DEVELOPMENT OF LOW-FREQUENCY RANGE WORD LISTS IN MALAYALAM

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ABSTRACT

Conventionally, it was trusted that high-frequency sounds are more important for understanding speech signals, and most of the reviews were done on individuals with high-frequency hearing loss. Later on, it was noted that even low-frequency signals are also essential for speech understanding, and thus, scientists began extending their work towards low-frequency signals. However, not many standardized tests have been developed to assess the same. Thus, this research was taken up to develop, standardize, and validate low-frequency bi-syllabic word lists in the Malayalam language.

During the initial phase, bi-syllabic words which contain prominent low-frequency words were collected, and it was assessed by native linguist and words were shortlisted based on familiarity ratings given by native speakers. Those words were then recorded five times each by a native male speaker. The subjective and objective analysis was performed in order to obtain the best-recorded words. Further, the energy of each word above and below 1.5 kHz were computed using FFT, and amplitude ratios were obtained for the same. Later, using k- mean clustering, words with more energy (by around 20dB) below 1.5 kHz were depurated from the rest of the words. Psychometric function curves were obtained by calculating the mean sensation level at which 50% SI scores to develop equally difficult wordlist. As a result, a total of five low-frequency Malayalam word lists each was developed.

In the second phase, lists were normalized by administering it on 100 native Malayalam speakers with normal hearing sensitivity. During the final phase, developed lists were validated on 15 individuals with simulated cochlear low-frequency hearing loss. Hearing loss was simulated using MATLAB and NIOSH hearing loss simulator software. Results of validation showed that low-frequency word lists are sensitive enough to tap the speech understanding difficulty in the clinical population.

Keywords: Malayalam, low frequency, simulation, bi-syllabic words

INTRODUCTION

Audiology, the branch of science which deals with the hearing and balance-related disorders, is showing up its relevance in modern society in a rapid way. When we compare the national census of 2011 with that of 2001, a clear hike is observed in hearing-related problems. According to the 2011 census, 18.9% in every 100 persons had a hearing related issue. There are different types of hearing loss, such as sensorineural hearing loss, mixed hearing loss, and conductive hearing loss.

Certain auditory signs and symptoms of these hearing losses are noted to be overlapped. One of the principal sign that helps us to guess the kind of hearing loss is the configuration of the audiogram. Different disorders portray different configuration of audiograms, for example, Presbycusis, Noise-Induced hearing loss, Ototoxicity are types of disorders known to cause high-frequency hearing loss while others like Auditory Dysynchrony, Meniere's Disease, and Otoslerosis have been recognized to cause low-frequency hearing loss (Wang et al., 2002; Harner, Fabry & Beatty, 2000; Knox & McPherson, 1997; Hannley, 1993; Tarter & Robins, 1990).

The pervasiveness of various patterns of hearing loss was evaluated by various specialists. A US-based review done by Margolis and Saly (2008) has uncovered that sloping configuration was the most widely recognized (40%), followed by flat (16%), peaked (5%), rising (3%), other (2%) and trough (1%) configurations.

National Speech and Hearing Survey conducted a study on 38568 kids between ages 1 to 12 years and reported that around 2% had low-frequency hearing loss, and 3% to 4% had high-frequency hearing loss (Hull, Mielke, Timmons & Willeford, 1971).

Rabinowitz, Slade, Galusha, Dixon-Ernst, and Cullen (2006) announced that among 2526 adults between the age range of 17 to 25 years, around 16% and 5 % had high and low-frequency hearing loss respectively. In elderly people (Age >60 years), the predominance of various hearing loss configuration was found to be 29% flat, 6% rising, 36% gradually sloping and 29% sharply sloping audiogram (Gates, Couropmitree & Myers, 1999). On breaking down these reviews, it was observed that the predominance of low-frequency hearing loss is less contrasted with high-frequency hearing loss, and over time there is a significant impact of low-frequency hearing loss on daily life functioning. Thus, it is essential to understand the perception of low-frequency sounds in individuals with sensorineural hearing loss. The main problem among people with sensorineural hearing loss is the trouble perceiving discourse, particularly under adverse listening conditions. In this way, speech audiometry is an essential supplement to pure tone audiometry.

Speech is a complex signal with an extensive variety of frequencies, running between 250 Hz and 8000 Hz (Dobie & Van Hemel, 2004). The hearing loss at any of these frequencies can influence the hearing and comprehension of speech signals. Conventionally, it was trusted that high-frequency sounds are more important for understanding speech signals, and most of the reviews were done on individuals with high-frequency hearing loss. A large number of investigators have given their effort in order to develop test materials for testing high-frequency speech perception difficulties (Eric, Benedicte, Jean-Fracois, Samia & Lionel, 2008; Sudipta & Yathiraj, 2006; Stelmachowicz, Pittman, Hoover, Lewis & Moeller, 2004; Nobel, Sinclair & Byrne, 1998; Pascoe, 1975; Gardner, 1971). Later, it was found that even low-frequency signals are also essential for speech understanding, and thus, scientists began extending their work towards low-frequency signals (Barman et al., 2016).

The speech spectrum shows that speech sounds such as stops (/p/, /b/, /d/, /m/, /n/, /g/), liquids (/l/, /r/) semivowels (/v/, /j/) and vowels (/o/, /u/,/a/) are in the low frequency (< 1 kHz) and affricates and fricatives at mid to high frequencies. Individuals with low frequency hearing loss will have difficulty hearing sounds in the frequency range of 125 Hz to 1000 Hz. There are a number of acquired causes of hearing loss in low frequency range. It is frequently associated with Meniere"s disease (Opheim & Flottrop, 1957), viral infections (Djupseland at al., 1979), and also with various retrocochlear lesions (Lundborg, 1955; Moller & Moller, 1983). Hearing loss in the low frequency range of sounds may also be caused by congenital causes that include: poor cochlear development, congenital cholesteatoma (a destructive cyst in the middle ear), and delayed familial progressive causes (Konigsmark et al., 1971; Parving, 1984). A gene called WFS1 also has been identified that may be responsible for hearing loss in the low frequency range. Children who were born with a mutated copy of this gene were studied and were found to suffer from low frequency hearing loss (Bespalova et al., 2001)

According to Berke (2011), low frequency hearing loss is not easily identified because it shows relatively symptom free. Although they do not exhibit much problem, they still have problems in understanding speech in groups. Miller and Nicely (1995) reported that place of articulation information for speech is located primarily in the frequencies of 1000 Hz and above, where as a great deal of voicing information is present at lower frequencies. Turner and Cummings (1999) reported that when the audible speech was being provided at frequency regions as low as 300 Hz, speech recognition ability was improved when tested on 10 listeners with high frequency hearing loss. It is reported that providing audible speech information to frequency regions of 1500Hz and below resulted improving speech recognition ability for the majority of the subjects who had hearing loss for frequencies less than 1500 Hz (Ching, Dillon, & Bryne, 1998).

Jin and Nelson (2010) studied the effect of low to mid-frequency information on sentence recognition and found that those listeners with more hearing losses in the low frequencies were poorest at understanding interrupted sentences. Also, low to mid-frequency hearing thresholds accounted for most of the variability in masking release for listeners with hearing impairment. Based on these findings, they concluded that low-frequency information within speech plays a very important role in the perceptual segregation of speech from competing for background noise. Turner, Gantz, Vidal, Behrens, and Henry (2004) studied the advantages of preserving low-frequency acoustic hearing in cochlear implant individuals for understanding speech in the presence of background noise. Results showed a clear advantage for preserving low-frequency residual hearing for speech understanding in the presence of background of other talkers.

Prabhu, Avilala, and Barman (2011) studied the speech perception abilities of individuals with auditory dyssynchrony, and they found that the speech understanding scores were poorer for low pass filtered words when compared to unfiltered words. They also suggested the use of low pass filtered words as a tool for proper assessment of speech perception difficulties in individuals with auditory dysynchrony. Speech has a wide range of frequencies; a hearing loss involving only a part of frequency range may go undetected if we use the available standard speech tests. Conventionally, Phonetically Balanced (PB) word lists are used to assess the speech understanding abilities. The efficiency of those tests has been verified on individuals with a flat configuration of hearing loss. Thus, the use of these tests for accessing speech-related problems may not be accurate if an individual has more hearing loss in low or high frequencies.

There are several tests materials developed in Indian languages to assess individuals with high-frequency hearing loss such as high-frequency word list in Hindi (Ramachandra, 2001), Kannada (Kavitha, 2002), English (Sudipta, 2006), Tamil (Sinthiya, 2009) and Telugu (Ratnakar, 2010). However, very few test materials are available to assess the individual"s perception of low-frequency speech information. Low-frequency word lists are developed in Manipuri (Konadath & Nigombam, 2014), Hindi (Barman et al., 2016), and Kannada (Barman et al., 2016) language. Manipuri's low-frequency word list includes two lists with 20 words in each of the lists. Hindi and Kannada contain 7 and 10 lists, respectively, with 25 words in each list. All three studies used methods of FFT, LTASS, k-mean clustering, and phonemic analysis for selecting low-frequency words. However, they did not consider only words with low-frequency phonemes before FFT and further analysis. In these studies, they have found that these test materials help in the selection of appropriate hearing devices/management options. Thus, there is a need to develop low-frequency word lists in other Indian languages.

Malayalam (/mʌləˈjɑːləm/) is a Dravidian language primarily spoken in the southwest of India (Summer, 1990) predominantly in the state of Kerala. It is one of the 22 scheduled languages of India, which is more nasalized and may contain more low-frequency energy. There are several speech materials developed in Malayalam to assess speech identification scores (SIS) and speech recognition threshold (SRT). The materials included the Malayalam Phonemically Balanced list (ISHA, 1990), Picture test of speech perception in Malayalam (Mathew & Yathiraj, 1996), Malayalam spondee list (ISHA, 1990) and speech identification tests developed in Malayalam by Jain, Konadath, Vimal, and Suresh (2014). However, the usefulness of these tests has been validated considering individuals with flat configuration of hearing loss. Narne et al. (2016) estimated the frequency importance function (FIF) in the Malayalam language, and it was compared with the FIF in English. The results of their study showed that Malayalam has more weightage for low frequencies compared to English. They suggested that the probable reason could be because of the inherent phonetic differences and the use of more nasalized speech, which has low-frequency content. Thus, the above-mentioned test materials which are developed in Malayalam won "t be much helpful in determining the communication problems in individuals with low-frequency hearing loss.

In order to select appropriate hearing aids for individuals with low-frequency sensorineural hearing loss, it is essential to use a test that is sensitive to their problems. There is a high possibility that, if a regular PB word list is used in such individuals, the aided and the unaided scores may not be significantly different. Thus, it would be difficult to assess the benefit which one might get from the hearing aid. We can expect a significant difference in aided and unaided performance if a low-frequency word range list is used in individuals with rising hearing loss. Thus, it is essential to develop a low-frequency range word list, which would help in the rehabilitation of Malayalam speaking individuals with low-frequency hearing loss.

Objectives of the study:

- To develop low-frequency range word lists in Malayalam to determine speech identification scores in individuals with predominantly low-frequency hearing loss.
- To establish the normative data for the developed material in normal-hearing adults who are native speakers of Malayalam.
- To check the equality of the different lists that are developed.

- To administer the test on a group of individuals with a rising type of audiogram pattern/simulates low-frequency hearing loss to check its utility.

METHODS

The present study aimed to develop low-frequency word lists in Malayalam (Dravidian language of south India). For this purpose, the study was conducted in the following three phases:

Phase 1: The development of the low-frequency range word lists

Phase 2: Administration of word lists on individuals with normal hearing

Phase 3: Determining the usefulness of the test material

Phase I. Development of the low-frequency word lists

This phase was subdivided into four stages. They were viz. Collection of words that contain low-frequency phonemes and obtaining familiarity rating, recording, and selection of best-recorded words, separating words with dominant low-frequency energy, and finally generating word lists with equal difficulty levels were generated.

Collection of words and obtaining familiarity ratings

A total of 280 bi-syllabic words with low-frequency phonemes were collected from common sources of Malayalam. The words contain predominantly low frequency phonemes such as (stops (/p/, /b/, /m/, /n/, /g/), semivowels (/v/, /j/) and vowels (/o/, /u/, /a/). Those words were checked by linguists for the presence of any script errors and correct categorization as bi-syllabic words. Further, a 5 point familiarity rating scale ("unfamiliar", "less familiar", "familiar", "more familiar" & "most familiar") was used to get familiarity ratings for all words by ten native adult speakers. "Less familiar" and "unfamiliar" words were taken out. Familiarity ratings by all the participants were compiled and analyzed. The words rated familiar, more familiar, or most familiar by 70% of the participants were considered, and rest of the words was excluded from the list.

Recording of words and selection of best-recorded words

Selected words were recorded in a sound-treated room using Computerized Speech Lab - Model 4500, an input/output recording device for the personal computer by KayPENTAX. The recording was done using 16-bit analog to digital converter and at a sampling rate of 44.1 kHz. Unidirectional dynamic microphone (Shure SM-48) was used for the recording and was kept at a distance of around 6 cm from the speaker"s mouth.

Initially, 20 words from the selected words were recorded considering three native adult male fluent speakers of Malayalam. The mean fundamental frequency of male speakers is lower compared to female speakers, and hence male voice was preferred for recording the words. These voice recordings were then given to 5 adult native speech and hearing professionals with normal hearing for judging the most appropriate voice to record the entire list. Evaluators were asked to rate the voice based on parameters like voice quality, clarity, and naturalness on a 3- point rating scale (poor, fair, and good). One of the recorded voices, which received the highest score ratings, was selected, and that person"s voice was used for recording all the words selected.

Selected familiar words were recorded with the selected speaker"s voice, and the entire list was recorded. Each word was recorded five times in a clear and monotonous voice. Out of five recordings, first and the last recordings were removed, and only the middle three were subjected to subjective and objective analysis to select the best-recorded words. Praat software (version 5.3.03) was used for objective analysis. Initially, words were subjectively analyzed and rated by an experienced audiologist for the clarity of the utterance, presence of any intonation patterns, and background audible noise. Out of three repetitions of each word, the best-rated recordings, which were free of background noise, clear and monotonous voice were considered. Further, among those recordings, one with visible pitch and formants observed using Praat software was finally selected during objective analysis. Those words for which all five repetitions got eliminated during subjective and objective analysis as they did not satisfy one or many of the criteria during analysis were re-recorded. The entire analysis procedure was repeated for the re-recorded words. The recordings of the selected words were subjected to intensity normalization using MATLAB software R2009b. Figure 1 depicts the spectrogram of a sample word in Malayalam.

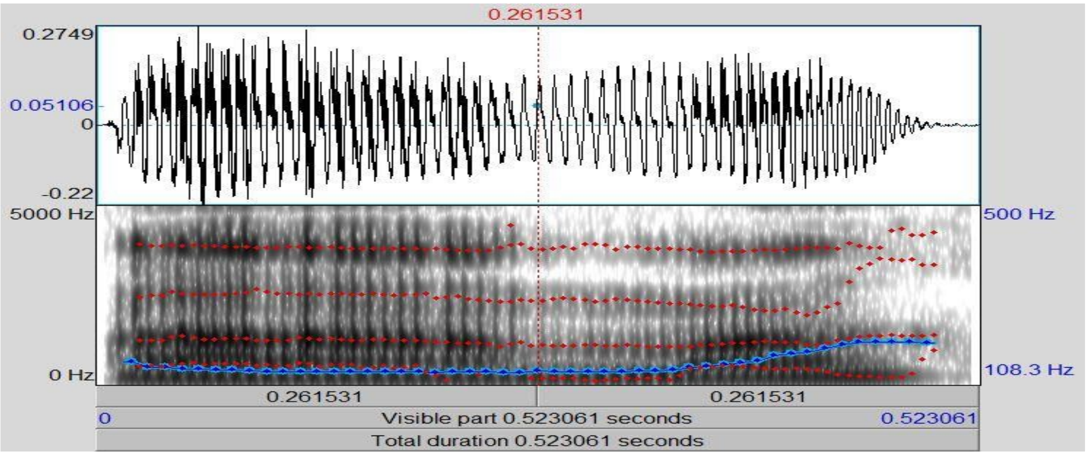

Figure 1: *Spectrogram of word /a:ma/ showing formants (red dotted line), and pitch (solid blue line).*

Separating words with dominant low-frequency energy

To further ensure that the lists do not include phonemes with high frequency energy and to separate words with predominantly low-frequency energy (<1.2 kHz) from rest of the words, F a s t F o u r i e r t r a n s f o r m a t i o n (F F T) was performed to calculate the Amplitude ratio. The ratio of energy below and above 1.2 kHz was obtained. Words with higher amplitude ratio are those with more low-frequency energy. Thus, to separate those low-frequency words, *k*-means clustering was carried out based on the amplitude ratio of the words. Amplitude cut off ratio was taken as 1.8. This resulted in separating low-frequency clusters of words from others. A total of 180 words were grouped as low-frequency words. To verify the difference in energy distribution across frequencies, Long Term Average Speech Spectrum (LTASS) was executed on the clusters of words grouped as low frequency.

Generating word lists with equal difficulty

All the low-frequency words were then presented to 25 adult native speakers with normal hearing at 5 different sensation levels (ref: PTA). SLs considered were +0, +4, +8, +12 and +16 dB. A calibrated dual-channel diagnostic audiometer, Maico MA-53, was used for screening participants' hearing and also to present the words. The recorded speech material was played using Adobe Audition Version 3.0. The signal was routed through a personal computer to the audiometer and presented through headphones, Sennheiser HD-200.

All the low-frequency words were presented at one sensation level (SL) for each participant, and at each SL data was collected from 10 participants. Further, speech identification (SI) scores were calculated using the following formula:

$$\text{SI Score} = \frac{\text{Total number of correct responses}}{\text{Total number of words presented}} \times 100$$

The SI scores obtained from the participants at each SL were averaged and tabulated. Based on the averaged scores at all SLs, psychometric functions were derived for all the words using MATLAB software R2009b. Mean sensation level where 50% SI scores occurred, and the mean slope of the psychometric functions were obtained. Words falling within ±1.5 standard deviation from overall mean and slope were accepted. These words were used to make the final word lists of 20 words each. This consisted of 110 words.

Using this word pool, the final Malayalam list was formed. These word lists were generated such that all lists had equal difficulty levels. Equality in difficulty was verified by firstly randomly selecting 20 words from 110 words, generating psychometric function curves for those words. Further, the mean level at which 50% SI scores were obtained, and the slope of the curve was found. If the mean level and slope fell within ± 1.5 standard deviations from the overall mean and slope obtained earlier, then those 20 words chosen randomly formed one final word list. The same procedure was repeated for forming the rest of the lists. Finally, a total of 5 lists with 20 words in each list were developed. Hence, these word lists developed can be called as psychometrically equivalent word lists. Appendix I provide the details of word lists developed in Malayalam

Phase II. Administration of word lists on individuals with normal hearing sensitivity

The developed test material in Malayalam was administered on 100 adult native Malayalam speakers. Speech identification scores were obtained for all the word lists separately. All the participants were in the age range of 16 to 35 years. It was ensured that all the participants had hearing thresholds within 15 dB HL at octave frequencies between 250Hz and 8000Hz and SI scores above 90% (ISHA, 1990)The participants had type "A" tympanogram with acoustic reflexes present bilaterally. Also, all the participants had bilateral TEOAEs present and more than 60% score on speech perception in noise test at 0 dB signal to noise ratio.

A calibrated dual-channel diagnostic audiometer, Maico MA 53, was used to carry out pure tone and speech audiometry. The recorded speech material was played using Adobe Audition (Version 3.0). The signal was routed through a personal computer to the audiometer and presented through headphones, Sennheiser HD-200.All the word lists were presented at 40 dB SL (ref: PTA) to 100 participants in Malayalam. To avoid ear effect, for 50 individuals, words were presented to the right ear, and for the remaining 50 participants left ear was considered for testing. An open set response in the form of verbal repetitions was obtained from all the participants. The SI scores at each SL were averaged, tabulated, and analyzed using the software Statistical Package for Social Sciences (SPSS), Version 20.

Phase III: Determining the usefulness of the test material

The low-frequency Malayalam word lists were presented to 15 normal-hearing adult native speakers with a simulated rising cochlear loss to obtain the SI scores. MATLAB R2009b and NIOSH Hearing Loss Simulator software (version 3.0.12151) were used to simulated rising cochlear hearing loss.

Table 1.

Demographic data of Malayalam speaking individuals with simulated

	Age (years)/ Gender	**Ear**	**Pure tone average (dB HL)**	**Speech Identification Scores**
1	24/M	Right	10	100
2	23/F	Left	12.5	100
3	21/F	Left	10	100
4	19/M	Right	11.25	100
5	28/M	Right	15	96
6	23/F	Left	12.5	100
7	20/M	Right	12.5	100
8	27/F	Right	11.25	100
9	26/M	Left	15	96

10	22/F	Right	15	100
11	26/M	Left	11.25	96
12	23/F	Right	10	100
13	28/M	Left	12.5	96
14	26/M	Left	11.25	96
15	27/F	Right	10	100

Using NOISH software, moderate rising low frequency hearing loss was simulated by manually setting the hearing thresholds for octave frequencies between 125 Hz to 8000 Hz. Using MATLAB software reduced frequency selectivity was added to the hearing loss simulation. The procedure followed to generate spectrally smeared output was described by Moore and Glasberg (1993). A schematic diagram of the sequence of operations used to perform spectral smearing is shown in Figure 2. That involved firstly calculating the short term spectrum using a Hamming window and an FFT. Followed by this, the spectrum was smeared, and then it was transformed back to the time domain using inverse FFT. At last, waveforms obtained from overlapping analysis frames were added to produce the final output.

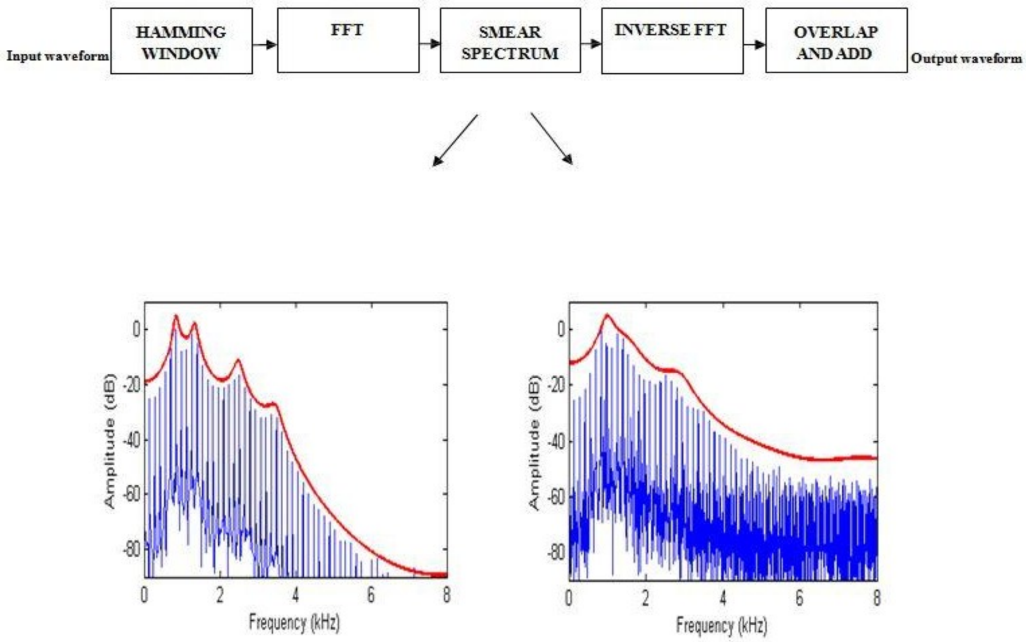

Figure 2: *Sequence of operations and LTASS of a sample word after performing spectral smearing*

The simulated low-frequency word lists (5 lists) and PB word lists were presented to 15 participants at 40 dB SL (ref. PTA). The presentations were randomized, both in terms of the order of words and lists. SI Scores were obtained using the formula given in Phase I. Further, and scores were averaged and tabulated for all the lists separately. To explore the difference in performance between individuals with normal hearing and individuals with rising cochlear hearing loss, data was analyzed using the SPSS software (Version 20).

RESULTS AND DISCUSSION

This study was carried out in three phases 1. Development of the low-frequency word lists. 2. Administration of word lists on a group on normal hearing individuals and 3. Validating the usefulness of the test material developed. The results of all the phases are provided separately in detail below.

1. Development of the low-frequency word lists

This phase involved 4 stages viz. a. Collection of words which contain low-frequency phonemes and obtaining familiarity ratings, b. Recording and selection of the best recorded words, c. Separating words with dominant low-frequency energy and d. Generating word lists with equal difficulty levels. A total of 280 bi-syllabic words with low-frequency phonemes were collected from common sources of Malayalam. A total of 180 words were grouped as low-frequency words based on FFT. After psychometric function analysis, final 100 low-frequency words were selected, which were grouped into five-word lists with 20 words in each of the lists.

Generating word lists with equal difficulty levels

One of the important considerations during the development of any speech material for testing is that the alternative forms of testing should be equivalent; that is they should produce comparable results (Gelfand, 2009). The conventional way followed to obtain equivalency between word lists developed was phonemic or phonetic balancing. However, recent researches in the field of development of speech identification materials have shown that the impact of phonetic or phonemic balancing is questionable (Martin, Champlin & Perez, 2000). Thus, to develop word lists that produce equivalent results, the following procedure considering psychometric function curves was carried out.

Using low-frequency word clusters, the results of speech identification (SI) scores obtained from 25 adult Malayalam native speakers with normal hearing at sensation levels of +0, +4, +8, +12, and +16 dB was analyzed. The SI scores were calculated, averaged, and tabulated. Based on the average scores at all SL"s, the psychometric function curves were obtained for all the words. Based on these psychometric function curves, a mean level at which 50% SI score was obtained, and the slope of function was derived. The words falling within ±1.5 standard deviation from the mean and the slope for the psychometric functions were separated. The results of psychometric tests are provided in Table 2. This consisted of 100 words with 20 words in each list. Based on the procedure explained in the method section, a total of 5 lists were developed in Malayalam.

Table 2

Results of psychometric tests at different sensation levels

Sensation level	**Mean SIS (%)**
0 dB SL	56.58%
4 dB SL	85.59%
8 dB SL	92.34%
12 dB SL	97.9%
16 dB SL	99.43%

2. Administration of the test material on individuals with normal hearing

The mean and SD of SI scores obtained at 40 dB SL in 100 individuals with normal hearing for 5 lists in Malayalam is shown in figure 3.

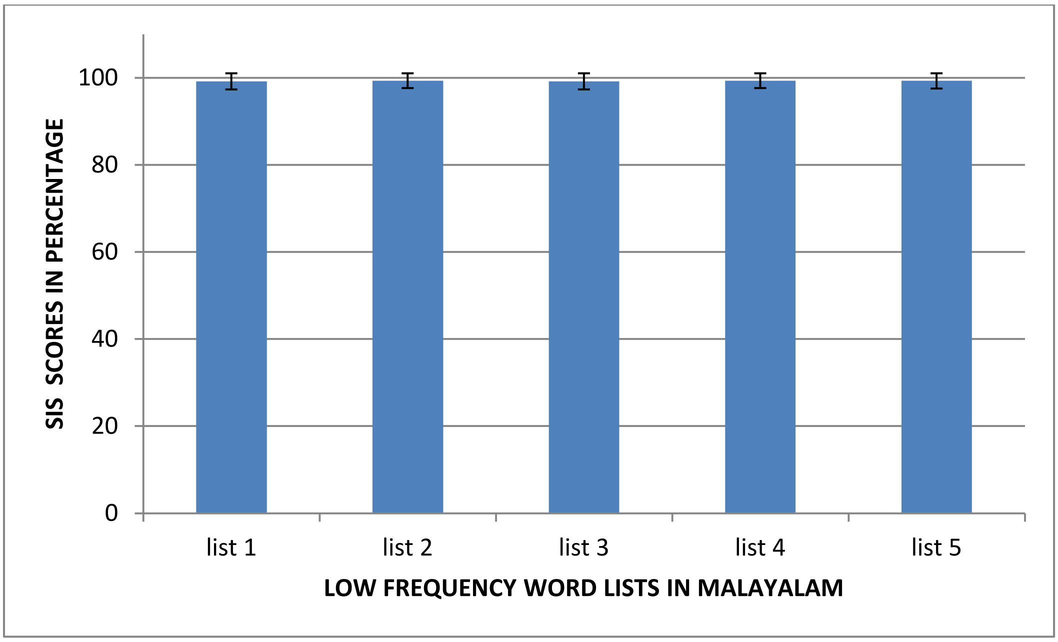

Figure 3: *Mean and SD of SI scores obtained for word lists in Malayalam at 40 dB SL*.

To study the statistical difference, data was analyzed using the software Statistical Package for Social Sciences (SPSS),Version 20..Shapiro Wilks test of normality was done in order to check whether the data is normally distributed and the results showed that the data was not normally distributed ($p<0.05$). Hence, the Friedman test was performed to compare the SIS between the five lists. The results of Friedman test revealed that there is no significant difference across the five list $\{\chi^2(4)=0.730,\ p>0.05\}$.

2. Determining the usefulness of the test material

To determine the usefulness of the developed list and Phonemically balanced , the lists were administered on 10 Malayalam speaking individuals with a simulated conditions resembling rising cochlear hearing loss using NIOSH Hearing Loss Simulator software (version 3.0.12151). Figure 4 shows the mean and standard deviation of SI scores between individuals with normal hearing and individuals with simulated low-frequency cochlear hearing loss (SLCHL). It is clear from the figure 4 that across lists, normals have outperformed SLCHL individuals.

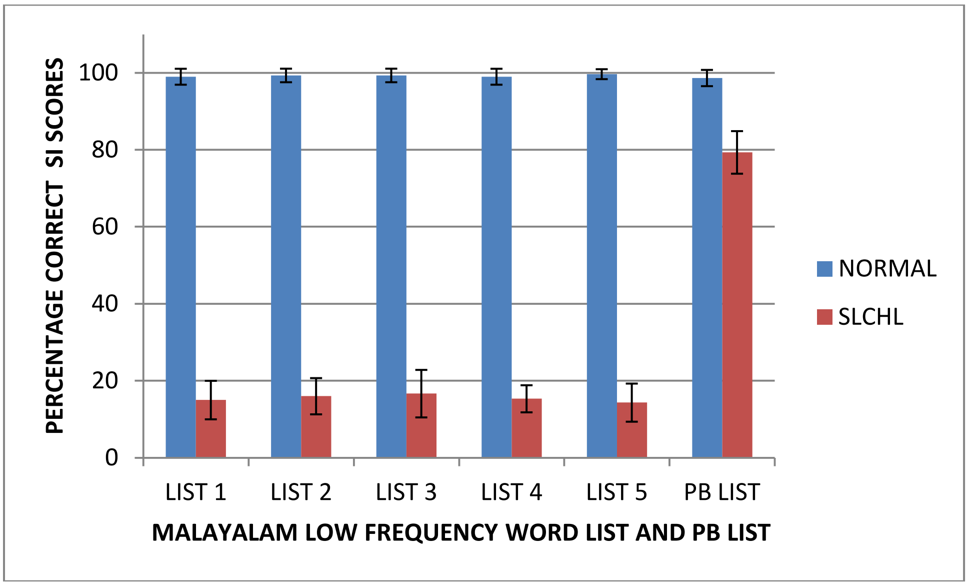

Figure 4: *Mean and SD of SI scores between normal and SLCHL group in Malayalam.*

Shapiro Wilks test of normality was done, and it showed that the data was not normally distributed ($p<0.05$). Thus, Mann-Whitney U tests were performed to compare the SIS of low-frequency word list and PB list across individuals with normal hearing and individuals with simulated low-frequency cochlear hearing loss. The results of Mann-Whitney U tests are shown in table 3.

Table 3.
Results of Mann-Whitney U Tests

LISTS	Z
LIST 1	-4.856*
LIST 2	-4.898*
LIST 3	-4.892*
LIST 4	-4.882*
LIST 5	-4.965*
PB LIST	-4.779*

Mann-Whitney test results revealed that the SIS scores for both low-frequency word list and PB list are significantly different($p<0.01$) for individuals with simulated low-frequency cochlear hearing loss from that of individuals with normal hearing. The scores obtained for PB list revealed less difference in both groups. Hence, PB list is not recommended for testing individuals with low-frequency hearing loss.

Friedman"s test was performed and the results showed a significant difference in the SIS scores across the low-frequency word lists and PB list in individuals with simulated low-frequency cochlear hearing loss [$\chi^2(5)=35.688$, $p<0.01$]. As Friedman tests revealed significant difference, Wilcoxon signed-rank tests were further administered to compare significant difference in the SIS between the five lists and PB list. The results of Wilcoxon signed rank test are shown in table 4.

Table 4.
Results of Wilcoxon signed rank test

	LIST 2	LIST 3	LIST 4	LIST 5	PB LIST
LIST 1	-1.089	-.895	-.166	-.074	-3.592
LIST 2		-.406	-.656	-.635	-3.496
LIST 3			-.951	-.763	-3.496
LIST 4				-.211	-3.592
LIST 5					-3.463

Low-frequency wordlist was developed in other languages such as Hindi, Kannada (Barman et al., 2016), and Manipuri (Konadath & Nigombam, 2014). Hindi low-frequency word list contains ten lists with 25 words in each, and Kannada contains 7 with 25 words in each. The present study also followed the same methodology except that the words collected at the initial phase contain prominent low-frequency phonemes. However, the SIS obtained by simulated low-frequency cochlear hearing loss individuals for Hindi, Kannada, and Manipuri low frequency word list was better than that of Malayalam. This difference could be due to various factors such as the difference in the method of the study as in present study we have collected words which contains predominant low frequencies (stops, semivowels & vowels) before proceeding with other objective test methods and another factor will be the language tested, as Malayalam has more weightage for low frequencies (Narne et al.,2016) the filtering out of low-frequency content would have made a negative impact on the overall perception of the speech signals.

The scores obtained for PB list and low frequency wordlist by Simulated low frequency cochlear hearing loss individuals show significant difference. The probable reason for this difference might be that phonemically balanced list contains phonemes (high and mid) other than low frequency, which is audible and understandable by individuals with low-frequency hearing loss.

CONCLUSIONS

The present study was conducted in three phases; during the initial phase the low-frequency range word lists were developed. It was followed by normalizing the test material by administering it on individuals with normal hearing sensitivity. The final phase was to determine the usefulness of the test material by administering it on 15 Individuals with simulated cochlear low-frequency hearing loss. In total, five low frequency word lists were developed. The study also validated the list on individuals with simulated low frequency cochlear hearing loss and recommends the use of these standardized word lists on clinical population to tap their difficulty in understanding low frequency information and these word lists can also be used for selecting appropriate hearing devices for individuals with low-frequency hearing loss.

Further, studies can be taken up to validate the use of this speech material on other clinical population also.

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Appendix - MALAYALAM LOW FREQUENCY WORD LISTS

Sl No.	List 1	List 2	List 3	List 4	List 5
1	ബലം	ബാണം	ദാനം	കഥ	ലാഭം
2	ആമ	കല	നട	മാല	ഭാരം
3	പക	മമാഹം	വക	നാണം	ഗുഹ
4	മരാമം	ഗുരു	മമഘലം	ഗന്ധം	ഗാനം
5	വണ്ണ◌ം	ആന	കാക്ക	പാപം	പണം
6	ഒപ്പ◌ം	നന്□	അമ്മ	ഭ്◌ഭ◌ാന്ത ◌ം	ഭാവം
7	മഠം	അക്കം	നുണ	ദീപം	കുട
8	കൂടട	പന	പാവ	വാതം	നന്ദ◌ി
9	നാഥ	വാഴ	വട	തല	ടമാത്തം
10	മലാകം	തുട	കക്ക	പുക	ഊമ
11	ഊഴം	ഭാവം	മമാണ	ഉപ്പ	ക◌ാന്ത ◌ം
12	മകാപം	പത	കുടം	പാകം	തൂമ്പ
13	മതി	ഓല	അവൻ	മണം	നാമം
14	വന്ന◌ു	കാലം	ദിനം	ഗുണം	വനം
15	കാത്തു	ബ◌ുദ്ധ◌ി	പാപി	ടമത്ത	പ◌ുതപ് പ◌്
16	മാല	ദാഹം	ബന്ധു	നടൻ	പടം
17	അന്ന◌ം	മഞ്ഞ	പാലം	മകൻ	പാവം
18	മുഖം	കപ്പ	മതാന്നൽ	തണുപ്പ്	തുണ
19	കഞ്ഞ◌ി	മവഗം	മല	ഭ്◌ഭമ◌ം	ദൂരം
20	കളം	ദനം	പദം	മീനം	ഭംഗി