The Effect of Stimulus Bandwidth on Perception of Fricative /s/ among Individuals with Different Degrees of Sensorineural Hearing Loss

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Abstract—Most of the speech sounds that contribute to speech intelligibility are dominated by high-frequency components. The phoneme /s/ is the third or fourth most frequently occurring phoneme in the English language and second most frequently occurring consonantal phoneme in Hindi language. Given the importance of the phoneme /s/, it is ironic that, this sound contains the highest frequency acoustic elements of any speech sound in English and most of the non-English languages ranging from 4500 Hz to more than 8000 Hz. The most common type of hearing impairment affecting speech perception is high-frequency sensorineural loss (SN) and such individuals require good high frequency audibility in order to better perceive fricative cues, regardless of hearing status. While many studies appear to support the general notion that high-frequency amplification may not always be beneficial, the inter-subject variability in most studies precludes a clearly defined rule that would distinguish listeners who are likely to benefit from high-frequency amplification from those who are not. The current study is aimed to determine and compare the effective bandwidth required for the perception of fricative /s/ in individuals with normal hearing and hearing impairment as a function of degree of hearing loss. A total of 100 Hindi speaking subjects equally divided into four groups (Group I: Normal hearing, Group II: Moderate SN hearing loss, Group III: Moderately severe SN hearing loss, Group IV: Severe SN hearing loss) participated in the study. Nonsense syllables containing the phonemes /s/, /f/, /s/ and /c/ in /i/ vowel context and low pass filtered at 1, 2, 3, 4, 5, 6, 7, 8 and 9 KHz produced by a female talker were used as stimulus. The results revealed that there was a statistically significant effect (p<0.05) of bandwidth for the perception /s/ between different groups at 1 KHz, 2 KHz, 3 KHz, 4 KHz, 5 KHz, 6 KHz, 7 KHz and 8 KHz and no significant effect (p>0.05) was seen at 9 KHz between groups. In addition, individuals with normal hearing required lower bandwidth for accurate fricative perception and there was a statistically significant difference (p<0.05) in mean bandwidth between groups. Among the hearing impaired group, as the degree of hearing loss increased the subjects required higher bandwidth for accurate perception of fricative. This study has important implications in knowing the effective bandwidth required for the perception of high frequency speech sounds among individuals with hearing loss on individual basis which in turn helps in the selection of appropriate rehabilitative devices.

Index Terms-High Frequency Hearing Loss, fricative /s/, stimulus bandwidth, speech perception

I. INTRODUCTION

Speech perception is the process of transforming a continuously changing acoustical signal into discrete linguistic units (Rvachew & Grawburg, 2006). The study of speech perception is concerned with the listener's ability to perceive the acoustic waveforms produced by a speaker as a string of meaningful words and ideas (Goldinger, Pisonic & Logan, 1991). Hearing is a vital sense that is necessary for the development and maintenance of acoustic communication skills. To be able to hear and comprehend speech, good auditory integrity is required. Individuals with hearing loss are bound to have difficulty in perception of speech. Therefore, it is the essential duty of audiologists to identify, evaluate and

rehabilitate aurally handicapped individuals. One of the common hearing impairment affecting speech perception is sensorineural hearing loss.

Sensorineural hearing loss occurs due to damage to the transduction mechanism of the inner ear and due to abnormality in the auditory nerve, which are responsible for sensing sounds of different pitches. A common complaint among individuals with sensorineural hearing loss (SNHL) is difficulty understanding speech, particularly under adverse listening conditions (Crandell, 1991). The extent and nature of the difficulty depends partly on the severity of the hearing loss. Individuals with mild or moderate loss can usually understand speech reasonably well when they are in quiet room with only one person talking. However, they have difficulty when more than one person is talking at a time, or when background noise or reverberations are present. Individuals with severe or profound loss usually have difficulty even when listening to a single talker in a quiet room and they generally have severe problems when background noise is present. Hence their ability to understand speech relies heavily on lip reading and use of context.

The most common type of hearing impairment affecting speech perception is high-frequency sensorineural loss and such individuals have some access to low-frequency sounds, with limited access to higher frequency sounds (Davis, 1995). These individuals often miss out on high-frequency components of speech, such as consonant sounds and can have difficulties understanding speech in background noise. Many sounds that contribute to speech intelligibility are dominated by high-frequency components. Furthermore, young children with hearing impairment who are learning a language for the first time benefit from being able to hear the high-frequency speech sounds that they are trying to produce (Stelmachowicz, Lewis, Choi & Hoover, 2007).

In addition to these benefits for speech perception and production, the audibility of high-frequency sounds, provides other advantages (Simpson, Hersbach & McDermott, 2005). For example, some valuable information about the source of sounds, such as birdsong and various important environmental noises are conveyed principally by high-frequency components. The subjective quality of these sounds tends to be judged as relatively poor if the high frequencies are too soft or inaudible (Moore & Tan, 2003).

Acoustically, conversational speech has the most energy between approximately 500 Hz and 3000 Hz. This mid frequency region is important for understanding speech, particularly speech that is meaningful such as words, sentences, or passages (Pavlovic, 1987; Studebaker, Pavlovic & Sherbecoe, 1987 and Studebaker & Sherbecoe, 2002). However, speech energy above 3000 Hz (high frequency region sounds) also offers listeners important linguistic information. High frequency speech information is extremely important for appreciation of music, detection of environmental sounds, and it serves several important linguistic functions in day to day communication (Kuk, Korhonen, Peeters, Keenan, Jessen & Andersen, 2006). Elfenbein, Hardin-Jones & Davis (1994) found that production and perception of fricatives may be difficult for listeners with sensorineural hearing loss.

Given the importance of the /s/ phoneme, this sound contains the highest frequency acoustic elements of any sound in the English and most of the non-English languages. Therefore, the perception of /s/ phoneme is the most challenging for the average hearing-impaired listener. It is the third or fourth most frequently occurring phoneme in the English language and serves multiple linguistic functions, including plurality, tense, and possession (Tobias, 1959; Denes, 1963 and Rudmin, 1983). Fricative /s/ is the second most frequently occurring phoneme among the overall used consonantal phonemes of Hindi (an Indo-Aryan) language (calculated from phonetically balanced words in Hindi (AIIMS, 1968 & 1969).

An analysis of the acoustic spectrum of /s/ shows that it has most of its significant energy well above 4000 Hz, ranging from 4500 Hz to more than 8000 Hz (Boothroyd, & Medwetsky, 1992). This suggests that most people with a high-frequency hearing loss must depend upon the lower frequency elements of /s/ and other high-frequency voiceless consonants in order to barely perceive them. Hence listeners require good high frequency audibility in order to better perceive fricative cues, regardless of hearing status. Among both adults and children with hearing loss, /s/ is one of the most frequently misperceived phonemes (Owens, Benedict & Schubert, 1972; Bilger & Wang, 1976; Owens, 1978; Dubno & Dirks, 1982 and Danhauer, Abdala, Johnson & Asp, 1986). Boothroyd & Medwetsky (1992) suggested that the current hearing aids may require a wider bandwidth (up to 10 KHz) to ensure the audibility of voiceless fricatives and high frequency linguistic information for female speakers.

As evidenced by many examples provided above, high frequency speech information is extremely important for speech comprehension, detection of environmental sounds, and safety. Unfortunately, this frequency region is difficult to amplify sufficiently using conventional hearing aids. Thus reduced audibility of the high frequency components of speech due to limited stimulus bandwidth of current hearing aids would be expected to impair self monitoring and thus may contribute to poorer production of fricatives and affricates.

The conventional hearing aid technology is limited in its ability to provide adequate gain for soft, high frequency speech sounds, particularly the fricative consonants. It is difficult to achieve sufficient gain in the frequency spectrum above 3000 Hz thus limiting the ability of the typical infant with hearing loss to hear high-frequency consonants, particularly the fricative sounds (Hayes & Northern, 1996). If suitable gain is achieved in the high frequency region, acoustic feedback may result when the hearing aid is worn by the listener (Beamer, Grant & Walden, 2000).

Apart from limited ability to provide sufficient high-frequency gain, conventional hearing aids provide too much gain at low frequencies (Bratt & Sammeth, 1991) and too much low-to mid-frequency gain which may mask the important

high-frequency speech information (i.e. upward spread of masking) potentially resulting in speech recognition deficits (Cook, Bacon & Sammeth, 1997 and Gange, 1998).

Additionally, the output bandwidth of conventional hearing aids is not broad enough to make high-frequency sounds consistently audible due to the technical difficulty of combining high power and high bandwidth in the same transducer (Gange, 1998). These factors limit the audibility of important high–frequency speech sounds, especially for children with sloping and/or severe to profound hearing loss (Stelmachowicz, Pittman, Hoover, Lewis & Moeller, 2004).

Studies suggested that listeners who are provided with audibility at frequencies where hearing levels are severe and/or sloping will not show speech recognition benefit due to the limited ability to use the amplified signal in that frequency region (Hogan & Turner, 1998 and Ching, Dillon, Katsch & Byrne, 2001). This lack of benefit of high-frequency amplification, when found, has been attributed by many researchers to the presence of non-functioning inner hair cells over a certain region of the cochlea- that is, dead regions (Baer, Moore & Kluk, 2002; Moore, Glasberg & Baer, 1997 and Vickers, Baer & Moore, 2001).

On the other hand, other studies have reported that significant improvements in speech understanding, especially in noisy environments, occur when listeners with sloping sensorineural hearing loss are provided with high frequency amplification (Turner & Henry, 2002). Additionally, listeners with suspected dead regions in the high-frequencies perform better on speech recognition tasks when broadband amplification is used (Mackersie, Crocker & Davis, 2004), while listeners without dead regions are better able to make use of high–frequency cues (Moore, 2004). Individual performance in such studies indicated that listeners receive varying degrees of speech recognition benefit from amplified high-frequencies.

II. NEED AND SIGNIFICANCE OF THE STUDY

The most challenging hearing loss configurations that audiologists face are high frequency sloping and/or severe to profound sensory neural hearing losses. Evidence has been mounting that the current conventional hearing aid technology may not provide enough audibility of the high frequency energy for individuals with sloping and/or severe to profound hearing loss (Glista, Scollie, Bagatto, Seewald & Johnson, 2009). Also recent studies suggest that reduced audibility in high frequencies (because of limited bandwidth of hearing instruments) may play role in delayed phonological development often seen in children with hearing impairment and also it leads to poor perception of fricative sounds in adult hearing aid users.

While many studies appear to support the general notion that high-frequency amplification may not always be beneficial, the inter-subject variability in most studies precludes a clearly defined rule that would distinguish listeners who are likely to benefit from high-frequency amplification from those who are not. Hence there is a need to determine the effective range of bandwidth required for each hearing impaired individual for the perception of high frequency speech sounds.

If the effective bandwidth for accurate perception of fricatives is determined, it will be useful to choose suitable amplification strategy required for better perception of high frequency speech sounds. The knowledge of effective stimulus bandwidth for hearing impaired individuals will help in determining candidacy for frequency compression hearing aids and cochlear implants. Hence, the current study is aimed to determine and compare the effective bandwidth required for the perception of fricative /s/ in individuals with normal hearing and hearing impairment as a function of varying degrees of hearing loss.

III. METHOD

A. Aim of the Study

The current study was undertaken to contribute to the existing review of literature for identifying the benefits of bandwidth variation on perception of high frequency speech sounds. The present study focused on perception of /s/ in context of other high frequency nonsense syllables as a function of varying degrees of hearing loss in a population of acquired sensorineural hearing impairment. The bandwidth cut-off frequency and degree of hearing loss were considered on assessing the benefits of bandwidth modulation.

B. Subjects

A total of 100 Hindi speaking subjects (200 ears) with an age range of 18-40 years participated in the study. The mean age of the group of subjects was 31.5 years. These subjects were further equally divided into four groups depending on their hearing status.

1. Group I: Consisted of 25 individuals (13 male & 12 female) with normal hearing sensitivity and had pure tone thresholds \leq 15 dB HL in the octave frequencies from 0.25 KHz to 8 KHz.

2. Group II: Consisted of 25 individuals (13 male & 12 female) with bilateral moderate sensorineural hearing loss and had pure tone thresholds in the range of 41-55 dB HL in the octave frequencies from 0.25 KHz to 8 KHz.

3. Group III: Consisted of 25 individuals (13 male & 12 female) with bilateral moderately severe sensorineural hearing loss and had pure tone thresholds in the range of 56-70 dB HL in the octave frequencies from 0.25 KHz to 8 KHz.

4. Group IV: Consisted of 25 individuals (13 male & 12 female) with bilateral severe sensorineural hearing loss and had pure tone thresholds in the range of 71-90 dB HL in the octave frequencies from 0.25 KHz to 8 KHz.

C. Instrumentation

All the testing was done using a calibrated dual channel clinical audiometer MAICO MA 53 in sound treated room under headphones (TDH 39) with ambient noise maintained at minimum level to minimize interference to the testing (ANSI, 1991). A calibrated Immitance audiometer (Madsen Zodiac 901) was used to rule out presence of middle ear pathology. A Dell Laptop (InspironN5010) with windows 7 was used to deliver the stimuli.

D. Development of the Test Stimuli

Test stimuli used were consonant - vowel (CV) nonsense syllables comprised of phonemes /s/, /f/, /\$ / and /c/ in /i/ vowel context produced by a female talker. The /i/ vowel was used to minimize the vocalic transition which might be used as a cue to distinguish the fricatives from one another. Although the primary interest of this study was the perception of /s/, it was necessary to provide subjects with alternative stimuli that would confuse the client and reduce practice and order-effect. Hence other phonemes /f/, /\$ / and /c/ were used as alternatives.

E. Recording of the Stimuli

All the recording and generation of speech stimuli was done using high quality audio-editing software "*PROTOOL*" in a sound treated audio studio. Speech sample were recorded at a comfortable utterance level in a sound-attenuated room using a condenser microphone at a distance of 12 cm from mouth, with flat frequency response at 10 KHz. All the speech stimuli were recorded by a female talker. Speech samples were then amplified and filtered at 10 KHz, and digitized at a sampling rate of 20 KHz and 12 bit quantization in "*PROTOOL*" audio editing software. 20 KHz sampling rate is selected in the study because use of relatively high sampling rates can have undesirable side-effects. The digital signal processor inside any modern hearing instrument is programmed to modify the sound signals at a rate that is equal or proportional to the sampling rate and it is common for the sampling rate in hearing instruments to be approximately 20 KHz. This choice means that the upper limit of the bandwidth in terms of sound produced by the HI must be about 10 KHz. In some devices, the sampling rate may be as low as 16 KHz resulting in an acoustic bandwidth of less than 8 KHz.

F. Signal Processing

Multiple repetitions of each sample were obtained and samples with little or no transition were selected as stimuli for the study. To determine the influence of bandwidth on perception of high frequency voiceless consonant /s/, each nonsense syllable (/si/, /fi/, /\$ / and /ci/) was low pass filtered in a sixth order Butterworth filter with rejection rate of 50 dB octave at 9 frequencies (1 KHz to 9 KHz) to form 36 stimuli (4x6) including 9 target stimuli (i.e. /s/ filtered at 1, 2, 3, 4, 5, 6, 7, 8 and 9 KHz). These 36 nonsense syllables were randomly arranged in terms of order of stimulus into two separate lists to form two different stimuli sequence. List 1 stimulus sequence was used for right ear and List 2 stimulus sequence was used for left ear. This was done to avoid order and practice effect.

G. Procedure

Before the experimental task all the subjects were screened for hearing sensitivity using a calibrated clinical audiometer MAICO MA 53 with TDH 39 ear phones. After the necessary screening of the clients, the line out of the Dell Laptop (InspironN5010) was connected to the dual channel audiometer MA 53 through an RF jack. The developed test material was played through a CD player, which was routed through MAICO MA 53 Diagnostic Clinical Audiometer and delivered through the TDH 39 headphones. All the subjects were tested monaurally with two lists and each ear was tested with different random list. The stimulus was presented at 65 dB SPL.

The subjects were tested in a sound-treated audiometric room. Each subject was given following instructions in Telugu "You will listen to few sounds presented through headphones. Listen carefully and when you hear sound you have to repeat as you hear them". An open set response in the form of an oral response was obtained. If the subject felt tired during the test, a short break was given. The lowest bandwidth where the subjects could repeat the syllable /si/ was calculated for each subject (both ears) in each group. The group percentages correct responses for each bandwidth was also calculated for each group.

H. Statistical Analysis

The data obtained was subjected to statistical analysis using the SPSS version 17.0 software. Since 25 subjects (50 ears) in each group were involved in the study the values were calculated for 50 ears in each group. Mean and standard deviation values of stimulus bandwidth required for the perception of /s/ were calculated for each group (both ears) and the data was subjected to one way ANOVA with repeated measures in order to find out significant difference between groups. The group percentage correct responses at each bandwidth was measured for each group (both ears) and in order to find out the significant effect of bandwidth among the group, the data was further subjected to Pearson Chi-Square test. The results are discussed in the next chapter.

IV. RESULTS AND DISCUSSION

The current study was conducted to determine the effective stimulus bandwidth required for accurate perception of fricative /s/ and to compare the stimulus bandwidth required for accurate perception of fricative /s/ in individuals with normal hearing and hearing impaired individuals with varying degrees of sensorineural hearing loss. The main objectives of the study were:

1. To determine and compare the effect of bandwidths (i.e. 1 KHz, 2 KHz, 3 KHz, 4 KHz, 5 KHz, 6 KHz, 7 KHz, 8 KHz, 9 KHz) on group performance scores (%) between different groups.

TABLE 1

2. To determine and compare the mean bandwidth required for the perception of fricative /s/ between different groups

A. The Effect of Stimulus Bandwidth on Group Performance Scores (%) for the Perception of Fricative /s/ between Different Groups

Frequency	Group Performance Correct Responses (%)					
	Group I	Group II	Group III	Group IV		
1 KHz	0	0	0	0		
2 KHz	6	0	0	0		
3 KHz	42	0	0	0		
4 KHz	76	28	0	0		
5 KHz	96	72	30	0		
6 KHz	100	86	62	0		
7 KHz	100	96	88	2		
8 KHz	100	96	96	26		
9 KHz	100	100	100	98		



Figure 1: Comparison of group performance scores (%) across various bandwidths

Individuals with normal hearing (Group I) obtained group mean percentage score of 0%, 6%, 42%, 76% & 96% for 1 KHz, 2 KHz, 3 KHz, 4 KHz, & 5 KHz respectively and a score of 100% at 6 KHz, 7 KHz, 8 KHz and 9 KHz. Individuals with moderate hearing loss (Group II) obtained mean percentage score of 0%, 0%, 0%, 0%, 28%, 72% & 86% at 1 KHz, 2 KHz, 3 KHz, 4 KHz, 5 KHz & 6 KHz respectively and a score of 96% at 7 KHz & 8 KHz and could achieve 100% score at 9 KHz. Individuals with moderately severe hearing loss (Group III) obtained mean percentage score of 0%, 0%, 0%, 0%, 30%, 62%, 88%, 96% & 100% at 1 KHz, 2 KHz, 3 KHz, 4 KHz, 5 KHz, 8 KHz and 9 KHz respectively. Individuals with severe hearing loss (Group IV) obtained mean percentage score of 0%, at 1 KHz, 2 KHz, 3 KHz, 4 KHz, 5 KHz, 6 KHz, 7 KHz, 8 KHz and 9 KHz respectively. Individuals with severe hearing loss (Group IV) obtained mean percentage score of 0%, at 1 KHz, 2 KHz, 3 KHz, 4 KHz, 5 KHz & 6 KHz and a score of 2%, 26% & 98% at 7 KHz, 8 KHz and 9 KHz respectively.

Thus the results revealed that individuals with normal hearing (Group I) could achieve a maximum group performance score of 100% at 6 KHz Bandwidth whereas individuals with moderate (Group II) and moderately severe hearing loss (Group III) achieved a maximum score of 100% at 9 KHz and individual with severe hearing loss (Group IV) could not achieve a score of 100% even at 9 KHz. They obtained a maximum score of 98% responses at 9 KHz bandwidth.

Group I reached 80% group performance correct score at approximately 4.2 KHz as compared to Group II, Group III and Group IV who reached 80% scores at 5.5 KHz, 6.6 KHz and 8.8 KHz respectively. Hence it can be inferred that hearing impaired individuals require higher bandwidths for better performance on perception of /s/ as compared to normal subjects.

Among the hearing impaired individuals, the group performance scores were better in group I as compared to group II and group III at 4 KHz, 5 KHz, 6 KHz and 7 KHz. Group II and Group III showed similar performance at 8 KHz and 9 KHz, whereas group IV performed poorly at all bandwidths.

The data was further subjected to Pearson Chi-square test of independence in order to find out significant effect of bandwidth for the perception of fricative /s/ between different groups. The results revealed that there was a statistically significant effect (p<0.05) of bandwidth for the perception /s/ between different groups at 1 KHz, 2 KHz, 3 KHz, 4 KHz, 5 KHz, 6 KHz, 7 KHz and 8 KHz and no significant effect (p>0.05) was seen at 9 KHz between groups. Hence, it can be inferred that the group performance was not similar up to 8 KHz bandwidth, whereas at 9 KHz the group performance was similar in all the groups.

B. Comparison of Mean Bandwidth Required for the Perception of Fricative /s/ in Individuals between Groups

		TA	ABLE 2				
MEAN BANDWIDTH REQUIRED FOR THE PERCEPTION OF /S/ IN DIFFERENT GROUPS							
Group	N (Fors)	Bandwidth	(KHz)	Significance			
	IN (Lais)	Mean	SD	p-value			
Ι	50	3.78	0.95				
II	50	5.22	1.20	0.000*			
III	50	6.26	1.08	(P<0.05)			
IV	50	8.72	0.49				
Total	200	6.00	2.04				
*Highly Significant							



Figure 2: Mean Bandwidth (KHz) required for the perception of /s/ in different groups

The subjects obtained a mean bandwidth of 3.78 KHz, 5.22 KHz, 6.26 KHz and 8.72 KHz for the perception of /s/ in group I, Group II, Group III and Group IV respectively. In order to find out the significant mean difference in bandwidth to perceive fricative /s/ among groups, the data was subjected to one way ANOVA with repeated measures and the results showed that there was significant difference (p<0.05) in mean scores between groups and within groups.

Hence, the data was subjected to LSD Post Hoc test in order to find out significant difference between groups (i.e. Group I vs. Group II, Group I vs. Group III, Group I vs. Group IV, Group II vs. Group III, Group II vs. Group IV and Group III vs. Group IV). The results revealed that there was a statistically significant difference (p<0.05) in mean bandwidth between groups.

Individuals with normal hearing (Group I) perceived /s/ at a lower bandwidth (3.78 KHz) as compared to the subjects in the hearing impaired groups. Among the hearing impaired groups, moderate hearing loss group perceived /s/ at lower bandwidth (5.22 KHz) followed by moderately severe hearing loss group (6.26 KHz) and severe hearing loss group (8.72 KHz). Hence it can be inferred that hearing impaired individuals require higher bandwidths for the perception of /s/ as compared to normal subjects.

These findings are in accordance with the findings of Stelmachowicz, Pittman, Hoover & Lewis (2001), who reported that listeners with moderate to moderately severe sensorineural hearing impairment needed an audible bandwidth of 4.2 KHz to 6.9 KHz for male speech, 6.3 to 8.8 KHz for female speech, and 9 KHz for child speech in order to understand fricatives especially /s/.

Among the hearing impaired individuals, the required bandwidth for the perception of /s/ increased, as the degree of hearing loss increased is an interesting finding of the study. These findings are in accordance with the findings of Ricketts, Dittberner & Johnson (2008), who studied if preference for bandwidth extension in hearing aid processed sounds was related to the magnitude of hearing loss in individual listeners. They took 10 participants with normal hearing and 20 with mild to moderate hearing loss and processed signals using hearing aid style compression algorithms

and filtered using two cut-off frequencies, 5.5 KHz and 9 KHz, which were selected to represent bandwidths that are achievable in modern hearing aids. In conclusion, consistent preference for wider bandwidth is present in some listeners with mild- to- moderate hearing loss.

Hence, the hypothesis stating that there will not be any significant difference in mean bandwidth required for the perception of fricative /s/ in different groups is rejected (i.e. Group I vs. Group II, Group I vs. Group II, Group I vs. Group IV, Group II vs. Group II, Group II vs. Group IV, Broup II, Group II vs. Group IV, Broup II, Group II, Group II, Group II, Group IV, Broup IV, Broup IV, Broup II, Group II, Group IV, Broup IV,

Although there was a significant effect of bandwidth on group performance, the subjects with moderate and moderately severe hearing loss could reach 100% at higher bandwidths. The performance of other groups improved as bandwidth increased but it was not seen in individuals with severe hearing loss despite providing the widest bandwidth (9 KHz). This could be explained in accordance with the results reported by Skinner (1980), Murray & Byrne (1986), Rankovic (1998), Hogan & Turner (1998) and Turner & Cummings (1999). They reported that systematic increase in high-frequency gain may not improve, and in some cases may degrade, speech recognition for listeners with greater degrees of hearing loss. If amplifying speech to audible levels in the high frequencies does not improve speech recognition, then attempts to provide gain may not be necessary or desirable in certain cases.

Hogan & Turner (1998) also investigated the effects of stimulus bandwidth on phoneme recognition in listeners with high frequency hearing losses. They reported benefit obtained by providing additional high-frequency audibility was negligible or negative when the degree of loss at and above 4 KHz exceeded 55 dB HL. In some cases, performance decreased with increases in high-frequency audibility. Although above studies justify poor performance of severe hearing loss individuals at 9 KHz, this study findings disagree with the results of Hornsby & Ricketts (2006), who reported improved speech recognition with increasing bandwidth in listeners with high-frequency hearing thresholds as poor as 85 dB HL. They reported small incremental improvements in speech recognition performance as the audible high-frequency energy was extended from 3.2 KHz up to approximately 7 KHz.

V. SUMMARY AND CONCLUSION

The most challenging hearing loss configurations that audiologists face are high frequency sloping and/or severe to profound sensory neural hearing loss. Evidence has been mounting that the current conventional hearing aid technology may not provide enough audibility of the high frequency energy for such individuals. While many studies appear to support the general notion that high-frequency amplification may not always be beneficial, the inter subject variability in most studies precludes a clearly defined rule that would distinguish listeners who are likely to benefit from high-frequency amplification from those who are not. Hence there is a need to determine the effective range of bandwidth required for each hearing impaired individual for the perception of high frequency speech sounds. If the effective bandwidth for accurate perception of fricatives is determined, it will be useful to choose suitable amplification strategy required for better perception of high frequency speech sounds. The current study revealed that hearing impaired subjects required greater bandwidth for the perception of fricatives as compared to normal subjects. Among the hearing impaired individuals as the degree of hearing loss increased they required broader bandwidth for accurate perception of high frequency speech sounds among individuals with hearing loss on individual basis which in turn helps in the selection of appropriate rehabilitative devices such as conventional hearing aids, cochlear implants, and frequency compression devices.

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