Research Article

Effect of Compression Type and Number of Channels on Speech Perception in Quiet in Listeners with Different Audiogram Configurations

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Highlights

- Less number of compression channels yields good aided performance in quiet
- It is not affected with either syllabic or dual compression mode
- Findings were consistent with flat, gently or steeply sloping audiogram configuration

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ABSTRACT

Background and Aim: The flexibility to control the gain in different frequency regions by setting compression parameters in a larger number of compression channels in hearing aids will be advantageous to individuals with a sloping audiogram. The objective of the study was to compare the aided speech identification scores and speech quality ratings in quiet for three aided conditions (i.e. 4-channel, 8-channel, and 16-channel), with syllabic and dual compression, at two input levels (60 dB SPL and 80 dB SPL) in individuals with flat, gently sloping, and steeply sloping sensorineural hearing loss.

Methods: The participants were 36 native speakers of Kannada adults with sensorineural hearing loss. In a repeated-measures design, aided speech identification score for sentences in quiet and speech quality ratings were obtained at two input levels (60 dB SPL and 80 dB SPL) with three hearing aids (having 4-, 8-, & 16- channels), programmed for dual and syllabic compression settings.

Results: The results revealed that there was no significant difference in the aided speech identification scores and speech quality ratings, in different aided conditions, in the three groups.

Conclusion: There was no additional perceptual benefit in quiet with an increase in the number of channels (from 4 to 16) in hearing aids, either in syllabic or dual compression, at conversation speech level or loud speech level, in individuals with different audiogram configurations.

Keywords: Multichannel compression; syllabic compression; dual compression; audiogram configuration; speech identification score; speech quality rating

Introduction

The hearing aids incorporate wide dynamic range compression (WDRC) to provide level dependent amplification and acceptable loudness [1, 2]. It is theorized that the difference in the hearing threshold and dynamic range at different frequency regions can be handled better with a multichannel compression system by providing varying amounts of gain across channels [3]. It is also reported that the multichannel amplification gives perceptual advantages in terms of speech perception, audibility for low level sounds, and listening in background noise than the single channel amplification [4-6].

Most of the currently available hearing aid models incorporate two to 24 compression channels and the cost of the hearing aids varies depending upon the number of channels and the features available. Numerous investigations have been carried out to explore the optimum number of compression channels in the multichannel compression system. There is a lack of consensus till date on the number of compression channels for a given hearing loss [7-14]. In addition, the choice of compression speed i.e. either fast compression or slow compression is very important while selecting the number of compression channels for those with different memory capacity and making listening in the presence of background noise [15-21]. The compression speed in the hearing aid can be manipulated by selecting syllabic or dual compression. Syllabic compression has a small release time, and the dual compression provides a long release time [22].

During hearing aid fitting, the audiologist often asked for when and why the number of channels matters for the listener. More channels in hearing aids were observed to be beneficial when the individual makes listening in noise and its outcome reported to be predicted by slow and fast compression and listener's cognitive abilities [15-21]. Individuals with sloping audiogram configuration may benefit from multichannel compression as they require flexibly managed compression amplification across the frequencies [8]. The flexibility of multichannel amplification to control the gain in different frequencies by setting frequency specific compression parameters will be advantageous to individuals with sloping audiograms. The perceptual effect of increasing the number of compression channels in individuals having sloping audiogram configuration is not well understood. Investigation on speech perception benefit from various combinations of the compression channel and compression type will help in understanding the appropriate compression parameter for individuals having different audiogram configurations.

This study aimed at finding an appropriate number of channels in dual and syllabic compression, for speech perception in quiet in listeners with different audiogram configurations. It is already understood that the benefit with multichannel compression is influenced by the noise type by interacting with the number of channels and the type of compression (fast or slow). But the interest of current study was to address the benefit in quiet listening conditions. Understanding the aided benefits in quiet conditions with hearing aids having more channels may be useful for making the selection of hearing aid for individuals having lesser communication or listening needs. The objectives of the study were to compare the aided sentence identification score in quiet and speech quality ratings obtained using three aided conditions (4-channel, 8- channel, and 16- channel) with two compression types (dual and syllabic) at two input levels (conversation speech level, 60 dB SPL and loud speech level, 80 dB SPL) in individuals having sensorineural hearing loss (SNHL) with flat, gently sloping, and steeply sloping configurations.

Methods

Study Design

A cross-sectional within group repeated-measures experimental design was utilized in this study [23].

Participants

The data were collected from 36 ears of 36 adults who were native speakers of Kannada language. The mean age of the participants was 48.61 years (SD=14.33). The better ear was the test ear when the hearing loss was asymmetrical, and either the right or left ear was the test ear if it was symmetrical hearing loss. The test ears met the inclusion criteria of a) SNHL with either flat, gently sloping or steeply sloping audiogram configuration, b) four frequency pure-tone average (PTA) between 30 dB HL and 70 dB HL, c) speech identification score in quiet of greater than 60%, d) A type tympanogram with acoustic reflex present at least in one frequency. The participants had post-lingual onset of hearing loss and were naïve hearing aid users. Naive hearing aid users were considered to control the effect resulting from prior hearing aid experience.

Those having any history or presence of middle ear infection, neurological (including auditory neuropathy and/or retrocochlear pathology) or psychological complaints were excluded. The participants were further categorized into three groups based on their audiogram configuration [24]. Group I consisted of 12 individuals having mild to moderately severe SNHL with a flat (F) audiogram configuration (FSNHL). The flat configuration was operationally defined as less than 15 dB difference between the mean hearing threshold at low frequency (average of 250 and 500 Hz), mid frequency (average of 1000 and 2000 Hz), and high frequency (average of 4000 and 8000 Hz). Group II included 12 individuals having mild to moderately severe gently (G) sloping SNHL (GSNHL). The gently sloping configuration was operationally defined as 15 to 29 dB difference between the mean hearing threshold of low frequency (average of 500 and 1000 Hz) and high frequency (average of 4000 and 8000 Hz). Group III consisted of 12 individuals having mild to moderately severe steeply (S) sloping SNHL (SSNHL). The steeply sloping configuration was operationally defined as greater than 30 dB difference between the mean hearing threshold of low frequency (average of 500 and 1000 Hz) and high frequency (average of 4000 and 8000 Hz). The demographic details of the participants are given in Table 1.

Procedure

The testing was carried out in a sound treated double room having the specification of ANSI [25]. Otoscopy was performed to ensure that there was no contraindication for hearing aid testing. A comprehensive audiological evaluation including pure-tone audiometry, speech audiometry, and immittance evaluation was carried out to select the participants.

In this study, the aided performance was assessed using three Audio Service HP behind the ear hearing aids which vary in terms of tech level and number of AGC channels. The three hearing aids were Audio Service Volta HP (4-channel), Audio Service HP4 G4 (8-channel), and Audio Service HP12 G4 (16-channel). The hearing aids were suitable for fitting mild to severe hearing loss and had the option to select syllabic and dual compression. Syllabic compression utilises short release time compared to dual compression. The dual compression combines both fast and slow compressor with a dominating slow compression. The verification of time constant was carried out in Fonix 8000 (Frye Electronics, Inc) using ANSI S3.22 2009 standards. The hearing aid was placed inside in the anechoic chamber of the test box with a connection to a HA2 2cc coupler for the measurement. Output from the coupler was picked by the measurement microphone inside the test box. The input signal of 2000 Hz tone was varied abruptly from 55 dB to 90 dB to measure the attack time and was varied from 90 dB to 55 dB abruptly to measure the release time. The verification of time constants and other electroacoustic characteristics of the hearing aids was carried out at the beginning of the study and every month until the completion of data collection. The time constants measured for syllabic and dual compression for each hearing aid is given in Table 2.

A personal computer, with NOAH and the hearing aid specific software installed, was used for hearing aid programming. The Hi-Pro 2 was used as an interface between the hearing aid and the programming computer. The demographic details of the participant and audiological findings were fed into the NOAH software. Initially, the hearing aids were programmed for 'first-fit' with the NAL-NL1 prescriptive formula. The acclimatization level was set as '2' for all participants. The compression parameters including the compression threshold and ratio were set according to the NAL-NL1 prescription. The other features like noise reduction, directional microphone, and automatic feedback cancellation were switched off to avoid the influence of these features on speech identification testing. The hearing aids are fitted using custom made shell moulds with no other acoustic modifications. Probe-microphone measurements including real ear unaided response, real ear aided response, and real ear insertion gain were carried out to verify and optimize the fitting. Fonix 8000 (Frye Electronics, Inc) was used to carry out the probe-microphone measurement. The frequency-gain adjustments were carried out until real ear insertion gain closely matched to within 5 dB of the NAL-NL1 target at 40 dB SPL, 60 dB SPL, and 80 dB SPL input level for Digi speech. After the verification of gain for each participant, two programs were saved in each hearing aid, one with dual compression and the other with syllabic compression. Thus, there were six settings for aided testing i.e. 3 channel settings (4-, 8-, and 16- channels) * 2 compression settings (dual and syllabic).

The hearing aid programming was followed by verification of the performance in the aided conditions. The aided sentence identification score in quiet was obtained using two types of stimuli which included phonemically balanced (PB) Kannada sentence lists from the Kannada Sentence Identification Test [26] and high frequency Kannada sentences from high-frequency (HF) Kannada speech identification test [27]. The recorded version of Kannada sentence identification test was used for estimating the phonemically balanced speech identification score (PB-SIS). The test consists of a total of 25 equivalent sentence lists in terms of familiarity, number of syllables, words, sentences, and perceptual difficulty. Each list has ten sentences with four keywords in each and a total of 40 key words per list. Twelve different sentence lists were utilized in this study since there were six aided condition in two presentation levels.

To assess the high-frequency speech identification score (HF-SIS), the recorded version of high-frequency Kannada speech identification test was used. It consisted of three sentence lists. The sentence lists consisted of speech sounds having more energy above 2000 Hz. Each sentence list has nine sentences with three key words in each sentence, and a total of 27 key words per list. The sentences within each list were iterated to form twelve lists. This was included in the study to observe any additional aided benefit in participants with gently sloping and steeply sloping hearing loss.

To obtain the aided SIS using the PB sentence lists (PB-SIS) and aided SIS using the HF sentence lists (HF-SIS), each participant was made to sit comfortably on a chair in the patient room of an air-conditioned two-room sound-treated test suite. A personal computer with recorded speech material was connected to the auxiliary input of the audiometer to present the speech stimuli to the participant in the sound field condition. The sentences were presented through a calibrated loudspeaker placed at 1 meter and 0° Azimuth from the participant. One PB and HF sentence list each was presented in each aided condition, at 60 dB SPL and at 80 dB SPL.

The aided PB-SIS and HF-SIS were obtained with different aided test conditions for each participant. The participants were instructed to repeat the sentences exactly as they heard. For aided PB-SIS, one sentence list was used in each aided test condition, and it was randomized across participants and test conditions. For aided HF-SIS, one sentence list was used in each aided test condition, and it was randomized across participants and test conditions. The responses were audio recorded and response analysis was carried out later. A score of '1' was given for each correctly repeated keyword and the raw total score for correctly recognized key words in each test condition was computed. The maximum SIS was 40 for PB-SIS and 27 for HF-SIS.

The aided speech quality judgment of the phonemically balanced Kannada sentences in quiet was also carried out for four parameters of speech quality, i.e. speech clarity, sound pleasantness, loudness, and overall impression using a 11-point rating scale ranging from 0 to 10 [6, 28]. Two sentences, per test condition, were used to judge the speech quality. The participants were instructed to rate the different parameters of speech quality on the rating scale, in each aided condition. Thus, the aided PB-SIS, HF-SIS, and speech quality ratings were obtained for six aided conditions and at two input levels for the three groups of participants.

Statistical analyses

Test for normality showed that the data were non-normal in distribution ($p<0.05$) and hence non-parametric tests were carried out. The comparison between the two types of compression was carried out using Wilcoxon signed rank test and the difference across channels were analysed using Friedman test.

Results

The aided speech identification score for phonemically balanced sentences (PB-SIS) and high-frequency sentences (HF-SIS), and speech quality ratings in six aided conditions at two presentation levels (60 dB SPL and 80 dB SPL) obtained in three groups were tabulated and analysed. The results of the present study are separately explained for the two stimulus presentation levels.

Effect of compression types and number of channels on phonemically balanced speech identification score, high-frequency speech identification score and speech quality rating, at 60 dB SPL presentation level

The descriptive statistics obtained for PB-SIS and HF-SIS at 60 dB SPL in FSNHL, GSNHL, and SSNHL groups are given in Table 3. The median and interquartile range (IQR) obtained for speech clarity, sound pleasantness, loudness appropriateness, overall impression of quality at 60 dB SPL for the three groups are represented in Figure 1. In all the groups, at 60 dB SPL, there is a negligible difference in the PB-SIS, HF-SIS, and the speech quality ratings across channels, in dual and syllabic compression. In order to evaluate if these differences were significant, further statistical tests were performed.

Effect of compression type

Pairwise comparison using Wilcoxon signed rank test was carried out between the syllabic and dual compression for the aided sentence identification scores and speech quality ratings obtained in a given channel setting at a presentation level of 60 dB SPL. The results of Wilcoxon signed rank test for the three groups were given in Tables 4. In the three groups, it was found that, at 60 dB SPL presentation level, there was no statistically

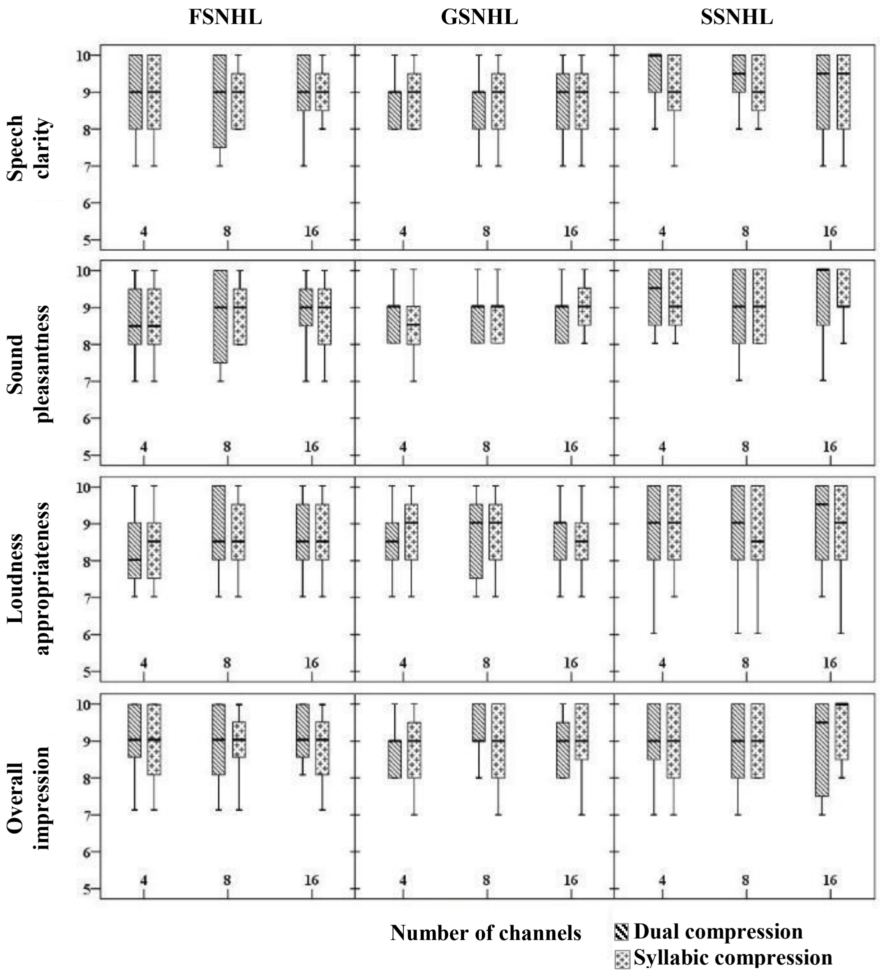

Figure 1. Box plot of the median score (with 95% confidence interval) for speech quality ratings at 60 dB SPL, in three groups. FSNHL; flat sensorineural hearing loss, GSNHL; gently sloping sensorineural hearing loss, SSNHL; steeply sloping sensorineural hearing loss

significant difference between the compression type on the scores obtained for aided PB-SIS, HF-SIS, and the ratings on four parameters of speech quality (p>0.05).

Effect of number of channels

Friedman test was carried out to infer the difference in the aided sentence identification scores and speech quality ratings obtained with the 4-, 8- and 16- channel hearing aids. Since there was no statistically significant difference between the scores obtained for syllabic and dual compression in all the groups, the data obtained for both compression types in each group were averaged for further analysis. At 60 dB SPL, the result showed that there is no statistically significant difference in PB-SIS across channels in FSNHL group [$\chi^2(2)=0.500$, p=0.779, Kendall's W=0.021], GSNHL group [$\chi^2(2)=4.769$, p=0.092, Kendall's W=0.199], and SSNHL group [$\chi^2(2)=0.429$, p=0.807, Kendall's W =0.018]. For the HF-SIS, Friedman's test was not carried out for the SSNHL group because the scores were constant in the SSNHL group. The findings in FSNHL and GSNHL groups, at 60 dB SPL revealed that there was no statistically significant difference in the aided HF-SIS across channels, in all the groups [FSNHL: $\chi^2(2)=2.000$, p=0.368, Kendall's W=0.083; GSNHL: $\chi^2(2)=3.000$, p=0.223, Kendall's W=0.125].

The Friedman test carried out for subjective rating for speech quality at 60 dB SPL also did not reveal no significant difference across channels in all groups for the measures of speech clarity [FSNHL: $\chi^2(2)=0.486$, p=0.784, Kendall's W=0.020; GSNHL: $\chi^2(2)=0.261$, p=0.878, Kendall's W=0.011; SSNHL: $\chi^2(2)=2.235$, p=0.327, Kendall's W=0.093], sound pleasantness [FSNHL: $\chi^2(2)=1.676$, p=0.433, Kendall's W=0.070; GSNHL: $\chi^2(2)=2.294$, p=0.318, Kendall's W=0.096; SSNHL: $\chi^2(2)=1.727$, p=0.422, Kendall's W=0.072], loudness appropriateness [FSNHL: $\chi^2(2)=0.722$, p=0.697, Kendall's W=0.030; GSNHL: $\chi^2(2)=2.056$, p=0.358, Kendall's W=0.086; SSNHL: $\chi^2(2)=2.296$,

Table 1. Demographic details of the subjects

Participants	Age (years)	Gender	Test ear	PTA (dB HL)	SIS (%)	Audiogram configuration
S1	58	Male	Left	50.00	100	Flat
S2	54	Male	Right	32.50	100	Flat
S3	31	Male	Right	46.25	100	Flat
S4	41	Male	Right	50.00	96	Flat
S5	52	Male	Right	56.25	72	Flat
S6	41	Male	Right	50.00	80	Flat
S7	48	Female	Right	32.50	100	Flat
S8	63	Male	Left	40.00	92	Flat
S9	38	Male	Left	43.75	80	Flat
S10	60	Male	Left	50.00	84	Flat
S11	41	Male	Right	47.50	92	Flat
S12	44	Male	Left	38.75	100	Flat
S13	24	Male	Right	65.00	88	Gently sloping
S14	32	Male	Right	42.50	68	Gently sloping
S15	31	Male	Right	31.25	100	Gently sloping
S16	23	Male	Right	62.50	92	Gently sloping
S17	32	Male	Right	31.25	100	Gently sloping
S18	49	Male	Right	68.75	76	Gently sloping
S19	36	Male	Left	48.75	100	Gently sloping
S20	55	Male	Right	51.25	80	Gently sloping
S21	71	Male	Right	45.00	92	Gently sloping
S22	55	Male	Right	52.50	88	Gently sloping
S23	68	Male	Right	48.75	100	Gently sloping
S24	56	Male	Right	50.00	92	Gently sloping
S25	47	Male	Right	38.75	100	Steeply sloping
S26	54	Female	Right	48.75	80	Steeply sloping
S27	57	Female	Right	41.25	100	Steeply sloping
S28	28	Male	Left	56.25	96	Steeply sloping
S29	51	Female	Right	47.50	88	Steeply sloping
S30	54	Male	Right	47.50	80	Steeply sloping
S31	68	Male	Left	31.25	100	Steeply sloping
S32	62	Male	Right	43.75	100	Steeply sloping
S33	65	Male	Left	25.00	100	Steeply sloping
S34	77	Male	Right	51.75	90	Steeply sloping
S35	22	Female	Right	33.75	100	Steeply sloping
S36	58	Male	Right	46.25	100	Steeply sloping

PTA; four frequency pure-tone average, SIS; speech identification score

Table 2. The attack time and release time measured with syllabic and dual compression in three hearing aids

Hearing Aids	Syllabic compression		Dual compression	
	Attack time (ms)	Release time (ms)	Attack time (ms)	Release time (ms)
Audio service volta HPC 4-channel	17.50	328.75	18.75	973.75
Audio service HP4 G4 8-channel	17.50	328.25	16.25	972.50
Audio service HP12 G4 16-channel	21.25	333.75	18.75	965.00

p=0.317, Kendall's W=0.096], and overall impression [FSNHL: $\chi^2(2)=0.242$, p=0.886, Kendall's W=0.010; GSNHL: $\chi^2(2)=3.692$, p=0.158, Kendall's W=0.154; SSNHL: $\chi^2(2)=0.963$, p=0.618, Kendall's W=0.040].

Effect of compression types and number of channels on phonemically balanced speech identification score, high-frequency speech identification score and speech quality rating, at 80 dB SPL presentation level

The mean, standard deviation, median, and inter quartile range (IQR for the aided PB-SIS and HF-SIS obtained at 80 dB HL in the three groups are given Table 5. Figure 2 represents the median and IQR for the ratings on four parameters of the speech quality, in the three groups, at 80 dB SPL presentation level. Similar to the findings in the 60 dB SPL presentation level, small differences can be noted in PB-SIS, HF-SIS, and the speech quality ratings across channels, in dual and syllabic compression, at 80 dB SPL presentation level for all the three groups. Further statistical tests were performed to evaluate if these differences were significant.

Effect of compression type

The aided SIS and speech quality ratings obtained for the syllabic and dual compression for a given channel setting at 80 dB SPL was compared using Wilcoxon signed rank test. The results of the Wilcoxon signed rank test for the three groups are given in Table 6. In the three

Table 3. The mean, standard deviation, median, and interquartile range of the phonemically balanced speech identification score (max. score=40) and high-frequency speech identification score (max. score = 27) at 60 dB SPL in three groups of participants

Type of compression		No. of channels	FSNHL (n=12)		GSNHL (n=12)		SSNHL (n=12)	
			Mean (SD)	Median (IQR)	Mean (SD)	Median (IQR)	Mean (SD)	Median (IQR)
PB-SIS	Syllabic compression	4-channel	37.33 (5.99)	40.00 (3.00)	34.63 (10.17)	40.00 (11.50)	39.20 (1.79)	40.00 (2.00)
		8-channel	38.08 (6.02)	40.00 (0.75)	36.13 (8.01)	40.00 (5.00)	39.20 (1.79)	40.00 (2.00)
		16-channel	37.00 (6.62)	40.00 (1.75)	35.50 (8.60)	40.00 (10.50)	38.80 (2.17)	40.00 (3.50)
	Dual compression	4-channel	37.25 (6.02)	40.00 (3.00)	36.00 (8.30)	40.00 (6.25)	38.40 (3.58)	40.00 (4.00)
		8-channel	37.67 (5.73)	40.00 (0.75)	34.25 (10.62)	40.00 (13.75)	39.60 (0.89)	40.00 (1.00)
		16-channel	38.00 (6.02)	40.00 (1.75)	36.63 (8.00)	40.00 (2.50)	39.00 (2.24)	40.00 (2.50)
HF-SIS	Syllabic compression	4-channel	26.67 (0.89)	27.00 (0.00)	26.88 (0.35)	27.00 (0.00)	27.00 (0.00)	27.00 (0.00)
		8-channel	25.92 (2.54)	27.00 (0.00)	27.00 (0.00)	27.00 (0.00)	27.00 (0.00)	27.00 (0.00)
		16-channel	26.42 (2.02)	27.00 (0.00)	26.88 (0.35)	27.00 (0.00)	27.00 (0.00)	27.00 (0.00)
	Dual compression	4-channel	26.33 (2.31)	27.00 (0.00)	26.88 (0.35)	27.00 (0.00)	27.00 (0.00)	27.00 (0.00)
		8-channel	26.42 (2.02)	27.00 (0.00)	27.00 (0.00)	27.00 (0.00)	27.00 (0.00)	27.00 (0.00)
		16-channel	26.42 (2.02)	27.00 (0.00)	27.00 (0.00)	27.00 (0.00)	27.00 (0.00)	27.00 (0.00)

FSNHL; flat sensorineural hearing loss, GSNHL; gently sloping sensorineural hearing loss, SSNHL; steeply sloping sensorineural hearing loss, IQR; interquartile range, PB-SIS; phonemically balanced speech identification score; HF-SIS; high frequency speech identification score

Table 4. Paired comparison of the sentence identification scores and speech quality ratings between the syllabic and dual compression in three groups, at 60 dB SPL on Wilcoxon singed rank test (Z and p)

Group	No. of channels		SIS		SQR			
			PB-SIS	HF-SIS	SC	SP	LA	OI
FSNHL	4-channel	Z	−1.000*	−0.447*	−0.447*	0.000*	−0.577*	−1.000*
		p	0.317	0.655	0.655	1	0.564	0.317
	8-channel	Z	−1.069*	−1.000†	−0.966*	−0.707†	−0.447†	−1.342†
		p	0.285	0.317	0.334	0.48	0.655	0.18
	16-channel	Z	−0.816†	0.000*	−0.333*	−0.378‡	0.000‡	−0.816*
		p	0.414	1	0.739	0.705	1	0.414
GSNHL	4-channel	Z	−1.604*	0.000*	−1.000*	−0.577*	−0.447*	−0.816*
		p	0.109	1	0.317	0.564	0.655	0.414
	8-channel	Z	−1.069†	0.000*	0.000†	−0.707†	−0.531*	−0.707*
		p	0.285	1	1	0.48	0.595	0.48
	16-channel	Z	0.000‡	−1.000†	−0.378*	−1.000†	−0.707†	−0.447†
		p	1	0.317	0.705	0.317	0.48	0.655
SSNHL	4-channel	Z	−1.000*	0.000*	0.000*	0.000*	−1.000*	−1.000‡
		p	0.317	1	1	1	0.317	0.317
	8-channel	Z	−1.000†	0.000*	0.000*	0.000*	0.000†	0.000†
		p	0.317	1	1	1	1	1
	16-channel	Z	−1.000†	0.000*	−1.000†	0.000*	−0.577*	−1.342‡
		p	0.317	1	0.317	1	0.564	0.18

SIS; speech identification score, SQR; speech quality ratings, PB-SIS; phonemically balanced speech identification score, HF-SIS; high frequency speech identification score, SC; speech clarity, SP; sound pleasantness, LA; loudness appropriateness, OI; overall impression, FSNHL; flat sensorineural hearing loss, GSNHL; gently sloping sensorineural hearing loss, SSNHL; steeply sloping sensorineural hearing loss

* Based on negative ranks, † Based on positive ranks, ‡ The sum of negative ranks equals the sum of positive ranks

groups, it was found that there was no statistically significant difference in the PB-SIS, HF-SIS and in the ratings on four parameters of speech quality obtained with the syllabic and dual compression when tested with 4-channel, or 8-channel or 16-channel hearing aids ($p>0.05$).

Effect of number of channels

Friedman test revealed no significant difference in PB-SIS across channels at 80 dB SPL presentation level in the three groups [FSNHL: $\chi^2(2)=1.400$, $p=0.497$, Kendall's $W=0.058$; GSNHL: $\chi^2(2)=3.800$, $p=0.150$, Kendall's $W=0.158$; SSNHL: $\chi^2(2)=0.286$, $p=0.867$, Kendall's $W=0.012$]. The Friedman test for the HF-SIS was carried out only in FSNHL and GSNHL. Similar to the PB-SIS findings, at 80 dB SPL there was no statistically significant difference in the aided HF-SIS across channels, in both the groups [FSNHL: $\chi^2(2)=2.000$, $p=0.3368$, Kendall's $W=0.083$, GSNHL: $\chi^2(2)=2.000$, $p=0.368$, Kendall's $W=0.083$].

Friedman test was carried out to compare the subjective ratings on speech quality across channels and it was found that in all the groups there was no statistically significant difference across the three channels for the ratings obtained for speech clarity [FSNHL: $\chi^2(2)=3.588$,

Table 5. The mean, standard deviation, median, and interquartile range of the phonemically balanced speech identification score (max. score=40) and high frequency speech identification score (max. score=27) at 80 dB SPL in three groups of participants

	Type of compression	No. of channels	FSNHL (n=12)		GSNHL (n=12)		SSNHL (n=12)	
			Mean (SD)	Median (IQR)	Mean (SD)	Median (IQR)	Mean (SD)	Median (IQR)
PB-SIS	Syllabic compression	4-channel	38.25 (5.75)	40.00 (0.00)	36.88 (6.96)	40.00 (3.25)	40.00 (0.00)	40.00 (0.00)
		8-channel	37.92 (5.82)	40.00 (0.00)	37.88 (6.01)	40.00 (0.00)	39.80 (0.45)	40.00 (0.50)
		16-channel	38.33 (5.77)	40.00 (0.00)	38.00 (4.50)	40.00 (1.75)	39.20 (1.79)	40.00 (2.00)
	Dual compression	4-channel	38.33 (5.47)	40.00 (0.00)	37.63 (5.55)	40.00 (1.75)	39.40 (1.34)	40.00 (1.50)
		8-channel	38.33 (5.77)	40.00 (0.00)	37.50 (5.90)	40.00 (1.75)	40.00 (0.00)	40.00 (0.00)
		16-channel	38.00 (5.78)	40.00 (0.00)	38.38 (3.85)	40.00 (1.50)	38.40 (3.58)	40.00 (4.00)
HF-SIS	Syllabic compression	4-channel	26.67 (0.89)	27.00 (0.00)	26.15 (0.71)	27.00 (0.00)	27.00 (0.00)	27.00 (0.00)
		8-channel	25.92 (2.54)	27.00 (0.00)	27.00 (0.00)	27.00 (0.00)	27.00 (0.00)	27.00 (0.00)
		16-channel	26.42 (2.02)	27.00 (0.00)	27.00 (0.00)	27.00 (0.00)	27.00 (0.00)	27.00 (0.00)
	Dual compression	4-channel	26.33 (2.31)	27.00 (0.00)	26.88 (0.35)	27.00 (0.00)	27.00 (0.00)	27.00 (0.00)
		8-channel	26.42 (2.02)	27.00 (0.00)	26.88 (0.35)	27.00 (0.00)	27.00 (0.00)	27.00 (0.00)
		16-channel	26.42 (2.02)	27.00 (0.00)	27.00 (0.00)	27.00 (0.00)	27.00 (0.00)	27.00 (0.00)

FSNHL; flat sensorineural hearing loss, GSNHL; gently sloping sensorineural hearing loss, SSNHL; steeply sloping sensorineural hearing loss, IQR; interquartile range, PB-SIS; phonemically balanced speech identification score; HF-SIS; high frequency speech identification score

p=0.166, Kendall's W=0.150; GSNHL: $\chi^2(2)=0.750$, p=0.687, Kendall's W=0.031; SSNHL: $\chi^2(2)=0.609$, p=0.738, Kendall's W=0.025], sound pleasantness [FSNHL: $\chi^2(2)=1.806$, p=0.405, Kendall's W =0.075; GSNHL: $\chi^2(2)=0.970$, p=0.616, Kendall's W=0.040; SSNHL: $\chi^2(2)=4.333$, p=0.115, Kendall's W=0.181], loudness appropriateness [FSNHL: $\chi^2(2)=3.722$, p=0.155, Kendall's W=0.155; GSNHL: $\chi^2(2)=2.882$, p=0.237, Kendall's W=0.120; SSNHL: $\chi^2(2)=0.333$, p=0.846, Kendall's W=0.014], and overall impression [FSNHL: $\chi^2(2)=2.077$, p=0.354, Kendall's W=0.087; GSNHL: $\chi^2(2)=1.043$, p=0.593, Kendall's W=0.043; SSNHL: $\chi^2(2)=2.333$, p=0.311, Kendall's W=0.097].

Discussion

The results of the study revealed that the PB-SIS and HF-SIS in quiet across the given aided conditions were similar for individuals having FSNHL, GSNHL, and SSNHL. That is varying the number of channels from four channels to eight to sixteen channels, in syllabic or dual compression, yielded comparable performance in terms of speech identification and speech quality rating in quiet listening conditions. The current observation revealed that the aided perception of speech in quiet is unaffected by the type of compression and increase in number of channels was consistent for three types of audiological configuration.

There are existing findings that increase in the number of compression channels and the type of compression either syllabic or dual did not affect the listening in quite [8, 18, 22]. For speech perception in quiet, the temporal envelope cues are important, and these cues are well preserved with 4 frequency bands and after which the response starts to increase or attain ceiling [29]. It was observed that temporal envelope cues are not affected by either syllabic or dual compression in 8- and 16- channel hearing aid [30]. As the perceptual cues for speech in quiet are well preserved in hearing aids with different numbers of channels both in syllabic and dual compression, the aided performance in quiet with hearing aids having 4-, 8-, 16- channels yielded comparable results in conversation speech level and loud speech level. The number of compression channels and compression types are unimportant for sentence perception in quiet conditions.

Table 6. Paired comparison of the sentence identification scores and speech quality ratings between the syllabic and dual compression in three groups, at 80 dB SPL on Wilcoxon singed rank test (Z and p)

Group	No. of channels		PB-SIS	HF-SIS	SC	SP	LA	OI
FSNHL	4-channel	Z	–1.000*	–1.000*	–1.633†	–0.577*	–0.816†	–1.732*
		p	0.317	0.317	0.102	0.564	0.414	0.083
	8-channel	Z	–1.000*	–1.000†	–0.577†	–1.414*	–1.930†	–1.134*
		p	0.317	0.317	0.564	0.157	0.054	0.257
	16-channel	Z	–1.000‡	–1.000†	–1.633†	–2.000†	–2.000†	–1.000†
		p	0.317	0.317	0.102	0.046	0.046	0.317
GSNHL	4-channel	Z	–1.069†	–1.000*	–0.707†	–0.577*	–0.707†	–0.557*
		p	0.285	0.317	0.48	0.564	0.48	0.577
	8-channel	Z	–1.342*	–1.000‡	–1.000†	–1.890*	–0.577†	0.000‡
		p	0.18	0.317	0.317	0.059	0.564	1
	16-channel	Z	–1.089†	0.000†	–0.577†	–0.577†	–1.190†	–0.577†
		p	0.276	1	0.564	0.564	0.234	0.564
SSNHL	4-channel	Z	–1.000†	0.000†	–0.447‡	–0.447*	–0.447†	0.000*
		p	0.317	1	0.655	0.655	0.655	1
	8-channel	Z	–1.000*	0.000†	–1.000*	0.000†	–1.000‡	–1.000†
		p	0.317	1	0.317	1	0.317	0.317
	16-channel	Z	–1.000†	0.000†	–1.604†	0.000†	–0.816†	–1.414‡
		p	0.317	1	0.109	1	0.414	0.157

PB-SIS; phonemically balanced speech identification score, HF-SIS; high frequency speech identification score, SC; speech clarity, SP; sound pleasantness, LA; loudness appropriateness, OI; overall impression, FSNHL; flat sensorineural hearing loss, GSNHL; gently sloping sensorineural hearing loss, SSNHL; steeply sloping sensorineural hearing loss

* Based on positive ranks, † Based on negative ranks, ‡ The sum of negative ranks equals the sum of positive ranks

Chen et al. [22] reported a marginal gain advantage with dual compression in a 20-channel hearing aid than with fast acting compression which did not provide a material effect in quiet. However, in noise, speech recognition thresholds with dual compression were significantly better than those with fast-acting compression, suggesting the type of compression matters while listening in noise. Hickson [7] opined that performance in quiet with multichannel compression may not necessarily be maintained in the presence of background noise. In the presence of background noise or reverberation, the speech recognition with multichannel hearing aid would differ depending on the number of compression channels and compression type [19, 20, 31]. Alexander and Masterson [19] suggested that short release time was slightly better when with 4-channels and that long release time was better with 16-channels when listening in steady and modulated maskers. The performance with a slow compression was associated with slow changes in the auditory ecology whereas the fast compression was associated with rapid changes [15, 32]. But Salorio-Corbetto et al. [31] reported that the number of channels and compression speed had no significant effect on speech recognition in two- and eight-talker speech babble at different signal-to-babble ratios. The studies on the effect of number of compression channels and compression type on speech identification in noise have given mixed results. This may be because of the difference in the type of speech stimuli and type of noise used for investigation [19, 31]. One of the limitations of the current study is

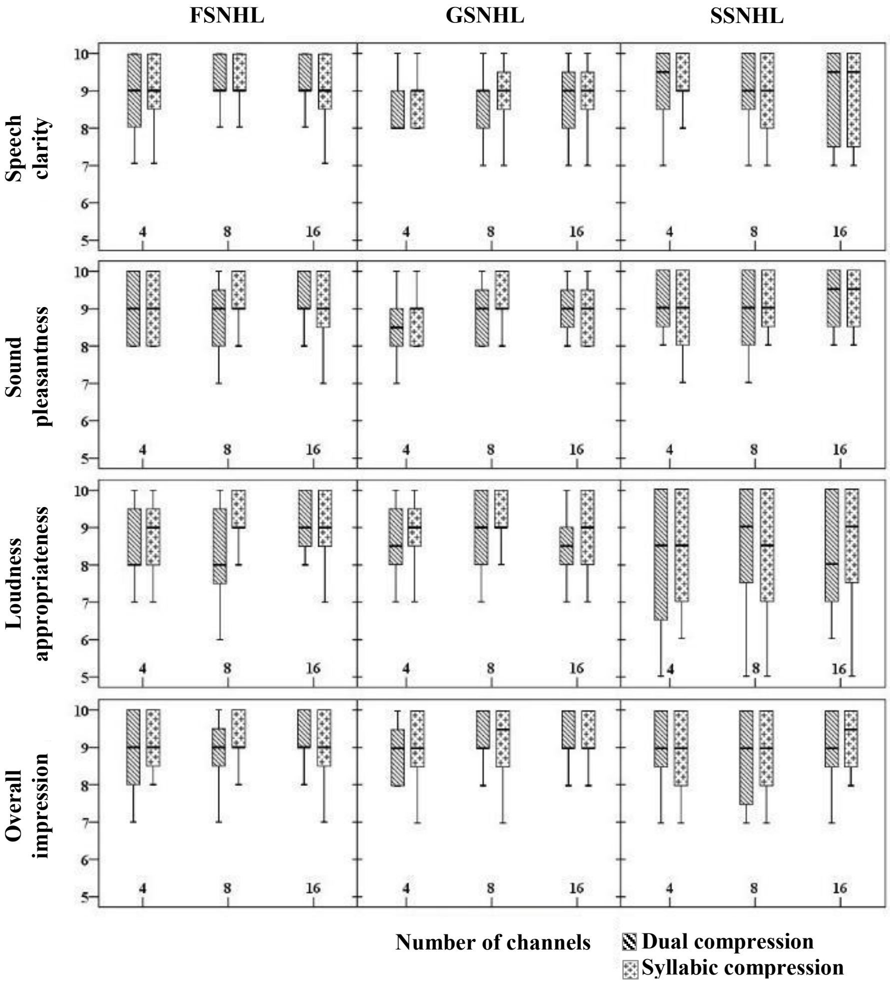

Figure 2. Box plot of the median score (with 95% confidence interval) for speech quality ratings at 80 dB SPL, in three groups. FSNHL; flat sensorineural hearing loss, GSNHL; gently sloping sensorineural hearing loss, SSNHL; steeply sloping sensorineural hearing loss

that it did not account for these variations in the background in determining the outcome from increasing the number of compression channels, in syllable and dual compression, in individuals with different audiogram configuration.

The findings revealed that the speech quality rating in quiet in terms of speech clarity, loudness appropriateness, sound pleasantness, and overall impression by the three groups was also not influenced by the number of channels and the syllabic or dual compression. This may be because of the same attribute of preservation of temporal cues for speech perception in quiet with syllabic or dual compression in multichannel amplification. But there are contradictory findings suggestive of improved speech quality judgment in quiet with slow compression than fast compression because of the less frequent changes in gain with slow compression [33]. The lack of sound-quality preferences may be because participants performed similarly with good scores in all aided conditions, thus preventing them from making differences in judgments.

Chen et al. [22] reported slight preferences for listening effort, listening comfort, speech clarity, and overall sound quality at 4 dB signal to noise ratio with a 20-channel dual compression having a dominant slow-acting compression. Previous reports also revealed the preference with slow-acting compression over fast-acting compression for listening effort, listening comfort, and overall sound quality in noise [16, 34]. But the current study in quite revealed that the listeners easily access the temporal cues with either type of compression in varying numbers of channels, thereby showing a comparable sentence identification score and the speech quality judgement. This aided benefit did not differ both in conversation speech level and loud speech level for three groups.

The number of channels and type of compression are not predicting factors for listening in quiet conditions. Hence, it can be inferred that for those individuals having low listening needs such as listening requirements in home environment, or indoor, hearing aids having 4-compression channels provide comparable listening as hearing aids with 8- and 16- channels in flat or sloping configuration. As the listening needs increase, the characteristics of the background or environment challenges the benefit with multichannel hearing aids. In that case, the selection of the number of channels and its interaction with slow or fast compression will be important for the listener's aided benefit. Also, the facts like individual differences in terms of audibility, suprathreshold hearing and cognitive abilities and the environmental differences in terms of stimulus type, presentation level, noise type, output speech in noise ratio levels and reverberation and the type of fitting like unilateral vs. bilateral need to be considered in multichannel WDRC amplification [15, 19, 20, 31-37]. Future research to address the way in which the number of compression channels and compression type interact with the above-mentioned factors to influence the speech perception in a large number of participants is warranted. More research is also needed to understand how the listener is going to benefit with the different WDRC settings over an extended period of real-world listening with wearable devices.

Conclusion

The current study encompassed the speech perception benefit in quiet with varying number of channels, in syllabic and dual compression, in listeners with three different audiogram configurations. It indicated that increasing the number of channels in syllabic or dual compression, did not affect the speech perception and quality in quiet in individuals with flat, gently sloping or steeply sloping sensorineural hearing loss. A similar pattern was noticed irrespective of the presentation level, of 60 dB SPL and 80 dB SPL. It can be inferred that listening in quiet through multichannel compression hearing aids at moderate or loud level may not be influenced by the number of channels and compression type.

Ethical Considerations

Compliance with ethical guidelines

Ethical guidelines for bio-behavioural research on human subjects of the Institute were followed in this study. The study was initiated after obtaining the ethical approval from the All India Institute of Speech and Hearing Ethics Committee (Ref No.Ph.D./WF- 173/2018-19, dated 21.12.2020. All the participants signed the informed consent prior to the data collection.

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Authors' contributions

SEN: Study design, acquisition of data, interpretation of the results and drafting the manuscript; PM: Study design and supervision, interpretation of the results, and critical revision of the manuscript.

Conflict of interest

The authors declared no conflicts of interest, financial or otherwise.

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