.299	0.456	6.294
DAN RIC L	188.86	66.67	1.223	1.261	13.279	0.310	6.828
HAN BTE H	161.82	59.14	0.688	1.186	11.223	0.141	11.625
HANS BTE L	158.4	67	0.537	0.955	8.702	0.203	9.802
HANS RIC H	183.98	71.41	1.907	1.362	15.764	0.371	5.683
HANS RIC L	185.67	70.1	2.326	1.706	18.398	0.413	5.221

Note: M: male, F0: fundamental frequency, NHR: noise-to-harmonics ratio, HNR: harmonics-to-noise ratio, DAN BTE H: Danavox BTE high cost hearing aid, DAN BTE L: Danavox BTE low cost hearing aid, DAN RIC H: Danavox RIC high cost hearing aid, DAN RIC L: Danavox RIC low cost hearing aid, HANS BTE H: Hansaton BTE high cost hearing aid, HANS BTE L: Hansaton BTE low cost hearing aid, HANS RIC H: Hansaton RIC high cost hearing aid , HANS RIC L: Hansaton RIC low-cost hearing aid, RIC: Receiver-in-canal, BTE: Behind-the-ear.

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a) F0 (Hz): It is observed (Table 4.10) that there is an increase in the fundamental frequency values for almost all the HA processed phoneme w.r.t the unprocessed stimuli and unaided phoneme /u/. Hansaton HAs have shown nearly negligible variations compared to the Danavox HA processed phoneme. F0 for RICs processed phoneme is **slightly more** compared to the BTEs, irrespective of the manufactures and cost of the HA's.

b) Intensity (dB): As observed in the table 4.10, that minimal increase in intensity can be seen for all the HA processed phonemes w.r.t the unaided phoneme /u/. It can also be seen that Hansaton HA shows slight to variation compared to the Danavox HA processed phoneme. However, RIC HAs have shown **slightly more** increase in intensity compared to the BTE.

c) Jitter (%): It is observed (Table 4.10) that there is an increase in the jitter values for almost all RICs HA processed phoneme w.r.t the unprocessed stimuli and unaided phoneme /u/. Whereas, opposite results are observed for the BTEs HA processed phoneme. Hansaton HAs have shown nearly similar variations compared to the Danavox HA processed phoneme. Jitter for RICs processed phoneme is more compared to the BTEs processed phoneme, irrespective of their manufactures and cost of the HA's.

d) Shimmer (dB): It is observed (Table 4.10) that there is an increase in the shimmer (dB) values for all HA processed phoneme w.r.t the unprocessed stimuli and unaided phoneme. However, no other noticeable differences are observed for shimmer (dB) variations in different comparisons like between manufacturers, between RIC and BTE, and between high-cost and low-cost hearing aid processed

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phoneme.

e) Shimmer (%): It is observed (Table 4.10) that there is an increase in the shimmer (%) values for all HA processed phoneme w.r.t the unprocessed and unaided phoneme /u/. Hansaton HAs have shown **slightly more** variations compared to the Danavox HA processed phoneme. **Increased** shimmer per cent values are observed for all RICs hearing aids compared to the BTEs HA processed phoneme, irrespective of their cost.

f) NHR: It is observed (Table 4.10) that there is an increase in the NHR values for all HA processed phoneme w.r.t the unprocessed stimuli and unaided phoneme. Hansaton HAs have shown slight to no variations compared to the Danavox HA processed phoneme /u/. However, **minimal increase** in NHR is observed for RIC, between RIC and BTE, irrespective of the cost of hearing aid (high-cost & low-cost hearing aid).

g) HNR: It is observed (Table 4.10) that there is decrease in the HNR values for all HA processed phoneme w.r.t the unprocessed stimuli, decrease is minimal in the HNR values for most of all HA processed phoneme w.r.t the unaided phoneme. Hansaton HAs have shown nearly similar variations as compared to the Danavox HA processed phoneme. RIC HAs have shown **slightly more** decrease in the HNR compared to the BTE HA processed phoneme, irrespective of the cost of hearing aid (high-cost & low-cost hearing aid).

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Table 4.11

Objective parameters value for male /s/ presented at 50 dB SPL across different conditions

M-/s/-50dB	F0(Hz)	Intensity(dB)	Jitter (%)	Shimmer(dB)	Shimmer (%)	NHR	HNR(dB)
Unprocessed	537.90	81.9	10.843	2.26	26.24	0.747	1.514
Unaided	563.46	71.53	8.773	2.035	23.203	0.450	4.124
DAN BTE H	561.46	72.9	10.284	1.646	20.947	0.603	3.102
DAN BTE L	454.56	74.73	10.363	1.552	18.715	0.674	2.247
DAN RIC H	491.21	75.35	8.336	2.003	23.448	0.531	3.509
DAN RIC L	556.99	74.44	9.294	1.991	23.918	0.584	3.116
HAN BTE H	562.73	74.86	9.965	1.509	16.929	0.510	4.43
HANS BTE L	560.60	78.92	8.821	1.523	15.812	0.633	2.643
HANS RIC H	542.38	78.76	10.077	1.431	17.119	0.428	4.104
HANS RIC L	553.38	70.34	8.645	1.62	15.841	0.494	3.667

Note: M: male, F0: fundamental frequency, NHR: noise-to-harmonics ratio, HNR: harmonics-to-noise ratio, DAN BTE H: Danavox BTE high cost hearing aid, DAN BTE L: Danavox BTE low cost hearing aid, DAN RIC H: Danavox RIC high cost hearing aid, DAN RIC L: Danavox RIC low cost hearing aid, HANS BTE H: Hansaton BTE high cost hearing aid, HANS BTE L: Hansaton BTE low cost hearing aid, HANS RIC H: Hansaton RIC high cost hearing aid , HANS RIC L: Hansaton RIC low-cost hearing aid, RIC: Receiver-in-canal, BTE: Behind-the-ear.

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a) F0 (Hz): It is noticed in the above table (4.11) that fundamental frequency values are varying inconsistently for all HA processed phonemes w.r.t the unprocessed stimuli and unaided phoneme /s/. Danavox hearing aids have shown **more** variations compared to the Hansaton HA processed phoneme /s/, irrespective of the model of hearing aids (BTE & RIC), and the cost of hearing aids (low-cost & high-cost).

b) Intensity (dB): It can be noticed (Table 4.11) that there is an increase in intensity level for all hearing aid processed phoneme w.r.t the unprocessed and unaided phoneme /s/. Hansaton HAs have more intensity variations compared to the Danavox HA processed phoneme /s/. Hansaton RIC high HAs has shown **more** intensity level variation as compared to the low-cost hearing aid.

c) Jitter (%): It can be noticed that decrease in Jitter is observed for all hearing aid processed phoneme w.r.t the unprocessed stimuli. But with reference to the unaided stimuli, there is increase in the most of the HA processed phoneme /s/. Hansaton HA have shown negligible variations compared to the Danavox HA, irrespective of the model of hearing aid (BTE & RIC) and cost of the hearing aid (High-cost & Low-cost).

d) Shimmer (dB): It can be noticed (Table 4.11) that shimmer (dB) is decreased across all hearing aid processed phoneme w.r.t the unprocessed and unaided phoneme. Danavox RIC HA shows **more** variations as compared to the Hansaton HA processed phoneme, irrespective of their cost.

e) Shimmer (%): It can be noticed in the above table that shimmer (%) values decrease for most of the HA processed phoneme w.r.t the unprocessed and unaided stimuli.

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Danavox hearing aids have shown **more** variations compared to the Hansaton HA processed phoneme. The decrease in shimmer is **slightly more** for BTE Danavox HA compared to the RIC Danavox processed phoneme. Low-cost hearing aids have shown lesser decrease as compared to the high-cost hearing aids.

f) NHR: It can be noticed in the above table that there is decrease in most HA processed phoneme w.r.t the unprocessed stimuli. But opposite results can be observed w.r.t the unaided phoneme /s/. Hansaton HAs have shown negligible variations in NHR as compared to the Danavox HA processed phoneme /s/, irrespective of their model and cost. No differences can be observed in the comparison between the different models of hearing aids (BTE v/s RIC) and cost of the hearing aid (high-cost v/s low-cost)

g) HNR: It can be noticed in the above table that there is increase in most HA processed phoneme w.r.t the unprocessed stimuli. But opposite results can be observed w.r.t the HNR of unaided phoneme. Hansaton HAs have shown slight to no increase in HNR as compared to the Danavox HA processed phoneme, irrespective of their model and cost. High-cost hearing aids have **more** HNR as compared to the low-cost HA processed phoneme, irrespective of their model (BTE & RIC).

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Table 4.12

Objective parameters value for male /ʃ/ presented at 50 dB SPL across different conditions

M-/ʃ/-50dB	F0(Hz)	Intensity(dB)	Jitter (%)	Shimmer(dB)	Shimmer (%)	NHR	HNR(dB)
Unprocessed	577.976	80.79	9.317	1.664	19.423	0.856	1.911
Unaided	535.447	73.46	10.867	1.671	18.442	0.905	1.074
DAN BTE H	550.268	73.67	8.472	1.48	19.338	0.449	4.117
DAN BTE L	430.393	73.29	9.384	1.69	22.511	0.534	3.533
DAN RIC H	414.607	77.63	10.131	1.927	23.719	0.529	3.55
DAN RIC L	401.707	76.92	9.37	1.663	19.835	0.558	3.387
HAN BTE H	586.977	68.75	8.117	1.568	20.496	0.740	3.297
HANS BTE L	422.956	78.75	10.947	1.949	23.065	0.588	3.261
HANS RIC H	488.074	79.16	10.049	2.204	24.168	0.447	4.461
HANS RIC L	496.71	79.4	9.336	1.584	19.619	0.678	3.616

Note: M: male, F0: fundamental frequency, NHR: noise-to-harmonics ratio, HNR: harmonics-to-noise ratio, DAN BTE H: Danavox BTE high cost hearing aid, DAN BTE L: Danavox BTE low cost hearing aid, DAN RIC H: Danavox RIC high cost hearing aid, DAN RIC L: Danavox RIC low cost hearing aid, HANS BTE H: Hansaton BTE high cost hearing aid, HANS BTE L: Hansaton BTE low cost hearing aid, HANS RIC H: Hansaton RIC high cost hearing aid , HANS RIC L: Hansaton RIC low-cost hearing aid, RIC: Receiver-in-canal, BTE: Behind-the-ear.

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a) F0 (Hz): It can be noticed in the above table (Table 4.12) that F0 for most hearing aid processed out phoneme is decreased w.r.t the unprocessed stimulus and unaided phoneme /ʃ/. Danavox hearing aids have shown a greater variation of F0 compared to Hansaton hearing aids. High-cost BTE of both the manufacturers showed an increase in F0 compared to RIC HA processed phoneme. Between the low-cost and high-cost hearing aids, low-cost hearing aids showed variation compared to high-cost.

b) Intensity (dB): It can be noticed in the above table (Table 4.12) that intensity for most of the hearing aid processed out phoneme /ʃ/ is increased w.r.t the unaided phoneme. Hansaton hearing aids have shown a **slightly more** intensity compared to Danavox hearing aids. RIC HA of both the manufacturers showed an increase in intensity compared to BTE HA processed phoneme, irrespective of cost of hearing aid.

c) Jitter (%): It can be noticed in the above table (Table 4.12) that variations can be observed for most of the hearing aid processed out phoneme w.r.t the unprocessed stimulus and unaided phoneme /ʃ/. Both, the manufacturers have shown nearly similar variations of Jitter (%) values, irrespective of the model (BTE & RIC). There is not much variation in jitter for the BTE and RIC of both the manufacturers. Between the low-cost and high-cost hearing aids, low-cost hearing aids showed **slightly more** variation compared to high-cost hearing aids.

d) Shimmer (dB): It can be noticed in the above table (Table 4.12) that shimmer for most of hearing aid processed out phoneme is increased w.r.t the unprocessed stimulus and unaided phoneme /ʃ/. Hansaton HAs have shown a greater variation

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of shimmer compared to Danavox HA hearing aids, irrespective of the model (BTE & RIC). High-cost RIC of both the manufacturers showed an increase in shimmer (dB) compared to BTE HA processed phoneme. Between the low-cost and high-cost hearing aids, high-cost HA have shown more shimmer (dB) compared to the low-cost hearing aids.

e) Shimmer (%): It can be noticed (Table 4.12) that shimmer (%) for most of hearing aid processed out phoneme /ʃ/ is slightly increased w.r.t the unprocessed stimulus and unaided phoneme shimmer (%). Both the manufacturers, Danavox and Hansaton HA have shown nearly similar variation of shimmer, irrespective of the model (BTE & RIC). High-cost RIC of both the manufacturers showed an increase in shimmer (%) compared to low- cost HA processed phoneme. Between the low-cost and high-cost hearing aids, high-cost HA have shown more shimmer (%) compared to the low-cost hearing aids for RIC HA.

f) NHR: It can be noticed in the above table (Table 4.12) that NHR for all hearing aid processed out phoneme is decreased w.r.t the unprocessed stimulus and unaided phoneme /ʃ/. Danavox and HA have shown more variation compared to NHR of Hansaton HA, irrespective of the model (BTE & RIC). High-cost BTE of both the manufacturers showed a **slight increase** in NHR compared to high-cost RIC HA processed phoneme. But the opposite result has been shown when low cost BTE HAs compared to the low-cost RIC HA processed phoneme.

g) HNR: It can be noticed that there is an increase for HNR for all hearing aid processed out phoneme is decreased w.r.t the unprocessed stimulus and unaided phoneme /ʃ/. Danavox HAs have shown nearly similar variation as compared to

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the Hansaton HA's. High cost BTE of Danavox had maximum HNR compared to all other Hansaton BTE HA's. But opposite results have been seen for high-cost RIC's HA's processed phoneme, where Hansaton high-cost RIC HA's have maximum HNR.

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Table 4.13

Objective parameters value for male /ma/ presented at 50 dB SPL across different conditions

M-/ma/-50dB	F0(Hz)	Intensity(dB)	Jitter (%)	Shimmer(dB)	Shimmer (%)	NHR	HNR(dB)
Unprocessed	115.664	82.59	1.644	0.842	6.716	0.068	14.755
Unaided	116.155	63.8	1.062	1.107	10.834	0.355	5.761
DAN BTE H	113.279	71.11	0.441	1.092	11.562	0.338	5.541
DAN BTE L	114.344	71.96	1.201	1.633	18.095	0.299	6.41
DAN RIC H	117.743	72.81	3.124	1.17	11.487	0.425	4.705
DAN RIC L	112.604	70.53	0.416	2	21.489	0.448	4.696
HAN BTE H	113.443	69.04	1.18	1.512	15.694	0.247	7.368
HANS BTE L	114.645	68.84	0.836	1.678	17.755	0.341	5.922
HANS RIC H	113.691	75.02	1.549	1.326	16.103	0.471	4.263
HANS RIC L	113.839	71.15	2.254	1.427	16.392	0.589	3.48

Note: M: male, F0: fundamental frequency, NHR: noise-to-harmonics ratio, HNR: harmonics-to-noise ratio, DAN BTE H: Danavox BTE high cost hearing aid, DAN BTE L: Danavox BTE low cost hearing aid, DAN RIC H: Danavox RIC high cost hearing aid, DAN RIC L: Danavox RIC low cost hearing aid, HANS BTE H: Hansaton BTE high cost hearing aid, HANS BTE L: Hansaton BTE low cost hearing aid, HANS RIC H: Hansaton RIC high cost hearing aid , HANS RIC L: Hansaton RIC low-cost hearing aid, RIC: Receiver-in-canal, BTE: Behind-the-ear.

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a) F0 (Hz): It can be noticed in the above table (Table 4.13) that F0 for most of hearing aid processed out phoneme is not varied w.r.t the unprocessed stimulus and unaided phoneme /ma/. For both manufactures, negligible variations has been observed, irrespective of their model. When comparing between BTE v/s RIC no variation is observed w.r.t their cost. No variation can be observed for high-cost v/s low cost HA's.

b) Intensity (dB): It can be noticed in the above table 4.13 that intensity for most of hearing aid processed out phoneme is increased w.r.t unaided phoneme /ma/. Hansaton hearing aids have shown a greater variation of intensity compared to Danavox hearing aids, irrespective of the model (BTE & RIC). RIC of Hansaton HAs have shown increase compared to BTE HA processed phoneme, irrespective to the cost of hearing aid. But Dananox has shown slight to no variations in intensity values. When compared between high-cost v/s low-cost, intensity values are greater for high-cost HA's compared to the low-cost HA processed phoneme.

c) Jitter (%): It can be noticed in the above table (Table 4.13) that inconsistent variations can be observed for most of hearing aid processed out phoneme w.r.t the unprocessed stimulus and unaided phoneme /ma/. Danavox HAs have shown more variation as compared to Hansaton HAs. Both, the manufacturers have shown a quite the opposite variations for Jitter (%) w.r.t the model (BTE & RIC) and cost of the HA's. For Danavox high cost BTE's have lesser jitter compared to the high-cost RIC, opposite result has been seen for Hansaton high-cost HA's. High-cost HA's have slightly more variation compared to the low-cost HA's.

d) Shimmer (dB): It can be noticed in the above table (Table 4.13) that shimmer for

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all of hearing aid processed out phoneme is increased w.r.t the unprocessed stimulus and unaided phoneme /ma/. Danavox HAs have shown slightly more variation of shimmer compared to Hansaton HA's, irrespective of the model (BTE & RIC). Low cost RIC's have more shimmer (dB) compared to the BTE of both the manufacturers. When compared between high-cost and lost cost HA's, values were more for low-cost HAs.

e) Shimmer (%): It can be noticed in the above table (Table 4.13) that shimmer (%) for most of hearing aid processed out phoneme is increased w.r.t the unprocessed stimulus and unaided phoneme shimmer (%). Danavox HA have shown slightly more variation of shimmer compared to Hansaton HAs, irrespective of the model (BTE & RIC). Low-cost HAs of Danavox showed an **increase** in shimmer (%) compared to high-cost HA processed phoneme. BTE HA have shown fewer variations in shimmer (%) compared to the RIC HA processed phoneme.

f) NHR: It can be noticed in the above table (Table 4.13) that NHR for most of hearing aid processed out phoneme is increased w.r.t the unprocessed stimulus and unaided phoneme /ma/. Hansaton HAs have shown slightly more variation compared to NHR of Danavox HA, irrespective of the model (BTE & RIC). RIC HAs of both the manufacturers showed an **increase** in NHR compared to BTE HA processed phonemes, irrespective of their cost. Between the low-cost and high-cost hearing aids, low-cost HAs have shown **more** NHR compared to the high-cost hearing aids processed phoneme.

g) HNR: It can be noticed in the above table (Table 4.13) that HNR for most of hearing aid processed out phoneme is decreased w.r.t the unprocessed stimulus

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while no such decrease can be observed w.r.t the unaided phoneme /ma/. Hansaton HA have shown slightly more variation compared to HNR of Danavox HA, irrespective of the model (BTE & RIC). BTE of both the manufacturers showed an increase in HNR compared to RIC HA processed phoneme, irrespective of their cost. Between the low-cost and high-cost hearing aids, most of the high-cost HA have shown **slightly more** HNR compared to the low-cost hearing aids processed phoneme /ma/.

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Table 4.14

Objective parameters value for male /ga/ presented at 50 dB SPL across different conditions

M-/ga/-50dB	F0(Hz)	Intensity(dB)	Jitter (%)	Shimmer(dB)	Shimmer (%)	NHR	HNR(dB)
Unprocessed	120.809	82.43	1.365	1.01	9.121	0.082	12.276
Unaided	149.505	66.9	1.16	1.512	12.116	0.456	5.102
DAN BTE H	129.144	70.78	0.622	1.218	10.947	0.462	5.387
DAN BTE L	128.748	70.66	0.863	0.931	14.343	0.485	4.629
DAN RIC H	341.388	74.17	6.402	1.858	16.962	0.560	3.929
DAN RIC L	311.912	72.24	7.179	1.595	20.872	0.408	3.737
HAN BTE H	182.969	69.21	1.531	1.302	13.387	0.262	7.193
HANS BTE L	135.283	71.89	1.495	1.349	15.109	0.665	4.041
HANS RIC H	244.589	75.02	8.952	1.948	19.317	0.580	3.399
HANS RIC L	258.529	74.87	11.789	1.956	21.776	0.584	3.059

Note: M: male, F0: fundamental frequency, NHR: noise-to-harmonics raito, HNR: harmonics-to-noise ratio, DAN BTE H: Danavox BTE high cost hearing aid, DAN BTE L: Danavox BTE low cost hearing aid, DAN RIC H: Danavox RIC high cost hearing aid, DAN RIC L: Danavox RIC low cost hearing aid, HANS BTE H: Hansaton BTE high cost hearing aid, HANS BTE L: Hansaton BTE low cost hearing aid, HANS RIC H: Hansaton RIC high cost hearing aid , HANS RIC L: Hansaton RIC low-cost hearing aid, RIC: Receiver-in-canal, BTE: Behind-the-ear.

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a) F0 (Hz): It can be noticed in the above table (Table 4.14) that F0 for most of hearing aid processed out phoneme is increased w.r.t the unprocessed stimulus and unaided phoneme F0(Hz). Danavox HA shows more variation compared to Hansaton HA, irrespective of their cost. RIC HA's have more F0 as compared to BTE HA's irrespective of the manufacture and cost. When comparing the high cost to low-cost HA, High cost showed more F0 value for hearing aid processed phoneme.

b) Intensity (dB): It can be noticed (Table 4.14) that intensity for most of hearing aid processed out phoneme is slightly increased w.r.t unaided phoneme /ga/. Hansaton hearing aids have shown a **slightly greater** variation of intensity compared to Danavox hearing aids, irrespective of the model of hearing aid (BTE & RIC). RIC HA of both the manufacturer has shown an **increase** compared to BTE HA processed phoneme, irrespective of the cost of hearing aid. When compared between high-cost v/s low cost, intensity values are greater for high-cost HA's compared to the low-cost HA processed phoneme.

c) Jitter (%): It can be noticed (Table 4.14) that there is an **slight increase** in values of jitter for most of the hearing aid processed out phoneme w.r.t the unprocessed stimulus and unaided phoneme Jitter (%). Hansaton HAs have shown more variation as compared to Danavox HA. RIC HA's have more jitter values compared to that of BTE HA processed phoneme irrespective of their manufacture. Low-cost HAs have shown **slightly more** variation when compared to the high cost HA processed phoneme.

d) Shimmer (dB): It can be noticed in the above table (Table 4.14) that shimmer for

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all of hearing aid processed out phoneme is increased w.r.t the unprocessed stimulus and unaided phoneme /ga/. Danavox HAs have shown slight to no variation of shimmer (dB) compared to Hansaton HA's, irrespective of the model (BTE & RIC). RIC's have **more** shimmer (%) value compared to the BTE of both the manufacturers. When compared between high-cost and lost-cost Hansaton HA, values were more for low-cost HA processed phoneme. But opposite has been seen for Danavox HA's.

e) Shimmer (%): It can be noticed in the above table (Table 4.14) that shimmer (%) for most of hearing aid processed out phoneme is increased w.r.t the unprocessed stimulus and unaided phoneme /ga/. Both the manufacturers, Danavox HA have shown negligible variation in shimmer values when compared to Hansaton HA. RIC HA of both the manufacturers have shown more shimmer (%) compared to the BTE HA processed phoneme. Low cost HAs have shown more value for shimmer when compared to the high cost HA for both the manufactures.

f) NHR: It can be noticed in the above table (Table 4.14) that NHR for most of hearing aid processed out phoneme is increased w.r.t the unprocessed stimulus and unaided phoneme /ga/. Hansaton HA have shown slightly more variation as compared to NHR of Danavox HA, irrespective of the model (BTE & RIC). High cost BTE of Danavox showed decreased value of NHR compared to the RIC, irrespective of their cost and manufacture. Between the low-cost and high-cost hearing aids, low-cost HA have shown **slightly more** NHR compared to the high-cost hearing aids processed phoneme.

g) HNR: It can be noticed in the above table (Table 4.14) that HNR for most of

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hearing aid processed out phoneme is decreased w.r.t the unprocessed stimulus while no such decrease can be observed w.r.t the unaided phoneme /ga/. Hansaton HAs have shown more variation compared to HNR of Danavox HA, irrespective of the model (BTE & RIC). BTE of both the manufacturers showed an increase in HNR compared to RIC HA processed phoneme, irrespective of their cost. Between the low-cost and high-cost hearing aids, most of the high-cost HA have shown more HNR compared to the low-cost hearing aids processed phoneme.

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Table 4.15

Objective parameters value for female /a/ presented at 80 dB SPL across different conditions

F-/a/-80dB	F0(Hz)	Intensity(dB)	Jitter (%)	Shimmer(dB)	Shimmer (%)	NHR	HNR(dB)
Unprocessed	229.874	81.15	1.231	0.569	4.87	0.064	17.67
Unaided	262.42	75.52	1.373	1.097	10.963	0.208	8.868
DAN BTE H	283.934	74.65	2.066	1.281	14.958	0.296	9.319
DAN BTE L	282.472	75.92	1.847	1.107	13.352	0.240	9.873
DAN RIC H	242.45	75.7	0.66	0.947	9.614	0.255	7.662
DAN RIC L	243.778	74.27	1.108	1.196	12.719	0.263	7.42
HAN BTE H	241.377	78.45	1.244	1.071	9.91	0.320	6.686
HANS BTE L	241.377	79.01	0.97	0.967	11.767	0.319	6.003
HANS RIC H	237.963	77.86	0.915	1.197	12.816	0.279	7.212
HANS RIC L	245.832	76.15	1.368	1.416	15.815	0.365	5.832

Note: F: female, F0: fundamental frequency NHR: noise-to-harmonics raito, HNR: harmonics-to-noise raito, DAN BTE H: Danavox BTE high cost hearing aid, DAN BTE L: Danavox BTE low cost hearing aid, DAN RIC H: Danavox RIC high cost hearing aid, DAN RIC L: Danavox RIC low cost hearing aid, HANS BTE H: Hansaton BTE high cost hearing aid, HANS BTE L: Hansaton BTE low cost hearing aid, HANS RIC H: Hansaton RIC high cost hearing aid , HANS RIC L: Hansaton RIC low-cost hearing aid, RIC: Receiver-in-canal, BTE: Behind-the-ear.

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a) F0 (Hz): It can be noticed (Table 4.15) that there is increase in fundamental frequency values for most of the HA processed phoneme w.r.t the unprocessed stimuli. But, there is decrease in most of the HA processed phoneme w.r.t unaided phoneme /a/. The variations for F0 (Hz) are more in the Danavox hearing aids compared to the Hansaton HA processed phoneme. Increase is slightly more for F0 in BTE HAs compared to the RIC HA processed phoneme. There is no noticeable difference for the high-cost v/s low-cost hearing aids.

b) Intensity (dB): It can be noticed in the above table 4.15 that intensity for most of hearing aid processed out phoneme is slightly increased w.r.t the unaided phoneme /a/. Hansaton hearing aids have shown slightly more variation of intensity compared to Danavox hearing aids, irrespective of the model (BTE & RIC). RIC HA of both the manufacturer has shown a slight to no variations compared to BTE HA processed phoneme /a/, irrespective of the cost of hearing aid. When compared between high-cost v/s low-cost, intensity values are greater for high cost HA’s compared to the low cost HA processed phoneme.

c) Jitter (%): It can be noticed in the above table (Table 4.15) that there is an increase in values of jitter for most of hearing aid processed out phoneme w.r.t the unprocessed stimulus and unaided phoneme Jitter /a/. Danavox HAs have shown slightly more variations as compared to Hansaton HA. Most of the BTE HA’s have more jitter values compared to that of RIC HA processed phoneme irrespective of their manufacture. Low cost HA’s has more Jitter when compared to the high cost HA processed phoneme in case of RIC HAs of both the manufacturer. But opposite results shown in cost comparison for BTE hearing aid.

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d) Shimmer (dB): It can be noticed in the above table (Table 4.15) that shimmer for most of hearing aid processed out /a/ is increased w.r.t the unprocessed stimulus and unaided phoneme. Hansaton HAs have shown a **slightly more** variation of shimmer (dB) compared to Danavox HA's, irrespective of the model (BTE & RIC). RIC's have more shimmer (dB) value compared to the BTE for Hansaton hearing aids. When compared between high-cost and low cost, values were more for low-cost HA processed phoneme for RIC hearing aids. But opposite has been seen for BTE HA's processed phoneme.

e) Shimmer (%): It can be noticed in the above table (Table 4.15) that shimmer (%) for most of hearing aid processed out phoneme is increased w.r.t the unprocessed stimulus and unaided phoneme /a/. Hansaton HAs have shown **slightly more** variation in shimmer values when compared to Danavox HA processed phoneme. RIC HA of both the manufactures has shown **more** shimmer (%) compared to the BTE HA processed phoneme. Low cost HAs have shown more value for shimmer when compared to the high cost HA for both the manufactures.

f) NHR: It can be noticed in the above table (Table 4.15) that NHR for most of hearing aid processed out phoneme /a/ is increased w.r.t the unprocessed stimulus and unaided phoneme NHR. Hansaton HAs have shown **slightly more** increase as compared to NHR of Danavox HA, irrespective of the model (BTE & RIC). RIC showed less increase of NHR compared to the BTE HA processed phoneme /a/, irrespective of their cost and manufacture. Between the low-cost and high-cost hearing aids, low-cost HA have shown more NHR compared to the high-cost hearing aids processed /a/.

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g) HNR: It can be noticed in the above table (Table 4.15) that HNR for most of hearing aid processed out phoneme is decreased w.r.t the unprocessed stimulus while no such decrease can be observed w.r.t the unaided phoneme HNR. Danavox HAs have shown more HNR compared to HNR of Hansaton HA, irrespective of the model (BTE & RIC). BTE of both the manufacturers showed an **increase** in HNR compared to RIC HA processed phoneme, irrespective of their cost. Between the low-cost and high-cost hearing aids, most of the high-cost HA have shown more HNR compared to the low-cost hearing aids processed phoneme.

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Table 4.16

Objective parameters value for female /i/ presented at 80 dB SPL across different conditions

F-/i/-80dB	F0(Hz)	Intensity (dB)	Jitter (%)	Shimmer(dB)	Shimmer (%)	NHR	HNR(dB)
Unprocessed	232.832	84.96	0.801	0.49	3.692	0.027	20.046
Unaided	231.808	77.38	0.653	1.113	11.679	0.302	6.746
DAN BTE H	287.144	74.64	0.912	1.377	15.716	0.332	6.544
DAN BTE L	290.691	73.74	0.899	1.547	17.007	0.235	8.005
DAN RIC H	355.779	77.87	3.184	1.573	15.164	0.305	6.698
DAN RIC L	350.526	76.42	3.515	1.656	18.25	0.321	6.201
HAN BTE H	221.25	79.96	1.326	1.266	13.648	0.293	7.188
HANS BTE L	275.201	69.93	1.985	1.423	16.357	0.353	5.976
HANS RIC H	232.721	80.09	2.53	1.419	14.934	0.322	6.425
HANS RIC L	290.496	79.73	3.891	1.577	16.798	0.370	5.444

Note: F: female, F0: fundamental frequency, NHR: noise-to-harmonics raito, HNR:harmonics-to-noise ratio, DAN BTE H: Danavox BTE high cost hearing aid, DAN BTE L: Danavox BTE low cost hearing aid, DAN RIC H: Danavox RIC high cost hearing aid, DAN RIC L: Danavox RIC low cost hearing aid, HANS BTE H: Hansaton BTE high cost hearing aid, HANS BTE L: Hansaton BTE low cost hearing aid, HANS RIC H: Hansaton RIC high cost hearing aid , HANS RIC L: Hansaton RIC low-cost hearing aid, RIC: Receiver-in-canal, BTE: Behind-the-ear.

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a) F0 (Hz): It can be noticed (Table 4.16) that there is increase in fundamental frequency values for all the HA processed phoneme w.r.t the unprocessed stimuli and unaided phoneme /i/. The variations for F0 (Hz) are more in the Danavox hearing aids compared to the Hansaton HA processed phoneme. Increase is more for F0 in RIC HAs compared to the BTE HA processed phoneme, irrespective to their cost. There is slightly more increase for high-cost HA's compared to the low-cost HA processed phoneme.

b) Intensity (dB): It can be noticed in the above table 4.16 that intensity for most of hearing aid processed out phoneme is slightly increased w.r.t the unaided phoneme /i/. Hansaton hearing aids have shown a greater variation of intensity compared to Danavox hearing aids, irrespective of the model (BTE & RIC). RIC HA of both the manufacturer has shown an increase compared to BTE HA processed phoneme /i/. When compared between high-cost v/s low-cost, intensity values are slightly more for high-cost HA's compared to the low-cost HA processed phoneme.

c) Jitter (%): It can be noticed in the above table (Table 4.16) that there is an increase in values of jitter for most of hearing aid processed out phoneme w.r.t the unprocessed stimulus and unaided phoneme /i/. Hansaton HAs have shown more variations for Jitter as compared to Danavox HA, irrespective of their model (BTE&RIC). RIC HA's have more jitter values compared to that of BTE HA processed phoneme, irrespective of their manufacture. Low-cost HA's has **slightly more** Jitter when compared to the high-cost HA processed phoneme /i/ in HAs of both the manufacturer.

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d) Shimmer (dB): It can be noticed in the above table (Table 4.16) that shimmer for all of hearing aid processed /i/ is increased w.r.t the unprocessed stimulus and unaided phoneme /i/. Danavox HAs have shown a slightly more variation of shimmer (dB) compared to Hansaton HA's, irrespective of the model (BTE & RIC). RIC's have showed slightly more shimmer (dB) value compared to the BTE for both the hearing aid manufacturer. When compared between high-cost and low cost, values were shown more for low-cost HA processed phoneme for all hearing aid processed phoneme /i/, irrespective of their model.

e) Shimmer (%): It can be noticed in the above table (Table 4.16) that shimmer (%) for most of hearing aid processed out phoneme is increased w.r.t the unprocessed stimulus and unaided phoneme. Danavox HAs have shown a greater variation of shimmer (%) compared to Hansaton HA's, irrespective of the model (BTE & RIC). RIC HA of both the manufactures has shown more shimmer (%) compared to the BTE HA processed phoneme. Low cost HAs have shown more value for shimmer when compared to the high cost HA for both the manufactures.

f) NHR: It can be noticed in the above table (Table 4.16) that NHR for most of hearing aid processed out phoneme /i/ is increased w.r.t the unprocessed stimulus and unaided phoneme NHR. Danavox HAs have shown slight to no variations as compared to NHR of Hansaton HA, irrespective of the model (BTE & RIC). RIC showed negligible of NHR compared to the BTE HA processed phoneme /i/, irrespective of their cost and manufacture. Between the low-cost and high-cost hearing aids, low-cost HA have shown **more** NHR compared to the high-cost hearing aids processed /i/.

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g) HNR: It can be noticed in the above table (Table 4.16) that HNR for most of hearing aid processed out phoneme is decreased w.r.t the unprocessed stimulus while no such decrease can be observed w.r.t the unaided phoneme /i/. Danavox HAs have shown more variation compared to HNR of Hansaton HA, irrespective of the model (BTE & RIC). BTE of both the manufacturers showed an increase in HNR compared to RIC HA processed phoneme, irrespective of their cost. Between the low-cost and high-cost hearing aids, most of the high-cost HA have shown more HNR compared to the low-cost hearing aids processed phoneme.

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Table 4.17

Objective parameters value for female /u/ presented at 80 dB SPL across different conditions

F-/u/-80dB	F0(Hz)	Intensity(dB)	Jitter (%)	Shimmer(dB)	Shimmer (%)	NHR	HNR(dB)
Unprocessed	240.996	85.88	1.196	0.406	3.143	0.026	26.88
Unaided	240.815	74.41	0.866	0.881	8.525	0.126	11.604
DAN BTE H	242.554	75.69	0.615	1.03	11.661	0.229	11.729
DAN BTE L	241.455	75.71	0.642	0.928	8.694	0.147	9.051
DAN RIC H	275.241	75.44	1.841	1.188	10.61	0.368	7.142
DAN RIC L	251.672	74.67	0.898	1.098	10.666	0.361	6.775
HAN BTE H	245.759	76.15	0.409	0.91	9.803	0.348	7.612
HANS BTE L	242.843	75.81	0.272	0.796	8.716	0.180	9.443
HANS RIC H	265.854	77.58	0.785	1.524	16.366	0.321	7.1
HANS RIC L	251.442	77.26	1.421	1.23	11.2	0.426	6.579

Note: F: female, F0: fundamental frequency, NHR: noise-to-harmonics raito, HNR: harmonics-to-noise raito, DAN BTE H: Danavox BTE high cost hearing aid, DAN BTE L: Danavox BTE low cost hearing aid, DAN RIC H: Danavox RIC high cost hearing aid, DAN RIC L: Danavox RIC low cost hearing aid, HANS BTE H: Hansaton BTE high cost hearing aid, HANS BTE L: Hansaton BTE low cost hearing aid, HANS RIC H: Hansaton RIC high cost hearing aid , HANS RIC L: Hansaton RIC low-cost hearing aid, RIC: Receiver-in-canal, BTE: Behind-the-ear

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a) F0 (Hz): It can be noticed (Table 4.17) that there is increase in fundamental frequency values for all the HA processed phoneme w.r.t the unprocessed stimuli and unaided phoneme. The variations for F0 (Hz) are more in the Danavox hearing aids compared to the Hansaton HA processed phoneme, irrespective to the model of hearing aid. Increase is more for F0 in RIC HAs compared to the BTE HA processed phoneme, irrespective to their cost. There is more increase for high-cost HA's compared to the low-cost HA processed phoneme.

b) Intensity (dB): It can be noticed in the above table 4.17 that intensity for most of hearing aid processed out phoneme is slightly increased w.r.t to unaided phoneme /u/. Hansaton hearing aids have shown a greater variation of intensity compared to Danavox hearing aids, irrespective of the model (BTE & RIC). RIC HA of both the manufacturer has shown an increase compared to BTE HA processed phoneme /u/. When compared between high-cost v/s low-cost, intensity values are greater for high cost HA's compared to the low cost HA processed phoneme.

c) Jitter (%): It can be noticed in the above table (Table 4.17) that there is an increase in values of jitter for most of hearing aid processed out phoneme w.r.t the unprocessed stimulus and unaided phoneme Jitter (%). Danavox HAs have shown more variations for Jitter as compared to Hansaton HA, irrespective of their model (BTE&RIC). BTE HA's have lesser jitter values compared to that of RIC HA processed phoneme, irrespective of their cost. Low cost HA's has more Jitter when compared to the high cost HA processed phoneme /u/ in HAs of both the manufacturer.

d) Shimmer (dB): It can be noticed in the above table (Table 4.17) that shimmer (dB)

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for all of hearing aid processed out /u/ is increased w.r.t the unprocessed stimulus and unaided phoneme. Hansaton HAs have shown a greater variation of shimmer (dB) compared to Danavox HA's, irrespective of the model (BTE & RIC). RIC's have showed more shimmer (dB) value compared to the BTE for both the hearing aid manufacturer. When compared between high-cost and low-cost, values were shown more for high-cost HA processed phoneme for all hearing aid processed phoneme /u/, irrespective of their model.

e) Shimmer (%): It can be noticed in the above table (Table 4.17) that shimmer (%) for most of hearing aids processed phoneme is increased w.r.t the unprocessed stimulus and unaided phoneme. Hansaton HAs have shown a greater variation of shimmer (%) compared to Danavox HA's, irrespective of the model (BTE & RIC). RIC HA of both the manufactures has shown more shimmer (%) compared to the BTE HA processed phoneme. High-cost HAs have shown more value for shimmer when compared to the low-cost HA for both the manufactures.

f) NHR: It can be noticed in the above table (Table 4.17) that NHR for most of hearing aid processed out phoneme /u/ is increased w.r.t the unprocessed stimulus and unaided phoneme NHR. Hansaton HAs have shown more increase as compared to NHR of Danavox HA, irrespective of the model (BTE & RIC). RIC HA showed more increase of NHR compared to the BTE HA processed phoneme /u/, irrespective of their cost and manufacture. Between the low-cost and high-cost hearing aids, low-cost HA have shown more NHR compared to the high-cost hearing aids processed /u/.

g) HNR: It can be noticed in the above table (Table 4.17) that HNR for most of hearing

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aid processed out phoneme is decreased w.r.t the unprocessed and the unaided phoneme /u/. Danavox HAs have shown more variation compared to HNR of Hansaton HA, irrespective of the model (BTE & RIC). BTE of both the manufacturers showed an increase in HNR compared to RIC HA processed phoneme, irrespective of their cost. Between the low-cost and high-cost hearing aids, most of the high-cost HA have shown more HNR compared to the low-cost hearing aids processed phoneme.

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Table 4.18

Objective parameters value for female /s/ presented at 80 dB SPL across different conditions

F-/s/-80dB	F0(Hz)	Intensity(dB)	Jitter(%)	Shimmer(dB)	Shimmer(%)	NHR	HNR(dB)
Unprocessed	528.594	77.22	8.614	1.891	19.987	0.652	2.026
Unaided	553.586	76.1	6.635	1.642	16.771	0.279	6.008
DAN BTE H	551.819	74.4	7.388	1.983	20.19	0.561	2.733
DAN BTE L	551.944	74.9	7.797	1.714	18.118	0.517	3.083
DAN RIC H	186.937	76.88	4.803	1.649	17.716	0.613	2.887
DAN RIC L	197.102	75.24	12.696	1.773	7.768	0.727	1.87
HAN BTE H	554.624	79.92	8.394	1.607	17.707	0.538	2.871
HANS BTE L	468.09	72.9	6.176	1.938	12.151	0.510	3.613
HANS RIC H	133.033	76.45	15.59	1.876	21.345	0.351	4.82
HANS RIC L	107.981	76.34	13.425	2.058	20.736	0.532	3.015

Note: F: female, F0: fundamental frequency, NHR: noise-to-harmonics ratio, HNR: harmonics-to-noise ratio, DAN BTE H: Danavox BTE high-cost hearing aid, DAN BTE L: Danavox BTE low cost hearing aid, DAN RIC H: Danavox RIC high cost hearing aid, DAN RIC L: Danavox RIC low cost hearing aid, HANS BTE H: Hansaton BTE high cost hearing aid, HANS BTE L: Hansaton BTE low cost hearing aid, HANS RIC H: Hansaton RIC high cost hearing aid , HANS RIC L: Hansaton RIC low-cost hearing aid, RIC: Receiver-in-canal, BTE: Behind-the-ear

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a) F0 (Hz): It can be noticed (Table 4.18) that there is increase in fundamental frequency values for all the HA processed phoneme w.r.t the unprocessed stimuli and unaided phoneme. The variations for F0 (Hz) are more in the Danavox hearing aids compared to the Hansaton HA processed phoneme, irrespective to the model of hearing aid. Increase is more for F0 in BTE HAs compared to the RIC HA processed phoneme/s/, irrespective to their cost. There is more increase for high-cost HA's compared to the low-cost HA processed phoneme.

b) Intensity (dB): It can be noticed in the above table 4.18 that intensity for most of hearing aid processed out phoneme is minimally increased w.r.t the unaided phoneme /s/. Hansaton hearing aids have shown a greater variation of intensity compared to Danavox hearing aids, irrespective of the model (BTE & RIC). BTE HA of both the manufacturer has shown an increase compared to RIC HA processed phoneme /s/. When compared between high-cost v/s low-cost, intensity values are more for high cost HA's compared to the low cost HA processed phoneme.

c) Jitter (%): It can be noticed in the above table (Table 4.17) that there is an increase in values of jitter for most of hearing aid processed out phoneme w.r.t the unprocessed stimulus and unaided phoneme /s/. Hansaton HAs have shown more variations for Jitter as compared to Danavox HA, irrespective of their model (BTE&RIC). RIC HA's have more Jitter values compared to that of BTE HA processed phoneme, irrespective of their cost. Low cost HA's has more Jitter when compared to the high cost HA processed phoneme /u/ in Hansaton HAs, whereas no such increase is there for Danavox hearing aids.

d) Shimmer (dB): It can be noticed in the above table (Table 4.18) that shimmer

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(dB) for most of all hearing aid processed out /s/ is increased w.r.t the unprocessed stimulus and unaided phoneme. Hansaton HAs have shown a greater variation of shimmer (dB) compared to Danavox HA's, irrespective of the model (BTE & RIC). RIC's have showed more shimmer (dB) value compared to the BTE for both the hearing aid manufacturer. When compared between high-cost and low-cost, values were shown more for low-cost HA processed phoneme for all hearing aid processed phoneme /s/, irrespective of their model.

e) Shimmer (%): It can be noticed in the above table (Table 4.18) that shimmer (%) for most of hearing aids processed phoneme is increased w.r.t the unprocessed stimulus and unaided phoneme. Hansaton HAs have shown a greater variation of shimmer (%) compared to Danavox HA's, irrespective of the model (BTE & RIC). RIC HAs have shown more shimmer (%) compared to the BTE HA processed phoneme for Hansaton HAs. However opposite result has been shown for Danavox hearing aids. High-cost HAs have shown more value for shimmer when compared to the low-cost HA for both the manufactures.

f) NHR: It can be noticed in the above table (Table 4.18) that NHR for most of hearing aid processed out phoneme /s/ is decreased w.r.t the unprocessed stimulus, while increase is noticeable w.r.t the unaided phoneme NHR. Danavox HAs have shown more increase as compared to NHR of Hansaton HA, irrespective of the model (BTE & RIC). RIC HA showed more increase of NHR compared to the BTE HA processed phoneme /s/, irrespective of their cost and manufacture. Between the low-cost and high-cost hearing aids, low-cost HA have shown more NHR compared to the high-cost hearing aids processed /s/.

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g) HNR: It can be noticed in the above table (Table 4.18) that HNR for most of hearing aid processed out phoneme is decreased w.r.t the unprocessed and the unaided phoneme /s/. Hansaton HAs have shown more variation compared to HNR of Danavox HA, irrespective of the model (BTE & RIC). RIC HAs of both the manufacturers showed an increase in HNR compared to BTE HAs processed phoneme, irrespective of their cost. Between the low-cost and high-cost hearing aids, most of the high-cost HA have shown more HNR compared to the low-cost hearing aids processed phoneme.

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Table 4.19

Objective parameters value for female /ʃ/ presented at 80 dB SPL across different conditions

F-/ʃ/-80dB	F0(Hz)	Intensity(dB)	Jitter (%)	Shimmer(dB)	Shimmer (%)	NHR	HNR(dB)
Unprocessed	527.771	69.88	5.574	1.772	18.996	0.557	2.671
Unaided	510.356	79.56	11.545	1.652	17.79	0.649	2.484
DAN BTE H	480.34	75.62	10.167	1.854	25.582	0.545	2.995
DAN BTE L	420.59	76.74	8.288	1.518	17.072	0.651	2.386
DAN RIC H	433.521	80.44	10.094	1.525	17.001	0.732	2.826
DAN RIC L	455.547	78.68	9.106	1.633	21.151	0.514	2.654
HAN BTE H	522.797	80.67	12.003	1.191	14.799	0.444	4.281
HANS BTE L	519.595	73.93	14.229	2.39	26.836	0.383	3.196
HANS RIC H	513.499	81.28	9.664	1.925	21.717	0.530	3.73
HANS RIC L	476.101	81.02	9.889	1.548	18.138	0.593	3.015

Note: F: female, F0: fundamental frequency, NHR: noise-to-harmonics ratio, HNR: harmonics-to-noise-ratio, DAN BTE H: Danavox BTE high cost hearing aid, DAN BTE L: Danavox BTE low cost hearing aid, DAN RIC H: Danavox RIC high cost hearing aid, DAN RIC L: Danavox RIC low cost hearing aid, HANS BTE H: Hansaton BTE high cost hearing aid, HANS BTE L: Hansaton BTE low cost hearing aid, HANS RIC H: Hansaton RIC high cost hearing aid , HANS RIC L: Hansaton RIC low-cost hearing aid, RIC: Receiver-in-canal, BTE: Behind-the-ear.

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a) F0 (Hz): It can be noticed (Table 4.19) that there is decrease in fundamental frequency values for most of the HA processed phoneme w.r.t the unprocessed stimuli and unaided phoneme. The variations for F0 (Hz) are more in the Hansaton HAs compared to the Danavox HA processed phoneme, irrespective to the model of hearing aid. Increase is more for F0 in BTE HAs compared to the RIC HA processed phoneme/ʃ/, irrespective to their cost. There is more increase for high-cost HA's compared to the low-cost HA processed phoneme.

b) Intensity (dB): It can be noticed in the above table 4.19 that intensity for most of hearing aid processed out phoneme is increased minimally w.r.t the unaided phoneme /ʃ/. Hansaton hearing aids have shown a greater variation of intensity compared to Danavox hearing aids, irrespective of the model (BTE & RIC). BTE HAs of both the manufacturer has shown an increase for intensity compared to RIC HA processed phoneme /ʃ/. When compared between high-cost v/s low-cost, intensity values are more for high cost HA's compared to the low cost HA processed phoneme.

c) Jitter (%): It can be noticed in the above table (Table 4.19) that there is an increase in values of jitter for most of hearing aid processed out phoneme w.r.t the unprocessed stimulus, whereas opposite results has been noticeable w.r.t the unaided phoneme /ʃ/ . Hansaton HAs have shown more variations for Jitter as compared to Danavox HA, irrespective of their model (BTE&RIC). BTE HA's have more Jitter values compared to that of RIC HA processed phoneme /ʃ/ , irrespective of their cost. Low cost HA's has more Jitter when compared to the high cost HA processed phoneme /ʃ/ in Hansaton HAs, whereas no such increase is there for Danavox hearing aids.

d) Shimmer (dB): It can be noticed in the above table (Table 4.19) that shimmer

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(dB) for most of the hearing aid processed out /ʃ/ is increased w.r.t the unprocessed stimulus and unaided phoneme. Hansaton HAs have shown a greater variation of shimmer (dB) compared to Danavox HA's, irrespective of the model (BTE & RIC). BTE's have showed more shimmer (dB) value compared to the RIC HAs processed phoneme for both the hearing aid manufacturer. When compared between high-cost and low-cost, values were shown more for low-cost HA processed phoneme for all hearing aid processed phoneme /ʃ/, irrespective of their model.

e) Shimmer (%): It can be noticed in the above table (Table 4.19) that shimmer (%) for most of hearing aids processed phoneme is increased w.r.t the unprocessed stimulus and unaided phoneme /ʃ/. Hansaton HAs have shown a greater variation of shimmer (%) compared to Danavox HA's, irrespective of the model (BTE & RIC). BTE HAs have shown more shimmer (%) compared to the RIC HA processed phoneme /ʃ/ for Hansaton HAs. However opposite result has been shown for Danavox hearing aids. High-cost HAs have shown more value for shimmer when compared to the low-cost HA for both the manufactures.

f) NHR: It can be noticed in the above table (Table 4.19) that NHR for most of hearing aid processed out phoneme /ʃ/ is decreased w.r.t the unprocessed stimulus, while increase is noticeable w.r.t the unaided phoneme NHR. Danavox HAs have shown more increase as compared to NHR of Hansaton HA, irrespective of the model (BTE & RIC). RIC HA showed more increase of NHR compared to the BTE HA processed phoneme /ʃ/, irrespective of their cost and manufacture. Between the low-cost and high-cost hearing aids, low-cost HA have shown more NHR compared to the high-cost hearing aids processed /ʃ/.

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g) HNR: It can be noticed in the above table (Table 4.19) that HNR for most of hearing aid processed out phoneme is decreased w.r.t the unprocessed and the unaided phoneme /ʃ/. Hansaton HAs have shown more variation compared to HNR of Danavox HA, irrespective of the model (BTE & RIC). BTE HAs of both the manufacturers showed an increase in HNR compared to RIC HAs processed phoneme /ʃ/, irrespective of their cost. Between the low-cost and high-cost hearing aids, most of the high-cost HA have shown more HNR compared to the low-cost hearing aids processed phoneme /ʃ/.

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Table 4.20

Objective parameters value for female /ma/ presented at 80 dB SPL across different conditions

F-/ma/-80dB	F0(Hz)	Intensity(dB)	Jitter (%)	Shimmer(dB)	Shimmer (%)	NHR	HNR(dB)
Unprocessed	243.274	85.25	0.574	0.473	3.616	0.006	24.432
Unaided	236.48	70.85	0.801	0.81	8.233	0.109	12.775
DAN BTE H	262.335	74.42	0.758	1.032	12.695	0.176	12.433
DAN BTE L	240.794	72.78	1.095	0.995	12.284	0.171	12.892
DAN RIC H	278.731	75.74	0.965	1.23	12.891	0.217	9.525
DAN RIC L	236.135	73.57	0.823	1.25	14.466	0.233	9.454
HAN BTE H	251.53	75.69	1.179	0.877	10.795	0.206	9.752
HANS BTE L	237.366	67.23	0.822	0.941	7.541	0.153	10.717
HANS RIC H	289.623	79.34	1.265	1.319	13.491	0.252	7.72
HANS RIC L	232.551	78.08	1.155	1.413	14.925	0.270	7.446

Note: F: female, F0: fundamental frequency, NHR: noise-to-harmonics ratio, HNR: harmonics-to-noise ratio, DAN BTE H: Danavox BTE high cost hearing aid, DAN BTE L: Danavox BTE low cost hearing aid, DAN RIC H: Danavox RIC high cost hearing aid, DAN RIC L: Danavox RIC low cost hearing aid, HANS BTE H: Hansaton BTE high cost hearing aid, HANS BTE L: Hansaton BTE low cost hearing aid, HANS RIC H: Hansaton RIC high cost hearing aid , HANS RIC L: Hansaton RIC low-cost hearing aid, RIC: Receiver-in-canal, BTE: Behind-the-ear.

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a) F0 (Hz): It can be noticed (Table 4.20) that there is increase in fundamental frequency values for most of the HA processed phoneme /ma/ w.r.t the unprocessed stimuli and unaided phoneme. The variations for F0 (Hz) are more in the Hansaton HAs compared to the Danavox HA processed phoneme, irrespective to the model of hearing aid. Increase is more for F0 in RIC HAs compared to the BTE HA processed phoneme /ma/, irrespective to their cost. There is more increase for high-cost HA's compared to the low-cost HA processed phoneme, irrespective of their manufacturer.

b) Intensity (dB): It can be noticed in the above table 4.20 that intensity for most of hearing aid processed out phoneme /ma/ is increased minimally w.r.t the unaided phoneme /ma/. Hansaton hearing aids have shown a greater variation of intensity compared to Danavox hearing aids, irrespective of the model (BTE & RIC). RIC HAs of both the manufacturer has shown an increase for intensity compared to BTE HA processed phoneme /ma/. When compared between high-cost v/s low-cost, intensity values are more for high cost HA's compared to the low cost HA processed phoneme.

c) Jitter (%): It can be noticed in the above table (Table 4.20) that there is an increase in values of jitter for most of hearing aid processed out phoneme w.r.t the unprocessed stimulus and the unaided phoneme /ma/. Hansaton HAs have shown more variations for Jitter as compared to Danavox HA, irrespective of their model (BTE&RIC). RIC HA's have more Jitter values compared to that of BTE HA processed phoneme /ma/, for Hansaton HAs, irrespective of their cost. No such result has been observable for Danavox HAs. High-cost HA's has more Jitter when compared to the high-cost HA processed phoneme /ma/, irrespective of their manufacturers.

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d) Shimmer (dB): It can be noticed in the above table (Table 4.20) that shimmer (dB) for most of the hearing aid processed /ma/ is increased w.r.t the unprocessed stimulus and unaided phoneme. Hansaton HAs have shown a greater variation of shimmer (dB) compared to Danavox HA’s, irrespective of the model (BTE & RIC). RIC HAs have showed more shimmer (dB) value compared to the BTE’s processed phoneme for both the hearing aid manufacturer. When compared between high-cost and low-cost, values were more for low-cost HA processed phoneme for all hearing aid processed phoneme /ma/, irrespective of their model.

e) Shimmer (%): It can be noticed in the above table (Table 4.20) that shimmer (%) for most of hearing aids processed phoneme is increased w.r.t the unprocessed stimulus and unaided phoneme /ma/. Hansaton HA’s has shown a greater variation of shimmer (%) compared to Danavox HA’s, irrespective of the model (BTE & RIC). RIC HAs have shown more shimmer (%) compared to the BTE HA processed phoneme /ma/ for Hansaton HAs. However opposite result has been shown for Danavox hearing aids. Most of the low-cost HAs have shown more value for shimmer when compared to the high-cost HAs processed phoneme for both the manufactures.

f) NHR: It can be noticed in the above table (Table 4.20) that NHR for most of hearing aid processed out phoneme /ma/ is increased w.r.t the unprocessed stimulus and the unaided phoneme /ma/. Hansaton HAs have shown more increase as compared to NHR of Danavox HA, irrespective of the model (BTE & RIC). RIC HA showed more increase of NHR compared to the BTE HA processed phoneme /ma/, irrespective of their cost and manufacture. Between the low-cost and high-cost hearing aids, most of the low-cost HA have shown

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more NHR compared to the high-cost hearing aids processed /ma/.

g) HNR: It can be noticed in the above table (Table 4.20) that HNR for most of hearing aid processed out phoneme is decreased w.r.t the unprocessed and the unaided phoneme /ma/. Hansaton HAs have shown more variation compared to HNR of Danavox HA, irrespective of the model (BTE & RIC). BTE HAs of both the manufacturers showed an increase in HNR compared to RIC HAs processed phoneme /ma/, irrespective of their cost. Between the low-cost and high-cost hearing aids, most of the high-cost HA have shown no difference of HNR compared to the low-cost hearing aids processed phoneme /ma/.

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Table 4.21

Objective parameters value for female /ga/ presented at 80 dB SPL across different conditions

F-/ga/-80dB	F0(Hz)	Intensity(dB)	Jitter (%)	Shimmer(dB)	Shimmer (%)	NHR	HNR(dB)
Unprocessed	212.96	81.09	0.532	0.556	4.452	0.019	20.923
Unaided	211.75	79.15	0.376	0.884	8.142	0.149	9.068
DAN BTE H	211.99	76.27	0.265	1.083	11.724	0.110	10.826
DAN BTE L	211.82	76.89	0.248	0.885	8.951	0.127	10.677
DAN RIC H	250.42	76.5	1.609	1.165	12.763	0.343	6.219
DAN RIC L	248.15	77.5	1.338	1.22	12.895	0.375	6.347
HAN BTE H	211.84	78.98	2.165	0.893	8.225	0.310	7.83
HANS BTE L	212.27	76.74	0.441	0.964	9.801	0.270	6.241
HANS RIC H	212.39	79.96	0.289	0.929	8.844	0.217	8.208
HANS RIC L	212.48	78.62	0.867	0.937	9.417	0.258	7.921

Note: F: female, F0: fundamental frequency, NHR: noise-to-harmonics raito, HNR: harmonics-to-noise raito, DAN BTE H: Danavox BTE high cost hearing aid, DAN BTE L: Danavox BTE low cost hearing aid, DAN RIC H: Danavox RIC high cost hearing aid, DAN RIC L: Danavox RIC low cost hearing aid, HANS BTE H: Hansaton BTE high cost hearing aid, HANS BTE L: Hansaton BTE low cost hearing aid, HANS RIC H: Hansaton RIC high cost hearing aid , HANS RIC L: Hansaton RIC low-cost hearing aid, RIC: Receiver-in-canal, BTE: Behind-the-ear.

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a) F0 (Hz): It can be noticed (Table 4.21) that there is increase in fundamental frequency values for some of the HAs processed phoneme /ga/ w.r.t the unprocessed stimuli and unaided phoneme. The variations for F0 (Hz) are more in the Danavox HAs compared to the Hansaton HA processed phoneme, irrespective to the model of hearing aid. Increase is more for F0 in RIC HAs compared to the BTE HA processed phoneme /ga/, irrespective to their cost. There is more increase for high-cost HA's compared to the low-cost HA processed phoneme, irrespective of their manufacturer.

b) Intensity (dB): It can be noticed in the above table 4.21 that intensity for most of hearing aid processed out phoneme /ga/ is increased minimally w.r.t the unaided phoneme /ga/. Hansaton hearing aids have shown more variation of intensity compared to Danavox hearing aids, irrespective of the model (BTE & RIC). RIC HAs of both the manufacturer has shown slightly more increase for intensity compared to BTE HA processed phoneme /ma/. When compared between high-cost v/s low-cost, intensity values are higher for high-cost HA's compared to the low cost HA processed phoneme /ga/ in Hansaton hearing aids, whereas no such difference is there for Danavox HAs.

c) Jitter (%): It can be noticed in the above table (Table 4.21) that there is an increase in values of jitter for most of hearing aid processed out phoneme w.r.t the unprocessed stimulus and the unaided phoneme /ga/. Hansaton HAs have shown more variations for Jitter as compared to Danavox HA, irrespective of their model (BTE&RIC). RIC HA's have more Jitter values compared to that of BTE HA processed phoneme /ga/, for Danavox HAs, irrespective of their cost. No such result has been observable for Hansaton HAs. High-cost HA's has more Jitter when compared to the high-cost HA processed phoneme /ga/, irrespective

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of their manufacturers.

d) Shimmer (dB): It can be noticed in the above table (Table 4.21) that shimmer (dB) for most of the hearing aid processed /ga/ is increased w.r.t the unprocessed stimulus and unaided phoneme. Danavox HAs have shown a greater variation of shimmer (dB) compared to Hansaton HA's, irrespective of the model (BTE & RIC). RIC HAs have showed more shimmer (dB) value compared to the BTE's processed phoneme for both the hearing aid manufacturer. When compared between high-cost and low-cost, values were more for most of the low-cost HA processed phoneme for all hearing aid processed phoneme /ga/, irrespective of their model.

e) Shimmer (%): It can be noticed in the above table (Table 4.21) that shimmer (%) for most of hearing aids processed phoneme is increased w.r.t the unprocessed stimulus and unaided phoneme /ga/. Danavox HA's has shown a greater variation of shimmer (%) compared to Hansaton HA's, irrespective of the model (BTE & RIC). RIC HAs have shown more shimmer (%) compared to the BTE HA processed phoneme /ga/ for Danavox HAs. However no such result has been noticed for Hansaton hearing aids. Most of the low-cost HAs have shown more value for shimmer when compared to the high-cost HAs processed phoneme for both the manufactures.

f) NHR: It can be noticed in the above table (Table 4.21) that NHR for most of hearing aid processed out phoneme /ga/ is increased w.r.t the unprocessed stimulus and the unaided phoneme /ga/. Danavox HAs have shown more increase as compared to NHR of Hansaton HA, irrespective of the model (BTE & RIC). RIC HAs showed more increase of NHR compared to the BTE HA processed phoneme /ga/, irrespective of their cost and manufacture. Between

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the low-cost and high-cost hearing aids, most of the low-cost HA have shown more NHR compared to the high-cost hearing aids processed /ga/.

g) HNR: It can be noticed in the above table (Table 4.21) that HNR for most of hearing aid processed out phoneme is decreased w.r.t the unprocessed and the unaided phoneme /ga/. Hansaton HAs have shown more variation compared to HNR of Danavox HA, irrespective of the model (BTE & RIC). BTE HAs of Danavox HAs showed an increase in HNR compared to RIC HAs processed phoneme /ga/, irrespective of their cost. No such result has been noticed for Hansaton HAs for HNR. Between the low-cost and high-cost hearing aids, most of the high-cost HA have shown more HNR compared to the low-cost hearing aids processed phoneme /ga/

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Table 4.22

Objective parameters value for male /a/ presented at 80 dB SPL across different conditions

M-/a/-80dB	F0(Hz)	Intensity(dB)	Jitter (%)	Shimmer(dB)	Shimmer (%)	NHR	HNR(dB)
Unprocessed	108.727	80.36	1.638	1.314	11.835	0.212	9.868
Unaided	104.719	80.22	3.349	1.47	17.04	0.468	5.008
DAN BTE H	114.719	80.12	4.449	1.875	15.04	0.575	6.748
DAN BTE L	105.087	77.95	1.832	0.743	8.227	0.442	6.006
DAN RIC H	188.073	79.9	3.969	1.291	15.408	0.430	6.837
DAN RIC L	108.057	80.25	1.667	1.663	18.028	0.391	5.421
HAN BTE H	231.149	82.28	3.994	1.385	13.119	0.567	3.951
HANS BTE L	222.032	78.83	3.244	1.636	15.527	0.567	3.73
HANS RIC H	257.217	81.32	3.655	1.782	14.276	0.601	2.878
HANS RIC L	224.808	81.25	3.491	1.298	16.156	0.591	3.136

Note: M: Male, F0: fundamental frequency, NHR: noise-to-harmonics raito, HNR: harmonics-to-noise raito, DAN BTE H: Danavox BTE high cost hearing aid, DAN BTE L: Danavox BTE low cost hearing aid, DAN RIC H: Danavox RIC high cost hearing aid, DAN RIC L: Danavox RIC low cost hearing aid, HANS BTE H: Hansaton BTE high cost hearing aid, HANS BTE L: Hansaton BTE low cost hearing aid, HANS RIC H: Hansaton RIC high cost hearing aid , HANS RIC L: Hansaton RIC low-cost hearing aid, RIC: Receiver-in-canal, BTE: Behind-the-ear.

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a) F0 (Hz): It can be noticed (Table 4.22) that there is increase in fundamental frequency values for some of the HAs processed phoneme /a/ w.r.t the unprocessed stimuli and unaided phoneme. The variations for F0 (Hz) are more in the Hansaton HAs compared to the Danavox HA processed phoneme, irrespective to the model of hearing aid. Increase is more for F0 in RIC HAs compared to the BTE HA processed phoneme /a/, irrespective to their cost. There is more increase for high-cost HA's compared to the low-cost HA processed phoneme, irrespective of their manufacturer.

b) Intensity (dB): It can be noticed in the above table 4.22 that intensity for most of hearing aid processed out phoneme /a/ is not decreased w.r.t unaided phoneme /a/. Hansaton hearing aids have shown more variation of intensity compared to Danavox hearing aids, irrespective of the model (BTE & RIC). RIC HAs of both the manufacturer has shown slightly more increase for intensity compared to BTE HA processed phoneme /a/. When compared between high-cost v/s low-cost, intensity values are higher for high-cost HA's compared to the low cost HA processed phoneme /a/ in Hansaton hearing aids.

c) Jitter (%): It can be noticed in the above table (Table 4.22) that there is an increase in values of jitter for most of hearing aid processed out phoneme w.r.t the unprocessed stimulus and the unaided phoneme /a/. Danavox HAs have shown more variations for Jitter as compared to Hansaton HA, irrespective of their model (BTE&RIC). HA's BTE have more Jitter values compared to that of RIC HA processed phoneme /a/, for both HAs manufacturers, irrespective of their cost. High-cost HA's has more Jitter when compared to the high-cost HA processed phoneme /a/, irrespective of their manufacturers.

d) Shimmer (dB): It can be noticed in the above table (Table 4.22) that shimmer

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(dB) for most of the hearing aid processed /a/ is increased w.r.t the unprocessed stimulus and unaided phoneme. Danavox HAs have shown a greater variation of shimmer (dB) compared to Hansaton HA's, irrespective of the model (BTE & RIC). RIC HAs have showed more shimmer (dB) value compared to the BTE's processed phoneme for both the hearing aid manufacturer, irrespective of their cost. When compared between high-cost and low-cost, there are no consistent differences observed for all hearing aid processed phoneme /a/, irrespective of their model.

e) Shimmer (%): It can be noticed in the above table (Table 4.22) that shimmer (%) for most of hearing aids processed phoneme is increased w.r.t the unprocessed stimulus and unaided phoneme /a/. Danavox HA's has shown a greater variation of shimmer (%) compared to Hansaton HA's, irrespective of the model (BTE & RIC). RIC HAs has shown more shimmer (%) compared to the BTE HA processed phoneme /a/ for both the manufacturers. Most of the low-cost HAs have shown more value for shimmer when compared to the high-cost HAs processed phoneme for both the manufactures.

f) NHR: It can be noticed in the above table (Table 4.22) that NHR for most of hearing aid processed out phoneme /a/ is increased w.r.t the unprocessed stimulus and the unaided phoneme /a/. Danavox HAs have shown more increase as compared to NHR of Hansaton HA, irrespective of the model (BTE & RIC). RIC HAs showed more increase of NHR compared to the BTE HA processed phoneme /a/, irrespective of their cost and manufacture. Between the low-cost and high-cost hearing aids, no consistent differences can be seen for NHR compared to the high-cost hearing aids processed /a/.

g) HNR: It can be noticed in the above table (Table 4.22) that HNR for most of

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hearing aid processed out phoneme is decreased w.r.t the unprocessed and the unaided phoneme /a/. Hansaton HAs have shown more variation compared to HNR of Danavox HA, irrespective of the model (BTE & RIC). BTE HAs of Danavox showed an increase in HNR compared to RIC HAs processed phoneme /a/, irrespective of their cost. No such result has been noticed for Hansaton HAs for HNR. Between the low-cost and high-cost hearing aids, most of the high-cost HA have shown more HNR compared to the low-cost hearing aids processed phoneme /a/.

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Table 4.23

Objective parameters value for male /i/ presented at 80 dB SPL across different conditions

M-/i/-80dB	F0(Hz)	Intensity(dB)	Jitter (%)	Shimmer(dB)	Shimmer (%)	NHR	HNR (dB)
Unprocessed	130.349	83.44	1.079	0.677	5.444	0.0613	14.99
Unaided	125.806	77.39	0.462	1.32	11.724	0.254	6.798
DAN BTE H	125.607	77.62	0.445	1.17	12.949	0.433	4.286
DAN BTE L	125.597	76.76	0.445	1.189	12.944	0.397	4.773
DAN RIC H	150.889	79.61	5.304	1.807	24.662	0.577	3.328
DAN RIC L	125.161	76.92	0.941	1.474	17.554	0.548	3.501
HAN BTE H	125.967	80.76	0.462	1.356	14.36	0.467	4.107
HANS BTE L	125.914	81.03	1.353	1.583	18.97	0.449	4.306
HANS RIC H	125.717	81.23	0.516	1.349	13.4	0.404	4.516
HANS RIC L	125.947	80.12	0.453	1.314	15.19	0.526	3.472

Note: M: Male, F0: fundamental frequency, NHR: noise-to-harmonics raito, HNR: harmonics-to-noise raito, DAN BTE H: Danavox BTE high cost hearing aid, DAN BTE L: Danavox BTE low cost hearing aid, DAN RIC H: Danavox RIC high cost hearing aid, DAN RIC L: Danavox RIC low cost hearing aid, HANS BTE H: Hansaton BTE high cost hearing aid, HANS BTE L: Hansaton BTE low cost hearing aid, HANS RIC H: Hansaton RIC high cost hearing aid , HANS RIC L: Hansaton RIC low-cost hearing aid, RIC: Receiver-in-canal, BTE: Behind-the-ear.

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a) F0 (Hz): It can be noticed (Table 4.23) that there is increase in fundamental frequency values for some of the HAs processed phoneme /i/ w.r.t the unprocessed stimuli and unaided phoneme. The variations for F0 (Hz) are more in the Danavox HAs compared to the Hansaton HA processed phoneme, irrespective to the model of hearing aid. Increase is more for F0 in RIC HAs compared to the BTE HA processed phoneme /i/, for Danavox hearing. No, such increase can be observed for Hansaton HAs, irrespective to the cost of HAs. There is more increase for high-cost RIC HA's compared to the low-cost HA processed phoneme/i/.

b) Intensity (dB): It can be noticed in the above table 4.23 that intensity for most of hearing aid processed phoneme /i/ is increased or nearly similar w.r.t the unaided phoneme /i/. Hansaton hearing aids have shown more variation of intensity compared to Danavox hearing aids, irrespective of the model (BTE & RIC). RIC HAs of both the manufacturer has shown slightly more increase for intensity compared to BTE HA processed phoneme /i/. When compared between high-cost v/s low-cost, intensity values are higher for high-cost HA's compared to the low cost HA processed phoneme /a/ in Hansaton hearing aids.

c) Jitter (%): It can be noticed in the above table (Table 4.23) that there is an decrease in jitter for most of the HAs processed phoneme /i/ w.r.t the unprocessed stimulus, whereas increase is there w.r.t the unaided phoneme /i/. Danavox HAs have shown more variations for Jitter as compared to Hansaton HA, irrespective of their model (BTE&RIC). RIC HA's have more Jitter values compared to that of BTE HA processed phoneme /i/, for both HA's manufacturers, irrespective of their cost. High-cost HA's has more Jitter when compared to the high-cost HA processed phoneme /i/, irrespective of their

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manufacturers.

d) Shimmer (dB): It can be noticed in the above table (Table 4.23) that shimmer (dB) for most of the hearing aid processed /i/ is increased w.r.t the unprocessed stimulus and unaided phoneme. Danavox HAs have shown a greater variation of shimmer (dB) compared to Hansaton HA's, irrespective of the model (BTE & RIC). RIC HAs have showed more shimmer (dB) value compared to the BTE's processed phoneme for both the hearing aid manufacturer, irrespective of their cost. When compared between high-cost and low-cost, there are no consistent differences observed for all hearing aid processed phoneme /i/, irrespective of their model.

e) Shimmer (%): It can be noticed in the above table (Table 4.23) that shimmer (%) for most of hearing aids processed phoneme is increased w.r.t the unprocessed stimulus and unaided phoneme /i/. Danavox HA's has shown a greater variation of shimmer (%) compared to Hansaton HA's, irrespective of the model (BTE & RIC). RIC HAs have shown more shimmer (%) compared to the BTE HA processed phoneme /i/, irrespective to the cost of HAs. Most of the low-cost HAs have shown more value for shimmer when compared to the high-cost HAs processed phoneme for both the manufactures.

f) NHR: It can be noticed in the above table (Table 4.23) that NHR for most of hearing aid processed out phoneme /i/ is increased w.r.t the unprocessed stimulus and the unaided phoneme /i/. Danavox HAs have shown more increase as compared to NHR of Hansaton HA, irrespective of the model (BTE & RIC). RIC HAs showed more increase of NHR compared to the BTE HA processed phoneme /i/, irrespective of their cost and manufacture. Between the low-cost and high-cost hearing aids, no consistent differences can be seen for NHR

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compared to the high-cost hearing aids processed /i/.

g) HNR: It can be noticed in the above table (Table 4.23) that HNR for most of hearing aid processed out phoneme is decreased w.r.t the unprocessed and the unaided phoneme /i/. Danavox HAs have shown more variation compared to HNR of Hansaton HA, irrespective of the model (BTE & RIC). BTE HAs of Danavox showed an increase in HNR compared to RIC HAs processed phoneme /i/, irrespective of their cost. No such result has been noticed for Hansaton HAs for HNR. Between the low-cost and high-cost hearing aids, most of the HA have shown no variations for HNR compared to the low-cost hearing aids processed phoneme /i/

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Table 4.24

Objective parameters value for female /u/ presented at 80 dB SPL across different conditions

M-/u/-80dB	F0(Hz)	Intensity(dB)	Jitter (%)	Shimmer(dB)	Shimmer (%)	NHR	HNR(dB)
Unprocessed	165.26	86.12	1.326	0.355	1.326	0.033	23.829
Unaided	161.13	77.09	1.068	0.938	9.219	0.210	9.193
DAN BTE H	169.63	74.31	0.623	1.386	13.891	0.265	8.757
DAN BTE L	169.60	74.12	0.598	1.347	13.162	0.236	8.765
DAN RIC H	174.03	76.51	2.055	1.18	10.905	0.510	5.442
DAN RIC L	169.31	77.27	0.508	1.445	11.1	0.419	5.93
HAN BTE H	170.38	76.47	1.207	0.81	7.798	0.352	6.306
HANS BTE L	169.12	78.17	1.175	1.138	10.753	0.418	5.929
HANS RIC H	169.72	75.75	0.909	1.349	12.192	0.353	6.627
HANS RIC L	171.45	75.15	1.355	1.424	13.768	0.431	5.545

Note: F: female, F0: fundamental frequency, NHR: noise-to-harmonics ratio, HNR: harmonics-to-noise ratio, DAN BTE H: Danavox BTE high cost hearing aid, DAN BTE L: Danavox BTE low cost hearing aid, DAN RIC H: Danavox RIC high cost hearing aid, DAN RIC L: Danavox RIC low cost hearing aid, HANS BTE H: Hansaton BTE high cost hearing aid, HANS BTE L: Hansaton BTE low cost hearing aid, HANS RIC H: Hansaton RIC high cost hearing aid , HANS RIC L: Hansaton RIC low-cost hearing aid, RIC: Receiver-in-canal, BTE: Behind-the-ear.

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a) F0 (Hz): It can be noticed (Table 4.24) that there is increase in fundamental frequency values for some of the HAs processed phoneme /u/ w.r.t the unprocessed stimuli and unaided phoneme. The variations for F0 (Hz) are more in the Danavox HAs compared to the Hansaton HA processed phoneme, irrespective to the model of hearing aid. Increase is more for F0 in RIC HAs compared to the BTE HA processed phoneme /u/, for Danavox hearing. No, such increase can be observed for Hansaton HAs, irrespective to the cost of HAs. There is more increase for high-cost RIC HA's compared to the low-cost HA processed phoneme /u/.

b) Intensity (dB): It can be noticed in the above table 4.24 that intensity for most of hearing aid processed phoneme /u/ is nearly similar w.r.t the unaided phoneme /u/. Hansaton hearing aids have shown more variation of intensity compared to Danavox hearing aids, irrespective of the model (BTE & RIC). RIC HAs of both the manufacturer has shown slightly more increase for intensity compared to BTE HA processed phoneme /u/ for Danavox HAs. Whereas, no such difference can be noticed for the Hansaton HAs. When compared between high-cost v/s low-cost, intensity values showed no difference for HA processed phoneme /u/ in Hansaton hearing aids.

c) Jitter (%): It can be noticed in the above table (Table 4.24) that there is an decrease in jitter for most of the HAs processed phoneme /u/ w.r.t the unprocessed stimulus, whereas increase is there w.r.t the unaided phoneme /u/. Danavox HAs have shown more variations for Jitter as compared to Hansaton HA, irrespective of their model (BTE&RIC). RIC HA's have more Jitter values compared to that of BTE HA processed phoneme /u/, for both HA's manufacturers, irrespective of their cost. High-cost HA's has more Jitter when

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compared to the high-cost HA processed phoneme /u/, irrespective of their manufacturers.

d) Shimmer (dB): It can be noticed in the above table (Table 4.24) that shimmer (dB) for most of the hearing aid processed /u/ is increased w.r.t the unprocessed stimulus and unaided phoneme. Danavox HAs have shown a greater variation of shimmer (dB) compared to Hansaton HA’s, irrespective of the model (BTE & RIC). RIC HAs have showed more shimmer (dB) value compared to the BTE’s processed phoneme for both the hearing aid manufacturer, irrespective of their cost. When compared between high-cost and low-cost, low-cost HAs have more shimmer (dB) compared to the high-cost hearing aid processed phoneme /u/, irrespective of their model.

e) Shimmer (%): It can be noticed in the above table (Table 4.24) that shimmer (%) for most of hearing aids processed phoneme is increased w.r.t the unprocessed stimulus and unaided phoneme /u/. Danavox HA’s has shown a greater variation of shimmer (%) compared to Hansaton HA’s, irrespective of the model (BTE & RIC). BTE HAs have shown more shimmer (%) compared to the RIC HA processed phoneme /u/, irrespective to the cost of HAs. Most of the low-cost HAs have shown more value for shimmer (%) when compared to the high-cost HAs processed phoneme for both the manufactures.

f) NHR: It can be noticed in the above table (Table 4.24) that NHR for most of hearing aid processed out phoneme /u/ is increased w.r.t the unprocessed stimulus and the unaided phoneme /u/. Danavox HAs have shown more increase as compared to NHR of Hansaton HA, irrespective of the model (BTE & RIC). RIC HAs showed more increase of NHR compared to the BTE HA processed phoneme /u/, irrespective of their cost and manufacture. Between the low-cost

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and high-cost hearing aids, no consistent differences can be seen for NHR compared to the high-cost hearing aids processed /u/.

g) HNR: It can be noticed in the above table (Table 4.24) that HNR for most of hearing aid processed out phoneme is decreased w.r.t the unprocessed and the unaided phoneme /u/. Danavox HAs have shown more variation compared to HNR of Hansaton HA, irrespective of the model (BTE & RIC). BTE HAs of Danavox showed an increase in HNR compared to RIC HAs processed phoneme /u/, irrespective of their cost. No such result has been noticed for Hansaton HAs for HNR. Between the low-cost and high-cost hearing aids, most of the HA have shown no consistent differences can be seen for NHR of hearing aids processed /u/.

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Table 4.25

Objective parameters value for male /s/ presented at 80 dB SPL across different conditions

M-/s/-80dB	F0(Hz)	Intensity(dB)	Jitter (%)	Shimmer(dB)	Shimmer (%)	NHR	HNR(dB)
Unprocessed	537.90	81.9	10.843	2.26	26.24	0.747	1.514
Unaided	562.08	80.11	9.25	1.396	16.874	0.520	3.341
DAN BTE H	547.89	78.1	8.637	1.471	15.942	0.743	2.48
DAN BTE L	505.57	77.91	8.48	1.271	13.21	0.541	3.658
DAN RIC H	493.76	79.27	7.462	1.789	20.795	0.652	2.362
DAN RIC L	565.94	78.78	8.715	1.691	19.372	0.646	2.533
HAN BTE H	568.17	81.05	8.886	1.74	20.179	0.575	3.014
HANS BTE L	555.56	78.07	8.768	1.865	20.187	0.678	2.247
HANS RIC H	514.95	79.96	9.764	1.752	18.45	0.670	2.328
HANS RIC L	558.	79.63	9.341	1.532	13.138	0.755	1.7

Note: M: Male, F0: fundamental frequency, NHR: noise-to-harmonics ratio, HNR: harmonics-to-noise ratio, DAN BTE H: Danavox BTE high cost hearing aid, DAN BTE L: Danavox BTE low cost hearing aid, DAN RIC H: Danavox RIC high cost hearing aid, DAN RIC L: Danavox RIC low cost hearing aid, HANS BTE H: Hansaton BTE high cost hearing aid, HANS BTE L: Hansaton BTE low cost hearing aid, HANS RIC H: Hansaton RIC high cost hearing aid , HANS RIC L: Hansaton RIC low-cost hearing aid, RIC: Receiver-in-canal, BTE: Behind-the-ear.

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a) F0 (Hz): It can be noticed (Table 4.25) that there are minimal changes in fundamental frequency for most of the HAs processed phoneme /s/ w.r.t the unprocessed stimuli and unaided phoneme. The variations for F0 (Hz) are similar in the Danavox HAs compared to the Hansaton HA processed phoneme, irrespective to the model of hearing aid. RIC HAs showed no differences for F0 compared to the BTE HA processed phoneme /s/, irrespective to the cost of HAs. There is more increase for low-cost HA's compared to high-cost HA processed phoneme /s/.

b) Intensity (dB): It can be noticed in the above table 4.25 that intensity for most of hearing aid processed phoneme /s/ is nearly similar w.r.t the unaided phoneme /s/. Danavox hearing aids have shown slight to no variation of intensity compared to Hansaton hearing aids, irrespective of the model (BTE & RIC). RIC HAs have shown slightly more increase for intensity compared to BTE HA processed phoneme /s/ for Danavox HAs. Whereas, no such difference can be noticed for the Hansaton HAs. When compared between high-cost v/s low-cost, intensity values showed no difference for HA processed phoneme /s/ in Hansaton hearing aids.

c) Jitter (%): It can be noticed in the above table (Table 4.25) that there is decrease in jitter for most of the HAs processed phoneme /s/ w.r.t the unprocessed stimulus, and the unaided phoneme /s/. Danavox HAs have shown more variations for Jitter as compared to Hansaton HA, irrespective of their model (BTE&RIC). RIC HA's have more Jitter values compared to that of BTE HA processed phoneme /s/, for both HA's manufacturers, irrespective of their cost. High-cost HA's has slightly more Jitter when compared to the high-cost HA processed phoneme /s/, irrespective of their manufacturers.

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d) Shimmer (dB): It can be noticed in the above table (Table 4.25) that shimmer (dB) for most of the hearing aid processed /s/ is decreased w.r.t the unprocessed stimulus, while increased w.r.t the unaided phoneme /s/. Danavox HAs have shown a greater variation of shimmer (dB) compared to Hansaton HA's, irrespective of the model (BTE & RIC). RIC HAs have showed more shimmer (dB) value compared to the BTE's processed phoneme for both the hearing aid manufacturer, irrespective of their cost. When compared between high-cost and low-cost, high-cost HAs have more shimmer (dB) compared to the high-cost hearing aid processed phoneme /s/, irrespective of their model.

e) Shimmer (%): It can be noticed in the above table (Table 4.25) that shimmer (%) for most of hearing aids processed phoneme is increased w.r.t the unaided phoneme /s/ while, decrease is seen w.r.t unprocessed stimulus. Danavox HA's has shown a greater variation of shimmer (%) compared to Hansaton HA's, irrespective of the model (BTE & RIC). BTE HAs have shown more shimmer (%) compared to the RIC HA processed phoneme /s/, irrespective to the cost of HAs. Most of the high-cost HAs have shown slightly more value for shimmer (%) when compared to the low-cost HAs processed phoneme for both the manufactures.

f) NHR: It can be noticed in the above table (Table 4.25) that NHR for most of hearing aid processed out phoneme /s/ is decreased w.r.t the unprocessed stimulus and the unaided phoneme /s/. Danavox HAs have shown slight to no variation compared to NHR of Hansaton HA, irrespective of the model (BTE & RIC). RIC HAs showed more NHR compared to the BTE HA processed phoneme /s/, irrespective of their cost and manufacture. Between the low-cost and high-cost hearing aids, low-cost have more variations as compared to the

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NHR of high-cost hearing aids processed /s/.

g) HNR: It can be noticed in the above table (Table 4.25) that HNR for most of hearing aid processed phoneme /s/ is increased w.r.t the unprocessed and the unaided phoneme /s/. Danavox HAs have shown more variation compared to HNR of Hansaton HA, irrespective of the model (BTE & RIC). BTE HAs showed an increase in HNR compared to RIC HAs processed phoneme /s/, irrespective of their cost. Between the low-cost and high-cost hearing aids, low-cost have less HNR as compared to the HNR of high-cost hearing aids processed /s/ for Hansaton HAs.

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Table 4.26

Objective parameters value for male /ʃ/ presented at 80 dB SPL across different conditions

M-/ʃ/-80dB	F0(Hz)	Intensity(dB)	Jitter (%)	Shimmer(dB)	Shimmer (%)	NHR	HNR(dB)
Unprocessed	577.97	80.79	9.317	1.664	19.423	0.856	1.911
Unaided	588.64	80.97	10.235	1.919	20.646	0.385	4.533
DAN BTE H	579.3	78.37	6.616	1.464	16.893	0.439	4.403
DAN BTE L	579.92	77.87	5.944	1.699	16.346	0.593	2.677
DAN RIC H	402.64	80.81	10.979	1.847	18.155	0.662	2.478
DAN RIC L	419.51	80.42	9.677	1.693	18.959	0.734	2.044
HAN BTE H	514.39	81.69	8.953	1.464	13.562	0.545	3.078
HANS BTE L	457.91	81.36	10.414	1.81	21.518	0.614	2.499
HANS RIC H	484.70	80.54	8.966	1.825	20.756	0.470	3.777
HANS RIC L	439.03	80.18	10.172	1.794	20.084	0.506	3.526

Note: F: female, F0: fundamental frequency, NHR: noise-to-harmonics raito, HNR: harmonics-to-noise raito, DAN BTE H: Danavox BTE high cost hearing aid, DAN BTE L: Danavox BTE low cost hearing aid, DAN RIC H: Danavox RIC high cost hearing aid, DAN RIC L: Danavox RIC low cost hearing aid, HANS BTE H: Hansaton BTE high cost hearing aid, HANS BTE L: Hansaton BTE low cost hearing aid, HANS RIC H: Hansaton RIC high cost hearing aid , HANS RIC L: Hansaton RIC low-cost hearing aid, RIC: Receiver-in-canal, BTE: Behind-the-ear.

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a) F0 (Hz): It can be noticed (Table 4.26) that there is decrease in fundamental frequency for most of the HAs processed phoneme /ʃ/ w.r.t the unprocessed stimuli and unaided phoneme. The variations for F0 (Hz) are more in the Danavox HAs compared to the Hansaton HA processed phoneme, irrespective to the model of hearing aid. RIC HAs showed more differences for F0 compared to the BTE HA processed phoneme /sh/, irrespective to the cost of HAs. There is more increase for low-cost Hansaton HA's compared to high-cost HA processed phoneme /ʃ/.

b) Intensity (dB): It can be noticed in the above table 4.26 that intensity for most of hearing aid processed phoneme /ʃ/ is nearly similar w.r.t the unaided phoneme /ʃ/. Danavox hearing aids have shown slight to no variation of intensity compared to Hansaton hearing aids, irrespective of the model (BTE & RIC). RIC HAs have shown slightly to no variation for intensity compared to BTE HA processed phoneme /ʃ/. When compared between high-cost v/s low-cost, intensity values showed no difference for HA processed phoneme /sh/ in the hearing aids.

c) Jitter (%): It can be noticed in the above table (Table 4.26) that there is decrease in jitter for most of the HAs processed phoneme /sh/ w.r.t the unprocessed stimulus, and the unaided phoneme /sh/. Danavox HAs have shown more variations for Jitter as compared to Hansaton HA, irrespective of their model (BTE&RIC). RIC HA's have slightly more Jitter values compared to that of BTE HA processed phoneme /sh/, irrespective of their cost. Low-cost HA's has more Jitter when compared to the high-cost HA processed phoneme /ʃ/, irrespective of their manufacturers.

d) Shimmer (dB): It can be noticed in the above table (Table 4.26) that shimmer

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(dB) for most of the hearing aid processed /ʃ/ is nearly similar w.r.t the unprocessed stimulus, while increased w.r.t the unaided phoneme /ʃ/. Danavox HAs have shown slight to no variation of shimmer (dB) compared to Hansaton HA's, irrespective of the model (BTE & RIC). RIC HAs have showed slightly more shimmer (dB) value compared to the BTE's processed phoneme for both the hearing aid manufacturer, irrespective of their cost. When compared between high-cost and low-cost, high-cost HAs have more shimmer (dB) compared to the high-cost hearing aid processed phoneme /ʃ/, irrespective of their model.

e) Shimmer (%): It can be noticed in the above table (Table 4.26) that shimmer (%) for most of hearing aids processed phoneme is slightly decreased w.r.t the unaided and unprocessed stimulus. Danavox HA's has shown a greater variation of shimmer (%) compared to Hansaton HA's, irrespective of the model (BTE & RIC). BTE HAs have shown more variation compared to the RIC HA processed phoneme /ʃ/, irrespective to the cost of HAs. Most of the low-cost HAs have shown more value for shimmer (%) when compared to the high-cost HAs processed phoneme for both the manufactures.

f) NHR: It can be noticed in the above table (Table 4.26) that NHR for most of hearing aid processed out phoneme /ʃ/ is decreased w.r.t the unprocessed stimulus and the unaided phoneme /ʃ/. Danavox HAs have shown similar variation as compared to NHR of Hansaton HA, irrespective of the model (BTE & RIC). RIC HAs showed slightly more NHR compared to the BTE HA processed phoneme /ʃ/, irrespective of their cost and manufacture. Between the low-cost and high-cost hearing aids, low-cost have more variations as compared to the NHR of high-cost hearing aids processed /ʃ/.

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g) HNR: It can be noticed in the above table (Table 4.26) that HNR for most of hearing aid processed phoneme /ʃ/ is increased w.r.t the unprocessed and the unaided phoneme /ʃ/. Danavox HAs have shown slightly more variation compared to HNR of Hansaton HA, irrespective of the model (BTE & RIC). BTE HAs of Danavox showed an increase in HNR compared to RIC HAs processed phoneme /ʃ/, irrespective of their cost. No such result has been noticed for Hansaton HAs for HNR. Between the low-cost and high-cost hearing aids, high-cost have more HNR compared to the NHR of low-cost hearing aids processed /ʃ/ for Hansaton HAs.

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Table 4.27

Objective parameters value for male /ma/ presented at 80 dB SPL across different conditions

M-/ma/-80dB	F0(Hz)	Intensity(dB)	Jitter (%)	Shimmer(dB)	Shimmer (%)	NHR	HNR(dB)
Unprocessed	115.66	82.59	1.644	0.842	6.716	0.068	14.755
Unaided	127.71	73.55	0.957	1.473	14.301	0.320	5.802
DAN BTE H	147.41	74.56	0.891	1.342	15.447	0.362	5.295
DAN BTE L	150.56	74.89	0.474	1.371	14.43	0.331	5.685
DAN RIC H	123.84	77.03	1.117	1.717	19.369	0.463	4.274
DAN RIC L	152.50	75.79	1.502	1.703	19.019	0.519	3.974
HAN BTE H	146.56	76.5	1.658	1.371	14.968	0.386	5.441
HANS BTE L	137.38	77.57	1.376	1.398	15.511	0.443	4.689
HANS RIC H	136.03	78.25	1.383	1.59	18.239	0.500	4.399
HANS RIC L	146.52	76.77	1.37	1.607	17.845	0.414	4.358

Note: F: female, F0: fundamental frequency, NHR: noise-to-harmonics ratio, HNR: harmonics-to-noise ratio, DAN BTE H: Danavox BTE high cost hearing aid, DAN BTE L: Danavox BTE low cost hearing aid, DAN RIC H: Danavox RIC high cost hearing aid, DAN RIC L: Danavox RIC low cost hearing aid, HANS BTE H: Hansaton BTE high cost hearing aid, HANS BTE L: Hansaton BTE low cost hearing aid, HANS RIC H: Hansaton RIC high cost hearing aid , HANS RIC L: Hansaton RIC low-cost hearing aid, RIC: Receiver-in-canal, BTE: Behind-the-ear.

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a) F0 (Hz): It can be noticed (Table 4.27) that there minimal changes in fundamental frequency for most of the HAs processed phoneme /ma/ w.r.t the unprocessed stimuli and unaided phoneme. The variations for F0 (Hz) are more in the Danavox HAs compared to the Hansaton HA processed phoneme, irrespective to the model of hearing aid. RIC HAs showed no differences for F0 compared to the BTE HA processed phoneme /ma/, irrespective to the cost of HAs. There is more increase for low-cost HA's compared to high-cost HA processed phoneme /ma/.

b) Intensity (dB): It can be noticed in the above table 4.27 that intensity for most of hearing aid processed phoneme /ma/ is nearly similar w.r.t the unaided phoneme /ma/. Danavox hearing aids have shown slight to no variation of intensity compared to Hansaton hearing aids, irrespective of the model (BTE & RIC). RIC HAs have shown slightly more increase for intensity compared to BTE HA processed phoneme /ma/. When compared between high-cost v/s low-cost, intensity values showed negligible difference for HA processed phoneme /ma/ in Hansaton hearing aids.

c) Jitter (%): It can be noticed in the above table (Table 4.27) that there is decrease in jitter for most of the HAs processed phoneme /ma/ w.r.t the unprocessed phoneme /ma/. Danavox HAs have shown more variations for Jitter as compared to Hansaton HA, irrespective of their model (BTE&RIC). RIC HA's have more Jitter values compared to that of BTE HA processed phoneme /ma/, for Danavox HA's. High-cost HA's has negligible differences when compared to the low-cost HA processed phoneme /ma/, irrespective of their manufacturers.

d) Shimmer (dB): It can be noticed in the above table (Table 4.27) that shimmer

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(dB) for most of the hearing aid processed /ma/ is increased w.r.t the unprocessed stimulus, while increased w.r.t the unaided phoneme /ma/. Danavox HAs have shown a slightly greater variation of shimmer (dB) compared to Hansaton HA's, irrespective of the model (BTE & RIC). RIC HAs have showed slightly more shimmer (dB) value compared to the BTE's processed phoneme for both the hearing aid manufacturer, irrespective of their cost. When compared between high-cost and low-cost, low-cost HAs have more shimmer (dB) compared to the high-cost hearing aid processed phoneme /ma/, irrespective of their model.

e) Shimmer (%): It can be noticed in the above table (Table 4.27) that shimmer (%) for most of hearing aids processed phoneme is increased w.r.t the unaided phoneme and unprocessed stimulus. Danavox HA's has shown greater variation of shimmer (%) compared to Hansaton HA's, irrespective of the model (BTE & RIC). BTE HAs have shown more shimmer (%) compared to the RIC HA processed phoneme /ma/, irrespective to the cost of HAs. Most of the high-cost HAs have shown more value for shimmer (%) when compared to the high-cost HAs processed phoneme for both the manufactures.

f) NHR: It can be noticed in the above table (Table 4.27) that NHR for most of hearing aid processed out phoneme /ma/ is increased w.r.t the unprocessed stimulus and the unaided phoneme /ma/. Danavox HAs have shown slightly more increase as compared to NHR of Hansaton HA, irrespective of the model (BTE & RIC). RIC HAs showed slight increase of NHR compared to the BTE HA processed phoneme /ma/, irrespective of their cost and manufacture. Between the low-cost and high-cost hearing aids, low-cost have more variations as compared to the NHR of high-cost hearing aids processed /ma/.

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g) HNR: It can be noticed in the above table (Table 4.27) that HNR for most of hearing aid processed phoneme /ma/ is decreased w.r.t the unprocessed and the unaided phoneme /ma/. Danavox HAs have shown slightly more variation compared to HNR of Hansaton HA, irrespective of the model (BTE & RIC). BTE HAs of Danavox showed a slight increase in HNR compared to RIC HAs processed phoneme /ma/, irrespective of their cost. Between the low-cost and high-cost hearing aids, low-cost have more variations as compared to the HNR of high-cost hearing aids processed /ma/ for Hansaton HAs.

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Table 4.28

Objective parameters value for male /ga/ presented at 80 dB SPL across different conditions

M-/ga/-80dB	F0(Hz)	Intensity(dB)	Jitter %	Shimmer(dB)	Shimmer (%)	NHR	HNR(dB)
Unprocessed	120.80	82.43	1.365	1.01	9.121	0.082	12.276
Unaided	157.23	74.45	0.799	1.042	9.153	0.415	5.197
DAN BTE H	129.13	74.36	0.629	1.303	15.971	0.482	5.033
DAN BTE L	132.16	73.2	1.042	1.06	9.401	0.542	4.192
DAN RIC H	281.27	78.47	4.498	1.842	21.109	0.477	5.126
DAN RIC L	395.92	76.49	6.988	1.946	21.524	0.550	3.414
HAN BTE H	156.40	77.91	0.928	1.57	15.646	0.470	4.262
HANS BTE L	130.37	78.47	0.845	1.015	9.981	0.287	7.959
HANS RIC H	246.75	79.26	4.594	1.96	22.656	0.429	4.637
HANS RIC L	338.93	78.02	5.508	1.451	18.422	0.523	3.966

Note: F: female, F0: fundamental frequency, NHR: noise-to-harmonics ratio, HNR: harmonics-to-noise ratio, DAN BTE H: Danavox BTE high cost hearing aid, DAN BTE L: Danavox BTE low cost hearing aid, DAN RIC H: Danavox RIC high cost hearing aid, DAN RIC L: Danavox RIC low cost hearing aid, HANS BTE H: Hansaton BTE high cost hearing aid, HANS BTE L: Hansaton BTE low cost hearing aid, HANS RIC H: Hansaton RIC high cost hearing aid , HANS RIC L: Hansaton RIC low-cost hearing aid, RIC: Receiver-in-canal, BTE: Behind-the-ear.

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(a) F0 (Hz): It can be noticed (Table 4.28) that there is increase in fundamental frequency for most of the HAs processed phoneme /ga/ w.r.t the unprocessed stimuli and unaided phoneme. The variations for F0 (Hz) are more in the Danavox HAs compared to the Hansaton HA processed phoneme, irrespective to the model of hearing aid. RIC HAs have showed more differences for F0 compared to the BTE HA processed phoneme /ga/, irrespective to the cost of HAs. There is more increase for low-cost HA's compared to high-cost HA processed phoneme /ga/.

(b) Intensity (dB): It can be noticed in the above table 4.28 that intensity for most of hearing aid processed phoneme is nearly similar w.r.t the unaided phoneme /ga/. Danavox hearing aids have shown slight to no variation of intensity compared to Hansaton hearing aids, irrespective of the model (BTE & RIC). RIC HAs have shown slightly more increase for intensity compared to BTE HA processed phoneme /ga/. When compared between high-cost v/s low-cost, intensity values showed slight to no differences for HA processed phoneme /ga/ in Hansaton hearing aids.

(c) Jitter (%): It can be noticed in the above table (Table 4.28) that there is increase in jitter for most of the HAs processed phoneme /ga/ w.r.t the unprocessed stimulus, and the unaided phoneme /ga/. Danavox HAs have shown more variations for Jitter as compared to Hansaton HA, irrespective of their model (BTE&RIC). RIC HA's have more Jitter values compared to that of BTE HA processed phoneme /ga/, for both HA's manufacturers, irrespective of their cost. Low-cost HA's has more Jitter when compared to the high-cost HA processed phoneme /ga/, irrespective of their manufacturers.

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(d) Shimmer (dB): It can be noticed in the above table (Table 4.28) that shimmer (dB) for most of the hearing aid processed /ga/ is increased w.r.t the unprocessed stimulus and unaided phoneme /ga/. Danavox HAs have shown a slight to no variation of shimmer (dB) compared to Hansaton HA's, irrespective of the model (BTE & RIC). RIC HAs have showed **more** shimmer (dB) value compared to the BTE's processed phoneme for both the hearing aid manufacturer, irrespective of their cost. When compared between high-cost and low-cost, high-cost HAs have more shimmer (dB) compared to the high-cost hearing aid processed phoneme /ga/, irrespective of their model.

(e) Shimmer (%): It can be noticed in the above table (Table 4.28) that shimmer (%) for most of hearing aids processed phoneme is increased w.r.t the unaided phoneme /ga/ while, decrease is seen w.r.t unprocessed stimulus. Danavox HA's has shown a slight to no variation of shimmer (%) compared to Hansaton HA's, irrespective of the model (BTE & RIC). RIC HAs have shown more shimmer (%) compared to the BTE HA processed phoneme /ga/, irrespective to the cost of HAs. Most of the high-cost HAs have shown more value for shimmer (%) when compared to the low-cost HAs processed phoneme for both the manufactures.

(f) NHR: It can be noticed in the above table (Table 4.28) that NHR for most of hearing aid processed out phoneme /ga/ is increased w.r.t the unprocessed stimulus and the unaided phoneme /ga/. Danavox HAs have shown slightly more increase as compared to NHR of Hansaton HA, irrespective of the model (BTE & RIC). RIC HAs showed slightly more increase of NHR compared to the BTE HA processed phoneme /ga/, irrespective of their cost

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and manufacture. Between the low-cost and high-cost hearing aids, low-cost have more variations as compared to the NHR of high-cost hearing aids processed /ga/.

(g) HNR: It can be noticed in the above table (Table 4.28) that HNR for most of hearing aid processed phoneme /ga/ is decreased w.r.t the unprocessed and the unaided phoneme /ga/. Danavox HAs have shown slightly more variation compared to HNR of Hansaton HA, irrespective of the model (BTE & RIC). BTE HAs showed a slight increase in HNR compared to RIC HAs processed phoneme /ga/, irrespective of their cost. Between the low-cost and high-cost hearing aids, high-cost have more HNR compared to the HNR of low-cost hearing aids processed /ga/ for Hansaton HAs.

4.2 Comparison across different groups

Tabulated data was analysed descriptively for meeting the different objectives of the study. On the basis of above tabulated data different inferences were obtained for the objectives of the present study.

4.2.(i) Comparison of variations observed for male v/s female voice processed phoneme

There are slight changes in fundamental frequency (F0) for vowels (/a/, /i/, /u/) spoken by females compared to the males in Danavox hearing aids. Intensity is increased for both the male and female spoken phonemes. Jitter is seen to be increased at 50dB SPL for (/i/, /u/, /ga/) spoken by female speaker in some cases with Danavox hearing aids. Jitter is also found to be increased at 50dB SPL for (/s/, /sh/) spoken by

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female speaker in low-end HAs. For shimmer (dB) and shimmer (%), there is slight to no difference observed between the manufacturers for vowels and consonants spoken by male and females at both the intensity. But there is increase in shimmer (dB) and shimmer (%) seen for Danavox RIC hearing aids for /i/ spoken by female at 80 dB SPL. For NHR, there are negligible differences among male and females except at 80dB SPL for /s/ spoken by female where high-end HAs have increased NHR compared to the low-end HAs. At 50dB SPL, decrease is seen in HNR of Hansaton RIC hearing aids for /ga/ spoken by female compared to the male. At high intensity, decrease is seen in HNR of Danavox BTE hearing aids for /ga/ spoken by female compared to the male. Also, it is noticed that at 50dB SPL /ʃ/ spoken by female where high-end hearing devices have increased HNR as compared to the low-end hearing aid. It is observed that for female spoken phonemes more variations are there for F0, Jitter, shimmer (dB), shimmer (%), NHR, and HNR compared to the male spoken phoneme stimuli.

4.2.(ii) Comparison of variations observed across phonemes

There is a slight increase in Fundamental frequency (F0) for vowels (/a/, /i/, /u/) in Danavox hearing aids, RIC HAs at 50dB SPL and 80dB SPL. There is slight difference observed for consonants (/s/, /ʃ/, /ma/, /ga/) in F0 at 50 dB SPL, but at 80dB SPL there is greater increase in F0 for RIC hearing aids (both males and females). Intensity level is increased in both the vowels and consonants, but no noticeable differences are seen. Jitter is seen to be slightly increased for vowels in low-end hearing aids while for consonants it is seen increased at 50dB SPL for (/ga/, /s, /ʃ/) consonants in some cases with Danavox hearing aids. For shimmer (dB) there is no major differences for vowels and consonants spoken by male and females at both the intensity. Slight increase in shimmer (dB) and shimmer (%) is seen for (/s/, /sh/) consonants. NHR for /s/ phoneme is increased for BTE as compared to the RIC. At

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80dB SPL for /s/ high-end hearing devices have increased NHR as compared to the low-end hearing aids. In case of HNR, slight decrease is seen for all the vowels and consonant. It has been observed that the parameters like F0, Jitter, Shimmer (dB), Shimmer (%), NHR have shown more variations for consonants compared to the vowels. However, no differences have been observed for Intensity and NHR, between vowels and consonants. Mostly, high consonants like /s/ and /sh/ have shown variations.

4.2.(iii) Comparison of processed speech stimuli between two different manufacturer hearing aids (Danavox & Hansaton)

There is increase in Fundamental frequency (F0) for phonemes spoken by females in Danavox hearing aids at 50dB SPL and 80dB SPL. Intensity level of phoneme is increased in both the manufacturers at 50dB SPL and slight differences are observed at 80 dB SPL. AT 50dB SPL, Jitter is seen increased in some cases with Danavox hearing aids while slight increase is seen for consonant in Hansaton hearing aids. At 80dB SPL, there is no such difference observed between the manufacturers. For shimmer (dB) and shimmer (%), slight increase in shimmer (dB) and (%) is seen for Danavox hearing aids (RIC). For NHR, there are no differences among the manufacturers at both the presentation level. Increase is seen in HNR of Danavox hearing aids for /ga/ compared to the other counterpart. Overall, it has been observed that most of the parameters like F0, Jitter, Shimmer (dB), Shimmer (%), and HNR have shown more variation for Danavox HAs compared to Hansaton HAs, whereas no differences have been observed in NHR, and Intensity.

4.2.(iv) Comparison of processed speech stimuli between BTE (Behind-the-ear) and RIC (Receiver-in-canal) hearing aids

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There is a significant increase in fundamental frequency (F0) for phonemes spoken by males and females in RIC hearing aids at 50dB SPL and 80dB SPL. Intensity level of phonemes is increased in RIC hearing aids compared to the BTE HAs. Jitter is seen increased at 50dB SPL and 80dB SPL for most of the phonemes spoken by male and female speakers in case of RIC hearing aids. For shimmer (dB) and shimmer (%), there is increase too in RIC for vowels and consonants spoken by male and females at both presentation levels. NHR is increased for RIC HAs compared to BTE HAs at 50 dB SPL but At 80 dB SPL NHR is increased for BTE as compared to the RIC. In case of HNR, decrease is seen for RIC hearing aids for most of the phonemes. It has been observed that most of the parameters like F0, Intensity, Jitter, Shimmer (dB), and Shimmer (%) have shown more variation for RIC HAs whereas NHR, HNR has more for BTE HAs.

4.2.(v) Comparison of processed speech stimuli between High-end and Low-end hearing aids:

There is a significant increase in Fundamental frequency (F0) for vowel and consonant only in high-end hearing aids at 50dB SPL and 80dB SPL. Intensity level of the processing signal has no differences are observed. But, High cost HAs have more intensity as compared to low-cost HA processed phoneme. Jitter is seen increased at 50dB SPL in low- end hearing aids. At 80 dB SPL, high-end hearing aids have also shown increase in Jitter. In shimmer (dB), there is increase for low-cost hearing aids at 50 dB SPL and 80 dB SPL while there is slight increase in shimmer for high-cost hearing aid observed at 80 dB SPL. In shimmer (%) there is increase seen in case of low cost hearing aids when presented at 50 dB SPL. But quite opposite results are seen when stimuli presented at 80 dB SPL. For NHR, there are slight to no differences among most of the high-cost and low-cost hearing aids at both the presentation level

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except at 80dB SPL where high-end hearing devices have increased NHR as compared to the low-end hearing aids. For HNR too, there are negligible differences among the high-cost and low-cost hearing aids at both the presentation level except at 50dB SPL /ʃ/ spoken by female where high-end hearing devices have increased HNR as compared to the low-end hearing aids. It has been observed that most of the parameters like F0, Intensity, NHR and HNR have shown more increase for high-cost hearing aids, whereas jitter, shimmer (dB), shimmer (%) more increase for low-cost HA processed phonemes.

4.2.(vi) Comparison of processed speech stimuli across different presentation level

For consonants, at 50 dB SPL there are negligible difference observed in both males and females but at 80dB SPL again there is increase in F0 for both males and females. Intensity level of phoneme signal is increased in RIC hearing aids at 80dB SPL, irrespective of the different HAs manufacturer. Jitter is seen slightly increased at 50dB SPL. But, for 80dB SPL there is more increase in jitter for most of the HAs. Slight increase in shimmer (dB) is seen for most of the hearing aids at both the intensity levels. In shimmer (%) there is slight increase seen when phonemes presented at 50 dB SPL. But, increase is seen when stimuli presented at 80 dB SPL. For NHR, there are no differences among the manufacturers at both the presentation level. NHR is slightly decreased for BTE as compared to RIC at 50 dB SPL. But, at 80 dB SPL NHR is increased for BTE compared to the RIC and increased for high-end HAs too compared to the low-end hearing aids HAs. In case of HNR, no noticeable differences are seen across different intensity levels. It has been observed that most of the parameters like F0, Intensity, Jitter, Shimmer (dB), Shimmer (%), NHR, have shown more variation for high intensity level (80 dB SPL) compared to the 50 dB SPL.

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4.3 Summary of Results:

Overall, intensity is increased for both the female and male spoken HA processed phonemes. Female spoken phonemes showed more variations for F0, Jitter (%), shimmer (dB), shimmer (%), and NHR compared to the male spoken phonemes. HNR has slightly similar variations in female spoken processed phonemes compared to the male spoken phonemes.

Most of the phonemes have shown an increase for F0, and Intensity for HA processed phonemes. Across phoneme, high consonants /s/, /sh/ showed more variations in jitter, shimmer (%), shimmer (dB), and NHR. HNR showed negligible variations when comparing variations across hearing aid processed phonemes.

Overall Intensity variations were similar for both the Danavox and Hansaton HAs. F0, Jitter, HNR, Shimmer (%) and Shimmer (dB) also have showed to be greater in the case of the Danavox HAs compared to the Hansaton HAs.

RIC showed more variation for F0 frequency compared to BTE HAs for almost all the phonemes. Overall Intensity has increased for both BTE and RIC with reference to unaided conditions for almost all phonemes. RIC has shown more variation for Jitter (%), Shimmer (dB), and Shimmer (%), NHR compared to the BTE HAs. Although HNR is seen to be reduced for RIC compared to the BTE HAs.

High-cost HAs showed more variations compared to the low-cost HAs for F0, and Intensity. The low-cost HAs have shown more variations for Jitter, shimmer (%), Shimmer (dB), and NHR compared to the high-cost HAs. Whereas, HNR showed more variations in high-cost HAs compared to the low-cost HAs.

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Various features like F0, Intensity, Jitter, shimmer (%), shimmer (dB), and NHR showed more variations for the High-intensity presentation level compared to the low-intensity presentation level. Whereas, two different intensity presentation levels showed negligible variations for HNR.

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CHAPTER V

DISCUSSION

The present study focused on comparing the objective parameters that include Fundamental frequency (F0), Jitter, Shimmer (dB), Shimmer (%), Intensity, Noise to Harmonic Ratio (NHR), Harmonics to Noise Ratio (HNR) of the unprocessed phoneme, unaided and aided phoneme across different gender, different manufacturing companies, style of the hearing aid, and cost of hearing aid. The result obtained from this study is discussed to meet the different objectives of the study.

5.1 Comparison of variations observed for male v/s female voice hearing aid processed phoneme

The findings showed that regardless of the hearing aids used, the variations for the female phonemes were greater than the male phonemes for various parameters such as F0, Shimmer, Shimmer (%), NHR, and HNR. The main factor could be the often-limited bandwidth of hearing aids (i.e., HA bandwidth is often restricted to 4-6 kHz because of attenuated real-ear gain). Similarly, Robinson et al (2012) reported females to have wide-spread spectral energy in phoneme production however the hearing aid can only provide a limited spectrum of energy which in turn affects the production of some speech sounds like /s/ and /sh/. Stelmachowicz et al., (2001) also agreed that in their investigation on CNC word perception, they found that there was a good agreement in the perception of /s/ sound w.r.t the male speaker compared to the female speaker. Furthermore, the differences in scores between the two genders could be due to the differences in the parameters of the male and female spoken phonemes, as females have high fundamental frequency and more high-frequency spectral information about the compared to the male spoken phoneme. Thus, it can be concluded

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that most of the variation seen for female uttered phonemes compared to males could be due to pitch differences and also restricted frequency range that can be provided by the hearing aids.

5.2 Comparison of variations observed across hearing aid processed phonemes

The findings showed that regardless of the type of hearing aids used, the variations of various parameters for consonants are greater than those for vowels. The high consonants /s/ and /sh/ showed the most variability, and the parameters that vary include the jitter shimmer (%), shimmer (dB), and NHR. Both /s/ and /sh/ are high-frequency consonants (>2.5Khz) and as mentioned before HA has limited gain and restricted bandwidth at high-frequency. Therefore, it may be difficult for HA to process /s/ and /sh/ with consistency (Robinson, 2012). And hence, the primary reason should be the limited bandwidth of the hearing aid. The study done by Van Eeckhoutte et al., (2020) found that for extended bandwidth hearing aids the discrimination scores for the sound /s/ were increased compared to restricted bandwidth conditions. This is supported by (Souza, 2020) where they have found that the sounds /s/ and /sh/ require more intensity for the perception compared to the other phonemes. Hence it can be concluded that high-frequency phonemes are likely to have more distortions if they are processed through hearing aids due to their limited frequency responses compared to high-frequency phonemes are likely to have more distortion if they are processed through hearing aids due to their limited frequency responses compared to low and mid frequency speech sounds. Also hearing aid processed speech stimuli likely to show more distortion for consonants, especially for high-frequency consonants than vowels.

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5.3 Comparison of hearing aid processed speech stimuli between two different manufacturers

The parameters such as F0, jitter, shimmer (%), shimmer (dB), and HNR, were more in Danavox than Hansaton hearing aid. Even though, the same prescriptive formula i.e., NAL NL2 was used in the present study the major reason for these differences observed could be due to the differences in manufacturer specifications for transducers and digital signal processing which are expected to vary across the manufacturers. These differences between manufacturers in turn could have affected the parameters. Thus, the results of the current finding suggest that there would be differences in the acoustic parameters of hearing aid processed speech stimuli, across two different manufacturers which might alter the quality of the output. These variations of the manufacturing specifications could intern cause perceptual differences between hearing aids. The results also suggests that objective analysis of all these parameters could be a potential tool to assess quality of the hearing aids.

5.4 Comparison of hearing aid processed speech stimuli between BTE (Behind-the-ear) and RIC (Receiver-in-canal) hearing aids

When compared there was more variability found in RIC hearing aids for F0, Intensity, jitter (%), shimmer (%), shimmer (dB), and NHR compared to the BTE HAs. The difference could be due to the reason that BTE mainly uses an earmold in the canal for proper fitting of the hearing aid whereas RIC uses a dome. Earmold might affect speech more as it alters the resonance properties of the ear canal (Killon, 2003). Whereas, RIC helps to preserve the resonance properties of the ear canal (Alworth & Plyler, 2010). Deeper placement of the receiver in the ear canal as in RIC HAs also

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permits the individual to benefit from high-frequency pinna effects (Griffing, 1976). Preserved resonance properties of the ear canal, pinna effects are likely to emphasize high-frequency output recorded from the KEMAR when it is passed through the RIC hearing aids. The most of the parameters which showed more variation are likely to be more dependent on high-frequency output. Also preserved ear canal resonance property would have also increased the overall intensity for RIC hearing aids more than BTE HA. One more possible explanation for this increase in the intensity could be due to the high functional gain values of RIC compared to the ear mold or ear tip at the high frequencies (Prakash, 2013). Thus, the results of the current finding suggest that there would be differences in acoustic parameter of hearing aid processed speech stimuli, between the BTE and RIC. These variations could intern cause perceptual differences between the different models of hearing aids. The results also suggest that an objective analysis of all these parameters could be a potential tool to assess the differences in speech perception with these hearing aids.

5.5 Comparison of hearing aid processed speech stimuli between High-cost and Low-cost hearing aids

High-cost hearing aids showed more variation for F0, Intensity, NHR, and HNR. Whereas in jitter, shimmer the low-cost hearing aid has more variation. The low-cost hearing aid has more variation in Jitter and shimmer which could be due to the quality of transducers used. The use of low-quality microphones in low-cost hearing aids might have led to more distortion leading to higher jitter and shimmer. Also, the quality of a hearing aid depends on the jitter and shimmer percentage. In high-cost hearing aids, manufacturers mainly work on improving the microphone characteristics. Which in turn reduces the variations in Jitter and shimmer than a low-cost hearing aid. In the

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high-end hearing aid, the HNR, and the intensity of vowels and consonants is also high indicating that the quality of the transducer especially the microphone would be playing a major role in picking the minute changes in the speech spectrum. Thus, the results of the current finding suggest that there would be differences in the acoustic parameter of hearing aid processed speech stimuli, w.r.t the cost of hearing aid too. These variations could intern cause perceptual differences between hearing aids. The results also suggest that an objective analysis of all these parameters could be a potential tool to assess the quality differences between different cost hearing aids.

5.6 Comparison of hearing aid processed speech stimuli between presentation levels

The result showed that the parameters F0, Intensity, Jitter, shimmer (%), shimmer (dB), and NHR are majorly varied at the high-intensity presentation level compared to the low-intensity presentation level. The reason could be that the transducer characteristics also has an impact on the variation of the acoustic features of phonemes at high intensities. Most microphones have sensitivity levels below 0 dB, while commercial microphones typically have sensitivities between -20 and -60 dB. (Woo, 2016). These specifications of the microphone could vary from the hearing aid type and across manufacturers. This also depends on incoming sound intensity to the microphone as well as the frequency bandwidth of the sound (Chasin, 2009). At high-intensity microphone might have reached the upper limit of tolerance due to which there would be distortion and leading to more variation in acoustic parameters compare to low-intensity input level. However, the high presentation that was used in the study is 80dB. So, it was expected that any hearing aid with good quality should not produce

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such distortion and distortion could be observed at around 100 dB input level. However, one needs to remember that hearing aids output was recorded using basic features on. So as the input intensity increased from 50 dB to 80 dB, output from the hearing aid also increased. This might have caused transducers distortion leading to more variation at high input intensity. Thus, the results indicate that as the input intensity increases acoustic parameters of the hearing aid processed signals are likely to change more leading to distortion.

So, in the present study, it was found that the HA processed phonemes differ in various parameters which were more affected for phonemes spoken by female subjects compared to males, which could have been due to the more high-frequency spectral information in the female spoken phoneme leading to more variations for female. Variations were also seen across different phonemes, and high frequency consonants (/s/ & /sh/) showed more variation in the present study possibly due to the limited gain and restricted high frequency bandwidth seen in the HAs. When the comparison was performed between manufacturers (Danavox v/s Hansaton), variations in different parameters were more for Danavox HAs mainly due to the differences in the technical specifications of transducers across manufacturers. Comparison across BTE and RIC HAs showed variations are more for RIC HAs which could be possibly due to the preserved external ear resonance properties by the RIC hearing aids. Jitter and shimmer were found more affected for low-cost hearing aid compared to the high-cost HAs. This could be due to the quality of the microphone used in low-cost hearing aids compared to a high-cost hearing aid. Finally, for comparison between different presentation level variations was more for high presentation levels suggestive of an increase in distortions as the intensity is changed from 50 dB SPL to 80 dB SPL.

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CHAPTER VI

SUMMARY AND CONCLUSION

The present study was carried out with the aim of comparing unprocessed, unaided and HA-processed phonemes. The following phonemes /a/, /i/, /u/, s/, /sh/, /ma/, and /ga/ were compared in all the conditions mentioned above across different manufacturers, different style of hearing aids, and different cost of hearing aid. The phonemes stated above were spoken by males and females and the phonemes were presented at two different intensity levels.

The present study showed that there were variations in the performance of the hearing aids used in most of the parameters analyzed for this study. The study showed that female speakers have more variations in F0, Jitter (%), shimmer (%), and NHR as compared to males, which could be due to the more spectral splatter in the females. However, no variations in intensity and HNR values when compared between the males and females.

It has been observed that the parameters like F0, Jitter, Shimmer (dB), Shimmer (%), and NHR have shown more variations for consonants compared to the vowels. However, no differences have been observed for Intensity and NHR, between vowels and consonants. Mostly, consonants /s/ and /sh/ have shown variations which could be due to the limited gain and restricted bandwidth of the HAs in the high-frequency region.

It has been found that most of the parameters like F0, Jitter, Shimmer (dB), Shimmer (%), and HNR have shown more variation for Danavox HAs compared to Hansaton HAs, which could be due to the differences in manufacturer specifications for the transducers.

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It has been observed that most of the parameters like F0, Intensity, Jitter, Shimmer (dB), and Shimmer (%) have shown more variation for RIC HAs whereas NHR, and HNR has more for BTE HAs. It could be due to the preserved external ear resonance characteristics in the case of RIC HAs.

It was observed that most of the parameters like F0, Intensity, NHR and HNR had increased for high-cost hearing aids, whereas jitter, shimmer (dB), shimmer (%) were more for low-cost HA processed phonemes. Low-cost hearing aids could have affected more because of the quality of the microphone sensitivity and the transducers used for these devices.

It has been observed that most of the parameters like F0, Intensity, Jitter, Shimmer (dB), Shimmer (%), and NHR, have shown more variation for high-intensity presentation level (80 dB SPL) compared to the 50 dB SPL. It could be due to increased distortions in the microphone or other transducers characteristics seen at high-intensity levels.

Therefore, from the current study, it can be concluded that various parameters like F0, jitter, shimmer, NHR, HNR, and intensity for HA processed phoneme vary across gender, different phonemes, different manufacturers, BTE v/s RIC, different cost of hearing aid, and different intensity levels. Hence all these parameters should be taken into consideration while prescribing a hearing aid and could be used for the objective assessment of hearing aid quality.

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CLINICAL IMPLICATIONS

a) The results of the present study will help in determining the manufacturer of hearing aids for individuals with the flat configuration of hearing loss.

b) The present study showed that high frequency components are more affected. Hence individuals with high-frequency hearing loss should be provided with a hearing aid having extended bandwidth or with a RIC hearing aid.

c) The present study also showed that high-cost hearing aid should be recommended as they have better output quality which improves the speech intelligibility.

d) The present study also provided information regarding the distortions at a high-intensity level of input. This can be used while programming a hearing aid.

LIMITATIONS OF THIS STUDY:

a) Natural stimulus and internationally accepted speech stimulus could have provided better generalization.

b) More number of recorded samples would have provided inferential statistical results.

c) The present study compared the responses only between two manufacturing companies of Hearing Aids.

d) The current study made use of only one prescriptive formula i.e., NAL-NL 2 which could have affected the outcome of the study.

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FUTURE DIRECTIONS:

a) Further research can be carried out using natural and internationally accepted speech stimuli.

b) Future studies can focus on recording more samples using the same model and company hearing aids and use inferential statistics to make the data more valid.

c) Different hearing aid manufacturers can also be considered for future studies.

d) Different prescriptive formula can be used to compare different hearing aid manufacturers, different types of hearing aids, and different phonemes.

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