Development and Standardization of High Frequency Word Lists in Malayalam for Adults

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CERTIFICATE

This is to certify that this dissertation entitled **"Development and Standardization of High Frequency Word List in Malayalam for Adults"** is a bonafide work submitted as part of fulfilment of the degree of Master of Science (Audiology) of the student with Registration Number **P01II24S023005**. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other university for the award of any other Diploma or Degree.

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CERTIFICATE

This is to certify that this dissertation entitled **"Development and Standardization of High Frequency Word Lists in Malayalam for Adults"**, has been prepared under my supervision and guidance. It is also being certified that this dissertation has not been submitted earlier to any other university for the award of any other Diploma or Degree.

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DECLARATION

This is to certify that this dissertation entitled **"Development and Standardization of High Frequency Word Lists in Malayalam for Adults"** is the result of my own study under the guidance of Dr. Chandni Jain, Associate Professor 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

Aim: *The present study aimed to develop and standardize a High Frequency Speech Identification Test in Malayalam for Adults.*

Methods: *The study was conducted in two phases. Phase 1 involved the development of a high-frequency word list. From an initial pool of 1000 Malayalam words, 707 were rated highly familiar by native speakers. Acoustic validation using LTASS and spectral centroid analysis yielded 100 words with dominant spectral energy above 2000 Hz, organized into bi-syllabic and tri-syllabic half lists of 25 words each. Phase 2 involved standardization of the developed material on 104 adult native Malayalam speakers (mean age 23 years, SD 3.09) with normal bilateral hearing. Speech Identification Scores (SIS) were obtained in quiet and at -4 dB SNR.*

Results: *Near-ceiling SIS was observed in quiet, with significantly reduced scores under noise, confirming the material's sensitivity to adverse listening conditions. No significant difference was found across bi-syllabic and tri-syllabic half lists in either condition, confirming list equivalency.*

Conclusion: *The developed Malayalam High-Frequency Speech Identification Test is a clinically valid, acoustically verified tool for assessing high-frequency speech perception in adults, with applications in diagnosis, hearing aid verification, and aural rehabilitation.*

Key words: High-frequency speech identification, Malayalam, speech audiometry, LTASS, spectral centroid, adults.

Chapter 1

Introduction

Hearing plays a crucial role in acquiring and preserving spoken communication skills. It forms the foundation of human communication. Speech perception can be described as interpreting or decoding messages from a sequence of sounds produced by a speaker (Borden & Harris, 1980). According to Goldinger et al. (1991), speech perception involves recognizing the acoustic signals generated by a speaker as meaningful words and concepts. Successful decoding of the speech signal requires functional integrity at all stages along the auditory pathway, including inner ear, cochlear nerve, brainstem and ultimately the auditory cortex (Hoppe et al., 2016).

Audiological testing must incorporate speech stimuli, a practice known as speech audiometry, to assess a person's understanding of spoken language. Carhart (1952) Speech audiometry has been defined as the measurement of specific aspects of hearing ability by means of standardized speech material presented through a calibrated system. Speech audiometry is an important part of audiological evaluation that measures an individual's ability to detect and comprehend spoken language. It is valuable in assessing how different degrees of hearing loss affect speech understanding, and the impact varies depending on the severity of the hearing impairment (Naqvi & Sutton, 2026). Speech measures are also useful for diagnostic purposes to observe how it is affected by disorders of the peripheral and central auditory system. Moreover, the test outcomes show a predictable relationship with pure-tone thresholds, making them a useful cross-check of the audiogram's validity (Naqvi & Sutton, 2026).

Speech audiometry serves a wide range of clinical utilities beyond the scope of conventional pure-tone audiometry. The purpose of the speech audiometry is threefold. First, it validates the pure tone air conduction thresholds (Carhart, 1952; Chaiklin & Ventry, 1964). Second, it provides an index of hearing sensitivity for speech. Third, it provides an estimate of speech perception abilities at supra-threshold levels (Letowski et al., 1992). Basic speech audiometric tests include Speech Detection Thresholds (SDT), Speech Recognition Thresholds (SRT), Speech Identification Scores (SIS), Most Comfortable Level (MCL), and Uncomfortable Level (UCL).

Speech audiometry materials should be developed in multiple languages, as testing is most effective when conducted in the client's native language. It was first developed in Standard American English bur are now available in various other languages such as Hindi (De, 1973), Spanish (Zubick et al., 1983), Italian (Puglisi et al., 2021; Turrini et al., 1993), Korean (Harris et al., 2003), Mandarin (Fu et al., 2011), Russian (Harris et al., 2007), etc. However, most of these materials are conventional speech audiometry tools, developed and standardized on individuals with predominantly flat or nearly flat audiometric configurations. Using such standard speech tests primarily allows estimation of optimal hearing threshold levels in the mid-frequency range of the auditory spectrum.

However, the high prevalence of sensorineural hearing loss (SNHL) increases rapidly with age, especially for high-frequency sounds above 2kHz, which causes a significant impact on speech perception in the elderly (Jerger & Hayes, 1977; Schuknecht, 1964). Age-related hearing loss, or presbycusis, is characterized by a gradual, bilaterally symmetrical decline in hearing sensitivity, predominantly in the high-frequency region, resulting from degenerative changes in the cochlea, auditory nerve, and central auditory pathways (Willott, 1991). Beyond ageing, noise exposure, prolonged use of personal listening devices, certain medical conditions, and surgical procedures such as microvascular decompression can also lead to high-frequency hearing loss (Gajendran et al., 2024; Mishra et al., 2022). Noise-induced hearing loss, in particular, preferentially affects the 3000–6000 Hz region due to the mechanical vulnerability of the outer hair cells at the basal turn of the cochlea, making high-frequency speech cues the earliest casualties of auditory damage (Dobie, 2004).

All the speech materials that are conventionally available for speech audiometry have been developed and standardized for individuals who have mostly flat or nearly flat audiometric configurations. These standard speech tests can predict the best hearing threshold levels in the mid-frequency region of the auditory range. The results of these tests may overestimate speech perception in individuals with high-frequency hearing loss, because of the inherent redundancy of natural speech. The spectral information in the low-frequency region (below 2kHz), where hearing is normal or near normal, may contribute to auditory closure perception of speech. Hence, the scores obtained for the high-frequency word list can more accurately assess the communication handicap of such an individual.

1.1 Need for the Study

A high-frequency hearing loss, common with aging, noise exposure, and other factors, predominantly affects frequencies above 2 kHz and causes significant deficits in speech perception that are not well assessed by conventional speech audiometry (De Castro Silva & Feitosa, 2006; Dobie, 2007; Moore, 2016). Standard speech tests use low-frequency redundancy and may overestimate performance, so high-frequency word lists are needed to accurately estimate communication difficulties in individuals with high-frequency hearing loss.

In conclusion, the conventional speech identification materials are not sensitive enough to evaluate perceptual difficulties in individuals with sloping high-frequency hearing loss; several high-frequency speech identification materials have been developed. The first such word list was created by Gardner in Standard American English (1971), and similar tests are now available in multiple Indian languages, including Hindi (Ramachandra, 2001), Kannada (Mascarenhas, 2002), Tamil (Sinthiya, 2009), Telugu (Ratnakar, 2010), Mizo

(Lalchewilena, 2012), Manipuri (Hmangte, 2012), Nepali (Ghimire, 2019), Indian English for Children (Sonal, 2017), and Mehta (2019). However, no equivalent material has yet been developed in Malayalam.

Kerala has a population of about 33,406,061 people, with Malayalam being the primary language of communication (Kerala State Planning Board, 2017). A significant number, particularly among the elderly who are more prone to age-related high-frequency hearing loss, can communicate only in Malayalam. Since speech identification scores are reported to be highest when testing is conducted in an individual's native language (De, 1973), there is a clear need for a dedicated high-frequency word list in Malayalam. In summary, high-frequency speech materials are critical for adults because many important speech sounds such as /s/, /ʃ/, /f/, and /t/ are in the high-frequency range and are needed for clarity of speech and discrimination of words. Testing with high-frequency speech materials offers a more realistic measure of communication ability, can assist in the identification of suprathreshold processing difficulties and can guide effective diagnosis, hearing aid fitting, and aural rehabilitation in those with high-frequency hearing loss.

1.2. Aim of the Study

The present study aimed to develop a High-Frequency wordlist to assess speech identification scores in Malayalam for Adults.

1.3. Objectives of the Study

The objectives of the study are:

- To develop high-frequency word lists in Malayalam for adults that capture commonly used words in daily communication.
- To develop norms for the developed Malayalam high-frequency word list in quiet and noise for adults.

- To check the equivalency of the different lists of the developed material.

- To assess the effect of listening condition on the developed test material.

Chapter 2

Review of Literature

Speech audiometry refers to procedures that use speech stimuli to assess auditory function (Konkle & Rintelmann, 1983). The clinical importance of a speech threshold lies primarily in its use as a check on the validity of the pure-tone audiogram. In most clinical cases, good agreement will be observed between the three-frequency pure-tone average and the speech recognition threshold. For cases with a sloping loss, agreement may be better between the speech recognition threshold and the two-frequency pure tone average (Fletcher, 1950).

Erber (1982) proposed a four-level framework of auditory processing that can also be incorporated into speech audiometry assessment procedures. These levels include detection/ awareness, auditory discrimination, identification or recognition, and comprehension. Most speech audiometry procedures commonly used in clinical practice primarily assess either awareness or recognition abilities. Roeser et al. (2007) described the processes as follows:

- **Awareness**: These tests evaluate whether an individual is able to perceive the presence of an auditory signal. Examples include speech detection threshold (SDT) and speech awareness threshold (SAT).
- **Discrimination**: Tests that require the individual to identify changes in the acoustic stimulus are categorized separately. At present, traditional speech audiometry does not include tests specifically designed to assess speech discrimination.
- **Identification/recognition:** These procedures evaluate the listener's ability to recognize an auditory stimulus and provide an appropriate response, such as naming, repeating, or selecting the corresponding item. Examples include

word recognition testing (WRS) and sentence-based speech recognition assessments (SRS).

- **Comprehension:** These tests require the patient to interpret the meaning of the presented stimulus by responding to questions either verbally or in written form, or by selecting a picture that represents the intended meaning. However, auditory comprehension is not typically evaluated in conventional speech audiometry.

2.1 Stimuli used for Speech Audiometry

Speech audiometry employs a variety of standardized speech stimuli to assess different levels of auditory function. Speech audiometry materials can be broadly classified into spondaic words, monosyllabic word lists, and sentence materials. Spondees, bisyllabic words with equal stress on both syllables, are primarily used to assess SRT. Monosyllabic word lists, such as the CID W-22 (Hirsh et al., 1952) and the NU-6 (Carhart & Tillman, 1970), are used for assessing suprathreshold word recognition ability and are typically phonetically balanced to ensure representative sampling of the phonemes of the target language (Gelfand, 2016). Sentence materials, such as the SPIN test and the HINT, offer a more ecologically valid measure of everyday communicative function by incorporating contextual linguistic cues (Katz et al., 2014). Since speech identification scores are reported to be highest when testing is conducted in the individual's native language (De, 1973), speech audiometry materials have been developed in numerous Indian languages to ensure valid and culturally appropriate assessment.

Hudgins and Hawkins (1947) proposed some guidelines for the development and assessment of recorded material used in speech audiometry testing. Later advancements in recording technology and psychometric methods further refined and elaborated these guidelines (ASHA, 1988; Brandy, 2002). First, the fundamental requirements for speech audiometry materials are that test items must be familiar to the listener. Since the primary objective is to assess speech intelligibility, not vocabulary or cognitive ability, stimuli should be as simple and linguistically transparent as possible. This principle was underscored by the early limitations of the PB-50 word lists, which contained many unfamiliar items and consequently demonstrated poor inter-list reliability (Hirsh et al., 1952). According to Ramkissoon (2001), the use of unfamiliar words can diminish the reliability and usefulness of SRT. This guideline further emphasizes that the test materials should be presented in the patient's native language and dialect. Weisleder and Hodgson, (1989) demonstrated that speech recognition performance on SRT tasks was adversely affected when listeners were exposed to recordings produced by a talker from a different dialectal background, even when both the talker and listener shared the same language. These findings recommend that, wherever feasible, native speakers of the target language should be involved in the development, recording, and administration of speech audiometric materials.

A second guideline is that words should be phonetically from one another. Rhyming or phonetically similar words only make the test harder without making the assessment any more accurate. Lexical properties of single words in a stimulus set can have strong effect on overall intelligibility (Bradlow & Pisoni, 1999). Lexical items can be grouped in an individual's mental lexicon according to either semantic or phonologic properties, thus creating a series of similarity (Dirks et al., 2001). Phonetic dissimilarity ensures that the words do not provide additional auditory cues like those found in rhyming words (Ramkissoon, 2001).

A third guideline considered in the development of word recognition (WR) materials is the representative sampling of speech sounds of the target language. This guideline has been regarded as less critical compared to others, as it is not considered essential for obtaining a valid measure of hearing ability. Although considerable effort was invested in ensuring that word lists used for word recognition testing achieved phonetic balance, a proportional representation of phonemes mirroring their frequency of occurrence in natural speech (Eldert & Davis, 1951; Lehiste & Peterson, 1959). Martin et al. (2000) reported that phonetic balance has no substantial effect on word recognition scores in individuals with normal hearing as well as those with sensorineural hearing loss. Their results showed that the word recognition score based on a randomly selected list of words was not significantly different from that based on a list of phonetically balanced words.

The fourth guideline concerns the homogeneity of audibility across test words. The audibility of each stimulus item can be characterized by two psychometric properties: the psychometric threshold, which corresponds to the intensity level at which a word is correctly recognized at a criterion performance level, and the psychometric slope, which reflects the rate at which recognition accuracy improves as a function of increasing signal intensity. Greater homogeneity of the stimulus materials leads to more accurate and consistent SRT results (Wilson & Carter, 2001). Likewise, recordings of native-language test materials with minimal background noise facilitate the evaluation of their consistent psychometric characteristics and presentation quality.

Young adults with healthy auditory function are generally able to perceive sounds across a frequency range of approximately 20 Hz to 20 kHz (Schnupp et al., 2012). Despite this wide auditory range, routine audiological evaluations seldom assess hearing sensitivity above 8 kHz. Although conventional speech perception is primarily associated with lower frequencies, evidence suggests that speech signals also contain important acoustic information in the extended high-frequency region above 8 kHz (Monson et al., 2019; Moore et al., 2008). High-frequency speech cues are especially prominent in fricative sounds, which carry substantial spectral energy and provide anticipatory acoustic information that supports rapid speech understanding. Furthermore, the intensity and spectral distribution of these cues differ across various fricatives (Jongman et al., 2000; Moore et al., 2008).

Several studies have demonstrated that acoustic information above 3 kHz plays an important role in speech understanding among individuals with normal hearing (Fletcher, 1953; Grant & Braida, 1991; Kryter, 1962). In listeners with normal auditory sensitivity, higher frequency components substantially support speech perception, particularly in noisy listening environments (Moore, 2016). Research by Besser et al. (2015) further indicated that the benefit obtained from spatial separation between target speech and competing speech signals, commonly referred to as "spatial advantage", is influenced by hearing sensitivity in the 6-10 kHz frequency range. Poorer thresholds within this high-frequency region were associated with reduced spatial benefit. Additionally, Hänsler and Schmidt (2006) suggested that when target and interfering sounds originate from different spatial locations, frequency information above 3 kHz becomes increasingly important, and wider audible bandwidths provided through bilateral hearing aids may improve listening performance.

Studies have demonstrated that amplification of frequencies above 3kHz can enhance speech understanding in individuals with mild-to-moderate high-frequency hearing loss (Baer et al., 2002; Hornsby & Ricketts, 2006; Johnson et al., 2009; Skinner & Miller, 1983; Vickers et al., 2001). However, hearing impairment may reduce the effective utilization of audible speech cues (Turner & Henry, 2002). In general, speech intelligibility depends on information derived from consonants, whereas vowels contribute to the power of speech (Niemeyer, 1976). It is thus crucial for a person to identify consonants properly in order to understand speech better. This requires the identification of place as well as manner of articulation, which in turn are cued by the dynamic filter cues like closure duration, burst, and transition. The spectral cues for the place and manner of the articulation of different high frequency speech sounds are given in Table 2.1.

Table 2.1

Spectral energy and major cues for perception of consonants

Phoneme	Energy Spectrum	Place Cue	Manner Cue
/s/	2000–4000 Hz	Spectral properties F2 transition, noise duration and amplitude (overall and relative amplitude)	Duration of frication noise, amplitude of noise component and fundamental frequency at vowel onset
/ʃ/	3500 Hz		
/f/	6800–8400 Hz		
/k/	1500–4000 Hz	Frequency position of burst, F2 transition, spectral pattern, voice onset time	Stop gap, silence, closure duration, duration of preceding vowel, F1 cutback
/t/	Above 4000 Hz		
/dʒ/	2500 Hz	Duration of noise segment, rise time of noise segment	Frication duration, closure duration

Note: The table is retrieved from Lalchewilena, J. (2012) with permission

Lawrence and Byers, (1969) examined the identification of voiceless fricatives in adults with steep high frequency hearing loss. Their findings indicated that fricative perception varied depending on vowel context, with greater confusion occurring for front vowels than back vowels. The authors proposed that acoustic factors such as low-frequency spectral information, duration, intensity and vowel transition contribute to fricative identification in individuals with hearing impairment.

From all the data, it is clear that high-frequency components are essential for speech intelligibility, especially for identifying consonants like fricatives. Although often overlooked in routine testing, frequencies above 3 kHz provide important cues for place and manner of articulation. Reduced high-frequency hearing leads to poorer speech understanding, particularly in noise, while amplification in these regions improves performance. Overall, access to high-frequency information is critical for accurate speech perception.

2.2 High Frequency Speech materials available in Western and Indian Languages

Bukya et al., (2025) emphasized the importance of incorporating high-frequency words (HFWs) along with conventional consonant-vowel (CV) speech materials in clinical audiological assessment, particularly for individuals presenting with sloping high-frequency hearing loss. The authors also highlighted the necessity of developing high-frequency speech materials in Indian languages to facilitate assessment among native speakers of different linguistic backgrounds. The various high frequency materials developed in English are given in Table 2.2 and in various Indian languages are given in Table 2.3.

Table 2.2

High frequency Speech audiometry materials available in English

Author(s)	Language	Stimuli Type	No. of Words	List Structure	Key Features
Gardner (1971)	English	Monosyllabic CVC	50	2 lists × 25	Voiceless consonants (/p, t, k, s, f, θ, h/) + vowel /i/; designed for hearing aid evaluation
Pascoe (1975)	English	Monosyllabic	50	Closed-set	High % voiceless phonemes; 3 vocalic nuclei (/I/, /ai/, /ou/); binaural master hearing aid investigation
Owens & Schubert (1977)	English	Consonant items	100	64 final + 36 initial consonant contrasts	4-choice closed-set; CCT; r = 0.35 with W-22; sensitive to high-frequency SNHL

Table 2.3

High frequency speech audiometry materials available in various Indian languages

Author(s)	Language	Stimuli Type	No. of Words	List Structure	Clinical Utility Validated
Ramanchandra (2001)	Hindi & Urdu	Monosyllabic CVC	50	2 lists — initial vs. final HF phonemes	Yes — superior to Mayadevi (1974) conventional test
Kavitha & Yathiraj (2002)	Kannada	Bisyllabic & trisyllabic + sentences	75 words + sentences	3 word sublists × 25 + sentence subtest (~9 sentences/list)	Sentence subtest included
Sinthiya & Sandeep (2009)	Tamil	Bisyllabic & trisyllabic	Not specified	3 lists (2 bisyllabic + 1 trisyllabic)	Sensitive to sloping HF loss; clinical utility not yet verified
Ratnakar & Mamatha (2010)	Telugu	Bisyllabic & trisyllabic	75	2 bisyllabic half-lists × 25 + 1 trisyllabic list × 25	Yes — compared with normal hearing scores
Lalchewilena & Jain (2012)	Mizo	Monosyllabic & bisyllabic	150	4 mono half-lists + 2 bisyllabic half-lists (25 words each)	Not validated in clinical population
Hmangte & Geetha (2012)	Manipuri	Not specified	50	2 subsets × 25	Not assessed in clinical population
Chintamani & Yathiraj (2017)	Indian English	Not specified	Not specified	Not specified	Yes — significant difference between groups confirmed sensitivity
Mehta & Neupane (2019)	Gujarati	90% voiceless consonants	50	2 half-lists × 25	Yes — significant difference in SIS scores with HF word list confirmed applicability

2.3 Speech Audiometry Materials available in Malayalam

Malayalam is predominantly spoken in the Indian state of Kerala and the Union Territory of Lakshadweep, and is used by a large population of speakers both within and outside India (Ishtiaq, 1999; Sreedevi & Irfana, 2013). Malayalam has a rich phonological system, with a wide range of consonants and vowels. At present, the only Malayalam speech audiometry materials available for adults are the phonetically balanced word lists developed by Kacker and Basavaraj (1990) and the standardized sentence lists used in the “Speech Perception in Noise in Malayalam-Speaking Young Adults with Normal Hearing” study by (Ghosh et al., 2024). However, there is still no standardized high-frequency speech material in Malayalam. Consequently, developing high-frequency speech test materials specifically for native Malayalam speakers is both necessary and timely.

2.4 Acoustic Validation of High-Frequency Speech Stimuli

The development of a clinically valid and acoustically reliable high-frequency speech identification test requires rigorous acoustic validation of the selected test stimuli. Two important acoustic measures commonly employed for this purpose are the Long-Term Average Speech Spectrum (LTASS) and spectral centroid analysis. These measures help ensure that the selected stimuli genuinely contain dominant high-frequency spectral information and are therefore appropriate for assessing speech perception in individuals with sloping high-frequency sensorineural hearing loss (SNHL).

The LTASS represents an analysis of sound levels recorded over time for a single talker or for multiple talkers in order to determine sound levels in different parts of the frequency range (Lawson & Peterson, 2011). Townsend, (1983) described the frequency range for speech as approximately 100 to 10,000 Hz. He noted that the LTASS rises slightly in intensity from 100 Hz to 500 Hz and then falls in intensity by approximately 10 dB per octave at higher frequencies.

Previous attempts in the development of high frequency speech identification tests (Chintamani & Yathiraj, 2017; Fu et al., 2011; Hmangte, 2012; Hmangte & Geetha, 2012; Kavitha, 2002; Mehta & Neupane, 2019) suggest that LTASS analysis is employed during the word selection phase to objectively verify that candidate words possess dominant spectral energy in the high-frequency region. The phonemes selected for high-frequency word lists including /s/, /ʃ/, /k/, /t/, /f/, /h/, and high front vowels /i/ and /e/ are known to carry energy predominantly above 1000–2000 Hz (Hughes & Halle, 1956). However, the actual spectral realization of these phonemes can vary substantially depending on phonological context, coarticulation, and talker characteristics. A word phonemically composed of high-frequency sounds may still carry its dominant energy below 2 kHz in connected speech. LTASS thus serves as an essential cross-validation tool, confirming that the phonemically selected words are also *acoustically* high-frequency dominant.

In addition to LTASS, spectral centroid analysis has been increasingly used to quantify the spectral distribution of speech stimuli. The spectral centroid, which represents the spectral centre of mass, is related to the perceived brightness of a sound. The higher the centroid, the brighter or sharper the sound (Dua et al., 2026). Giannakopoulos and Pikrakis (2014) explained that the spectral centroid is the center of 'gravity' of the spectrum. The value of spectral centroid, C_i, of the ith audio frame is defined as:

$$C_i = \frac{\sum_{k=1}^{Wf_L} kX_i\,(k)}{\sum_{k=1}^{Wf_L} X_i\,(k)}.$$

Where:

- C_i= Spectral centroid of the i^{th}audio frame
- W_f= Total number of frequency bins (or frequency components) in the frame
- k= Frequency bin index (represents the frequency location)

- $X_i(k)$= Magnitude or amplitude of the spectrum at the k^{th}frequency bin in the i^{th}frame
- $\sum$= Summation across all frequency bins

Spectral spread represents the second-order moment of the spectrum and reflects the distribution of spectral energy around the spectral centroid. It is calculated by determining how far the spectral components deviate from the centroid value using the following equation.

$$S_i = \sqrt{\frac{\sum_{k=1}^{Wf_L}(k\text{-}C_i)^2\, X_i(k)}{\sum_{k=1}^{Wf_L} X_i\,(k)}}.$$

Where

- = Spectral spread of the i^{th}audio frame
- W_f= Total number of frequency bins in the frame
- k= Frequency bin index
- C_i= Spectral centroid of the i^{th}frame
- $X_i(k)$= Magnitude (or amplitude) of the spectrum at the k^{th}frequency bin in the i^{th}frame
- $(k - C_i)^2$= Squared distance between each frequency bin and the spectral centroid
- $\sum$= Summation across all frequency bins
- $\sqrt{}$ = Square root operation

Together, LTASS and spectral centroid analyses provide complementary information regarding the acoustic characteristics of candidate stimuli. While LTASS evaluates the overall frequency distribution of speech energy over time, spectral centroid analysis quantifies the relative dominance of high-frequency energy within individual words. By selecting words with spectral centroids consistently above 2 kHz, high frequency speech materials reduce the availability of low-frequency redundancy and compel listeners to rely primarily on high-frequency acoustic cues for accurate identification.

2.5 Speech Perception in the Presence of Noise

Speech perception in noise (SPIN) assessment provides valuable information regarding an individual's functional listening abilities in everyday situations. Difficulty understanding conversations in the presence of competing background noise is among the most frequently reported concerns of individuals with hearing impairment. Speech-in-noise measures help clinicians evaluate how effectively a listener can perceive speech under adverse listening conditions. However, these assessments should be administered only when clinically appropriate, as individuals with poor speech recognition performance in quiet are also likely to perform poorly on SPIN measures (Benson & Messersmith, 2022).

Speech recognition in background noise remains a great challenge to all listeners, especially those relying on amplification devices. It has the potential to be used in diagnosing and evaluating the hearing system's functional capability, providing clinicians with extremely useful information while needing very little clinical time (Ghosh et al., 2024). Carhart and Tillman (1970) suggested that an audiologic evaluation should include some measure of an individual's ability to understand speech in the presence of background speech noise. van Zyl and Hanekom, (2011) compared how well normal-hearing listeners could recognize words/sentences versus prosodic patterns (suprasegmental features) under increasingly noisy conditions. They investigated whether prosody specifically, cues signalling conditional vs. unconditional permission or approval, is more resilient to noise than segmental speech content. Word and sentence recognition deteriorated significantly as SNR worsened, with a marked drop at –8 dB SNR ($p<0.01$ compared to –5 dB). Prosody recognition remained resilient, it did not significantly deteriorate even at –8 dB SNR, staying well above chance level. He concluded that listeners with hearing loss require a signal-to-noise ratio (S/N) that is 10–15 dB greater than normal-hearing listeners to achieve comparable performance.

According to Plomp (1978), every 1 dB improvement in S/N yields approximately a 3% improvement in intelligibility for listeners with hearing loss, meaning a 10 dB S/N improvement translates to ~30% gain in word recognition (McArdle et al., 2005a) found that the 50% recognition point on the Words-in-Noise (WIN) test was 12.5 dB S/N for hearing-impaired listeners versus 6 dB S/N for normal-hearing listeners. McArdle et al., (2005b) found that the S/N difference between normal-hearing and hearing-impaired listeners was 7.6 dB for both monosyllabic words and IEEE sentences, confirming that words and sentences are equally sensitive to hearing loss effects in descending speech-in-noise paradigms. For older listeners with hearing loss, 50% recognition required S/N values of −4, 12.4, and 11.7 dB for digits, words, and sentences, respectively.

Speech perception in noise is essential for assessing real-world listening ability. Individuals with hearing loss require higher signal-to-noise ratios and show reduced speech understanding in noisy environments. Although speech recognition declines with noise, prosodic cues may remain relatively stable. Overall, speech-in-noise testing is a valuable clinical tool for diagnosis, hearing aid fitting, and counselling, but should be used appropriately.

2.6 Factors Affecting Speech Audiometry

The validity and reliability of speech audiometry outcomes are influenced by a wide range of variables, including the listener, test stimuli, administration conditions, and equipment used. Language background significantly affects performance when test materials are not in the listener’s native language. Non-native listeners require considerably better signal-to-noise ratios for sentence-based tests, and limited linguistic experience consistently produces lower discrimination scores under degraded conditions (Gat & Keith, 1978; Warzybok et al., 2015). Similarly, several research findings support that speech audiometric materials must be administered in the individual's native language for the accurate measurement of their communication difficulties (Danhauer et al., 1984; Shi & Sánchez, 2010; Smiljanić & Bradlow, 2011)

Word familiarity is another important factor affecting speech audiometric performance. As described by Owens, (1961) the test performance is shaped not only by audibility and phonetic features, but also by how well the listener knows the test words. Controlling for word familiarity through frequency norms is therefore essential to ensure comparable list difficulty across populations (Gelfand, 2016).

Presentation level is another factor, which determines whether maximum word recognition performance is achieved. A fixed sensation level (SL) relative to SRT is not universally appropriate, particularly for individuals with sensorineural hearing loss and sloping audiograms. Optimal scores are often obtained at approximately 5 dB below the uncomfortable loudness level (Gelfand, 2016; Guthrie & Mackersie, 2009).

Carrier phrases have a variable and minor effect on speech audiometric scores. While some studies have reported significantly better scores when carrier phrases are included (Galdstone & Siegenthaler, 1971; Gelfand, 1975), but others found no significant differences (Martin et al., 1962; McLennan & Knox, 1975). Individual responses also vary: some patients perform better with carrier phrases, possibly because they act as alerting cues, whereas others may find them distracting or irritating. Therefore, regardless of routine practice, audiologists should remain attentive to the patient’s response pattern and be flexible in adding, modifying, or omitting carrier phrases as needed.

The mode of delivery (recorded versus live voice) also consistently affects speech audiometric scores. Variability in speaker production and articulation style makes recorded materials preferable for standardised testing. However, monitored live-voice testing may still be appropriate in situations where patient needs require flexibility or when recorded versions of the test materials are unavailable. Of course, monitored live-voice testing is often appropriate when the special needs of the patient call for a flexible approach and when a recorded version of the speech recognition test being used is not available (Gelfand, 2016).

Speech recognition tests are usually scored on a whole word basis. An alternative method is to score on a phoneme-by-phoneme basis. According to Gelfand (2016), phonemic scoring offers several advantages over whole-word scoring, including a more precise and valid assessment of the perception of acoustic speech cues and improved reliability due to the increased number of scorable units.

In conclusion, the review of literature highlights the importance of speech perception assessment in adults and emphasizes the need for language-specific high-frequency speech identification materials for reliable and accurate audiological evaluation. Previous studies conducted across various Indian languages have demonstrated that high-frequency word lists are clinically useful in identifying speech perception difficulties associated with high-frequency hearing loss and in providing a better understanding of the real-world communication difficulties experienced by individuals. The reviewed literature also reviewed various factors that significantly influence speech identification performance in adults. However, standardized high-frequency speech identification materials in Malayalam for adult audiological assessment are limited.

Chapter 3
Methods

The following method was adopted to verify the study's objectives. The study was conducted in the following two phases.

Phase 1: The development of high-frequency word lists in adults.

Phase 2: Standardization of the developed test material

3.1 Phase 1: The development of high-frequency word lists in adults

The following steps were followed to arrive at the high-frequency word lists:

- Selection of high-frequency words.
- Assessment of familiarity with the selected words.
- Acoustic validation of the familiar words
- Construction of word subtests
- Recording of the test material

3.1.1. Selection of high-frequency words

Bisyllabic and trisyllabic words with good redundancy were selected for constructing the high-frequency word lists. These words were collected from various sources, such as dictionaries, magazines, newspapers, articles, and books. Preferences were given to words containing the phonemes /s/, /ʃ/, /tʃ/, /t͡ʃʰ/, /k/, and /t/ as these phonemes have spectral energy above 1 kHz. Additionally, the words containing vowels, /i/ and /e/, were preferred because F2 and F3 of these vowels are higher than those of the other vowels (Cooper et al., 1952). Totally, 1000 words were collected from various sources mentioned.

3.1.2. Assessment of familiarity with the selected words

To make sure the chosen words were well-known and often utilized by Malayalam native speakers, their familiarity was evaluated. The familiarity of the test items was assessed on seven adults who were native Malayalam speakers. A printed version of the word list, along with instructions for rating familiarity, was provided to the participants, and each participant was instructed to tick the most appropriate column. A three-point rating scale (very familiar, familiar, and not familiar) was used to assess the familiarity. The categories were defined as follows:

- **Very familiar:** Words that were commonly used by the participants.
- **Familiar:** Words that were used occasionally but were familiar to the participants.
- **Not familiar:** Words that were not used by the participants.

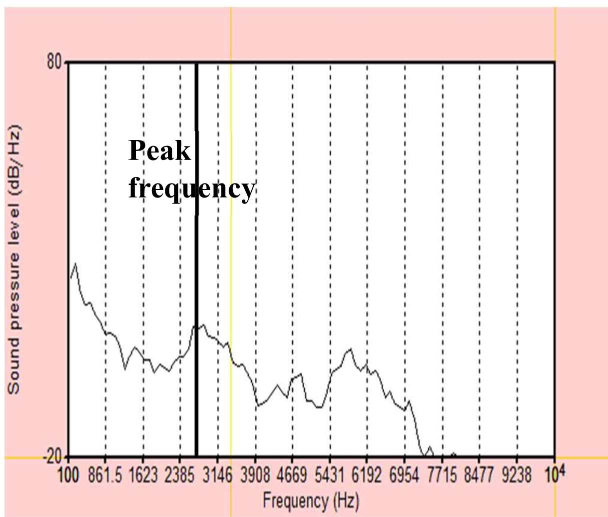
Out of the 1000 words assessed, 707 words were rated as "very familiar" and were subjected for acoustic validation.

3.1.3. Acoustic validation of the familiar words

The familiar words were acoustically validated using long-term average speech spectrum (LTASS) and spectral centroid analysis. Initially, LTASS was used to ensure the spectral information on familiar words is predominantly in the higher frequencies. It was necessary as the spectral information of the phonemes /s/,/ʃ/, /tʃ/,/t͡ʃ^h/,/k/, and /t/ could differ depending on the context, and hence the so-called high-frequency word may not have high-frequency spectral information. An adult female, who was a native Malayalam speaker, recorded the words. The words were recorded in an acoustically treated room at a 44.1 kHz sampling rate and 16-bit quantization using Adobe Audition 2025 software, and the samples were stored on a Lenovo laptop (Intel Pentium 4415U processor (2.30 GHz) and 8 GB RAM, Windows 10). LTASS was generated using PRAAT by feeding the audio samples individually, and the spectral information was manually derived. The peak frequency of the spectra with the highest energy concentration was considered as the target parameter. Out of 707 words, 262 words showed the highest energy above 2000 Hz. For the present study, it was decided to consider the criteria as 2000 Hz in order to make it more sensitive to high-frequency hearing loss (Hmangte, 2012). The spectrum derived from LTASS for a representative word is shown in Figure 3.1.

Figure 3.1

Spectrum derived from LTASS for a representative word.



Further, the 262 words that were selected based on LTASS results were subjected to spectral centroid analysis for the most accurate selection. The spectral centroid represents the centre of mass of the spectrum and is proportional to the sharpness of the sound (Dua et al., 2026). Each stimulus (stored as a .wav audio file) was imported into MATLAB R2025b (MathWorks, Inc., Natick, MA, USA). A custom MATLAB script was developed to compute the spectral centroid of each stimulus. The signal was pre-processed by removing the DC offset for centering the waveform around zero and applying a Hanning window to reduce spectral leakage. A Fast Fourier Transform (FFT) was then used to obtain the frequency-domain representation of the signal. The absolute value of the FFT coefficient was calculated to get the magnitude spectrum. Only the positive frequency components were used in further analysis. A frequency vector with respect to the signal length and the sampling frequency was created. The spectral centroid was calculated as the weighted mean of the frequency components, where the magnitude of each frequency bin was used as the weight. The ratio of the sum of the product of frequency and its corresponding magnitude to the total sum of magnitudes was calculated. This is the spectral energy distribution of the signal. From the selected words, 113 words showed a central frequency above 2000 Hz.

3.1.4. Construction of word subsets

From the selected words, 113 words showed a central frequency above 2000 Hz. These words were further categorized based on different cutoff frequencies such as 2.0-2.5 kHz, 2.5-3.0 kHz, 3.0-3.5 kHz, and 3.5-4.0 kHz. Out of 113 words, 100 words were randomly selected for the construction of a high- frequency word list.

The 100 words were further categorized into bisyllabic and trisyllabic words. There were 50 bisyllabic and 50 trisyllabic words. Each of the lists was further divided into two half- lists, each containing 25 words. The frequency of the occurrence of high-frequency sounds was maintained the same in all half lists. The bisyllabic and trisyllabic word lists are given in Appendix I and II.

3.1.5 Recording of the test material.

The test material was recorded in a sound-treated room according to ANSI guidelines (1999). Five native speakers of Malayalam were initially selected, and they recorded a sample of words. These sample recordings were then evaluated by five Speech-Language Pathologists (SLPs)/Audiologists who were native Malayalam speakers based on clarity, pronunciation, and fluency. The speaker with the best clarity and fluency was chosen for the audio recording of the final test list. The recording of words with the selected speaker was done using Adobe Audition 2025 software, with a Dual Diaphragm Condenser Microphone B.2 Pro and MOTU M2. The microphone was placed 5 inches away from the speaker and the VU meter was monitored at optimum levels during the recording. The speaker was instructed to speak the words with their normal pitch and to maintain a constant loudness throughout the words. The recording was carried out using a 44.1 Hz sampling rate and 16-bit quantization in a mono channel. The intensity of each word was normalized to -3 dB. After normalization, each word was saved as a .wav file. The words are organized as a continuous string, according to each half-list, with an interstimulus interval of 3 seconds (Runge & Dunn, 1985).

3.2. Phase 2: Standardization of the test material

The developed test material was standardized by maintaining the following criteria and procedure:

3.2.1 Participants

To standardize the developed high-frequency word identification test material, speech identification scores were obtained from adult native speakers of Malayalam within the age range of 18 to 30 years with a mean age of 23 years (SD: 3.09). 104 participants were enrolled in the study, of whom 75 were females and 29 were males.

Participant sélection criteria

All participants were subjected to a preliminary case history to record demographic data, medical and any relevant audiological history. Hearing status was also verified by pure-tone audiometry to exclude hearing loss or middle ear pathology. The inclusion criteria of the participants:

- Bilateral normal hearing sensitivity ranges from 250 Hz to 8000 Hz for air conduction and 250 Hz to 4000 Hz for bone conduction as obtained by a modified version of the Hughson and Westlake procedure (Carhart & Jerger, 1959).
- Speech recognition thresholds (SRT) within +/- 12 dB (re: PTA 0.5, 1, 2 & 4 kHz) in both ears obtained by using Malayalam Spondees (Kacker & Basavaraj, 1990).
- Speech identification scores (SIS) of >90% in both ears using the PB word list in Malayalam (Kacker & Basavaraj ,1990).
- Bilateral A-type tympanogram and acoustic reflex (ipsilateral & contralateral reflex) present in both ears to ensure normal middle ear functioning.
- Pass in screening checklist for auditory processing for Adults (SCAP-A)(Vaidyanath & Yathiraj, 2014).

Further, participants included in the study had no history of hearing loss, ear disease, trauma, ototoxic drug intake, ear surgery, or neurological problems. It was also ensured that none of the participants had any current illness that could affect their hearing abilities or overall test performance.

3.2.2 Test environment

All evaluations were carried out in an acoustically treated two-room situation as per ANSI S3.1 (1991).

3.2.3. Informed Consent

The Institutional Ethical Board ethically approved the study (Ref: SH/IRB/M.4/AUD.20/2025-26) (Appendix III). All potential participants were informed about the aims, procedures and confidentiality of the study. Participation was voluntary and those who agreed to participate gave written informed consent. Participants were told that they were free to withdraw from the study at any time without penalty.

3.2.4. Instrumentation

- Pure tone air conduction threshold and speech identification scores were estimated using a calibrated two-channel audiometer (GSI AudioStar Pro™, Grason-Stadler, 2012) with acoustically matched TDH-39 Supra-aural headphones and Radio ear B-71 bone vibrator.
- A calibrated clinical middle ear analyzer (GSI TympStar Pro™; Grason-Stadler, 2015) was used to perform tympanometry and acoustic reflexes.
- A Lenovo laptop (Intel Pentium 4415U processor (2.30 GHz) and 8 GB RAM, Windows 10) calibrated with Sennheiser HD 599 headphones and Windows Media Player software was used to present the developed test material.

3.2.5 Procedure

Pure tone air conduction thresholds were estimated for frequencies from 250 Hz to 8000 Hz for air conduction and 250 Hz to 4000 Hz for bone conduction to ensure normal peripheral hearing sensitivity in all participants. Then the SRT were estimated using the Malayalam spondee word lists developed by Kacker and Basavaraj (1990). The first level of presentation was 20 dB SL with respect to the pure tone average. The threshold was monitored by the bracketing method. SIS were obtained at 40 dB SL relative to the SRT using the Malayalam PB word lists (Kacker & Basavaraj ,1990). Following the estimation of SRT and SIS, screening for auditory processing was also conducted using the SCAP-A (Vaidyanath & Yathiraj, 2014). Then the high-frequency word list developed in Phase 1 was administered via a Lenovo laptop with an Intel Pentium 4415U processor at a calibrated output level and was delivered monoaurally via Sennheiser HD 599 headphones. Prior to data collection, the headphone output was calibrated to 60 dB SPL using a KEMAR manikin to ensure acoustic accuracy.

Initially a pilot study was conducted across five signal-to-noise ratios (SNR) (+3, 0, −3, −4, and −5 dB SNR) to determine the SNR at which 50% word identification score (SNR-50) was achieved across all half-lists. The different SNR conditions were made using MATLAB R2025b software. Of the conditions evaluated, −4 dB SNR consistently yielded a 50% identification score and was therefore selected as the presentation level for actual testing. All participants were tested monaurally using the developed test material, with the right ear assessed in 50% of the participants and the left ear assessed in the remaining 50%. Further, the participants were initially tested under noise condition, and the quiet condition scores were obtained from the same participants after an interval of one week. Open-set oral responses were obtained from the participants, and all responses were scored with the assistance of a native Malayalam interpreter throughout data collection. Responses were only scored as correct if they matched the target stimuli exactly in pronunciation and lexical tone. Instructions for word recognition testing were given to each subject in Malayalam prior to testing.

"You will hear lists of Malayalam words several times at a specific level. The silent gap between each word will be about 3 seconds. Please listen carefully and repeat out loud the word that you hear. If you are unsure of a word, you are encouraged to guess. If you have no guess, say *I do not know,* or wait silently for the next word. Do you have any questions?

3.2.6. Scoring

After estimation of the speech identification scores using the Malayalam high frequency word identification test for adults, the responses were scored as follows:

- Each correct response was given a score of 1

- Each incorrect response was given a score 0

The raw score was converted to percentage as follows:

$$\textbf{Total score (\%)} = \frac{\textbf{Total number of correct responses} \times \textbf{100}}{\textbf{Total number of words presented}}$$

3.2.7 Statistical Analysis

Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS, Version 26.0; IBM Corp.). Descriptive statistics, including mean and standard deviation, were calculated for all variables. The normality of the data distribution was assessed using the Shapiro–Wilk test. Equivalence between the half-lists and performance across the two listening conditions (quiet and noise) was evaluated using a two-way repeated-measures ANOVA, with listening condition and lists treated as within-subject factors. Post hoc pairwise comparisons were performed using the Bonferroni test to examine list equivalence and differences between listening conditions.

Chapter 4

Results

The development of the Malayalam high-frequency word lists for adults involved a systematic multi-phase process including word selection and familiarity assessment, acoustic validation of words through Long-Term Average Speech Spectrum (LTASS) analysis and spectral centroid assessment, and final construction of balanced word subtests. This was followed by the development of normative data in adults. The results of each phase are described in the following headings:

4.1 Development of the high-frequency word lists.

4.2 Development of the normative for the Malayalam High Frequency Wordlist for Adults.

4.3 Comparison of the speech identification score obtained across each list to check the equality of the lists developed.

4.1 Development of the high-frequency word list

4.1.1. Selection of words and their familiarity

Initially, a total of 1000 Malayalam words were collected from various resources, including dictionaries, magazines, newspapers, articles, and books. While selecting the words, preference was given to high-frequency consonants /s/, /ʃ/, /tʃ/, /t͡ʃʰ/, /k/, and /t/ and vowels /i/ and /e/. The collection of words included bisyllabic and trisyllabic words. A printed version of the collected words was subjected to a familiarity rating by seven native Malayalam speakers. A three-point rating scale, along with clear instructions, was given for the familiarity rating. Out of the 1000 words, 707 words were rated as very familiar by all the speakers. The selected familiar words were then subjected to LTASS analysis and spectral centroid assessment for the acoustic validation of high-frequency target words.

4.1.2. Acoustic validation of high frequency words

The familiar words obtained after the familiarity assessment were subjected to LTASS analysis to identify words containing greater high-frequency spectral energy. Based on the LTASS results, words exhibiting greater spectral energy concentration above 2000 Hz were identified as potential high-frequency target words. Out of the 707 words analysed, 262 words showed peak spectral energy above 2000 Hz and were retained. The criterion of 2000 Hz was adopted to make the test more sensitive to high-frequency hearing loss (Hmangte, 2012).

Further, spectral centroid analysis using MATLAB was done to confirm the high frequency spectral energy in the shortlisted words. The results of spectral centroid analysis showed that out of the 262 words analysed, 113 words exhibited a spectral centroid above 2000 Hz and thus were selected for word list construction. The 113 words were further distributed across spectral centroid frequency ranges, categorised by spectral centroid values as shown in Table 4.1.

Table 4.1

Distribution of selected words across spectral centroid frequency ranges based on spectral centroid analysis

Spectral Centroid Values (kHz)	**Number of words**
2 kHz to 2.5 kHz	41
2.5 kHz to 3.0 kHz	32
3.0 kHz to 3.5 kHz	28
3.5 kHz to 4.0 kHz	8
Above 4 kHz	4
Total	**113**

From Table 4.1, it can be noted that the majority of the selected words had spectral centroid values concentrated between 2 kHz and 3.5 kHz. In contrast, only a small number of words exhibited spectral centroid values above 3.5 kHz.

4.1.3. Construction of the word subsets

A total of 113 words met the spectral centroid criterion of above 2 kHz, including 58 bisyllabic and 55 trisyllabic words. Based on their spectral centroid values, the words were grouped into different frequency ranges (e.g., 2–2.5 kHz, 2.5–3 kHz, and above) to facilitate balanced list construction and minimize inter-list variability. From these, 50 bisyllabic and 50 trisyllabic words were selected and organized into four half-lists containing 25 words each, comprising two bisyllabic and two trisyllabic half-lists. Table 4.2 shows the mean and standard deviation (SD) of the spectral centroid values of words in each half-list.

Furthermore, a one-way ANOVA was conducted to compare the spectral centroid values across the four half-lists. The results revealed that there was no significant difference in the spectral centroid values among the lists $[F(3,96) = 0.570, p > 0.05]$ indicating that all the lists had similar spectral energy distribution and were acoustically equivalent.

Table 4.2

Mean and SD of spectral centroid values of four lists

List	Number of words	Mean Spectral centroid (Hz)	SD
List 1: Half-list 1	25	2965.44	557.5008
List 1: Half-list 2	25	2917.679	511.336
List 2: Half-list 1	25	2839.662	577.5174
List 2: Half-list 2	25	2781.472	513.0288
Total	100	2876.06	539.84

4.2. Development of the normative for the Malayalam Speech Identification test for adults

Normative data for the developed test material were established by administering the four half-lists to 104 normal-hearing adults (native speakers of Malayalam) in two listening conditions: quiet and −4 dB SNR. A The pilot study was conducted at five SNR conditions of +3, 0, -3, -4 and -5 dB SNR for obtaining SNR 50. Table 4.3 depicts the speech identification scores (SIS) obtained across all conditions and it can be noted that -4 dB SNR consistently yielded a 50% speech identification score for all half-lists, thus, SIS in quiet and -4dB SNR were obtained for all four lists.

Table 4.3

Speech Identification Scores (%) obtained during the pilot study across different signal-to-noise ratios (SNRs).

SNR	List 1 Half List 1	List 1 Half List 2	List 2 Half List 1	List 2 Half List 2
+3 dB	100	100	100	100
0 dB	88	92	92	96
-3 dB	64	64	68	72
-4 dB	56	52	60	64
-5 dB	40	32	44	44

The mean and SD of SIS for all lists in both conditions are presented in Table 4.4. and 4.5. Further, Figure 4.1 shows the mean and SD of SIS in quiet and noise across all four lists. From Figure 4.1, it can be noted that the scores in quiet are better than in noise, and the scores in quiet and noise are similar across the lists.

Table 4.4

Mean and SD of SIS (%) for the four half-lists in the quiet condition.

List	Number of Words	Mean Score (%)	SD
List 1: Half-list 1	25	99.73	1.007
List 1: Half-list 2	25	100.00	0.000
List 2: Half-list 1	25	99.46	1.678
List 2: Half-list 2	25	99.77	0.937

Note: N = 104 normal-hearing adults

Table 4.5

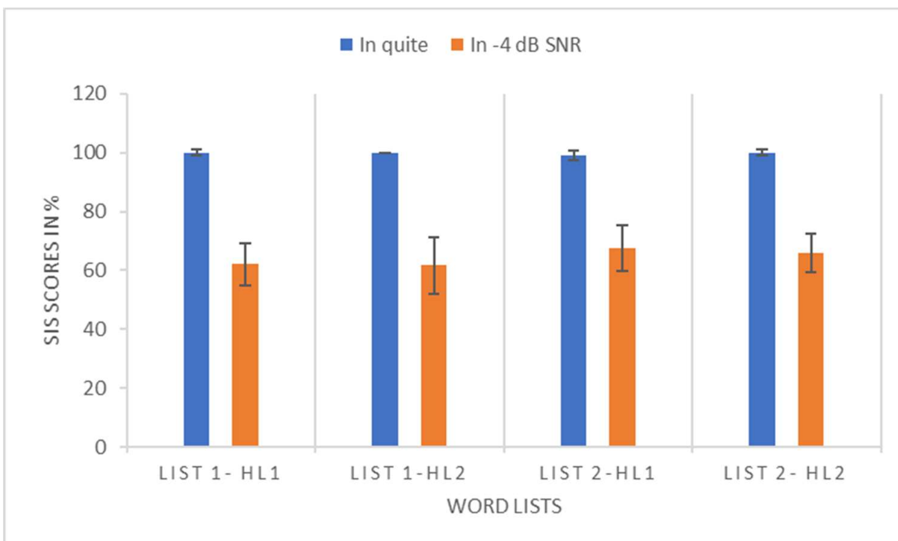
Mean and SD of SIS (%) for the four half-lists in the noise condition

List	Number of Words	Mean Score (%)	SD
List 1: Half-list 1	25	62.12	7.027
List 1: Half-list 2	25	61.69	9.601
List 2: Half-list 1	25	67.42	7.812
List 2: Half-list 2	25	65.88	6.734

Note: N = 104 normal-hearing adults.

Figure 4.1

Bar graph showing mean and SD of SIS in quiet and in noise (-4 dB SNR) across lists.



* *HL- Half List.*

Further, ANOVA was done to assess the effect of listening condition on the SIS scores for all the lists. For the bisyllabic lists, the two-way repeated measures ANOVA revealed a significant main effect of listening condition (quiet vs. noise) on SIS ($F(1, 103) = 3403.297$, $p < .001$, partial $\eta^2 = .971$), indicating significantly poorer performance in noise compared to quiet. Similarly, for the trisyllabic lists, a significant main effect of listening condition was observed ($F(1, 103) = 2803.137$, $p < .001$, partial $\eta^2 = .965$), with SIS scores being significantly lower in noise than in quiet.

4.3.Comparison of SIS across each list to check the equality of the lists developed.

To examine whether the four half-lists developed for the Malayalam Speech Identification Test were equivalent in difficulty, SIS (%) obtained under both quiet and noise listening conditions were compared across the two bisyllabic half-lists and the two trisyllabic half-lists using a two-way repeated measures ANOVA.

The two-way repeated measures ANOVA for the bisyllabic half-lists revealed that the main effect of list was not statistically significant (F (1, 103) = 0.024, p = .878), and the condition × list interaction was also non-significant (F (1, 103) = 0.449, p = .504), confirming that both bisyllabic half-lists performed equivalently across conditions.

The two-way repeated measures ANOVA for the trisyllabic half-lists also demonstrated that the main effect of list was not statistically significant (F(1, 103) = 2.696, p = .104), indicating broad equivalence between the two trisyllabic lists overall. However, a statistically significant condition × list interaction was observed (F(1, 103) = 6.071, p = .015, partial η^2 = .056), suggesting that the relative performance on the two lists varied depending on the listening condition.

Chapter 4

Discussion

The present study aimed to develop and standardize a high-frequency word list in Malayalam for adults to assess speech identification scores (SIS). This study addressed the various aspects related to the development and standardization of a speech audiometry material, including the importance of using familiar words, the role of acoustic analyses such as Long Term Average Speech Spectrum (LTASS) and spectral centroid analysis, the importance of establishing normative data in both quiet and noise and the need to ensure the equivalency of the developed half lists. In this chapter, the results of the present study are discussed in relation to the existing literature.

5.1 Development of High-Frequency Word List

5.1.1 Word selection and familiarity assessment

In the present study, 1000 Malayalam words were initially collected from various sources. Only those words that met the required familiarity criteria were included for further acoustic and perceptual analyses. This step was consistent with the fundamental requirement for speech audiometry materials that test items must be familiar to the listener (Hudgins & Hawkins, 1947). They postulated that the speech audiometry materials should consist of familiar and commonly occurring lexical items in order to accurately measure the threshold of intelligibility for speech, rather than vocabulary or intelligence. The selection of familiar words for the development of high frequency word list in the present study are also consistent with the previous studies that developed speech audiometry materials in Indian languages. Ramachandra (2001) in Hindi, Kavitha (2002) in Kannada, Sinthiya (2009) in Tamil, and Ratnakar (2010) in Telugu also highlighted the importance of selecting highly familiar words during the development of high-frequency speech materials. Similar criteria were adopted in the present study to ensure that the SIS obtained from the developed materials truly reflected auditory performance. Thus, the inclusion of familiar words in the present study improved the ecological validity and clinical applicability of the developed Malayalam high-frequency word list.

5.1.2 Acoustic validation of the familiar words

The acoustic validation of the familiar words was done using LTASS and spectral centroid analysis. LTASS analysis was conducted to examine the spectral distributions of the familiar words selected for the study. LTASS provides information on the average spectral energy distribution of speech stimuli and helps identify words with greater high-frequency acoustic emphasis. The 2 kHz cutoff criterion used in the present study is in line with the procedures adopted by Hmangte (2012) in the development of the Manipuri High-frequency Speech Identification Test, and is an intentional decision to make the test sensitive to high-frequency hearing loss in the clinically important range. Similar observations were reported by studies conducted in Hindi and Urdu (Ramachandra, 2001), Kannada (Kavitha, 2002), Tamil (Sinthiya, 2009) and Telugu (Ratnakar, 2010), where LTASS analysis was used to ensure adequate high-frequency spectral representation. The LTASS findings of the present study, therefore suggest that the selected words possess the necessary acoustic characteristics to function as high-frequency speech identification materials.

Further, the spectral centroid analysis confirmed that the words in the developed lists were well above 2kHz. This frequency range is important for speech intelligibility, especially for the perception of consonantal cues (French & Steinberg, 1947). The lesser number of words with spectral centroid values greater than 4 kHz indicates that naturally occurring Malayalam words are less likely to contain very high frequency acoustic energy. The use of spectral centroid analysis in the present study also strengthened the acoustic validity of the developed material. Acoustic analysis is important in speech material development because perceptual judgment alone may not accurately determine spectral properties. Objective acoustic measures help ensure uniformity and consistency across test items.

5.1.3 Construction of word subsets

A total of 100 words were selected and were organized into bisyllabic and trisyllabic word lists with two half lists of 25 words in each. ANOVA showed no significant difference in the spectral centroid values among the four half-lists. This agrees with the recommendations for speech audiometry material development (ASHA, 1988; Hudgins & Hawkins, 1947) that test lists should be homogeneous in spectral content. The acoustic equivalence of the developed lists before standardization is a crucial prerequisite for the later demonstration of the clinical interchangeability, as highlighted in the development of comparable materials in other languages (Kavitha, 2002; Mehta & Neupane, 2019). The multiple equivalent lists allow repeated administration without significant practice effects and can be used during hearing aid evaluations, auditory training, and monitoring of rehabilitative progress.

5.2 Development of Normative Data on the Developed High Frequency Wordlists

The second phase of the study involved the development of normative data for the Malayalam high-frequency speech identification tests in adults. SIS were obtained under quiet and noise conditions in order to establish normative performance levels. The results indicated that participants demonstrated higher SIS in quite when compared to noise condition. These findings is expected because background noise adversely affects speech perception by reducing the audibility and clarity of speech cues (George et al., 2010; Le Prell & Clavier, 2017; Nilsson et al., 1994).

5.2.1 SIS scores across different listening conditions

In quiet listening conditions, all four lists yielded near-ceiling performance. The present findings support the importance of assessing speech perception in noise in addition to quiet conditions. The extremely small standard deviations (SD) in the quiet condition suggest that there is little intersubject variability. This provides evidence that the four lists are easily identifiable by normal hearing adults in a quiet environment. The near ceiling performance in quiet is a desirable and expected feature of speech audiometry materials designed for normal hearing normative groups and confirms that the word lists do not present an inappropriate perceptual challenge in a listening environment without degradation (Konkle & Rintelmann, 1983).

Under the noise listening condition, a marked reduction in mean SIS was observed across all four lists. The higher SD in SIS in the noise condition reflect greater inter subject variability. This pattern is consistent with a well-established principle that background noise reduces speech perception by masking high-frequency consonantal cues that carry important phonemic information (Stelmachowicz et al., 2001) and a wide range of variability in performance across individuals (Billings et al., 2024). The clinical justification for the use of a noise condition in the present study is given by the fact that speech identification in noise yields greater discriminatory power than quiet conditions alone to detect high-frequency hearing loss, the primary clinical target of the present test. Conventional speech audiometry conducted only in quiet may not adequately reflect real-world communication difficulties. Speech communication in daily life often occurs in the presence of competing background noise, making speech-in-noise assessment clinically relevant.

5.2.2 SIS scores across different lists

The two-way repeated measure ANOVA results of the present study showed that the SIS obtained for the bisyllabic and trisyllabic half lists confirmed the equivalence across both quiet and noise conditions. The present results are in agreement with the observations of (Konkle & Rintelmann, 1983) that phonetically balanced word lists that produce similar scores can be used interchangeably for clinical audiology testing. The current lists thus satisfy the requirement of clinical interchangeability and may be applied as alternative forms for test-retest comparisons, hearing aid benefit assessment, and longitudinal monitoring.

In conclusion, the present study successfully developed and standardized a Malayalam high-frequency speech identification word list for adults. The bisyllabic and trisyllabic half-lists developed were equivalent under both quiet and noisy listening conditions, suggesting clinical interchangeability. Normative data from normal hearing adults showed near-ceiling performance in quiet and reduced scores in noise, indicating the sensitivity of the materials to listening difficulty in adverse conditions. In general, the developed Malayalam high-frequency speech identification test appears to be a reliable and clinically relevant tool for the assessment of high-frequency speech perception abilities in adults, and could be used for diagnostic evaluation, hearing aid assessment, and auditory rehabilitation.

Chapter 6

Summary and Conclusions

The present study aimed to develop and standardize high frequency speech identification wordlists in Malayalam for adults. Speech audiometry is an important part of the assessment of an individual's ability to detect and understand spoken language. Conventional speech identification materials assess perception based on speech cues from the low and mid-frequency regions, which may lead to an overestimation of speech perception in persons with high-frequency hearing loss. High-frequency speech cues are critical for consonant perception and speech clarity, and there is a need for specialized speech materials sensitive to deficits associated with high frequency hearing loss. Although high-frequency speech identification tests have been developed in several Indian languages, no such standardized materials were previously available in Malayalam. Therefore, the present study was undertaken to develop high-frequency word lists in Malayalam to assess speech identification scores (SIS) among adults, establish normative data in quiet and in noise conditions, and evaluate the equivalency across the developed lists.

The study was conducted in two phases. Phase 1 focused on the development of the high-frequency word lists. Initially, 1000 Malayalam words with bisyllables and trisyllables were taken from various sources. Familiarity ratings yielded 707 highly familiar words, which were submitted to LTASS and spectral centroid analysis to determine dominant high-frequency characteristics. Acoustic analyses showed that 113 words had a predominant spectral energy above 2 kHz. Finally, 100 words were selected and split into bisyllabic and trisyllabic categories, each comprising two equivalent half-lists of 25 words. The materials were later recorded by a native Malayalam speaker in a sound-treated room.

Phase 2 focused on standardization of the test material. The developed test was standardized on 104 normal hearing adults who were native Malayalam speakers. SIS in quiet and in noise were obtained for all four half-lists. The results of the study are summarized below:

- Acoustic analysis indicated that the selected words possessed sufficient acoustic homogeneity and appropriate high-frequency spectral characteristics for high-frequency speech identification testing.
- Participants demonstrated near-ceiling SIS under quiet conditions and comparatively reduced SIS scores under noise conditions, and the SIS scores differed significantly for quiet and noisy conditions.
- No significant differences in SIS scores were noted between the bisyllabic and trisyllabic half-lists under both quiet and noise conditions.

Thus, to conclude the study, a Malayalam High-Frequency Speech Identification Test for adults was successfully developed and standardised. The developed bisyllabic and trisyllabic half-lists can be reliably used for speech identification assessment under both quiet and noise listening conditions. The findings of the study also highlight the importance of considering listening environment while assessing speech perception performance in children and support the need for speech perception testing under ecologically valid listening conditions involving background noise.

6.1 Implications of the Study

The developed Malayalam High-Frequency Speech Identification Test has several important clinical applications:

- It can provide a realistic assessment of communication difficulties in adults with high-frequency hearing loss.

- It can be used to evaluate speech perception abilities in adverse listening conditions such as background noise.
- It may help in identifying suprathreshold auditory processing difficulties that are not detected using conventional speech audiometry materials.
- It can be useful during hearing aid selection, fitting and verification procedures, especially for adults with sloping high-frequency hearing loss.
- It can serve as an outcome measure for auditory rehabilitation and hearing aid benefit assessment.

6.2. Future directions

The present study was standardized only on normal-hearing adults who were native Malayalam speakers. The applicability of the developed materials to people with hearing impairment, especially, to the sloping high-frequency sensorineural hearing loss, need to be further investigated. Further research might also be conducted to assess the sensitivity, specificity and test-retest reliability of the developed test. Comparative studies with conventional speech identification materials and studies on the usefulness of the test in hearing aid verification and auditory training programs are also recommended.

References

ASHA. (1988). *Determining Threshold Level for Speech*. American Speech-Language-Hearing Association. https://www.asha.org/policy/gl1988-00008

Baer, T., Moore, B. C. J., & Kluk, K. (2002). Effects of low pass filtering on the intelligibility of speech in noise for people with and without dead regions at high frequencies. *The Journal of the Acoustical Society of America*, *112*(3), 1133–1144. https://doi.org/10.1121/1.1498853

Benson, E. A., & Messersmith, J. J. (2022). Audiologic Assessment. *Seminars in Hearing*, *43*(2), 58–65. https://doi.org/10.1055/s-0042-1749176

Besser, J., Festen, J. M., Goverts, S. T., Kramer, S. E., & Pichora-Fuller, M. K. (2015). Speech-in-speech listening on the LiSN-S test by older adults with good audiograms depends on cognition and hearing acuity at high frequencies. *Ear and Hearing*, *36*(1), 24–41. https://doi.org/10.1097/AUD.0000000000000096

Billings, C. J., Olsen, T. M., Charney, L., Madsen, B. M., & Holmes, C. E. (2024). Speech-in-Noise Testing: An Introduction for Audiologists. *Seminars in Hearing*, *45*(01), 055–082. https://doi.org/10.1055/s-0043-1770155

Bradlow, A. R., & Pisoni, D. B. (1999). Recognition of spoken words by native and non-native listeners: Talker-, listener-, and item-related factors. *The Journal of the Acoustical Society of America*, *106*(4 Pt 1), 2074–2085. https://doi.org/10.1121/1.427952

Brandy, W. T. (2002). Speech audiometry. In *Handbook of Clinical Audiology* (5th ed., pp. 96–110). Lippincott Williams & Wilkins.

Bukya, S., Gupta, M. K., & Kumar, S. B. R. (2025). Speech Perception in High-Frequency Sloping Hearing Loss Under Different Aided Conditions: Single Case Study. *Indian*

Journal of Otolaryngology and Head & Neck Surgery, *77*(3), 1301–1306. https://doi.org/10.1007/s12070-025-05325-7

Carhart, R. (1952). Speech audiometry in clinical evaluation. *Acta Oto-Laryngologica*, *41*(1–2), 18–48. https://doi.org/10.3109/00016485209124357

Carhart, R., & Tillman, T. W. (1970). Interaction of competing speech signals with hearing losses. *Archives of Otolaryngology*, *91*(3), 273–279. https://doi.org/10.1001/archotol.1970.00770040379010

Chintamani, N. S., & Yathiraj, A. (2017). *Development and Evaluation of High Frequency Speech Identification Test for Children in Indian-English (HF-WITCIE)* [Master's Degree Dissertation]. University of Mysore.

Danhauer, J. L., Crawford, S., & Edgerton, B. J. (1984). English, Spanish, and bilingual speakers' performance on a nonsense syllable test (NST) of speech sound discrimination. *The Journal of Speech and Hearing Disorders*, *49*(2), 164–168. https://doi.org/10.1044/jshd.4902.164

De, N. S. (1973). Hindi PB list for speech audiometry and discrimination test. *Indian Journal of Otolaryngology*, *25*(2), 64–75. https://doi.org/10.1007/BF02993883

Dirks, D. D., Takayana, S., & Moshfegh, A. (2001). *Effects of lexical factors on word recognition among normal-hearing and hearing-impaired listeners—PubMed*. *12*(5), 233–244.

Dua, M., Chakravarty, N., & Dua, S. (2026). *Audio Spoof Detection from Theory to Practical Application*. CRC Press.

Eldert, E., & Davis, H. (1951). *The articulation functions of patients with conductive deafness*. *61*(9), 891–909.

Erber, N. P. (1982). *Auditory training*. Alexander Graham Bell Association for the Deaf.

Fletcher, H. (1950). *A method of calculating hearing loss for speech from an audiogran*. *90*, 26–37.

Fletcher, H. (1953). *Speech and hearing in communication, 2nd ed* (pp. x, 461). D. Van Nostrand.

French, N. R., & Steinberg, J. C. (1947). Factors Governing the Intelligibility of Speech Sounds. *The Journal of the Acoustical Society of America*, *19*(1), 90–119. https://doi.org/10.1121/1.1916407

Fu, Q.-J., Zhu, M., & Wang, X. (2011). Development and validation of the Mandarin speech perception test. *The Journal of the Acoustical Society of America*, *129*(6), EL267–EL273. https://doi.org/10.1121/1.3590739

Galdstone, V. S., & Siegenthaler, B. M. (1971). Carrier phrase and speech intelligibility test score. *Journal of Auditory Research*, *11*(1), 101–103.

Gat, I. B., & Keith, R. W. (1978). An effect of linguistic experience. Auditory word discrimination by native and non-native speakers of English. *Audiology: Official Organ of the International Society of Audiology*, *17*(4), 339–345. https://doi.org/10.3109/00206097809101303

Gelfand, S. A. (1975). Use of the carrier phrase in live voice speech discrimination testing. *Journal of Auditory Research*, *15*(2), 107–110.

Gelfand, S. A. (2016). *Essentials of audiology: 290 illustrations* (Fourth edition). Thieme.

George, E. L. J., Goverts, S. T., Festen, J. M., & Houtgast, T. (2010). Measuring the Effects of Reverberation and Noise on Sentence Intelligibility for Hearing-Impaired Listeners. *Journal of Speech, Language, and Hearing Research*, *53*(6), 1429–1439. https://doi.org/10.1044/1092-4388(2010/09-0197)

Ghosh, V., Devananda, D., S B, H., & Kumar, H. (2024). SPEECH PERCEPTION IN NOISE IN MALAYALAM-SPEAKING YOUNG ADULTS WITH NORMAL

HEARING. *Journal of Hearing Science*, *14*(2), 33–38. https://doi.org/10.17430/jhs/191377

Giannakopoulos, T., & Pikrakis, A. (2014). *Introduction to Audio Analysis: A MATLAB Approach*. Academic Press. https://doi.org/10.1016/C2012-0-03524-7

Grant, K. W., & Braida, L. D. (1991). Evaluating the articulation index for auditory–visual input. *The Journal of the Acoustical Society of America*, *89*(6), 2952–2960. https://doi.org/10.1121/1.400733

Guthrie, L. A., & Mackersie, C. L. (2009). A comparison of presentation levels to maximize word recognition scores. *Journal of the American Academy of Audiology*, *20*(6), 381–390. https://doi.org/10.3766/jaaa.20.6.6

Hänsler, E., & Schmidt, G. (Eds.). (2006). Evaluation of Algorithms for Speech Enhancement. In *Topics in Acoustic Echo and Noise Control: Selected Methods for the Cancellation of Acoustical Echoes, the Reduction of Background Noise, and Speech Processing* (pp. 431–484). Springer. https://doi.org/10.1007/3-540-33213-8_11

Harris, R. W., Kim, E., & Eggett, D. L. (2003). *Psychometrically Equivalent Korean Monosyllabic Speech Discrimination Materials Spoken by Male and Female Talkers*. *8*(1), 217–243.

Harris, R. W., Nissen, S. L., Pola, M. G., McPherson, D. L., Tavartkiladze, G. A., & Eggett, D. L. (2007). Psychometrically equivalent Russian speech audiometry materials by male and female talkers: Materiales de logoaudiometría en ruso psicométricamente equivalentes para hablantes masculinos y femeninos. *International Journal of Audiology*, *46*(1), 47–66. https://doi.org/10.1080/14992020601058117

Hirsh, I. J., Davis, H., Silverman, S. R., Reynolds, E. G., Eldert, E., & Benson, R. W. (1952). Development Of Materials For Speech Audiometry. *Journal of Speech and Hearing Disorders*, *17*(3), 321–337. https://doi.org/10.1044/jshd.1703.321

Hmangte, M. (2012). *DEVELOPMENT OF HIGH FREQUENCY SPEECH IDENTIFFICATION TEST IN MANIPURI LANGUAGE* [University of Mysore]. Dissertation.

Hmangte, M., & Geetha, C. (2012). *Development of High-frequency Speech identification est in Manipuri language* [Master's Degree Dissertation]. University of Mysore.

Hoppe, U., Hocke, T., Müller, A., & Hast, A. (2016). Speech Perception and Information-Carrying Capacity for Hearing Aid Users of Different Ages. *Audiology and Neurotology*, *21*(Suppl. 1), 16–20. https://doi.org/10.1159/000448349

Hornsby, B. W. Y., & Ricketts, T. A. (2006). The effects of hearing loss on the contribution of high- and low-frequency speech information to speech understanding. II. Sloping hearing loss. *The Journal of the Acoustical Society of America*, *119*(3), 1752–1763. https://doi.org/10.1121/1.2161432

Hudgins, C. V., & Hawkins, J. E. (1947). The development of recorded auditory tests for measuring hearing loss for speech. *The Laryngoscope*, *57*(1), 57–89.

Hughes, G. W., & Halle, M. (1956). Spectral Properties of Fricative Consonants. *The Journal of the Acoustical Society of America*, *28*(2), 303–310. https://doi.org/10.1121/1.1908271

Ishtiaq, M. (1999). *Language Shifts Among the Scheduled Tribes in India: A Geographical Study*. Motilal Banarsidass Publishing House.

Johnson, E., Ricketts, T., & Hornsby, B. (2009). The effect of extending high-frequency bandwidth on the acceptable noise level (ANL) of hearing-impaired listeners.

International Journal of Audiology, *48*(6), 353–362. https://doi.org/10.1080/14992020802662964

Jongman, A., Wayland, R., & Wong, S. (2000). Acoustic characteristics of English fricatives. *The Journal of the Acoustical Society of America*, *108*(3), 1252–1263. https://doi.org/10.1121/1.1288413

Kacker, S. K., & Basavaraj, V. (1990). Indian speech, language and hearing tests: the ISHA battery-1990. *Mysore: Indian Speech and Hearing Association*.

Katz, J., Chasin, M., English, K. M., Hood, L. J., & Tillery, K. L. (2014). *Handbook of Clinical Audiology* (7th ed.). Wolters Kluwer / Lippincott Williams & Wilkins.

Kavitha, E. (2002). *A High Frequency Kannada Speech Identification Test(HF-KSIT)* [Master's Dissertation]. University of Mysore.

Konkle, D. F., & Rintelmann, W. F. (Eds.). (1983). *Principles of speech audiometry*. University Park Press.

Kryter, K. D. (1962). Methods for the Calculation and Use of the Articulation Index. *The Journal of the Acoustical Society of America*, *34*(11), 1689–1697. https://doi.org/10.1121/1.1909094

Lawrence, D. L., & Byers, V. W. (1969). Identification of Voiceless Fricatives by High Frequency Hearing Impaired Listeners. *Journal of Speech and Hearing Research*, *12*(2), 426–434. https://doi.org/10.1044/jshr.1202.426

Lawson, G. D., & Peterson, M. E. (2011). *Speech Audiometry*. Plural Publishing.

Le Prell, C. G., & Clavier, O. H. (2017). Effects of noise on speech recognition: Challenges for communication by service members. *Hearing Research*, *349*, 76–89. https://doi.org/10.1016/j.heares.2016.10.004

Lehiste, I., & Peterson, G. E. (1959). Linguistic Considerations in the Study of Speech Intelligibility. *The Journal of the Acoustical Society of America*, *31*(3), 280–286. https://doi.org/10.1121/1.1907713

Martin, F. N., Champlin, C. A., & Perez, D. D. (2000). The question of phonetic balance in word recognition testing. *Journal of the American Academy of Audiology*, *11*(9), 489–493; quiz 522.

Martin, F. N., Hawkins, R. R., & Bailey, H. A. T. (1962). *The nonessentiality of the carrier phrase in phonetically balanced (PB) word testing*. *2*(4), 319–322.

McArdle, R. A., Wilson, R. H., & Burks, C. A. (2005a). Speech Recognition in Multitalker Babble Using Digits, Words, and Sentences. *Journal of the American Academy of Audiology*, *16*(9), 726–739. https://doi.org/10.3766/jaaa.16.9.9

McArdle, R. A., Wilson, R. H., & Burks, C. A. (2005b). Speech Recognition in Multitalker Babble Using Digits, Words, and Sentences. *Journal of the American Academy of Audiology*, *16*(9), 726–739. https://doi.org/10.3766/jaaa.16.9.9

McLennan, R. O., & Knox, A. W. (1975). Patient-Controlled Delivery of Monosyllabic Words in a Test of Auditory Discrimination. *Journal of Speech and Hearing Disorders*, *40*(4), 538–543. https://doi.org/10.1044/jshd.4004.538

Mehta, G., & Neupane, A. K. (2019). *DEVELOPMENT AND STANDARDISATION OF HIGH FREQUENCY WORD IDENTIFICATION TEST FOR ADULTS IN GUJARATI LANGUAGE*. https://doi.org/10.17430/1003590

Monson, B. B., Rock, J., Schulz, A., Hoffman, E., & Buss, E. (2019). Ecological cocktail party listening reveals the utility of extended high-frequency hearing. *Hearing Research*, *381*, 107773. https://doi.org/10.1016/j.heares.2019.107773

Moore, B. C. J. (2016). A review of the perceptual effects of hearing loss for frequencies above 3 kHz. *International Journal of Audiology*, *55*(12), 707–714. https://doi.org/10.1080/14992027.2016.1204565

Moore, B. C. J., Stone, M. A., Füllgrabe, C., Glasberg, B. R., & Puria, S. (2008). Spectro-Temporal Characteristics of Speech at High Frequencies, and the Potential for Restoration of Audibility to People with Mild-to-Moderate Hearing Loss. *Ear and Hearing*, *29*(6), 907. https://doi.org/10.1097/AUD.0b013e31818246f6

Naqvi, Y., & Sutton, A. E. (2026). Speech Audiometry. In *StatPearls*. StatPearls Publishing. http://www.ncbi.nlm.nih.gov/books/NBK613286/

Niemeyer, W. (1976). Speech audiometry and fitting of hearing aids in noise. *Audiology: Official Organ of the International Society of Audiology*, *15*(5), 421–427. https://doi.org/10.3109/00206097609071802

Nilsson, M., Soli, S. D., & Sullivan, J. A. (1994). Development of the Hearing In Noise Test for the measurement of speech reception thresholds in quiet and in noise. *The Journal of the Acoustical Society of America*, *95*(2), 1085–1099. https://doi.org/10.1121/1.408469

Owens, E. (1961). Intelligibility of Words Varying in Familiarity. *Journal of Speech and Hearing Research*, *4*(2), 113–129. https://doi.org/10.1044/jshr.0402.113

Puglisi, G. E., Di Berardino, F., Montuschi, C., Sellami, F., Albera, A., Zanetti, D., Albera, R., Astolfi, A., Kollmeier, B., & Warzybok, A. (2021). Evaluation of Italian Simplified Matrix Test for Speech-Recognition Measurements in Noise. *Audiology Research*, *11*(1), 73–88. https://doi.org/10.3390/audiolres11010009

Ramachandra, P. (2001). *High-Frequency Speech Identification Test (HFSIT) for Hindi and Urdu speakers*.

Ramkissoon, I. (2001). Speech Recognition Thresholds for Multilingual Populations. *Communication Disorders Quarterly*, *22*(3), 158–162. https://doi.org/10.1177/152574010102200305

Ratnakar, V. (2010). *High Frequency Speech Identification Test in Telugu* [Master's Degree Dissertation]. University of Mysore.

Roeser, R. J., Valente, M., & Dunn, H. H. (2007). *Audiology Diagnosis* (Second Edition). Thieme Medical Publishers, Inc.

Schnupp, J., Nelken, I., & King, A. (2012). *Auditory neuroscience: Making sense of sound*. The MIT Press.

Shi, L.-F., & Sánchez, D. (2010). Spanish/English Bilingual Listeners on Clinical Word Recognition Tests: What to Expect and How to Predict. *Journal of Speech, Language, and Hearing Research*, *53*(5), 1096–1110. https://doi.org/10.1044/1092-4388(2010/09-0199)

Sinthiya, K. (2009). *High Frequency Speech Identification test in Tamil* [Master's Degree Dissertation]. University of Mysore.

Skinner, M. W., & Miller, J. D. (1983). Amplification bandwidth and intelligibility of speech in quiet and noise for listeners with sensorineural hearing loss. *Audiology: Official Organ of the International Society of Audiology*, *22*(3), 253–279. https://doi.org/10.3109/00206098309072789

Smiljanić, R., & Bradlow, A. R. (2011). Bidirectional clear speech perception benefit for native and high-proficiency non-native talkers and listeners: Intelligibility and accentedness. *The Journal of the Acoustical Society of America*, *130*(6), 4020–4031. https://doi.org/10.1121/1.3652882

Sreedevi, N., & Irfana, M. (2013). *Frequency of occurrence of phonemes in Malayalam* [Funded Project].

Stelmachowicz, P. G., Pittman, A. L., Hoover, B. M., & Lewis, D. E. (2001). Effect of stimulus bandwidth on the perception of /s/ in normal- and hearing-impaired children and adults. *The Journal of the Acoustical Society of America*, *110*(4), 2183–2190. https://doi.org/10.1121/1.1400757

Townsend, T. H. (1983). Acoustics and perception of speech. In *Principles of Speech Audiometry* (pp. 25–53). University Park Press.

Turner, C. W., & Henry, B. A. (2002). Benefits of amplification for speech recognition in background noise. *The Journal of the Acoustical Society of America*, *112*(4), 1675–1680. https://doi.org/10.1121/1.1506158

Turrini, M., Cutugno, F., Maturi, P., Prosser, S., Leoni, F. A., & Arslan, E. (1993). [Bisyllabic words for speech audiometry: A new italian material]. *Acta Otorhinolaryngologica Italica: Organo Ufficiale Della Societa Italiana Di Otorinolaringologia E Chirurgia Cervico-Facciale*, *13*(1), 63–77.

Vaidyanath, R., & Yathiraj, A. (2014). Screening checklist for auditory processingin adults (SCAP-A): Development and preliminaryfindings. *Journal of Hearing Science*, *4*(1), 27–37. https://doi.org/10.17430/890788

van Zyl, M., & Hanekom, J. J. (2011). *SPEECH PERCEPTION IN NOISE: A COMPARISON BETWEEN SENTENCE AND PROSODY RECOGNITION*. *1*(2).

Vickers, D. A., Moore, B. C., & Baer, T. (2001). Effects of low-pass filtering on the intelligibility of speech in quiet for people with and without dead regions at high frequencies. *The Journal of the Acoustical Society of America*, *110*(2), 1164–1175. https://doi.org/10.1121/1.1381534

Warzybok, A., Brand, T., Wagener, K. C., & Kollmeier, B. (2015). How much does language proficiency by non-native listeners influence speech audiometric tests in noise?

International Journal of Audiology, *54*(sup2), 88–99. https://doi.org/10.3109/14992027.2015.1063715

Weisleder, P., & Hodgson, W. R. (1989). Evaluation of four Spanish word-recognition-ability lists. *Ear and Hearing*, *10*(6), 387–392. https://doi.org/10.1097/00003446-198912000-00012

Wilson, R. H., & Carter, A. S. (2001). Relation between slopes of word recognition psychometric functions and homogeneity of the stimulus materials. *Journal of the American Academy of Audiology*, *12*(1), 7–14.

Zubick, H. H., Irizarry, L. M., Rosen, L., Feudo, P., Kelly, J. H., & Strome, M. (1983). Development of Speech-Audiometric Materials for Native Spanish-Speaking Adults. *Audiology*, *22*(1), 88–102. https://doi.org/10.3109/00206098309072772

APPENDIX: I
List 1
(Bisyllabic List)

Half List 1		Half List 2	
ചിഹ്നം	t͡ʃiɦn̪am	ശത്രു	ʃat̪ru
ദേഷ്യം	d̪e:s̢jam	ഭാഷ	bʱa:s̢a
ചെടി	t͡ʃet̢i	കക്ഷം	kaks̢i
ശെരി	ʃeɾi	ലക്ഷം	laks̢am
ശിശു	ʃiʃu	സൗഖ്യം	sau̯kʰjam
ശ്രുതി	ʃrut̪i	ചേമ്പ്	t͡ʃe:mpə
സൃഷ്ടി	srɨs̢t̢i	ജഡ്ജി	ɟad̢ɟi
ചെവി	t͡ʃeʋi	ശേഷം	ʃe:s̢am
സ്വൈര്യം	sʋai̯ɾjam	ശുദ്ധം	ʃud̪d̪ʱam
കൃഷി	krɨs̢i	സദ്യ	sad̪ja
സൂക്ഷ്മം	su:ks̢mam	ചേച്ചി	t͡ʃe:t͡ʃt͡ʃi
ക്രിസ്തു	krist̪u	ശിവം	ʃiʋam
ജൂലൈ	ɟu:lai̯	ശുദ്ധി	ʃud̪d̪ʱi
ശേഷി	ʃe:s̢i	ശ്രേഷ്ഠം	ʃre:s̢t̢am
ശനി	ʃani	സൂചി	su:t͡ʃi
സാക്ഷി	sa:ks̢i	ഇസ്ലാം	isla:m
ശില്പി	ʃilpi	കഷ്ടം	kas̢t̢t̢am
ചട്ടി	t͡ʃat̢t̢i	കൊറ്റി	kot̠t̠i
കക്ഷി	kaks̢i	സേന	se:na
ഇഞ്ചി	iɲt͡ʃi	ചിപ്പി	t͡ʃippi
ശക്തി	ʃakt̪i	സീത	si:t̪a
ശ്രമം	ʃramam	സിദ്ധി	sid̪d̪ʱi
ശുഭം	ʃubʱam	ചിരി	t͡ʃiɾi
ചെളി	t͡ʃel̢i	ലക്ഷ്യം	laks̢jam
സ്ഥിതി	st̪ʰit̪i	ചേര	t͡ʃe:ɾa

APPENDIX: II
List 2
(Trisyllabic List)

Half List 1		Half List 2	
സ്വാശ്രയം	sʋa:ʃrajam	ആഘോഷം	a:gʱo:ʂam
സൗകര്യം	sʋaka:ɾjam	സാധനം	sa:d̪ʱanam
ചിമ്മിനി	t͡ʃimmini	സാദൃശ്യം	sa:d̪ɾɨʃʃjam
ശ്രീലക്ഷ്മി	ʃri:lakʂmi	ചെങ്കല്ല്	t͡ʃeŋkallə
സ്വാഗതം	sʋa:gat̪am	കഷായം	kaʂa:jam
സുന്ദരി	sun̪d̪aɾi	ചേട്ടത്തി	t͡ʃe:ʈʈat̪t̪i
ചിലന്തി	t͡ʃilan̪t̪i	സന്തോഷം	san̪t̪o:ʂam
ചട്ടുകം	t͡ʃaʈʈukam	സാക്ഷരം	sa:kʂaɾam
സൂരക്ഷ	su:ɾakʂa	ചവിട്ടി	sʋad̪e:ʃi
ചുറ്റിക	t͡ʃut̠t̠ika	ജലാംശം	ɟala:mʃam
സംസാരം	samsa:ɾam	ചട്ടമ്പി	t͡ʃaʈʈampi
ദക്ഷിണ	d̪akʂiɳa	കാർഷികം	ka:rʂikam
ശൃങ്കാരം	ʃrɨŋka:ɾam	സൗജന്യം	sau̯ɟanjam
ചിരവ	t͡ʃiɾaʋa	ചൂഷണം	t͡ʃu:ʂaɳam
ജയിച്ചു	ɟajit͡ʃt͡ʃu	ഇഷ്ടിക	iʂʈika
ഇറച്ചി	irat͡ʃt͡ʃi	സ്വകാര്യം	sʋaka:ɾjam
കഷണ്ടി	kaʂaɳʈi	സന്ദേശം	san̪d̪e:ʃam
ചികിത്സ	t͡ʃikit̪sa	ശൂന്യത	ʃu:njat̪a
ശിശിരം	ʃiʃiɾam	ശ്രവണം	ʃraʋaɳam
ഇംഗ്ലീഷ്	imgli:ʂə	സുലഭം	sulabʱam
സ്വദേശി	sʋad̪e:ʃi	ശിങ്കിടി	ʃiŋkiʈi
സ്ഥാപക	st̪ʰa:paka	ജനിച്ചു	ɟanit͡ʃt͡ʃu
ശുശ്രുഷ	ʃuʃruʂa	കസേര	kase:ɾa
ഇസ്തിരി	ist̪iɾi	വിജയം	ʋiɟajam
ചട്ടിണി	t͡ʃaʈʈiɳi	ചിതറി	t͡ʃit̪ari

APPENDIX: III

ETHICAL CLEARENCE CERTIFICATE

All India Institute of Speech and Hearing
(An autonomous Institute under the
Ministry of Health and Family Welfare, Govt. of India)
Center of Excellence - Assessed & Accredited by NAAC with 'A' Grade
ISO 9001:2015 Implemented Institute
Manasagangothri, Mysuru-570006

ಅಖಿಲ ಭಾರತ ವಾಕ್ ಮತ್ತು ಶ್ರವಣ ಸಂಸ್ಥೆ
ಮಾನಸಗಂಗೋತ್ರಿ, ಮೈಸೂರು-570006
अखिल भारतीय वाक् श्रवण संस्थान
मानसगंगोत्री, मैसूरु - 570 006

INSTITUTE REVIEW BOARD (IRB) APPROVAL FOR BIO-BEHAVIOURAL RESEARCH PROPOSAL INVOLVING HUMAN SUBJECTS AT AIISH

AIISH Institute Review Board (IRB)

Ref: SH/IRB/M.4/AUD.20/2025-26 **Date: 06.01.2026**

Title of the Dissertation	: Development and Standardization of High Frequency Word List in Malayalam for Adults
Name of the Investigator	: Anagha V
Guide	: Dr. Chandni Jain
Co-Guide (if any)	: Nil
Proposed Duration of the Project	: 08 months
Source of funding	: Non-funded Master's dissertation
Estimated budget	: Nil
Reference Number of the Project	: Nil
Date on which the IRB meeting was held	: 02.01.2026

A clear statement of the decision reached IRB meeting (In the vent of the proposal is not approved, a statement of reasons for the same must be indicated) : **APPROVED**

Advice & suggestions (if any) : NIL

Signature & Name of the Member Secretary-IRB
Dr. Animesh Barman
Professor of Audiology
All India Institute of Speech and Hearing, Mysore-570006

सदस्य सचिव / Member Secretary
संस्थागत समीक्षा बोर्ड
Institutional Review Board
अखिल भारतीय वाक् श्रवण संस्थान
All India Institute of Speech and Hearing
मानसगंगोत्री / Manasagangothri
मैसूरु / Mysuru-570 006.

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