Comparison of Coarticulation Perception in Individuals with Normal Hearing and Hearing Impairment

Pratibha Nagalakshmi, N. G.
Register No.: 14AUD018

This Dissertation is submitted as part of fulfillment

for the Degree of Master of Science in Audiology

University of Mysore, Mysuru

May, 2016

CERTIFICATE

This is to certify that this dissertation entitled "***Comparison of Coarticulation Perception in Individuals with Normal Hearing and Hearing Impairment***" is a bonafide work submitted in part fulfillment for degree of Master of Science (Audiology) of the student Registration Number: 14AUD018. 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
May, 2016

Dr. S.R. Savithri
Director
All India Institute of Speech and Hearing
Manasagangothri, Mysore-570006

CERTIFICATE

This is to certify that this dissertation entitled "***Comparison of Coarticulation Perception in Individuals with Normal Hearing and Hearing Impairment"*** is a bonafide work submitted in part fulfillment for the degree of Master of Science (Audiology) of the student Registration Number. 14AUD018. This has been carried out under my guidance and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru,
May, 2016

Dr. Asha Yathiraj
Guide
Professor of Audiology
Department of Audiology
All India Institute of Speech and Hearing
Manasagangothri, Mysore-570006

DECLARATION

This is to certify that this dissertation entitled "***Comparison of Coarticulation Perception in Individuals with Normal Hearing and Hearing Impairment***" 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, Mysore, and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru,
May, 2016

Registration No.: 14AUD018

Dedicated to all

who passionately pursue research!

Acknowledgements

"It is our choices that show us who we truly are, far more than our abilities."

\- *Albus Dumbledore*

At the outset I would like to express sincere gratitude to my guide Prof. Asha Yathiraj for her guidance throughout the dissertation.

I would also like to thank the Director for having permitted me to carry out the study.

A long list of people have to be thanked…….A very special thanks to Ajith Sir and Nisha Ma'am for having been generous with the Motu recording interface. I would also like to thank Nike Sir for having helped us decipher the intricacies of the Motu interface! My sincere thanks to Sriraj Sir and Kishore Sir for having taken their time out and helping with the instrumental set up for recording. A special thanks to Jim, for helping me out with the recording of stimuli!

Thanks to Lakshmi Akka and Srikar Sir for the timely help and the much required moral boost!

I would also like to express gratitude to all the participants who patiently sat through the testing procedure!

I would like to thank my parents and family for having always been there for me….. I don't think I say this enough….I love you guys and you mean the world to me! Amma, you are my best friend, you are there for me even when the entire world is against me! You give me a lot of moral support and strength…..Appa, I have always looked up to you, your approach to life in general is an inspiration…..and I owe a huge thanks to my dear brother without whom I wouldn't have had a laptop to type into, I owe you for a lot more than just a laptop, you are one of my most favourite persons!! Deepshikha, Ira and Swara…..you guys have brought us a lot of joy and happiness! My dearest, dearest Tommy, simply seeing you wagging your short tail and welcoming me home lifts up my mood…..

They say friends are the family we choose for ourselves. I consider myself lucky to have found amazing friends. Vimala, you are more of a soul sister than just a friend! Vimala, Rakshita, Meghana and Mamatha……I cannot imagine these 6 years of college life without you guys….you guys have stuck with me through thick and thin!!! Words simply cannot describe the bond I share with you all! Maala and Varsha you are special friends for life!

Minions and Masterminds.…….M. Sc would not have been so memorable if not for all of you guys………all the last minute exam preparations, the pizza partiesssss, the theme days, the road trips and the crazzzy photos will always be cherished!!!

Vindhya and Pancham….my partners in crime…..thank you for having been there for me throughout the dissertation! Special thanks to Indu, for having been a very special friend and a huge support during dissertation…..you are very dear to my heart!

My gratitude to Animesh Sir because of whom I have come to love the field of Audiology!

At the very end I would like to thank Mr. P G Wodehouse whose humor kept me sane through the dissertation process!

ABSTRACT

Aim: The aim of the study was to compare the ability of normal hearing listeners and those with hearing impairment to utilize coarticulation cues in the identification of the fricative /ʃ/.

Method: The participants included 19 listeners with normal hearing and 18 listeners with hearing impairment. Among the 18 individuals with hearing impairment, 9 had mild sensorineural hearing loss (flat configuration) and 9 had moderate sensorineural hearing loss (flat configuration). They were evaluated using the stimuli /aʃa/, /iʃi/ and /uʃu/ spoken by two talkers, one male and one female. Further, in the anticipatory condition the stimuli were truncated to include the preceding vowel with varying durations of the fricative noise (0%, 20%, 40%, 60%, & 80%). Similarly, in the carryover condition the stimuli were truncated to include the following vowel along with varying durations of the fricative noise (0%, 20%, 40%, 60%, 80%, & 100%). The participants were asked to write down the speech sounds heard by them from a given set of choices. The number of /ʃ/ responses heard by the participants at each truncation was analyzed.

Results: A Shapiro- Wilk test of normality was carried out. Since the data were not normally distributed, nonparametric statistical tests were carried out. A significant difference in performance was noted between individuals with normal hearing and those with moderate hearing impairment, and between listeners with mild and moderate hearing impairment. Also, significant differences were noted across adjacent truncations in each of the three participant groups. It was further noted that performance in anticipatory coarticulation was significantly better than carryover coarticulation.

Conclusions: The study indicated that the overall ability to utilize coarticulatory cues reduced with increasing degrees of hearing loss. Also, in each of the groups, the performance in the anticipatory condition was better than the carryover condition.

Table of contents

List of Tables

List of figures

CHAPTER 1

INTRODUCTION

In daily listening conditions, normal hearing listeners are reported to utilize a number of acoustic cues for speech perception. These include direct acoustic cues of the consonant or vowel as well as coarticulated cues (Delattre, Liberman, & Cooper, 1955). As reported, coarticulated information present in the transitions acts as a major cue in the perception of nasals (Ali, Gallagher, Goldstein, & Daniloff, 1970), stops and fricatives (Kunisaki & Fujisaki, 1977)**.** Zeng and Turner (1990) report that by removing the fricative segment of a nonsense syllable and presenting the vowel and transition segments only, the fricatives /s/, /f/, /ʃ/, /θ/ were often perceived as the stop consonants /d/, /b/, or /g/. It has also been demonstrated by Nittrouer and Studdert-Kennedy (1987a) that listeners use their knowledge of coarticulation and its acoustic consequences for perception of speech.

Although there are a number of studies regarding the effects of vowels on the perception of the adjacent consonant in normal hearing adults and children, relatively fewer studies have been carried out on the population with hearing impairment. Carney and Moeller (1998) noted that individuals with sensorineural hearing loss may use listening strategies that differ from the strategies used by normal listeners. Pittman and Stelmachowicz (2000) also reported that the portions of the transition utilized by normal hearing individuals and individuals with hearing impairment are different. Zeng and Turner (1990) suggested that although the transition segments may be audible to individuals with hearing impairment, they may not be able to use this information as efficiently as normal hearing listeners due to a loss of discrimination. Previous studies also have found that adults with hearing impairment require higher levels of audibility than normal hearing adults to achieve equivalent levels of performance (Ching, Dillon, & Byrne, 1998; Dubno, Dirks, & Ellison, 1989; Hogan & Turner, 1998; Robb & Turner, 1987).

Pittman and Stelmachowicz (2000) reported that the perceptual weighting strategies of normal hearing listeners and listeners with hearing impairment differed. It was noted that normal hearing listeners relied on and weighted the transition portion heavily when the amplitude of the fricative noise was low. However, the listeners with hearing impairment were unable to utilize the dynamic transition portion when the amplitude of the fricative noise was low and weighted the vowel, transition and frication noise of the fricative low.

Need for the study:

Studies report that the vowel transitions in coarticulation serve as important cues in identification of adjacent consonants (Nittrouer & Studdert-Kennedy, 1987a; Pittman & Stelmachowicz, 2000). Nittrouer and Studdert-Kennedy (1987a) observed that since identification of phonemes varies with the phonetic context, listeners use their knowledge of coarticulation and its acoustic consequences for speech perception. Studies report that despite providing sufficient amplification in the high frequencies, the speech perception scores of individuals with high frequency hearing loss does not improve (Ching et al., 1998; Stelmachowicz, Pittman, Hoover, & Lewis, 2002; Turner & Cummings, 1999; Zeng & Turner, 1990). One such high frequency speech sound that individuals with hearing impairment may have difficulty hearing is /ʃ/. Further, it has been reported that consonants are much less intense than vowels and also that vowels are generally higher in intensity, longer in duration, lower in frequency, as a result of slower movement of the articulators for vowels compared to consonants. The perception of such consonants that are relatively less intense and of high frequency may prove to be challenging for individuals with hearing impairment. However, coarticulated information in vowels that have relatively lower frequency compared to consonants could provide information of the relatively high frequency consonants. This could result in better perception of the consonant and thereby aid in better speech intelligibility. Studies related to the coarticulation perception of fricatives by individuals with relatively lesser degree of hearing loss are limited. Studies in this direction may help in understanding as to whether the loss of audibility alone or loss of discrimination alone or a combination of the two affect the coarticulation perception in hearing impaired, since discrimination abilities are generally unaffected in individuals with lesser degrees of hearing impairment.

Aim of the study:

The aim of the study was to determine the effectiveness with which individuals with hearing impairment and normal hearing listeners effectively utilize coarticulated cues in vowels in the identification of an adjacent fricative.

Objectives:

- To compare coarticulatory perception of adjacent fricative across male and female talker
- To compare the ability of normal hearing individuals and those with hearing impairment in utilizing coarticulatory cues
- Determine the extent of coarticulation cues from the adjacent fricative that are used by normal hearing individuals and individuals with hearing impairment.
- Determine whether anticipatory or carry over coarticulatory vowel cues have more effect on the perception of consonants in normal hearing listeners and those with hearing impairment.
- To compare the coarticulatory perception across the context of vowels /a/, /i/ and /u/ in normal hearing listeners and those with hearing impairment.

CHAPTER 2

REVIEW OF LITERATURE

Traditionally, it has been viewed that the steady state portion of consonants serve as the primary cues in the perception of consonants (Harris, 1958). The relative importance of direct acoustic cues and coarticulated acoustic cues has been extensively researched. It has been reported that the transitions occurring between a consonant and vowel, seen as curvature in the formants at the spectrogram of the vowel, also provide a cue in the perception of adjacent consonants (Liberman, Delattre, Cooper, & Gertsman, 1954; Nittrouer & Studdert-Kennedy, 1986). These shifts in the formant frequencies are presumed to be due to the overlapping articulatory movements in ongoing speech.

Studies have been carried out to determine the ability of listeners to utilize these coarticulated cues in the identification of the adjacent sounds. These studies have reported that the coarticulatory transition cues help in the identification of the adjacent phoneme (Ali, Gallagher, Goldstein, & Daniloff, 1970; Benguerel & Cowan, 1974; Pittman & Stelmachowicz, 2000; Zeng & Turner, 1990). These studies evaluated the effect of consonant transitions cuing adjacent consonants (Liberman et al., 1954), consonants cuing adjacent vowels (Bohn & Steinlen, 2003; Jenkins, Strange, & Edman, 1983), vowels cuing adjacent consonants (Nittrouer & Studdert-Kennedy, 1987b; Wagner, Ernestus, & Cutler, 2006) and vowels cuing adjacent vowels (Magen, 1997). It has also been reported that the coarticulatory effects are dependent on the acoustic context (Mann & Repp, 1981; Zeng & Turner, 1990). Similar to other consonant groups, it has been reported that the noise spectrum of the fricatives also undergo coarticulation. Further, authors have also reported that the effects are varied depending upon the vowel context (Mann & Repp, 1981; Soli, 1981).Thus, it can be noted from the literature that not only do the direct spectral cues aid in the perception of phonemes, but also the coarticulatory transitions help in phoneme perception and identification. Research has been carried out to determine the extent of contribution of the direct cues and the coarticulated cues available for speech perception.

2.1 Direct Cues for the perception of fricatives in Normal hearing individuals:

Studies have indicated that the acoustic cues that aid in the perception of consonants are varied. Several of these studies have been carried out using fricatives (Behrens & Blumstein, 1988; de Manrique & Massone, 1981; Gurlenkian, 1981; Harris, 1958; Heinz & Stevens, 1961; Jongman, 1988; Zeng & Turner, 1990). The relative importance of specific acoustical cues have been studied in the identification of fricatives These cues include spectral properties of the frication noise, amplitude of the frication noise, duration of the frication noise and the spectral properties of the transition from the fricative into the following vowel (Jongman, Wayland, & Wong, 1988).

A study carried out by Manrique and Massone (1981) established the relative importance of the spectral peaks in the identification of sibilants. Through an acoustic analysis they concluded that different fricatives peaked at different frequencies (/s/ peaks around 5000 to 8000 Hz, /f/ around 1500 to 8000 Hz and /ʃ/ around 2500 to 5000 Hz). In order to determine the relative importance of the spectral peaks in the identification of fricatives, they filtered a set of four unvoiced fricatives using high-pass and low-pass filters. The percentage of correct identification of fricatives was determined. They concluded that the spectral zones had an important role in correct identification of consonants.

Zeng and Turner (1990) evaluated the cues used in the perception of the fricatives /s/, /ʃ/, /f/, and /θ/ that were followed by the vowel /i/. The audibility spectra as a function of frequency was calculated at various presentation levels ranging from 20 to 70 dB in 10 dB intervals for the fricative portion. It was concluded that the critical region for the frication portion mostly consisted of the high frequency regions (> 1500 Hz). Further, it was noted that when frication noise above 1500 Hz was audible, almost perfect (92%) recognition scores were obtained. It was concluded that frequencies below 1500 Hz did not contribute to the identification of unvoiced fricatives when truncated unvoiced stimuli consisting of only the frication portion was presented.

Studies have been carried out to study the perceptual role of the amplitude of the fricative noise in identifying the place of articulation of fricatives (Behrens & Blumstein, 1988; Gurlenkian, 1981). Gurlenkian (1981) studied the effects of overall amplitude of the frication noise relative to the vowel in the perception of /fa/ and /sa/. The fricative portion of the stimuli had spectral characteristics corresponding to /s/ and the transition portion corresponding to the stimuli /f/. A ten step continuum was generated wherein the overall amplitude of the noise was varied in 3 to 4 dB steps from -32 to -2 with respect to the overall amplitude of the vowel. The study concluded that low amplitude of the fricative noise relative to the vowel amplitude was perceived as /f/ and high amplitude of the fricative noise relative to the vowel amplitude was perceived as /s/. Thus, it was noted that the amplitude of the fricative noise had an effect on the identification of the fricative.

In contrast to the previous study, Behrens and Blumstein (1988) reported that the manipulation of the fricative amplitude had relatively smaller effects on the place of articulation identification. They increased the amplitude of the fricative noise of /f/ and /θ/ so that the relative amplitude of the noise to the adjacent vowel was similar to /s/ and /ʃ/.They also decreased the amplitude of the fricative noise of /s/ and /ʃ/, so that the relative amplitude of the noise to the adjacent vowel was similar to that of /f/ and /θ/. It was concluded that when the spectral properties of the fricative noise and the fricative transition were compatible, the amplitude of the fricative noise did not significantly affect the identification of the fricative place of articulation.

Jongman (1988) evaluated the relative importance of fricative noise duration in determining the place of articulation of fricatives. Six fricatives (/f/, / s/, /θ/, /v/, /z/, /dh/) were used in combination with the vowels /a/, /i/, and /u/ in a CV context. The duration of the fricative noise ranged from 20 to 70 ms in steps of 10 ms from the onset. The results indicated that the entire length of the fricative noise was not required for the identification of the fricative. However, the identification of the correct place of articulation improved with increase in duration of the fricative. The duration of the fricative noise required for the correct identification of the fricative varied based on the fricative, with it being approximate 30 ms for /ʃ/ and /z/, 50 ms for /f/, /s/, and /v/, while

/θ/ and /dh/ were identified with reasonable accuracy in only the full frication and syllable condition.

Thus, it may be inferred from the existing literature that spectral peaks play a major role in the identification of fricatives. However, the amplitude of the fricative noise relative to the adjacent vowel was noted to mostly serve as a cue in the identification of the place of articulation of the fricative. Further, it was noted that although the entire duration of the noise is not required for fricative identification, the identification of the place of articulation improved with increasing duration of the fricative noise.

2.2 Coarticulatory cues in relation to direct cues in the perception of fricatives:

Researchers have explored the possibility for listeners utilizing coarticulatory cues in the identification of fricatives. It has been documented that the transitions occurring in the vocalic portion serves as cues in the perception of adjacent consonant and the fricative portion cues for both the fricative as well as the adjacent vowel(Harris, 1958; LaRiviere, Winitz, & Herriman, 1975; Mann & Soli, 1991; Yeni-Komshian & Soli, 1981). Along with the direct primary cues, authors have reported that the vocalic portions also help in the identification of fricatives.

2.2.1 Influence of vocalic transition in fricative perception

In order to determine the relative importance of the vocalic transition portion in the identification of fricatives, Harris(1958) carried out a study wherein the vocalic portion including the transition of a spoken fricative-vowel combination was combined with the noise portion of another fricative. The results indicated that the perceptual weightage placed by the listener varied based on the fricative in question. The important cue for the differentiation of /s/ and /ʃ/ was given by the fricative noise portion, whereas the vocalic transition portion played a role in the differentiation of /f/ and /θ/. Similar results were noted for their voiced counter parts wherein, identification of /z/ and /zh/ was mostly based on the frication portion whereas the identification of /v/ and /dh/ was based on the vocalic transition portion.

Heinz and Stevens (1961) reported similar results in an experiment carried out using synthetic synthesis of speech. Isolated turbulence, turbulence along with the steady state vowel, and turbulence and transition along with the vowel portions were presented to the listeners. Based on the turbulence alone, the listeners were able to group the fricatives into mid frequency (/s/), high frequency (/f-θ/) and low frequency (/ʃ/) sibilants. However, the listeners had difficulty in discriminating between /f-θ/ in the isolated turbulence and turbulence and isolated vowel condition. The authors concluded that the F2 transition played a role in differentiating between consonants (/f-θ/).

Using stimuli similar to that used by Heinz and Stevens(1961), Zeng and Turner (1990) evaluated audibility spectra by measuring the output at various auditory filters across different frequencies for both the transition and the frication portions. It was noted that the audibility spectra for the transition portion of the fricatives /s/, /ʃ/, /f/, and /θ/ in the context of the vowel /i/ was much higher than the audibility spectra for the frication portion at lower levels (20 & 30 dB SPL). This was considered to imply that the transitions served as cues for the identification of fricatives at lower levels when the frication noise became inaudible. This was further reflected in the percent audibility function. It was reported that substantial recognition scores were obtained at lower presentation levels with 0% audibility of frication and 20 to 50% audibility of the transition cue reflecting the importance of the transition cues in the identification at lower presentation levels. Zeng and Turner also studied audibility spectra using the same four fricative-vowel syllables that were synthetically generated using a Klatt synthesizer. The results obtained using the synthetic stimuli were similar to that obtained using natural stimuli. The authors thus concluded that though the frication cue alone may be sufficient to cue the fricative identification at higher intensities, the transitions served as cues in the identification of fricatives at lower intensities.

Whalen (1991) studied the relative importance of the transition and frication noise in the identification of fricatives. The fricative noise in the initial part of the words /suit/ and /shoot/ were synthesized to form a nine-step continuum (0 to 200 ms in steps of 25 ms) from /s/ to /ʃ/, or vice versa. These hybrid noises were followed by the transitions of either of the syllable /suit/ or /shoot/. The vocalic transition portions were combined with these frication noises. The duration of noise required to judge the given stimuli as agreeing with the initial noise was noted. Thus, half the stimuli had the transitions supporting the initial part of the stimuli and the transitions supporting the final part of the stimuli in the other half. It was reported that as the duration of the initial noise increased there was an increase in the identification of the fricative corresponding to the noise. Also, it was noted that the fricative that was reported tended to be more consistent with the longer of the two fricative noises, though some amount of weight was placed on the later part with some influence of the transition. It was noted that when the transition supported the category of the initial noise, lesser duration of the noise was required to report that fricative. The study indicated that the frication in the initial part of the noise was identified when its duration was short and the transitions supported the initial portion. Similarly, the final fricative was chosen when its duration was shorter and when it was supported by the transition.

Studies thus indicate that though the direct frication noise does serve as a cue in the identification of fricatives, the vocalic transition also plays a role. Also, the studies indicate that the perceptual importance of the fricative noise and transition is relative and varies depending on the fricative sound in question and the presentation level.

2.2.2 Influence of vowel context in fricative perception

It has been documented that a vowel can provide perceptual cues for both the vowel and the adjacent fricative (Mann & Repp, 1981), and the fricative portion consists of cues for both the fricative and the adjacent vowel (Yeni-Komshian & Soli, 1981). The authors attributed this to the coarticulatory spread of the articulatory gestures to the adjacent phoneme. These studies raised questions regarding the effect of the vowel context on the extent of the coarticulatory spread and in the identification of the adjacent consonant and vice versa.

A study by Kunisaki and Fujisaki (1977) addressed some of these questions. A ten step synthetic fricative continuum (from /ʃ/, to /s/), followed by synthetic vowels /a/ and /u/ consisting of the first and the second transitions was developed. It was noted that the phoneme boundary shifts significantly based on the context of the vowel. The authors reported that the phoneme boundary shifted earlier to the fricative /s/ in the context of the rounded vowel /u/ than when followed by the unrounded vowel /a/. The authors proposed that the contrast effect may explain these shifts in perceptual boundaries i.e., fricative noises of lower frequencies maybe perceived as phonemes of higher frequencies in the context of lower frequency rounded vowels /u/ than in the context of unrounded vowel /a/.

Mann and Repp (1980) carried out a similar study to investigate the vowel context effects on the perception of fricatives. A nine step synthetic continuum was generated such that the center frequency increased from stimulus 1 to stimulus 9, in the context of the vowels /a/ and /u/. It was noted that listeners were more likely to identify the fricative as /ʃ/, in the context of the vowel /a/. However, in an extension of their study, Mann and Repp (1980) determined the perceptual effects of prolonged frication duration and the effect of the presence or absence of a silent gap between the noise and the periodic portion. The authors noted that variation in the duration of the fricative noise did not change the context effect, but the vowel context effect was completely eliminated by introduction of a silent interval between the frication and the vowel. Thus, the authors concluded that the temporal contiguity of the two stimuli is essential for perceptual interaction. In a further extension of the study, the synthetic portion of the fricative was combined with the synthetic vowels with no transitions. It was noted that vowel context effects completely disappeared in these conditions. The authors reasoned that the removal of the transitions introduced a discontinuity in the perception. The authors related their findings to the results reported by Cole and Scott (1973) who also noted that a transition-less syllables segregate into separate auditory streams.

The study carried out by Whalen (1981) replicated the results of Kunisaki and Fujisaki (1977) by demonstrating a significant vowel context effect on the identification of fricative in a continuum from /ʃ/, to /s/. Also, the authors noted that the vowel context was insensitive to the linguistic experience of the listener as there was no significant difference between the performance of naïve listeners and listeners with some level of linguistic sophistication.

The reports of the study carried out by Nittrouer and Studdert-Kennedy (1987) are in parallel with earlier mentioned studies, indicating a significant vowel context effect. However, the results reported by Nittrouer and Studdert-Kennedy are contrary to the results reported by Kunisaki and Fujisaki (1977), Whalen(1981). Contrasting the previously reported results, Nittrouer and Studdert-Kennedy (1987) reported that the subjects perceived the consonant /s/ in the context of unrounded vowel /i/ transitions than in the context of rounded /u/.

Spectral analysis of fricatives spoken in isolation and in syllables revealed reliable anticipatory coarticulation effects in syllables lasting up to 30-60 ms before the vowel onset in the form of spectral peaks associated with the formants of the adjacent vowel. This was noted by Soli (1981) in a study carried out to determine the acoustic effects of coarticulation. It was noted that there was an upward shift in the spectral peak of the fricative before the front vowel /i/ as compared to the context of vowels /a/, and /u/. The occurrence of these peaks in the spectra of the fricative indicated that the latter part of the constriction of the fricative was open to assimilate the adjacent vowel. Also, it was noted that these effects of coarticulation varied across the context of the vowels. The acoustic evidence thus obtained correlated with the perceptual study carried out by Yeni-Komshian and Soli (1981) wherein it was noted that high vowel /i/ could be identified in the context of fricatives but not the low vowel /a/.

Mann and Soli (1991) reported of vocalic context effects in the identification of fricatives /s/ and /ʃ/, in the context of vowels /a/ and /u/. The results, much like the results of the study carried out by Whalen (1981), indicated that the perception of fricative /s/ was significantly higher in the context of the rounded vowel /u/ than the unrounded /a/. In addition to this, the effect of the perceptual order in terms of efficacy of the direction of coarticulation was also studied in Fricative Vowel (FV) and Vowel Fricative (VF) conditions. Symmetrical effects of lip rounding were observed on the frication segments and hence the asymmetries observed in the anticipatory and carry over coarticulation perception could not be attributed to this. There were various changes observed like reduction in the peak spectral frequency, shift in the highest amplitude region in the context of the vowel /u/. Though there were differences in the effects of anticipatory and perseveratory lip rounding, the magnitude of change remained the same in the VF and FV utterances. The authors noted that the symmetry between VF and FV syllables was remarkably similar and hence the differences in the perception of anticipatory and carry over coarticulation could not be attributed to the acoustic differences in the frication portion. However, the authors reported differences in the vocalic portions of the FV and VF syllables. In the context of /u/, the onset and offset frequencies of the transitions were similar in both FV and VF transitions but there were variations in the dynamic characteristics. Also, the authors noted that the amplitude of the transitions remained relatively stable in the FV transitions but there was a rapid reduction in the formant amplitude of the VF transitions. It was further reported that the vowel context effects of following segments was significantly stronger than that of the preceding segments. The authors provide two possible explanations for the same, one to the acoustic structure of the vocalic segments i.e., the coarticulatory effects are asymmetric, and another to the memory process i.e., the listeners maybe biased towards the more recently occurring stimulus. In order to test the second possibility, the stimuli VF and FV were presented in reverse order and it was noted that the perceptual order had a significant effect on the differences noted with reverse FV showing significantly more vowel context effects than reverse VF.

Thus, it may be drawn that a significant vowel context effect is evident and it has an influence on the coarticulation perception. The extent of coarticulation is found to be varied across the context of the different vowels with the perception of the fricative /s/ being higher in the context of the rounded vowel /u/ than in the context of the unrounded /i/ or /a/. Also, studies have reported a difference in the extent of coarticulation based on the direction of coarticulation with perception of carry over coarticulation being better than the anticipatory coarticulation.

2.2.3 Influence of vowel duration in fricative perception

It has been reported that the duration of a consonant is significantly affected by the extent of opening of the vowel and also the duration of the vowel depends on the nature of the adjacent consonant (Lisker, 1974). Denes (1955) noted that the duration of vowel preceding a voiced and an unvoiced consonant varied. It was reported that the duration of the vowel preceding the unvoiced /s/ (as in /the use/) ranged from 0.04 to 0.08 seconds, whereas the duration of the vowel preceding the voiced /z/ (as in /tu juze/) ranged between 0.12 to 0.2 seconds. As an extension of the same study, the final unvoiced consonant (of /da juse/) was cut off and shortened to use only the central third portion. This was combined with the spliced /ju/ portion of the word /tu juze/. Similarly, the spliced final voiced consonant of /tu juze/ was lengthened and further combined with the spliced /ju/ portion of the segment /da juse/. The author reported that the original unvoiced /s/ sound, shortened and attached in front of /tu juze/ sounded similar to /z/. Likewise, the voiced /z/ was perceived as unvoiced /s/ in the edited context. Thus, the author reported that the perception of voicing does not depend so much upon the presence of vocal cord vibrations during the final sound as much on the duration of the preceding vowel and the duration of the final consonant.

As a continuation of the same study, Denes (1955) manipulated the same set of stimuli /tu juze/ and /da juse/ such that the spectrogram of the two stimuli remained same. However, only the duration of the preceding vowel and the final consonant were varied. The effect of these variations on the voicing perception was noted. It was observed that with increasing duration of the preceding vowel, the stimuli were perceived as a voiced consonant. Similar effects were seen with increased duration of the final consonant, wherein longer duration stimuli were perceived more as unvoiced. It was concluded that the perception of voicing of the final consonant increased as the ratio of duration of the final consonant to the preceding vowel decreased.

Using a pattern play back technique, Raphael (1972) studied the effects of preceding vowel duration on voicing perception in minimal pairs consisting of cognate pairs in the word final position using stops, fricatives and clusters. The voiced series was generated by varying the steady state duration of the vowel from 150 to 350 ms. Following the preparation of the voiced stimuli, the unvoiced counterpart was generated by eliminating 50 ms of the F1 transition. The fricative cognates considered were /f-v/, /θ-dh/, /s-z/, /sh-zh/. It was noted that regardless of the voicing used in the synthesis, the final consonants were perceived as unvoiced at shorter durations of the preceding vowel and were perceived as voiced as durations of the preceding vowel increased. It was also concluded that the preceding vowel duration served as a stronger cue for the perception of voicing in stops as compared to fricatives and clusters. Also, it was noted that the perception cued by preceding vowel was continuous and not categorical.

Hogan and Rozyspal (1980) reported that the length of the vowel nucleus in a word ending with a voiced consonant was much longer than the duration of a vowel followed by its unvoiced cognate. The authors related their finding to a study carried out by Peterson and Lehiste (1960) wherein it was observed that the duration of a vowel followed by a voiced consonant was longer than the duration of the same vowel followed by an unvoiced consonant by a ratio of approximately 3:2. The study was carried out using CVC and CVCC syllables with fricatives, stops and clusters in the final position including both intrinsically short and long duration vowels in the medial position. It was concluded from the study that though the preceding vowel duration was a major cue in aiding voicing identification, it was true only for intrinsically longer utterances. However, in the case of intrinsically shorter vowels, it was noted that preceding vowel duration did not significantly affect the voicing perception and listeners required other cues like voicing bar in order to perceive voicing. Also, it was noted that the unvoiced consonants remained relatively unaffected by the increase in the vowel duration.

Thus, it can be summarised that listeners do utilize coarticulatory transition cues for the identification of fricatives. However, the perceptual weightage placed on the transition and the frication noise however varies with respect to the fricative in concern. Studies regarding the effects of vowel context report a significant effect of the vowel environment on the fricative perception. Also, the duration of the preceding vowel has been demonstrated to be a significant cue for the perception of voicing characteristics of the fricatives in the final position.

2.3 Intelligibility of fricatives by individuals with hearing impairment

It has long been acknowledged that individuals with sensorineural hearing impairment experience difficulty in speech perception. Since the 1950s various authors have tried to explain the pattern of errors that are commonly seen in individuals with hearing impairment. A general consensus is that the error patterns vary based on the degree of hearing loss. However, the use of these error patterns for diagnostic purposes was disregarded since the phonemic error patterns observed were infrequent and idiosyncratic, both within and across diagnostic groups (Schultz, 1964).

Lawrence and Byers (1969) investigated the effects of high frequency hearing loss on the perception of unvoiced fricatives. The consonant confusions of individuals with high frequency sloping hearing loss in the identification of consonants /s/, /ʃ/, /f/, and /θ/ in the context of vowels /I/, /e/, /o/, and /u/ were documented. It was noted that the consonants /s/ and /ʃ/, were confused for one another and the consonants /f/ and /θ/ for one another. The authors reported idiosyncrasy in the error patterns noticed among the subjects. Though it has been documented in literature about the importance of high frequencies in the perception of unvoiced fricatives, only moderate difficulty was documented in their study. The authors explained their findings saying that various cues apart from the high frequency cue could have played a potential role in the identification. It was further reported that the errors in the identification were significantly higher in the context of front vowels /i/ and /e/ than with the back vowels /o/ and /u/. Following spectral analysis, the authors reported that the transitions for the vowels /i/ and /e/ occurred in frequency regions audible to the participants with hearing impairment but was out of the audible frequency range for the vowels /o/ and /u/. Thus, the authors concluded that these indirect transition cues might aid in the perception of fricatives.

Owens, Benedict, and Schubert (1972) documented the error patterns noticed in subjects with hearing impairment as a function of the configuration of hearing loss. It was noted that the percentage error in identification increased with increase in the slope of hearing loss, and also with reduction in frequency at which the sloping began. The authors concluded that /s/, /ʃ/, /ch/, and /dz/ were easily identified by patients with flat hearing loss, but were difficult for patients with sharply sloping loss between 500 to 4000 Hz. It was also noted that the identification of /s/ was significantly affected in individuals with high frequency hearing loss. Further, it was reported that individuals with different degrees of hearing impairment experienced different levels of consonant confusions.

In parallel with the study by Owens, Benedict, and Schubert (1972), Bilger & Wang (1976) reported that the consonant confusions vary with both the degree and the configuration of hearing loss. The authors reported that though homogeneity among the error patterns was not very high, listeners could be grouped into three groups based on the error patterns: mild flat losses, moderate to severe flat losses, high frequency hearing losses. It was also observed that individuals with high frequency hearing loss experienced difficulty in the perception of sibilants. On similar lines, Boothroyd (1984) reported that the errors and the performance on the speech perception tests fell with increasing hearing loss. It was also reported that the value of hearing loss at which the scores fell to 50% was 75 dB HL for consonant place, 85 dB HL for consonant initial voicing, and 100 dB HL for vowel place.

Maniwa, Jongman, and Wade (2008) studied the effect of clear speech on the intelligibility of fricatives in normal hearing and individuals with simulated hearing impairment and recruitment impairment. It was reported that clear speech helped both groups, which was reflected as an overall improvement in scores. However, it was noted that in case of listeners with hearing impairment, reliable clear speech intelligibility advantages were not found for non-sibilant pairs.

Other studies have also documented that individuals with hearing impairment experience greater difficulty in the perception of fricatives as compared to other class of consonants. This was attributed to the poor audibility, poor frequency and temporal resolution. However, improving the audibility was noted to not result in improved performance, and hence the reason was attributed to poor frequency and temporal resolution and also to poor loudness growth (Lawrence & Byers, 1969; Robb & Turner, 1987; Zeng & Turner, 1990).

From the above studies on individuals with hearing impairment it may be concluded that those with hearing loss may often face difficulties in the identification of consonants. Hearing loss in the high frequency regions generally results in consonant confusions involving high frequency consonants such as fricatives.

2.4 Coarticulation perception of fricatives and the perceptual strategies utilized by individuals with hearing impairment:

As discussed earlier, various studies have documented that steady state portion of the fricative noise and the dynamic spectral cues in the vowel aid in the perception of fricatives (Mann & Soli, 1991; Nittrouer & Studdert-Kennedy, 1987; Whalen, 1981). However, in individuals with hearing impairment the ability to utilize these coarticulatory cues is limited compared to normal hearing individuals. Various authors have attributed this affected speech perception to the reduced audibility and poor discriminability (Lawrence & Byers, 1969; Zeng & Turner, 1990).

Robb and Turner (1987) evaluated the recognition scores for stop consonants in the context of the vowel /i/ as a function of audibility. They compared the performance of normal listeners with listeners having moderate to severe hearing impairment. It was noted that in the normal listeners, the performance in terms of the recognition scores and percentage information transfer improved with increasing audibility. However, in case of individuals with hearing impairment the improvement in recognition scores with increasing audibility was poorer as compared to normal listeners. The authors concluded that though reduced audibility might be an important factor affecting those with hearing impairment, this alone could not explain the effects of sensorineural hearing loss. It has been suggested by Robb and Turner (1987) and Zeng and Turner (1990) that poor frequency resolution, impaired temporal discrimination and affected loudness growth patterns may result in affected suprathreshold discriminability.

Revoile and Pickett (1985) studied the ability of listeners with hearing impairment to identify voicing differences of fricatives in the final position based on the preceding vowel duration cues. The stimuli used were /dʌF/ in the context of fricatives /f/, /v/, /s/, and /z/. It was observed that the preceding vowel duration, vowel offset and frication duration varied across the voiced and the unvoiced counterparts. Each stimulus was manipulated to generate five conditions: unaltered syllable, frication deleted, vowel durations equalized, frication deleted from syllables with equalized vowel durations and vowel offsets deleted from syllables with equalized vowel durations and frication removed. It was observed that the perception of voicing distinction varied significantly across normal hearing and those with hearing impairment. It was also noted that in the individuals with hearing impairment all the conditions that involved manipulation of the preceding vowel duration degraded the voicing perception abilities. Also, significant deterioration was observed when the vowel offset cues were deleted. Thus, the authors concluded that individuals with hearing impairment utilized vowel duration cues majorly to distinguish the voicing since they were unable to utilize the cues present in the fricative portion and the vowel offset.

A report of the differences between the normal hearing listeners and three hearing impaired listeners in utilization of the coarticulatory cues was provided by Zeng and Turner (1990).The individuals with a hearing loss had moderate to severe cochlear loss. Synthetic fricative-vowel stimuli (for fricatives/f/, /s/, /ʃ/, & /θ/) were used as stimuli in the context of the vowel /i/. The performance audibility function was determined for the fricative portion alone and the transition alone portion and the percentage correct identification of the fricative was noted. The presentation levels ranged from the level at which those with hearing impairment obtained 25% scores for frication alone and transition portions separately to the level at which they achieved 100% scores. Thereby, the audibility levels were maintained equivalent across the normal hearing individuals those with hearing impairment. It was noted that the individuals with hearing impairment were unable to utilize the transition cues as efficiently as the normal hearing group. It has also been reported that the poor ability to utilize transition cues did not imply a complete lack of ability to utilize transition cues. It was further noted that the ability of listeners to utilize the transitional cues varied. Additionally, it was documented that listeners with hearing impairment showed an improvement in the identification of fricatives with increase in the percentage audibility of the frication portion alone. Thus, the author concluded that the individuals with hearing impairment fail to utilize the dynamic transition cues with efficiency comparable to listeners with normal hearing, but relied on the frication noise for identification. It was also concluded that the findings implied that listeners with hearing impairment experience difficulty in fricative identification not only due to the elevated thresholds but also due to the poorer than normal discrimination abilities that is reflected as an ability to utilize the dynamic spectral transition cues.

Pittman and Stelmachowicz (2000) evaluated the weightage given for the perception of different cues for the perception of fricatives by individuals with normal hearing and hearing impairment. The frication, transition and vowel segments were spectrally identified and using MATLAB the relative amplitude of each of these segments was varied randomly. The authors noted a high positive correlation between the frication noise and the performance in both normal hearing listeners and those with hearing impairment, implying that the performance improved with increase in the audibility of the frication portion. It was noted that both normal listeners and listeners with hearing impairment gave equal perceptual weightage to the frication portion for the identification of /s/ and /ʃ/. For /uθ/, the normal hearing listeners weighted the transition segment higher than the vowel or the frication portion. However, the listeners with hearing impairment weighted all three segments equally low. The authors concluded that listeners with hearing impairment were unable to use transition cues as effectively as normal hearing listeners. Also, the authors observed that as listeners with hearing impairment were poor users of transition cues, they mostly rely on the frication noise for Fricative- Vowel syllable. The authors further noted that at equal levels of audibility individuals with hearing impairment can utilize the fricative cues as well as normal listeners. However, when the fricative noise is inaudible the listeners with hearing impairment fail to utilize the dynamic transition cues though they are audible. The authors have attributed this to the poor audibility and lack of discriminability.

Pittman, Stelmachowicz, Lewis, and Hoover (2002) investigated the perceptual strategies used by individuals with hearing impairment and normal hearing listeners. Four meaningful Fricative-Vowel-Consonant words in English (sack, shack, sock, shock) were used. The words were created in two conditions, one with appropriate transition and another without. During each trial, each stimulus was presented in its entirety with manipulations in the relative amplitude of one of the segments i.e., either the frication or transition without varying the final stop /k/. The perceptual weightage was calculated and represented in terms of correlation values. It was noted that the performance of both those with hearing impairment and those with normal hearing improved when transitions were provided. However, it was observed that improvement in performance when transitions were provided was not noted in those with hearing impairment in the context of the fricative /s/. Further, it was noted that both individuals with hearing impairment and normal hearing listeners relied heavily on the vowel portion for the identification of the fricative when the transition was provided. It was also observed the weightage shifted to the frication when the transition was removed. Also, the authors noted that the participants with hearing impairment relied more heavily on the frication cues and the weightage placed on the frication portion was greater in the identification of /ʃ/. This was considered to suggest that this difference in the perceptual weightage was due to variations in the formant transitions which was more extensive in /ʃ/. Thus, the removal of these transition cues caused detrimental changes in the context of /ʃ/, as compared to /s/ in case of those with hearing impairment. The results of the study by Pittman et al. are contrastive to the results of the study conducted by Zeng and Turner (1990). Pittman et al. reported that individuals with hearing impairment are capable of utilizing the dynamic transition cues, though not as efficiently as normal hearing listeners since the results revealed a reduction in the performance of listeners with hearing impairment as the formant information was reduced. The authors have suggested that these differences in performance might be attributed to the variations in the vowels and thereby the magnitude of transition considered in the two studies.

From the available review of literature it can be concluded that the ability of individuals with hearing impairment to utilize transition cues in the perception of fricatives is limited compared to normal hearing listeners. Though individuals with hearing impairment can utilize the steady state fricative noise cues at equal levels of audibility, their ability to utilize the dynamic spectral cues is found to be poor even at equal levels of audibility. This has been attributed to the poor frequency discrimination abilities and the inability to utilize time varying dynamic spectral cues. Studies related to the coarticulation perception of fricatives by individuals with relatively lesser degree of hearing loss are limited. Also, though studies discuss the coarticulatory perception in individuals with hearing impairment, literature regarding the effect of direction of coarticulation, especially in individuals with hearing impairment, is limited.

CHAPTER 3

METHODS

The present study compared the coarticulation perception of the fricative /ʃ/, across normal hearing individuals and those with hearing impairment. The perception of anticipatory and carryover coarticulation across the context of vowels /a/, /i/ and /u/ were also studied. Standard group comparison research design was used.

3.1 Participants:

A purposive sampling procedure was used in selecting the participants. Two groups of participants were assessed. Group-1 included 19 participants with mean age of 44.8 years (age range of 18 to 60 years). This group included participants with thresholds < 15dB HL across the frequencies 250 Hz to 4 kHz for both AC and BC. They had speech identification scores greater than 90% on the Kannada Phonetically Balanced word test developed by Yathiraj and Vijayalakshmi (2005). Additionally, they had 'A' type tympanograms with acoustic reflex thresholds within normal limits. None of the participants had any neurological or otological history. Only those who had passed 8^{th} grade were included in the study. All were fluent speakers of Kannada and had used the language from early childhood.

Group-2 included 18 individuals with mean age of 45.2 years (age range of 18 to 60 years). Of them 9 were diagnosed to have mild sensorineural hearing loss and the other 9 were diagnosed to have moderate sensorineural hearing loss. All the participants had flat audiometric configuration with pure-tone averages between 26 dB HL to 55 dB HL for the frequencies 500 Hz, 1 kHz, 2 kHz and 4 kHz with the air-bone gap being less than 10 dB. Their speech identification scores were at least 75%, indicating only slight difficulty (Goetzinger, 1978), on the Kannada Phonetically balanced word test developed by Yathiraj and Vijayalakshmi, (2005) . They had 'A' type tympanogram with elevated or absent acoustic reflex thresholds and absent or reduced amplitude of transient evoked otoacoustic emission. Like Group-1, these participants had no history of neurological symptoms. They had passed at least 8^{th} grade and spoke Kannada fluently and had used the language from early childhood.

3.2 Test environment:

The recording of the stimuli and all the evaluations of participants were carried out in a two-room sound treated suite that was well illuminated. The ambient noise levels were within permissible limits as given by ANSI S3.1- 1999 (R2008)

3.3 Equipment:

A Toshiba core i5 generation laptop loaded with Adobe Audition (version 3.0) was used for recording and playing the stimuli. The participant selection and their further evaluations were done with the help of a two channel diagnostic audiometer (Piano Inventis). A calibrated Grason Stadler v-26 immitance meter was utilized to assess the middle ear status. Transient evoked otoacoustic emissions were recorded with an ILO version 6 instrument.

3.4 Procedure:

Prior to testing the participants, informed consent was obtained from all the participants as detailed in the ethical guidelines of AIISH (Ethical Guidelines for Bio-Behavioral Research Involving Human Subjects, 2009). The study was carried out in three phases. These included the following: (i) stimuli development, (ii) pilot study and (iii) closed set identification task.

3.4.1 Stimuli development:

The stimuli used for the study were /aʃa/, /iʃi/, and /uʃu/. These stimuli were recorded by two adult talkers, a male and a female, with clear production. The recording was done using a Senhieser directional microphone, placed at a distance of 6 cm from the speakers' mouth. The microphone was connected via a Motu Microbook II audio interface to a computer loaded with Adobe Audition (version 3.0). A 16 bit analog to digital convertor and a sampling rate of 44,100 Hz was utilized for the recording. Normalization was carried out in order to ensure that the intensity was equal across the stimuli and across the speakers. A goodness test was performed on 5 adults to confirm the clarity of the recorded stimuli. Also, the participants were asked to rate the similarity in intonation of the pair of stimuli spoken by the male and female talker on a three point rating scale, with 3 being similar, 2 being almost similar and 1 being not similar. The stimuli were considered acceptable only after 4 out of the 5 individuals were able to correctly identify the stimuli and rated the pair of stimuli as similar in terms of intonation. Figure 3.1 depicts a sample wave form of the stimulus (/aʃa/) used for the study.

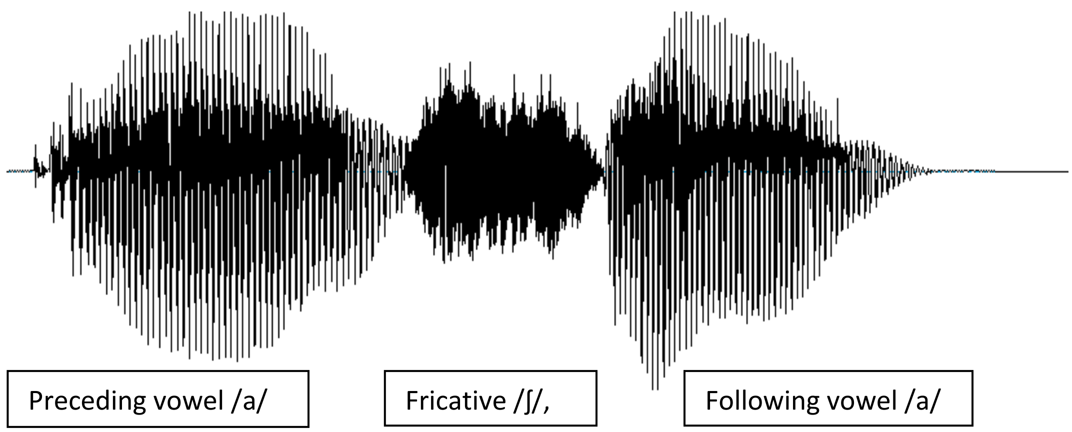

Figure 3.1: Sample wave form of the stimulus /aʃa/, produced by a female talker.

Initially, using Praat software, the formants available in the wave form were located. Using this as a guideline and along with visual analysis, the steady state portion of the vowel and the transition portion of the vowel were identified. For each stimulus the vowel along with the transition from the recorded VCV stimuli was truncated to isolate the preceding vowel and the final vowel. This was considered to have 0% of the aperiodic noise of /ʃ/. Following this, the isolated initial vowel steady state portion along with the vowel transition was further truncated along with portions of the aperiodic frication noise. Four such truncations were done to have 20%, 40%, 60% and 80% of the total duration of the fricative noise (Figures 3.2). All truncations were done at points the nearest zero crossing. Similarly, the final vowel steady state portion along with the vowel transition was further truncated at portions corresponding to 20%, 40%, 60% ,80% and 100% of the total duration of the fricative noise at the nearest zero crossing (Figure 3.3). The truncation commenced from the portion of the vowel adjacent to the consonant for both the preceding and the following vowels. The stimuli thus contained 5 tokens from the preceding vowel portion and 6 tokens from the following vowel portion. Each of these tokens was presented thrice in a random order for the male as well as female talker. Thus, a total of 198 stimuli were generated (11 tokens * 3 vowels * 3 random trials * 2 talkers). Prior to the tokens a 1 kHz calibration tone was recorded.

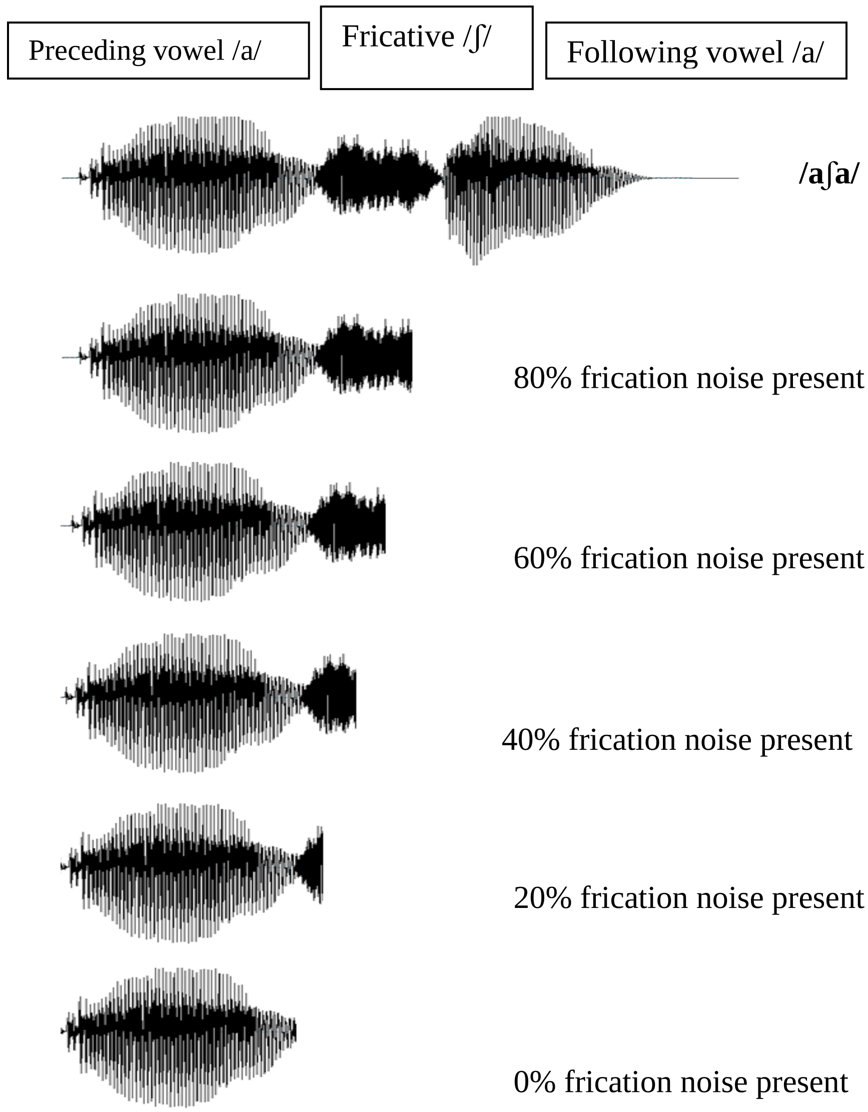

Figure 3.2: Sample waveform of anticipatory coarticulation stimuli having different extents of truncation

3.4.2 Pilot study:

A pilot study was carried out on 10 participants who met the selection criteria for Group-1. The purpose of the pilot study was to determine the consonants that the participants identified when the tokens formed from the VCVs were played to them.

The stimuli were presented using a Toshiba laptop with a core i5 generation processor. The output from the laptop was routed to the audio input of a calibrated audiometer. A 1 kHz calibration tone was presented prior to the stimuli in order to set the VU meter deflection to 0. The stimuli were presented to the listener through a TDH-39 headphone at 40 dB SL (reference PTA). The recorded stimuli were presented to the participant unilaterally. Half the participants heard the stimuli in their right ear and half in their left ear.

The responses were obtained using an open-set identification task. The participants were informed that they would hear a consonant along with vowels /a/, /i/, or /u/. They were asked to write down the speech sounds that they identified. Each participant heard 66 tokens (11 tokens * 3 vowels * 2 talkers). The responses of the participants were tabulated. The consonants that were identified by ≥ 50% of the participants were noted. The responses given by the participants for the tokens used for anticipatory and carryover coarticulation are depicted in Table 3.1.

Table 3.1: Open-set responses of the pilot study that served as the closed-set response choices for the vowels /a/, /i/ and /u/ in anticipatory and carryover coarticulation

	Open-set Responses to Coarticulatory stimuli	
Vowel	**Anticipatory**	**Carryover**
/a/	/ar/, /a/, /atʃ/, /at/, /aʃ/	/a/, /ta/, /tʃa, /ʃa/
/i/	/i/, /it/, /itʃ/, /iʃ/	/i/, /ti/, /tʃi/, /ʃi/
/u/	/u/, /ut/, /utʃ/, /uʃ/	/u/, /tu/, /tʃu/, /ʃu/

3.4.3 Procedure for testing coarticulation:

The procedure to test the coarticulation of the19 normal hearing participants and 18 individuals with hearing impairment was similar to that used in the pilot study. However, the participants were asked to carry out a closed-set identification task unlike the open-set identification task done in the pilot study. The open-set responses given by the participants in the pilot study (Table 3.1) served as the choices for the closed-set task. The participants were instructed that they would be hearing a certain phoneme and were asked to write down the same from the choices given to them. The presentation of the tokens was randomized to avoid any stimuli order effect. Initially, each participant was provided with 10 practice trials prior to the test trials in order to familiarize them with the procedure.

3.5 Scoring:

The responses of the participants were tabulated and scored. The number of times the fricative /ʃ/ /was heard by each participant across the different cuts (0%, 20%, 40%, 60% and 80% in anticipatory coarticulation condition, 0%, 20%, 40%, 60%, 80% and 100% in the carryover coarticulation condition) was noted. This was tabulated for both the anticipatory and carryover coarticulation condition across the context of the vowels /a/, /i/ and /u/. The scoring procedure was similar for both the participant groups.

3.6 Statistical Analyses:

The responses obtained were analyzed using the IBM Statistical Package for the Social Sciences (version 21) software. Descriptive and inferential analyses were carried out. A Shapiro-Wilk test indicated that the data were not normally distributed. Hence, nonparametric statistics were used. A Kruskal-Wallis test and a Mann Whitney-U test were used to determine differences across the groups of individuals with normal hearing and individuals with mild and moderate hearing impairment. A Wilcoxon Signed rank test was used to test for differences in perception for the male and female speakers. In order to compare the perception at different truncation durations, a Wilcoxon Signed rank test was used. Anticipatory and carryover coarticulation perception were compared using the Wilcoxon Signed Rank test. Following this, the Friedman's test and the Wilcoxon Signed rank test were used to compare perception across different vowel contexts.

CHAPTER 4

RESULTS

The study aimed at comparing coarticulation perception in individuals with hearing impairment and normal hearing individuals. The coarticulatory perception of the fricative /ʃ/ in the context of the vowels /a/, /i/ and /u/ were assessed. Also, the perception of the fricative /ʃ/ across varying durations of the fricative noise was studied. Further, the differences in the ability to utilize the anticipatory and carryover coarticulatory cues were studied in both normal hearing individuals and individuals with hearing impairment. A total of 198 stimuli tokens were presented to each participant and the /ʃ/ responses were noted. The number of /ʃ/ responses in each truncation were analysed using the SPSS (Version 21) software.

The results of the study have been discussed under the following subheadings:

4.1 Comparison of Coarticulation Perception across Male and Female Talkers (analysed with Wilcoxon Signed Rank test).

4.2 Comparison of Coarticulation Perception across Individuals with Normal Hearing and Individuals with Hearing Impairment (analysed using Kruskal- Wallis test and Mann Whitney-U tests).

4.3 Comparison of Coarticulation Perception across Different Extents of Consonant Truncation (analysed with Wilcoxon Signed Rank test)

4.4 Comparison of Coarticulation Perception across Anticipatory and Carryover Coarticulation (analysed with Wilcoxon Signed Rank test)

4.5 Comparison of Coarticulation Perception across Different Vowel Contexts (analysed using Friedman's test and Wilcoxon test)

Initially, a Shapiro-Wilk test of normality was carried out in order to test if the data were normally distributed. As the data were not normally distributed, nonparametric statistical tests were used. Descriptive and inferential statistics were carried out on the data.

4.1 Comparison of Coarticulation perception across Male and Female talkers:

The difference in the coarticulatory identification of the fricative /ʃ/ across male and female talkers were analysed. The performance across various durations of the fricative noise (0%, 20%, 40%, 60%, 80%, & 100%) were analysed in the context of the vowels /a/, /i/ and /u/.

In order to test for the difference in perception across male and female talker, Wilcoxon Signed Rank test was used. This was carried out separately for the normal hearing listeners (N = 19), listeners with mild hearing impairment (N = 9) and listeners with moderate hearing impairment (N = 9). The results of the test have been shown in Table 4.1a, b, c. Across each of the groups, > 75% of the stimuli did not show a significant difference across the male and female talker. Hence, the responses for male and female talker were combined during all further statistical analyses. The mean, standard deviation and the median scores obtained for combined male and female talker stimuli in the context of the vowel /a/, /i/ and /u/ across normal hearing listeners, listeners with mild and moderate hearing impairment has been shown in Table 4.2a, b, c.

Table 4.1a: Pair wise comparison of /ʃ/ responses across male and female talkers in the context of the vowel /a/, /i/ and /u/ in normal hearing listeners

	Truncations	Vowel /a/		Vowel /u/		Vowel /i/	
		/z/	***p* value**	**/z/**	***p* value**	**/z/**	***p* value**
Anticipatory	0%	.00	1.00	1.000	.31	.00	1.00
	20%	.00	1.00	.073	.94	2.39	.01**
	40%	1.63	.10	1.732	.08	.37	.70
	60%	1.00	.31	.000	1.00	1.41	.15
	80%	1.00	.31	1.000	.31	.00	1.00
Carryover	0%	.00	1.00	.000	1.00	.00	1.00
	20%	.00	1.00	.000	1.00	.00	1.00
	40%	1.00	.31	.000	1.00	1.00	.31
	60%	1.00	.31	1.000	.31	2.23	.02**
	80%	.33	.73	1.406	.16	1.50	.13
	100%	2.22	.026**	.632	.52	1.13	.25

Note: ** = $p < 0.05$

Table 4.1b: Pair wise comparison of /ʃ/ responses across male and female talkers in the context of the vowel /a/, /i/ and /u/ in listeners with mild hearing impairment

	Truncations	Vowel /a/		Vowel /u/		Vowel /i/	
		/z/	***p* value**	**/z/**	***p* value**	**/z/**	***p* value**
Anticipatory	0%	1.00	.31	.57	.56	1.41	.15
	20%	2.36	.01**	1.94	.05	2.24	.02**
	40%	.00	1.00	.90	.36	1.26	.20
	60%	1.41	.15	2.00	.04**	.70	.48
	80%	1.41	.15	2.00	.04**	.57	.56
Carryover	0%	.00	1.00	1.00	.31	.00	1.00
	20%	.00	1.00	.00	1.00	.00	1.00
	40%	1.00	.31	.00	1.00	.00	1.00
	60%	1.89	.05	1.63	.10	3.12	.00**
	80%	.90	.36	.23	.81	3.37	.00**
	100%	3.15	.00**	.70	.48	1.00	.31

Note: ** = $p < 0.05$

Table 4.1c: Pair wise comparison of /ʃ/ responses across male and female talkers in the context of the vowel /a/, /i/ and /u/ in listeners with moderate hearing impairment

	Truncations	**Vowel /a/**		**Vowel /u/**		**Vowel /i/**	
		/z/	***p* value**	**/z/**	***p* value**	**/z/**	***p* value**
Anticipatory	0%	.00	1.00	.00	1.00	.00	1.00
	20%	.55	.57	.21	.83	1.73	.08
	40%	1.00	.31	.41	.67	1.72	.08
	60%	1.13	.25	1.00	.31	2.00	.04**
	80%	1.89	.05	2.00	.04**	.74	.45
Carryover	0%	.00	1.00	1.00	.31	.00	1.00
	20%	.00	1.00	1.00	.31	.00	1.00
	40%	.00	1.00	1.73	.08	.00	1.00
	60%	1.13	.25	2.00	.04**	2.25	.02**
	80%	1.66	.09	.35	.72	2.55	.01**
	100%	1.40	.16	1.00	.31	1.89	.05

Note: ** = $p < 0.05$

Table 4.2a: Mean, Standard Deviation (SD) and Median for different consonant truncations in the context of the vowel /a/ in normal hearing listeners, listeners with mild and moderate hearing impairment

	Truncations	Normal (N = 19)		Mild (N = 9)		Moderate (N = 9)	
		Mean (SD)	**Median**	**Mean (SD)**	**Median**	**Mean (SD)**	**Median**
Anticipatory	0%	0.16 (0.68)	.00	.00 (.00)	.00	.00 (.00)	.00
	20%	3.84 (1.26)	4.00	3.33 (1.23)	3.00	2.22 (2.05)	2.00
	40%	5.58 (0.77)	6.00	5.33 (0.50)	5.00	4.33 (1.41)	5.00
	60%	5.79 (0.54)	6.00	5.89 (0.34)	6.00	4.78 (1.30)	5.00
	80%	5.89 (0.32)	6.00	5.8 (0.34)	6.00	5.33 (0.87)	6.00
Carryover	0%	.00 (.00)	.00	.00 (.00)	.00	.00 (.00)	.00
	20%	.00 (.00)	.00	.00 (.00)	.00	.00 (.00)	.00
	40%	.00 (.23)	.00	.00 (.34)	.00	.00 (.00)	.00
	60%	.68 (1.29)	.00	.22 (.67)	.00	1.22 (1.30)	1.00
	80%	3.16 (.61)	3.00	2.5 (1.10)	2.00	3.67 (0.88)	4.00
	100%	4.68 (.75)	5.00	3.56 (1.81)	3.00	4.67 (1.12)	5.00

Note: Maximum score = 6 and minimum = 0

Table 4.2b: Mean, Standard Deviation (SD) and Median for different consonant truncations in the context of the vowel /u/ in normal hearing listeners, listeners with mild and moderate hearing impairment

	Truncations	Normal (N = 19)		Mild (N = 9)		Moderate (N = 9)	
		Mean (SD)	Median	Mean (SD)	Median	Mean (SD)	Median
Anticipatory	0%	0.47 (1.02)	.00	0.7 (1.20)	.00	0.00 (.00)	.00
	20%	3.53 (1.95)	3.00	4.00 (0.86)	4.00	3.00 (1.41)	3.00
	40%	5.11 (1.15)	5.00	5.44 (1.01)	6.00	4.11 (1.96)	4.00
	60%	5.47 (0.90)	6.00	6.00 (0.00)	6.00	4.44 (1.94)	5.00
	80%	5.68 (0.58)	6.00	5.89 (0.33)	6.00	5.11 (1.26)	5.00
Carryover	0%	.00 (.22)	.00	.00 (.00)	.00	.00 (.11)	.00
	20%	.11 (.45)	.00	.00 (.00)	.00	.11 (.33)	.00
	40%	.21 (.53)	.00	.00 (.00)	.00	.33 (.50)	.00
	60%	.42 (.76)	.00	.11 (.33)	.00	.67 (1.00)	.00
	80%	2.47 (1.61)	3.00	1.8 (1.05)	2.00	2.56 (1.50)	3.00
	100%	4.53 (1.30)	4.00	3.78 (1.64)	4.00	4.33 (1.22)	4.00

Note: Maximum score = 6 and minimum = 0

Table 4.2c: Mean, Standard Deviation (SD) and Median for different consonant truncations in the context of the vowel /i/ in normal hearing listeners, listeners with mild and moderate hearing impairment

	Truncations	**Normal (N = 19)**		**Mild (N = 9)**		**Moderate (N = 9)**	
		Mean (SD)	**Median**	**Mean (SD)**	**Median**	**Mean (SD)**	**Median**
Anticipatory	0%	0.21 (0.71)	.00	0.00 (0.00)	.00	0.22 (0.66)	.00
	20%	2.05 (1.71)	2.00	2.33 (1.22)	3.00	1.22 (1.78)	.00
	40%	4.58 (1.89)	6.00	5.00 (1.11)	5.00	3.22 (2.10)	3.00
	60%	5.47 (1.02)	6.00	5.33 (0.86)	6.00	4.00 (1.73)	4.00
	80%	5.63 (0.68)	6.00	5.78 (0.66)	6.00	4.89 (0.92)	5.00
Carryover	0%	.00 (.00)	.00	.00 (.00)	.00	.00 (.00)	.00
	20%	.00 (.00)	.00	.00 (.00)	.00	.00 (.00)	.00
	40%	.00 (.00)	.00	.11 (.33)	.00	.00 (.00)	.00
	60%	1.05 (.97)	1.00	.56 (.52)	1.00	1.22 (.83)	1.00
	80%	3.16 (1.38)	4.00	2.78 (1.64)	3.00	3.11 (.60)	3.00
	100%	5.63 (.76)	6.00	4.78 (1.64)	6.00	5.00 (1.11)	5.00

Note: Maximum score = 6 and minimum = 0

4.2 Comparison of coarticulation perception across Individuals with Normal Hearing and Individuals with Hearing Impairment

Comparison was done across the data of 19 individuals with normal hearing, 9 individuals with mild hearing impairment and 9 individuals with moderate hearing impairment. The mean, standard deviation and median obtained for the normal hearing individuals and individuals with mild and moderate hearing impairment in the context of vowel /a/, /u/ and /i/ are reported in Table 4.2a, b, c. It can be noticed from the Table that the mean scores obtained by the normal hearing listeners is better than the mean scores obtained by individuals with hearing impairment. Further, the mean scores obtained by individuals with moderate hearing impairment are poorer than the mean scores obtained by individuals with mild hearing impairment. A similar pattern was noted across the context of the three vowels. Across the three vowel contexts, the differences in the mean scores between normal hearing listeners and listeners with hearing impairment is greater in anticipatory context as compared to the carryover context.

The results of the Kruskal-Wallis test (Table 4.3) showed significant overall differences across a few truncations with the participant groups combined. This was seen only for the anticipatory coarticulation conditions and not the carryover coarticulation conditions. To determine which of the 3 participant groups differed from each other, those truncations that showed a significant difference, were further subjected to Mann Whitney-U (Table 4.4a, b, c).

Table 4.3: Significance of difference between normal hearing listeners, listeners with mild and moderate hearing impairment in the perception of fricative /ʃ/ in the context of vowels /a/, /u/ and /i/ across various truncation durations

	Truncation	Vowel /a/	Vowel /u/	Vowel /i/
		p value df = 2	*p* value df = 2	*p* value df = 2
Anticipatory	0%	.62	.20	.60
	20%	.07	.43	.19
	40%	.02**	.18	.14
	60%	.01**	.01**	.05
	80%	.06	.11	.03**
Carryover	0%	1.00	.59	1.00
	20%	1.00	.61	1.00
	40%	.59	.19	.21
	60%	.12	.28	.23
	80%	.45	.55	.78
	100%	.11	.50	.16

Note: ** = $p < 0.05$

Table 4.4a: Significance of difference in /ʃ/ responses between individuals with normal hearing and mild hearing impairment

	Vowel context	Truncation	**/z/**	***p* value**
Anticipatory	Vowel /a/	40%	1.44	.14
	Vowel /a/	60%	.36	.71
	Vowel /u/	60%	1.85	.06
	Vowel /i/	80%	.79	.43

Note: ** = $p < 0.05$

Table 4.4b: Significance of difference in /ʃ/ responses between individuals with normal hearing and moderate hearing impairment

	Vowel context	Truncation	**/z/**	***p* value**
Anticipatory	Vowel /a/	Vowel /a/- 40%	2.63	.00**
	Vowel /a/	Vowel /a/- 60%	2.71	.00**
	Vowel /u/	Vowel /u/-60%	1.75	.07
	Vowel /i/	Vowel /i/ -80%	2.17	.03**

Note: ** = $p < 0.05$

Table 4.4c: Significance of difference in /ʃ/ responses between individuals with mild and moderate hearing impairment

	Vowel context	Truncation	**/z/**	***p* value**
Anticipatory	Vowel /a/	40%	1.57	.11
	Vowel /a/	60%	2.42	.01**
	Vowel /u/	60%	2.84	.00**
	Vowel /i/	80%	2.19	.02**

Note: ** = $p < 0.05$

The Mann Whitney-U test comparison between those with normal hearing and individuals with mild hearing impairment (Table 4.4a) showed no significant difference between the two groups. On the other hand, the normal hearing listeners and listeners with moderate hearing impairment showed significant differences for three stimuli (Table 4.4b). Similarly, a significant difference between those with mild and moderate hearing impairment was obtained for three of the stimuli (Table 4.4c) reflecting that at lesser degrees of hearing loss coarticulation perception is comparable to normal listeners, but reduces with increasing degrees of hearing loss. Significant difference between the groups were noted only for anticipatory coarticulation between the normal hearing listeners and those with moderate hearing impairment, as well as between the listeners with mild and moderate hearing impairment.

4.3 Comparison of Coarticulation Perception across Different Extents of Truncation:

The coarticulatory perception of the fricative /ʃ/ was analysed across different durations of the fricative noise. The mean, standard deviation and median obtained for /ʃ/ responses at different truncation duration in the context of the vowels /a/, /u/, /i/ in listeners with normal hearing, mild and moderate impairment has been shown in Table 4.2a, b, c. Across the context of all the vowels, it was observed that the /ʃ/ responses improve with increase in the duration of the fricative noise (from 0 to 80% in anticipatory coarticulation, from 0 to 100% in carryover coarticulation). This was noted across all the three groups of participants. However, at any given truncation duration, the mean scores obtained by normal hearing listeners were better than the scores obtained by those with moderate hearing impairment. In the anticipatory coarticulation, the mean scores reached closer to the maximum possible score of 6 at shorter durations of the fricative noise as compared to the carryover coarticulation condition in normal hearing listeners. Further, it can be noted that in case of listeners with moderate hearing impairment, the mean scores were poorer than that of normal hearing listeners even at longer truncation durations (i.e., 60%, & 80% in anticipatory coarticulation an 60%, 80%, & 100%) However, the mean scores of normal hearing listeners and those with mild hearing impairment are comparable at longer truncation durations in the anticipatory condition.

Table 4.5a: Pair wise comparison and significance of difference across adjacent consonant truncations for vowel /a/ in normal hearing listeners and those with mild and moderate hearing impairment

	Adjacent Truncations	**Normal (N= 19)**		**Mild (N= 9)**		**Moderate (N= 9)**	
		/z/	***p* value**	**/z/**	***p* value**	**/z/**	***p* value**
Anticipatory	10%-20%	3.75	.000**	2.68	.007**	2.37	.017**
	20%-40%	3.44	.001**	2.55	.011**	2.55	.011**
	40%-60%	2.00	.046**	2.23	.025**	1.19	.234
	60%-80%	1.00	.317	.00	1.000	1.89	.059
Carryover	0%- 20%	.00	1.000	.00	1.000	.00	1.000
	20%-40%	1.00	.317	1.00	.317	.00	1.000
	40%-60%	2.23	.026**	1.00	.317	2.04	.041**
	60%-80%	3.84	.000**	2.39	.017**	2.58	.010**
	80%- 100%	3.56	.000**	1.62	.105	1.93	.047**

Note: ** = $p < 0.05$

A pair wise comparison of perception across adjacent truncation durations was analyzed using Wilcoxon Signed Rank test. The results of the pair wise comparison of adjacent truncations in the three groups of participants in the context of the vowels /a/, /u/ and /i/ have been depicted in Table 4.5a, b, c. Across all the vowel contexts and the three groups of participants, significant difference was noted at truncations involving shorter duration of frication noise in the anticipatory condition. However, in the carryover coarticulation condition significant difference were noted across longer truncation durations.

Table 4.5b: Pair wise comparison and significance of difference across adjacent consonant truncations for vowel /u/ in normal hearing listeners and those with mild and moderate hearing impairment

	Adjacent Truncations	Normal (N = 19)		Mild (N = 9)		Moderate(N = 9)	
		/z/	***p* value**	**/z/**	***p* value**	**/z/**	***p* value**
Anticipatory	10%-20%	3.74	.000**	2.55	.01**	1.84	.06
	20%-40%	3.08	.002**	2.71	.00**	2.58	.01**
	40%-60%	2.64	.008**	.81	.41	2.33	.02**
	60%-80%	1.63	.102	1.63	.10	1.78	.07
Carryover	0%- 20%	1.00	.317	.00	1.00	.00	1.00
	20%-40%	1.41	.157	1.00	.31	.00	1.00
	40%-60%	2.00	.046**	2.00	.04**	2.42	.01**
	60%-80%	3.43	.001**	2.55	.01**	2.73	.00**
	80%- 100%	3.68	.000**	2.71	.00**	2.54	.01**

Note: ** = $p < 0.05$

Table 4.5c: Pair wise comparison and significance of difference across adjacent consonant truncations for vowel /i/ in normal hearing listeners and those with mild and moderate hearing impairment

	Adjacent Truncations	Normal (N = 19)		Mild (N = 9)		Moderate(N = 9)	
		/z/	***p* value**	**/z/**	***p* value**	**/z/**	***p* value**
Anticipato	0%-20%	3.43	.00**	2.72	.00**	2.68	.00**
	20%-40%	3.63	.00**	2.59	.00**	2.23	.02**
	40%-60%	2.69	.00**	1.63	.10	1.13	.25
	60%-80%	.70	.48	1.00	.31	1.73	.08
Carryover	0%- 20%	.00	1.00	.00	1.00	.00	1.00
	20%-40%	.00	1.00	.00	1.00	1.41	.15
	40%-60%	3.12	.00**	1.00	.31	1.34	.18
	60%-80%	3.86	.00**	2.54	.01**	2.53	.01**
	80%- 100%	3.75	.00**	2.384	.017**	2.55	.011**

Note: ** = $p < 0.05$

This is in consensus with the results reported in the previous section stating that in the anticipatory condition, the mean scores reached closer to maximum score(6) at shorter truncation duration as compared to the carry over condition.

4.4 Comparison of Perception across Anticipatory and Carryover Coarticulation

The mean, standard deviation and the median scores obtained for the performance across anticipatory coarticulation condition in listeners with normal hearing and those with mild and moderate hearing impairment in the context of the vowels /a/, /u/ and /i/ have been shown in Table 4.2a, b, c respectively. Across the different truncation durations, the scores obtained in the anticipatory coarticulation condition were better than the scores obtained in the carryover coarticulation condition. This was noted across all the three groups in the context of the vowels /a/, /u/ and /i/. At the longest duration of the truncation too, the mean scores obtained in the anticipatory condition were better than the scores obtained in the carryover condition in all the three groups of participants for the vowels /a/, /u/ and /i/. Further, it has been observed that that in the anticipatory condition, the mean scores reached closer to maximum score (6) at a shorter truncation duration as compared to the carryover condition. A pair wise comparison of perception of fricative /ʃ/ in the anticipatory and carryover condition was carried out using Wilcoxon Signed Rank test. The test was carried out separately across the group of individuals with normal hearing, individuals with mild hearing impairment and individuals with moderate hearing impairment. The results of the test have been shown in Table 4.6. In the normal hearing listeners, a significant difference was noted across all comparisons except for the shortest truncation duration (0%) in the context of the vowels /a/ and /u/. A similar trend was observed in listeners with mild hearing impairment also. However, in listeners with moderate hearing impairment, for all the three vowel contexts, a significant difference in perception between anticipatory and carryover coarticulation was noted across all stimuli tokens except for the shortest and the longest truncations.

Table 4.6: Pair wise comparison and significance of difference between anticipatory and carryover coarticulation in normal hearing individuals and individuals with mild and moderate hearing impairment in the context of vowels /a/, /u/ and /i/

	Anticipatory (A) vs Carryover (C) Truncation	**Normal (N = 19)**		**Mild (N = 9)**		**Moderate (N = 9)**	
		/z/	***p* value**	**/z/**	***p* value**	**/z/**	***p* value**
Vowel /a/	A-0% vs C-0%	1.00	.31	.00	1.00	.00	1.00
	A-20% vs C-20%	3.85	.00**	2.68	.00**	2.37	.01**
	A-40% vs C-40%	3.97	.00**	2.72	.00**	2.68	.00**
	A-60% vs C-60%	3.89	.00**	2.80	.00**	2.68	.00**
	A-80% vs C-80%	3.76	.00**	2.68	.00**	2.23	.02**
	A-80% vs C-100%	3.62	.00**	2.41	.01**	1.40	.16
Vowel /u/	A-0% vs C-0%	1.85	.06	1.63	.10	1.00	.31
	A-20% vs C-20%	3.74	.00**	2.69	.00**	2.53	.01**
	A-40% vs C-40%	3.87	.00**	2.75	.00**	2.53	.01**
	A-60% vs C-60%	3.88	.00**	2.88	.00**	2.55	.01**
	A-80% vs C-80%	3.74	.00**	2.68	.00**	2.41	.01**
	A-80% vs C-100%	2.85	.00**	2.37	.01**	1.55	.12
Vowel /i/	A-0% vs C-0%	1.34	.18	.00	1.00	1.00	.31
	A-20% vs C-20%	3.43	.00**	2.55	.01**	1.82	.06
	A-40% vs C-40%	3.89	.00**	2.69	.00**	2.67	.00**
	A-60% vs C-60%	3.87	.00**	2.75	.00**	2.53	.01**
	A-80% vs C-80%	3.65	.00**	2.69	.00**	2.72	.00**
	A-80% vs C-100%	.17	.86	1.84	.06	.35	.72

Note: ** = $p < 0.05$

4.5 Comparison of Coarticulation Perception across Different Vowel Contexts

The effect of the three vowels /a/, /u/ and /i/ in the perception of the fricative /ʃ/ was analyzed. Table 4.7a, b, c represent the mean, standard deviation and median scores obtained in the context of vowels /a/, /u/ and /i/ by individuals with normal hearing, those with mild and moderate hearing impairment respectively. From the table it can be seen that in the anticipatory coarticulation condition, the mean scores obtained by the normal hearing listeners in the context of the vowel /a/ and /u/ are better than the mean scores obtained in the context of the vowel /i/. Also, when longer durations of the consonant were provided, the mean scores obtained in the context of the vowel /a/ were better than the other two vowels. Across all the three vowel contexts, the mean scores improved with increase in the duration of the fricative noise in both the anticipatory and carryover condition. However, in the carryover condition the mean scores obtained in the context of the vowel /i/ were better than the scores obtained in the context of /a/ and /u/.

In order to test for differences in performance across the three vowel contexts, initially a Friedman's test was used. The Friedman's test was carried out for each of the participant groups separately. Within each group, the Friedman's test was carried out for the responses for equivalent truncation duration for each of the three vowels. The results of the test have been shown in Table 4.8. In the normal hearing listeners, an overall difference across the vowels was noted in the anticipatory condition at 20% truncation and at 80% and 100% truncation in the carryover condition. In the listeners with mild and moderate hearing impairment a significant difference was noted in the anticipatory coarticulation at 60% and 20% truncations respectively.

To determine which of the pairs of vowel differed from each other, these stimuli were further tested using a Wilcoxon Signed Rank test. The results of the test have been shown in Table 4.9 a, b, c. Significant vowel effects were noted at the shorter truncations in the anticipatory condition and at longer durations in the carryover condition in normal hearing listeners. Further, it was noted that, a significant difference was observed between vowels /a/ and /i/; /u/ and /i/ in the anticipatory condition at 20% truncation. At 100% truncation in the carryover condition also significant differences were noted between vowels /a/ and /i/; /u/ and /i/. Similarly, in the listeners with moderate hearing impairment, differences were noted between vowels /u/ and /i/. However, pair wise comparison revealed no differences in the listeners with mild hearing impairment.

Table 4.7a: Comparison of mean, standard deviation and median in anticipatory and carry over condition across various truncation durations in the context of vowels /a/, /u/ and /i/ in normal hearing listeners

	Truncations	**Vowel /a/**		**Vowel /u/**		**Vowel /i/**	
		Mean (SD)	**Median**	**Mean (SD)**	**Median**	**Mean (SD)**	**Median**
Anticipatory	0%	0.16 (0.68)	.00	0.4 (1.02)	.00	0.21 (0.71)	.00
	20%	3.84 (1.26)	4.00	3.53 (1.95)	3.00	2.05 (1.71)	2.00
	40%	5.58 (0.77)	6.00	5.11 (1.15)	5.00	4.58 (1.89)	6.00
	60%	5.79 (0.54)	6.00	5.47 (0.90)	6.00	5.47 (1.02)	6.00
	80%	5.89 (0.32)	6.00	5.68 (0.58)	6.00	5.63 (0.68)	6.00
Carryover	0%	.00 (.00)	.00	.00 (.22)	.00	.00 (.00)	.00
	20%	.00 (.00)	.00	.11 (.45)	.00	.00 (.00)	.00
	40%	.00 (.23)	.00	.21 (.53)	.00	.00 (.00)	.00
	60%	.68 (1.29)	.00	.42 (.76)	.00	1.05 (.97)	1.00
	80%	3.16 (.61)	3.00	2.47 (1.61)	3.00	3.16 (1.38)	4.00
	100%	4.68 (.75)	5.00	4.53 (1.30)	4.00	5.63 (.76)	6.00

Note: maximum score= 6, Minimum score = 0

Table 4.7b: Comparison of mean, standard deviation and median in anticipatory and carry over condition across various truncation durations in the context of vowels /a/, /u/ and /i/ in individuals with mild hearing impairment

	Truncations	**Vowel /a/**		**Vowel /u/**		**Vowel /i/**	
		Mean (SD)	**Median**	**Mean (SD)**	**Median**	**Mean (SD)**	**Median**
Anticipatory	0%	.00 (.00)	.00	0.7 (1.20)	.00	0.00 (0.00)	.00
	20%	3.33 (1.23)	3.00	4.00 (0.86)	4.00	2.33 (1.22)	3.00
	40%	5.33 (0.50)	5.00	5.44 (1.01)	6.00	5.00 (1.11)	5.00
	60%	5.89 (0.34)	6.00	6.00 (0.00)	6.00	5.33 (0.86)	6.00
	80%	5.8 (0.34)	6.00	5.89 (0.33)	6.00	5.78 (0.66)	6.00
Carryover	0%	.00 (.00)	.00	.00 (.00)	.00	.00 (.00)	.00
	20%	.00 (.00)	.00	.00 (.00)	.00	.00 (.00)	.00
	40%	.00 (.34)	.00	.00 (.00)	.00	.11 (.33)	.00
	60%	.22 (.67)	.00	.11 (.33)	.00	.56 (.52)	1.00
	80%	2.5 (1.10)	2.00	1.8 (1.05)	2.00	2.78 (1.64)	3.00
	100%	3.56 (1.81)	3.00	3.78 (1.64)	4.00	4.78 (1.64)	6.00

Note: Maximum score = 6 and minimum = 0

Table 4.7c: Comparison of mean, standard deviation and median in anticipatory and carry over condition across various truncation durations in the context of vowels /a/, /u/ and /i/ in individuals with moderate hearing impairment

	Truncations	**Vowel /a/**		**Vowel /u/**		**Vowel /i/**	
		Mean (SD)	**Median**	**Mean (SD)**	**Median**	**Mean (SD)**	**Median**
Anticipatory	0%	.00 (.00)	.00	0.00 (.00)	.00	0.22 (0.66)	.00
	20%	2.22 (2.05)	2.00	3.0 (1.41)	3.00	1.22 (1.78)	.00
	40%	4.33 (1.41)	5.00	4.11 (1.96)	4.00	3.22 (2.10)	3.00
	60%	4.78 (1.30)	5.00	4.44 (1.94)	5.00	4.00 (1.73)	4.00
	80%	5.33 (0.87)	6.00	5.11 (1.26)	5.00	4.89 (0.92)	5.00
Carryover	0%	.00 (.00)	.00	.00 (.11)	.00	.00 (.00)	.00
	20%	.00 (.00)	.00	.11 (.33)	.00	.00 (.00)	.00
	40%	.00 (.00)	.00	.33 (.50)	.00	.00 (.00)	.00
	60%	1.22 (1.30)	1.00	.67 (1.00)	.00	1.22 (.83)	1.00
	80%	3.67 (0.88)	4.00	2.56 (1.50)	3.00	3.11 (.60)	3.00
	100%	4.67 (1.12)	5.00	4.33 (1.22)	4.00	5.00 (1.11)	5.00

Note: Maximum score = 6 and minimum = 0

Table 4.8: Comparison of vowel (/a/, /i/, /u/) context effects across individuals with normal hearing, mild and moderate hearing impairment

	Truncations	**Normal**	**Mild**	**Moderate**
		p value (df= 2)	*p* value (df= 2)	*p* value (df= 2)
Anticipatory	0%	0.24	0.05	0.36
	20%	0.00**	0.05	0.02**
	40%	0.06	0.54	0.045
	60%	0.16	.03**	0.045
	80%	0.22	1.00	0.24
Carryover	0%	0.36	-	0.36
	20%	0.36	-	0.36
	40%	0.17	0.36	0.05
	60%	0.11	0.09	0.32
	80%	0.04**	0.80	0.10
	100%	0.00**	0.27	0.23

Note: ** = $p < 0.05$

Table 4.9a: Pair wise comparison and significance of difference between vowel pairs in normal hearing listeners

	Truncation		**/u/ vs /a/**	**/i/ vs /a/**	**/i/ vs /u/**
Anticipatory	20%	z	0.68	2.95	2.95
		p value	0.49	0.00**	0.00**
Carryover	80%	z	1.77	1.88	1.88
		p value	0.07	0.05	0.05
Carryover	100%	z	0.49	2.99	2.99
		p value	0.62	0.00**	0.00**

Note: ** = $p < 0.05$

Table 4.9b: Pair wise comparison and significance of difference between vowel pairs in listeners with mild hearing impairment

	Truncation		**/u/ vs /a/**	**/i/ vs /a/**	**/i/ vs /u/**
Anticipatory	60%	z	1.00	1.63	1.85
		p value	0.31	0.10	0.06

Note: ** = $p < 0.05$

Table 4.9c: Pair wise comparison and significance of difference between vowel pairs in listeners with moderate hearing impairment

	Truncation		**/u/ vs /a/**	**/i/ vs /a/**	**/i/ vs /u/**
Anticipatory	20%	z	1.02	0.95	2.58
		p value	0.30	0.33	0.01**

Note: ** = $p < 0.05$

The results of the study revealed the following:

- There was no significant difference in performance across male and female talker across most of the stimuli.
- The overall performance of individuals with moderate hearing was poorer than normal hearing listeners.
- No significant difference was noted between listeners with normal hearing and mild hearing impairment.
- A significant difference occurred between those with normal hearing and those with moderate hearing impairment anticipatory coarticulation of the vowel /a/ with 40% and 60% truncation, and vowel /i/ with 80% truncation.
- A significant difference was observed between listeners with mild hearing impairment and those with moderate hearing impaired in the anticipatory

condition in vowel /a/ with 60% truncation, vowel /u/ with 60% truncation and vowel /i/ with 80% truncation.

- The performance in each of the group improved with increasing frication duration. A significant difference was noted across truncations of shorter durations in the anticipatory condition (0%, 20%, & 40%) and across truncations of longer duration in the carryover condition (60%, 80%, & 100%).
- The performance in anticipatory condition was significantly better than the carry over across all truncations (except the shortest truncation duration of 0%) in normal listeners and those with mild hearing impairment.
- In individuals with moderate hearing loss performance in anticipatory condition was significantly better than the carryover across all truncations except the shortest and the longest truncation durations (0% and 100%).

CHAPTER 5

DISCUSSION

The study aimed at determining the effectiveness with which individuals with normal hearing and hearing impairment utilise coarticulation cues in the perception of the fricative /ʃ/. The perception of the fricative /ʃ/ in the context of the vowels /a/, /i/ and /u/ was analyzed across different truncation durations of the fricative noise recorded using a male and a female talker. The results of the study have been discussed in terms of differences in perception between normal hearing listeners and listeners with hearing impairment; The extent of coarticulation across different truncation durations; The differences between anticipatory and carryover coarticulation effects and; and the effect of different vowel contexts on coarticulation effects.

5.1 Coarticulation Perception with Male and Female Talkers:

Although the overall performance of the female speakers was found to be better than that of the male talker, no significant difference was in performance across genders was noted. This absence of difference was seen for > 75% of the stimuli evaluated in a group of listeners with normal hearing, as well as those with mild and those with moderate hearing impairment. No significant difference was noted across the context of the vowels /a/, /u/ and /i/. This indicates that the speaker gender does not significantly affect the perceptual coarticulatory effects.

In contrast to the results of the present study, Mann and Repp (1980) reported of a difference in coarticulatory performance across male and female talker, with higher /ʃ/ responses when the stimuli was spoken by a female talker. These discrepancies noted between the present study and the study by Mann and Repp can be attributed to the differences in the stimuli used in the two studies. The study by Mann and Repp involved a /s/- /ʃ/ fricative continuum, where the periodic vowel portion of the stimuli spoken by a male and a female talker were retained but the fricative portion was replaced by a synthetic 9-step fricative continuum. Thus, the periodic vowel portions alone had cues reflecting the speaker gender characteristics and it was absent in the consonant portion.

However, in the current study, the entire signal reflected the gender of the speaker. It is possible that the natural vowel reflecting gender characteristics in combination with the synthetic fricative may have resulted in better performance with the female talker due to a contrast effect. This contrast effect would have been relatively less in stimuli having the vowel produced by a male talker. Thus, this could have led to the better performance for stimuli spoken by the female talker. However, this contrast effect that may have resulted in a gender difference does not apply to the current study as the fricative noise as well as the periodic vowel characteristics represented the gender differences. This would have resulted in no contrast effect difference in the stimuli produced by the male and female speakers. Hence, this would have resulted in there being no significant difference between the genders in the current study.

Further, unlike the findings of the current study as well as that of Mann and Repp (1980), Oh (2010) reported that coarticulated cues of male speakers were better than that of female speakers. Thus, from the findings of the current study and from information present in the review, it can be noted that there is no consensus regarding the effect of speaker gender on perception of coarticulation cues.

5.2 Comparison of Coarticulation Perception across Individuals with Normal Hearing and Individuals with Hearing Impairment

The current study reported of no significant difference between individuals with normal hearing and those with mild hearing impairment. In contrast the overall performance of the group of listeners with moderate hearing impairment was significantly poorer than those with normal hearing. Thus, it can be inferred that the ability to utilise coarticulatory cues reduced with increasing hearing loss.

Studies mentioned in literature also reported of similar findings. Like what has been observed in the current study, Dorman, Lindholm, and Hannley (1985) reported that individuals with mild sloping hearing loss could overcome masking effects and could utilise their intact temporal and spectral resolution abilities. The relatively preserved discrimination and resolution abilities in individuals with mild hearing impairment may explain the absence of a significant difference across listeners with normal hearing and hearing impairment. This would have let those with a mild hearing loss utilise spectral cues. Thus, it can be inferred that those with a mild hearing impairment tend to function similar to those with normal hearing.

The findings of the current study regarding the poorer performance of those with moderate hearing loss is in line with previous reports. Revoile (1999) noted that individuals with moderate hearing impairment could effectively utilize transition cues as long as these were audible and the auditory resolution was intact. As the present study evaluated the participants at a level that made the signals audible (40 dB SL, wrt to PTA), it can be inferred that the transition and coarticulatory cues were audible. Despite the signals being audible to all the participants, those with a moderate hearing loss were unable to utilise the coarticulated cues to the same extent as those with normal hearing or those with mild hearing loss. They were unable to extract these cues even when longer durations of the fricative noise were provided. Thus, it can be construed that the perceptual difficulties of those with a moderate hearing impairment probably be attributed to poor auditory resolution abilities.

Studies carried on individuals with higher degrees of hearing of hearing impairment (moderately-severe to severe) noted that such participants failed to effectively utilize the dynamic transition cues in order to identify fricatives /s/ and /ʃ/ (Pittman, Stelmachowicz, Lewis, & Hoover, 2002a,; Revoile & Pickett, 1985; Robb & Turner, 1987). Thus, it is evident that as the degree of hearing impairment increases, their coarticulation perception decreases.

Thus, it can be concluded that the ability to utilize coarticulatory cues varies with varying degrees of hearing loss with individuals. Individuals with lesser degrees of hearing loss are able to perform better due to the intact discrimination and resolution abilities. However, individuals with relatively higher degrees of hearing loss cannot effectively utilize the same due to poor auditory resolution.

5.3 Comparison of Coarticulation Perception across Different Extents of Truncation:

The results of the present study indicated that the performance in each of the groups improved with increasing duration of the fricative noise being provided. This pattern was observed in the context of all the three vowels /a/, /u/ and /i/. Thus, it can be interpreted that performance improves with increasing frication spectral cues. Unlike the results of current study, Ali, Gallagher, Goldstein, and Daniloff (1970) reported that listeners were able to discriminate between nasals and non-nasals when the nasal consonant was completely spliced off. The discrepancies noted between the results of the current study and the study by Ali et al. can be attributed to the difference in the consonants considered. The coarticulatory perception of consonant /ʃ/ was analysed in the current study whereas the study by Ali et al. used nasals. Also, in the current study the participants were asked to identify the fricative whereas in the study by Ali et al. the individuals were asked discriminate whether the given sound was nasal or not. These differences may have led to the contrasting in the results across the two studies.

In the present study, normal hearing listeners and those with mild hearing impairment showed a significant difference in performance between all the adjacent truncation durations considered except when longest duration of the frication noise was presented (60% & 80%). It may be inferred that individuals with normal hearing and those with mild hearing impairment achieve maximum performance and are able to maximally utilize the spectral cues even when the entire frication portion is not provided. Their performance progressively improved as larger segments of the frication noise were presented. This improvement plateaued after 60% of the frication noise was provided. However, in individuals with moderate hearing impairment no significant difference was noted between the two shortest truncations (0% & 20%) indicating that they required larger frication cues in order to perceive the consonant coarticulation cues. Only when over 20% of the frication noise was presented, could they start perceiving the fricative /ʃ/. Further, the performance of individuals with moderate hearing impairment was poorer than that of normal listeners even at longer truncation durations presented at equal level of audibility (i.e., 60%, & 80% in anticipatory coarticulation an 60%, 80%, & 100%).

This indicates that even when provided with larger cues, individuals with moderate hearing loss fail to utilize them effectively. This may be ascribed to their poor temporal and spectral resolution abilities in these individuals.

Thus, it can be noted that coarticulation perception significantly improves with increasing spectral cues of the target consonant. This occurs in normal hearing individuals and those with a mild hearing loss. However, individuals with moderate hearing loss do not effectively utilize these cues though provided at equal levels of audibility probably due to poor spectral and temporal abilities.

5.4 Comparison of Coarticulation Perception across Anticipatory and Carryover Coarticulation:

The results of the present study revealed that perception of the fricative /ʃ/ was significantly better in the anticipatory coarticulation condition as compared to the carryover condition. This pattern was observed in each of the three participant groups across the context of the three vowels /a/, /u/ and /i/. Thus, it can be reasoned that listeners can utilize anticipatory cues more effectively as compared to carryover cues.

The results of a spectral analysis study by Samuel and Savitri (2003) are on similar lines as that of the current study, indicating spread of anticipatory coarticulation for 10 to 60 ms and spread of carryover coarticulation for 0 to 30 ms. This difference in spread of spectral effects on the temporal domain with the anticipatory coarticulation being longer than carryover may also explain why the former was found to be better than the latter in the present study.

Unlike the findings of the current study, the results of Bell-Berti and Harris (1975) and Mann and Soli (1991) indicated that the perception of fricative was significantly better in the carryover context as compared to the anticipatory context. This discrepancy may be due to the language background of the speakers and the listeners in the current study and the previously mentioned studies. It has been reported that the coarticulation effects observed and the directionality of coarticulation are affected by the phonetic inventories and are language specific (Manuel & Krakow, 1984). The impact of language has also been noted in a study by Manuel and Krakow (1984). They reported that the anticipatory coarticulatory effects were more prominent than the carryover in Swahili, unlike what is generally reported in studies carried in English Bell-Berti and Harris (1975) and Mann and Soli (1991). In the current study, all the participants and the talkers were native speakers of Kannada. Hence, it may be interpreted that variations in languages do result in variations in the utility of anticipatory and carryover coarticulation.

Further, it may be argued that a listener may utilise the anticipatory cues more than the carryover as it provides information about a phoneme that is yet to be heard and hence proving to be of greater utility. This may have also contributed to the listeners attending to anticipatory cues more than to carryover cues.

5.5 Comparison of Coarticulation Perception across Different Vowel Contexts:

In individuals with normal hearing a significant vowel context effect was noted in the anticipatory condition at 20% truncation (between vowels /a/ and /i/, and /i/ and /u/) with performance being poorer in the context of vowel /i/ as compared to vowels /a/ and /u/. The performance was best in the context of /u/. Similarly, in individuals with moderate hearing impairment also a significant difference in performance was noted between the vowels /u/ and /i/. This is in consensus with the results of the study by Nittrouer and Studdert-Kennedy (1986) who observed that /ʃ/ responses increased in the context of the vowel /u/ as compared to the vowel /i/. This may have occurred due to a contrast effect. The fricative /ʃ/ would have been perceived higher in frequency in the context of a low frequency vowel /u/ compared to the context of /i/ or /a/. Hence, when cues due to feature spreading are not available, normal hearing individuals probably utilise contrast effect cues.

From the finding of the current study, it can be inferred that those with a mild hearing impairment function similarly as normal hearing listeners. Unlike them, those with a moderate hearing impairment do not use coarticulatory cues to the same extent. Based on this find it is suggested that in individuals with higher degrees of hearing impairment, listening in adverse listening conditions should be avoided, as they would be unable to use coarticulatory redundant cues.

CHAPTER 6

SUMMARY AND CONCLUSIONS

A number of studies have documented the relative importance of various acoustic cues in the identification of fricatives (Behrens & Blumstein, 1988; de Manrique & Massone, 1981; Jongman, 1988; Nittrouer & Studdert-Kennedy, 1986; Zeng & Turner, 1990). Studies carried out to investigate the utility of coarticulatory cues in the identification of fricatives have documented that listeners with normal hearing use coarticulatory cues effectively, especially in conditions where the direct cues are unavailable (Harris, 1958; Mann & Soli, 1991; Soli, 1981; Whalen, 1981). Similarly, studies have been carried out to compare the ability of individuals with hearing impairment to effectively utilize these coarticulatory cues (Pittman, Stelmachowicz, Lewis, & Hoover, 2002; Pittman & Stelmachowicz, 2000; Revoile & Pickett, 1985; Robb & Turner, 1987; Zeng & Turner, 1990). However, most of the studies have been carried out on those with higher degrees of hearing impairment and information on the ability of individuals with relatively lesser degree of hearing loss to utilize coarticulatory cues is limited. The current study was carried out with the aim to compare coarticulatory abilities between individuals with normal hearing and those with mild and moderate hearing impairment. Further, the extent of coarticulation, differences in the ability to utilize anticipatory and carryover cues and the effect of different vowel contexts on coarticulatory perception were studied.

Stimuli /aʃa/, /iʃi/ and /uʃu/ recorded by both a male and female talker were used. These stimuli were further truncated so as to include the preceding vowel along with varied durations of the overall frication noise (0%, 20%, 40%, 60% & 80%) in the anticipatory condition. Similarly, in the carryover condition the stimuli were truncated so as to include varied durations of the fricative noise (0%, 20%, 40%, 60%, 80% & 100%) along with the following vowel. Each of these stimuli was presented thrice randomly to 19 normal hearing listeners, 9 listeners with mild hearing impairment and 9 with moderate hearing impairment. The participants were asked to write down the speech sound heard by them from a given set of choices. The responses were scored as the number of /ʃ/ responses at each truncation duration.

A Shapiro-Wilk test indicated that the data were not normally distributed. Hence, nonparametric statistics were used.

From the finding of the study at hand, it may be noted that the ability of listeners to utilize coarticulatory cues deteriorates with increasing degrees of hearing loss. The performance of individuals with mild hearing impairment was similar to that of the normal hearing listeners, reflecting the possibility that reduction in audibility alone with intact discrimination abilities does not affect coarticulatory perception. Further, it was noted that increasing the spectral cues in terms of the duration of the fricative noise resulted in a significant improvement across each of the three groups. However, the performance of individuals with moderate hearing impairment was poorer than that of normal hearing listeners even when the largest duration of frication noise was presented, indicating that individuals with hearing impairment are unable to effectively utilize the spectral cues. Also, it was noted that the perception in the anticipatory condition was significantly better than the carryover condition in each of the three participant groups. It was also observed that in the anticipatory condition, the number of /ʃ/ responses were higher in the context of the vowel /u/ as compared with /i/ or /a/. However, significantly better scores were obtained in the context of /i/ in the carryover condition.

Thus, it can be concluded from the current study that the ability of listeners to utilize coarticulated cues reduces with increasing hearing loss that may be attributed to the poor temporal and spectral resolution abilities. Based on this find it is suggested that for individuals with higher degrees of hearing impairment, listening in adverse listening conditions should be avoided, as they would be unable to use coarticulatory redundant cues.

Implications:

The implications of the study are as follows:

- The study provides a good understanding why individuals with different degrees of hearing impairment perform differently even when the signal is made audible to them.

- The outcome of the study can be used to counsel individuals with hearing impairment regarding the reason for their speech perception difficulties.
- Modifications in therapeutic programs can be made to help individuals with hearing impairment utilize the coarticulated cues better by utilizing the vowel context effects.
- The management programs can progress in a step-wise manner by first training individuals with hearing impairment to extract cues from anticipatory coarticulation due to better ability of listeners to utilize the anticipatory cues.

REFERENCES

Ali, L., Gallagher, T., Goldstein, J., & Daniloff, R. (1970). *Journal of the Acoustical Society of America*, *49*(2), 538– 540.

ANSI S3.1- 1999(R2008). American National Standards Maximum Permissible Noise Level for Audiometric Test Rooms.

Behrens, S., & Blumstein, S. E. (1988). On the role of the amplitude of the fricative noise in the perception of place of articulation in voiceless fricative consonants. *Journal of the Acoustical Society of America*, *84*(3), 861–867.

Bell - Berti, F., & Harris, K. (1975). Some acoustic measure of Anticipatory and Carryover Coarticulation. *Haskins Laboratries: Status Report on Speech Research SR- 42/44*.

Benguerel, A. P., & Cowan, H. (1974). Coarticulation of upper lip protrusion in French. *Phonetica*, *30*, 41–55.

Bilger, R. C., & Wang, M. D. (1976). Consonant confusions in patients with hearing University of Pittsburgh , Pennsylvania University of Maryland Baltimore County. *Journal of Speech, Language and Hearing Research*, *19*(4), 718–748.

Bohn, O.-S., & Steinlen, a K. (2003). Consonantal Context affects Cross-Language Perception of Vowels. *Proceedings of the XVth International Congress of Phonetic Sciences*, (August), 2289–2292. Retrieved from http://www.hum.au.dk/engelsk/engosb/pdf/ICPhS226bostei.pdf

Boothroyd, A. (1984). Auditory Perception of Speech Contrasts by subjets with Sensorineural Hearing Loss. *Journal of Speech and Hearing Research*, *27*(1), 133–144.

Carney, & Moeller. (1998). Treatment efficacy: hearing loss in children. *Journal of Speech, Language & Hearing Research*, *41*(1), S61–84 1p.

Ching, T. Y., Dillon, H., & Byrne, D. (1998). Speech recognition of hearing-impaired listeners: predictions from audibility and the limited role of high-frequency amplification. *The Journal of the Acoustical Society of America*, *103*(2), 1128–40. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/9479766

Cole, R. A., & Brian, S. (1973). Perception of temporal order- The role of vowel transitions. *Canadian Journal of Psychology*, *27*(4), 441–449. Retrieved from http://psycnet.apa.org/?&fa=main.doiLanding&doi=10.1037/h0082495

de Manrique, A. M., & Massone, M. I. (1981). Acoustic analysis and perception of Spanish fricative consonants. *The Journal of the Acoustical Society of America*, *69*(4), 1145–1153. doi:10.1121/1.385694

Delattre, C. P., Liberman, M. . A., & Cooper, F. (1955). Acoustic Loci and Transitional Cues for Consonants. *The Journal of the Acoustical Society of AmericaJournal of Speech, Language and Hearing Research*, *27*(4), 769– 773.

Denes, P. (1955). Effect of Duration on the Perception of Voicing. *Journal of the Acoustical Society of America*, *27*(4), 761–764. doi:10.1121/1.1908020

Dorman, M. F., Lindholm, J. M., & Hannley, M. T. (1985). Influence of the First Formant on the Recognition of voiced stop consonants by hearing- impaired listeners. *Journal of Speech Language and Hearing Research*, *28*(8), 377–380.

Dubno, J. R., Dirks, D. D., & Ellison, D. E. (1989). Stop-consonant recognition for normal-hearing listeners and listeners with high-frequency hearing loss. I: The contribution of selected frequency regions. *The Journal of the Acoustical Society of America*, *85*(1), 347. doi:10.1121/1.397686

Ethical Guidelines for Bio- Behavioral Research Involving Human Subjects,. (2009). *All India Institute of Speech and Hearing*. Mysore, India.

Gurlenkian, J. A. (1981). Recognition of the Spanish fricatives /s/ and /f/. *Journal of the Acoustical Society of America*, *70*(6), 1624–1627. doi:10.1121/1.387228

Harris, S. K. (1958). Cues for the discrimination of American English Fricatives in Spoken Syllables. *Language and Speech*, *1*(1), 1–7.

Heinz, J. M., & Stevens, K. N. (1961). on the properties of voiceless fricative consonants. *The Journal of the Acoustical Society of America*, *33*(5), 589–596.

Hogan, C. A., & Turner, C. W. (1998). High-frequency audibility: benefits for hearing-impaired listeners. *The Journal of the Acoustical Society of America*, *104*(1), 432–41. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/9670535

Hogan, J. T., & Rozsypal, A. J. (1980). Evaluation of vowel duration as a cue for the voicing distinction in the following word-final consonant a). *The Journal of the Acoustical Society of America*, *67*(5), 1764–1771.

Jenkins, J. J., Strange, W., & Edman, T. R. (1983). Identification of vowels in "voweless" syllables. *Perception and Psychophysics*, *34*(5), 441–450.

Jongman, A. (1988). Duration of frication noise required for identification of English. *Journal of the Acoustical Society of Americca*, *85*(4), 1718– 1725.

Jongman, A., Wayland, R., & Wong, S. (1988). Acoustic Characteristics of English Fricatives: I Static Cues. *Working Papers of the Cornell Phonetics Laboratory*, *12*, 195–205.

Kunisaki, 0., & Fujisaki, H. (1977). On the influence of context upon perception of voiceless fricative consonants. *Annual Bulletin, (Tokyo: Research Institute for Logopedics and Phoniatrics)*, *11*, 85–91.

LaRiviere, C., Winitz, H., & Herriman, E. (1975). The distribution of perceptual cues in English prevocalic fricatives. *Journal of Speech and Hearing Research*, *18*(4), 613–622.

Lawrence, D. L., & Byers, V. (1969a). Identification of voiceless by high frequency hearing impaired listeners. *Journal of Speech, Language and Hearing Research*, *12*(2), 426–434.

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

Liberman, M. . A., Delattre, C. P., Cooper, F., & Gertsman, J. L. (1954). The Role of Consonant- Vowel Transitions in the Perception of the Stop and Nasal Consonants. *Psychological Monographs: General and Applied*, *68*(8), 1–13.

Lisker, L. (1974). On explaining vowel duration variation.pdf. *Glossa: An International Journal of Linguistics*.

Magen, H. S. (1997). The extent of vowel to vowel coarticulation in English. *Journal of Phonetics*, *25*(2), 187–205.

Maniwa, K., Jongman, A., & Wade, T. (2008). Perception of clear fricatives by normal-hearing and simulated hearing-impaired listeners. *The Journal of the Acoustical Society of America*, *123*(2), 1114–25. doi:10.1121/1.2821966

Mann, V. a, & Repp, B. H. (1980). Influence of vocalic context on perception of the [sh]-[s] distinction. *Perception & Psychophysics*, *28*(3), 213–228. doi:10.3758/BF03204377

Mann, V. A., & Repp, B. H. (1981). Influence of preceding fricative on stop consonant perception. *The Journal of the Acoustical Society of America*, *69*(2), 548– 558.

Mann, V., & Soli, S. D. (1991). Perceptual order and the effect of vocalic context of fricative perception. *Perception & Psychophysics*, *49*(5), 399–411. doi:10.3758/BF03212174

Mann, V., & Soli, S. D. (1991). Perceptual order and the effect of vocalic context of fricative perception. *Perception & Psychophysics*, *49*(5), 399–411. doi:10.3758/BF03212174

Mann, Virginia A & Repp, B. H. (1980). Influence of vocalic context on perception of the [sh] - [s] distinction. *Perception & Psychophysics*, *28*(3), 213–228.

Manuel, S. Y., & Krakow, R. A. (1984). Universal and Language particular aspects of vowel to vowel coarticulation. *Haskins Laboratries: Status Report on Speech Research SR- 77/78*, 69–78.

Nittrouer, S., & Studdert-Kennedy, M. (1987a). The role of coarticulatory effects in the perception of fricatives by children and adults. *Journal of Speech and Hearing Research*, *30*, 319–329. doi:10.1044/jshr.3003.319

Nittrouer, S., & Studdert-Kennedy, M. (1987b). The role of coarticulatory effects in the perception of fricatives by children and adults. *Journal of Speech and Hearing Research*, *30*(3), 319–329. doi:10.1044/jshr.3003.319

Nittrouer, & Studdert-Kennedy. (1986). The role of coarticulatory effects in the perception of fricatives by children and adults. *Journal of Speech and Hearing Reserach*, *88*, 73– 93.

Oh, E. (2010). Speaker Gender and the Degree of Coarticulation. *Korean Journal of Linguistics*, *35*(3), 743– 746. doi:10.1017/CBO9781107415324.004

Owens, E., Benedict, M., & Schubert, E. D. (1972). Consonant Phonemic Errors Associated With Pure-Tone Configuration and Kinds of Hearing Impairment. *Journal of Speech, Language and Hearing Research*, *15*(2), 308–322.

Peterson, G. E., & Lehiste, I. (1960). Duration of Syllable Nuclei in English. *The Journal of the Acoustical Society of America*, *32*(6), 693. doi:10.1121/1.1908183

Pittman, A. L., & Stelmachowicz, P. G. (2000). Perception of Voiceless Fricatives by Normal-Hearing and Hearing- Impaired Children and Adults. *Journal of Speech, Language and Hearing Research*, *43*(December), 1389–1401.

Pittman, A. L., Stelmachowicz, P. G., Lewis, D. E., & Hoover, B. M. (2002a). Influence of Hearing Loss on the Perceptual Strategies of Children and Adults, *45*(12), 1276–1284.

Pittman, A. L., Stelmachowicz, P. G., Lewis, D. E., & Hoover, B. M. (2002b). Influence of hearing loss on the perceptual strategies of children and adults. *Journal of Speech, Language, and Hearing Research : JSLHR*, *45*(6), 1276–84. doi:10.1044/1092-4388(2002/102)

Raphael, L. J. (1972). Preceding vowel duration as a cue to the perception of the voicing characteristic of word- final consonants in American English. *The Journal of the Acoustical Society of America*, *51*(4B), 1296–1303.

Revoile, S. G., & Pickett, J. M. (1985). Perceptual cues to the voiced-voiceless distinction of final fricatives for listeners with impaired or with normal hearing. *Journal of the Acoustical Society of America*, *77*(3), 1263–1265.

Robb, M. P., & Turner, C. W. (1987). Audibility and recognition of stop consonants in normal and hearing-impaired subjects and hearing-impaired subjects. *Journal of the Acoustical Society of America*, *81*(3), 1566–73. doi:10.1121/1.394509

Samuel, M. C., & Savitri, S. R. (2003). *Labial coarticulation in Malayalam*. AIISH, Mysore.

Schultz. (1964). Word familiarity influences in speech discrimination. *Journal of Speech and Hearing Research*, *7*, 395–400.

Soli, S. D. (1981). Second formants in fricatives : Acoustic consequences of. *The Journal of the Acoustical Society of America*, *70*(4), 976–984.

Stelmachowicz, P. G., Pittman, A. L., Hoover, B. M., & Lewis, D. E. (2002). Aided Perception of / s / and / z / by Hearing-Impaired Children. *Ear and Hearing*, *23*(4), 316–324. doi:10.1097/01.AUD.0000027406.51909.06

Turner, C. W., & Cummings, K. J. (1999). Speech Audibility for Listeners With High-Frequency Hearing Loss. *American Journal of Audiology*, *8*(1), 47. doi:10.1044/1059-0889(1999/002)

Wagner, A., Ernestus, M., & Cutler, A. (2006). Formant transitions in fricative identification : The role of native fricative inventory. *The Journal of the Acoustical Society of America*, *120*(4), 2267–2277. doi:10.1121/1.2335422

Whalen, D. H. (1981a). Effects of vocalic formant transitions and vowel quality on the English /s/-/ʃ/ boundary. *The Journal of the Acoustical Society of America*, *69*(1), 275–282.

Whalen, D. H. (1981b). Effects of vocalic formant transitions and vowel quality on the English [s]-[ŝ] boundary. *The Journal of the Acoustical Society of America*, *69*(1), 275–282. doi:10.1121/1.385348

Whalen, D. H. (1991). Perception of the English /s/-/ʃ/ distinction relies on fricative noises and transitions, not on brief spectral splices. *The Journal of the Acoustical Society of America*, *90*(4), 1776– 1785.

Yathiraj, A., & Vijayalakshmi. (2005). *Phonemically balanced word test in Kannada*. AIISH, Mysore.

Yeni-Komshian, G. H., & Soli, S. D. (1981). Recognition of vowels from information in fricatives: perceptual evidence of fricative-vowel coarticulation. *The Journal of the Acoustical Society of America*, *70*(4), 966–75. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/7288043

Zeng, F., & Turner, C. W. (1990a). Recognition of voiceless fricatives by normal and hearing-impaired subjects. *Journal of Speech and Hearing Research*, *33*(September), 440–449.