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Original Research Article

Effect of Multichannel and Channels Free Hearing Aid Signal Processing on Phoneme Recognition in Quiet and Noise

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ABSTRACT

Introduction: Older adults with sensorineural hearing loss (SNHL) find it difficult to understand speech especially, in noise. Hearing aid is one among the rehabilitative option available to them. Even with advent in hearing aid technology, adequate benefit for hearing loss is a colossal challenge. It was hypothesized that channel free hearing aid improves the speech perception in presence of noise.
Aim & Objective: To document consonant identification scores (CIS) and sequential transfer of information from multichannel and channel free hearing aids, in noise.
Materials and Methods: Fourteen participants having bilateral sloping SNHL were included. Each participant was presented 21 syllables in unaided and aided conditions (4 channels, 12 channels, and channel free hearing aids) at quite, +10 dBSNR and 0dBSNR, to determine CIS and sequential transfer of information.
Results: It was observed that signal-processing strategies did not significantly affect consonant identification at quiet condition. At +10 dBSNR and 0 dBSNR, significantly higher CIS was noted in channel free hearing aid than compared to other multichannel hearing aids. In addition, the total sequential transfer of information transmitted from channel free hearing aid was higher than compared to other strategies at quiet and +10 dB SNR. However, it was observed that 12 channels hearing aid was superiorly transferred the manner and voicing information than compared to other strategies.
Conclusion: Channel free hearing aid is a feasible alternative to multichannel hearing aids for listeners with sloping audiometric contours.

Key Words: Channel Free Hearing Aids, Multichannel hearing aids, Consonant Identification scores.

INTRODUCTION

Older adults with sensorineural hearing loss (SNHL) often complain of difficulty in understanding speech, especially in noise. [(1)] The possible reasons include reduced audibility of signal, impaired temporal resolution [(2)] and reduced frequency selectivity. [(3)] In SNHL, damage to OuterHairCells(OHC) produces loss of cochlear amplifier function, [(4)] wider auditory filters, [(5)] and neural asynchronous firing to varying acoustic cues. [(6,7)] A hearing aid is the most common option available for reducing the problem faced by individuals with sensorineural hearing loss. The primary goal of a hearing aid is to restore audibility via frequency selective amplification. Moore, Glasberg, and Stone [(8)] reported that compressions in multi channel hearing aids are beneficial in three ways. First, they allow the speech to be understood over a wide range of input levels without the speech ever becoming uncomfortably loud. Second, compressions improve the intelligibility of low to medium intensity speech in background noise, and third, they also restore the loudness perception across frequencies to some extent. Yund and Buckles [9,10] reported that hearing aids consisting of at least six channels are optimum and sufficient to convey useful high frequency information in individuals with mild to moderate sloping SNHL. In addition, six channels also facilitate speech discrimination in the presence of speech babble noise, which contains lesser energies in higher frequencies and therefore has minimal masking effect on high frequency information. With further increase in the number of channels, bandwidth becomes narrower and there is a higher chance of frequency components falling into their respective channels. Whenever there is a positive signal to noise ratio (SNR) present in any channel, then the signal level decides how much gain to be provided by an amplifier. When SNR is negative then the gain given to the speech also gets reduced as the channel is overloaded due to presence of noise.

Plomp [11] postulated that multichannel hearing aids assign compression ratios across different channels depending on hearing loss at each frequency, which reduces spectral contrast and alters the shape of speech resulting in decreased speech recognition scores. Bar, Souza, and Wright [12] reported reduced spectral contrast and altered shape of speech signals with increased number of channels. Other studies have reported instances of channel interaction [13] and channel summation. [14] Souza and Boike [15] reported reduced performance in speech perception in older adults with SNHL than in their younger counterparts, in quiet condition. This was regardless of the number of channels in the hearing aid and was attributed to temporal asynchronous firing. Turner and Cummings [16] opined that temporal cues are obscured by noise. Compression ratios in different channels might cause further temporal alteration thereby having a deleterious effect on speech perception. [17] From this, it is evident from literature that results on speech perception by multichannel hearing aids are equivocal.

In light of the above concerns related to multichannel hearing aids (i.e., channel interaction, channel summation, spectral smearing and altered temporal information), channel free hearing aids have been developed. Free channel hearing aid process wide band signal 20000 times without dividing the signal into narrow frequency bands. It exhibits parallel processing by measuring the sound pressure level of input signal and assigns a gain to the fed signal into the filter control at any moment of time as dictated by the measured sound pressure level. Finally amplifies soft input signal and preserves comfort sound for high level sound without altering temporal envelope of speech. Schaub [18] reported that the working principle of channel free hearing aids closely resembles cochlear nonlinearity by providing a higher gain to low level signal and compressing a high level signal. It was also suggested that spectral contrast is preserved as the gain is adjusted rapidly to the incoming signal. Plyler et al [19] investigated sentence recognition and sound quality by WDRC hearing aid and channel free processing strategy. Their study participants of experienced and naïve hearing aid users showed no significant difference in sentence recognition between the processing strategies. They speculated their findings of recognition scores among strategies to the target test stimuli, as their study participants would have used contextual cues. An interesting finding observed was 12 of 14 participants preferred channel free processing strategy as the sound quality and clarity was relatively better than WDRC hearing aid, in background noise condition.

Thus, the purpose of this study was to investigate whether free channel hearing aid gives better consonant recognition than WDRC hearing aid. Further how much feature information is transferred from these processing strategies is studied. To conduct this experiment, a set of naturally produced nonsense vowel–consonant–vowel (VCV) syllables were produced by female speaker was used to control for linguistic or phonemic context cues found in sentences and single words. The syllables were presented in both unaided and three aided conditions: 4 channel, 12 channel and free channel hearing aids. For each of this experimental condition, the VCV syllables were presented in quiet and in a speech shaped noise at + 10 dB SNR and 0 dB SNR. Further, study was focused on overall features transferred from each processing strategy. Thus, the research question formulated was does the signal processing strategies affect the consonant identification and the features of information transferred in quiet and/or in noise? If it affects which processing strategy successfully transmits the feature of information and identification of consonants in quiet or at noise.

MATERIALS AND METHODS

Participants: A total of 14participantsin the age ranges from 50 to 70years (mean age = 64.2 years; range 57.2 years to 68.5 years) were selected for the present study. The criteria for subject selection were: post-lingual acquired symmetrical bilateral sloping sensorineural hearing loss. The sloping hearing loss is operationally defined as threshold from 250 Hz to 500 Hz is being ≥ 35 dB HL, 1000 Hz to 2000 Hz is being ≥ 45 and from 3000 to 8000 Hz is being ≥ 65 dB HL. [20] The thresholds at different frequencies from each participant are represented in Figure-1. The participants had normal middle ear status as indicated by ‘A’ type tympanometry. All the participants were native speakers of Kannada (A language belonging to the Dravidian family), and had no prior experience of using hearing aids.

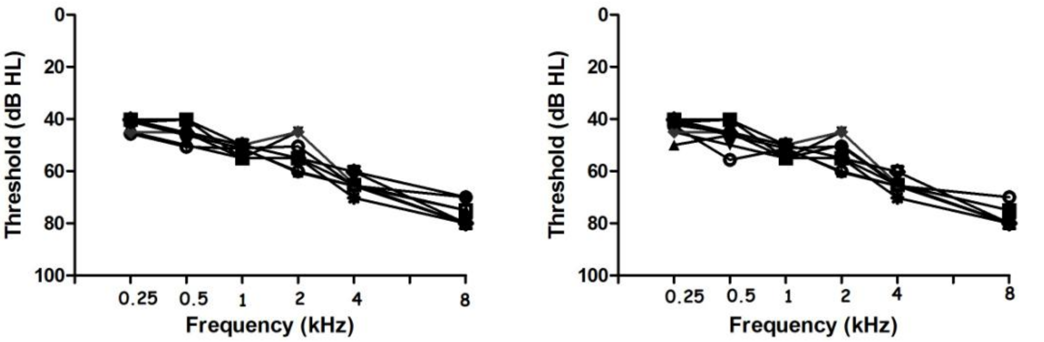

Figure -1.Absolute thresholds (in dBHL)of each participant in right and left ear as a function of frequency (in KHz).

Test environment: All the measurements include recording of the stimuli and consonant identification scores in different experimental conditions were carried out in an acoustically treated room, with ambient noise levels well within the permissible limits. [21]

Stimuli preparation: The phonemes in Kannada with greater than 0.5 %of frequency of occurrence [22] were selected. The phonemes were(/k/,/g/, /tʃ/, /t/, /d/, /ŋ/, /ɵ/, /ḍ/, /n/, /p/, /b/, /m/, /j/, /r/, /l/, /v/, /ʃ/, /s/, /h/, /l̩/ and /dʒ/) paired with a high short central vowel /i/ int he initial and final positions. The Vowel Consonant Vowel (VCV) syllables were used to obtain consonant identification scores (CIS). Three females who are native speakers of Kannada uttered the syllables with normal vocal effort. These VCV syllables were recorded using Adobe Audition software via the recording microphone placed at a distance of 10 cm from the lips of the speaker. [23] The recorded stimuli were digitized using a 32-bit processor at 44,100 Hz sampling frequency. Goodness test was performed informally to verify the test stimuli. The test involved presenting the 21 stimuli uttered by the three speakers to ten normal hearing individuals. The consonants uttered by one speaker who was judged to be most natural on a 3-point rating scale (3= natural 2= less natural 1= unnatural) were selected. In addition, the recorded VCV syllables were mixed with noise. Each VCV syllable was digitally mixed with speech babble noise (5)at +10 dB signal to noise ratio (SNR) using the SNR MATLAB code. The noise onset preceded the onset of a VCV syllable by 100 ms and continued till 100 ms after the end of each syllable. The noise was ramped using the Cosine square function with ramp duration of 30 ms. A similar procedure was carried out to mix the speech shaped noise at 0 dB signal to noise ratio to each VCV syllable.

Programming of hearing aids: Digital behind the ear hearing aid having an option of 4 channels, 12 channels and channel free hearing aid from the same company were used to assess the Consonant Identification Scores (CIS) and the information of features transferred(voicing, place and manner), in quiet and at different SNRs. Audiometric pure tone thresholds (from 250 Hz to 8 kHz for air conduction and from 250 Hz to 4 kHz for bone conduction) of the test ear of the participant were fed into the NOAH software in the personal computer, using the audiogram module. Participant was made to sit comfortably and fitted with the BTE digital hearing aids with four channels on both the ears. The hearing aid connected to the HiProwas in turn connected to a personal computer in which the NOAH and hearing aid specific software were installed. The hearing aids were detected in and programmed using the option of first fit of NAL-NL1prescriptive formula. Noise reduction circuit in the hearing aids was set to off and omni-directional microphone was opted. The gain in hearing aids was optimized using the audibility of Ling six sound test [24,25] Similar steps were incorporated in programming for 12 channels and channel free hearing aids.

Procedure: The consonant identification scores and transfer of feature information were obtained from both unaided and aided conditions (4 channels, 12 channels and free channel). The recorded VCV speech material was played through GUI of MATLAB loaded in the laptop. The output of the laptop was connected to the auxiliary input of the audiometer. The output of the audiometer was delivered through the sound field at 65 dB SPL. During the presentation of the stimuli average deflection on the VU meter measured was 0 dB. Each VCV speech syllable was presented twice in a randomized order. Each participant was made to sit comfortably at a distance of 1 meter away from the loudspeaker at 45^0azimuth. Instruction was provided to point out to the heard stimulus in a closed set of VCV stimuli, which was displayed on computer. The next stimulus was delivered only after response to the previous stimulus. Date was collected in quiet and at 0 dB SNR and + 10 dB SNR, in each experimental condition.

Similar procedure was carried out in aided condition. The hearing aids programmed with respect to participant's hearing loss were fitted binaurally. The order of testing in different processing strategies and SNRs were randomized across participants. A single mark was assigned for correct identification of consonant so that the maximum marks obtained by a subject would be 42 (i.e 21 consonant x two repetitions) in each experimental condition. The data analysis of SINFA is explained in result section.

RESULTS

The recognition of consonants was documented from three processing strategies, in quiet and noise at different SNRs. These data were subjected to statistical analyses using Statistical Package for Social Science (version 17). Further, comparison was made on feature information transferred from consonants in each processing strategy at quiet and at noise at different SNRs. In unaided condition study participants are unable to recognize syllables in both quiet and noise conditions.

CIS from different channels of hearing aid in each SNR: The mean (M) and standard deviation (SD) of consonant identification scores (CIS) from different processing strategies of hearing aid in quiet and each SNR condition are tabulated in Table 1. It is observed that, the mean CIS was higher in free channel hearing aid followed by 12 channels and then 4 channels of hearing aid. The data was subjected to normality test using Kolmogorov-Smirnov (K-S) test and the results revealed that all the variables were distributed normally (p>0.05). Thus, a parametric statistical analysis was carried out. In order to evaluate the effect of processing strategy on CIS in each SNR, we conducted a two way repeated measures Analysis of Variance (ANOVA) [quiet and 2 SNRs (+10 dB SNR and 0 dB SNR)* Channels (4, 12 and channel free)]. The results revealed that there was a significant main effect of channels [F (2, 26) = 39.5, *p* = 0.000] and SNRs [F (2, 26) = 66.78, *p* = 0.001]. Two way interaction analysis revealed that the effect of channels had a significant interaction with SNR [F (4, 52) =2.70, p= 0.041], such that in each SNR, the CIS was higher in channel free hearing aid followed by 12 channels and 4 channels of hearing aids.

Table 1 Mean and standard deviation of CIS from different channels in each SNR.

Channels	Quiet	+ 10 dB SNR	0 dB SNR
	Mean (SD)	Mean (SD)	Mean (SD)
4 Channel hearing aid	16.78 (6.25)	11.50 (3.61)	4.64 (2.30)
12 Channel hearing aid	18 (5.35)	15 (4.20)	10.21 (1.31)
Free Channel hearing aid	22.92 (5.31)	19.50 (4.98)	11.57 (2.92)

In order to identify in which SNR, the channels had an effect on consonant identification scores, we performed post hoc analyses using paired samples t-test with Bonferroni adjustment of alpha level to control for type -1 error. Three paired comparisons were performed to evaluate the effect of channels on CIS in each SNR. Thus, the power of significance (p value) judged significant value of ≤ 0.016 instead of 0.05 for these comparisons. The results of paired samples t test revealed (Table 2) that except in quiet condition, significant differences were noted between channels on CIS at+10 dB SNR and 0 dB SNR.

Table 2 paired samples t-test results for CIS obtained from different channels of hearing aids in quiet and in different SNR conditions.

Conditions	t-value	p-value
Quiet		
4 channels vs 12 channels	0.69	0.051
4 channels vs Free channel	2.78	0.017
12 channels vs. Free channel	2.14	0.052
+10 dB SNR		
4 channels vs 12 channels	3.76	0.002
4 channels vs Free channel	9.69	0.000
12 channels vs. Free channel	3.74	0.002
0 dB SNR		
4 channels vs 12 channels	0.48	0.000
4 channels vs Free channel	10.79	0.000
12 channels vs. Free channel	6.68	0.000

Sequential transfer of information: Sequential information analysis procedure utilized in the present study was adopted from Wang and Bilger. [26] Sequential information analysis was performed for each hearing aid having different channels in different SNR conditions to assess the amount of information transmitted from stimulus to response for a set of place, manner and voicing features in each of 21 phonemes. Table 3 lists the 21 consonants and their classification with regard to three phonetic features.

Table 3: Classification of consonants by phonetic features

Features	/k/	/g/	/m/	/tʃ/	/l/,	/s/,	/ʃ/,	/ḷ/	/b/,	/d/,	/ḍ/	/dʒ/	/t/,	/ɵ/	/v/	/j/	/ŋ/	/p/	r	n	h
Voicing	-	+	+	-	+	-	-	+	+	+	+	+	-	-	+	+	+	-	+	+	-
Place	vel	vel	bil	paa	alv	alv	paa	lal	bil	alv	den	pal	alv	den	lab	pal	ret	bil	alv	alv	glo
Manner	plo	plo	nas	aff	lat	fri	fri	liq	plo	plo	Plo	aff	Plo	plo	fri	gli	nas	plo	lat	nas	fri

Place: bil- bilabial;lad-labiodental;alv-alveolar; paa- palatoalveolar;den- dental; ret-retroflex; pal-palatal; glo-glotal; lal-linguaalveolar; Manner: nas - Nasal;plo -plosive;fri - fricative;lat - lateral; aff - affricative;liq – liquid, Voice: '+' Voiced; '-'Unvoiced

This analysis was performed using feature information transfer software package (developed by university college of London, Department of Linguistics and Phonetics). The working principle of sequential information transmitted as follows. The features with the highest percentage of information transmitted in the previous iteration are held constant and partialled out.

The maximum information in bits that can be transmitted for the 21 stimuli is 4.39. Table 4 represents the CIS and total information transmitted from each hearing aid having different channels in various SNR conditions. The total information transmitted from free channel hearing aid was greater than other channels of hearing aid (4 and 12 channels of hearing aid) in quiet condition. This was true in other SNRs conditions.

Further, the information transmitted in each feature was computed from conditional information transmitted divided by input information by each feature. The information transmitted for each feature ranges from 0 (particular feature of information is not transmitted) to 1 (particular feature of information is maximally transmitted). Figure 2 show the information transmitted for voicing, place and manner features from different channels of hearing aid in each SNR.

Table 4 Mean (SD) of CIS and total information transmitted for different channels of hearing aid in quiet and at different SNR

	Conditions	Mean (SD)	Total information transmitted (Bits)
4 channels hearing aid	Quiet	16.78 (6.25)	1.40
	10 dBSNR	11.50 (3.61)	1.56
	0 dBSNR	4.64 (2.30)	1.90
12 channels hearing aid	Quiet	18 (3.35)	1.65
	10 dBSNR	15 (4.20)	2.07
	0 dBSNR	10.21 (1.31)	2.09
Free channel hearing aid	Quiet	22.92 (5.31)	1.75
	10 dBSNR	19.50 (4.98)	2.43
	0 dBSNR	11.57 (2.92)	2.59

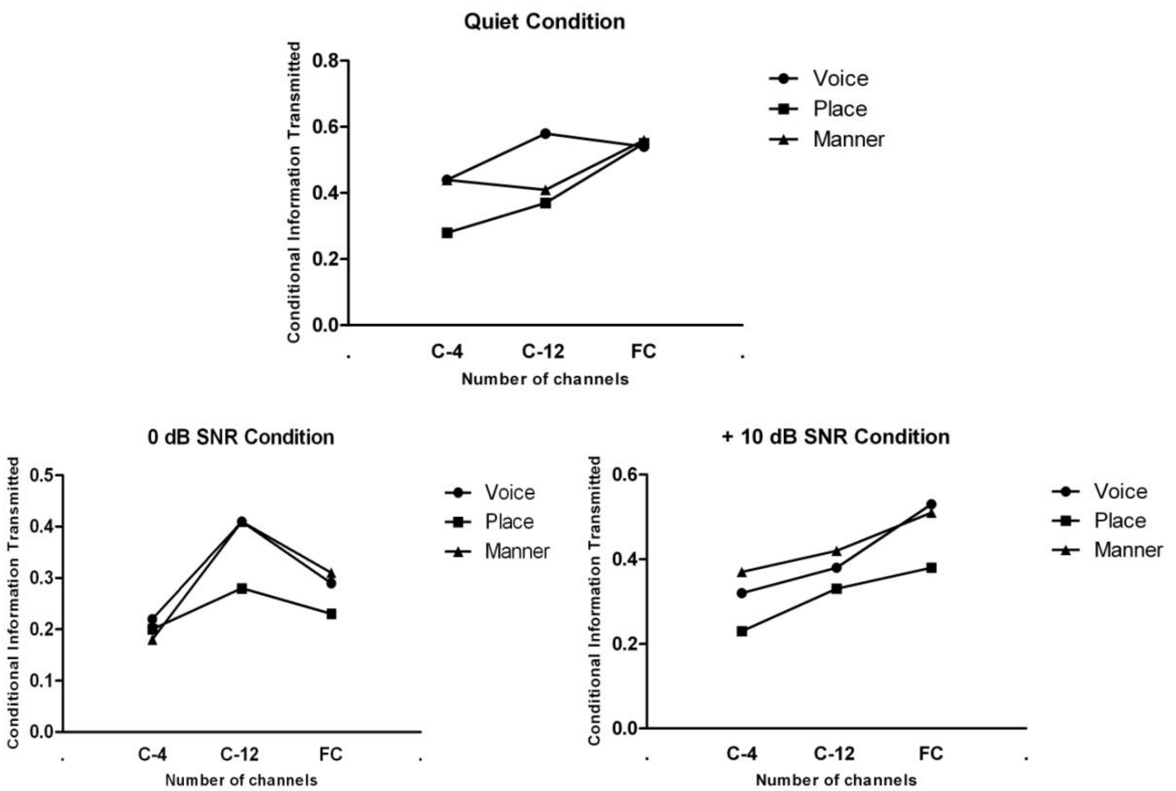

Figure-2: Information transmitted in each channel for voicing, place, and manner in quiet and in different SNR

In quiet condition, place of articulation transmitted by free channel hearing aid was way high than compared to 12 channels and then by 4 channels of hearing aid. The manner of articulation was conveyed by free channel hearing aid was greater than compared to 4 channels and then by 12 channels of hearing aid. Whereas, feature of voicing information transmitted by 12 channels of hearing aid was greater than compared to free channel hearing aid and then by 4 channels hearing aid. At +10 dB SNR, each feature of information conveyed was higher in free channel than compared to 12 channels hearing aid followed by 4 channels hearing aid. Whereas, at 0 dB SNR, place, manner and voicing information transmitted was greater by 12 channels hearing aid than compared to free channel hearing aid followed by 4 channels of hearing aid.

DISCUSSION

The purpose of the study was to investigate the consonant identification in the different processing strategies at various SNRs upon older adults having bilateral sloping sensorineural hearing loss. In addition, the amount of feature information transmitted in each experimental condition was also measured.

CIS from different channels in each SNR condition: The results of the present experiment demonstrated that in channel free hearing aid the CIS score was better than 4 channels and 12 channels of hearing aid, in quiet condition. This is because free channel hearing instrument adjusts the gain on an average of 20000 times for each phoneme by measuring its sound pressure level in the level measurement block. This information was fed into the filter control to determine the appropriate gain and finally controllable filter in the free channel hearing aid assign the gain. Thus, the audibility was maintained within restricted dynamic range of hearing impaired participants. This scheme closely resembles healthy cochlea by amplifying the soft sounds and compressing the loud sounds. [17] In case of 12 channels hearing aid, the entire VCV syllable is splits into separate frequency bands, such that, discrete gain is assigned per frequency band. This leads to reduction of spectral contras, that is, more amplification might be provided to the trough portion and lesser gain assigned to the peak portion of VCV syllables making spectral contrast less distinct. [27] Thus, the CIS in 12 channels was relatively lesser than free channel hearing aid though no statistically significant difference was noted. Further, in 4 channels hearing aid the CIS score was reduced compared to 12 channels and channel free hearing aids. Although, the spectral contrast was minimized in 4 channels of hearing aid, the broadened auditory filters of auditory system unable to process the information due to reduced frequency resolution. [28,29]

In the presence of noise, identification of consonants became more difficult for the study participants. It is evident that irrespective of signal to noise ratio, i.e., either +10 dB SNR or 0 dB SNR, the CIS was better in free channel hearing aid than in the 12 channels and 4 channels of hearing aids. The exact reason on how the channel free hearing aid challenges the noise at different SNR is not known objectively. Thus, further research is warranted in this regard. However, improvement in CIS was observed with increasing the number of channels. At +10 dB SNR condition, noise level across channels was relatively less than speech signal. Thus, the amplifier might have increased the frequency response of the signal level above the threshold of audibility. This speculation was supported by a research report by Yund and Buckles [9] who stated that more number of channels in hearing aid amplifies the signal relatively better than compared to lesser numbers of channels, especially in the presence of noise. This increased spectral energy of speech than noise with more number of channels accounted for better CIS. At 0 dB SNR, noise has deleterious effect on the spectral component of consonants, this certainly load the auditory system as it is already suffering from impaired spectral resolution. Thus, the impaired auditory system was unable to process the closely spaced spectral components of speech and noise, in lesser number of channels. [30]

Sequential transfer of information: At quiet condition, the channel free hearing aid conveyed all the feature information equally well and these features transferred were relatively better than compared to 12 and 4 channels of hearing aid. This is because the channel free hearing aid rapidly adjusts the gain with respect to the input signal. The scheme in free channel hearing aid compensates for the lost mechanism of the cochlea in amplifying soft sounds and compressing loud sounds. [17] In 12 channels hearing aid, different compression ratios and compression thresholds across the channels altered the temporal cues, this was reflected to unable to convey manner of articulation. Yet another negative factor could be the effect of channels interaction [13] and channels summation [14] alter the temporal content in speech. Furthermore, in 4 channels hearing aid, the place information is poorly transmitted, due to reduced spectral contrast and altered spectral shape of VCV with lesser number of channels. [30] This brings an additional load on auditory system as the widened filter unable to process the spectral information, which conveys the place of articulation. [31] However, the manner of articulation and voice information has transmitted relatively better than place of articulation. The finding of the present study is in accordance with the research report of Souza and Turner. [32] They reported with lesser number of channels, the temporal envelopes are relatively preserved than the more number of channels in the hearing aid.

Although, at +10 dB SNR, each feature of information conveyed was higher in free channel than compared to other processing strategies, the place information was conveyed relatively less than compared to manner and voicing information. This indicates noise alters the spectral content of speech. The present study results are in consonance with the research report of Simpson, Moore and Glasberg [33] who states that spectral peaks and valleys which are important cues for the perception of spectral features in speech signals are obscured by noise. In addition, accumulation of noise in higher number of channels lessens spectral alteration than compared to less number of channels. This is because there is a counter balance in the spectral analysis between the information processed in narrow bands of different channels of hearing aids and the cues available in the widened auditory filters. [34]

Whereas, at 0 dB SNR, place, manner and voicing information transmitted was lesser by 4 channels hearing aid than compared to free channel and 12 channels of hearing aid. In 0 dB SNR, the ratio of audible noise and audible speech signal is same across 4 channels of hearing aid. Thus, the amplification provided is relatively less for VCV syllables and the power spectra of weak consonant partly might have reached participant supra threshold level [35] This lack of audibility taxed the auditory system, which in turn caused the confusion in the each feature of information. However, in 12 channels hearing aids the place of articulation is least transmitted than voicing and manner of articulation. As explained earlier that as the number of channel increases the spectral contrast and shape of VCV syllable reduces i.e., more amplification might have provided to trough portion of speech signal makes less distinct between troughs and peaks of signals. Further, noise in each channel obscures the trough portion of speech syllables and reduces the spectral contract even more and also alters the spectral shape of speech syllables. [11] In addition, the widened auditory filters unable to process these closely spaced spectral contrast and shape of VCV syllables. [36] To conclude, in quiet and lesser SNR condition (+10 dB SNR) free channel hearing aid conveyed all the feature of information relatively better than other strategies. However, at 0 dB SNR, 12 channels of hearing aid conveyed voicing and manner features of information relatively better than compared to other strategies.

CONCLUSION

The purpose of the study was to know the best strategy convey all features of information and consonant identification. Results indicated that channel free hearing aid provide significant improvement and conveyed all the features of information relatively better than compared to other channels of hearing aid. This finding helps the audiologist to select the optimum channel of hearing aid. The extent of benefit and or reduction in speech perception from a number of channels in hearing aids and in different SNRs provides the information to the naïve hearing aid user at the time of purchasing the hearing aid.Future research should examine the effect of hearing loss and slope on performance and preference with free channels and multichannel hearing aid.

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