Comparison of Co-articulation Perception in Individuals with Normal Hearing and Hearing Impairment

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Abstract

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/. The participants included 19 listeners with normal hearing and 18 listeners with flat sensorineural hearing impairment. Among the 18 individuals with hearing impairment, 9 had mild hearing loss and 9 had moderate hearing loss. 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. 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. 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.

Key words: *Reliabi*

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/, /tʃ/, /ʃ/ were often perceived as the stop consonants /d/, /b/, or /g/. It has also been demonstrated by Nittrouer and Studdert-Kennedy (1987) 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 have also 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.

Studies report that the vowel transitions in coarticulation serve as important cues in identification of adjacent consonants (Nittrouer & Studdert-Kennedy, 1987; Pittman & Stelmachowicz, 2000). Nittrouer and Studdert-Kennedy (1987) 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

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perception scores of individuals with high frequency hearing loss do 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 have been noted to have difficulty hearing is /ʃ/. Further, it has been reported that consonants are much less intense than vowels. 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. Thus, the current study was carried out with the aim 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.

METHODS

The present study compared the perception of coarticulated cues 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. A standard group comparison research design was used.

Participants

A purposive sampling procedure was used in selecting the participants. Two groups of participants were assessed who were age matched. 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 < 15 dB 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 8th 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 8th grade and spoke Kannada fluently and had used the language from early childhood.

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)

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.

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.

(i) 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 1 depicts a sample wave form of the stimulus (/aʃa/) used for the study.

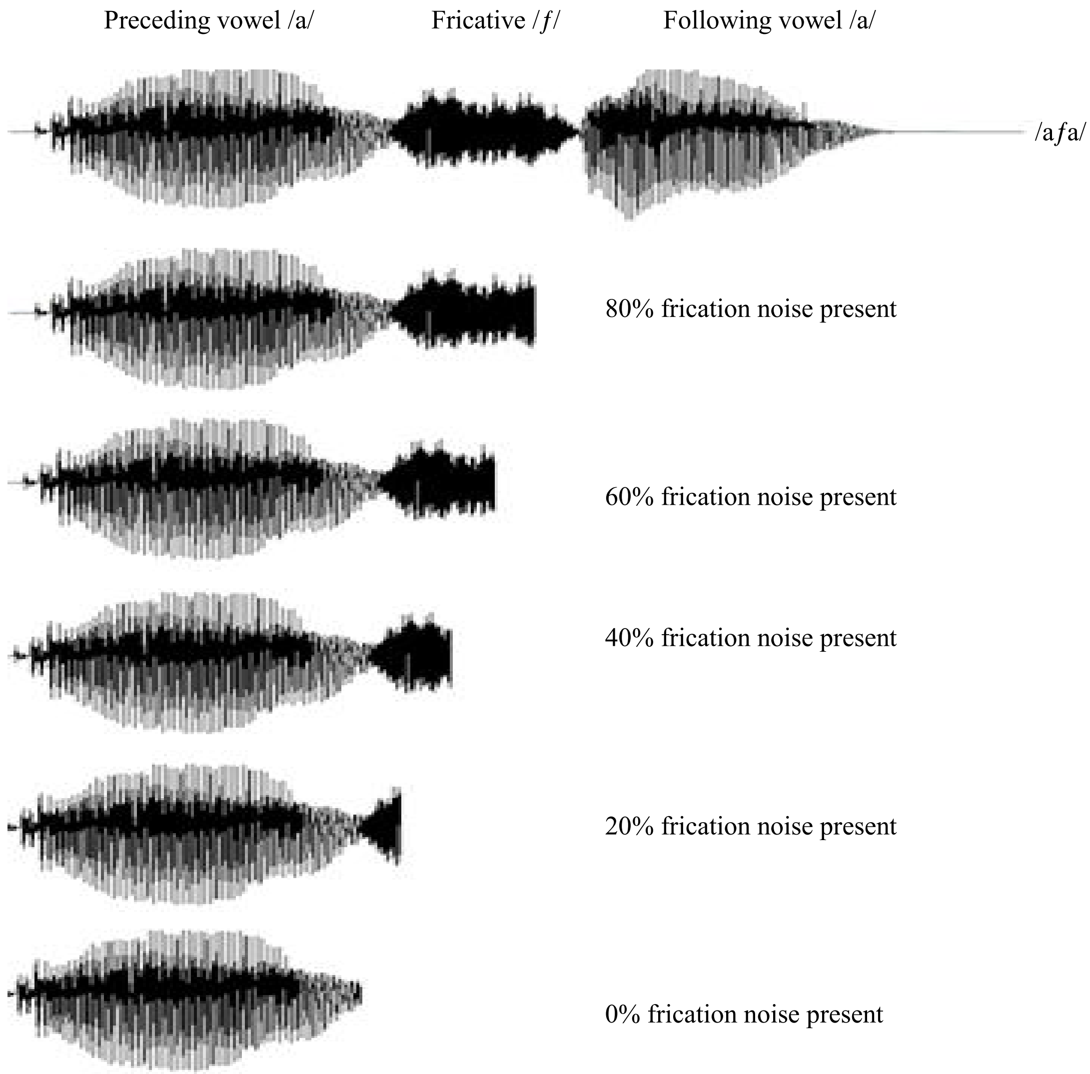
Figure 1: Sample waveform of the stimulus /a?a/, produced by a female talker.

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 /?/. 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 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. 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.

(ii) 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.

Figure 2: Sample waveform of anticipatory coarticulation stimuli having different extents of truncation

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 1. The participants evaluated in the pilot study were not included in the later part of the study.

	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/

Table 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

(iii) 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 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.

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.

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 utilized 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, a Friedman's test and a Wilcoxon Signed rank test were used to compare perception across different vowel contexts.

RESULTS

The findings of the scores obtained for the 198 stimuli tokens are provided below for the 19 normal hearing participants and the 18 participants with hearing impairment. The results are provided for the comparison between the male and female talker; normal hearing participants and those with hearing impairment; coarticulation perception across different extents of truncation; perception across anticipatory and carryover coarticulation; and perception across different vowel contexts.

Comparison of Coarticulation perception across Male and Female talkers:

The differences in the coarticulatory identification of the fricative /?/ across male and female talkers were analysed using Wilcoxon Signed Rank test was used. 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/. 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 2a, b, c. Across each of the groups, more than 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 for 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 3a, b, c.

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 3a, 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) 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 5a, b, c).

Table2a: Pair wise comparison of /?/ 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 2b: 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%	.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 2c: Pair wise comparison of /?/ 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%	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 3a: 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 3b: 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 3c: 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
	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

Table 4: Significance of difference between normal hearing listeners, listeners with mild and moderate hearing impairment in the perception of fricative /?/ in the context of vowels /a/, /u/ and /i/ across various truncation durations

	Truncation	Vowel /a/ *p* value df = 2	Vowel /u/ *p* value df = 2	Vowel /i/ *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 5a: 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 5b: Significance of difference in /ʃ/ responses between individuals with normal hearing and moderate hearing impairment

Note: ** = $p < 0.05$

	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**

Table 5c: Significance of difference in /?/ responses between individuals with mild and moderate hearing impairment

Note: ** = $p < 0.05$

	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**

The Mann Whitney-U test comparison between those with normal hearing and individuals with mild hearing impairment (Table 5a) 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 5b). Similarly, a significant difference between those with mild and moderate hearing impairment was obtained for three of the stimuli (Table 5c) 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.

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 3a, 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 (maximum possible score = 6) at shorter durations of the fricative noise as compared to the carryover coarticulation condition in normal hearing listeners. Further, it was 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 were comparable at longer truncation durations, in the anticipatory condition.

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 6a, 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 6a: 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: ** = $p < 0.05$

Table 6b: 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 6c: 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
Anticipatory	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 earlier where it was noted that in the anticipatory condition the mean scores reached closer to the maximum score (6) at shorter truncation duration as compared to the carry over condition.

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 3a, 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 /ƒ/ 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 7. 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.

Comparison of Coarticulation Perception across Different Vowel Contexts

The effect of the three vowels /a/, /u/ and /i/ in the perception of the fricative /?/ was analyzed. Table 3a, 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 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 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 7: 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/

	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**

	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*

Table 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 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 9b: Pair wise comparison and significance of difference between vowel pairs in listeners with mild hearing impairment

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

Note: ** = p < 0.05

Table 9c: Pair wise comparison and significance of difference between vowel pairs in listeners with moderate hearing impairment

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

Note: **p= < 0.05

The results of the current study revealed that the overall performance of individuals with normal hearing sensitivity was significantly better than those with moderate hearing impairment. However, no significant differences were noted in the performances of normal hearing individuals and those with mild hearing impairment. Across all the three groups of participants, it was noted that the performance in the anticipatory condition was significantly better than the carry over condition in the context of all the three vowels /a/, /u/ and /i/. Further, it was noted that the performance of each of the groups improved with increasing frication duration.

DISCUSSION

The results of the study are 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.

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 more than 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 most of the cues used for the perception of coarticulation.

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 /?/ 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. 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.

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. Similar to what was 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, 2002; Revoile & Pickett, 1985; Robb & Turner, 1987). Hence, 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.

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/. Therefore, 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 evaluated. The coarticulatory perception of consonant /ʃ/ was analysed in the current study whereas the study by Ali et al. used nasals. It is possible that the way feature spreading takes place for high frequency fricatives differs from that of low frequency 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 /?/. 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.

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.

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.

CONCLUSIONS

From the findings of the study, it may be concluded 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.

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