J Hear Sci, 2020; 10(1): 33–40
DOI: 10.17430/JHS.2020.10.1.4

COMPARISON OF TEMPORAL AND ENVELOPE CUES IN HEARING AIDS: USE OF MALAYALAM LANGUAGE CHIMERIC SENTENCES AND TWO COMPRESSION STRATEGIES

Contributions:
A Study design/planning
B Data collection/entry
C Data analysis/statistics
D Data interpretation
E Preparation of manuscript
F Literature analysis/search
G Funds collection

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Abstract

Objective: The human auditory system perceives any speech sound through the inherent temporal cues i.e., the temporal fine structure (TFS) and envelope (ENV) cues which has its own predominance for perception across languages. Research in English and Mandarin Chinese language showed the difference between these cues with tonal language employ more of TFS cues and non-tonal language employ ENV cues for perception. Earlier studies on Indian language (Kannada and Malayalam) revealed ENV cues predominance for perception. Based on this, the aim of this study was to compare stimuli in which the TFS and ENV cues had been interchanged (so-called auditory chimeras). The stimuli were Malayalam language sentences delivered through a hearing aid using two compression schemes – syllabic compression and dual compression – and processed by a nonlinear 8-channel and 16-channel system.

Method: Thirty-five normal hearing individuals were assessed for the perception of chimeric sentences across eight sets of frequency bands (1, 4, 6, 8, 16, 24, 32, and 64 bands). Before the administration of the chimeric sentences all the individuals were assessed for normal hearing abilities through routine audiological evaluations.

Results: The results of the present study reveal there is a significant difference across frequency bands on both the syllabic and dual compression processed stimuli using either 8 or 16 channels. The ENV cues were better perceived whether 4, 6, 8, or 16 frequency bands were used, with dual compression being marginally better than syllabic compression for both 8 and 16 channels. However, 16 channels gave overall better perception than 8 channels.

Conclusions: The results of the study revealed a better processing of envelope (ENV) cues, which are most important for understanding speech through a hearing aid.

Key words: chimeric sentences • dual compression • envelope • syllabic compression • temporal fine structure

PORÓWNANIE SYLABICZNIE I PODWÓJNIE SKOMPRESOWANYCH MALAJSKICH ZDAŃ CHIMERYCZNYCH PRZETWORZONYCH PRZEZ APARAT SŁUCHOWY

Streszczenie

Cel: Ludzki układ słuchowy odbiera każdy dźwięk mowy poprzez sekwencje czasowe, tj. sygnały o strukturze subtelnej dźwięku (TFS) i sygnały obwiedni (ENV), które mają swoją przewagę w percepcji w różnych językach. Badania w języku angielskim i chińskim mandaryńskim wykazały różnicę między tymi sygnałami, przy czym język tonalny wykorzystuje więcej sygnałów TFS, a język nie tonalny wykorzystuje sygnały ENV do percepcji. Wcześniejsze badania języka indyjskiego (kannada i malajalam) ujawniły przewagę sygnałów ENV w percepcji. Celem tego badania było porównanie dwóch schematów kompresji malajskich zdań chimerycznych - kompresji sylabicznej i podwójnej kompresji - i przetwarzane przez nieliniowy system 8-kanałowy i 16-kanałowy.

Metoda: Badaniem objęto 35 osób normalnie słyszących pod kątem percepcji zdań chimerycznych w ośmiu zestawach pasm częstotliwości (1, 4, 6, 8, 16, 24, 32 i 64 pasma). Przed podaniem zdań chimerycznych wszystkie osoby zostały zbadane pod kątem normalnych zdolności słyszenia poprzez rutynowe testy audiologiczne.

Wyniki: Wyniki niniejszego badania pokazują, że istnieje znacząca różnica między pasmami częstotliwości zarówno w przypadku sylabicznych, jak i podwójnie przetwarzanych bodźców wykorzystujących 8 lub 16 kanałów. Sygnały ENV były lepiej postrzegane bez względu na to, czy zastosowano pasma częstotliwości 4, 6, 8 czy 16, przy czym podwójna kompresja jest nieznacznie lepsza niż kompresja sylabiczna dla obu kanałów 8 i 16. Jednak 16 kanałów dało ogólnie lepszą percepcję niż 8 kanałów.

Wnioski: Wyniki badania ujawniły lepsze przetwarzanie sygnałów obwiedni (ENV), które są najważniejsze dla zrozumienia mowy za pomocą aparatu słuchowego.

Słowa kluczowe: zdania chimeryczne • kompresja podwójna • obwiednia • kompresja sylabiczna • subtelna struktura czasowa

Introduction

The hearing system processes sounds by transducing a signal through the auditory nerve after which further processing occurs at the level of auditory cortex. Usually, speech stimuli consist of two temporal cues: the temporal envelope cue (ENV) and the temporal fine structure (TFS) cue. The ENV cues are the slowly varying amplitudes of a speech signal, while the TFS cue is the rapid oscillation which varies in time at the centre frequency of the band [1,2]. Essentially, the TFS is the carrier of the signal and the ENV is the amplitude modulation. In a normal hearing individual the TFS cues are processed by the phase-locking ability of a normal cochlea, although the ability is restricted to below 4 kHz [3,4]. However, for normal hearing individuals the ENV cue is more important because reconstruction of the envelope takes place at the level of cochlea [5].

To study the relative contribution of these cues, several algorithms have been employed. One among them is the peak clipping method; however, with this method the distortion of the signal is more, which in turn affects the intelligibility of the signal [6]. Later, the Hilbert transform [7] has been used so that the perceptual significance of ENV and TFS cues can be studied separately by constructing hybrid sounds called 'auditory chimeras'. These chimeras interchange the TFS and ENV cues from two different speech stimuli across frequency bands. Perceptual studies have revealed that, for speech perception in quiet, the ENV cues are adequate; however speech perception in noise needs the involvement of TFS cues for better understanding of speech [8,9].

Individuals with hearing impairment who have a moderate level of hearing loss experience difficulty in processing TFS cues due to impaired phase-locking ability, probably because depletion of inner hair cells causes broadening of auditory filters [10]. However, in normal hearing individuals, ENV cues in 4 to 6 important frequency bands are adequate for processing speech stimuli. However, for pitch perception tasks, where TFS cues are predominantly used for perception, 32 frequency bands are normally required [9].

Perception of auditory chimeras in both tonal and non-tonal language (by manipulation of the frequency bands) has revealed that, for a tonal language, TFS cues predominate. However, for a non-tonal language ENV cues are generally more important for the perception of speech, although there is better perception starting with 4 frequency bands and a gradual increase in perception as the number of frequency bands increases [11].

With these research works as support, studies have been done on south Indian languages such as in Malayalam and Kannada using chimeric sentences. In Malayalam, the speech stimuli in the lower bands have been identified as TFS cues, whereas speech stimuli in the higher bands rely on ENV cues [12]. However, when Kannada chimeric words and sentences are used, the results reveal that ENV cues are used more than TFS cues [13]. Since divergent results have been reported with two different south Indian languages, there is a need to investigate the relative importance of these cues when an individual with hearing loss perceives speech through a hearing aid.

This study of simulation for moderate hearing loss was carried out on normal hearing individuals using stimuli processed through a hearing aid using two different sorts of hearing aid (8-channel and 16-channel) and two different compression systems (syllabic and dual compression). The reason for employing these two compression systems is that studies have shown that syllabic compression and dual compression have the same effect on speech identification scores (SISs) for both quiet and noisy conditions, but that a hearing aid user prefers to use syllabic compression for understanding speech [14]. The present study therefore aimed to compare the perception of ENV and TFS cues using different compression systems and different number of signal processing channels. In all cases, hearing-aid processed Malayalam chimeric sentences were employed across different frequency bands.

Methods

A total of 35 participants (15 male and 20 females), in the age range 18 to 30 years (mean = 22 years, SD = ±2.58) who had normal hearing and were native speakers of Malayalam participated in the present study. Written informed consent was obtained. The included individuals had normal hearing thresholds on pure tone audiometry, normal middle ear function as indicated by type 'A' tympanogram, present acoustic reflexes on immittance evaluation, and no history of speech and language disorder, neurologic disorder, or cognitive deficit. The present study was carried out in four phases. In phase I the speech stimuli were prepared as auditory chimeras across frequency bands and consisted of 180 Malayalam sentences from developed and standardised Malayalam sentence lists [15]. In phase II the chimeric words were prepared. In Phase III, two types of hearing aids (8-channel and 16-channel) were chosen and programmed with syllabic and dual compression. The hearing aid processed speech samples were then recorded. In Phase IV identification of processed speech through the hearing aids and recording of responses was carried out.

Phase I

The stimuli were chosen from the developed sentence list in Malayalam [15] which is routinely used in our clinic for testing speech identification. The full sentence list consisted of 12 lists, each consisting of 10 sentences; all the sentences were in recorded format. All the sentences in the list had 4 words with all 4 being key words for scoring. To prepare the chimeric sentences across 8 sets of frequency bands (1, 4, 6, 8, 16, 24, 32, and 64 bands), a total of 16 individual full sentence lists were needed, but in the developed sentence list in Malayalam [15] there are only 12 full lists available. Hence there were 4 full lists lacking, and so 4 lists from the original 12 were again randomized to give the 16 full lists needed. In this way, a total of 160 sentences was obtained and these were employed for the preparation of chimeric sentences.

Phase II

In this phase, the preparation of chimeric sentences was done using a Hilbert transform algorithm performed on a personal computer loaded with MATLAB 7.12.0 software (The MathWorks Inc., release 2011a). The recorded

Malayalam sentences were fed in to extract the separate ENV and TFS cues; the separated cues from two different sentences were then mixed together to form a hybrid sentence in which the sentences varied across 8 sets of frequency bands (1, 4, 6, 8, 16, 24, 32, and 64). A total of 80 sentences were prepared using 10 sentences for each of the frequency bands. Henceforth, this stimulus set is referred as the unprocessed stimuli.

Phase III

In this phase, the prepared chimeric sentences were utilized for the preparation of processed chimeric sentences. First, nonlinear 8- and 16-channel hearing aids from the Rexton Company (Sivantos group, Singapore), Joy series 20 and 30 model respectively were chosen. The features, technical advances, and fitting range of the hearing aid were similar except for the number of channels. These hearing aids were programmed with two compression systems, i.e., syllabic and dual compression, to simulate 40 dB flat hearing loss using NOAH 4.0 software for Windows (Hearing Instrument Manufacturers Software Association, release 2014, Copenhagen, Denmark). During programming, only the compression system was made functional with all other technical features disabled in both the hearing aids to control variables which might have a possible effect on the outcome. After programming the hearing aid, the hearing aid was coupled to a KEMAR (Knowles Electroacoustic Manikin for Auditory Research) and the stimuli were presented through a Radio Ear SP85A loudspeaker at 0° to the KEMAR through Cubase SX 2.0 software (released 2003; Steinberg, Hamburg, Germany) and the output of the KEMAR was recorded using a Brüel & Kjær *(BZ-5503) sound level meter* and software (Brüel & Kjær Sound & Vibration Measurement A/S, Nærum, Denmark) and recorded in .WAV format.

Phase IV

The prepared syllabic and dual compression processed chimeric Malayalam sentences from the 8-channel and 16-channel hearing aids were presented to participants through a PC loaded with Adobe Audition 3.0 software (released 2007; Adobe Inc, San Jose, CA) and circumaural High Definition Audio 300 headphones. The response of the participants was recorded using PRAAT 6.0.39 software (released 2018, University of Amsterdam). Further analysis was carried out on the recorded responses where scoring of repeated sentences was based on the number of keywords repeated, which ranged from 0 (no response) to 4 (all words correctly repeated).

Statistical analysis

The data were collected and subjected to statistical analysis using the Statistical Package for Social Sciences (SPSS) v20 software (released 2011; IBM Corp., Armonk, NY).

Ethics

In the present study, all testing procedures were carried out using non-invasive techniques, adhering to the conditions of the Ethics Approval Committee of the institute [16].

Results

The data was tabulated into ENV and TFS cues based on the overall frequency of the participants' response to check whether the cues were the same across different numbers of channels of hearing aid and across different compression systems. The results are shown in Table 1.

The data in Table 1 show a predominance of ENV cue over TFS cue, with TFS exhibiting zero values. Hence further statistical analysis was applied only to the ENV cues. Descriptive statistics was done and the mean, median, and standard deviation were computed and are tabulated in Table 2; the median values are plotted in Figure 2.

From Table 2 and Figure 1 it is evident that there is an increase in speech perception scores with increase in the number of frequency bands. A marginal increase in scores was observed with the 16-channel hearing aid processed

Table 1. Representation of participant frequency (%) for identification of fine structure and envelope cues in dual and syllabic compression system across frequency bands and across hearing aid

Frequency band	8-channel hearing aid				16-channel hearing aid			
	Dual		Syllabic		Dual		Syllabic	
	TFS (%)	ENV (%)	TFS (%)	ENV (%)	TFS (%)	ENV (%)	TFS (%)	ENV (%)
S 1	94.28	5.72	94.28	5.72	92.64	7.36	94.28	5.72
S 4	0	100	0	100	0	100	0	100
S 6	0	100	0	100	0	100	0	100
S 8	0	100	0	100	0	100	0	100
S 16	0	100	0	100	0	100	0	100
S 24	0	100	0	100	0	100	0	100
S 32	0	100	0	100	0	100	0	100
S 64	0	100	0	100	0	100	0	100

Note: S = Chimeric sentence list, 1–64 indicates number of frequency band

Table 2. Mean, median, and standard deviation of chimeric sentences across different frequency bands and with compression system across hearing aids

Stimulus	8-channel hearing aid			16-channel hearing aid		
	Mean	SD	Median	Mean	SD	Median
Du 1	7.00	4.95	5.00	8.14	5.012	7.50
Du 4	13.07	7.07	15.00	18.92	8.93	17.50
Du 6	10.35	5.85	10.00	15.28	9.90	15.00
Du 8	17.85	8.47	17.50	23.00	11.09	17.50
Du 16	78.64	10.83	77.50	80.71	8.84	82.50
Du 24	88.92	4.89	90.00	91.14	5.15	90.00
Du 32	95.07	3.76	95.00	95.78	5.17	97.50
Du 64	99.71	0.80	100.00	99.57	0.95	100.00
Sy 1	7.14	4.62	7.50	9.28	4.71	10.00
Sy 4	14.85	6.99	15.00	18.42	6.67	17.50
Sy 6	11.28	5.15	10.00	14.57	7.96	15.00
Sy 8	18.57	8.42	17.50	24.85	15.71	17.50
Sy 16	80.00	9.17	80.00	81.07	7.77	80.00
Sy 24	89.42	6.03	90.00	90.78	5.31	90.00
Sy 32	95.50	4.32	95.00	95.00	4.96	95.00
Sy 64	99.71	0.80	100.00	99.92	0.42	100.00

Note: Du = dual compression, Sy = syllabic compression, 1–64 indicates number of frequency bands

stimulus compared to that of the 8-channel hearing aid for both the dual and syllabic compression processing.

A Shapiro–Wilks test of normality revealed that the data was not distributed normally. Hence a Friedman test was done to find if there was a significant difference across different frequency bands (1, 4, 6, 13, 16, 24, 32 and 64) for both the 8- and 16-channel hearing aid processed stimuli and for both the dual and syllabic compression systems. The results revealed a significant difference across frequency bands with dual compression on both 8-channel and 16-channel hearing aids (χ^2 = 231.14; p<0.05) and (χ^2 = 228.65; p<0.05), and for syllabic compression on both 8-channel and 16-channel hearing aids (χ^2 = 233.31; p<0.05) and (χ^2 = 231.15; p<0.05). Further, a Wilcoxon signed ranked pairwise comparison was done. The number of comparisons among each of Tables 3, 4, 5, and 6 was 28, and the estimated family-wise error rate (FWER) was ≤0.76. Hence, the probability of 28 pairwise comparisons exhibiting a Type 1 error is around 76%. To control for FWER, a correction was estimated based on the level of significance hypothesized earlier and the number

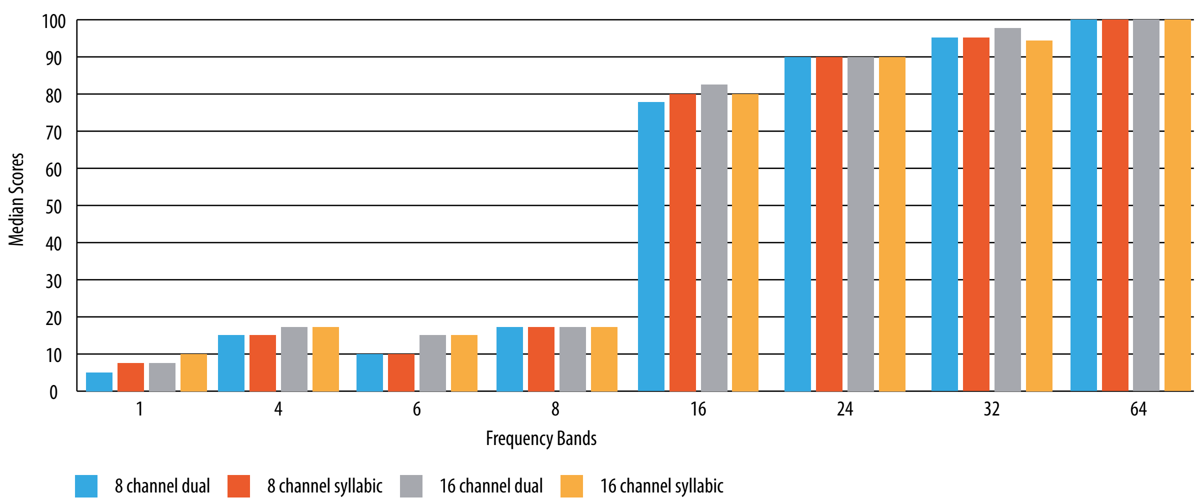

Figure 1: Overall median score across frequency bands and compression systems among 8-channel and 16-channel hearing aid processed chimeric sentences

Table 3. Result of Wilcoxon signed rank test for comparison across frequency bands for 8-channel dual compression processed chimeric sentence

	1 Du	4 Du	6 Du	8 Du	16 Du	24 Du	32 Du	64 Du
1 Du		5.03*	5.17*	5.17*	5.17*	5.18*	5.19*	5.56*
4 Du			2.07	2.67	5.17*	5.17*	5.17*	5.16*
6 Du				3.87*	5.17*	5.17*	5.17*	5.18*
8 Du					5.16*	5.17*	5.17*	5.16*
16 Du						4.43*	4.94*	5.09*
24 Du							4.63*	5.12*
32 Du								4.59*
64 Du								

*Note: * = p <0.0018 (after family-wise error rate correction); Du = dual compression, 1 to 64 bands*

Table 4. Result of Wilcoxon signed rank test for comparison across frequency bands for 8-channel syllabic compression processed chimeric sentence

	1 Sy	4 Sy	6 Sy	8 Sy	16 Sy	24 Sy	32 Sy	64 Sy
1 Sy		5.17*	5.10*	5.17*	5.17*	5.18*	5.21*	5.60*
4 Sy			2.13	1.96	5.18*	5.17*	5.16*	5.17*
6 Sy				3.87*	5.17*	5.17*	5.17*	5.18*
8 Sy					5.16*	5.17*	5.17*	5.18*
16 Sy						4.35*	5.18*	5.18*
24 Sy							4.21*	5.05*
32 Sy								4.53*
64 Sy								

*Note: * = p <0.0018 (after family-wise error rate correction), Sy = syllabic compression, 1 to 64 bands*

Table 5. Result of Wilcoxon signed rank test for comparison across frequency bands for 16-channel dual compression processed chimeric sentence

	1 Du	4 Du	6 Du	8 Du	16 Du	24 Du	32 Du	64 Du
1 Du		4.87*	4.97*	5.17*	5.17*	5.21*	5.21*	5.55*
4 Du			1.97	2.62	5.16*	5.16*	5.17*	5.17*
6 Du				3.34*	5.17*	5.17*	5.17*	5.17*
8 Du					5.17*	5.17*	5.17*	5.17*
16 Du						4.92*	5.10*	5.10*
24 Du							4.20*	4.84*
32 Du								4.16*
64 Du								

Note = p <0.0018 (after family-wise error rate correction); Du = dual compression, 1 to 64 bands*

of comparisons done. The correction was estimated to be 0.0018, and hence a value of < 0.0018 was considered as denoting the power of the statistics. The results are shown in Tables 3–6.

From Tables 3–6 it is evident that the speech identification scores significantly improve starting from 4 frequency bands through to 16 bands, after which the scores are found to be 100%, with a significant difference across all frequency bands except for the comparison of 4 bands versus 6 bands and 4 bands versus 8 bands under all four conditions (i.e. the 8-channel hearing aid programmed for syllabic and dual compression, and the 16-channel hearing aid programmed for syllabic and dual compression).

A Wilcoxon signed ranked test was done to compare the difference between syllabic and dual compression in both 8- and 16-channel hearing aids and the data is

Table 6. Result of Wilcoxon signed rank test for comparison across frequency bands for 16-channel syllabic compression processed chimeric sentence

	1 Sy	4 Sy	6 Sy	8 Sy	16 Sy	24 Sy	32 Sy	64 Sy
1 Sy		5.17*	5.03*	5.17*	5.18*	5.20*	5.19*	5.84*
4 Sy			2.25	2.47	5.17*	5.17*	5.17*	5.18*
6 Sy				4.35*	5.17*	5.17*	5.17*	5.16*
8 Sy					5.16*	5.17*	5.17*	5.17*
16 Sy						4.64*	5.05*	5.18*
24 Sy							3.39*	4.85*
32 Sy								4.40*
64 Sy								

*Note: * = p <0.0018 (after family-wise error rate correction); Sy = syllabic compression, 1 to 64 bands*

Table 7. Result of Wilcoxon signed rank test for comparison between dual and syllabic compression within frequency bands on 8-channel processed chimeric sentence

	1 Sy	4 Sy	6 Sy	8 Sy	16 Sy	24 Sy	32 Sy	64 Sy
1 Du	0.00							
4 Du		0.92						
6 Du			0.85					
8 Du				0.69				
16 Du					1.05			
24 Du						0.99		
32 Du							0.64	
64 Du								0.00

Note: Du = dual compression, Sy = syllabic compression, 1 to 64 bands

Table 8. Result of Wilcoxon signed rank test for comparison between dual and syllabic compression within frequency bands on 16-channel processed chimeric sentence

	1 Sy	4 Sy	6 Sy	8 Sy	16 Sy	24 Sy	32 Sy	64 Sy
1 Du	1.73							
4 Du		0.03						
6 Du			0.80					
8 Du				0.58				
16 Du					0.23			
24 Du						1.03		
32 Du							0.82	
64 Du								2.24

Note: Du = dual compression, Sy = syllabic compression, 1 to 64 bands

tabulated in Tables 7 and 8. The number of comparisons in Tables 7 and 8 was eight and the computed FWER was ≤0.33 (33%) and the correction was estimated to be 0.006. Hence, a value of < 0.006 was considered as denoting the power of the statistic.

From Tables 7 and 8 the results revealed no significant difference between either the 8-channel or 16-channel hearing aid for both syllabic and dual compression system processed Malayalam chimeric sentences. However a marginal difference was observed based on median values, with the 16-channel being better compared to the 8-channel hearing aid. Similarly, for both the 8- and 16-channel hearing aids, the dual compression processed Malayalam chimeric sentences were better across each frequency band compared to syllabic compression processed stimuli. Based on the current results, it is evident that at least 4 through 16 frequency bands are essential to perceive ENV cues in Malayalam language stimuli processed by a hearing aid, irrespective of the type of compression system and number of signal processing channels used. Since there was no significant difference in scores between using syllabic or dual compression, it is apparent that both compression systems invariably affect the perception of temporal envelope cues in speech processed through hearing aids with either 8 or 16 channels. The present study reveals that the number of signal processing channels might partially affect the perception of envelope cues in speech processed through a hearing aid.

Discussion

The objectives of the study relate to the effect of envelope and temporal fine structure cues with both syllabic and dual compression systems across two different channels of hearing aid processed chimeric sentences. The results revealed a larger influence of envelope cue for the perception of speech. This enhanced perception of envelope cue could be due to its slowly varying nature and because it also acts as an amplitude modulator enhancing perception [7]. However, the TFS cue perception was much less due to the inability of the auditory nerve to phase lock to the rapid oscillations of the fast varying TFS cue [2]. This inability was mainly because TFS cues largely work by placing cues in speech sounds; however, voicing and nasality basically utilise ENV cues, which in turn show a poor contribution of TFS cues to perception as the band number increases [17].

The results of the study showed an increase in response starting from 4 frequency bands in all four conditions. The possible reason is that the performance between 4, 6, and 8 bands were almost the same because this is the range over which temporal cues start to get perceived. This supports earlier research that the envelope cue starts to predominate at or around 4 frequency bands, after which the response starts to increase or attain a ceiling [9]. The possible reason for this envelope cue enhancement might be due to ENV cue reconstruction which might take place at the level of cochlea; this phenomenon has been studied by presenting only TFS cues to normal hearing individuals. However, individuals with normal hearing can respond to ENV cues which are not actually present in a stimulus [17].

Studies on tonal and non-tonal foreign language have also found a difference in predominance of ENV and TFS cues between languages. The perception of ENV cues has been found to be significantly higher in non-tonal languages, even at low frequency bands. Whereas in tonal languages (such as Mandarin Chinese) the trend is opposite, with the TFS cues being perceived better than the ENV cues, starting from low frequency bands [11]. In an Indian context, little research has been done on understanding the perceptual importance of temporal cues using chimeras. One study in the Kannada language using auditory word and sentence chimera revealed that ENV perception to be predominant starting from lower frequency bands than the TFS cues [13].

Here, the performance and predominance of the cues was assessed using two different compression conditions and revealed no difference between compression system or number of channels. The results of this study support findings that the effect of both compression systems on speech identification is similar, although the subjective preference is more toward syllabic compression rather than dual compression [14]. However, researchers have also found there is a preference towards dual compression system by hearing-impaired individuals, finding that the dual compression system sounds better on the basis of loudness parameters for the perception of processed music [18]. The present study showed some marginal improvement in the dual compression system compared to syllabic compression in terms of overall descriptive statistics. However, the study also has a contraindicated result of the syllabic compression system to be better [14, 15, 19].

Conclusions

There is a better processing of envelope cues through a hearing aid, cues which are important for understanding speech. The reason for this finding may be because subjects were normal hearing individuals whose peripheral mechanisms were intact. Also, earlier research work has found that for understanding speech in noise the participation of TFS cues is also important for better perception of speech. Hence, further study on a comparison between individuals with hearing impairment and normal hearing individuals, as well as studies relating to understanding the temporal cue predominance in speech in noise simulation conditions, will provide better understanding regarding the difficulties, if any, in perception.

Disclaimer

The information in this document is provided for information purpose only. It does not constitute any offer or recommendation from any hearing aid company. The details of the hearing aids used in the research have been revealed as per the request of the editor.

Conflict of interest

None

Acknowledgements

The authors thank the participants for their cooperation. We thank the Director, All India Institute of Speech and Hearing, Mysuru, for permission to carry out the study.

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