Development and Evaluation of High Frequency Word Identification Test for Children in Indian-English (HF-WITCIE)

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University of Mysore, Mysuru

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May, 2017

CERTIFICATE

This is to certify that this dissertation entitled ***"Development and Evaluation of High Frequency Word Identification Test for Children Indian-English (HF-WITCIE)"*** is a bonafide work submitted in part fulfillment for degree of Master of Science (Audiology) of the student Registration Number: 15AUD016. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru
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DECLARATION

This is to certify that this dissertation entitled ***"Development and Evaluation of High Frequency Word Identification Test for Children Indian-English (HF-WITCIE)"*** is the result of my own study under the guidance of Dr. Asha Yathiraj, Professor of Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysuru, and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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May, 2017

Dedicated to all

Who has faith in me!!!

(Especially Dad, Mom & Sisters)

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“The single greatest cause of happiness is gratitude.”

— **Auliq-Ice**

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ABSTRACT

Aim: The aim of the study was to develop a 'High frequency word identification test for children in Indian-English (HF-WITCIE)' and validate the same on typically developing children. Additionally, the study aimed to checking the equivalency of the four lists of the tests and establishing whether the age of the participants (6 to 9 years) had an effect on the scores of the test. The study also determined the utility of the test on children simulated to have high frequency hearing loss.

Methods: The 'HF-WITCIE' was developed using high frequency phonemes (/i/, /e/, /j/, /r/, /l/, /t/, /tʰ/, /s/, /f/, /ʃ/, /tʃ/). The test was constructed to have four lists, each having 25. The developed test material was validated on 48 typically developing children aged 6 to 9 years (16 each in the age groups ≥ 6 to < 7 years, ≥ 7 to < 8 years, and ≥ 8 to < 9 years). Half the children were tested in a sound-treated set-up and half within a school premises. The utility of the test was evaluated on 12 children simulated to have high frequency hearing loss (6 gradual sloping hearing loss & 6 sharply sloping hearing loss). The written as well as oral responses of the children were scored to obtain word scores and phoneme scores.

Results: No significant difference was seen between the scores of the test carried out in two locations (school & sound treated room set-up). The children in the three age groups performed similarly, indicating no age effect. The four lists of the test were found to be equivalent for the word scores and phoneme scores. Further, word and phoneme scores were noted to be similar in the typically developing children, but the former was significantly poorer than the latter in those with simulated high frequency hearing loss. Significant differences were seen in the scores of the typically developing children when compared to those with simulated gradual sloping hearing loss and sharply sloping hearing loss.

Conclusions: The study indicates that the developed test can be used to assess speech identification difficulties faced by children with high frequency hearing loss. As the four lists of the test were found to be equivalent, the test can be used in situations where children need to be tested multiple times.

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Chapter 1

INTRODUCTION

Hearing loss is considered to be the most prevalent congenital abnormality in newborns and is more than twice as prevalent other conditions that are screened for at birth, such as sickle cell disease, hypothyroidism, phynilketonuria, and galactosaemia (Finitzo & Crumley, 1999). Johnson, Tabangin, Meinzen-Derr, Cohen, and Greinwald (2016) noted that among the 2,867 children studied by them, 7.6% had high frequency sensorineural hearing loss. Also as observed by le Clercq, van Ingen, Ruytjens, and van der Schroeff (2016) the prevalence of high-frequency hearing loss was found to be 9.3% after the exposure to loud music.

Ross (2009) reported that the most common type of hearing impairment is a high-frequency loss, resulting in individuals having difficulty in perceiving many high frequency unvoiced consonants such as the /t/, /k/, /f/, /t^h/, /ʃ/, and /s/. Ineffective perception of stop consonants by those with high frequency hearing loss has also been reported (Dubno, Dirks, & Ellison, 1989). A study of simulated high frequency hearing loss revealed that place error confusion was seen to be more compared to manner cues and these errors were more in sharp high frequency sloping as compared to gradual high frequency sloping hearing loss (Geetha, Ashly, & Yathiraj, 2006; Kumar & Yathiraj, 2009). Further, it has been observed that noise has a deleterious effect on speech perception in those with sloping audiogram configuration (Cohen & Keith, 1976). People with this type of problem were observed to often complain of hearing and not understanding. Besides resulting in difficulties in perception of high frequency speech sounds (Ahmed, Mourad, El-Banna, & Talaat, 2015; Pichora-Fuller & Souza, 2003), high frequency hearing loss has been noted to result in difficulty in adequate monitoring of fricative production (Stelmachowicz, Pittman, Hoover, Lewis, & Moeller, 2004).

Studies mainly report of high frequency hearing loss being present in adults (Gates & Mills, 2005; Peng, Tao, & Huang, 2007; Rabinowitz, Sircar, Tarabar, Galusha, & Slade, 2005; Thelin, Joseph, Davis, Baker, & Hosokawa, 1983a). However, high frequency hearing loss has been found to be associated with otitis media after middle ear disease resolves and after middle ear dysfunction was excluded (Dieroff & Schuhmann, 1985; Hunter et al., 1996). Middle ear effusion has been reported to be a common problem in children (Alles et al., 2001; Hall-Stoodley et al., 2006; Tasker et al., 2002). Also, severe-to-profound high frequency hearing loss was reported to be prevalent in survivors of congenital diaphragmatic hernia (Robertson, Cheung, Haluschak, Elliott, & Leonard, 1998). It is well established that high levels of noise results in high frequency hearing loss. In the past exposure to high levels of noise was mainly associated with adults. However, due to the increasing availability of personal music players and mobile phone, the younger population is also susceptible to noise induced high frequency hearing loss (le Clercq et al., 2016; Shargorodsky, Curhan, Curhan, & Eavey, 2010). The presence of high frequency hearing loss in children necessitates the availability of speech identification tests to identify their perceptual problems.

As reported in literature, regular speech identification tests are not sensitive to detect the perceptual problems in those with high frequency hearing loss. Low frequency cues, available to the individual in such tests were reported to contribute redundant cues for the perception of speech sounds, thus under estimating their perceptual difficulties

(Chung & Mack, 1979; McDermott & Dean, 2000; Owens & Schubert, 1977). To detect the perceptual problems of those with high frequency hearing loss, many researchers have developed speech identification tests having a high concentration of high frequency speech sounds. A few of the existing high frequency speech identification tests are in western context are 'The Gardner High Frequency Word Lists' (Gardner, 1971), 'The Pascoe High Frequency Test'(Pascoe, 1975), 'The California Consonant test'(Owens & Schubert, 1977), and in Indian context are 'High Frequency Speech Identification Test for Hindi and Urdu Speakers'(Ramachandra, 2001), 'High-Frequency Kannada Speech Identification Test'(Mascarenhas, 2002),'High Frequency-English Speech Identification Test'(Sudipta & Yathiraj, 2005-2006), 'High Frequency Speech Identification Test in Tamil'(Sinthiya & Sandeep, 2009), 'High Frequency Speech Identification Test in Telugu' (Ratnakar & Mamatha, 2009-2010) and 'High Frequency Speech Identification Test in Manipuri Language' (Hmangte & Geetha, 2014). These high frequency speech tests have been developed for adults.

Need for the study

Generally, speech recognition/identification tests are developed for assessing communication problems of individuals with flat audiogram configurations. Such tests are not likely to detect the speech identification problems faced by those with high frequency hearing loss. Those with a high frequency hearing loss are known to have higher scores with regular speech identification tests (Chung & Mack, 1979; McDermott & Dean, 2000; Owens & Schubert, 1977). Hence, using speech identification tests designed for those with flat audiogram configurations may not detect the perceptual problems of those with high frequency hearing loss. Additionally, selection of appropriate listening devices for such individuals would be difficult with standard speech identification tests. Based on these requirements, high frequency tests have been developed for adults. However, such tests are not available for children having high frequency hearing loss. Tests developed for adults cannot be used to evaluate children due to differences in vocabulary. To avoid poor performance in children with high frequency hearing loss by using tests not designed for them, it is necessary to develop high frequency speech identification tests with age appropriate vocabulary. Such tests will not just help detect their perceptual problems and select appropriate listening devices, but also provide direction regarding the measures that should be taken while administrating therapy. The outcome of the therapy can also be measured to ensure that the training is useful or not. Further, such tests will assist while deciding whether a child with hearing loss can continue to use hearing aids or should switch over to cochlear implants. Additionally, high frequency audibility is important for self-monitoring of speech that in turn is noted to help in language development (Stelmachowicz et al., 2004) Hence, it is essential to develop high frequency speech identification tests for children in different languages, using age appropriate vocabulary.

Aim of the study

The aim of the study is to develop a high frequency speech identification test in Indian-English for children.

Objectives of the study:

- To develop a speech identification word test for children with high frequency hearing loss.
- To validate the developed test on normal hearing children.
- To substantiate the effect of location (school and sound treated room set-up) on the performance of the test.
- To check the equivalence of the different lists of the developed test.
- To evaluate the effect of age of children on the performance of the test.
- To confirm the utility of test material on simulated high frequency hearing loss.

Chapter 2

REVIEW OF LITERATURE

One of the parameter that is known to affect speech perception in individuals with hearing impairment is the audiogram configuration (Kumar & Yathiraj, 2009; Owens, Benedict, & Schubert, 1972; Turner & Cummings, 1999). The configuration of SNHL has been noted to vary across individuals (Owens et al., 1972). Most studies report of the presence of high frequency hearing loss in adults (Gates & Mills, 2005; Peng et al., 2007; Rabinowitz et al., 2005; Thelin et al., 1983a). However, Johnson et al. (2016) noted that among the 2,867 children studied by them, 7.6% had high frequency sensorineural hearing loss.

High frequency hearing loss has been found to be associated with otitis media after middle ear disease resolves and after middle ear dysfunction was excluded (Hunter et al., 1996). Middle ear effusion has been reported to be a common problem in children (Alles et al., 2001; Hall-Stoodley et al., 2006; Tasker et al., 2002). Hence, children with middle ear effusion are likely to have high frequency hearing loss. Additionally, ototoxicity due to the use of cisplatin, a chemotherapy medication used to treat cancers, has been found to result in high frequency hearing loss in children (Weissenstein, Deuster, Knief, am Zehnhoff-Dinnesen, & Schmidt, 2012). Further, it is known that exposure to loud music results in high frequency hearing loss (Shargorodsky et al., 2010). This exposure to loud music has been noted to have increased due to the availability of personal music players and mobile phones. le Clercq et al. (2016) reported that the prevalence of high-frequency hearing loss was found to be 9.3% after the exposure to loud music. Thus, it can be observed that high frequency hearing loss occurs both in adults as well as in children. Studies reported in literature have noted that those with high frequency hearing loss have specific speech perception problems.

2.1 Speech Perception difficulties of those speech with high frequency hearing loss

Information about the difficulty individuals with high frequency hearing loss have in speech perception has been either extrapolated from the acoustic properties of speech sounds or through direct measurement. The former has been established based on speech sounds that have major segmental cues above 2 kHz. According to Hughes and Halle (1956), the resonance region for /s/ is between 2000 Hz and 4000 Hz; for /ʃ/ it is 3500 Hz and above; and for /f/ it is between 6800 Hz and 8400 Hz. Pascoe (1975) reported that the critical range of frequencies that have a significant effect on word recognition score, particularly in the presence of noise, is between 2500 Hz and 6300 Hz. This indicated that high frequency information was necessary for speech recognition in quiet as well as noisy situation. Hence, it can be construed that individuals with high frequency hearing loss would have difficulty in perception of sound falling in this region.

Studies on individuals having high frequency hearing loss substantiates that speech sounds that have high frequency segmental cues are misperceived. Dubno et al. (1989) reported of stop-consonants not been perceived effectively in those with high frequency hearing loss and more errors were seen for the recognition of /d/ sound as it has a rising spectra. In adults having sensorineural hearing loss due to different causes, Owens et al. (1972) observed that speech perception difficulties varied depending on the audiogram configuration. They reported that /s/,/ʃ/, /tʃ/, dz/ and initial / tʃ/ and /θ/ were easily identifiable by those with flat configuration of hearing loss but was difficult for those with sharply sloping hearing loss having slopes from 500 Hz to 4000 Hz. The probability of errors were different for those with noise induced hearing loss when compared to those with presbycusis, where in slightly higher probability of errors were seen for /s/, /tʃ/, /dz/, initial /tʃ/ and initial /θ/ in noise induced hearing loss as they had slopes that were sharply falling when compared to those with presbycusis. They also reported that error for individual phoneme closely correlated to pure-tone configuration rather than type of hearing loss.

To determine the effect of noise on speech identification scores, Cohen and Keith (1976) did a study wherein subjects with high frequency cochlear hearing loss and flat cochlear hearing loss were studied. The participants were evaluated in a quiet condition and in the presence of 500 Hz low pass noise in two signal-to-noise ratio conditions (-4 dB and -12 dB). The results indicated that the word recognition scores were similar between the two groups in the quiet condition, but scores deteriorated in the presence of noise in those with a sloping hearing loss as compared to those with a flat cochlear hearing loss. Similar results were seen by Chung and Mack (1979) who evaluated the effect of masking noise on word discrimination scores in normal listeners and with noise-induced hearing loss.

Johnson, Stein, Broadway, and Markwalter (1997) studied consonant identification of children having normal hearing and children with minimal high frequency hearing loss. In a quiet situation there was a significant difference in consonant identification score between the two groups. Individuals with minimal high frequency hearing loss had poorer scores compared to the normal hearing children. Thus, they concluded that high frequency information is necessary for consonant identification.

Geetha et al. (2006), who simulate hearing loss using high frequency filtered speech, discussed the difference in speech perception difficulty in gradual and sharply sloping audiogram configuration. Based on the findings of 30 normal hearing adults who were evaluated using speech stimuli that simulated different audiogram configurations, they reported that a gradual slope results in higher speech identification score than a sharp slope for word and phoneme scores. Maximum place error confusion was found between /d/ and /b/, followed by /d/ and /g/ and /p/ and /t/. Among the manner errors, the fricatives /f/ was substituted by /h/ and /s/ and the nasals /m/ and /n/ were substituted by /l/. They speculated that such errors are likely to be seen in individuals with high frequency hearing loss.

Likewise, Kumar and Yathiraj (2009) studied the perception of speech by simulating different configuration of hearing loss in normal hearing adults. Monosyllabic words were acoustically modified to represent gradual falling, sharply falling and rising audiogram configurations. The modification was done by attenuating the speech material at specific frequencies according to the criteria given by Lloyd and Kaplan (1978). The performance of the participants on phonetically balanced monosyllabic words indicated that the error patterns seen were dependent on the configuration of hearing loss. In a rising configuration, voicing errors were maximum, but place errors were less. In a gradually falling configuration, manner and place errors were evident. On the other hand, in the sharply falling configuration, place errors were evident. Thus, it was inferred that subjects with high frequency hearing loss are likely to have difficulty perceiving place cues.

2.2 Performance of individual with high frequency hearing loss on routine speech identification tests

The speech perception difficulties of individuals with high frequency hearing loss are reported to be not easily identifiable. The condition is noted to be often missed out due to the use of speech identification tests that are not sensitive enough to identify high frequency hearing loss (Carhart, 1965; Gordon-Salant, 1986; Keith & Talis, 1972; Sher & Owens, 1974). The available literature provided below shows how routine speech identification tests are insensitive for identifying speech perception difficulties in those with sloping hearing loss.

On a standard speech identification test (CID-22 word list), Sher and Owens (1974) reported that the mean score of 35 subjects with high frequency hearing loss (slope 2000 Hz onwards) was 94.6%. However, the scores were found to not match the perceptual problems faced by them, indicating that the test was not sensitive to identifying their problems. Similarly, other reporters also noted that CID W-22 was often incapable of differentiating between normal listeners and listeners with high frequency hearing loss (Carhart, 1965; Keith & Talis, 1972).

A comparison of normal hearing individuals (N = 12) and individuals with high frequency hearing loss (N = 12) was done using a standard test (NU-6 test) and two tests meant for those with high frequency hearing loss (California Consonant Test & Pascoe High Frequency word Test) by Maroonroge and Diefendorf (1984). The result indicated that those with a high frequency hearing loss had varying degree of difficulty in perceiving and distinguishing similar sounds. On the standard test scores of the participants ranged from 80% to 100%. On the other hand, for the Pascoe test the scores ranged from 100% to 70%, with the majority of the participants getting scores of less than 90%. The range of scores on the California Consonant test was similar to that of the Pascoe test. It was concluded that the NU-6 test was less sensitive in detecting the perceptual problems faced by individuals with high frequency hearing loss.

Gordon-Salant (1986) compared the response of young and elderly normal and hearing impaired listeners using NU-6 and the California Consonant Test. Those with a hearing impairment had mild-to-moderate sloping high frequency hearing loss. The tests were presented at 80 dB and 95 dB SPL respectively. The subjects were required to compare their ability to judge the accuracy of their response on the two speech recognition tests. The judgment of accuracy was higher for all groups using NU-6 than for the California consonant test. From the above studies it was seen that the routine speech identification tests were not capable of identifying perceptual problems faced by individuals with high frequency hearing loss.

2.3 Speech identification tests for evaluating high frequency hearing loss in adults

As routine speech identification test have been noted to not detect the perceptual problem faced by individuals having high frequency hearing loss, researchers have developed tests sensitive to their perceptual difficulties. These tests have been found to aid in correct diagnosis for individuals with sloping hearing loss. A few of the existing tests designed for individuals with high frequency hearing loss are: Gardner High

Frequency Word List (Gardner, 1971), Pascoe High Frequency Test (Pascoe, 1975), California Consonant Test (Owens & Schubert, 1977), High Frequency Speech Identification Test for Hindi and Urdu speaker (Ramachandra, 2001), High Frequency Kannada Speech Identification Test (Mascarenhas, 2002), High Frequency English Speech Identification Test (Sudipta & Yathiraj, 2005-2006), High Frequency Speech Identification Test in Tamil (Sinthiya & Sandeep, 2009), High Frequency Speech Identification Test in Telugu (Ratnakar & Mamatha, 2009-2010) , High Frequency Speech Identification Test in Manipuri Language (Hmangte & Geetha, 2014). Details of these tests are described below.

2.3.1 The Gardner High Frequency Word List (Gardner, 1971)

The Gardner high frequency word list was made to assess the perceptual difficulties of individuals with high frequency hearing loss and to determine the perceptual changes that are brought about by electro acoustical modification of listening devices. The list consists of seven voiceless consonants /p/, /t/, /k/, /s/, /f/, /θ/, /h/ followed by vowel the /i/. Fifty words were constructed that were arranged in random order into two lists consisting of 25 words each. The words were known to be confusing for individuals with high frequency hearing loss. The Gardner high frequency word list was recommended to be delivered using live voice presentation or through tape recording of a female talker. The word orders were required to be randomized during testing, especially when evaluating hearing aid performance. Although it was developed for assessing hearing aid performance, it has been used for auditory training.

2.3.2 The Pascoe High Frequency Test (Pascoe, 1975)

To assess the perception abilities of adults with high frequency hearing loss, Pascoe developed a high frequency test in 1975. The monosyllabic test was constructed by using phonemes that were perceptually difficult for individuals with hearing impairment. The 50 words of the test had voiceless fricatives and plosives that constituted 63% of the consonants and remaining consonants were nasals, laterals, and voiced plosives along with three vocalic nuclei /I/, /ai/ and /ou/. The words were divided into two lists and were recorded by a male and female speaker.

Pascoe (1975) used the developed material to test eight individuals with hearing impairment using binaural master hearing aids with five different frequency responses. Additionally, the performance of the participants on the Pascoe high frequency test was compared with a PB-word list in quiet as well as in noise. A high correlation was seen between different frequency band as well as greater identification score with the Pascoe high frequency test. The Pascoe high frequency test was considered useful as it provided standardized information for male and female speaker version of the test. The test was found to be useful in hearing aid evaluation and also for detecting perceptual problem faced by individuals with hearing impairment in noise.

2.3.3 The California Consonant Test (Owens & Schubert, 1977)

The California Consonant Test developed by Owens and Schubert (1977) consists of 100 monosyllables, divided into two lists each having 50 words each. This multiple choice test was developed to evaluate consonant identification in adults. A computer assisted analysis of the responses from 550 individuals with sensorineural hearing loss was obtained. The test was found to be sensitive to high frequency hearing loss, but a low correlation (-0.40) was seen with respect to degree of hearing loss mainly for flat configurations. The author also compared W-22 test with the California Consonant test in individuals with varying audiogram configurations. The analysis of the test words revealed that W-22 word list consisted of 22% of high frequency sounds, and the California Consonant test consisted of 38% of high frequency sounds. The reliability of the California Consonant test was observed to be high and was appropriate to identify different degrees of difficulty of patients due to its range of difficulty. The low correlation between the two tests (r = 0.35) was considered to indicate that the two tests, W-22 and the California Consonant test, measured different aspects of speech perception. The W-22 test was considered to measure the overall speech perception difficulties and the California Consonant test was observed to measure the speech perception difficulties faced due to high frequency hearing loss.

According to Owens and Schubert (1977), despite the test being designed to detect the perceptual difficulties of individuals with high frequency loss perceptual, it was found to contain only 38% words with high frequency speech sounds. Thus, the major part of the test did not evaluate high frequency hearing loss.

2.3.4 High Frequency Speech Identification Test for Hindi and Urdu speaker (Ramachandra, 2001)

The High frequency speech identification test for Hindi and Urdu adult speaker in India consists of two lists that were developed with words rated for familiarity. The list consisted of monosyllabic words with high frequency phonemes (/k/, /k^h/, /g/, /g^h/, /c/,

/c^h/, /j/, /j^h/, /t/, /t^h/, /d/, /d^h/, /t/, /p/, /p^h/, /b/, /b^h/, /s/, /z/, /f/, /ʃ/), wherein first list consists of high frequency phonemes in the initial position and the second list consists of high frequency phonemes in the final position. The test was administered on 15 patients with sloping high frequency hearing loss. It was found that the test was more sensitive to detect the perceptual problems faced by these individuals when compared to the 'Common speech identification test for Indians developed by Mayadevi (1974). Further, it was established that there existed no significant difference between Hindi and Urdu speakers when the test was presented at 0 to 40 dB SL. Hence, it was recommended that the test could be used to evaluate speakers of either language. Although the test was reported to have been constructed using high frequency stimuli, it utilized stimuli that have their major segmental cues in the low frequency. These stimuli included /p/, /p^h/, /b/, /b^h/ and the voiced counterparts of high frequency stimuli.

2.3.5 High frequency Kannada speech identification test (Mascarenhas, 2002)

The Speech identification test in Kannada for adults with sloping high frequency hearing loss was constructed using the vowels /a/, /i/, /e/, /o/, /u/, semi vowel /j/, /r/, /l/, stops /k/,/t/, fricatives /s/, /f/, /ʃ/ and affricate/tʃ/. Using these phonemes, a word subtests and a sentence subtest were constructed, each having of 3 lists. The three lists were administered on 30 individuals with normal hearing and 30 individuals with sloping high frequency hearing loss with and without hearing aids. The results were compared with the performance of the participants using the 'Common speech discrimination test for Indians' developed by Mayadevi (1974). No significant difference was found between the word and sentence subtests among the normal hearing individuals. Also, there was no significant difference seen between the 'High frequency speech identification test in

Kannada' and the 'Common speech discrimination test for Indians' among the normal hearing individuals. However, the individuals with a high frequency hearing obtained poorer scores on the word subtest than the sentence subtest, suggesting that the word subtest was more sensitive to detect their problems. Further, in individuals with the high frequency hearing loss, a significant difference was obtained between their aided and unaided performance on the high frequency test. Hence, the test was considered useful for selection of hearing aids for those with a high frequency hearing loss. It was also noted that the High Frequency Kannada Speech Identification test was a more sensitive test for assessing sharply sloping hearing loss than other sloping configuration.

2.3.6 High frequency English speech identification test (Sudipta & Yathiraj, 2005-2006)

For Indian English speakers, Sudipta and Yathiraj (2005-2006) developed a speech identification test to assess perceptual problem of adults with high frequency hearing loss. The test includes four lists of words containing high frequency phonemes /i/, /e/, /j/, /r/, /l/,/s/, /ʃ/, /t/, /t^h/,/k/ and /tʃ/, as well as four sentence subtests. The test was administered on 30 individuals with normal hearing and 10 individuals with sloping hearing loss. The scores were compared with English monosyllabic word test developed by Rout (1996). A significant difference between individuals with normal hearing and individuals with hearing loss was found. The individuals with high frequency hearing loss scored poor on the word subtest than the sentence subtest. Thus, it was reported that the word subtest was more sensitive to detecting the perceptual problem of those with high frequency hearing loss. There was also significant improvement seen in aided condition when compared to unaided conditions. Thus, it was recommended to be used in the selection of hearing aids.

2.3.7 High frequency speech identification test in Tamil (Sinthiya & Sandeep, 2009)

The test was developed to evaluate Tamil speaking adults having high frequency hearing loss. The test consists of 3 lists, two bisyllabic words and 1 trisyllabic word. Initially, 355 words were selected with phonemes /k/, /tʃ/, /s/, /dz/, /l/, /i/ and /e/ for familiarity. The most familiar words (111) were taken up for construction of test material. Later for the selected 111 words, long term average speech spectrum was calculated to determine if the selected words had spectral information predominantly in the high frequency region. Seventy-five words used for the development of the test that included bisyllabic and trisyllabic words. The test was administered on 100 normal hearing individuals to obtain their identification scores. It was established that the participants got no significant difference in their identification scores between the two ears. The three lists were found to be equivalent, and hence it was recommended that any list could be used to obtain scores for individuals with high frequency hearing loss. The actual utility of the test on individuals with high frequency hearing loss was not established.

2.3.8 High frequency speech identification test in Telugu (Ratnakar & Mamatha, 2009-2010)

In lines with the ‘High frequency speech identification test in Tamil’ the ‘High frequency speech identification test in Telugu’ was developed to detect the perceptual problems faced by adults with high frequency hearing loss speaking the language.

Around 300 Telegu words consisting of phonemes /i/, /e/, /k/, /g/, /h/, /s/, /p/, /t/, /tʃ/, /ʃ/ were selected for which the familiarity test was carried out. The most familiar words (157 words) were selected on which Long term average speech spectrum was done. Out of 157 words 75 words were found to be having highest energy above 1500 Hz, which were considered for construction of test material. The test consisted of 3 lists, two bisyllabic and 1 trisyllabic word list, each consisting 25 words each. The test was administered on 100 normal hearing individuals and 5 individuals with high frequency hearing loss. It was reported that there was no significant difference between the identification score across the two ears in individuals with normal hearing. A comparison across the three lists indicated that the bisyllabic words scored were poorer than the trisyllabic word list in the normal hearing group, that was attributed to redundancy of trisyllabic words. There was a significant difference in scores between the two participant groups with those with a high frequency hearing loss scoring poorer than the normal hearing individuals in all three lists. Hence, the author considered the test to be usefulness in detecting perceptual deficits of those with a high frequency hearing loss.

2.3.9 Development of High Frequency Speech Identification Test in Manipuri Language (Hmangte & Geetha, 2014)

Hmangte and Geetha (2014) developed the high frequency speech identification test in Manipuri language for adult speakers of the language having sloping high frequency hearing loss. The test consisted of two list, each having 25 words with the high frequency phonemes /k/, /k^h/,/h/, /s/, /p/, /p^h/, /t/,/t^h/,/ʃ/, /tʃ/ along with /i/, /e/ & /ei/. The Long term averaged speech spectrum (LTASS) was done to assess the energy of the words that lie above 2000 Hz. Among the 230 words selected, 78 words met the criteria and were used for the construction of the test material. The test was administered on 20 native Manipuri speakers with normal hearing at three different presentation levels [20, 40, 60 dB SL (Re: SRT)] to determine their speech identification scores. The result showed significant differences between the three intensity levels, with the scores being higher with increase in level. There was no significant difference between the two lists, suggesting that they were equal at all presentation levels. However, the test was not validated on a clinical population to establish its utility.

From the review it is evident that there have been specially developed tests for the assessment of individuals with a sloping hearing loss. However, all the available tests have been developed for adults. Researchers have shown the likelihood of children also having high frequency hearing loss. Due to the vocabulary of children being different from that of adults, the use of tests meant for the latter group cannot be used in the former group. Hence, it is essential to develop high frequency speech identification tests specifically for children having high frequency hearing loss.

Chapter 3

METHODS

The study was undertaken in three stages. Stage I involved the development of a ‘High Frequency Word Identification test for children in Indian-English (HF-WITCIE). Stage II dealt with the validation of HF-WITCIE on typically developing children and Stage III involved validation of HF-WITCIE on children with hearing impairment. A standard comparison design was used to conduct the study.

Participants

Twenty typically developing children, aged 6 to 9 years, from different schools were selected to check the familiarity of the test material in Stage I. The developed test was validated on 48 typically developing children (16 each in the age groups ≥ 6 to < 7 years, ≥ 7 to < 8 years, and ≥ 8 to < 9 years) in Stage II. The utility of the test was established on 12 typically developing children aged 6 to 9 years in Stage III of the study.

The participants for the study were selected using a purposive sampling technique. For *Stages I, II and III* of the study, children studying in English medium schools for at least 3 years were selected. They had hearing sensitivity within normal limits, with air conduction and bone conduction thresholds being within 15 dB HL, and the air-bone gap being not more than 10 dB HL. It was ensured that they had normal speech and language and no history of ear discharge. They were not selected if they had failed any class.

Instruments:

A calibrated audiometer (Inventis Piano) with headphones (TDH 39 with MX41/AR ear cushion) and with facility for audio input was used for testing the hearing abilities of the children as well as evaluating speech identification. An immittance audiometer (GSI-Tympstar) was used to rule out middle ear pathologies. The recorded material used in the study was presented from a computer loaded with Adobe Audition (Version 3.0) that was routed through the audiometer.

Test environment:

Audio recording of the tests and part of the validation of the material was carried out in a sound treated double room for both Stage II and Stage III. The ambient noise level in the test suite was as recommended by the American National Standards Institute (1999 -R2013) . A part of the validation of the developed test was carried out within the premises of schools, in rooms that were quiet and distraction-free.

Procedure:

Stage I: *Development of the High Frequency Word Identification test for Children in Indian-English (HF-WITCIE)*

Initially, a list of monosyllabic words containing high frequency phonemes (Table 3.1) was selected from story books and text books that were appropriate for children aged 6 to 9 years. Only words having high frequency phonemes that were likely to be familiar to children were selected. The 150 words that were shortlisted were evaluated to determine whether they were familiar to children.

Table 3.1

High frequency phonemes used for the construction of High Frequency Word Identification test for Children in Indian-English (HF-WITCIE)

Phoneme Class	**Phonemes**
Vowels	/i/, /e/
Semi vowels	/j/, /r/, /l/
Stops	/t/, /t^h/
Fricatives	/s/, /f/, /ʃ/
Affricatives	/tʃ/

The *familiarity of the monosyllabic words* was tested on 20 children aged 6 years. The children were instructed to inform whether they knew the meaning of each word either verbally or through action. Based on the responses of the children, each word was classified as ‘highly familiar’, ‘familiar’, and ‘not familiar’. Words that the children report that they had heard of and could describe / demonstrate the meaning were classified as ‘highly familiar’. Words that they had heard of but did not know the meaning was classified as ‘familiar’. The words were grouped as ‘unfamiliar’ if the children had neither heard of them nor knew the meaning.

The words that were categorised as ‘highly familiar’ or ‘familiar’ were utilized for the construction of final test. Four lists were constructed, with each list having 25 words which are shown in Appendix 1. The word-lists were equated in terms of occurrence of different phonemes and level of familiarity. The developed test, ‘High Frequency Word Identification Test for Children in Indian-English’ (HF-WITCIE) was audio recorded before being further evaluated.

Audio recording of the test material was done by a female speaker who was fluent in Indian-English and had a neutral Indian accent. It was recorded in a sound treated room using a condenser microphone (B-2 PRO) with an audio interface (MOTU micro book II). The material was recorded on to a computer loaded with Adobe Audition (Version 3) using a sampling frequency of 44100 Hz and resolution of 32 bits. The recording was done with the microphone placed 6 inches from the mouth of the speaker. The microphone was placed on a stand at the level of her mouth. The mono recorded material was normalized to ensure that the average RMS power of each word was within +/- 4dB from the mean value. A 1 kHz calibration tone having an intensity equal to the root mean square value of the words was generated before each wordlist. A goodness test was performed on 5 adults, fluent in Indian-English, to establish whether the quality of the recording was acceptable. As all the words could be identified with ease, no further modification was done.

Further, the material was filtered to *simulate high frequency hearing loss* based on criteria given by Lloyd and Kaplan (1978). This was done by using Adobe Audition (Version 3.0). The attenuation at specific frequencies to simulate gradual and sharply sloping configurations of high frequency hearing loss is provided in Table 3.2.

Table 3.2

Attenuation levels for simulating gradual and sharply sloping high frequency hearing loss

Frequency (Hz)	**Attenuation (dB)**	
	Gradually Falling configuration	**Sharply Falling configuration**
500	12.4	9.4
1000	3.4	-5.6
2000	-8.6	-19.9
4000	-16.1	-34.1

Stage II: *Validation of HF-WITCIE on typically developing children*

The developed HF-WITCIE test was validated on 48 typically developing children who meet the participant selection criteria. Prior to evaluating each child, informed consent was obtained from the caregivers of the children, adhering to Ethical Guidelines for Bio-Behavioural Research Involving Human Subjects. (2009) of All India Institute of Speech and Hearing. Half the children were randomly selected and evaluated in the sound treated set-up and the other half were evaluated within the school premises. For those who were tested in the sound treated set-up, the stimuli were played through a computer, the output of which was routed to through a diagnostic audiometer (Inventis Piano). The participants heard the test stimuli through headphones (TDH 39 with Mx41/AR ear cushion) at 40 dB SL (Ref. PTA). The 1 kHz calibration was used to adjust the VU meter deflection of the audiometer to zero.

The children who were tested within the school set-up were evaluated using the computer loaded with Adobe Audition (Version 3) via headphones (TDH 39 with

Mx41/AR ear cushion). Prior to testing the children, the volume control of the computer as well as that of the audio software were manipulated such that the output via the headphones was 70 dB SPL. It was set to this value as it was observed that the majority of the children tested in the sound-treated room had average pure-tone thresholds of 10 dB HL. This output level was set using the 1 kHz calibration tone for each list using a Larson Davis Sound level meter (SLM. The output was measured for the left and right headphone separately. The stimuli were played using Adobe Audition (Version 3) the output was heard by the participants through the headphones having noise excluding domes.

The word lists were randomised to avoid a list order effect. Further, the half the participants were tested in their left ear and the other half were tested in their right ear so as to avoid an ear effect. The participants were instructed to repeat and write the words heard by them.

Stage III: *Validation of HF-WITCIE on children with hearing impairment*

Twelve typically developing children were tested with the material that simulated high frequency hearing loss in Stage III. This was done as children with high frequency hearing loss were not available to check the utility of the developed test. Among the 12 children, 6 children were evaluated using the material that simulated gradual sloping configuration and the other 6 children with material that simulated sharply sloping configuration. The procedure used for evaluation was similar to that used in Stage II of the study.

Scoring:

Word as well as phoneme score were calculated for each list for each child. Every correctly identified word/phoneme was given a score of one and an incorrectly identified word/phoneme was given a score of zero. The scores for each child for each list was tabulated. The maximum obtainable word score was 25 and maximum obtainable phoneme score was 59 for each list. The responses were scored in a similar manner in Stage II and Stage III of the study.

Statistical Analyses:

The raw scores of the participants were statistically analysed using Statistical Package for the Social Sciences (Version 17) software. Descriptive and inferential analyses were carried out. A Shapiro-Wilk test indicated that the data were not normally distributed. Hence, non-parametric statistics were used. A Mann Whitney-U test was used to determine the difference across the two set-ups (sound treated set-up & school set-up). A Friedman's test was used to determine the differences within the four lists developed. In order to check for an age effect on four lists, for both word scores and phoneme scores, a Kruskal-Wallis test was carried out. To compare the scoring procedures (word versus phoneme), Wilcoxon Signed Rank test was used.

Chapter 4

RESULTS

The data obtained from all the participants for the four high frequency word-lists were analysed to determine the effect of the test location (school set-up & sound treated room set-up) and also the effect of age on the performance of the children. Additionally, inter-list equivalency and the effect of the scoring procedure (word score & phoneme score) were analysed. Analysis was also done to compare the performance of the normal hearing children with those of children listening to the test stimuli simulating high frequency hearing loss. The phoneme errors were also calculated for the children with normal hearing and simulated high frequency hearing loss. Cronbach's alpha was administered to check the test-retest reliability of the newly developed 'High frequency word identification test for children in Indian-English (HF-WITCIE)'. As mentioned earlier, as Shapiro-Wilk test of normality indicated that the data were not normally distributed, non-parametric tests were used.

The results of the study are provided under following sub-heading:

4.1. Effect of test location (school set-up & sound treated room set-up) on the test scores (analysed using Mann Whitney-U test),

4.2. Effect of age of children on test scores (analysed using Kruskal-Wallis test),

4.3. Comparison of scores (word & phoneme scores) across the lists (analysed using Friedman's test), 4.4. Comparison between word and phoneme scores (analysed using Wilcoxon Signed Rank test),

4.5. Comparison of scores across individuals with normal hearing and simulated high frequency hearing loss (analysed using Kruskal Wallis test & Mann Whitney-U test),

4.6. Phoneme errors in normal hearing listeners and simulated high frequency hearing loss.

4.1. Effect of test location (school & sound treated room set-up) on scores obtained on the test scores

The mean, standard deviation (SD) and median obtained for the scores of the HF-WITCIE in two different locations (school & sound treated room set-up), across the age groups is shown in the Table 4.1. This information is provided for both for word scores and phoneme scores. It can be observed that both word scores and phoneme scores are similar in the two locations (school & sound-treated room set-ups).

To determine if the scores obtained in the two locations were significantly different, Mann Whitney-U test was carried out. The results revealed that there was no significant difference in the test scores obtained in the two set-ups, with the z values ranging from -0.13 to -0.70 and $p > 0.05$ (Table 4.2).

Table 4.1

Mean, Standard deviation (SD), and Median for school and sound treated room set-up across age groups for word and phoneme scores.

Age group (yrs)	Score type		School set-up				Sound-treated room set-up			
			List 1	**List 2**	**List 3**	**List 4**	**List 1**	**List 2**	**List 3**	**List 4**
6 to 7	Word Scores	Mean	23.37	23.12	23.37	23.50	23.50	23.25	23.375	23.87
		SD	0.91	0.64	0.91	0.75	0.92	0.70	0.70	0.64
		Median	24.00	23.00	23.00	23.00	23.50	23.00	24.00	24.00
	Phoneme Scores	Mean	57.37	56.62	57.12	57.12	57.37	57.12	57.50	57.62
		SD	0.91	1.59	1.24	1.12	1.18	0.83	0.92	0.91
		Median	58.00	57.00	57.00	57.00	57.50	57.00	57.50	58.00
7 to 8	Word Scores	Mean	23.00	23.00	23.37	23.75	23.25	23.12	23.25	23.37
		SD	0.75	0.75	0.74	0.88	1.38	0.64	1.03	0.74
		Median	23.00	23.00	23.50	23.50	24.00	23.00	23.00	23.00
	Phoneme Scores	Mean	56.87	57.12	57.37	57.75	57.00	56.87	57.12	57.25
		SD	0.99	0.83	0.74	0.88	1.77	0.83	0.99	0.88
		Median	57.00	57.00	57.50	57.50	58.00	57.00	57.00	57.50
8 to 9	Word Scores	Mean	23.50	23.50	23.87	23.12	23.25	23.62	23.00	23.37
		SD	0.75	0.75	1.12	0.83	0.88	0.91	1.19	0.91
		Median	23.00	23.00	24.00	23.00	23.00	23.00	23.00	23.00
	Phoneme Scores	Mean	57.50	57.12	57.75	57.00	57.00	57.50	56.87	57.25
		SD	0.99	0.99	1.16	0.75	1.41	1.06	1.35	1.16
		Median	57.00	57.00	57.50	57.00	57.00	57.00	57.50	57.50

Note. Maximum possible word score = 25; Maximum possible phoneme score = 59

Table 4.2

Significance of difference between scores obtained across two locations (school & sound-treated room set-up) for word scores and phoneme scores for each list

	Word scores				**Phoneme scores**			
	List 1	**List 2**	**List 3**	**List 4**	**List 1**	**List 2**	**List 3**	**List 4**
/z/ value	- 0.22	-0.51	-0.55	-0.52	-0.13	-0.32	-0.70	-0.43
***p* value**	0.81	0.60	0.58	0.60	0.89	0.74	0.47	0.66

As there was no significant difference between the scores obtained by the children in the two locations, the data obtained in the school set-up and the sound treated set-up were combined for further analyses. The effect of age of the participants was determined with scores of the two locations combined.

Table 4.3

List-wise mean, standard deviation (SD) and median for word scores and phoneme score for HF-WITCIE for each age group and age groups combined.

Age groups (yrs)		Word Scores				Phoneme Scores			
		List 1	List 2	List 3	List 4	List 1	List 2	List 3	List 4
6 to 7	Mean	23.44	23.19	23.56	23.69	57.38	56.88	57.31	57.38
	SD	0.86	0.63	0.78	0.68	0.99	1.21	1.04	0.99
	Median	24.00	23.00	23.50	24.00	58.00	57.00	57.00	57.50
7 to 8	Mean	23.13	23.06	23.31	23.56	56.94	57	57.25	57.50
	SD	1.05	0.65	0.84	0.78	1.34	0.79	0.82	0.86
	Median	23.00	23.00	23.00	23.50	57.00	57.00	57.00	57.5
8 to 9	Mean	23.38	23.56	23.43	23.25	57.50	57.31	57.31	57.12
	SD	0.78	0.78	1.17	0.82	1.08	0.98	1.26	0.92
	Median	23.00	23.00	24.00	23.00	57.00	57.00	57.50	57.00
6 to 9	Mean	23.31	23.27	23.43	23.50	57.18	57.06	57.29	57.33
	SD	0.92	0.73	0.96	0.79	1.17	1.03	10.7	0.95
	Median	23.00	23.00	23.50	23.00	57.00	57.00	57.00	57.00

Note. Maximum possible word score = 25; Maximum possible phoneme score = 59

4.2 Effect of age of children on the performance of the test.

Across the four age groups, the word as well as the phoneme scores were observed to be similar (Table 4.3). This was especially true for the mean scores. The median scores increased marginally with increase in age. To establish whether there exists a significant difference between the performances of the three age groups, Kruskal-

Wallis was administered for each of the four lists. This was done separately for the word scores and the phoneme scores. The statistical test revealed no significant difference ($p >$ 0.05) between the three age groups for each list, irrespective of the scoring procedure used (Table 4.4).

Table 4.4

Level of significance of difference between three age groups on four lists for word score and phoneme score

	Word Scores **p value (df=2)**	**Phoneme Scores** **p value (df=2)**
List 1	0.68	0.67
List 2	0.76	0.73
List 3	0.27	0.91
List 4	0.32	0.54

4.3 Comparison of scores (word & phoneme scores) across the lists.

From Table 4.3 it can be observed that the scores obtained across the four lists were similar. It is evident for the word scores as well as phoneme scores, irrespective of the age of the participants. Likewise, there was only a marginal variation in the standard deviation across the four lists.

Friedman's test was administered to confirm the equivalence of the lists. This was done for the data obtained on the typically developing children as well as that of the simulated hearing loss. In the typically developing children, the results indicated that there was no significant difference within the four lists for the word scores [χ^2 (48) = 3.75, $p > 0.05$] and the phoneme scores [χ^2 (48) = 2.77, $p > 0.05$].

The analysis done with the data that simulated gradual hearing loss, revealed no significant difference between the four lists for the word scores [χ^2 (6) = 2.02, $p > 0.05$] and for the phoneme scores [χ^2 (6) = 1.73, $p > 0.05$]. Likewise, for the data simulating sharply sloping hearing loss, no significant difference was observed for the word scores [χ^2 (6) = 1.00, $p > 0.05$] and for the phoneme scores [χ^2 (6) = 0.15, $p > 0.05$].

4.4 Comparison between the scoring procedures (word & phoneme scores).

As the maximum words scores (25) and phonemes scores (59) were different, the responses obtained from the participants were converted into percentage to the comparison of the two scoring procedures. In the typically developing children, the mean and median percentage word score was 93% and mean phoneme score was 97% (Table 4.5). Thus, it can be observed that the word scores were poorer than that of the phoneme scores. The significance difference between word scoring and phoneme scoring procedure was checked using Wilcoxon Signed Rank test. The results revealed that there was no significant difference seen for normal hearing participants for both scoring procedure. (z = -5.96, $p > 0.05$, two-tailed).

The mean and median for word scores (71%) and phoneme scores (85%) for the gradual sloping hearing loss was found to be higher than the scores obtained by those with simulated sharply sloping hearing loss (65% & 77%, respectively), as shown in Table 4.5. Also, when the comparison was done for scores obtained by those with simulated hearing loss, there was a significant difference seen between the two scoring procedures for gradual sloping hearing loss (z = -2.32, $p < 0.05$, two-tailed) as well as for sharply sloping hearing loss (z = -2.21, p <0.05, two-tailed). Thus, the phoneme scores were significantly higher than the word scores for both gradual and sharply sloping simulated hearing loss.

4.5 Comparison of the performance across individuals with normal hearing and simulated hearing impairment.

As can be noted from Tables 4.5 and Figure 4.1, the scores were poorest for the simulated sharply sloping hearing loss group followed by the simulated gradual sloping hearing loss. The normal hearing listeners obtained the best scores. To check the significance difference between the performance of the three participant groups for the word scores and phoneme scores, Kruskal-Wallis test was carried out. The test results revealed that there was a significant difference between the performance of the three groups on the test for all the four lists for both word scores and phoneme scores (p = < 0.05).

As the Kruskal-Wallis test indicated that there was a significant difference between the three participant groups, Mann Whitney-U test was administered to check which of the group were significantly different from each other. This was done each of the four lists. There was significant difference seen between all pairs of groups (normal hearing listeners vs simulated gradual sloping hearing loss; normal hearing listeners vs simulated sharply sloping hearing loss; and simulated gradual sloping hearing loss vs simulated sharply sloping hearing loss). This was observed for both word scores and phoneme scores (Table 4.6).

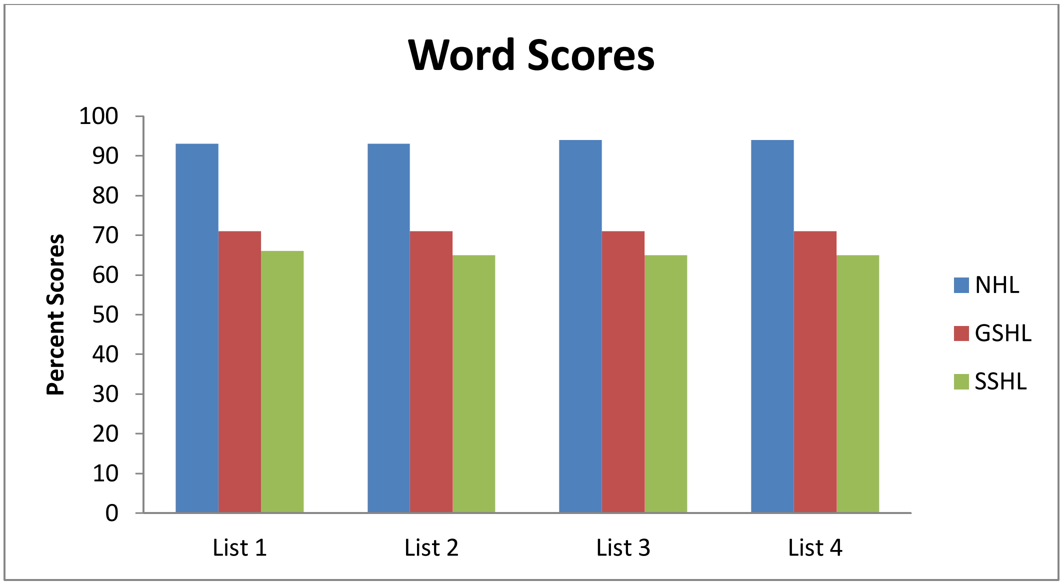

Figure 4.1a. Mean scores across all three participants group (normal hearing listeners, simulated gradual sloping, & simulated sharply sloping hearing loss) for word scores (NHL = Normal hearing listeners; GSHL = gradual sloping hearing loss; SSHL = Sharply sloping hearing loss).

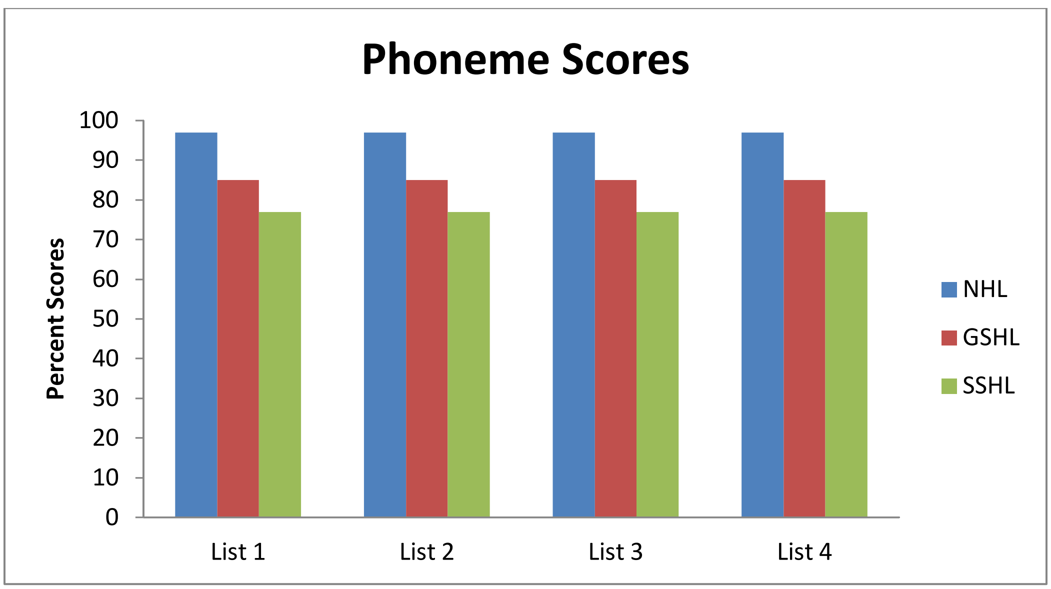

Figure 4.1b. Mean scores across all three participants group (normal hearing listeners, simulated gradual sloping, & simulated sharply sloping hearing loss) for phoneme scores (NHL = Normal hearing listeners; GSHL = gradual sloping hearing loss; SSHL = Sharply sloping hearing loss).

Table 4.5

Mean, Standard deviation (SD), and Median across three groups (normal hearing listeners, simulated gradual sloping hearing loss and simulated sharply sloping hearing loss)

		Word Scores					Phoneme Scores				
		List 1	**List 2**	**List 3**	**List 4**	**Total**	**List 1**	**List 2**	**List 3**	**List 4**	**Total**
Normal hearing	**Mean**	23.31 (93%)	23.27 (93%)	23.43 (94%)	23.50 (94%)	23.37 (93%)	57.18 (97%)	57.06 (97%)	57.29 (97%)	57.33 (97%)	57.21 (97%)
	SD	0.92	0.73	0.96	0.79	0.90	1.17	1.03	1.07	0.95	1.05
	Median	23.00 (93%)	23.00 (93%)	23.50 (94%)	23.00 (93%)	23.12 (93%)	57.00 (97%)	57.00 (97%)	57.00 (97%)	57.00 (97%)	57.00 (97%)
Gradual sloping	**Mean**	17.66 (71%)	17.66 (71%)	18.00 (72%)	18.00 (72%)	17.83 (71%)	50.16 (85%)	50.50 (86%)	50.33 (85%)	50.50 (86%)	50.37 (85%)
	SD	0.47	0.74	0.57	0.57	0.62	0.68	0.76	0.94	0.95	0.9
	Median	18.00 (71%)	17.50 (70%)	18.00 (71%)	18.00 (71%)	17.87 (71%)	50.00 (85%)	50.00 (85%)	50.00 (85%)	50.50 (86%)	50.12 (85%)
Sharply sloping	**Mean**	16.50 (66%)	16.16 (65%)	16.16 (65%)	16.16 (65%)	16.24 (65%)	45.33 (77%)	45.33 (77%)	45.50 (77%)	45.16 (77%)	45.33 (77%)
	SD	0.95	0.68	0.37	0.89	0.85	1.37	0.47	1.70	1.57	1.35
	Median	16.50 (66%)	16.00 (64%)	16.00 (64%)	16.50 (66%)	16.25 (65%)	45.00 (76%)	45.00 (76%)	45.50 (77%)	45.00 (76%)	45.12 (77%)
Gradual + Sharply sloping	**Mean**	17.08 (68%)	16.91 (68%)	17.08 (68%)	17.08 (68%)	17.03 (68%)	47.75 (81%)	47.91 (81%)	47.91 (81%)	47.83 (81%)	47.78 (81%)
	SD	0.95	1.03	1.03	1.18	1.10	2.64	2.66	2.78	2.96	2.99
	Median	17.00 (68%)	17.00 (68%)	17.00 (68%)	17.00 (68%)	17.00 (68%)	48.50 (82%)	48.00 (81%)	48.50 (82%)	48.00 (81%)	48.25 (81%)

Note. Maximum possible score for words = 25; Maximum possible score for phonemes = 59

Table 4.6

Pairwise comparison and level of significance of difference across three groups for four lists on word scores and phoneme scores

	Word Scores				Phoneme Scores			
	List 1 *z* **value**	**List 2** *z* **value**	**List 3** *z* **value**	**List 4** *z* **value**	**List 1** *z* **value**	**List 2** *z* **value**	**List 3** *z* **value**	**List 4** *z* **value**
NHL & GSHL	-4.11**	-4.30**	-4.10**	-4.17**	-4.10**	-4.13**	-4.08**	-4.09**
NHL & SSHL	-4.11**	-4.30**	-4.10**	-4.17**	-4.10**	-4.12**	-4.08**	-4.09**
GSHL & SSHL	-2.04**	-2.51**	-2.97**	-2.75**	-2.92**	-2.99**	-2.90**	-2.93**

Note. NHL = Normal hearing listeners; GSHL = Gradual sloping hearing loss; SSHL = Sharply sloping hearing loss; ** $p < 0.05$

4.6 Phoneme errors

To determine the errors in phoneme perception, initially percentages of the frequency of occurrence for all the phonemes were calculated. Later, using the formula given below the percentage of errors calculated.

$$Percentage\ of\ error = \left(\frac{No\ of\ errors\ observed\ for\ particular\ phoneme}{Frequency\ occurrence\ of\ phoneme\ \times Total\ number\ of\ children}\right) \times 100$$

This was calculated separately for each of the three participant groups (normal hearing listeners, simulated gradually sloping & simulated sharply sloping high frequency hearing loss). Additionally, the percentage of phoneme errors were calculated separately for the high frequency phonemes (/i/. /e/, /j/, /r/, /l/, /s/, /ʃ/, /t/, /t^h/, /f/, /tʃ/) and the low frequency phonemes (/ɔ/, /u/, /b/, /g/, /w/, /k/, /m/, /n/, /h/, /d/, /p/), as shown in Table 4.7a and 4.7b. While the high frequency speech sounds constituted of 71% of the phonemes in the test, the low frequency speech sounds constituted 29%. From the Table 4.7a and 4.7b, it is observed that there were more errors were seen for the high frequency phonemes compared to the low frequency phonemes for all the three participants group. While most of the participants, substituted a high frequency phoneme with other phonemes, a few participants had addition errors and omission errors. Examples of the addition errors included the addition of the phoneme /h/ such that the word ‘art’ was identified as ‘heart’, and ‘ear’ as ‘hear’, as well as /t^h/ was added to the word ‘tea’ and identified as ‘teeth’. Examples of omission errors included the deletion of the phonemes /f/ and /t/ such that the word ‘fear’ was identified as ‘ear’ and ‘tent’ as ‘ten’.

Table 4.7a

Percentage of high frequency phoneme errors in the normal hearing listeners and simulated high frequency hearing loss listeners.

High Frequency Phonemes	**Participant groups**			
	Normal Hearing (N = 48) (% error)	**Gradual sloping (N = 6) (% error)**	**Sharply sloping (N = 6) (% error)**	**Gradual + Sharply sloping hearing loss (N = 12) (% error)**
/i/	2	33	38	36
/e/	7	40	53	61
/j/	0	48	50	54
/r/	4	61	77	83
/l/	2	33	33	34
/t/	5	13	14	14
$/t^h/$	6	22	39	30
/s/	5	23	57	40
/f/	8	26	92	60
/ʃ/	3	25	61	43
/tʃ/	6	61	77	83

Table 4.7b

Percentage of low frequency phoneme errors for normal hearing and simulated high frequency hearing loss.

Low frequency Phonemes	**Participant groups**			
	Normal Hearing (N = 48) (% error)	**Gradual sloping (N = 6) (% error)**	**Sharply sloping (N = 6) (% error)**	**Gradual + Sharply sloping hearing loss (N = 12) (% error)**
/ɔ/	0	8	9	11
/u/	1	7	11	10
/b/	1	8	9	10
/w/	1	3	5	6
/k/	0	11	13	15
/m/	0	7	9	11
/n/	0	9	10	14
/h/	2	9	12	13
/d/	2	10	15	14
/p/	3	9	13	11

4.7 Test-retest reliability

Test-retest reliability was done using Cronbach's alpha test for 6 typically developing children (2 in each age group) and 1 child from each of the two simulated sloping hearing loss groups. The test-retest reliability was high ($\alpha > 0.99$) for all the three age groups and hearing ability groups.

From the findings of the study, it was seen that there was no significant difference in performance, irrespective whether the children were tested in school or in a sound-treated facility. No significant difference was seen between the three age groups of children. Further, the four lists that were developed were found to be equivalent in all the participant groups who were evaluated. Thus, the lists may be used interchangeably. Significant differences were seen between word and phoneme scores, indicating that the information obtained from the two scoring procedures were not identical. Further, significant differences were seen between the normal hearing and gradual sloping hearing loss as well as sharply sloping hearing loss. The phoneme errors varied depending on the hearing status of the children. Also, the test was found to yield reliable test-retest scores.

Chapter 5

DISCUSSION

The results of the newly developed ‘High frequency word identification test for children in Indian-English (HF-WITCIE)’, evaluated on 48 typically developing children and 12 children simulated to have hearing loss, are discussed with reference to the variables studied. The discussion is in terms of the effect of test location (school & sound treated room set-up) on the scores obtained; the effect of age of the participants on the performance of the test; equivalency of the four lists of the test; comparison between the scoring procedures (word score & phoneme score); and the performance of children simulated to have high frequency hearing loss (gradual sloping hearing loss listeners & sharply sloping hearing loss listener). Additionally, the phoneme errors made by the three groups of children (normal hearing, simulated gradual sloping hearing loss, & simulated sharply sloping hearing loss) are discussed.

5.1. Effect of test location (school set-up & sound treated room set-up) on scores obtained on the test scores.

The results of the 48 typically developing children indicated that no significant difference was seen in the performance of the test when administered in the school premises and in an acoustically sound-treated room. In literature, it has been recommended that speech identification testing should be carried out in sound-treated facilities (Bamford et al., 2007; Margolis & Madsen, 2015). However, the findings of the current study indicate that similar performance, as seen in a sound-treated facility, are possible if adequate precautions are taken when testing in non-sound-treated rooms. In the present study, while evaluating the children within the school premises, caution was taken to ensure that the noise levels within and around the room was low. Additionally, the use of noise excluding domes in the headphones must have further attenuated any noise present in the environment. Thus, when speech stimuli are presented at supra-threshold levels (70 dB SPL), in a quiet room using noise excluding domes, results similar to what is seen in a sound-treated room can be expected. Under these conditions, noise in the environment will not have much influence. Thus, from the results on location of evaluation it can be recommended that the testing can also be carried out within a school, provided necessary measures are taken to minimise the adverse effects of environmental noise while evaluating children.

5.2. Effect of age of children on the performance of the test.

The findings of the current study revealed that the three age group studied (≥ 6 to < 7 years, ≥ 7 to < 8 years, and ≥ 8 to < 9 years) performed in similar manner on the four lists of HF-WITCIE. This indicates that the four lists of the newly developed test can be used for individuals above the age of 6 years who have had at least 3 years of education in an English medium school. No age effect was probably seen as the familiarity of the test stimuli was established on the lowest age group studied (6 years olds). Thus, the words used for constructing the test material would have been familiar to all the age groups studied, resulting in no age effect.

5.3. Comparison of scores (word & phoneme scores) across the 4 lists of HF-WITCIE.

The analysis done to check the equivalency of the four lists of HF-WITCIE revealed that there was no significant difference seen across the four lists for all the three participant groups (normal hearing listeners, simulated gradual sloping hearing loss listeners, & sharply sloping hearing loss listeners). The equivalence between the four lists was observed for word scores as well as phoneme scores. The measures taken while constructing the four lists, to ensure that they are equal, would have resulted in them being equivalent. During the construction of the test, the word-lists were equated in terms of occurrence of different phonemes and the level of familiarity. This would have contributed to the lists resulting in equal performance in normal hearing as well as those with simulated hearing loss.

In literature, the need for equivalent lists has been recommended as they avoid familiarity of the stimuli influencing responses when evaluating individuals repeatedly. Multiple lists are required while selecting listening devices (Killion, Niquette, Gudmundsen, Revit, & Banerjee, 2004) or while check the impact of any rehabilitation procedure (Wang, Wu, & Kirk, 2010). Thus, the newly developed HF-WITCIE can be used while selecting listening devices for individuals with high frequency hearing loss above the age of 6 years as well as for evaluating the impact of any form of listening training.

5.4. Comparison between word and phoneme scores.

In the normal hearing participants, no significant difference was found to occur between word and phoneme scoring procedures. This occurred due a ceiling effect where the children obtained near perfect scores. It was noted that standard deviation was only marginally higher for phoneme scores compared to the word scores. Similar results were seen by Mascarenhas (2002) and Sudipta and Yathiraj (2005-2006) for their normal hearing groups. Unlike what was observed in the normal hearing participants, in the present study there was a significant difference seen in word and phoneme score for the simulated high frequency hearing loss listeners. The word scores were noted to be poorer than the phoneme scores for both gradual and sharply sloping hearing loss listeners.

The word scores were found to be poorer than the phoneme scores as a phoneme error within a word resulted in the entire word being scored wrong. However, the same error resulted in only one among the three or four phonemes on the word being marked wrong. This result is in agreement with the findings of Dillon, Ching, Plant, and Spens (1995), Mascarenhas (2002) & Sudipta and Yathiraj (2005-2006).

Depending on the purpose of running the newly developed test, either only word score be calculated or both forms of scoring be used. If the purpose of evaluation is to get an overall idea of the perceptual difficulties of the individuals, then calculation of only word score is adequate. However, if the purpose of evaluation is to determine the specific difficulties of the individual to plan auditory listening training, the phoneme score would enable in planning therapy better.

5.5. Comparison of the performance of the test across Individuals with normal hearing and Individuals with hearing impairment

The comparison between the performance of the normal hearing listeners and the two groups of simulated high frequency hearing loss participants (gradual sloping hearing loss & sharply sloping hearing loss) revealed that there was a significant difference across the three groups. The normal hearing listeners had significantly better scores compared to the simulated gradually sloping hearing loss listeners. The group simulating sharply sloping hearing loss had the poorest scores. This was observed for the word as well as the phoneme scores. The findings of the study indicate that the newly developed test is sensitive to the perceptual errors observed in individuals with high frequency hearing loss.

The sensitivity of the high frequency test can further be observed from the difference in phoneme errors seen across the three participant groups. In the simulated high frequency hearing loss participants, all the high frequency phonemes were affected. Furthermore, the numbers of errors seen per phoneme were more in those with simulated hearing loss compared to the normal hearing listeners. On the contrary, the percentage of errors for the low frequency speech sounds were markedly low for all three groups, with it being similar in the two sloping hearing loss groups. Further, the maximum errors seen for two groups combined were for /r/, /tʃ/ followed by /e/, /f/, /j/ ,/l/, /ʃ/, /s/,/e/,/tʰ/, and least error was seen for phoneme /t/. This trend was seen for both those with simulated gradual and sharply sloping hearing loss.

Studies on individuals having high frequency hearing loss have indicated that the speech sounds that they mainly have difficulty in include /t/,/k/,/f/, /t^h/, /s/ and /ʃ/ (Dubno et al., 1989; Ross, 2009). Fricative perception were found to be more affected in simulated audiogram configuration than other manner of articulation, as reported by Kumar and Yathiraj (2009). Owens et al. (1972) also reported that /s/, /ʃ/ and /t/ were more often affected by individuals with sharply sloping hearing loss than individuals with flat hearing loss.

In the present study, more errors were seen for the phonemes /t/, /f/,/t^h/,/s/ and /ʃ/ in those with a simulated high frequency hearing loss. These findings are similar to that of Dubno et al. (1989). Also, the findings that fricatives are more affected and /s/, /ʃ/ are markedly affected in sharply sloping hearing loss, are in agreement with studies reported in literature (Kumar & Yathiraj, 2009; Owens et al., 1972).

Hence, be it can be inferred that the newly developed test is sensitive to detecting the perceptual difficulties seen in individuals high frequency hearing loss. The test is also sensitive to differentiating the perceptual difficulties faced by individuals with high frequency hearing loss having varying steepness.

Chapter 6

SUMMARY AND CONCLUSION

High frequency hearing loss is usually reported to be seen in adults (Gates & Mills, 2005; Peng et al., 2007; Rabinowitz et al., 2005; Thelin, Joseph, Davis, Baker, & Hosokawa, 1983b). However, studies in literature have also reported of the presence of high frequency hearing loss in children (Hunter et al., 1996; Shargorodsky et al., 2010; Weissenstein et al., 2012). Further, it has been noted in literature that standard speech identification test are not sensitive to detecting the perceptual problems faced by individuals having high frequency sloping hearing loss (Carhart, 1965; Gordon-Salant, 1986; Keith & Talis, 1972; Sher & Owens, 1974). Hence, several tests were developed with the intention of detecting the specific speech perception difficulties faced by those with high frequency hearing loss (Hmangte & Geetha, 2014; Mascarenhas, 2002; Owens & Schubert, 1977; Pascoe, 1975; Ramachandra, 2001; Ratnakar & Mamatha, 2009-2010; Sinthiya & Sandeep, 2009; Sudipta & Yathiraj, 2005-2006). However, the test developed for this target group have been designed for adults (Hmangte & Geetha, 2014; Mascarenhas, 2002; Owens & Schubert, 1977; Pascoe, 1975; Ramachandra, 2001; Ratnakar & Mamatha, 2009-2010; Sinthiya & Sandeep, 2009; Sudipta & Yathiraj, 2005-2006). It is known that tests developed for adults cannot be used for children due to differences in vocabulary. Hence, if speech identification of children with high frequency hearing loss is to be evaluated, tests require to be developed specifically for them. As no high frequency speech identification tests are available for children, the current study aimed to develop a high frequency speech identification in Indian-English for children.

The test, ‘High frequency word identification test for children in Indian-English (HF-WITCIE)’, was developed using monosyllabic words majorly having high frequency phonemes (/i/, /e/, /j/, /r/, /l/, /t/, /t^h/, /s/, /f/, /ʃ/, /tʃ/). Words that were familiar to children aged 6 years were selected to construct four lists, each having 25 words. It was ensured that the four lists had equal representation of the high frequency phonemes. The four lists of the test were validated on 48 typically developing children aged 6-9 years. Half these children were evaluated within the school premises and half in a sound treated facility. The utility of the test was also checked on simulated gradual sloping high frequency hearing loss (N = 6) and simulated sharply sloping high frequency hearing loss (N = 6). For all children both word as well as phoneme scores were calculated.

A Shapiro-Wilk test was carried out and the data were observed to be not normally distributed. Hence, non-parametric statistical tests were used for the analyses of the data (Mann-Whitney-U test, Kruskal-Wallis test, Friedman’s test, Wilcoxon Signed Rank test). The results of study revealed that there was no significant difference in performance of children evaluated in the school premises and those evaluated in a sound treated room set-up. The scores of the children in all three age groups were found to not differ statistically for all the four lists. Further, all four lists of the test were found to be equivalent, indicating the lists can be used interchangeably to assess the speech identification of children with high frequency hearing loss. The utility of the test was confirmed as those with simulated high frequency hearing loss performed significantly poorer that those with normal hearing. Additionally, the test was able to differentiate the performance of those with gradual sloping hearing loss and sharply sloping hearing loss.

Thus, it can be conclude that the developed High frequency word identification test for children in Indian-English (HF-WITCIE) is sensitive to detect the speech perception problems faced by children with high frequency hearing loss. However, the utility of the test requires to be confirmed on children who actually have a high frequency hearing loss.

Implications of the study:

- The perceptual problem faced by children with high frequency hearing loss can be easily identified using the developed test material.
- The test will provide information that will help in planning and managing rehabilitation of children with high frequency hearing loss.
- It can also help in assessing the effectiveness of therapy for the perception of high frequency speech sounds undergone by children.
- The developed test will also aid in making the decision to either continue use of hearing aid or else go for cochlear implant.

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APPENDIX

APPENDIX 1

High Frequency Word Identification Test for Children in Indian-English (HF-WITCIE)

Developed in the Department of Audiology,
All India Institute of Speech and Hearing, Mysuru, India

Background Information:

The High Frequency Word Identification Test for Children in Indian-English (HF-WITCIE) is developed as a part of a master's dissertation by Nakhawa Sonal C. under the guidance of Dr. Asha Yathiraj, Professor of Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysuru, India. The test is designed to assess the speech perception difficulties faced by children having high frequency hearing loss aged 6 years and above. The test consists of four equivalent lists.

Test administration procedure:

The test is to be carried out 40 dB SL (ref. PTA) in a sound treated room, either under headphones or through sound-field loudspeakers using the CD version of the test. The individual administering the test should instruct the child to listen to the words carefully repeat them or write them down on the response sheet provided.

The response of the child is to be scored by the tester, wherein both word and phoneme scoring are recommended to be calculated. Each correctly repeated response will be given a score of 1 and an incorrect response a score of 0. For each list, the maximum word score is 25 and maximum phoneme score is 59.

High Frequency Word Identification Test for Children in Indian-English (HF-WITCIE)

WORD LISTS

List 1	**List 2**	**List 3**	**List 4**
1. Shelf	1. Sit	1. Chest	1. Fish
2. First	2. Fill	2. Real	2. Test
3. Lie	3. Chess	3. Still	3. Yes
4. Rice	4. Tea	4. Chain	4. Fall
5. Tell	5. Eyes	5. Height	5. Ship
6. Ear	6. Short	6. Search	6. Lot
7. Shirt	7. Fail	7. Sheet	7. Four
8. Six	8. Thin	8. Eight	8. Race
9. Best	9. Shoot	9. Toy	9. Child
10. State	10. Fear	10. Left	10. Torch
11. Face	11. Shell	11. Tie	11. Suit
12. Loss	12. Teach	12. Hit	12. Stick
13. Right	13. Less	13. Ten	13. Wish
14. Tall	14. Rat	14. Melt	14. Feed
15. Sweet	15. Chart	15. His	15. Life
16. Three	16. Sheep	16. Sat	16. Sea
17. Soft	17. Tent	17. Thief	17. Leaf
18. Tin	18. Waist	18. Late	18. Seat
19. Gift	19. Heat	19. Last	19. Check
20. Which	20. She	20. Miss	20. Teeth
21. Lost	21. Meet	21. Safe	21. Slate
22. Like	22. Farm	22. Fast	22. Lip
23. Chat	23. Feet	23. Cheek	23. Silk
24. Rush	24. Rule	24. Art	24. Chair
25. Fat	25. Start	25. Fit	25. Pet

Response Sheet

Name: Date:

Class/ Section: Age/Gender:

Case No. Contact No:

School: Address:

(Note the response of the child in the space provided and indicate the word scores and phoneme scores for the list used in the space provided)

	List No:_____	**Right ear**		**List No:_____**	**Left ear**	
	Response	Word score	Phoneme score	Response	Word score	Phoneme score
1						
2						
3						
4						
5						
6						
7						
8						
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10						
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12						
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14						
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21						
22						
23						
24						
25						
	Total Scores (RE)			**Total Scores (LE)**		

Note. RE = Right ear; LE = Left ear; Maximum score for word = 25; Maximum score for phoneme = 59