# EFFECT OF DISTANCE OF SOURCE ON THE ACOUSTIC FEATURES AND SPEECH PERCEPTION OF INDIVIDUALS WITH SENSORINEURAL HEARING LOSS WITH AND WITHOUT HEARING AID

**Sumanth C P**

**Registration No: P01II21S0072**

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(Audiology)

University of Mysore, Mysuru

ALL INDIA INSTITUTE OF SPEECH AND HEARING,

MANASAGANGOTHRI, MYSURU – 570006

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***Dedicated to all***

***my Teachers and***

***my Parents***

# CERTIFICATE

This is to certify that this dissertation entitled ***"Effect of Distance of Source on the Acoustic Features and Speech Perception of Individuals with Sensorineural Hearing Loss with and without Hearing Aid"*** is a bonafide work submitted in part fulfilment for the degree of Master of Science (Audiology) of the studentRegistration Number: P01II21S0072. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru

September 2023

**Dr. M. Pushpavathi**

**Director**

All India Institute of Speech and Hearing

Manasagangothri, Mysuru-570006

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Mysuru

September 2023

**Guide**

**Dr. P. Jawahar Antony**

Assistant Professor in Audiology

All India Institute of Speech and Hearing

Manasagangothri, Mysuru-570006

## DECLARATION

This is to certify that this dissertation entitled **"*Effect of Distance of Source on the Acoustic Features and Speech Perception of Individuals with Sensorineural Hearing Loss with and without Hearing Aid*"** is the result of my own study under the guidance of Dr. P. Jawahar Antony, Assistant professor in Audiology, Department of 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.

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# Abstract

Individuals with hearing impairment have a major complaint of understanding speech from a distance, even after using a hearing aid. To determine the cause of the problem, a study was conducted to see if any spectral features changes over distance, affecting understanding speech from a distance. The study was carried out in three phases. In the first phase, the intensity required for the person to understand speech from three different distances was identified. In the second phase, the recorded speech in the first phase across three distances was acoustically analysed to see if any spectral features changes with the increase in distance using Long Term Average Spectrum (LTAS), Cepstral Peak Prominence (CPP), and Harmonic to Noise ratio (HNR) measures. In the third phase, the Speech identification scores (SIS) were identified in both unaided and aided conditions across three distances using the average intensity level obtained in the first phase. The results showed that the average intensity level was increased with an increase in distance. The acoustic analysis of LTAS revealed that with an increase in distance, the energy in the higher harmonics was increased, but CPP was similar, and HNR was reduced with an increase in distance. In the third phase, the Speech identification scores were similar at 1m and 3m, but it was reduced at 5m, as seen in both the unaided and aided condition and the scores in the aided condition improved compared to the unaided condition. However, the speech identification scores were less at 5m compared to 1m and 3m. The CPP was similar, and HNR reduced across distance, indicating the addition of noise with increased distance. The study concluded that as distance increases, the SNR decreases, which can be the factor affecting understanding speech from a distance.

Keywords: Understanding Speech from a Distance, Acoustic features, unaided and aided scores, Speech-to-noise ratio (SNR).

# Chapter 1

## Introduction

According to the Global Burden of Disease estimation, people globally have hearing loss is around 1.57 billion people (Haile et al., 2021). In India, 2.68 Cr persons have some disability out of the 121 Cr population, of which 19 % (0.5 Cr) are with disability in hearing and 76th National Sample Survey 2018 report, there are 2.2% of disabled people in India, with 0.3% having hearing loss (*Census, 2016*; National statistical office, 2019).

Hearing loss is defined as a reduced sense of audibility; some major causes of hearing loss include infections, presbycusis, ototoxicity, hereditary, congenital deafness and so on (Varshney, 2016). Hearing-impaired individuals have major complaints with watching Television, general conversation, conversation in groups, speech in noise, telephone conversation and speech from one side and listening to speech from a distance (Lormore & Stephens, 1994; Stephens, 1980; Tyler et al., 1983). Because of hearing loss, individuals have difficulties at home and in the workplace, which can lead to psychosocial and emotional effects, leading to social isolation and reduced quality of life (Cunningham & Tucci, 2017).

Understanding speech at a distance is also a common issue. The cues related to auditory distance perception are intensity, spectral information, and binaural cues (Courtois et al., 2019; Kolarik et al., 2016; Lombera et al., 2022; Westermann & Buchholz, 2015, 2017; Zahorik et al., et al., 2005). The most predominant cue is signal intensity (Westermann & Buchholz, 2015). The intensity decreases as the distance increases between a speaker and a listener (Courtois et al., 2019; Kolarik et al., 2016; Zahorik et al., 2005). This cue is especially relevant for speech signals, affecting distance speech perception. In spectral cues, the spectral shape can be utilised to estimate the listener's distance from sound sources that are more than 15meters away (Blauert, 1997; Kolarik et al., 2016). Higher frequencies are more attenuated than lower frequencies from distant sources, altering the spectral shape (Courtois et al., 2019; Kolarik et al., 2016). Compared to low-frequency sounds, sounds with a decreased high-frequency content are perceived to be farther away (Kolarik et al., 2016). The interaural level difference (ILD) for binaural cues in the near field (distance less than 1m) rises sharply with decreasing distance. ILD and interaural time difference (ITD) are ineffective for auditory distance perception at greater distances because sound diffraction around the head becomes distance-independent (Courtois et al., 2019).

Since intensity is an important factor for comprehending speech across distances, it's essential to maintain sufficient intensity for clear speech understanding. According to numerous researchers, speakers increase their vocal intensity for every doubling of distance with varying vocal levels. Warren. (1968) found a 6dB increase in vocal intensity with every doubling of distance. Johnson et al. (2018) and Michael et al. (1995) indicated that a more conservative increase between 1.7 dB and 2.46 dB. However, findings from Healey et al. (1997) support Warren's assertion, especially in the case of women who showed a 6dB increase, while men demonstrated a maximum increase of 4 dB.

The intensity level decreases as the distance increases, if the intensity is not increased with distance, it can affects speech recognition from a distance. The Speech recognition scores decreased from 77.8% to 35.9% as the distance increased from 11 to 33m (Meyer et al., 2013).

The intensity of a speech is essential for understanding speech from a distance. So, in our research, the intensity loss is compensated for the propagation loss with distance to see if any spectral features vary over distance, which affects understanding speech from a distance. As a result, the primary goal of this study is to compare changes in acoustic features and speech perception scores in hearing impairment from a distance.

## 1.1 Need For the Study

Individuals with hearing impairment have significant problem in understanding speech from a distance (Lormore & Stephens, 1994; Stephens, 1980; Tyler et al., 1983). Because of their hearing loss, individuals have difficulties at work, at home, while travelling/driving, and so on, which can lead to psychological and emotional depression (Adigun, 2017).

The main management option for hearing loss is fitting a hearing aid. With hearing aids, there is improvement in person-to-person conversation, group interaction, watching television, and an increase in the quality of life of hearing-impaired individuals and significant others (Brooks et al., 2001). However, the problem is not completely solved. Some studies found that even after fitting hearing aids, people have difficulty understanding speech in noisy environments, telephone conversations, and understanding speech from a distance (Bennett et al., 2020; Tyler et al., 1983). Even after the intervention, one of the primary challenges that individuals with hearing impairment and significant others are facing is understanding speech from a distance (Bennett et al., 2020; Tyler et al., 1983).

However, there are limited studies on difficulty in understanding speech from a distance, as this is also a major complaint of most individuals with hearing impairment. The study is carried out to determine the underlying cause of the problem and provide a solution. So, the primary goal of our research is to determine whether any acoustic aspects of speech have an impact on understanding speech from a distance.

### 1.2 Aim of the Study

To compare the changes in the acoustic features and speech perception scores in hearing impairment from a distance.

### 1.3 Objectives

1. To identify the average intensity levels of the speaker at three different distances (1m, 3m and 5m).
2. To analyse the acoustic characteristic features of speech at three different distances.
3. To evaluate and compare speech identification scores across three distances in the unaided and aided condition.
4. To study the relation between the changes in acoustic features and speech perception abilities in hearing impaired at these three distances.

# Chapter 2

# Review of Literature

Hearing-impaired individuals have major complaints with watching Television, general conversation, conversation in groups, speech in noise, telephone conversation and speech from one side and listening to speech from a distance (Lormore & Stephens, 1994; Stephens, 1980; Tyler et al., 1983). Due to hearing loss, individuals have difficulties at home and in the workplace, which can lead to psychosocial and emotional effects, leading to social isolation and reduced quality of life (Cunningham & Tucci, 2017). Understanding speech at a distance is also a common issue, the present study aims to investigate the effect of distance on the speech perception of individuals with sensorineural hearing loss. The literature review is discussed in the following sections.

2.1 The distance effects on vocal intensity.

2.2 The distance effects on speech understanding.

2.3 Cues for Auditory distance perception.

2.4 Acoustic analysis of speech.

## 2.1 The distance effects on the vocal intensity

The inverse square law states that for every doubling of distance, the sound intensity decreases by 6dB (Healey et al., 1997; Zahorik & Kelly, 2007)**.** Warren (1968) explored how individuals adjust their voice loudness based on distance changes using the inverse square law principle. The study involved 40 college students who were selected to participate. The participants were seated 10 feet from a microphone and instructed to sustain the vowel sound /a/. The microphone captured the sound produced by the participants. After the initial recording, the microphone was moved to a location 5 feet away from the participants. The study suggests that people possess the natural capacity to adjust their voice intensity based on the principle of the inverse square law when speaking at different distances and increasing or reducing their voice level by 6 dB for every doubling or halving distance.

Johnson et al. (1981) investigated the distance effects on vocal intensity across three age groups: three-year-olds, five-year-olds, and college-aged adults. Each group consisted of twelve participants. They measured vocal intensity at three distances: 6 feet, 12 feet, and 24 feet from the subject. The subjects were instructed to converse with a listener placed at various distances from the subject. They found increased vocal intensity with distance for all three age groups. An average adult's vocal intensity was 1.21 dB louder at the far distance compared to the middle distance and 1.68 dB louder than the near distance. The average vocal intensity for the 5-year-old group was 1.67 dB higher at the far distance than the middle and 0.37 dB higher at the middle distance than the near. For the 3-year-old group, the vocal intensity was on average, 0.76 dB higher at the far distance than the middle and 0.38 dB higher at the middle distance than the near. They concluded that the average changes in vocal intensity for doubling of distance did not reach 6 dB for any age group. The most extreme effect observed was changes of up to 1.7 dB.

Michael et al. (1995) studied the effect of distance on vocal intensity. The researchers took 28 native English speakers with an age range of 20-52 years. The participants were placed into four groups. The two normal groups and two barely speaking groups. The two groups of normal were instructed to talk to the person at the microphone as if they were sitting in the same room, while the two groups of barely speaking were instructed to talk just loud enough for the person at the microphone to comprehend them. These two groups were further separated into ascending and descending groups. The test was carried out at three different distances of 5 feet, 10 feet, and 20 feet. All four groups of speakers were told to say "ah" for approximately 5 seconds at each distance and then to explain how to fry eggs. The findings revealed that for the "normal" group, vocal intensity for the /a/ vowel sound varied from 75.9 dB A at a distance of 5 feet to 77.8 dB A at 20 feet. In terms of speech, the intensity ranged from 77.0 dB A at 5 feet to 77.6 dB A at 20 feet. For the "barely" group, the vocal intensity of the /a/ vowel ranged from 71.7 dB A at 5 feet to 76.3 dB A at 20 feet, while their speech intensity varied from 73.2 dB A at 5 feet to 75.7 dB A at 20 feet. The vocal intensities of the "normal" group were noticeably higher than those of the "barely" group. During the /a/ vowel task, the "barely" group experienced the most significant mean change, increasing by 2.46 dB when the distance extended from 10 to 20 feet. An interaction of distance and task uncovered significant intensity differences between each adjacent distance for a vowel task. However, a noticeable difference in intensity was only identified between 5 and 20 feet for a speech task.

Healey et al. (1997) aimed to investigate how speakers adjust their vocal intensity based on the perceived and actual distances between themselves and the listener. The research involved 24 participants, twelve men and twelve women with normal voices. Participants were asked to read aloud a passage at three imagined distances (3, 15, and 30 feet) in the perceived listener condition (PLC). In contrast, an experimenter stood at each distance in the actual listener condition (ALC). The results indicated that both men and women increased their voice loudness for all interspeaker distances in both conditions. In the PLC, males increased their vocal intensity by 3 dB when the perceived distance increased from 3 to 15 feet and by 5 dB from 15 to 30 feet. Women increased their vocal level by an average of 6 dB for distances from 3 to 15 feet and 4 dB from 15 to 30 feet. In the ALC, men showed an increase in vocal intensity of 4 dB for distances from 3 to 15 feet and 3 dB from 15 to 30 feet. Conversely, women increased their vocal intensity by 9 dB for distances from 3 to 15 feet and by 6 dB from 15 to 30 feet. Women exhibited a higher increase in vocal intensity than men at all distances in both conditions. Contrary to the inverse square law, speakers did not proportionally adjust their vocal intensity with distance. The average increase for both genders collectively was less than 6 dB.

Zahorik & Kelly (2007) examined how individuals adjust their vocal output to compensate for the loss of intensity as the distance increases in natural environments. The researcher took ten normal individuals and tested them in two environments (outdoor and indoor) and with two orientations (0° and 180°). It was carried out at four distances (1, 2, 4 and 8m). Subjects were instructed to produce the vowel /a/ and to adjust vocal efforts according to various distances. The researcher found that sound propagation decreases with increasing distance to the source in all four conditions. Specifically, propagation loss was almost similar to inverse square law in outdoor conditions for 0° but not for 180° orientation. Still, in the indoor environment, the propagation loss was less than 6 dB in both orientations and indoor 180° was found to be the least in propagation loss. The study concluded that talkers can accurately modify their vocal production to compensate for sound propagation losses ranging from -1.8 to -6.4 dB for doubling distance. Across all participants, distances, and propagation loss situations, the participant's compensation was within 1.2 dB of accuracy.

To summarise, According to Warren (1968), a 6dB increase in vocal intensity with every doubling of distance has been supported and contradicted by subsequent studies. The results from various investigations such as Johnson et al. (2018) and Michael et al. (1995), indicate a more conservative increase between 1.7 dB and 2.46 dB. However, findings from Healey et al. (1997) support Warren's assertion, especially in the case of women who showed a 6 dB increase, while men demonstrated a maximum increase of 4 dB. Similarly, Zahorik and Kelly. (2007) found that talkers can accurately modify their vocal production to compensate for sound propagation losses within 1.2 dB per doubling distance.

Notably, these variations in vocal adjustments might be influenced by multiple factors, including the speaker's gender, individual acoustic environments, cognitive factors, and cultural and linguistic variables. So, the study was aimed to find the vocal intensity across different distances without providing any feedback to the speaker to see how they will modify their vocal level across different distances in Indian context.

## 2.2 The distance effects on Speech Understanding

Tyler et al. (1983) studied problems faced by hearing aid candidates versus users. The patients were given a questionnaire with open-ended questions and instructed to list Challenges faced due to hearing loss for hearing aid candidates and the challenges faced with hearing aids for hearing aid users. Two hundred fifty hearing aid candidates and Two hundred fifty hearing aid users completed a questionnaire. Results showed that the most frequently listed specific problem in both groups was watching television (47% and 37%), communicating on the phone (21% and 21%) and understanding speech from a distance (6.8% and 4.8%). The study revealed that using hearing aids reduces the problems but does not solve them completely.

Bennett et al. (2020) investigated the prevalence of hearing aid-related device difficulties. A total of 413 hearing aid users participated in this survey. The results revealed that over 98% of participants had at least one of the hearing aid difficulties, with a mean number of problems of 10. The four most common problems were difficulties hearing in noisy surroundings (87.25%), understanding specific voices (76.41%), listening in windy environments (74.56%) and speaking from another room (72.73%). They concluded that most hearing aid users have issues with their devices. Addressing these issues would almost certainly contribute to better hearing aid outcomes.

Lormore and Stephens (1994) did a study to list the problems faced by hearing-impaired individuals due to hearing loss. One hundred twenty-one hearing-impaired individuals and their accompanying adult significant other participated in the study. The patients were given an open-ended questionnaire and instructed to list all the difficulties in order of the most significant difficulties faced due to hearing loss. The questionnaire is also given to the patient's significant others (SOs) and instructed to list the difficulties in order of biggest difficulties which the patient has due to hearing loss. The study is divided into eight categories, of which 3 are major and 5 are minor. Major groups include live speech, electronic speech and environmental signals. Moreover, minor difficulties include music, psychosocial problems, localization and medical difficulties. The results showed that in the live speech category, there were 19 subcategories of difficulties reported. The most frequently mentioned issues included general conversation, conversation in noise, background noise, and difficulties hearing due to distance. This study showed how patients and their significant others (SOs) perceive and manage hearing loss and how this condition affects their personalities and lifestyles.

Meyer et al. (2013) studied how environmental noise and distance from the speaker to the listener can impact the comprehension of spoken words. The 36 participants were native French speakers ranging in age from 18 to 30 years, with normal hearing thresholds. The experiment took place in a setting simulating real-world conditions with low-level background noise and evaluated the capability of native French speakers to identify French monosyllabic words at a distance of one meter from the source. The reference mean value for words is 65.3 dB (A), whereas background noise is created at 41.6 dB (A). The participants were located at varying distances, from 11 to 33meters away from the source of the speech, with Signal-to-Noise ratios (SNRs) ranging from -8.8 dB to -18.4 dB, respectively. The stimulus consisted of a 19-word list with 17 French isolated words in each list, and the task was to listen and repeat the words. Results showed that the distance and the loss of intelligibility for word recognition performance showed a substantial quasi-linear association. All participants' average word recognition performance at all distances was 54.6% correct answers. With continuous inter-individual variability at each distance, the performances revealed a general decline in the average proportion of correct answers, from 77.8% at 11meters to 35.9% at 33meters. The study showed the impact of environmental noise and distance, ranging from 11 to 33meters, on the recognition of spoken words.

## 2.3 Cues for Auditory distance perception

Zahorik et al. (2005) summarised the cues for auditory perception that auditory distance perception seems to be influenced by acoustic and non-acoustic cues. The acoustic cues are the intensity level, direct-to-reverberant energy ratio, spectral information, and binaural cues. Non-acoustic cues involve visual cues and pre-existing familiarity with the sound's characteristics. These factors can change from one situation to another or from one environment or sound source.

Kolarik et al. (2016) reviewed auditory distance perception and identified several auditory cues that influence distance perception. The most critical among these cues were the sound level, reverberation, and frequency. These elements significantly influence the normally sighted and hearing humans to perceive the distance of sound sources.

Westermann and Buchholz (2015) explored how spatial separation in distance of source affects speech reception thresholds (SRTs). This study included sixteen people in the age range of 20 to 49 years with normal hearing. The testing was carried out in two conditions. In the first condition, the masker was moved from 0.5m to 10m by keeping the target constant at 0.5m. In a second condition, the target is moved from 0.5m to 10m by keeping the masker at a constant distance of 0.5m. Results showed that in the first condition, the SRTs reduced monotonically, which resulted in an improvement of up to 10 dB in SRT. However, a significant difference between subjects was seen in the second condition. They concluded that either short-term SNR enhancements or cross-ear glimpsing could not explain the observed improvement in intelligibility. However, the result could be explained by SNR in the modulation domain and a reduction of informational masking.

Akeroyd et al. (2007) assessed the ability of hearing-impaired individuals to distinguish the difference in the cues for the speech spoken from a distance. A synthetically created distance design was utilised to measure these cues. A total of 77 hearing-impaired individuals participated in the study. The results showed that when the overall level cue, according to inverse square law was available, the hearing impaired performed similarly to controls, However, when the overall level was equalized to distance and the cue was unavailable, the hearing impaired performed poorer than the control. The study concluded that hearing-impaired people have difficulty using some auditory distance cues.

Akeroyd (2010) investigated how hearing aid compression affects relative distance judgment. Twenty-six hearing aid users participated in the study. A synthetically created distance design was utilised to measure JND in distances ranging from 2 to 5meters. The results showed that the compression feature of the hearing aid had no influence on JND in distance. They found this could be due to hearing aid users acclimatized to sounds.

Courtois et al. (2019) studied the auditory perception of distance in moderate to profound hearing loss individuals and the effects of nonlinear amplification (WDRC) of hearing aids on auditory distance cue perception. Ten normal-hearing individuals and twenty hearing-impaired individuals with moderate to profound hearing loss who were experienced hearing aid users participated in the study. The test was conducted in a reverberant classroom. Three loudspeakers were installed 67 cm, 113 cm and 200 cm apart from the listener's location. They were situated on the right side of the listeners with an azimuth of 30. The stimuli were 10-second portions of male speech derived from the French HINT database by concatenating numerous sentences. The participants are instructed to listen to different stimuli and to rate their perception of the location of the sound source on a continuous scale between 0 and 100 with five steps. In the centre of my head (0), at the top of my head (20), at Loudspeaker 1 (40), at Loudspeaker 2 (60) and at Loudspeaker 3 (80). The range from 80 to 100 was labelled further than Loudspeaker 3. The results revealed that hearing-impaired listeners, even those with profound hearing loss, could differentiate between adjacent and distant sounds when levels were equalized. Moreover, non-linear amplification can distort spatial cues, but no evidence showed that it affects the perception of auditory distance cues.

Many studies have examined the cues related to auditory distance perception. However, our study was aimed to find the change in speech identification scores over varying distances and the factors that might cause these scores to decrease as distance increases.

**2.4 Acoustic analysis of speech**

Speech is a complex signal that can be analyzed acoustically using spectral and temporal parameters. Among Spectral parameters, the long-term average spectrum measurements, Harmonic to Noise to ratio and Cepstral-based measures are widely used for voice and speech analysis because they are the most reliable measure of voice quality (De Krom, 1993; Phadke et al., 2020; Yüksel & Gündüz, 2019).

Long-term average spectrum (LTAS) provides speech information on how the spectral information of speech signal is distributed over a period of time (Leino, 2009). Cornelisse et al. (1991) investigated the ear-level recordings of the long-term average spectrum of speech (LTASS). A total of 30 participants were divided into three groups. The stimuli used were text speech, and all the participants were instructed to read at a normal rate with vocal effort. Speech recording was done in a noise-free room, with two microphones placed at different positions: one at the reference position and ear level, at a distance of 30 cm, at an angle of 0-degree azimuth and 0-degree altitude. The microphones were connected to a sound level meter, and the output was recorded by a tape recorder.

Acoustic speech analysis measured the LTASS and 1/3 octave band level. The results revealed that the LTASS measured at the ear level position showed more low-frequency energy than high-frequency energy compared to the reference microphone. The authors concluded that these findings would help set the gain in the hearing aid to understand speech better.

Both Cepstral Peak Prominence (CPP) and Harmonics-to-Noise Ratio (HNR) are acoustic measures used primarily in speech signal processing to quantify the periodicity and the amount of noise in a given signal (Sampaio et al., 2020). The cepstrum is the result of taking the inverse Fourier transform of the logarithm of the estimated spectrum of a signal. CPP measures the prominence of this peak, which can be related to the periodicity of the signal. A more prominent peak can indicate a clearer periodic component (such as a clear voice), while a less prominent peak can suggest more aperiodic noise or disturbances (Sampaio et al., 2020). The Harmonic-to-noise ratio is defined as a means of assessing the proportion of added noise in a voice signal (Awan & Frenkel, 1994). This measure evaluates the ratio between the energy of the harmonic components (periodic) and the energy of the noise components (aperiodic) in a speech signal. A higher HNR indicates that the speech has more energy in its harmonics relative to the noise, meaning the speech is clearer. Conversely, a lower HNR indicates more noise relative to the harmonics (Sampaio et al., 2020).

The study was aimed to find the acoustic characteristics change with an increase in distance. However, to our knowledge, there is a dearth of literature on measuring the acoustic characteristic change with an increase in distance for speech stimulus using these measures.

# Chapter 3

# METHOD

The study aims to compare the changes in the acoustic features and speech identification scores in hearing impairment from a distance. There were four objectives of the study. The first objective was to find the speaker's average intensity levels at three distances (1m, 3m, and 5m). The second objective was to assess the acoustic characteristics of speech at three different distances, the third objective was to identify Speech Identification scores across three distances in the unaided and aided condition, and the fourth objective was to investigate the relationship between changes in acoustic features and speech perception abilities in individuals with hearing impairment at these three distances.

## 3.1 Instrumentation:

- A calibrated two-channel diagnostic audiometer (MADSEN Astera² 1066-ACP) with a speaker (Martin Audio C 115) was used to obtain the pure tone threshold, air conduction and bone conduction thresholds, speech recognition thresholds, speech recognition scores, and discomfort level.
- A calibrated immittance meter Titan Suite IMP440 version 3.0 was utilised to obtain the tympanogram and acoustic reflex.
- Knowles Electronics Mannequin for Acoustics Research (KEMAR) (G.R.A.S Sound & Vibration, type 45 BA, Demark) and Ear Simulator (GRAS RA0045 Externally Polarized Ear Simulator According to (IEC 60318-4) connected to an SLM (BRUEL & KJAER, Hand-held Analyzer Type 2270) was used to record and

to note the intensity level (LAeq value) of speech.

- Acoustic analysis was done using PRAAT software (v.6.3.16).
- NOAH link wireless and hearing aid programming software.
- A digital behind-the-ear (BTE) hearing aid with eight channels, having a fitting range from mild to severe degree of hearing loss.
- Ear muffs (Bilsom 717 700-series) with Disposable foam ear tips (ER3- 14A, Ear tips 13mm) were used to block the contralateral ear if required.

## 3.2 Testing Environment

The testing was carried out in a single/double sound-treated room. The noise level was maintained within permissible limits as per ANSI/ASA S3.1-1999 (R2018) Standards (ANSI, 2018).

## 3.3 Phase I

### *3.3.1 Participants*

The study involved twenty-eight native Kannada speakers in the age range of 19 - 38 years. Participants with a pure tone average (PTA) of less than 15 dB across all frequencies. (The frequency ranges for air conduction and bone conduction thresholds are 250 to 8 kHz and 250 to 4 kHz, respectively). Speech identification scores of 90% or higher at 40 dB SL with reference to PTA in both ears on the bi-syllabic Kannada word test (Yathiraj and Vijayalakshmi, 2005.) The participants had normal middle ear function with "A" or ‘As’ type tympanogram and the presence of acoustic reflex in both ipsi and contra (500 – 4000 Hz) on immittance evaluation participated in the study.

### *3.3.2 Stimuli*

The word and sentence were randomly selected from the Kannada word list and sentence list developed at AIISH, Mysore. The fifth word from the first Kannada phonemically balanced (PB) word lists (Manjula et al., 2015) and the fifth sentence from the first Kannada sentence lists (Geetha et al., 2014) were utilised for the testing.

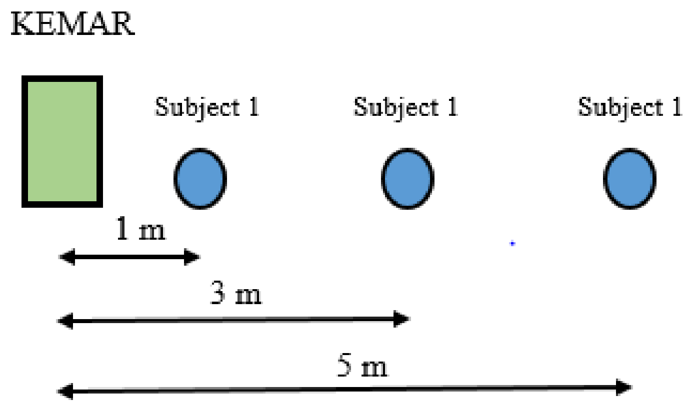
### *3.3.3 Procedure*

The KEMAR connected to SLM was kept constant at 0 m, and testing was done at three different distances (1m, 3m and 5m) and carried out in two ways, ascending or descending. The subject was made to randomly sit at a 1m or 5m distance with respect to the KEMAR and instructed to say the word ($5^{th}$ word of word list 1) and sentence ($5^{th}$ sentence of sentence list 1) orally with the required loudness to reach the target distance. The speech is recorded through KEMAR, and the intensity level of speech is noted through SLM. The same procedure is carried out at 3m and 5m for those who recorded with 1m distance first. 3m and 1m for those who recorded with a 5m distance first. This was to ensure that no order effect could take place. Figure 3.1, shows the illustration figure of the testing procedure. The instructions for the testing were as follows:

"I will make you sit at three different distances, and you will have to say a word and a sentence at each distance, assuming how much vocal effort you will use to speak if anyone is standing at that distance."

**Figure 3.1**

*Illustration figure of the testing procedure.*




*Note: Subject 1 was sequentially placed at 1m, 3m, and 5m for recording.*

**3.4 Phase II**

The speech sample of the same word and sentence was recorded using the KEMAR at the three distances (1m, 3m, and 5m) and analysed the acoustic characteristics of the speech sample word and sentences.

The average intensity value at each distance was compared with individual speaker values. The three most approximate individual's value near the average intensity value for all three distance recordings was taken. The Spectral analysis of speech was analysed through the PRAAT software. The parameters taken were Harmonic to Noise ratio (HNR), Cepstral Peak Prominence (CPP) and Long-Term Average Spectrum (LTAS). These parameters are widely used for voice and speech analysis because they are the most reliable measure of voice quality (Krom, 1993; Phadke et al., 2020; Yüksel & Gündüz, 2019).

### *3.4.1 Long-term Average Spectrum (LTAS)*

Long-term average spectrum (LTAS) provides the speech information on how the spectral information of speech signal is distributed over a period of time (Leino, 2009)**.** Praat was used to perform the LTAS, the frequency range of 0-8 KHz and a Hanning window with a bandwidth of 100 Hz was used for each sample in the LTAS. In the LTAS window, the acoustic variables were labelled for mean energy for frequency range and ratios as energy level differences between the frequency ranges. The pitch-corrected version was used to remove unvoiced sounds and pauses from the samples automatically.

Parameters of LTAS:

- Energy in the frequency band between 50 – 1000 Hz.
- Energy in the frequency band between 1000 – 5000 Hz.
- Energy in the frequency band between 5000 – 8000 Hz.
- Alpha is a ratio of average energy between 50-1000 Hz and 1000-5000 Hz (Guzman, Higueras, et al., 2013).
- Beta is a ratio of average energy between 0-2000 Hz and 2000-8000 Hz (Kumar, 2013).
- Gamma is a ratio of average energy between 0-1000 Hz and 5000-8000 Hz (Kumar, 2013).

### *3.4.2 Cepstral peak prominence (CPP)*

The Cepstral Peak Prominence (CPP) is a measure used to quantify the prominence of the cepstral peak relative to the background noise in the cepstrum (Heman-Ackah et al., 2002). Cepstral Peak Prominence - Praat with and without voice detection plug-in was downloaded and installed in Praat to obtain the CPP value (Heller Murray et al., 2022). The recorded sample was uploaded, and the CPP values were determined.

### *3.4.3 Harmonic to Noise ratio (HNR)*

The Harmonic-to-Noise Ratio (HNR) is a measure used to quantify the amount of periodic content versus noise content in a signal (Awan & Frenkel, 1994). The HNR is obtained using Praat software, the recorded sample was opened in Praat, the show pulses setting was turned on, and the HNR was noted from the voice report.

## 3.5 Phase III

### *3.5.1 Participants*

The study included fourteen native Kannada speakers in the age range of 18 to 54 years with moderate sensorineural hearing loss (eight with symmetrical hearing loss and six with asymmetrical hearing loss), and normal middle ear function was chosen. The testing was done for six right ears and eight left ears, as indicated in Table 3.1 shows the mean and SD for PTA, SRT, and SIS for the right and left ears of the participants. Figure 3.2 and Figure 3.3 shows the average pure tone threshold for the right ear and left ear, respectively.

**Table 3.1**

*Mean PTA, SRT, and SIS of participants included in the study.*

| | Right ear (n = 6) | | Left ear (n = 8) | |
|---|---|---|---|---|
| | **Mean** | **SD** | **Mean** | **SD** |
| **PTA (dB HL)** | 52.7 | 7.04 | 49.5 | 5.71 |
| **SRT (dB HL)** | 55 | 7.07 | 51.87 | 6.51 |
| **SIS (%)** | 92.66 | 6.88 | 97.5 | 2.97 |

**Figure 3.2**

*Average pure tone threshold of Right ear with SD*

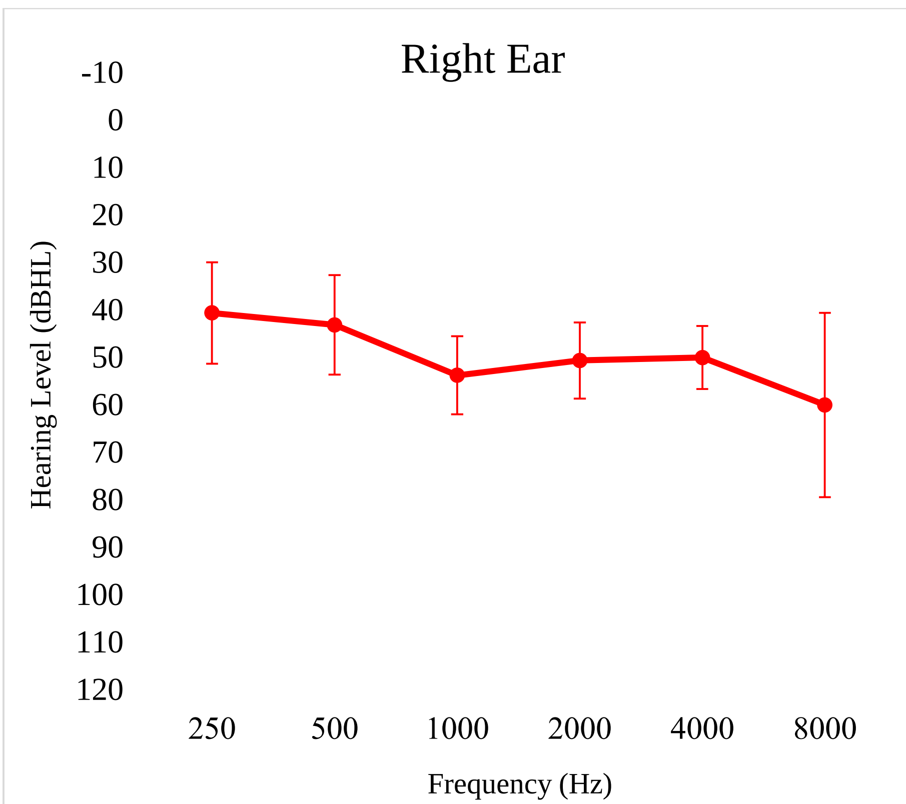
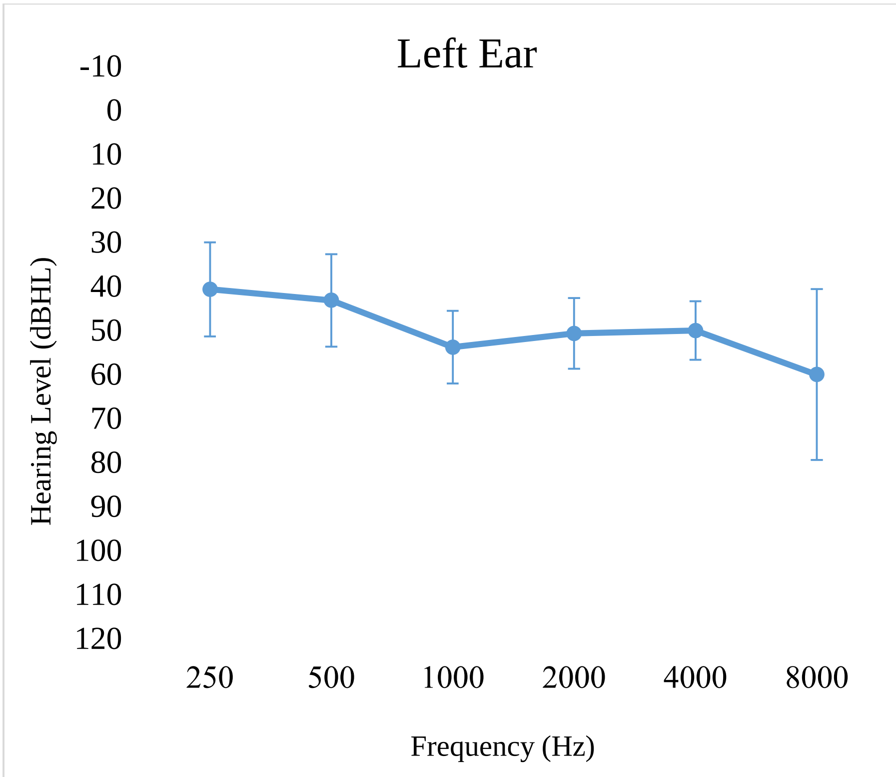


**Figure 3.3**

*Average pure tone threshold of Left ear with SD*




***3.5.2 Hearing aid Programming***

Each participant was unilaterally fitted with the digital hearing aid. The participant's air-conduction and bone-conduction hearing thresholds were fed into NOHA software. The hearing aid was linked to a NOHA link wireless, which connected to a personal computer. The NOHA and hearing aid fitting software were loaded into the computer. The NAL-NL 2 fitting formula is used to program the linked hearing aid to provide the proper gain based on the participant's hearing loss. In addition, the gain for a hearing aid was optimized as per the participant's comfort. The volume control was turned off during the programming, and the directional microphone and other additional features were deactivated.

### *3.5.3 Presentation Level and Stimuli*

The presentation level was decided based on the average intensity obtained at three distances in phase I. According to the Inverse-square law, the average intensity level was added with the compensated level for propagation loss; for every doubling of the distance, there is a decrease of 6 dB (Healey et al., 1997; Zahorik & Kelly, 2007). Thus, 10 dB and 14 dB are added for 3m and 5m from the average intensity levels, respectively. Hence, the presentation level was 51 dB SPL at 1m, 62 dB SPL at 3m and 69 dB SPL at 5m, as indicated in Table 3.2, shows the Presentation level across three distances with the addition of compensation for propagation loss of intensity. The initial six Kannada phonemically balanced (PB) Kannada word lists (Manjula et al., 2015) were used to present stimulus for speech recognition scores.

**Table 3.2**

*Presentation level across three distances with the addition of compensation for propagation loss of intensity.*

| Sl.no | Distance | Average intensity obtained for a word across distances | Compensation of intensity loss added according to the inverse square law | Presentation level |
|---|---|---|---|---|
| 1 | 1m | 51 dB SPL | 0dB | 51 dB SPL |
| 2 | 3m | 52 dB SPL | 10dB | 62 dB SPL |
| 3 | 5m | 55 dB SPL | 14dB | 69 dB SPL |

### *3.5.4 Procedure*

The fourteen subjects with moderate sensorineural hearing loss were selected for the testing. Each participant was made to sit at three distances (1m, 3m and 5m). The unaided speech identification scores were obtained using the Kannada PB word lists (Manjula et al., 2015) presented through speakers placed at 0-degree azimuth at the presentation levels 51, 62 and 69 dB at 1m, 3m, and 5m distances, respectively. In each distance, twenty-five words were presented, and the total number of correct responses was noted out of twenty-five. The programmed hearing aid was fitted to the participant, and the aided speech recognition scores were obtained with the same procedure as the unaided speech recognition scores.

## 3.6 Statistical analyses

The data from each test ear was entered and analysed using the statistical package for social sciences (SPSS for Windows, version 26) software. The following tests are performed in order to achieve the study's objectives.

1. Friedman's test for comparing SIS within a group across three distances. If a significant difference was found, the Wilcoxon signed-rank test was used.
2. Mann Whitney U test was used to compare parameters between groups.
3. The effect size was determined wherever it was required.

# Chapter 4

# Results

The aim of the study was to compare the changes in the acoustic features and speech perception scores in sensorineural hearing loss individuals across three distances in unaided and aided conditions.

**The Results of the study are represented as follows.**

4.1 The average intensity levels of the speaker at three different distances (1m, 3m, and 5m).

- 4.1.1 Average intensity level for a word and sentence across three different distances.

4.2 The acoustic characteristic features of speech at three different distances.

- 4.2.1 Long-Term Average Spectrum (LTAS).
- 4.2.2 Cepstral Peak Prominence (CPP).
- 4.2.3 Harmonic to Noise ratio (HNR).

4.3 Comparison of speech identification scores across distance in the unaided and aided condition.

- 4.3.1 Comparison of speech identification scores across distance in unaided condition.
- 4.3.2 Comparison of speech identification scores across distance in aided condition.
- 4.3.3 Comparison of speech identification scores across distance in the unaided and aided condition.

4.4 The relation between the changes in acoustic features and speech perception abilities in hearing impaired at these three distances.

## 4.1 The average intensity levels of the speaker at three different distances (1m, 3m and 5m).

The speaker changes the vocal intensity as distance increases to compensate for increased distance. Thus, the change in vocal intensity is noted for a word and sentence across three distances. Twenty-eight individuals with normal hearing in the age range of 19-38 years data were taken for statistical analysis, the mean and SD were calculated across three distances.

### *4.1.1 Average intensity level for a word and sentence across three different distances.*

Table 4.1 displays the results of the Mean and SD of vocal intensities across three distances for a word and sentence. The result revealed that speakers increase their vocal intensity as distance increases for both words and sentences. The mean vocal intensities were higher for a sentence than a word across all three distances.

**Table 4.1**

*Mean and standard deviation (SD) of vocal intensities across three distances for a word and sentence.*

| Distance | Word | | Sentences | |
|---|---|---|---|---|
| | Mean (dB SPL) | SD (dB SPL) | Mean (dB SPL) | SD (dB SPL) |
| 1m | 50.53 | 3.98 | 53.94 | 3.24 |
| 3m | 52.02 | 3.4 | 54.50 | 3.21 |
| 5m | 54.61 | 4.97 | 56.74 | 4.39 |

## 4.2 The acoustic characteristic features of speech at three different distances.

The speech recorded across all three distances were acoustically analyzed for three individuals who were approximately equal in mean vocal intensity. The parameters analyzed were LTAS, CPP and HNR.

### *4.2.1 Long-Term Average Spectrum (LTAS).*

The parameters for LTAS taken were

- Energy in the frequency bands between 50 – 1000 Hz, 1000-5000 Hz and 5000-8000 Hz.
- Alpha, Beta and Gamma ratios.

#### *4.2.1.1 Energy in the frequency bands between 50 – 1000 Hz, 1000-5000 Hz and 5000-8000 Hz*

Table 4.2 displays the results of the mean energy in the frequency bands between 50 – 1000 Hz, 1000-5000 Hz and 5000-8000 Hz. Mean energy for 50-1000 Hz showed less increase as distance increased. As distance increases for 1000-5000 Hz and 5000-8000 Hz, the mean energy increases considerably higher than 50-1000 Hz.

**Table 4.2**

*Mean energy in the frequency bands between 50 – 1000 Hz, 1000-5000 Hz and 5000-8000 Hz.*

| | Word | | | Sentence | | |
|---|---|---|---|---|---|---|
| **Distance** | **50-1000 Hz (dB SPL)** | **1000-5000 Hz (dB SPL)** | **5000-8000 Hz (dB SPL)** | **50-1000 Hz (dB SPL)** | **1000-5000 Hz (dB SPL)** | **5000-8000 Hz (dB SPL)** |
| 1m | 33.42 | 20.13 | 1.79 | 28.74 | 14.30 | -3.78 |
| 3m | 32.84 | 21.67 | 2.09 | 29.87 | 16.58 | -2.91 |
| 5m | 33.80 | 22.27 | 5.47 | 29.37 | 17.52 | -1.32 |

#### *4.2.1.2 Alpha, Beta, and Gamma ratios.*

Table 4.3 displays the mean results for Alpha, Beta and Gamma ratios across three distances.

- **Alpha**

  As distance increases, the Alpha ratio becomes less negative for both word and sentence. The Alpha ratio was almost similar for a word at 3m and 5m, but it was changing linearly for a sentence.

- **Beta**

  As distance increases, the Beta ratio becomes less negative for both word and sentence. The Beta ratio was almost similar for a sentence at 3m and 5m, but it was changed linearly for words.

- **Gamma**

  As distance increases, the Gamma becomes less negative for both word and sentence. The Gama ratio was almost similar for a sentence at 1m and 3m, but it was changing linearly for a word.

**Table 4.3**

*Mean Alpha, Beta and Gamma ratios for a word and sentence across three distances.*

| | **Word** | | | **Sentence** | | |
|---|---|---|---|---|---|---|
| **Distance** | **Alpha (dB SPL)** | **Beta (dB SPL)** | **Gamma (dB SPL)** | **Alpha (dB SPL)** | **Beta (dB SPL)** | **Gamma (dB SPL)** |
| 1m | -13.30 | -17.59 | -31.97 | -14.29 | -19.98 | -32.21 |
| 3m | -11.31 | -13.69 | -30.70 | -13.10 | -17.81 | -32.87 |
| 5m | -11.41 | -11.99 | -28.05 | -11.69 | -16.38 | -30.33 |

### *4.2.2 Cepstral Peak Prominence (CPP)*

Table 4.4 displays the results of CPP across three distances. The CPP was almost similar across all three distances for both word and sentence. Not much difference was seen across distance.

**Table 4.4**

*Mean CPP for a word and sentence across three distances.*

| | **Word** | | | **Sentence** | | |
|---|---|---|---|---|---|---|
| **Distance** | **1m** | **3m** | **5m** | **1m** | **3m** | **5m** |
| Mean CPP (dB) | 13.0 | 13.11 | 13.16 | 11.28 | 11.14 | 11.58 |

### *4.2.3 Harmonic to Noise ratio (HNR)*

Table 4.5 displays the results of HNR across distances. The HNR was reduced for an increase in distance. This is observed for both words and sentences.

**Table 4.5**

*Table 4.2 Mean HNR for a word and sentence across three distances.*

| | **Word** | | | **Sentence** | | |
|---|---|---|---|---|---|---|
| **Distance** | **1m** | **3m** | **5m** | **1m** | **3m** | **5m** |
| Mean HNR (dB) | 9.7 | 7.15 | 6.21 | 10.18 | 8.25 | 7.9 |

## 4.3 Comparison of speech identification scores across distance in the unaided and aided condition.

SIS was identified across three distances with respective intensity levels in two conditions, unaided and aided condition. The SIS was compared within the group across three distances and between groups across three distances.

### *4.3.1 Comparison of speech identification scores across distance in unaided condition.*

Table 4.6 displays the mean, median and SD for SIS across three distances in the unaided condition. The results revealed that SIS was similar for 1m and 3m, but scores were reduced at a 5m distance. The Friedman test was performed to determine the significant difference between SIS scores between distances. The results showed a significant difference between SIS across distances [$\chi 2=9.385$, $p=.009$].

**Table 4.6**

*Mean, median and SD for SIS across three distances in the unaided condition*

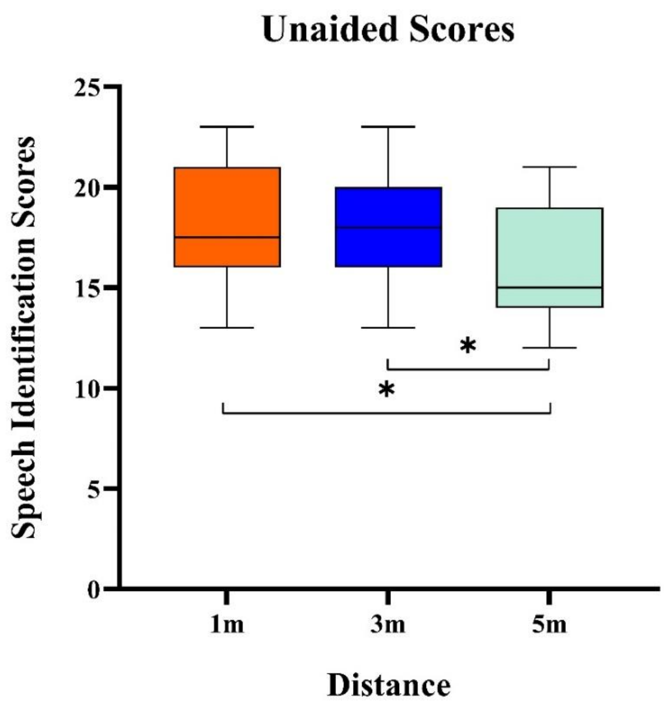
| Distance | Mean | Median | SD |
|---|---|---|---|
| 1m | 17.85 | 17.5 | 2.82 |
| 3m | 17.85 | 18 | 2.82 |
| 5m | 16 | 15 | 2.82 |

Since there was a significant difference in SIS across distances, the Wilcoxon signed-rank test was performed to check that the SIS was significantly different between distances. The results revealed no significant difference in SIS observed between 1m and 3m [$z = -0.119$, $p = 0.905$]. A significant difference was observed between 3m and 5m [z

= -3.086, p = 0.002, r = 0.82] and between 1m and 5m [z = -2.328, p = 0.020, r = 0.622], with large effect size (Cohen, 1992), as indicated in Figure 4.1, box plot displaying the unaided SIS scores across three distances with significant difference in SIS between 3m and 5m, and also between 1m and 5m.

**Figure 4.1**

*Box plot of unaided SIS scores across three distances*




*Note: *p<0.05*

### *4.3.2 Comparison of speech identification scores across distance in aided condition.*

Table 4.7 displays the mean, median and SD for SIS across three distances in the aided condition. The results revealed that SIS was similar for 1m and 3m, but scores were reduced at a 5m distance. The Friedman test was performed to determine the significant difference between SIS scores between distances. The results showed a significant difference between SIS across distances [$\chi2$=7.091, p=.029].

**Table 4.7**

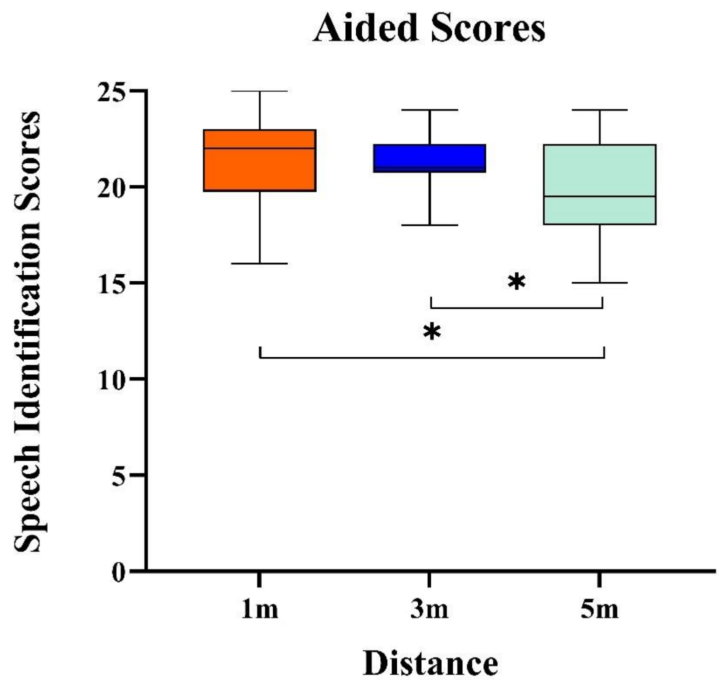
*Mean, median and SD for SIS across three distances in the aided condition*

| Distance | Mean | Median | SD |
|---|---|---|---|
| 1m | 21.35 | 22 | 2.43 |
| 3m | 21.35 | 21 | 1.49 |
| 5m | 19.85 | 19.5 | 2.65 |

Since there was a significant difference in SIS across distances, the Wilcoxon signed-rank test was performed to check that the SIS was significantly different between distances. The results revealed no significant difference in SIS observed between 1m and 3m [$z = -0.119$, $p = 0.905$]. A significant difference was observed between 3m and 5m [$z = -2.359$, $p = 0.031$, $r = 0.63$] and also between 1m and 5m [$z = -2.16$, $p = 0.018$, $r = 0.577$], with large effect size (Cohen, 1992), as indicated in Figure 4.2, box plot displaying the unaided SIS scores across three distances with significant difference in SIS between 3m and 5m, and also between 1m and 5m.

**Figure 4.2**

*Box plot of aided SIS scores across three distances*




*Note: * p<0.05*

**4.3.3 Comparison of speech identification scores across distance in the unaided versus aided condition.**

Figure 4.3, Bar graph displaying the unaided SIS and aided SIS across three distances. The results revealed that SIS increased in aided conditions compared to unaided conditions across all three distances.

Mann-Whitney U test was performed to find differences between unaided SIS and aided SIS across distances. Table 4.8 shows the (U, z, p and r) values for SIS between unaided SIS and aided SIS. The result revealed that SIS between unaided and aided conditions is significantly different across all three distances (p<0.05).

**Table 4.8**

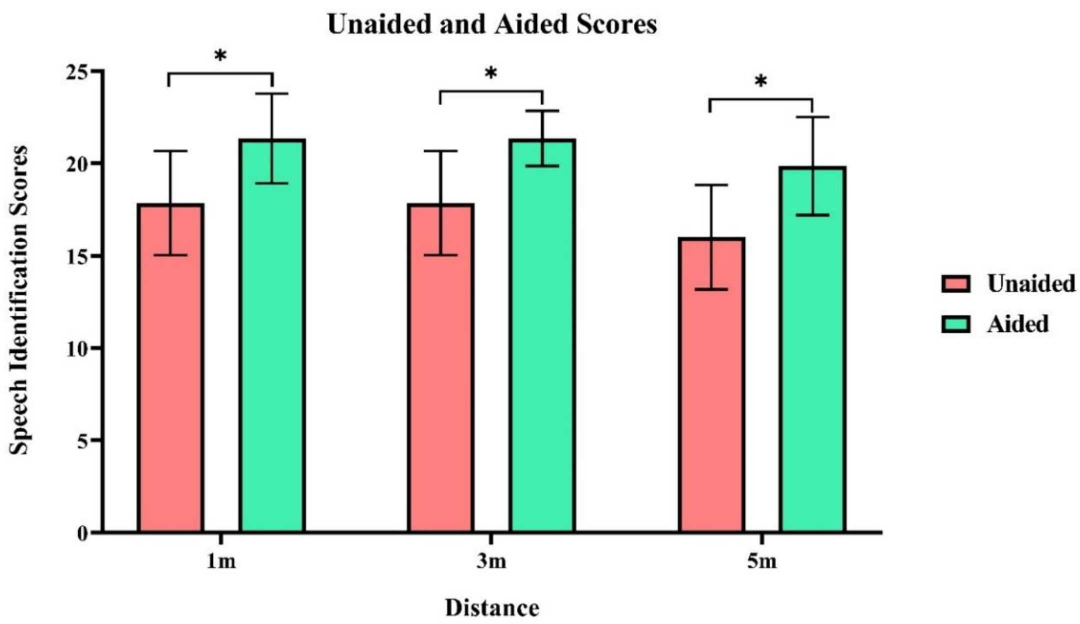
*Results of Mann Whitney U test for SIS between unaided and aided conditions*

| Distance | U | z | P | r |
|---|---|---|---|---|
| **1m** | 35 | -2.911 | 0.004* | 0.777 |
| **3m** | 25.5 | -3.367 | 0.001* | 0.899 |
| **5m** | 33 | -3.007 | 0.003* | 0.803 |

Note: *p<0.05

**Figure 4.3**

*Bar graph of unaided SIS and aided SIS across three distances.*




*Note:* *p<0.05

### 4.4 The relation between the changes in acoustic features and speech perception abilities in hearing impaired at these three distances.

The mean vocal intensity increases with an increase in distance. However, as distance increased, the Speech Identification Scores decreased. In terms of spectral features, as distance increases, the LTAS showed increased energy in the higher harmonics, HNR was reduced, while CPP remained similar across all distances.

# Chapter 5

# DISCUSSION

The main objective of the study was to see the effect of changes in acoustic features of speech across distance on speech perception abilities in the hearing impaired.

The objectives are discussed as follows.

5.1 The average intensity levels of the speaker at three different distances (1m, 3m and 5m).

5.2 The acoustic characteristic features of speech at three different distances.

5.3 The Speech identification scores across distance in the unaided and aided condition.

5.4 The relation between the changes in acoustic features and speech perception abilities in hearing impaired across three distances.

## 5.1 The average intensity levels of the speaker at three different distances (1m, 3m and 5m).

The result revealed that speakers increase their vocal intensity as distance increases for both words and sentences. The mean vocal intensities were higher for a sentence than a word across all three distances. After adding the propagation loss across distance, the vocal intensity raised by speakers is 11.48 dB from 1m to 3m and 6.59 dB from 3m to 5m for a word. For sentence, the vocal intensity increased by 10.56 dB from 1m to 3m and 6.24 dB from 3m to 5m, a study done by Warren (1968) reported a 6 dB increase in vocal intensity for every doubling of distance and similarly Healey et al. (1997) found that particularly in the case of women showed an increase of 6 dB, while men showed a maximum increase of 4 dB. However, research by Johnson et al. (2018) and Michael et al. (1995) reveals a more conservative increase of 1.7 dB to 2.46 dB per doubling the distance.

In our study, for every doubling of distance, there was a vocal intensity increase of more than 6 dB by the speaker. This may be attributed to the speech measurement process and the addition of propagation loss to balance the intensity. In most other research, speech is recorded using a microphone close to the mouth to determine intensity levels (Healey et al., 1997; Johnson et al., 2018; Michael et al., 1995). However, while the microphone remained stationary in our approach, the speaker moved further away. We compensated for the propagation loss intensity with the assumption of a 6 dB decrease for every doubling of distance, based on the Inverse Square Law. However, Zahorik and Kelly (2007) found less than 6 dB propagation loss in indoor settings and a 6 dB reduction in outdoor settings. Given that our study was conducted indoors, this could also be a contributing factor.

### 5.2 The acoustic characteristic features of speech at three different distances.

The LTAS parameters showed that with an increase in distance, energy in the high-frequency region are increased. The LTAS for 50 – 1000 Hz, 1000 – 5000 Hz and 5000 – 8000 Hz showed that as distance increases, the high-frequency energy increases more than low frequency, i.e. energy at 5000 – 8000 H and 1000 – 5000 Hz increased more than 50 – 1000 Hz, which shows an increase in the high-frequency energy and other parameters of LTAS, the Alpha, Beta, and Gama ratios increased for both word and sentence with an increase in distance, which shows increased energy in higher harmonics. Studies have shown that if the alpha ratio increases (becomes less negative values) energy in the higher harmonics increases (Guzman, Angulo, et al., 2013; Guzman, Higueras, et al., 2013). Chan and Liberman (2021) reported that the alpha values were increased with increased vocal effort by the speaker. Similarly, Nordenberg and Sundberg (2003) reported that with an increase in the level of speech, the gain varies across frequency from 0.5 for lower frequencies to about 1.5 in the 1.5 to 3 kHz frequency region. However, the vocal level has an influence on the alpha ratio with increased vocal loudness, the alpha ratio increases, which signifies more energy in higher harmonics (Guzman et al., 2013; Silva et al., 2011). In our study, the speaker increases their vocal output as distance increases, which could have increased energy in the higher harmonics.

The CPP were almost similar across all three distances for both word and sentence; not much difference was not seen across three distances. A higher CPP is typically observed in signals with high periodicity, whereas signals with low periodicity or aperiodic signals tend to have a lower CPP amplitude (Phadke et al., 2020). The level of speech has an effect on CPP, with an increase in the voice SPL, the CPP becomes higher (Awan et al., 2012; Brockmann-Bauser et al., 2021; Phadke et al., 2020), and CPP is also influenced by noise. If there is more noise in a voice, the CPP typically decreases (Heman-Ackah et al., 2002; Hillenbrand et al., 1994). However, in our study, with the increase in the level of speech with an increase in distance, there is no effect seen in CPP, which may be due to the addition of noise in the signal with an increase in distance.

The HNR were reduced as the distance increased for both word and sentence. The HNR quantifies the ratio of the energy in the periodic components of the voice to the energy in the aperiodic components. A high HNR indicates a voice with more harmonics and less noise, while a low HNR suggests a voice with more noise relative to its harmonics (Krom, 1993), and with an increase in the SPL of the voice, the HNR also increases (Brockmann-

Bauser et al., 2018; Sampaio et al., 2020; Till et al., 1992). However, in our study, HNR was decreased with an increase in vocal level with an increase in distance, which shows an increase in the noise in a signal with an increase in distance.

### 5.3 The Speech identification scores across distance in the unaided and aided condition.

Speech identification scores were similar at 1m and 3m but reduced at 5m. This is seen in both aided and unaided conditions; the scores were higher in aided conditions compared to the unaided conditions at all distances. Some studies reported that hearing-impaired individuals frequently complain about understanding speech from a distance (Lormore & Stephens, 1994; Stephens, 1980; Tyler et al., 1983). Meyer et al. (2013) reported that the intensity decreases with an increase in distance, and SNR becomes poorer, so the scores reduced from 77.8% at 11m to 35.9% at 33m. However, in our study, the intensity is compensated for propagation loss with an increase in distance then also, the scores are comparatively poorer at 5m than at 1m and 3m.

### 5.4 The relation between the changes in acoustic features and speech perception abilities in hearing impaired across three distances.

Some important cues that help in auditory distance perception are intensity level, spectral features, and direct-to-reverberant sounds (Kolarik et al., 2016; Zahorik et al., 2016).

In our study, the propagation loss was compensated by adding the intensity to exclude the effect of intensity as a factor influencing the understanding of speech from a distance. LTAS revealed that with increasing distance, the high-frequency energy increases more than the low-frequency region. This change is attributed to the rise in vocal loudness as distance increases (Da Silva et al., 2011; Guzman, Higueras, et al., 2013). However, a study by Butler et al. (1980) found that when sound waves travel over long distances, the higher frequencies tend to get attenuated more than the lower frequencies. As a result, sounds that have a diminished high-frequency component, compared to their low-frequency content, often give the perception of being more distant to listeners. According to Blauert (1997), the spectral shape helps listeners perceive the distance of sound sources positioned more than 15 meters away. However, LTAS results showed increased energy in the higher harmonics with increased distance and vocal loudness. Therefore, the LTAS findings suggest that spectral degradation was not seen with the increase in distance. The CPP was almost similar, and HNR reduced with an increase in distance in our study. Both CPP and HNR are acoustic measures used primarily in speech signal processing to quantify the periodicity and the amount of noise in a given signal (Heman-Ackah et al., 2002; Hillenbrand et al., 1994; Krom, 1993; Sampaio et al., 2020). According to Sampaio et al. (2020), with an increase in the SPL of voice, both CPP and HNR increased, but in our study, CPP was almost similar, and HNR was reduced with an increase in loudness with an increase in distance, which can be due to addition of noise with an increase in distance.

The intensity level is corrected for propagation loss, and the LTAS parameters showed an increase in energy in the higher harmonics with increasing loudness and distance. Despite this, Speech Identification Scores continue to deteriorate as distance increases. This could be due to poor SNR, which can be related to low HNR and similar CPP with increased distances and vocal levels in our study.

Numerous researches have demonstrated that the Signal-to-Noise Ratio (SNR) is crucial in enhancing speech comprehension for individuals with hearing impairments.

Needleman et al. (1995) showed that simulated mild to moderate hearing loss individuals have higher speech recognition thresholds than normal hearing individuals in the presence of noise. Crandell (1993) reported minimal hearing loss SNHL children obtained poorer scores than normal-hearing children. The speech recognition scores become poorer with a decrement in the SNR or more adverse listening conditions.

According to (Stelmachowicz et al., 1985), hearing-impaired people require more SNR than normal people, and as SNR improves, it also improves the SIS. Similarly, Individuals with hearing impairments performed worse than normal in speech in noise conditions (Andrade et al., 2016; Dubno et al., 1984; Suter, 1985). However, some studies showed that using non-linear frequency compression enhanced speech recognition when there was background noise (Shehorn et al., 2018). However, hearing aids have limited advantages when the interfering sound exhibits both energetic and informational masking components (Hornsby et al., 2006).

To conclude, while certain acoustic parameters can be optimized to improve speech perception, the fundamental issue remains the SNR. Individuals with hearing impairment require a greater SNR to achieve comparable speech intelligibility to those without hearing impairments. This underscores the importance of ensuring an optimal SNR, especially in environments or scenarios where communication is crucial and where there is a likelihood of background noise.

# Chapter 6

## Summary and Conclusion

The aim of the study was to compare the changes in the acoustic features and speech perception scores in sensorineural hearing loss individuals across three distances in unaided and aided conditions. The study was carried out in three phases, and the four main objectives are as follows:

The average intensity levels of the speaker at three different distances (1m, 3m and 5m) for a word and sentence were identified. Twenty-eight individuals with normal hearing in the age range of 19-38 years participated in the study. The result revealed that speakers increase their vocal intensity as distance increases for both words and sentences. The mean vocal intensities were higher for a sentence than a word across all three distances.

The speech recorded across all three distances were acoustically analyzed for three individuals who were approximately equal in mean vocal intensity. The parameters analyzed were LTAS, CPP and HNR. The result revealed that as distance increases, the LTAS showed increased energy in the higher harmonics, HNR was reduced, while CPP remained similar across all distances.

Speech Identification Scores were identified across three distances with respective intensity levels in two conditions, unaided and aided condition. The SIS was compared within the group across three distances and between groups across three distances. Statistical Package for Social Sciences (SPSS for Windows, version 26) software was used for the statistical analysis. Friedman's test, Wilcoxon signed-rank test and Mann-Whitney U statistical tests used to compare SIS within and between groups across three distances.

The results showed that in both unaided and aided conditions, the SIS was similar at 1m and 3m, but scores were reduced at a 5m distance. No significant difference in SIS was observed between 1m and 3m, but a significant difference was observed between 3m and 5m and also between 1m and 5m. The SIS was compared between unaided and aided conditions, and the result showed that SIS between unaided and aided conditions is significantly different across all three distances.

The intensity level is corrected for propagation loss, and the LTAS parameters showed an increase in energy in the higher harmonics with increasing loudness and distance. Despite this, Speech Identification Scores continue to deteriorate as distance increases. This could be due to poor SNR, which can be related to low HNR and similar CPP with increased distances and vocal levels in our study.

**Implication of the study**

- The average intensity level reaching different distances will be helpful for further studies.
- The study has thrown a light on the acoustic characteristic changes of speech with increase in distances.
- The result of the present study showed the SNR of the signal is crucial for perception of speech in individuals with hearing impairment. This will help to develop strategies to improve the understanding speech from a distance in individuals with hearing impairment.

**Limitations of the study**

- The propagation loss was added based on the assumption of Inverse square law, and it is important to note that propagation loss can vary depending on the environment.
- A smaller number of data was used for acoustic analysis.

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