Development of Low Frequency Word List in Nepali Language

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ALL INDIA INSTITUTE OF SPEECH AND HEARING
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Dedicated to

My Mom, My Dad

and my Guide

CERTIFICATE

This is to certify that this dissertation entitled "**Development of Low Frequency Word List in Nepali Language**" bonafide work submitted in part fulfillment for the degree of Master of science (Audiology) of the student (Registration No: 16AUD005). 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 or any other diploma or degree.

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DECLARATION

I hereby declare that this dissertation entitled "**Development of Low Frequency Word List in Nepali Language**" is the result of my own study under the guidance of **Dr.Prashanth Prabhu**, Reader Audiology, Department of Audiology, All India Institute of Speech and Hearing, Manasagangothri, Mysore and has not been submitted earlier to any other university for the award or any other Diploma or Degree.

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Abstract

Speech audiometry can tell us, in a more realistic manner than with pure tones, how an auditory disorder might impact communication in daily living. Regular speech identification test would be insensitive towards identification of the problem of a person with low frequency hearing loss. There are limited speech materials developed to assess low frequency hearing loss in individuals who speak Nepali language. The aim of the study was to develop low frequency word lists in Nepali 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 short listed based on familiarity ratings given by native speakers. Those words were then recorded 5 times each by a native male speaker. Subjective and objective analysis was performed in order to obtain best recorded words. Further, 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 rest of the words. Psychometric function curves were obtained by calculating mean sensation level at which 50% SI scores to develop equally difficult wordlist As a result, a total of 10 low frequency Nepali word lists were developed. In second phase, lists were normalized by administering it on 100 native Nepali speakers with normal hearing sensitivity. During the final phase, developed lists were validated on 10 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.

Chapter 1

Introduction

Most common mode of communication in humans is through verbal mode. Verbal language is learned mainly through perceiving the speech surrounding of the person and practicing. Speech perception is a specialized aspect of a general human ability, the ability to seek and recognize patterns. These patterns are in acoustic form, used as cues to perceive speech. The cues are redundant, which permits speech perception to take place under difficult conditions. Speech sounds have come to occupy a pivotal place among the auditory stimuli that are used in clinical audiometry. Speech audiometry refers to procedures that use speech stimuli to assess auditory function (Wilson, Margolis, Konkle, & Rintelmann, 1983). Since the classic work of Carhart (1951), speech audiometry has involved the assessment of sensitivity for speech as well as assessment of clarity when speech is heard. These concepts were described by Plomp (1978), in his framework of hearing loss, as an audibility component (i.e., loss of sensitivity) and a distortion component (i.e., loss of clarity). Speech audiometry is a key component of audiological assessment. Because it uses the kinds of auditory signals present in everyday communication, speech audiometry can tell us, in a more realistic manner than with pure tones, how an auditory disorder might impact communication in daily living. Also, the influence of disorder on speech processing can be detected at virtually every level of the auditory system.

Researcher has suggested that speech understanding cannot be accurately predicted based upon pure tone threshold (Martin, & Clark, 2011). An individual with relatively poor pure tone threshold may perform surprisingly well on speech understanding tests, where in some person with relatively good or even normal pure tone threshold may have poor performance in speech understanding tests (Martin, & Clark, 2011). So speech audiometry gives more diagnostic information then provided only by pure tone audiometry. Hence, it is logical that speech audiometry also be included as a part of hearing assessment (Martin, & Clark, 2011).

Speech audiometric measures are used routinely in an audiological evaluation and contribute in a number of important ways, including:

- Measurement of threshold for speech,
- Crosscheck of pure-tone sensitivity,
- Quantification of suprathreshold speech-recognition ability,
- Assistance in differential diagnosis,
- Assessment of auditory processing ability, and
- Estimation of communicative function.

Speech audiometry tests like speech detection threshold (SDT), Speech reception/recognition threshold level (SRT), Speech identification score (SIS), most comfortable loudness level (MCL), uncomfortable loudness level (UCL) etc. are the most commonly used speech tests.

A person with a hearing loss will have difficulty in perception of speech. The kind and degree of perceptual difficulty depends on several factors. These include the degree of hearing loss, the type of hearing loss and the configuration of the audiogram (Gardner, 1971; Jerger & Jerger, 1971; Lacroix, Harris, & Randolph, 1979; Owens & Schubert, 1977; Pascoe, 1975). 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 (< 1KHz) 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 (Djupesland, Flottorp, Degre, Stien, & Skrede, 1979; Opheim & Flottorp, 1957), viral infections (Djupesland et al., 1979) and also with various retrocochlear lesions (Tore Lundborg, 1955).

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, Mengel, & Berlin, 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. The perception of speech at low frequencies will be affected in individuals with rising type of hearing loss. However, there are limited speech materials only with low frequencies to assess unaided and aided speech perception in individuals with low frequency hearing loss.

1.1 Need for the study

Speech is a stimulus of high redundancy because of the information in it is conveyed in several ways simultaneously (Martin, Armstrong, & Champlin, 1994). Hearing loss involving only the part of the frequency range may go undetected in a speech test which is not carefully controlled. A standard speech test can give reasonably accurate prediction of the best hearing threshold levels in the mid frequency region of the auditory range. However, the use of a regular speech identification test would be insensitive towards identification of the problem of a person with low frequency hearing loss. Thus, it is essential to have a speech test material having only low frequency speech sounds.

There are high frequency speech identification tests developed by Ramachandra (2001) for Hindi and Urdu speakers, Mascarenhas (2002) in Kannada, Sudipta (2006) in English, Sinthiya (2009) in Tamil, Ratnakar (2010) in Telugu which can assess the communication ability of individuals with high frequency hearing loss. However, there is limited test material which can be used to assess the communication ability of individuals with low frequency hearing loss.

In India, low frequency word lists are developed in Hindi (Barman et al., 2016) and Kannada (Barman, Narne, Prabhu, Singh, & Thammaiah, 2017). Barman et al., (2017) aimed to develop, standardize and validate low frequency bi-syllabic wordlists in Kannada, a South-Indian language. They developed 7 lists in which each list had 25 low frequency words. They collected bi-syllabic familiar words, recorded them and selected the words with dominant low frequency energy by acoustical (Fast Fourier) transform and statistical means (k-means clustering) then generating equivalent word lists using psychometric function. All the wordlists developed were normalized through estimation of speech identification scores in 100 individuals with normal hearing and through re-verification of equivalence of wordlists' difficulty level by obtaining psychometric function. The developed word lists were evaluated for usefulness by administering them along with conventional phonemically-balanced Kannada wordlist on 10 individuals with cochlear hearing loss having rising audiometric configurations (i.e. more loss at lower frequencies). Rojina (2014), developed in low frequency word list in Manipuri language. The study was conducted in two phase one is development of low frequency word lists and administering the developed test materials on individuals with normal hearing. They developed 2 word lists of 20 word on each list.

Similar procedure was also used in developing low frequency word lists in Hindi (Barman et al., 2016).They developed 10 word lists with 25 words in each list. The word list was also normalized on 100 Hindi speakers at 40 dB SL and also during the final phase, developed lists were validated on 10 participants with simulated low-frequency cochlear hearing loss. Hearing loss was simulated using National Institute for Occupational Safety and Health (NIOSH) software. The results of validation revealed that auditory low-frequency word lists were sensitive enough to tap the speech understanding difficulty in the simulated condition.

Nepali is spoken by a large group of population across the world and it is essential to develop word lists even in Nepali language. Lal (2012) developed test for speech identification in Nepali which is useful in determining the communication problems of children with flat frequency hearing loss. However, there are limited speech materials developed to assess low frequency hearing loss in individuals who speak Nepali language. Thus, there is a need to develop low frequency word lists in Nepali.

In order to select appropriate hearing aids for individuals with low frequency sensorineural hearing loss, it is essential to use a test which 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 list is used in individuals with rising hearing loss. Thus, it is essential to develop low frequency word list which would help in rehabilitation of Nepali speaking individuals with low frequency hearing loss.

1.2 Aim of the study

The aim of the study was to develop low frequency word lists in Nepali language.

1.3 Objectives of the study

- To develop low frequency word lists in Nepali to determine speech identification scores in individuals with predominantly low frequency hearing loss.
- To administer the developed material in normal hearing adults who are native speakers of Nepali.
- To check the equality of the different lists that is developed.
- To administer the test on a group of individuals with rising type of audiogram pattern/simulates low frequency hearing loss to check its utility.

1.4 Null hypotheses

- There is no significant difference between the list in normal hearing group and individual with low frequency hearing loss,
- There is no significant difference in speech identification score for all the lists between normal hearing group and low frequency hearing loss group.

Chapter 2

Review of Literature

In the process of assessing the hearing, if speech stimulus is used it is classified as speech audiometry. The diagnostic importance of traditional speech audiometry is extremely limited. If measurement is restricted to the traditional combination of spondee threshold and "PB max" at a single suprathreshold level, the performance discrepancy within distinct diagnostic categories will be exaggerated that there is a real problem of overlying ranges. Speech tests are intended to deliver more useful diagnostic information. The test battery comprises of performance intensity (PI) functions for both synthetic sentence identification (SSI) task and phonemically balanced (PB) monosyllables (Jerger & Hayes, 1977).

It has been documented that pure tone thresholds cannot accurately predict ability of understanding. Either clinically or day-to-day a person may perform well for a speech understanding task, even though the person has poor pure tone threshold. Alternatively, a person may reports of having difficulty hearing and comprehending speech, or may show unpredictably reduced speech discrimination score in a clinical setting in spite of having relatively good or normal pure tone thresholds. It is always essential to correlate to pure tone results with speech audiometry findings (McGrath & Summerfield, 1984).

2.1 Importance of Speech Audiometry

Speech recognition assessment is an important tool in diagnostic audiology as it measures listener’s ability to understand speech and provides some estimate of degree of communication handicap created by hearing loss. Speech recognition score helps an audiologist in validating the results of the pure tone audiometry, differentiating between cochlear and retrocochlear disorders; success of different types of medical and surgical intervention; in selecting amplification devices; in determining the cochlear implant candidacy; in planning aural rehabilitation, as well as monitoring performance throughout the intervention process (Waghmare, Mohite, & Gore, 2011).

Speech tests can thus be used diagnostically to inspect processing ability and the manner in which it is affected by disorders of peripheral from the middle ear, cochlea, auditory nerve to central system; brainstem pathways, and auditory center in the cortex. In addition, a person's hearing for pure tones and hearing for speech has predictable relation. Consequently, speech testing can be used for validation pure-tone testing. Young children usually react poorly to pure tone but can react more effortlessly to the presentation of speech materials. As a consequence, threshold estimation for speech recognition are first choice for children to provide the audiologist direction in establishing pure tone thresholds.

In adults, speech testing is a sensitive indicator of a retrocochlear disorder which is indicated by poor performance at suprathreshold level, even in the presence of normal hearing sensitivity. A detailed assessment of speech recognition in these patients may assist in the diagnosis of neurologic disease. The actual communication difficulty cannot be predicted by pure tone audiometry, as it always underestimates the problem and supra threshold speech audiometry can provide pivotal information for estimating the amount of hearing impairment resulting from the disorder.

2.2 Importance of different frequency speech material

2.2.1 High Frequency energy

Information in the frequencies above 2000 Hz are significant while perceiving the speech in the presence of noise. (Kryter, Williams, & Green, 1962). The auditory cues above 2 KHz are essential for discriminating words in isolation which cover high frequency phonemes (Sher & Owens, 1974). Pascoe (1975) advocated that the frequency from 2500 Hz and 6300 Hz have a significant consequence on word recognition, predominantly in the existence of background noise.

Fricatives have the highest spectral peak in comparison to other phonemes (affricates, nasals, Plossives, semivowel and liquid) when analyzing voiceless consonants from samples of adult. Though other voiceless phonemes have less marked peaks in their individual spectra, they have important spectral energy located at higher frequencies with rising spectral slope above 1600Hz (Kuk, Keenan, Korhonen, & Lau, 2009). Hence, in order to perceive speech one should have good auditory integrity at all frequencies.

Speech identification assessments should measure the individuals' ability to understand speech, and provide some estimate of the degree of communication disabilities caused by hearing loss (Waghmare et al., 2011). However, many individuals with sensorineural hearing loss often do not manifest reduced speech identification performance when assessed with conventional speech identification tests.

In a study done on 2867 children found 7.6% had high frequency slopping sensorineural hearing loss (HFSHL) (Johnson, Tabangin, Meinzen-Derr, Cohen, & Greinwald, 2016) also it was found that 9.3% of children, adolescents, and young adults had high-frequency hearing loss after exposure to loud music (le Clercq, Van Ingen, Ruytjens, & van der Schroeff, 2016).

The HFSHL is the most challenging configurations that audiologists face (Stelmachowicz, Pittman, Hoover, Lewis, & Moeller, 2004). Individuals with HFSHL would have difficulties largely in comprehending speech sounds which have energy concentration in the higher frequency regions i.e. above 1000 Hz (T Lundborg, Risberg, Holmqvist, Lindström, & Svärd, 1982; McDermott & Dean, 2000) . Hence, they have more difficulties in perceiving voiceless consonants (Gardner, 1971) since voiceless consonants have spectral energy above 1000 Hz (Kuk et al., 2009) , and contain little acoustic energy than voiced consonants in average rapid conversation . In addition individuals with SHFHL would have difficulties in perceiving vowels /i/ and /e/ as their second and third formant frequencies (F2 and F3) are higher than that of other vowels (Cooper, Delattre, Liberman, Borst, & Gerstman, 1952).

2.2.2 Low Frequency energy

Audibility of weak low frequency sounds can be achieved by increasing gain in the low frequency area which consequences in improvement of sound quality and increase in loudness. Speech perception was enhanced when lower to mid frequency additional amplification was given to individual with severe to profound sensori-neural hearing loss (Turner & Brus, 2001). Studies have shown that cues for recognition of fundamental frequency (F0) lies in lower frequency region (Brown & Bacon, 2009). Especially in the situations when speech and noise are not spatially separated, extraction of speech in noise requires F0 cues (Carroll, Tiaden, & Zeng, 2011). In support, Jin and Nelson (2010) reported that individuals with higher degrees of loss at lower frequencies have greater difficulty segregating speech from competing background noise. In addition, surprisingly, previous research from our lab indicated that, in South-Indian languages like Kannada, information below 1.2 kHz (i.e. at lower frequencies) results in around 70% Speech Intelligibility (Avilala, Prabhu, & Barman, 2010). However, the cut-off frequency for obtaining the same SI performance in English has been reported to be higher (Bornstein, Wilson, & Cambron, 1994).

Studies have shown that low to mid frequency information are important on sentence recognition and also found that those listeners with higher degree of hearing losses in the low frequencies performed poorer in understanding interrupted sentences (Jin & Nelson, 2010). Also, low to mid frequency hearing thresholds accounted for most of the variability in perception of speech in the presence of noise (a masker) for listeners with hearing impairment. Based on these findings, they concluded that low-frequency information within speech plays an important role in segregating speech from competing background noise. Providing low to mid frequency additional amplification to people with severe-to-profound sensorineural hearing loss has been shown to improve their speech comprehension abilities (Turner & Brus, 2001). Gantz et al. (2005) studied the benefit of a hybrid cochlear implant on 21 patients and found a significant improvement in speech understanding in noise over standard cochlear implant participants (Gantz, Turner, Gfeller, & Lowder, 2005). They concluded that low-frequency hearing is important for speech perception, especially in noise.

Further, it has been reported that the importance of frequency for speech perception is language-dependent. That is, in certain languages more weighting is given to low frequencies in understanding speech. Avilala et al.(2010) examined the filtering effect of monosyllables and words on speech perception in 30 normal healthy adults. They revealed that in Kannada, a south Indian language, the low-pass cut-off frequency for words at which 70% speech identification scores were acquired was at

1200 Hz, which is slightly lower than the cut-off frequency (1500 Hz) reported for English words (Bornstein et al., 1994).

Owing to the diversity and the varying underlying pathology of auditory disorders, it is reasonable to speculate that speech perception of different clinical populations is different. One set of patients may have good speech perception abilities at high frequencies while another may be at lower frequencies. Factors underlying their varying capacities may be the degree of hearing loss, configuration of hearing loss, or the underlying pathology itself. For instance, Prabhu et al. (2011) studied the speech perception abilities of persons with auditory neuropathy and found that speech understanding scores was poorer for low-pass filtered words in comparison to unfiltered words. Low-pass filtered words was recommended as a tool for accurately assessing speech perception difficulties in ipersons with auditory neuropathy.

The impacts of low frequency acoustic information in cochlear implant individueal with sharply sloping hearing loss or in normal hearing individuals were evaluated by simulating this type of hearing loss. These investigation have prescribed that the benifit of consolidated electric and acoustic stimulation is a result of the F0 cue existent in the low-frequency acoustic signal (Brown & Bacon, 2009; Cullington & Zeng, 2008). They have inspected the role of various F0 prompts in simulated electro-acoustic- stimulation then they conclude that together amplitude and frequency modulation information added to the consolidated hearing benefit. Low frequency cue cochear implantation simulation, concluded contradictory results in that Frequency modulation doesnot provide extra benefit while comparing with flat F0 contour, signifying that only the presence of voicing may reason for the mutual hearing benefit (Kong, Stickney, & Zeng, 2005).

For both real implant processing and simulated hearing, the additional low-frequency acoustic stimulation generally augment sspeech understanding, mostly when attending to speech in the presence of competing signal (Dorman, Spahr, Loizou, Dana, & Schmidt, 2005; Kong et al., 2005; Turner, Gantz, Vidal, Behrens, & Henry, 2004). The assistance of electric-acoustic stimulation (EAS) arises even when the acoustic stimulation alone provides slight or not any intelligibility. Many study have could not explore fully about the auditory processing or acoustic cues underlying this effect but they have suggested that listeners adds relatively weak pitch information provided by the electric stimulation along with the robust pitch cue from the talker's fundamental frequency(F0). They use the low-frequency acoustic region to segregate target and background signal (Assmann et al., 1999; Assmann & Summerfield, 1990; Brokx & Nooteboom, 1982; Chang, Bai, & Zeng, 2006; Kong et al., 2005; Qin & Oxenham, 2006).

Recent studies have revealed that fundamental frequency (F0) is expected to play an pivotal role independent of any role that the first formant might play. Adding to vocoder stimulation of low-pass speech of 300 Hz, which itself should not comprise much if any first formant information (Hillenbrand, Getty, Clark, & Wheeler, 1995) or yield any intelligibility, improved speech intelligibility in a competing background signal (Chang et al., 2006; Qin & Oxenham, 2006). However, the question remains of what low-frequency cues are responsible for the EAS effect. In another study, simulated EAS conditions, and found that voicing and amplitude envelope information provided benefit over vocoder alone (Kong et al., 2005). On the other hand, F0 cues provided no additional benefit at any SNR tested. They argued against F0 as a cue for segregation, and suggested that, in addition to the voicing cue, the amplitude envelope may help listeners by indicating when to listen or “glimpse” the target.

2.2 Speech perception in individuals with different types of hearing loss

Functional and anatomical integrity of the peripheral and central auditory structure also an acoustically appropriate communication context is vital in recognition of speech. Speech perception is a robust process for listeners with normal hearing. It is possible to follow a conversation without having to lip read in background noises that contain as much energy as the speech and in rooms where echoes take more than a second to die away. Serious difficulties are not encountered until the noise contains about four times as much power as the speech (i.e. The signal-to-noise ratio, SNR, is 6 dB), or until the reverberation time exceeds five seconds. However, the majority of people with moderate sensorineural hearing impairment find it impossible to understand speech in such circumstances. To achieve an adequate level of understanding in noise, they may require the SNR to be improved by 5-10 dB, and by a further 3 to 6 dB in rooms where there is noticeable reverberation. Often, it is difficulties experienced in such circumstances that first alert listeners to their hearing impairments, rather than problems in detecting faint sounds in quiet or anechoic environments. Sensorineural hearing impairments acquired in adulthood constitute the vast majority of hearing losses. The adjectives 'moderate', 'severe', and 'profound' will be used here to describe average reductions in sensitivity to pure tones between 500 Hz and 4 kHz of 30-50, 50-70, and 70-90 dB, respectively. Although in someelderly impaired listeners difficulty in understanding speech is exacerbated by a reduced ability to exploit a knowledge of the structure of language to interpret acoustic speech patterns, the major problems stem from the distortions introduced by impaired peripheral auditory analysis (Moore, Tyler, & Marslen-Wilson, 2008)

Extent of speech difficulty depends on the degree and configuration of hearing loss. Individuals with mild to moderate hearing loss do not have much problem in understanding speech in quiet situation, but have difficulty understanding speech in background noise whereas individual with severe to profound hearing loss generally have severe problem of understanding speech in both quite and noisy situation (Moore, 1998). Individuals with low frequency hearing loss also demonstrated poor speech recognition performance when low pass filter were used (Thornton & Abbas, 1980). Speech perception ability also varies according to the configuration of hearing loss. Age-related hearing loss tends to be sensorineural, high-frequency and bilateral. It is associated with reduced speech recognition and discrimination, particularly in background noise and adverse listening conditions (Bilger & Wang, 1976; Boothroyd, 1984; Moore, 2003). Low-frequency and flat hearing loss configurations are less common and typically have less impact on speech perception. More generally, the more severe the hearing loss, the greater the impact on speech perception (Boothroyd, 1984). Vowel perception tends to be more resistant to hearing loss than consonants, with consonant place cues being more impacted than manner cues followed by voicing cues (Bilger & Wang, 1976; Walden & Montgomery, 1975).

2.4 Speech perception in individuals with low frequency hearing loss

Low frequency hearing loss is defined as a hearing loss most pronounced for the frequency range below 2 kHz and 20 dB or more (Thornton & Abbas, 1980). Low frequency hearing loss is hereditary or genetic in origin. Heterozygous mutations in the WEST gene are responsible for autosomal dominant low frequency hearing loss at

DFNA6/14 locus (Cryns et al., 2003). An inherited low frequency sensorineural hearing loss is reported to be due to otosclerotic changes in the cochlea (Schuknecht & Kirchner, 1974). Several conditions like Meniere's disease that influence the integrity of hair cells in the apex part of the cochlea (Opheim & Flottorp, 1957). Viral infections (Djupesland et al., 1979), sudden hearing loss, renal failure, poor cochlea development and congenital cholesteatoma are mainly associated with low frequency hearing loss. Many studies on the prevalence of different configurations of hearing loss have been done. Out of 2526 young adults, 16% had high frequency hearing loss and 5% had low frequency hearing loss (Rabinowitz, Slade, Galusha, Dixon-Ernst, & Cullen, 2006). Further, A US based study which analyzed the database of academic health center audiology clinic (Margolis & Saly, 2008). Results showed that the prevalence of sloping hearing loss was 40%, which was followed by flat hearing loss of 16% and rising hearing loss of 3% which was the less common. Hence, on studying the prevalence of low frequency hearing loss it is observed that occurrence of low frequency hearing loss is less compared to a high frequency hearing loss.

Identification of low frequency is not easy task because it shows comparatively symptom free (Young, Reilly, & Burke, 2011). An individual with a moderate low frequency hearing loss will not show any hints of hearing loss. One reason of why low frequency hearing loss does not show hints of hearing loss is low frequency details may likewise carried through temporal coding by the high frequency fibers. Besides, low frequency sounds do not have much information as in the high frequency sounds and individuals with hearing in the middle and high frequencies usually make up for the sounds which are in the lower frequencies. Although they do not exhibit much problem, they still have problems in difficulties understanding speech in groups or in noisy environments (Young et al., 2011).

Rosenthal, Lang, and Levitt (1975) studied to determine the relative contribution to the consonant reception of auditory cues contained in the low frequencies of the speech signal. A split band technique was used where the low frequency band (LR) was added to the high frequency band (HB). Three low frequency bands, 55-110 Hz, 110-220 Hz and 220-440 Hz were used. Two listening modes, monotic and dichotic were used. They showed each of the low frequency bands improved the articulation score significantly when added to the high frequency band. The improvement was greatest for the highest of the three low frequency bands and smallest for the lowest band since the contribution to intelligibility per unit bandwidth is less for the lowest frequency band than for the next highest frequency band. Simultaneous presentation of HB and LB decreases the percent of error for all sound types except glides /w/, /r/ and /j/, greatest improvement seen for nasals and substantial improvement in the perception of the voiceless plosives, voiced plosives and lateral sounds.

Thornton and Abbas (1980) studied to determine whether low frequency stimuli were being detected by low frequency or high frequency nerve fibers and also speech discrimination under conditions of filtering and masking selected to contribute information on the perception of speech encoded by high frequency nerve fibers. Four individuals of moderate low frequency sensorineural hearing loss participated in the study. Psychophysical tuning curve and masking of a variable frequency probe by a high level, fixed frequency, and pure tone masker were used. A low pass cutoff of 1500 Hz and high pass cutoff of 3000 Hz were employed. Speech discrimination performance under all conditions of filtering and masking were compared. Low pass scores for individuals of low frequency hearing loss were greatly diminished when low pass filtered at 1500 Hz was used and the addition of high frequency noise further decreases the scores. Results interpreted evidenced that low frequency information close to threshold were being sensed by high frequency fibers in three of the participants and the less influence of high frequency fibers for the perception of low frequency speech stimuli.

Turner and Brus (2001) studied speech recognition in person with a low frequency dead region, which diagnosed on the basis of Psycho acoustic tuning curves with upward shifted tips. Different speech materials like monosyllabic words, sentences and nonsense syllables were used. Two conditions which are unfiltered and law pass cut off frequency of 1000 Hz was used for all the stimulus materials. For unfiltered conditions they reported that all the individuals performed very well in speech recognition task which were almost 100% score when speech was delivered at moderate intensity level, whereas, when speech stimulus processed with low pass filter. The performance score of all hearing loss individuals reduced to below that of normal individuals. When the score of filtered sentence stimuli was compared with filtered monosyllabic words, the scores of filtered sentences were much higher than monosyllabic condition and it reflects the increased amount of linguistic and contextual information which are available in sentences.

Halpin, Thornton, and Hasso (1994) measured word recognition on 14 individuals with low frequency hearing loss. CID W-22 wordlists were used and measured speech recognition scores. They reported that speech identification scores were lesser (10% to 88%) for the individuals with dead region than another group without having dead region (84% to 100%). They derived that for broadband speech stimuli, subjects who have low frequency dead region extracted very less or no information from low frequency constituents of speech.

Turner and Brus (2001) studied the benefits of low frequency speech audibility for listeners with sensorineural hearing loss in that frequency region. Eighteen subjects participated in the study and the most of the subject were having pure tone thresholds lesser than 20 dB HL for the frequencies of 1000 Hz and below. Six consonant vowel (CV) lists and six vowel consonant (VC) speech materials were used. The vowels were /u/, /i/, /a/ and consonants phonemes were /b/, /t/, /d/, / ʒ/ /z/ /f/,/g/,/k/,/l/,/m/,/h/,,/m/ ,/h/, /n/,/p/,/r/,/ ʃ/ /v/,/w/,/y/,/ θ/ and / ð/ . Speech materials were low pass filtered speech with cutoff frequencies of 560, 700, 900. 1120, 1400. 2250 or 2800 Hz. Speech intelligibility index (SIT) was used to quantify the audible speech information available for each subject for different filter settings. They got hearing impaired listeners performed more poorly than the individuals with normal hearing for equivalent degrees of audible speech information. When speech information at 2800 Hz and below were used, efficiency values for the hearing impaired were less than 1,0, indicating they did not receive benefit from audible speech and also participants who had severe degree of hearing loss scored poorer than the smaller amount of hearing loss in perceiving place of articulation.

Kumar and Yathiraj (2009) studied the Perception of filtered speech, in which various simulated configurations of hearing loss (rising ,flat, sharply falling and gradually falling configuration) in normal hearing individuals. 30 normal individuals, 16 females and 14 males were participating in the study. Four phonemically balanced monosyllabic word lists; each having 25 words was used. Three lists were modified acoustically to represent various audiogram configurations. Voicing errors where maximum in rising type of configuration. Errors were extra evident amongst fricatives followed by stops. It was observed that the voicing bars that are main in the lower frequencies were excluded in the rising type of configuration

Avilala et al., (2010) invistagated the consequence of filtered speech on the perception of speech in 30 Kannada speaking normal hearing adults. Speech identification scores were obtained by sing Kannada phonemically balance word list by Yathiraj and Vijayalakshmi (2005). Frequencies of 800, 1200, 1500 and 1700 Hz was used as low pass cutoff and frequencies of 1700, 2100, 2500 and 3000 Hz were used as high pass cutoff in their study. They reported that spectral cues from 1200Hz to 2100 Hz are pivotal for the perception of speech in Kannada normal hearing adults. They also reported the divergence in scores between low pass cut off frequency of 1500 Hz in English with 1200 Hz in Kannada which could be due to the high proportion of low frequency information in Kannada language.

Prabhu et al., (2011) studied speech perception capacities for spectrally revised speech signals in persons with auditory neuropathy spectrum disorder. PB word lists were utilized for spectral modification to get the speech identification scores. Low pass cutoff frequency of 1700 Hz and high pass cutoff frequency of 1700 Hz was used to filtering the wordlist. 30 adult with normal hearing sensitivity and 12 individuals with acquired auditory neuropathy spectrum disorder were participated in the study. Speech recognition scores were calculated and three trials was given to each (unfiltered, 1700 Hz low pass and 1700 Hz high pass filtered) to every ear. It was reported that in individuals with auditory dys-synchrony, scores for 1700 Hz high pass filtered words are comparable to scores for unfiltered words; but. Steep drop in scores was found for 1700 Hz low pass cutoff filtered words. The reduced speech identification scores in individual with auditory neuropathy spectrum disorder could be credited to poor frequency discrimination abilities (Zeng, Kong, Michalewski, & Starr, 2005) .

In India, low frequency word lists are developed in Manipuri (Rojina, 2014) Hindi (Barman et al., 2016) and Kannada (Barman et al., 2017). In Kannada word lists, they aimed to develop, standardize and validate low frequency bi-syllabic wordlists in Kannada, a South-Indian language. They developed 7 lists in which each list had 25 low frequency words. They collected bi-syllabic familiar words, recorded them and selected the words with dominant low frequency energy by acoustical (Fast Fourier) transform and statistical means (k-means clustering) then generating equivalent wordlists using psychometric function. All the wordlists developed were normalized through estimation of speech identification scores in 100 individuals with normal hearing and through re-verification of equivalence of wordlists' difficulty level by obtaining psychometric function. The developed word lists were evaluated for usefulness by administering them along with conventional phonemically-balanced Kannada wordlist on 10 individuals with cochlear hearing loss having rising audiometric configurations (i.e. more loss at lower frequencies). Rojina (2014) developed a low frequency Manipuri language which aimed to develop low frequency monosyllabic word list for administering speech identification test. They have conducted the study in two phase one is development of low frequency word lists and administering the developed test materials on individuals with normal hearing. They collected 221 monosyllabic words and familiarisation was done and 194 words were selected and then 2 word list of 20 word on each list was developed based on presence of dominant low frequency energy.

Similar procedure was also used in developing low frequency word lists in Hindi (Barman et al., 2016).They developed 10 word lists with 25 words in each list. The word list was also normalized on 100 Hindi speakers at 40 dB SL and also during the final phase, developed lists were validated on 10 participants with simulated low-frequency cochlear hearing loss. Hearing loss was simulated using National Institute for Occupational Safety and Health (NIOSH) software. The results of validation revealed that auditory low-frequency word lists were sensitive enough to tap the speech understanding difficulty in the simulated condition.

2.5 Role of speech tests in hearing aid selection of low frequency hearing loss

A low frequency sensory hearing loss also termed a “reverse-slope audiogram” is one of the less frequent audiometric configurations. Though numerous researcher have suggested for the explanations to deal with this type of hearing loss configuration, certain of these explanations were not fully practicable because of the restrictions of the hearing aid technology. With the introduction of digital multi-channel digital hearing aids that compromise of greater flexibility of tuning and increased specificity, an audiologist may experience that heightened success in dealing with this type hearing loss configuration.

Low frequency hearing losses are tough to identify. Unless an individual has a hereditary history of low frequency sensory hearing loss or she/he undertakes regular audiometric testing, this category of hearing loss cofiguration is not effortlessly identified as it is comparatively symptom-free. One reason is that low frequency sounds are more intense and carry less information than high-frequency sounds. A person with a moderate degree of low frequency hearing loss may not exhibit any outward signs of a hearing loss, such as missing speech sounds or aberrant speech production patterns then relatively intact intelligibility in quiet. One reason why people with a low frequency hearing loss are able to identify the low-frequency speech data is because low frequency data could also be passed over high frequency fibers through temporal coding.

Thornton and Abbas (1980) related the speech identification ability of 3 participants who were diagnosed with a low frequency dead region. In addition, 5 normal-hearing participants in various filtered situations. In the unfiltered circumstance, the speech recognition scores were found to be 56% to 88% for the hearing impaired group and 94% to 100% in normal-hearing group. For another condition where speech was processed in high-pass condition, the scores were found to be 34% to 46% for the group of hearing-impaired but 16% to 38% for the group of normal-hearing. Where in the low-pass situation, the recognition scores were found to be 12% to 44% for the group of hearing-impaired but then again 76% to 84% for the normal-hearing.

Amplifying the section of loss in cochlea, determining the frequency section to provide amplification and how much to gain to provide is not as simple. Schum & Collins (1992) inspected speech identification skills of 6 participants with a low frequency hearing loss by spectrally modified speech materials (NST and CCT) to estimated different amplification structures. These comprised: a) broadband amplification; b) high-pass filtering; c) low-pass filtering; and d) unaided. Their results revealed that “low-pass” condition had the lowest intelligibility ranking (4/10) and “broadband” condition had rated highest (7.5/10). This advocates that amplifying the low frequency is not adequate. A broadband method, where a adjacent frequency area is also amplified, is required. These results are in line with the annotations of other investigator (Thornton & Abbas, 1980; Turner & Brus, 2001). Moore (1998) suggested that “possibly amplification should be applied over a frequency range extending somewhat into the dead region”. However, the amount into the dead region and amount of amplification will probably hinge on the etiology of low frequency hearing loss. In spite of these approvals, a practical method to customize the specific fittings with linear hearing aids has been difficult.

Vinay and Moore (2007) studied the ability of subject with low frequency dead region to use information frequency component if the speech falling within the dead reason. 28 subjects with hearing loss at frequencies 500,750 and 1000Hz of 40 dB or more were used. Individual without low frequency dead reason had threshold 70 dB or less whereas 70 dB or more in case with individual with dead reason. Vowel consonant vowel (VCV) nonsense syllable was used and speech intelligibility was measured. For low cutoff frequency condition speech identification score were highest (78%) for the individual without dead regions and constant up to 862 Hz and then scores become poor with increasing cutoff frequency. Whereas, for subject with dead regions, identification score was poor for lowest cutoff (100Hz) and enhanced while increasing the cutoff and worsened with extra increase. This study has practical application for the hearing aid for the individual with low frequency dead regions.

Clinical technique using concurrent pure-tone masking to improve the aspect of localization in cochlear disease, predominantly for low-frequency hearing damages, and a model for using the Articulation Index (AI) to advance prognoses for hearing aid performance in these individual, which can then be examined. 14 participants with low-frequency hearing loss were distributed into two groups constructed based on threshold alterations caused by a pure-tone masker: persons that showed normal low-frequency threshold alterations and those that showed significant shifts at frequencies lower than the masker, representing a greater loss of function than revealed by the unmasked audiogram. Imaginary audiograms were then created to demonstrate a complete loss of apical function for all participants. AI predictions for the actual and hypothetical audiograms were compared based on speech identification score. Greatest agreement of the participants presenting normal masking shifts was between the obtained scores and the AI for the real audiogram, while the greatest agreement for the participants showing significant shifts was with the AI for the hypothetical audiogram. The clinical implications for hearing aid selection and fitting in these cases are deliberated (Halpin et al., 1994).

2.6 Speech audiometry tests in Nepali

There is only one published speech audiometry test material available in Nepali language. Lal, (2012) developed a screening picture speech recognition test for Nepali speaking children. They have used monosyllabic words. They have developed material in 3 different stages. In the first stage construction of test material in this stage they have done familiarization of the 100 words selected from different books of their level on 15 children of the age of 5-6 years. 80 words were finalized. In stage two they have obtained normative on 30 children.

Few test have been developed in Indian language but there are no speech materials developed to assess low frequency hearing loss in individuals who speak Nepali language. Thus, there was a need to develop low frequency word lists in Nepali.

In order to select appropriate hearing aids for individuals with low frequency sensorineural hearing loss, it is essential to use a test which is sensitive to their problems. There is a high possibility that, if a regular PB word list is used in such individuals, they 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 list is used in individuals with rising hearing loss. Thus, it was essential to develop a low frequency word list which would help in rehabilitation of Nepali speaking individuals with low frequency hearing loss.

Chapter 3

Methods

The study aimed at developing low frequency by-syllabic word list in Nepali language for administering speech identification test.

The study was carried out in three stages:

- Stage 1: The development of the low frequency word list
- Stage 2: Administration of word list on individuals with normal hearing
- Stage 3: Determining the usefulness of the test material

3.1 Stage 1: Development of the low frequency word list

3.1.1 Selection of the words and familiarity rating

Bi-syllabic Nepali words were collected from different sources (common newspapers, magazines, & books). Low frequency word was selected based on the energy of phonemes which have more than 60% of low frequency phonemes (For E.g. /p/, /b/, /m/, /n/, /w/, /a/, /o/). Those words were verified for the presence of any script errors and correct categorization as bi-syllabic words. Further, corrected word list were given to 10 adult native Nepali speakers to rate the words on a 5-point familiarity rating scale. The words rated familiar, more familiar or most familiar by 70% of the participants were considered and the rest of the words were excluded from the list.

3.1.2 Recording of words and selection of best recorded words

The selected words were recorded in a sound treated room. Each word was recorded five times in clear and monotonous voice. Out of five recordings, first and the last recordings were removed and only the middle three will be subjected to subjective and objective analysis to select the best recorded words. Praat software was used for objective analysis. Firstly, 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 was considered. Further, among those recordings, one with visible pitch and formants observed using Praat software was finally selected during objective analysis. The selected words were normalized for its intensity.

3.1.3 Separating words with dominant low frequency energy

The verification of the words was done using MATLAB software, Fast Fourier Transform (FFT) was carried out for all the words. Amplitude of energy below and above 1.2 kHz was calculated for all the words individually. These amplitudes were used to obtain amplitude ratios; the ratio of energy below 1.2 kHz to that of above 1.2 kHz. Further, considering these amplitude ratios, *k*-means clustering was administered on all the words. During *k*-means clustering, total data were divided into a number of clusters with its nearest mean. The words having dominant low frequency energy compared to the rest of the words was selected. Thus, a group of words with the energy concentration maximum phoneme in word with low frequencies was selected.

Further, long term average speech spectrum (LTASS) was obtained for the clusters of low frequency words using MATLAB software. This was done to further verify the correct categorization of words as low frequency dominant. Thus, the word list was further shortlisted making sure the predominance of low frequency energy.

3.1.4 Generating word lists with equal difficulty

All the low frequency words were then presented to 25 adult native Nepali speakers (5 participants for each SL) with normal hearing at 5 different sensation levels (ref: PTA). Sensation levels (SLs) of +0, +4, +8, +12 and +16 dB were considered. The signal was routed through a personal computer to calibrated audiometer and presented through headphones, Sennheiser HDA-200. All the low frequency words were presented at one sensation level (SL) for each participant and at each SL, data were collected from 5 participants for each SL. Further, speech identification (SI) scores will be calculated using the following formula:

$$SIS = \frac{\text{Obtained number of responses}}{\text{Total number of responses}} * 100$$

The speech identification scores obtained from the participants at each SL was averaged and tabulated. Based on the average scores at all SLs, psychometric functions was derived for all the words using MATLAB software. Mean sensation level where 50% SI scores occurred and mean slope of the psychometric functions was 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 25 words each. For constructing equalized list, firstly 25 words were randomly selected from the available word pool. For each list, mean SL where 50% scores occurred and mean slope was found out. This mean SL and slope was compared with the overall mean SL and the slope of the low frequency word pool obtained initially. If the mean value was within ±1.5 standard deviation, then the list considered was selected. If not, then another set of 25 words was randomly selected and this procedure was repeated. It was attempted to develop at least 10 word lists with 25 words in each list.

3.2 Stage 2: Administration of word lists on individuals with normal hearing

Speech identification scores with the developed test material were obtained for 100 adult native speakers of Nepali. All the participants were literate with an education level of at least 7th standard or 10th Standard who know to write Nepali. The participants in the age range of 16 to 35 years, with normal hearing sensitivity (<

15 dB HL thresholds at all octave frequencies from 250 Hz to 8 KHz) were selected. There was no history of any otological problems in all participants and normal middle ear functioning based on immittance findings.

3.2.1 Inclusion Criteria for the Participant control group and simulation

- All participants had normal hearing threshold within 15 dB at octave frequencies 250 Hz to 8 KHz.
- They were native Nepali speakers within the age range of 16 to 35 years
- All the participants had 'A' type tympanogram with bilateral acoustic reflex present
- They had no history of Neurological or motor problems

Prior to participation in the study, written consent was obtained from all the participants.

3.3 Equipment

3.3.1 Audiometer

A calibrated dual channel diagnostic audiometer, GSI-61 audiometer coupled with headphones, sennheiser HD-200 was used for assessing PTA and Speech identification test. A radio ear B-71 bone vibrator was used to estimate bone conduction thresholds.

3.3.2 Tympanometer

A calibrated GSI Tympstar middle ear analyzer was used to obtain tympanogram and middle ear reflex thresholds.

3.3.3 Computer

The recorded words were played using MATLAB software R2009b. The signal was routed through a personal computer to the audiometer and presented those words through headphones, Sennheiser HD-200.

3.3.4 Speech Material used

The word lists of 25 words each, which were constructed in the study, were used to obtain speech identification score for all the individuals participated in the study.

3.3.5 Test Environment

The test was carried out in an air-conditioned, well illuminated and acoustically treated two-room situation as per ANSI S3.1 (1999).

3.4 Test Procedure

Routine audiological evaluation was carried out for all the participants. Evaluations were carried out in an air-conditioned, well illuminated and acoustically treated two-room situation as per ANSI S3.6 (2010)). A calibrated dual channel diagnostic audiometer GSI-61 was used to carry out pure tone and speech audiometry. The developed speech materials were routed through MATLAB software R2008b. The speech material was routed through a personal computer connected to the auxiliary input of the calibrated audiometer

The speech materials developed were used to find out SI scores at +40 dBSL (ref: PTA), SI scores were obtained by using the developed list for both right and left ears on 100 individuals with normal hearing who were native speakers of the Nepali language. The participants were asked to follow the instructions and respond by ‘Verbal repetition’. Approval was taken from ethical approval committee of the institute and the testing was done using non-invasive procedures. The objectives and procedures of the study were explained to the participants before the evaluation and informed consent was taken from them.

3.4.1 Administration of test

A calibrated dual channel audiometer was used to determine pure tone and speech audiometry. After the estimation of pure tone thresholds, the speech recognition threshold (SRT) was determined. The speech identification scores (SIS) were determined at 60 dB SPL with the word list developed in Phase I. All the participants were tested only one ear with all the lists developed to avoid the practice effect. To avoid ear effect, 50 individuals were tested in right ear and the other 50 in left ear. The speech material recorded for the study was played using Adobe Audition (Version 3.0) software. The signal was routed through a computer using calibrated headphones. The intensity of the presentation level was controlled from the audiometer. An open set response in the form of written response was taken from all the participants.

The following criteria were considered to conclude that the list is appropriate:

- The speech identification scores obtained using each list should be more than 90 %.
- There should be no significant difference between the scores obtained between the lists to conclude that all the lists are equally intelligible or equally difficult.

3.5. Stage 3: Determining the usefulness of the test material

10 adults with normal hearing in the age range of 16 to 35 years were used for simulation study to determine the utility of the test material. Low frequency hearing loss was simulated using NIOSH Hearing Loss Simulator software (version 3.0.12151). The classification of rising type will be based on the classification given by (Lloyd & Kaplan, 1978), cited in (Silman & Silverman, 1991). All the participants

of the study were tested with low frequency word list developed. The scores obtained by individuals with rising hearing loss were compared with individuals with normal hearing. In addition, scores obtained for by-syllabic word list in Nepali and developed a low frequency word list were compared. The data obtained were analyzed using SPSS software for significant differences, if any.

3.6 Ethical Consideration

Approval was taken from ethical approval committee of the institute and the testing was done using non-invasive procedures. The objectives and procedures of the study were explained to the participants before the evaluation and informed consent was taken from them.

Chapter 4

Results and Discussion

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

4.1 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. The procedure for collection of words and recording, selection of best recorded words and separating words with dominant low frequency energy are explained in the Method section.

4.1.1 Generating word lists with equal difficulty levels

One of the important considerations during development of any speech material for testing is that the alternative forms of testing should be equivalent, which is they should produce comparable results (Gelfand, 2009). Conventional way, followed to obtain equivalence between word lists developed was phonemic or phonetic balancing. However, recent researches in the field of development of speech identification materials have shown that impact of phonetic or phonemic balancing is questionable (Martin, Champlin & Perez, 2000). Thus, to develop word lists which produce equivalent results, following procedure considering psychometric function curves was carried out. Using low frequency word cluster, the results of speech identification (SI) score obtained from 25 adult native Nepali 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, mean level at which 50% SI score was obtained and the slope of a function was derived. The words falling within ±1. 5 standard deviation from the mean and the slope for the psychometric functions were separated. This consisted of 250 words with 25 words in each list. Based on the procedure explained in the method section, a total of 10 lists was developed in Nepali.

4.2 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 10 lists in Nepali is shown in figure.

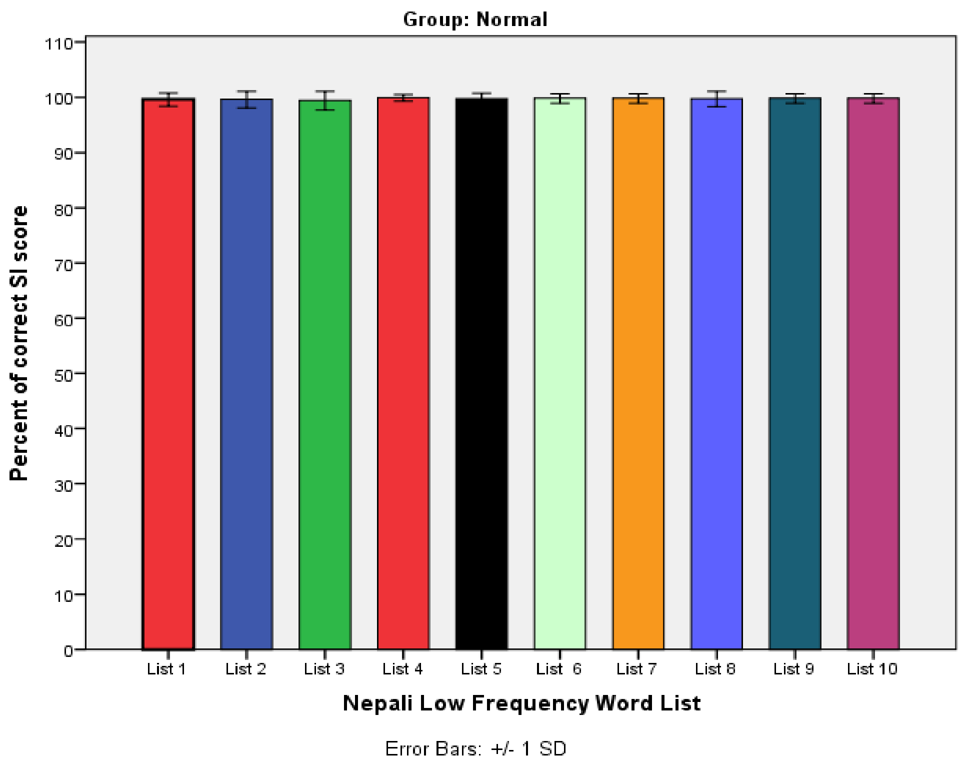

Figure 4.1: *Mean and SD of SI scores obtained for word lists in Nepali at 40 dB SL*.

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, Friedman test was performed to compare the SIS between the ten lists. The results of Friedman test revealed that there is no significant difference across the 10 lists {$\chi 2(9)= 5.216$, $p>0.05$}.

4.3 Administration of the test material on simulated condition

To determine the usefulness of the developed list, the lists were administered on 10 Nepali speaking individuals with simulated condition resembling rising cochlear hearing loss using NIOSH Hearing Loss Simulator software (version 3.0.12151).

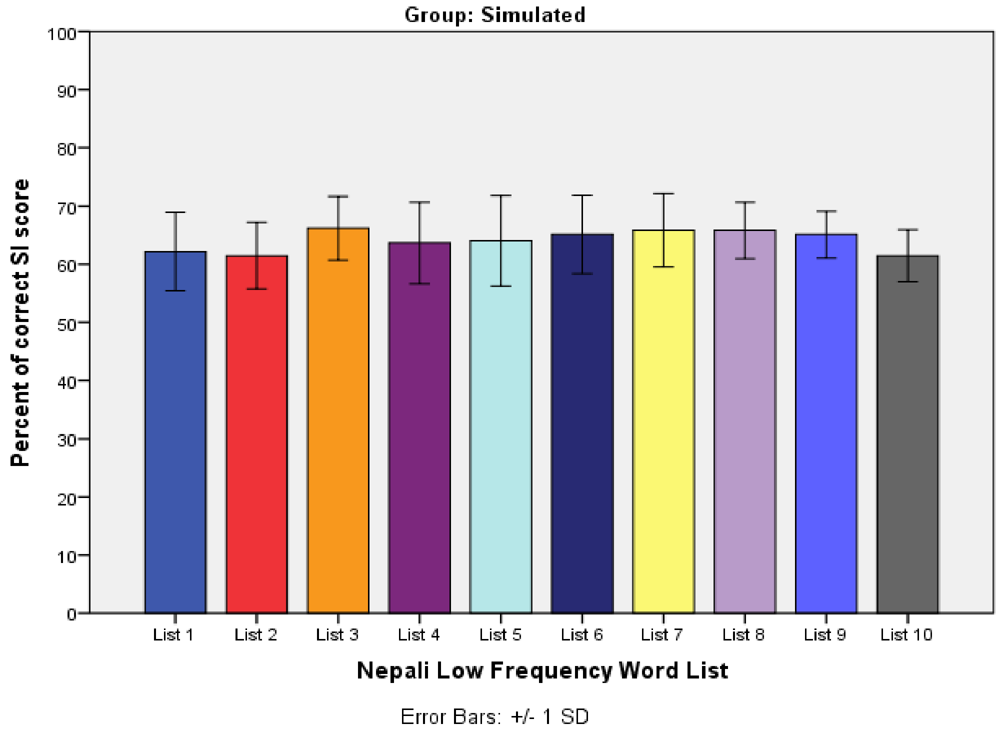

Figure 4.2: *Mean and SD of SI scores between normal and SLCHL group in Nepali.*

Friedman's test was performed and the results showed no significance difference in the SIS scores across the low frequency word lists in individuals with simulated low frequency cochlear hearing loss [$\chi2(9)=11.84$, $p>0.05$].

4.4 Comparison of the speech identification scores between the two groups

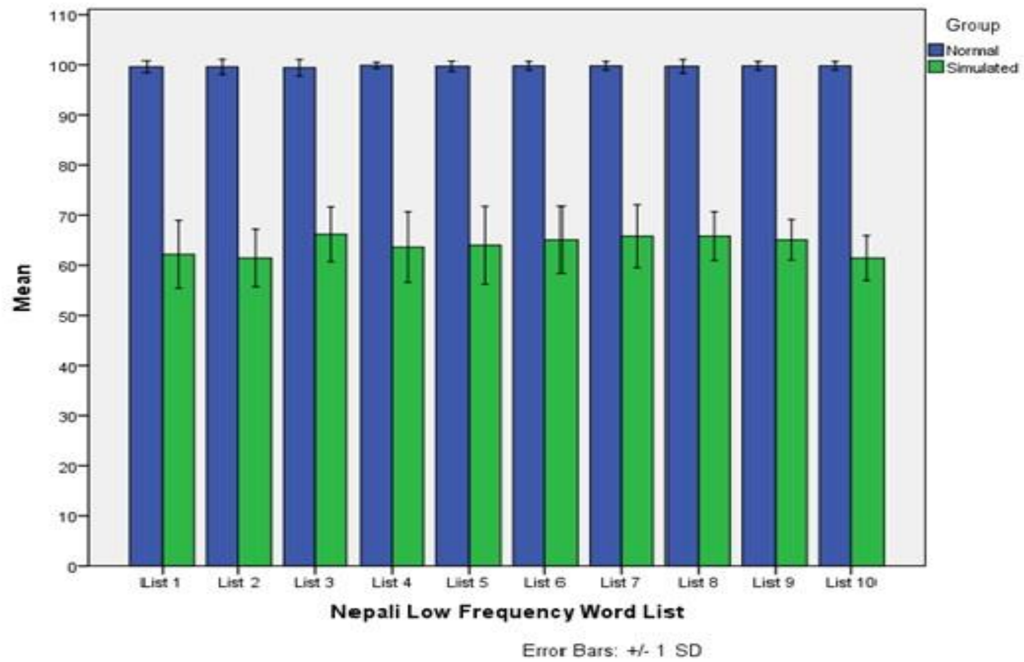

Figure 4.3: *Mean and SD of SI scores between normal and SLCHL group in Nepali.*

Figure 3 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 that across lists, normals have outperformed SLCHL individuals.

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 between individuals with normal hearing and individuals with simulated low frequency cochlear hearing loss. The results of Mann-Whitney U tests are shown in table 4.1.

Table No 4.1

Results of Mann-Whitney U Tests

	List 1	List 2	List 3	List 4	List 5	List 6	List 7	List 8	List 9	List 10
Z	-6.321	-6.473	-6.186	-6.846	-6.473	-6.647	-6.650	-6.648	-6.649	-6.648
Asymp. Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000

Mann-Whitney test results revealed that, the SIS scores for both Group low frequency word list are significantly different ($p<0.01$) for individuals with simulated low frequency cochlear hearing loss from that of individuals with normal hearing.

Speech is a stimulus of high redundancy because of the information in it is conveyed in several ways simultaneously (Martin et al., 1994). Hearing loss involving only the part of the frequency range may go undetected in a speech test which is not carefully controlled. A standard speech test can give reasonably accurate prediction of the best hearing threshold levels in the mid frequency region of the auditory range. However, the use of a regular speech identification test would be insensitive towards identification of the problem of a person with low frequency hearing loss. Thus, it is essential to have a speech test material having only low frequency speech sounds.

Low frequency wordlist were developed in other languages such as Hindi, Kannada (Barman et al., 2016, 2017) and Manipuri (Konadath & Nigombam, 2014). Hindi low frequency word list contains 10 lists with 25 words in each and Kannada contains 7 with 25 words in each. Present study also followed the same methodology except that the words collected at the initial phase contains prominent low frequency phonemes. SIS obtained by simulated low frequency cochlear hearing loss individuals for Hindi, Kannada and Manipuri low frequency word list were similar to Nepali. This suggests that the Nepali word list might have similar low frequency content as that of the other languages. Nepali is spoken by a large group of population across the world and it is essential to develop word lists even in Nepali language. Lal (2012) developed test for speech identification score in Nepali which is useful in determining the communication problems of children with flat frequency hearing loss. However, there are limited speech materials developed to assess low frequency hearing loss in individuals who speak the Nepali language. Thus, the present study overcomes the nuance by developing a low frequency word list in Nepali.

In order to select appropriate hearing aids for individuals with low frequency sensorineural hearing loss, it is essential to use a test which is sensitive to their problems. There is a high possibility that, if a regular PB word list is used in such individuals, 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 list is used in individuals with rising hearing loss. Thus, the results of the study would help in rehabilitation of Nepali speaking individuals with low frequency hearing loss.

The scores obtained for the low frequency word list and simulated low frequency cochlear hearing loss individuals shows significant difference. The reason for this difference might be that normal hearing individual can perceive all phonemes (high and mid) where as in simulated condition low frequency information is missing and low frequency phonemes are not perceived. An individual with low frequency hearing loss can perceive other frequency information than low frequency information. This confirms that the low frequency word list is an effective tool for the assessment of low frequency hearing sensitivity.

Chapter 5

SUMMARY AND CONCLUSIONS

Speech is a stimulus of high redundancy because of the information in it is conveyed in several ways simultaneously (Martin et al., 1994). A hearing loss involving only the part of the frequency range may go undetected in a speech test which is not carefully controlled. A standard speech test can give reasonably accurate prediction of the best hearing threshold levels in the mid frequency region of the auditory range. An individual with low frequency hearing loss would have difficulty in perceiving low frequency sounds (McDermott & Dean, 2000). Hearing loss involving limited region of frequency range may go undetected in speech test when the speech stimuli used for speech audiometry is not carefully controlled,. Thus, the use of a regular speech identification test would be insensitive towards identification of the problem of a person with low frequency hearing loss.

The present study was conducted in three phases, during the initial phase the low frequency range word lists were developed. This was done by collecting 361 words from different sources. Further, the 361 words were used for familiarity rating using three point rating scale and 290 words were selected for this corpus. FFT was done by using MATLAB software (R2009b) for the remaining words to determine if the words selected were in low or high frequency spectrum and 1.5 KHz was taken to be the cutoff frequency. Later, k-means clustering was performed based on the amplitude ration of words above and below 1.5 kHz and words having amplitude ratio >1.45 were considered for making list . LTASS was also performed to determine the remaining words are having low frequency spectrum. In order to generate equally difficult word in the list speech identification scores were obtained for all the remaining words at different sensation levels (+0, +4, +8, +12 and +16 dB) scores obtained from each sensation level were averaged. Based on average scores, psychometric function was derived. 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, mean level at which 50% SI score was obtained and the slope of a function was derived. The words falling within ±1.5 standard deviation from the mean and the slope for the psychometric functions were separated. This consisted of 250 words with 25 words in each list. Based on the procedure explained in the method section, a total of 10 lists was developed in Nepali.

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 10 Individuals with simulated cochlear low frequency hearing loss. In total, 10 low frequency word lists were developed, each list consisted of 25 words. 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 a clinical population to tap their difficulty in understanding low frequency information and this word lists can also be used for selecting appropriate hearing devices for individuals with low frequency hearing loss.

5.1 Utility of the developed test material

1. The low frequency speech identification test can be utilized for assessing the perceptual difficulties of individual with low frequency hearing loss who are native speakers of Nepali language
2. This word list can also be used for selecting and verification of appropriate hearing aid device for individual with low frequency hearing loss.
3. Administering both low and high frequency word list would provide information regarding the configuration of the hearing loss.

5.2 Limitations of the study

1. The developed low frequency could have been administered in actual low frequency hearing loss individual instead of simulated condition.
2. The number of participants in the experimental group was less.
3. The developed word list could be compared with a phonetically balanced word list.

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Appendix

Low Frequency Word list for Speech Identification Test in Nepali Language for Adults

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SL.No.	List 1	List 2	List 3	List 4	List 5
1	आधा	कम्ती	कडा	कुन्ड	कीरा
2	पंखा	केटो	भालू	बैङ्ग	सानु
3	ठुलो	नाती	मासु	खण्ड	खोलो
4	निधो	ताउ	कहाँ	काँचो	नारा
5	वेला	जुवा	पिठो	कस्ट	पापि
6	पक्का	अनार	जुङ्गा	वार्ता	बाबू
7	पार्टि	व्यक्त	पुजा	बुडो	रातो
8	टिक्नु	रात	मुन्द्रा	कैयौं	काले
9	मञ्च	कालो	कानो	टोली	खाल्डो
10	काखी	पानी	मैना	अम्बा	ताजा
11	मुल्य	उल्टो	टुपि	फुपु	कोठा
12	युवा	कान्छि	लामो	ताप्नु	मन्त्री
13	पुर्खा	मिठो	रक्षा	तला	भेला
14	बाह्र	ऊनी	पट्टी	भुडि	कुर्नु
15	पुर्न	खन्नु	छाला	रुघा	पारी
16	सामु	अन्तै	ल्वाङ	लात्ती	लोभी
17	बाधा	मोटो	मैदा	खम्बा	अर्ती
18	माछा	पर्व	ठन्डा	बाजा	जिम्मा
19	भदौ	रुमाल	केरा	नानी	मेवा
20	पोथी	तर्क	रोटि	वस्तु	काकी
21	खैरो	मैया	शुन्य	छर्नु	अन्न
22	सानो	बाखी	बाख्रा	मुक्त	कार्य
23	वंश	जोडि	काँडा	तला	माटो
24	अन्डा	मौरी	नाता	लुगा	बाटो
25	बुवा	बेला	मुठ्ठी	बायाँ	टाटो

SL.No.	List 6	List 7	List 8	List 9	List 10
1	पाको	मेला	मुनि	पर्दा	पाठो
2	जाडो	न्याय	जुठो	सम्म	लप्सी
3	निकै	लुक्नु	ऊखु	माग्ने	मकै
4	काका	नदी	ज्यादा	अंश	बारी
5	रुनु	आफै	गन्ती	कुचो	कुवा
6	गोरा	गाई	ग्राम	कैदी	तातो
7	कान्ड	धारा	तल	धनी	काँक्रो
8	सुगा	घोडा	खाली	मैलो	मुसा
9	गाली	लौरो	दायाँ	नेता	लौरो
10	गन्जी	गोही	प्रथा	भाडा	राजा
11	मुसो	मान्छे	हात्ती	शड्ढा	अमृत
12	तालु	डोरि	मृत्यु	केटि	बडा
13	अगाडि	दुखी	बडी	अग्लो	आगा
14	नारी	चुलो	गाग्री	बोका	वृक्ष्य
15	वर्ग	गला	आत्मा	हाम्रो	हिजो
16	गारा	अमर	पाचौँ	मोजा	धर्म
17	टुक्रा	बानी	भाँडो	खानु	गर्मी
18	डालो	मुला	नक्शा	निको	दारी
19	टाडा	डाँफे	दिनु	ढोका	खडा
20	भेडा	धर्ना	जाली	औंसी	मुटु
21	घाँटि	गीलो	नब्बे	बत्ती	बेच्नु
22	तारा	आँखा	पुरी	डाँडा	जुन
23	छाना	ढिडो	धन	चर्को	थोपो
24	राम्रो	जनै	झन्डा	बज्यै	हावा
25	बाजे	वेद	धारा	पत्ता	पुरा