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Speech perception performance of Telugu speaking elderly population and number of compression channels in digital hearing aid technology

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Abstract

Background: We assessed the speech perception performance of the elderly population with hearing impairment in quiet and noisy listening environments as a function of the number of compression channels in digital hearing aids. **Materials and Methods:** Participants were 14 elderly individuals with hearing impairment in the age range of 65 to 70 years (M=67.35; SD=± 1.63). Speech recognition score (SRS) testing as a measure of speech perception was performed on each participant in quiet and +5 dB SNR listening environments with hearing aids in 2, 4, 6, 8, 10, and 12 channel settings respectively. **Results:** Results revealed significant difference in SRS between 2 vs 4, 2 vs 6, 2 vs 8, 2 vs 10, 2 vs 12, 4 vs 12 channel settings, and no significant difference between 4 vs 6, 4 vs 8, 4 vs 10, 4 vs 12, 6 vs 8, 6 vs 10, 6 vs 12, 8 vs 10, 8 vs 12, 10 vs 12 channel settings in quiet listening environment. Whereas in +5 dB SNR listening environment, there was significant difference in SRS between 2 vs 4, 2 vs 6, 2 v 8, 2 vs 10, 2 vs 12, 4 vs 6, 4 vs 8, 4 vs 10, 4 vs 12 channel settings, and no significant difference between 6 vs 8, 6 vs 10, 6 vs 12, 8 vs 10, 8 vs 12, 10 vs 12 channel settings. **Conclusions:** Participants achieved maximum speech perception benefit with hearing aids in 4 and 6 channel settings in quiet and noisy listening environments respectively. Further, it was noticed that besides greater performance in the quiet listening environment, the presence of background noise considerably degraded speech perception irrespective of channel settings.

Keywords: Hearing impairment; elderly population; speech recognition score; compression channels; digital hearing aids

1 Introduction

Hearing impairment is a prevalent condition in the elderly population. More than 6% of the world's population (466 million) has disabling hearing loss and approximately one-third of people are over 65 years [1]. One of the most detrimental symptoms in the elderly population with sensorineural hearing loss (SNHL) is the reduced ability to understand speech in everyday communication environments that are surrounded by background noise, reverberation, and in the presence of multiple speakers [2]. The proportion of the population with difficulties in perceiving speech doubles in every decade of life from 16% at the age of 60 years to 32% at the age of 70 years, and to 64% at the age of 80 years [3]. This population forms the majority of the hearing aid (HA) users. According to the ISO report for thresholds of hearing loss as a function of age, every second person above 65 years of age needs HA [4]. There has been a convergence of technologies in the HA industry, and new digital signal processing strategies have been developed and used in the HA technology to improve the speech perception performance of individuals with SNHL. Over the years, HAs have shifted from analog to digital technology, and currently, this technology has taken the place of the analog HAs and in due course, it has turned out to be the basic type.

Modern digital signal processing technology in HAs includes nonlinear, compression, multichannel, adaptive, noise reduction, feedback manager, directional microphones, multiple memories, etc. [5]. HAs with multiple compression channels are the predominant type of emerging technology in today's HA market. The advantages of compressions in multichannel HAs have been well-documented: 1) allows the speech to be understood over a wide range of input levels without the speech ever becoming uncomfortably loud; 2) improves the intelligibility of low-to-medium intensity speech in background noise, and 3) restores the loudness perception across frequencies to some extent [6]. Multiple channels in HAs allow for finer tuning of the response for fitting unusual or fluctuating audiograms thereby increasing the specificity of noise reduction, allowing specialized feedback and occlusion management [7]. Apart from the advantages of multichannel HAs, disadvantages have also been documented including channel summation [8], temporal or spectral smearing [9], and increased processing delay [10].

Hearing loss in the elderly population is usually symmetrical high frequency sloping SNHL loss which gradually increases with age [11]. A timely fitting of HAs on both ears to provide the auditory system with appropriate acoustic information to improve communication is a central aspect in the rehabilitation of the elderly population with hearing impairment [12]. Hence, due to variations in the degree of hearing loss at different frequencies, the electroacoustic characteristics programmed into the HA should differ for different frequencies and match the residual auditory area so that as much of the speech signal is made audible to the listener. The multiple channels in HAs allow for finer tuning of the frequency response for fitting such audiogram configurations [7]. Hence, it can be assumed that the multichannel HAs would aid in alleviating the difficulties encountered by the elderly population due to the existence of hearing loss that varies at different frequencies.

One of the most important technological features that are commonly addressed by HA manufacturers and audiologists to differentiate one end of HAs (low-end hearing devices) from another (high-end hearing devices) in terms of technology is the number of channels available within the HAs. However, in patients' points of view, a difference in technology level often means a difference in the cost of HAs [13]. The cost of the HAs increases with an increase in the number of channels within the HAs (high-end hearing devices). Unlike, developed countries, in the developing world like India, most people have a monthly income that is lesser than the cost of high-end hearing devices. Besides, they are not privileged to avail of high-end digital hearing devices through government and/or medical insurance schemes in India [14]. They have to contribute to the cost of HAs and ongoing expenses for maintenance, spares, repairs, etc. Hence, their hopes and expectations for the performance of these high-end digital hearing devices might be much higher. If their hopes and expectations are not encountered, that might affect the aural rehabilitation process of the elderly population.

Although the advantages of multichannel HAs have been reported, the disadvantages have also been documented [8–10]. Hence, it is unclear as to what may be the optimum number of channels that would yield maximum speech perception benefits in the elderly population with hearing impairment. Therefore, it is the responsibility of an audiologist to determine the minimum number of channels that are needed in a HA to derive maximum benefit in terms of speech perception, especially in the presence of background noise and provide accurate information to patients on realistic outcomes that can be expected from multichannel hearing devices. Hence, the present study aimed to assess the speech perception performance of the elderly population in quiet and noisy listening environments as a function of the number of compression channels in the HAs. Findings of the present study will be valuable in addressing the common communication difficulties encountered by the elderly population (i.e. difficulties in understanding speech in noisy listening environments) due to the existence of hearing impairment with evidence-based hearing validation as part of counseling during HA fitting to make the whole aural rehabilitation process more effective.

2 Materials and Methods

Repeated-measures descriptive research design with purposive sampling technique was incorporated in the present study. The following method has been constituted to fulfill the aim of the present study.

2.1 Participants

A total of 14 elderly individuals in the age range of 65 to 70 years of age (M=67.35; SD=±1.63) served as participants in the present study. All the participants had post-lingual acquired symmetrical bilateral high frequency sloping SNHL. The pure-tone audiometric thresholds at different frequencies of each participant are depicted in Figure 1. All the participants had normal middle ear status as indicated by 'A' type tympanogram. All the participants were native speakers of Telugu (a south Indian Dravidian language). None of the participants had prior experience of HA usage.

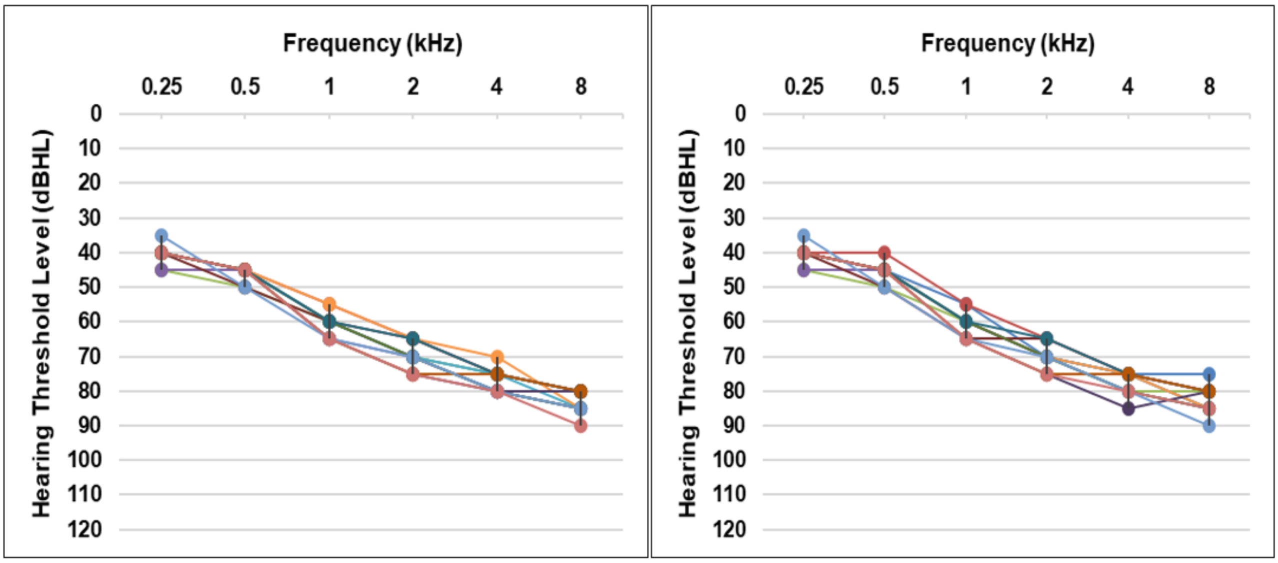

Fig 1. Pure-tone audiometric thresholds (dBHL) of each participant in right and left ears as a function of frequency (kHz)

2.2 Procedure

Audiological evaluations and fitting of HAs on each participant were performed in an air-conditioned sound-treated double-suit room where the ambient noise levels were well-maintained within the permissible limits. A calibrated dual-channel clinical audiometer (Maico MA 42) was used to carry out pure-tone audiometry and also for presenting speech stimuli. A calibrated immittance meter (GSI Tympstar) was used to rule out the presence of middle ear pathology. Six pairs of behind-the-ear HAs from same manufacturer with each pair consisting of 2, 4, 6, 8, 10, and 12 channels respectively have been used as hearing devices. The frequency ranges in each channel of HAs were set according to the default frequency range recommended by the manufacturer. Hi-Pro programming interface connected with personal computer and NOAH based programming software was used to program each HA according to individuals' hearing loss configuration. Each pair of HAs were programmed according to the NAL-NL1 fitting strategy for each participant bilaterally. It was ensured that all the HAs were programmed such that the signal processing conditions were as similar as possible, except for the difference in the number of channels.

A battery for assessing speech recognition performance of adult native speakers of Telugu (recorded voice test) developed by[15] was used as speech stimuli to assess speech perception. This battery consisted of four wordlists with each list consisting of 25 disyllabic words in Telugu. Every wordlist was randomized twice in the order of words to form a total of 12 word-lists. The SRS testing as a measure of speech perception was carried out under twelve listening conditions [i.e. 6 settings of compression channels (2, 4, 6, 8, 10, and 12) and two listening environments (quiet and +5 dB SNR)] on each participant. The stimuli were presented using a laptop (Dell 180 Inspiron) that was routed through a calibrated dual-channel clinical audiometer. The stimuli were then delivered through a single loudspeaker (Ahuja SCM-15T 10 W Tower Speaker) placed in front at an angle of the 0-degree azimuth of the participant at a distance of one meter.

The speech was presented at 65 dB SPL in quiet and noisy listening environments. The noise was four-talker babble that was recorded while two male and two female speakers were reading a passage. The four-talker babble was then embedded with speech stimuli at +5 dB SNR using Adobe Audition (Version 3.0) Software (Adobe, San Jose, California, USA). A double-blinded design was used where the participants were not informed about the number of channels to avoid any bias regarding the benefit of the different number of channels in the HAs. The sequence of testing conditions and order of word lists presented at each test condition were also randomized to counterbalance any order and practice effects. All the participants were tested with bilaterally fitted HAs. An open-set response in the form of an oral response was obtained. A short break was given whenever the participants required rest to avoid fatigue effects. This study involved non-invasive behavioral measurements for assessing the speech perception performance of participants. Informed consent was obtained from all participants included in the study.

2.3 Scoring the responses

SRS was then calculated by dividing the number of words correctly repeated by the participant with the total number of words presented and then multiplying this calculation with hundred. SRS was calculated for each participant in each testing condition separately for further analysis.

2.4 Statistical analysis

The data were subjected to repeated measures one-way ANOVA to determine the difference in SRS between different channel settings in quiet and +5 dB SNR listening environments respectively. The data were further subjected to paired sample t-test to evaluate the difference in SRS between quiet and +5 dB SNR listening environments for each channel setting respectively.

3 Results and Discussion

3.1 Results

Figure 2 shows the mean and standard deviation of SRS between quiet and +5 dB SNR listening environments at each channel setting. The results of one-way ANOVA revealed a significant difference ($p<0.05$) in SRS within and between channel settings in quiet and +5 dB SNR listening environments. When the data were further subjected to LSD post hoc analysis, it revealed significant difference ($p<0.05$) in SRS between 2 vs 4, 2 vs 6, 2 vs 8, 2 vs 10, 2 vs 12 channel settings, and no significant difference ($p>0.05$) between 4 vs 6, 4 vs 8, 4 vs 10, 4 vs 12, 6 vs 8, 6 vs 10, 6 vs 12, 8 vs 10, 8 vs 12, 10 vs 12 channel settings in quiet listening environment (Tables 1, 2 and 3). Further, there was significant difference ($p<0.05$) in SRS between 2 vs 4, 2 vs 6, 2 vs 8, 2 vs 10, 2 vs 12, 4 vs 6, 4 vs 8, 4 vs 10, 4 vs 12 channel settings but no significant difference ($p>0.05$) between 6 vs 8, 6 vs 10, 6 vs 12, 8 vs 10, 8 vs 12, 10 vs 12 channel settings in +5 dB SNR listening environments (Table 4).

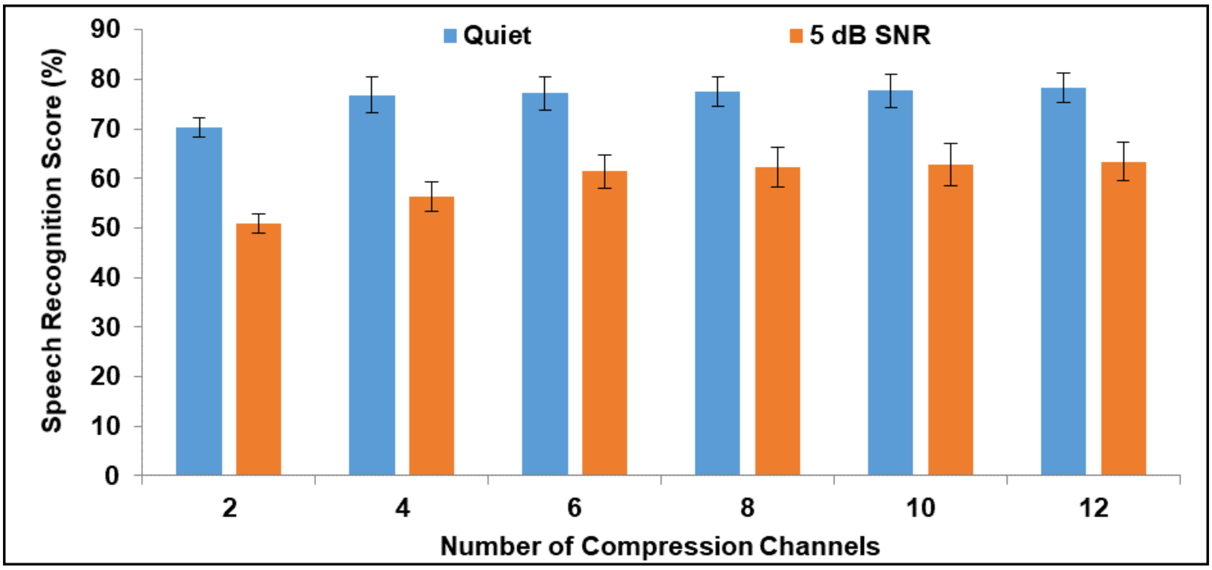

Fig 2. Mean and standard deviation of SRS between quiet and +5 dB SNR listening environments at each channel setting

Table 1. One-way ANOVA results showing the comparison of mean SRS (%) between and within channel settings in the quiet listening environment

	Sum of Squares	df	Mean Square	F	Sig
Between Groups	621.714	5	124.343	12.976	0.000
Within Groups	747.429	78	9.582		
Total	1369.143	83			

Table 2. LSD post hoc multiple comparisons of mean SRS (%) among different channel settings in the quiet listening environment

Channel Settings		MD (I-J)	SE	Sig	95% CI	
I	J				Lower	Upper
2 channels	4 channels	-6.57143*	1.17001	0.000	-10.5664	-2.5765
	6 channels	-6.85714*	1.17001	0.000	-10.8521	-2.8622
	8 channels	-7.14286*	1.17001	0.000	-11.1378	-3.1479
	10 channels	-7.42857*	1.17001	0.000	-11.4235	-3.4336
	12 channels	-8.00000*	1.17001	0.000	-11.9950	-4.0050
4 channels	6 channels	-0.28571	1.17001	1.000	-4.2807	3.7093
	8 channels	-0.57143	1.17001	0.999	-4.5664	3.4235
	10 channels	-0.85714	1.17001	0.990	-4.8521	3.1378
	12 channels	-1.42857	1.17001	0.913	-5.4235	2.5664
6 channels	8 channels	-0.28571	1.17001	1.000	-4.2807	3.7093
	10 channels	-0.57143	1.17001	0.999	-4.5664	3.4235
	12 channels	-1.14286	1.17001	0.965	-5.1378	2.8521
8 channels	10 channels	-0.28571	1.17001	1.000	-4.2807	3.7093
	12 channels	-0.85714	1.17001	0.990	-4.8521	3.1378
10 channels	12 channels	-0.57143	1.17001	0.999	-4.5664	3.4235

*The mean difference is significant at the 0.05 level. MD: Mean Difference, SE: Standard Error, CI: Confidence Interval

Table 3. One-way ANOVA results showing the comparison of mean SRS (%) between and within channel settings in +5 dB SNR listening environment

	Sum of Squares	df	Mean Square	F	Sig
Between Groups	1867.429	5	373.486	30.564	0.000
Within Groups	953.143	78	12.220		
Total	2820.571	83			

Table 4. LSD post hoc multiple comparisons of mean SRS (%)among different channel settings in +5 dB SNR listening environment

Channel Settings		MD (I-J)	SE	Sig	95% CI	
I	J				Lower	Upper
2 channels	4 channels	-6.000000*	1.32124	0.002	-10.5114	-1.4886
	6 channels	-11.14286*	1.32124	0.000	-15.6542	-6.6315
	8 channels	-12.00000*	1.32124	0.000	-16.5114	-7.4886
	10 channels	-12.57143*	1.32124	0.000	-17.0828	-8.0601
	12 channels	-13.14286*	1.32124	0.000	-17.6542	-8.6315
4 channels	6 channels	-5.142860*	1.32124	0.015	-9.65420	-0.6315
	8 channels	-6.000000*	1.32124	0.002	-10.5114	-1.4886
	10 channels	-6.571430*	1.32124	0.001	-11.0828	-2.0601
	12 channels	-7.142860*	1.32124	0.000	-11.6542	-2.6315
6 channels	8 channels	-0.857140	1.32124	0.995	-5.36850	3.6542
	10 channels	-1.428570	1.32124	0.947	-5.93990	3.0828
	12 channels	-2.000000	1.32124	0.806	-6.51140	2.5114
8 channels	10 channels	-0.571430	1.32124	0.999	-5.08280	3.9399
	12 channels	-1.142860	1.32124	0.980	-5.65420	3.3685
10 channels	12 channels	-0.571430	1.32124	0.999	-5.08280	3.9399

*The mean difference is significant at the 0.05 level. MD: Mean Difference, SE: Standard Error, CI: Confidence Interval

Results of the paired sample t-test revealed a significant difference ($p<0.05$) in SRS between quiet and +5 dB SNR listening environments in all channel settings (Table 5). Hence, it can be inferred from the findings of the present study that 4 is the optimum number of channels needed in a HA for achieving maximum benefit in terms of speech perception in a quiet listening environment. Whereas, 6 is the optimum number of channels needed in a HA for achieving maximum benefit in terms of speech perception in the +5 dB SNR listening environment. Besides, despite greater speech perception in the quiet listening environment, the presence of background noise considerably degraded speech perception irrespective of channel settings.

Table 5. Paired sample t test results showing paired differences between quiet and +5 dB SNR listening environments at each channel setting

Channel Settings and Listening Environments		Paired Differences					t	df	Sig. (2-tailed)
		Mean Difference	SD Difference	SE Mean Difference	95% CI Difference				
					Lower	Upper			
2 channels	Quiet vs +5 dB SNR	19.42857*	1.45254	0.38820	18.58989	20.26724	50.047	13	0.000
4 channels	Quiet vs +5 dB SNR	20.57143*	1.45255	0.38821	19.73275	21.41010	52.991	13	0.000
6 channels	Quiet vs +5 dB SNR	15.71429*	2.46291	0.65824	14.29224	17.13633	23.873	13	0.000
8 channels	Quiet vs +5 dB SNR	15.14286*	3.57033	0.95421	13.08141	17.20430	15.870	13	0.000
10 channels	Quiet vs +5 dB SNR	14.85714*	4.27618	1.14286	12.38815	17.32614	13.000	13	0.000
12 channels	Quiet vs +5 dB SNR	14.85714*	3.9779	1.06315	12.56034	17.15395	13.975	13	0.000

3.2 Discussion

The present study aimed to assess speech perception performance in quiet and noisy listening environments to predict the minimum number of compression channels that are needed in the HA to derive maximum speech perception benefit in the elderly population. It is a reasonable expectation that increasing the number of channels in HAs improves the signal processing performance which in turn improves speech perception performance. However, the results of this study revealed that the participants needed only four and six channels in the HAs to achieve maximum benefit in terms of speech perception in quiet and noisy listening environments respectively. Speech perception performance significantly improved from two to four channels but remained consistent above four channels in the quiet listening environment. These results are continuous with findings of[16] who have reported that four channels provided adequate flexibility for frequency shaping and ability to control feedback for flat or slightly sloping hearing loss, but a great number of adjustment bands were needed for fitting accuracy for steeply sloping losses. However, the findings are contrary to that of[17] who have postulated that the ideal number of channels needed for optimum speech perception changes with audiometric configuration and HAs with nine channels would be ideal for the majority of audiograms.

Hearing loss in the elderly typically slopes towards high-frequency region of hearing[11]. Natural speech carries abundant acoustic cues in both spectral and temporal aspects. Limited spectral and temporal resolutions may be sufficient to understand speech in quiet listening environments[18]. Also, the spectral and temporal resolutions are relatively preserved in low-frequency residual acoustic hearing[19]. This could be the reason for the participants to achieve maximum speech perception performance with four channels in the quiet listening environment in this study. Whereas, in the +5 dB SNR listening environment, the participants needed six channels in HAs for achieving maximum benefit in terms of speech perception. The speech perception performance significantly improved from two to four channels and four to six channels and saturated above six channels. Similar findings were reported by Yund & Buckles[20] who have reported that speech perception improved as the number of channels increased from four to eight channels and remained consistent above eight channels in noisy listening environments. Also, Galster & Galster[13] reported that HAs with as few as eight channels offer sufficient frequency resolution to restore audibility, even in listening conditions with background noise.

Although speech perception performance did not improve above four and six channels in quiet and noisy listening environments respectively, none of the participants demonstrated decreased speech perception performance with an increase in the number of channels. Hence, it can be assumed that there was no interference from channel summation, spectral and temporal smearing, and delay in processing the signal that has been reported to be expected with increasing the number of channels in HAs[8–10]. Despite greater speech perception performance in quiet listening environments, the presence of background noise consistently and significantly degraded the performance of the elderly population irrespective of the number of channels in HAs. It is well-established that adverse listening environments arising from various types of background noises and hearing impairment degrade hearing, affect the quality and reliability of the speech signals, and negatively influence the perception of speech signals[21]. Therefore, more precise spectral and temporal resolutions are needed to understand speech in noisy listening environments[18]. Hence, a reduction in the ability to resolve the frequency components of complex sounds and to process the temporal fine structure of sounds are some of the factors contributing to difficulty in understanding speech especially in noisy listening backgrounds[22]. Although SNHL is characterized by degeneration in the cochlea, a range of effects in central auditory processing due to aging is also likely to influence understanding speech in the presence of background noise[23].

In addition to peripheral and central effects of auditory processing, aging is another major contributing factor in the elderly population for speech perception difficulties in noisy listening conditions despite adequate amplification provided by properly fitted HAs. Listeners require high demands from cognitive resources such as attention, working memory, etc. to cope with adverse listening environments arising from background noise[24]. However, the cognitive functions in the elderly population are reduced due to aging and hence encounter difficulties in adverse listening environments arising from various types of background noises[25]. Studies have reported that hearing training improves cognitive functions such as working memory[26], executive function[27], short-term memory[28], and attention[29] which are known to improve speech perception in noisy listening environments. Hence, formal hearing training along with adequate amplification would be an effective way to improve the speech perception performance of the elderly population, especially in noisy communication environments. Studies have also reported that individuals with higher cognitive abilities adapt to HAs with fewer efforts and require less hearing training as compared to those with poorer cognitive abilities[30]. Hence, there is a need to assess cognitive functions in addition to the hearing functions of the elderly population that are valuable in the understanding of 'who benefit from HAs' and 'who need hearing training'. Moreover, it is important to evaluate speech perception performance using high-frequency speech identification tests, given the high-frequency sloping pattern of hearing loss typically found in the elderly population[31].

4 Conclusion

It was noticed from the findings that four and six are the minimum number of channels needed in HAs to achieve maximum benefit in terms of speech perception performance by the elderly population in quiet and noisy listening environments respectively. It was further noticed that besides greater performance in a quiet listening environment, the participants experienced greater speech perception difficulties in a noisy listening environment irrespective of channel settings in HAs. The study considered the elderly population only those who neither have the prior nor post-fit auditory experience with HAs and post-fit hearing training. Hence, these findings may not apply to younger and other clinical populations with hearing impairment. The present study provides an insight on the need for formal hearing training programs along with properly fitted HAs and assessment of cognitive hearing functions along with routine hearing assessment which are not common practice in the aural rehabilitation program of the elderly population in developing world like India. In future studies, we plan to investigate the effect of post-fit auditory experience with HAs and post-fit hearing training programs on outcomes in terms of speech perception in noise and reverberation, cognitive hearing functions, subjective HA satisfaction, etc.

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